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DOE/NASA/0051–79/1
NASA CR–159633

(NASA-CR-159633) PARAMETRIC STUDY OF POTENTIAL EARLY COMMERCIAL MHD POWER PLANTS Final Report (Avco Corp., Wilmington, Mass.) 246 p HC A11/MF A01 CSCL 10B G3/44
N80-18559
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PARAMETRIC STUDY OF POTENTIAL EARLY COMMERCIAL MHD POWER PLANTS

Finn A. Hals
Avco Everett Research Laboratory, Inc.

December 1979

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Under Contract DEN 3-51

for
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Under Interagency Agreement EF-77-A-01-2674

TABLE OF CONTENTS

Section Page

Appendices

LIST OF ILLUSTRATIONS

LIST OF TABLES

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1.0 INTRODUCTION

1.1 SCOPE

This report is the final document reporting information developed in the first task, Task I, of a Study of Potential Early Commercial MHD Power Plants under NASA Contract DEN 3-51. The total program is divided into two separate and sequential tasks, Task I and Task II.

The first task reported on here consisted of parametric analyses of three different power plants (reference plants) with parametric variations of the various design parameters for each of these reference plants.

Task II will consist of conceptual design studies of power plants which have been identified as attractive in the parametric analysis of Task I. The conceptual designs of Task II will be based on information and initial plant design data developed in the first task.

The study has been conducted by a contract team consisting of AERL as the prime contractor and program manager, and Combustion Engineering, Inc. and Chas T. Main, Inc., as contract team members and subcontractors. The main responsibilities of each team member in performing the work reported on in Task I is outlined in Table I-1.

1.2 OBJECTIVE

The major objective of this program is to develop information on the performance, cost, natural resource requirements and environmental impact, and technical feasibility and development requirements of commercial scale "moderate technology" MHD/steam power plants, in order to identify attractive entry level power plant designs. These attractive power plants shall have acceptable performance and acceptable cost of electricity but shall not require the development of high temperature air heaters directly fired with hot MHD generator exhaust gas. Thus, the development requirements and hence, development costs and times for these "moderate technology" entry level power plants is considered to be less than those for more advanced and mature power plant designs defined by previous studies such as ECAS.

TABLE I-1. CONTRACT TEAM

AERL Program Manager	Comb. Eng., Inc. Subcontractor	Chas T. Main, Inc. Subcontractor
Responsible for:	Responsible for:	Responsible for:
1. Plant Definition and Main Design Parameters	1. HRSR	1. Plant Arrangement and Layout
2. Plant Integration + Performance	2. Coal Processing	2. Plant Costs and COE
3. MHD Equipment ● MHD Combustor + Nozzle ● MHD Generator incl. electrode consolidating circuitry and diffuser ● Superconducting Magnet ● H. T. Air Heater	3. Advanced Gasifier	3. Inversion
4. SOA Gasifier		4. Seed Processing
5. O_2 Plant		5. BOP Equipment

2.0 REFERENCE PLANTS OVERALL POWER SYSTEM DESIGN AND PERFORMANCE

2.1 BASIC PLANT DESIGNS AND PERFORMANCE ANALYSIS

The parametric analysis considered the following three different reference MHD Power Plants:

Case I - Reference Plant 1. Power plant with separately fired high temperature air heater and the use of state-of-the-art gasifier and heat exchanger technology.

Case II - Reference Plant 2. Power plant with separately fired high temperature air heater and the use of advanced gasifier and heat exchanger technology.

Case III - Reference Plant 3. Power plant with the use of oxygen enrichment of the combustion air.

The basic design parameters for the above three reference plants are summarized in Table II-1. The coal analyses of the two different coal types considered, Montana Rosebud subbituminous and Illinois #6 bituminous, are contained in Appendix A. Montana Rosebud coal was selected as the basic coal fuel type for all reference plants. Appendix A contains also EPA standards and emission limitations and regulations specified for this study (NSPS).

The overall power system designs and the results of performance calculations for the assumed basic plant design conditions and all parametric variations are described in this section for each reference plant separately. Before this description, a general discussion is first presented of the overall power cycle performance analysis.

A description and technical discussion of the design and performance of individual plant equipment and major items are contained in Section III.

The overall cycle efficiency of a binary MHD/Steam Power Cycle is in simple terms expressed as:

$$\eta_o = \frac{P_{MHD} - P_{compr} + P_{steam} - P_{aux}}{Q_{fuel}}$$

TABLE II-1

BASIC DESIGN PARAMETERS FOR THREE REFERENCE PLANT DESIGNS (PLANTS #1, #2 AND #3)

	PLANT #1	PLANT #2	PLANT #3
1. Plant Size	900 MW_e	*	*
2. Fuel	Mont. sub. bit. dried to 5% moisture	*	*
3. MHD Combustion			
Fuel	Pulverized Coal	Pulv. coal + char	Pulv. coal
Oxidizer	Air	*	Air enriched to 34.1% O_2
Combustor Type	Single stage	*	*
Ash Removal	70-80%	*	*
Oxidizer/Fuel Equiv. ratio	0.92	*	*
Combustor Coolant	HPBF Water	*	*
4. Preheater			
Type	Indirect, Regenerator	*	Direct, Recuperator
Preheat Temperature	2700°F	3000°F	1100°F
Fuel	LBtu Gas	*	N.A.
5. Gasifier for H. T. Preheater			
Type	Fixed bed, atm.	Entrained bed, atm.	N.A.
Fuel Produced	LBtu Gas	LBtu Gas & Char	N.A.
Fuel Gas Clean-up	Cold, 1/2 of gas produced	Cold, all of gas produced	N.A.
6. MHD Generator			
Magnetic Field	6T	*	*
Gas Seed Conv.	1%K	*	*
Channel Gas Vel.	Subsonic	*	*
Electrical Load Parameter	0.80	*	*
Diffuser recovery factor	0.60	*	*
Diffuser exit pressure	1 atm	*	*
Channel Coolant	LPBF water	*	*
7. Bottoming Plant			
Steam Conditions	2400 psig/1000°F/1000°F	*	*
Final MHD Gas Ox/Fuel Equiv. Ratio	1.05	*	*
Heat Rejection	Wet Cooling Towers	*	*
8. Seed Regeneration Process	Formate	*	*

---

*Same as items listed under Plant #1 column.

Neglecting auxiliary loss (P_{aux}) this is again expressed as

$$\eta_o = {}_{MHD} + \eta_s (1 - {}_{MHD}) \cdot f$$

where

$$\eta_{MHD} = \frac{P_{MHD} - P_{compr}}{Q_{fuel}} \quad \text{(MHD eff.)}$$

$$\eta_s = \text{steam plant efficiency} \left(\frac{\text{Steam Power}}{\text{Heat Absorbed in Steam Cycle}} \right)$$

f = waste heat recovery factor

Thus, it is seen that the overall efficiency depends upon the net energy output ($P_{MHD} - P_{compr}$) or efficiency (η_{MHD}) of the prime MHD cycle and the efficiency of the bottoming steam plant along with the fraction of waste heat that can be absorbed in the bottoming plant. The basic way to optimize the overall cycle efficiency is to increase η_{MHD}, which means to raise the relative fraction of net power ($P_{MHD} - P_{compr}$) from the prime MHD cycle. The amount of power which can be extracted from the MHD generator is governed by the thermodynamic and electrical properties of the working fluid along with design parameters and constraints selected for the channel. The MHD generator working fluid is again specified by the fuel, oxidizer and seed compositions and its preheat temperatures along with the heating value of the fuel and assumed MHD combustion conditions.

Efficient utilization of the waste heat contained in the higher temperature MHD generator exhaust gas and lower temperature exhaust gas from the high temperature air preheater system becomes important for maximizing, $f \cdot \eta_s$ and hence overall cycle efficiency, η_o. Maximum heat recovery is obtained by cooling the combustion gases to the lowest temperature level so as to minimize stack losses, and to recover all heat losses from the prime cycle components [MHD combustor cooling, nozzle cooling, channel cooling, diffuser cooling, high temperature air heater system cooling (if applied), gasifier system cooling (if applied), compressor intercooling (if applied) etc.]. The actual heat energy which can be utilized is limited by physical and economical constraints in heat exchanger design.

The design of heat exchanger equipment must be based on a minimum acceptable heat temperature difference between the fluids involved in order to avoid pinch-point problems.

An effort was made in the parametric analysis to develop design information which could be utilized for direct comparison between all design cases considered. Thus, for all of the assumed design conditions for the three reference plants, the critical electrical (E_x, E_y, J_y, $\omega\tau$) and gasdynamic (L/D) operating parameters of the MHD generator channel were kept within the same specified limitations. Furthermore, for each plant design and its parametric variations, the net energy output ($P_{MHD} - P_{compr}$) from the prime MHD cycle was optimized. In simplified terms, this means that the pressure ratio across the channel in all design cases was optimized. Also, the recovery and utilization of waste heat in the bottoming plant was optimized. However, it should be recognized, that a complete and detailed design optimization of the MHD generator channels and of the respective power plant power cycles was not conducted. This requires substantial detailed design effort with iterations which were beyond the scope of the parametric analysis of Task I. Further design optimization is expected to be an important part of conceptual designs in the subsequent Task II activity. Rather Task I serve to provide the information and basis for a comparative evaluation between different plant designs and of the effects of variations in specific plant design assumptions and parameters.

2.2 CASE I - REFERENCE PLANT I

The flow schematic in Figure 2-1 shows the power plant configuration of Reference Plant 1. The state-of-the-art gasifier selected for production of the LBtu fuel gas for separate firing of the high temperature air preheater is a fixed bed gasifier of the Wellman-Galusha type. Data obtained for the characteristics of the fuel gas produced from the Wellman-Galusha gasifier for Montana Rosebud subbituminous coal assumed dried to 5% moisture content and Illinois #6 bituminous coal assumed dried to 2% moisture content are presented in Table II-2 and II-3 respectively. The fuel gas is delivered from the gasifier reactor at a temperature of about 680°F for Montana Rosebud coal feed and about 100°F higher for Illinois #6 coal feed. An overall heat balance for the Wellman-Galusha gasifier systems based on the use of Montana Rosebud coal feed is shown in Table II-4.

The relatively low operating temperature of the Wellman-Galusha fixed bed type gasifier results in tar and oil formation. These tar components are vaporized in the hot gas at the gas temperature delivered from the gasifier, but will condense in the gas when the gas is cooled for the purpose of gas cleaning and sulfur removal. The total hot gas thermal efficiency $\left(\frac{\text{Btu product gas}}{\text{Btu coal feed}}\right)$ including sensible heat and the heating value of vaporized tars is projected to be 91%. The total cold gas efficiency is projected to be 81%. This includes the heating value of condensed tars recovered from the gas.

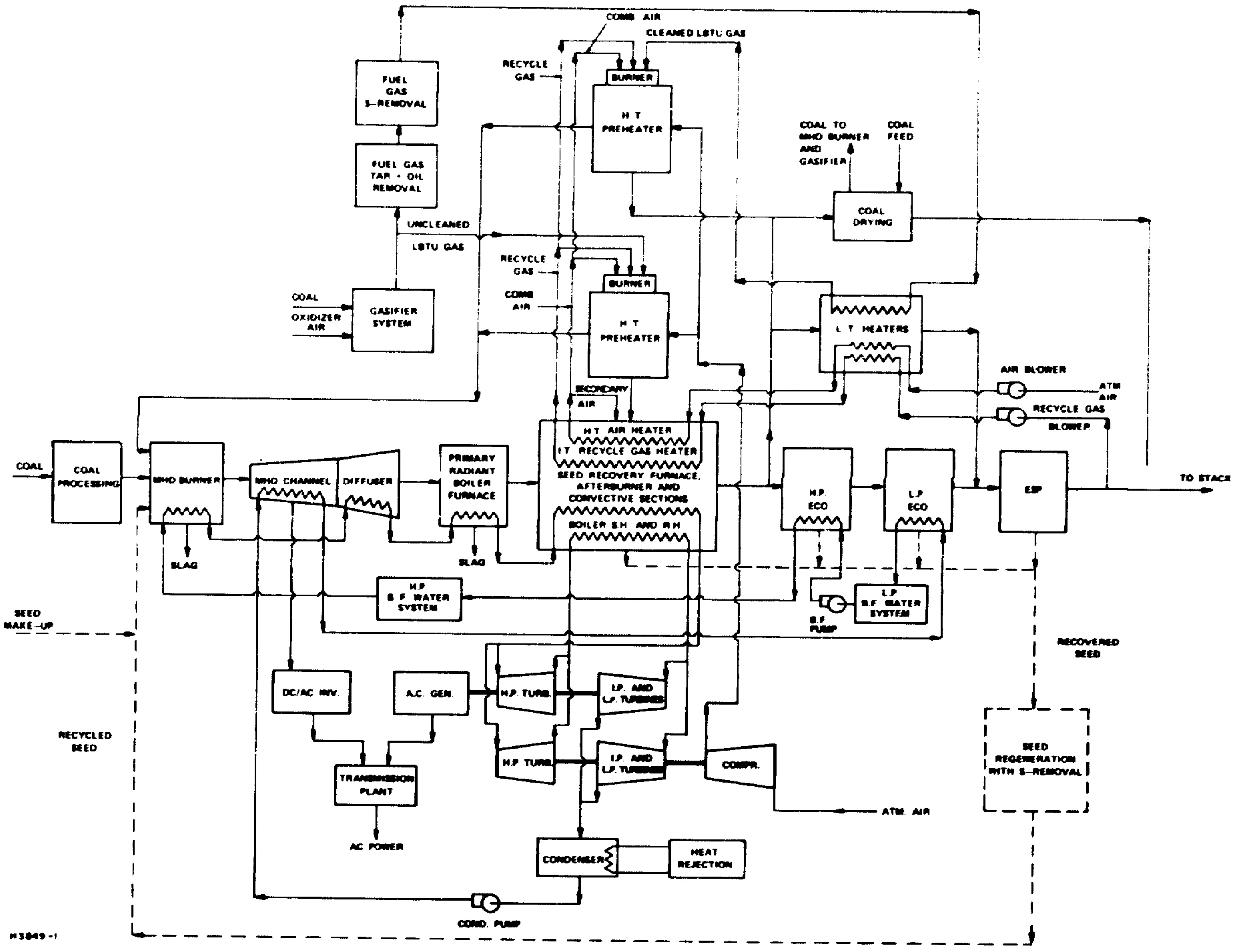

Fig. 2-1 Cycle Configuration of Reference Plant 1

TABLE II-2

PRODUCT GAS CHARACTERISTICS

(Montana Rosebud Feed)*

Composition (Vol. percent)	
CO	24.43
CH_4	2.93
CO_2	4.40
H_2	9.92
N_2	47.76
H_2S	0.22
H_2O	10.36
Average Mol. Wt.	24.75
Product Gas HHV (wet basis Btu/SCF)	139.8
HHV of Tar Component	15.4
Product Gas Temperature (°F)	680.
Heat Capacity (dry gas) (Btu/SCF)	0.0196

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*Dried to 5% moisture

TABLE II-3

PRODUCT GAS CHARACTERISTICS

(Illinois No. 6 Feed)*

Composition (Vol. percent)	
CO	25.10
CH_4	2.76
CO_2	3.77
H_2	12.48
N_2	47.29
H_2S	0.69
H_2O	7.92
Mol. Wt.	24.17
Product Gas, HHV, wet basis, Btu/SCF	148.5
HHV of Tar Component	16.3
Product Gas Temperature (°F)	784.
Heat Capacity (dry gas) (Btu/SCF)	0.0196

---

*Dried to 2% moisture

TABLE II-4

GASIFIER HEAT BALANCE - REFERENCE PLANT #1

	Btu/lb Coal Gasified	Per Cent
Heat Input		
Coal HHV (5% H_2O)	10,962	100.0
Heat Output		
Gas HHV (139.8 Btu/scft)	8,355	76.2
Gas Sensible Heat (680°F)	700	6.4
Tar HHV	920	8.4
Unreacted Steam	307	2.8
Unreacted Carbon and Other Losses	680	6.2
	10,962	100.0
Hot Gas Eff. (Incl. Tar)		% 91.0
Cold Gas Eff. (Incl. Tar)		% 81.0
Overall Gasifier Eff. (Incl. Tar)		% 86.0

The emission standards specified for use in this study require that 85% of the sulfur contained in the total coal feed to the plant must be removed. The fuel heat input to the high temperature air heater is roughly 1/3 of the total fuel heat input to the plant for the basic preheat design temperature of 2700°F for Reference Plant 1. Consequently, more than half of the sulfur contained in the coal feed to the gasifier must be removed in order to satisfy specified sulfur emission regulations. This assumes complete sulfur removal otherwise by seed contained in the MHD combustion gases.

The sulfur in the coal feed to the gasifier system for production of the fuel gas to the high temperature air preheater system was considered removed as follows: Half of the high temperature preheater system is fired with fuel gas delivered directly from the gasifier without prior sulfur removal. It is noted that the fuel gas produced in the gasifier is cleaned of particulate matter in cyclones which are part of the gasifier equipment. However, no reliable data is yet available on the exact amount of particulate matter contained in the product fuel gas. The combustion gases exhausting from the section of the high temperature preheater system which burns fuel gas delivered directly from the gasifier are mixed with MHD combustion gases in the bottoming steam plant in order to utilize the seed in the MHD combustion gases for sulfur removal from this gas also. The temperature range for mixing of these gases is important. On the one hand the mixing temperature should be above the dew point for seed in the gas (~1500°K) so that sulfur oxides contained in the high temperature air heater exhaust gas can react rapidly with seed to form K_2SO_4. On the other hand, the high temperature air heater exhaust gas should not be mixed with MHD combustion gases at temperatures above 1900°K so as to interfere with NO_x decomposition in the MHD combustion gases.

Thermodynamic calculations showed that the total adiabatic gas mixture temperature is 1660°K (2528°K) when high temperature air preheater exhaust gas at 700°F is mixed with MHD combustion gas exiting from the primary radiant furnace at 1866°K (2900°F) and afterburning of the MHD combustion gases is simultaneously performed with secondary combustion air preheated to 1100°F. The actual gas mixture temperature would be somewhat less since heat transfer from the gases is involved. Considering this, it still appears feasible to perform sulfur removal of the high temperature preheater exhaust gas as discussed above. However, these analyses show that no more than about half of the exhaust gas from the high temperature air preheater system as here considered should be mixed with MHD combustion gases in order to avoid a gas mixture temperature which is too low. The other half of the high temperature preheater system is fired with fuel gas which has been cleaned of sulfur. This involves first scrubbing, cooling and cleaning of the gas including water treatment and separation and removal of condensed tars, phenols and ammonia. The sulfur is subsequently removed from the cooled gas in a cold gas Stretford sulfur cleaning process. The recovered tar oils are considered burned in the high temperature air preheater system (alternatively MHD combustor) so that their heating values are utilized within the power system. The sensible heat of the fuel gas is considered lost in cooling of the gas since recovery of this heat appears impractical. The cleaned fuel gas is preheated to 600°F before firing in the high temperature preheater system by heat recovery from combustion gases. Figure 2-2 is a schematic block diagram of the gasifier subsystem for reference plant 1. The overall thermal efficiency of the total gasifier system with cold gas cleaning and sulfur removal of about half of the gas produced from the gasifier as described above is projected to be 86%.

The assumed basic design conditions and all parametric points variations for Reference Plant 1 are shown in Table II-5. Corresponding calculated design and performance data for the MHD prime cycle of this reference plant including the MHD coal combustor and MHD generator channel are listed in Table II-6. Mass and energy balances for the high temperature air heater subsystem and for the combined MHD/bottoming plant are listed in Table II-7 and Table II-8 respectively.

Figure 2-3 is a flow diagram with a heat balance for the total steam and feed water cycle for the base case (p.p.1) of Reference Plant 1. The economizer duty is split into low pressure and high pressure sections and seven feed water heaters are utilized. This results in a steam cycle efficiency $\left(\frac{\text{Total steam plant output}}{\text{Total heat absorbed steam plant}}\right)$ of 42.67%. This calculated steam cycle efficiency for the base case is used for all other parametric points of Reference Plant 1 except for the parametric point case 12. This latter case considers Illinois #6 as the coal fuel type. The raw moisture content of Illinois #6 is about half of that of Montana Rosebud (8.7% versus 22.7%). Consequently, less heat is required for drying of Illinois #6 coal. This means that relatively more low grade heat must be absorbed from the combustion gases in the economizer which again reduces the amount of possible regenerative feed water heating. Because of this, the steam cycle efficiency for the parametric point case 12 with the use of Illinois #6 has been reduced slightly from the base case value of 42.67% to 42.3%.

The overall energy balance of Reference Plant 1 is shown in Table II-9.* Figure 2-4 is a bar chart showing comparative calculated net plant efficiency values for the various design cases considered for Reference Plant 1. The net plant efficiency decreases with plant size and the relative reduction increases as

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*Appendix B lists the auxiliary power requirements of all three reference plants

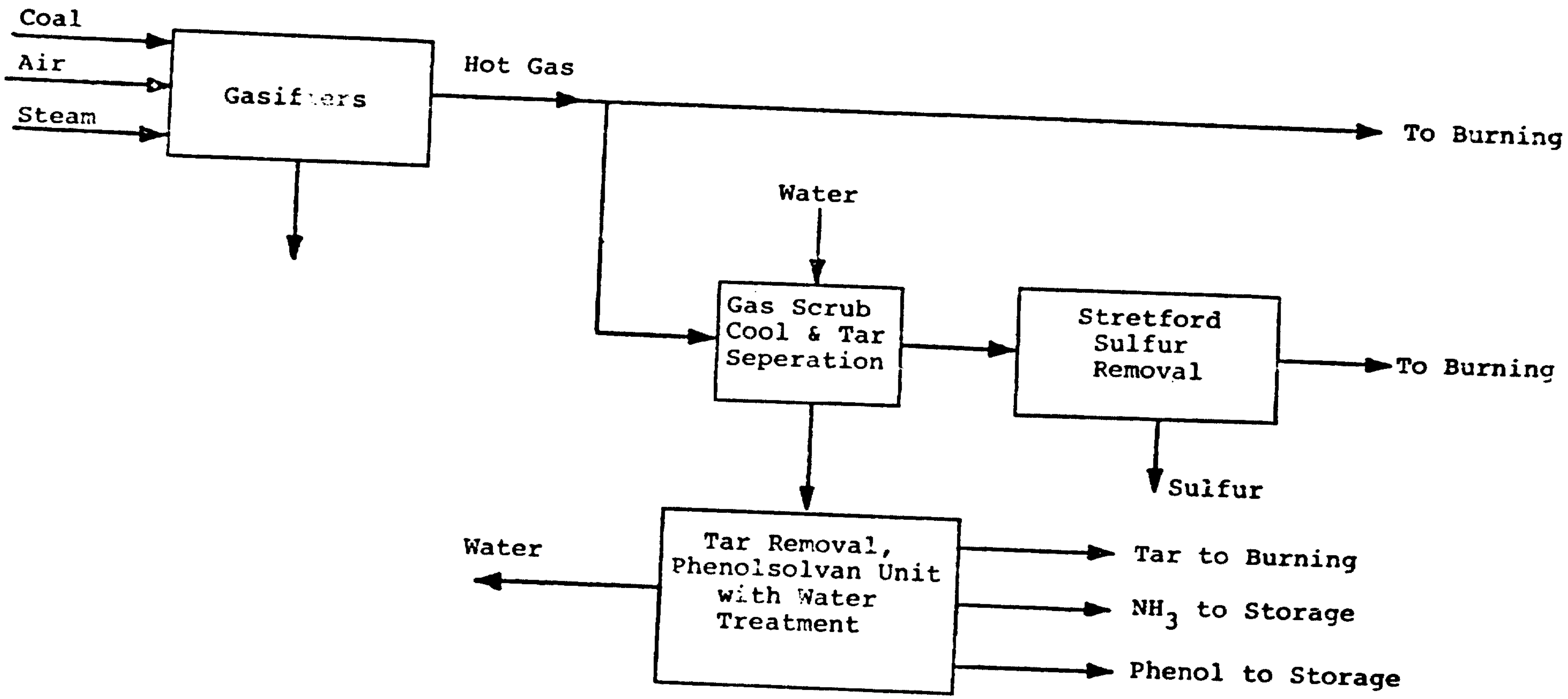


Fig. 2-2 Gasifier System for Reference Plant 1

TABLE II-5. PARAMETRIC VARIATIONS FOR REFERENCE PLANT DESIGN NO. 1

	1 (Basis)	2	3	4	5	6	7	8	9	10+	11+	12
1. Plant Size - MW	900	400	600	900								
2. Fuel Type	Mont. Subbit.											Ill. #6
3. MHD Combustion:												
Oxidizer	Air				Air + O_2	Air						
Fuel Moist. as fired - %	5					10	5					2
Combustor Type	Single Stage											
Ash Removal - %	80											
Oxidizer/Fuel Equiv. Ratio	0.92											
Combustor Coolant	HPBF Water											
4. High Temp. Regenerative Htr:												
Oxidizer Preheat Temp. - °F	2700			3000	2700							
Reheat Gas Press. - atm	~1.1											
Reheat Fuel Gas	LBTU Gas											
5. Gasifier for HT Preheater Fuel:												
Type	Fixed Bed											
Fuel Produced	LBTU Gas											
Oxidizer	Air											
Fuel Gas Clean-up	Cold (1/2 of gas prod.)											
6. MHD Generator:												
Channel Type	Diagonal											
Peak Magnetic Field - Tesla	6											
Gas Seed Conc. - %K	1.0											
Channel Elect. Load Par.	0.80							0.77	0.83	0.80		
Diffuser Recovery Factor	0.60									0.50	0.60	
Diffuser Exit Press. - atm	1.0											
Channel Coolant	LPBF Water											
7. Bottoming Plant:												
Main Steam	2400 psia, 1000°F											
Reheat Steam	1000°F											
Final Ox/Fuel Equiv. Ratio	1.05											
HT Preheater Comb Air PH Temp-°F	1100						1300	1100				
HT Preheater Recycle Gas PH Temp. - °F	1100			N. A.			1300	1100				
8. Seed Regeneration Process	Formate										Carb. red.	Formate

+Performance analysis only.

TABLE II-6. MHD PRIME CYCLE DESIGN DATA - REFERENCE PLANT # 1

PARAMETRIC POINT		BASIS 1	2	3	4	5	6	7	8	9	10	11	12
MHD COMBUSTOR		900 MW	400 MW	600 MW	3000°F Preheat	Air + Ox.	10% H_2O	1300°F PH Pre-heat	α = 0.77	α = 0.83	η_D=0.5	Carb. Red	Ill. #6
Fuel Thermal Input (HHV)	MW	1443	641	962	1443	1632	1421		1443	1443	1443		1468
Exit Pressure	ATA.	6.74	5.71	6.43	8.3	8.3	6.54		7.26	6.12	6.85		7.26
Exit Temperature	°F	4597	4561	4584	4715	4752	4572		4606	4586	4599		4672
Heat Loss	MW	55	30.5	40.2	62	62	52		55	55	55		55
MHD GENERATOR													
Magnetic Field Strength	Tesla	6.0											→
Electrical Load Parameter		0.8						→	0.77	0.83	0.8		→
Inlet Mach.No.		0.8											→
Max Axial Field (Ex)	KV/M	2.7	2.2	2.4	2.3	2.1	2.7		3.2	2.2	2.7		2.6
Max Transverse Current (Jy)	amp/cm²	0.9	0.9	0.9	1.0	1.1	0.8		1.0	0.8	0.9		1.0
Max Hall Parameter (Wτ)		6.0	5.8	5.7	5.8	5.6	5.5		6.0	5.7	5.8		5.9
Channel Inlet Dimension	MXM	1.1 x 1.1	0.8x0.8	0.9x0.9	1.0x1.0	1.0x1.0	1.1x1.1		1.0x1.0	1.1 x1.1	1.0x1.0		1.0x1.0
Channel Exit Dimension	MXM	2.6 x 2.6	1.7x1.7	2.2x2.2	2.6x2.6	2.6x2.6	2.6x2.6		2.6x2.6	2.6x2.6	2.6x2.6		2.6x2.6
Channel Length	M	16.6	13.8	16.2	19.5	17.5	16.6	SAME AS BASIS	15.6	16.7	16.4	SAME AS BASIS	16.0
Diffuser Reco. Factor		0.6								→	0.5		0.6
Channel Heat Loss	MW	65	35.2	51.8	83	80.2	64		64	64.4	66.7		66.6
Channel Enth. Extr.	%	23.5	21.0	22.7	25.3	24.7	23.1		23.7	22.8	23.1		24.5
MHD PRIME CYCLE													
MHD Power	MW	495	195	318	556	560	480		500	480	487		519
Compressor Power	MW	113	44.8	73.8	129	142*	109		119	106	114.3		120
Net Power	MW	382	150.2	244.2	427	418	371		381	374	372.7		399
MHD Cycle Eff.	%	17.5	15.5	16.8	18.6	17.9	17.2	17.9	17.5	17.1	17.1	17.5	18.1

* Includes 16.4 MW For O_2 Compressor

TABLE II-7. REFERENCE PLANT 1 - HIGH TEMPERATURE AIR HEATER SYSTEM

Parametric Point	1	2	3	4	5	6	7	8	9	10	11	12
MASS FLOW RATES-10^3 pph												
Fuel Gas	920.2	408.9	613.4	1062	880.0	912.6	867.3	911	929.1	920.2	920.2	856
Comb. Air	1317.6	585.6	878.4	1530	1260.0	1306.7	1317.6	1317.6	1317.6	1317.6	1317.6	1305
Recycle Gas	508.0	225.8	338.7		485.8	503.8	508.0	508.0	508.0	508.0	508.0	502
TOTAL	2745.8	1220.3	1830.5	2592	2625.8	2723.1	2692.9	2736.6	2754.7	2745.8	2745.8	2663
HEAT INPUTS-MW												
Fuel Gas (HHV + Sensible)	654.2	290.8	436.1	755.0	625.6	645.0	616.6	648.2	661.2	654.2	654.2	648.0
Comb. Air	98.8	43.8	65.9	114.7	94.5	98.0	125.2	98.8	98.8	98.8	98.8	97.9
Recycle Gas	39.6	17.6	26.4		37.9	39.3	47.8	39.6	39.6	39.6	39.6	39.4
TOTAL	792.6	352.3	528.4	869.7	758.0	782.3	789.6	786.6	799.6	792.6	792.6	785.3
HEAT OUTPUTS-MW												
Cycle Air	605.0	270.2	405.3	688.0	574.7	600.0	605	599	612	605	605	601.0
Exhaust to Bottoming Plant	62.6	27.8	41.7	59.2	59.9	61.8	62.6	62.6	62.6	62.6	62.6	61.8
Coal Drying	52.0	23.1	34.7	54.6	55.6	36.5	52.0	52.0	52.0	52.0	52.0	*48.3
Stack Loss	45.8	20.4	30.5	43.3	43.8	60.0	45.8	45.8	45.8	45.8	45.8	50.0
Heat Loss	27.2	10.8	16.1	24.6	24.0	24.0	24.2	27.2	27.2	27.2	27.2	24.2
TOTAL	792.6	352.3	528.3	869.7	758.0	782.3	789.6	786.6	799.6	792.6	792.6	785.3

*Includes 32.1 MW for heating of secondary air leaving 16.2 MW for coal drying.

TABLE II-8. MASS AND ENERGY BALANCE - MHD/BOTTOMING PLANT -REFERENCE PLANT #1

PARAMETRIC POINT		BASIS 1	2	3	4	5	6	7	8	9	10	11	12
MASS FLOW RATES	(10³ PPH)												
Raw Coal (22.7% H₂0)		552.14	245.4	368.1	552.14	624.6	543.26	552.14	→	→	→	→	439.26
Dried Coal (5% H₂0)		449.29	199.68	299.53	449.29	508.3	466.6	449.29	→	→	→	→	408.33
Primary Air (92% of theor)		3453	1534.7	2302	3453	3204.5A 163.70	3409.7	3453	→	→	→	→	3468
Secondary Air (5% excess)		468	208	312	468	468	461	468	→	→	→	→	468
Seed (All as K₂SO₄)		89.7	39.9	59.8	89.7	89.7	89.7	89.7	→	→	→	→	89.7
HEAT INPUTS	(MW)												
Coal (HHV)		1443	641	962	1443	1632	1421	1443	→	→	→	→	1450
Coal Drying		34.8	15.46	23.2	34.8	39.4	24.57	34.8	→	→	→	→	10.8
Primary Air		718	319	479	817	700.3	709	718	→	→	→	→	721
Secondary Air		32.1	14.3	21.4	32.1	32.1	31.6	32.1	→	→	→	→	32.2
HTAH Exhaust		62.6	27.8	41.7	59.2	59.2	61.8	62.6	→	→	→	→	61.8
Seed Chemistry		16.0	7.3	10.0	16.0	16.0	16.0	16.0	→	→	→	7.0	48
TOTAL		2306.5	1024.9	1538.3	2402.1	2475.0	2264	2306.5	2306.5	→	→	2297.5	2323.8
HEAT OUTPUTS	(MW)												
MHD Power		495	195	318	556	560	480	495	500	480	487	495	519
MHD Heat Losses													
Burner		55	30.5	40.2	62	62	52	55	55	55	55	55	55
Channel		65	35.2	51.8	83	80.2	64	65	64	64.4	66.7	65	66.6
Diffuser		53	22.9	36.2	53	54.2	51.8	53	54.2	52.6	53	53	52.6
I.T. Air Heater (1100°F)		64.2	28.9	42.8	74.4	62.0	63.4	90.6	63.2	64.6	64.2	642	63.6
I.T. Recycle Gas Heater (1100°F)		19.7	8.9	13.1		18.6	19.4	27.8	19.4	19.8	19.7	19.7	19.6
L.T. Air Heater (600°F)		66.7	30.1	44.4	72.3	64.5	65.8	66.7	65.7	67.1	66.7	66.7	34.2
L.T. Recycle Gas Heater (600°F)		12.8	5.8	8.5		12.1	12.6	12.8	12.6	12.9	12.8	12.8	12.7
L.T. Fuel Gas Htr. (600°F)		20.5	9.2	13.7	23.7	19.4	20.2	20.5	20.2	20.6	20.5	20.5	20.4
H.P. & L.P. Econ.		78.5	34.9	52.3	78.5	78.5	78.5	78.5	→	→	→	→	78.5
Stack Loss		163.2	72.5	108.8	163.2	175.2	160.7	163.2	→	→	→	→	140
Heat Losses		31.3	14.1	20.2	31.0	31.3	31.3	31.3	→	→	→	→	31.3
Steam Generator		1181.6	536.9	788.3	1204.7	1261.0	1164.3	1147.1	1179	1196.5	1188	1172.6	1230.1
TOTAL	MW	2306.5	1024.9	1538.3	2402.1	2475.0	2264	2306.5	2306.5	→	→	2297.5	2323.8

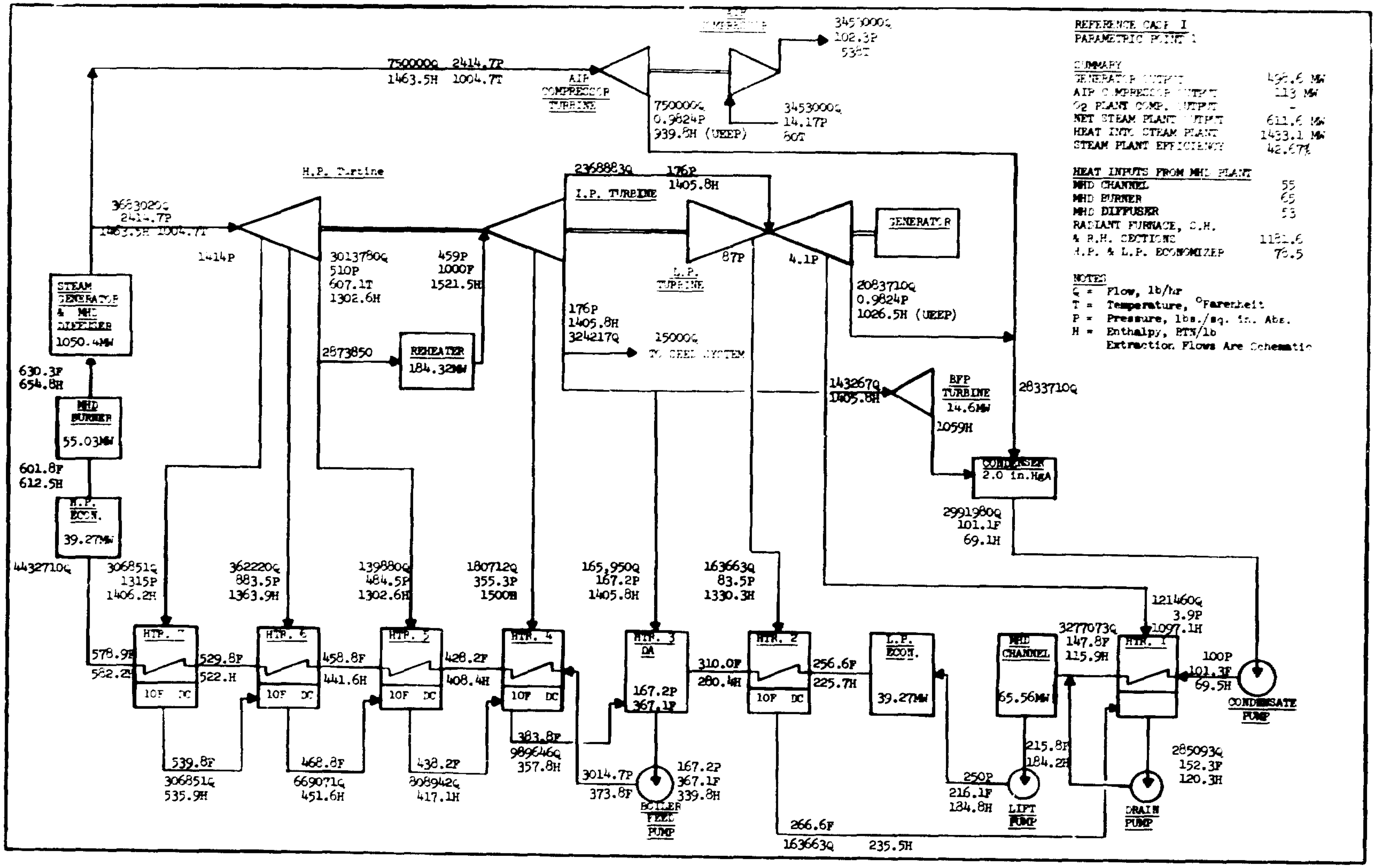
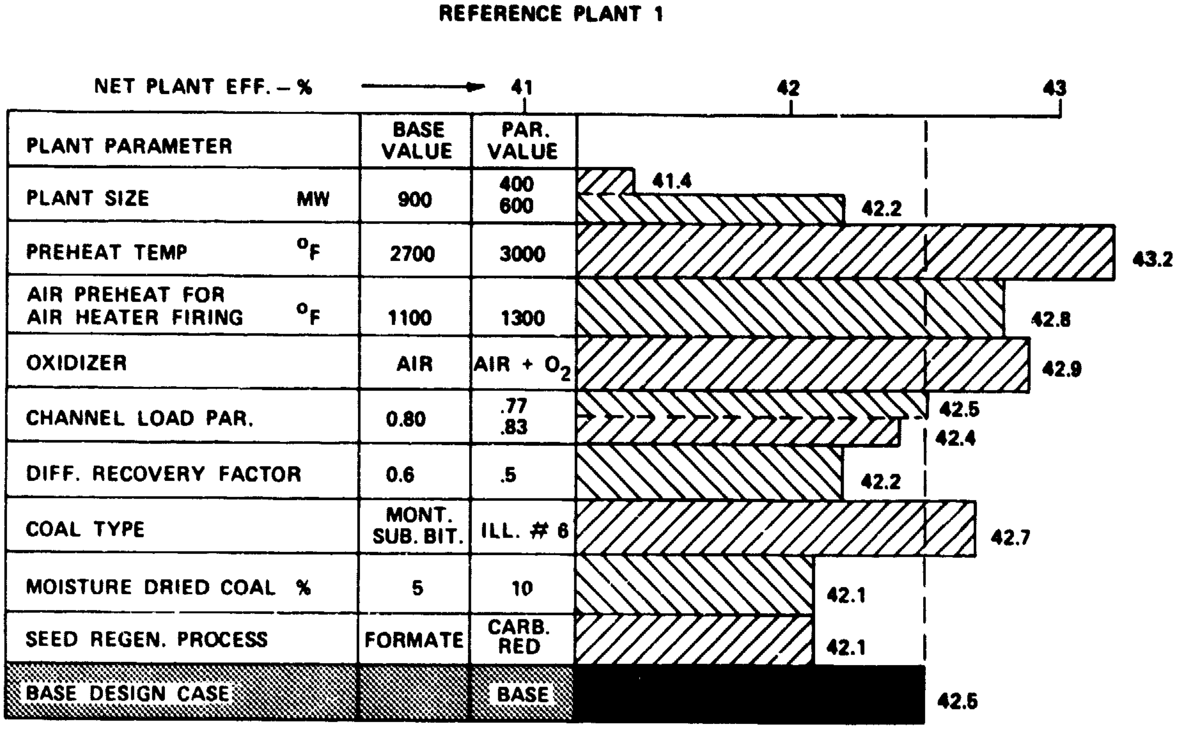


Fig. 2-3 Steam and Feed Water Cycle for Reference Plant 1

TABLE II-9. OVERALL ENERGY BALANCE - REFERENCE PLANT #1

Parametric Point	1	2	3	4	5	6	7	8	9	10	11	12
	900 MW	400 MW	600 MW	3000°F Preheat	Air + O	$10\%H_2O$	1300°F PH Pre-heat	α =0.77	α =0.83	h_D=0.5	Carb. Red.	Ill #6
Fuel Heat Inputs-MW												
MHD Burner	1443	641	962	14[illegible]	[illegible]32	1421	1443	1443	1443	1443	1443	1450
Gasifier for H.T. Air Heater	737	327	491	8[illegible]	705	732	693	734	741	737	737	730
Gasifier for Seed Regeneration	20	9	1[illegible].5	20.5	22	20.5	20	20	20	20	34	60
TOTAL	2200	977	1466.5	2313.5	2359	2173.5	2156	2197	2204	2200	2214	2240
Gross Power Outputs-MW												
MHD Power	495.0	195	318	556	560	480	495	500	480	487	495	519
Steam Power	611.6	281	413	632	655	602	597	610	617	615	608	*628
TOTAL	1106.6	476	731	1188	1215	1082	1092	1110	1097	1102	1103	1147
Auxiliaries and Losses-MW												
Compressor	113.0	44.8	73.8	129.0	142.0	109.0	113.0	119.0	106.0	114.3	113.0	120.0
Aux. and Other	47.5	21.6	31.9	47.2	49.7	47.3	46.6	47.3	47.6	47.4	47.5	61.8
Inverter and Transformer	10.0	5.0	6.5	11.0	11.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
TOTAL	170.5	71.4	112.2	187.2	202.7	166.3	169.6	176.3	162.6	171.7	170.5	191.8
Net Plant Output-MW	936.1	404.6	618.8	1000.8	1012.3	915.7	922.4	933.7	933.4	930.3	932.5	955.2
Net Plant Efficiency-%	42.5	41.4	42.2	43.2	42.9	42.1	42.8	42.5	42.4	42.2	42.1	42.7
												*42.3%



PLANT PARAMETER		BASE VALUE	PAR. VALUE	NET PLANT EFF. – %
PLANT SIZE	MW	900	400 600	41.4 42.2
PREHEAT TEMP	°F	2700	3000	43.2
AIR PREHEAT FOR AIR HEATER FIRING	°F	1100	1300	42.8
OXIDIZER		AIR	AIR + O_2	42.9
CHANNEL LOAD PAR.		0.80	.77 .83	42.5 42.4
DIFF. RECOVERY FACTOR		0.6	.5	42.2
COAL TYPE		MONT. SUB. BIT.	ILL. # 6	42.7
MOISTURE DRIED COAL	%	5	10	42.1
SEED REGEN. PROCESS		FORMATE	CARB. RED	42.1
BASE DESIGN CASE			BASE	42.5

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Fig- 2-4 Comparative Plant Efficiencies for Reference Plant 1 the plant size decreases. The increase in cycle air preheat temperature from 2700°F to 3000°F results in a gain of plant efficiency from 42.5% to 43.2%. (It is noted that the relative increase in plant efficiency with increase of preheat temperature for an MHD power plant cycle with separately fired high temperature air preheater as here considered would be less than expected for a mature power plant cycle with the use of a directly fired high temperature air preheater.) An increase of the heat input of the combustion air used for separate firing of the high temperature air heater by increasing the preheat temperature of this air from 1100°F to 1300°F increases the plant efficiency slightly or with 0.3 percentage point, because of a corresponding reduction in the fuel heat input required for the high temperature air heater. The use of a relatively low degree of oxygen enrichment of the cycle air (24.1% O_2 by volume) and the same level of preheat of 2700°F as in the base case increases the plant efficiency slightly from the base case value of 42.5% to 42.8% after the amount of power required for production of the oxygen necessary for oxygen enrichment of the cycle air has been deducted. However, this plant efficiency of 42.8% is still less than that attained by the use of air only with an increase of the air preheat temperature to 3000°F (43.2%). A decrease of the channel load parameter from the base case value of 0.80 to 0.77 resulted in the same plant efficiency of 42.5% as in the base and an increase of the load parameter to 0.83 decreased the efficiency with 0.1 percentage point only. This indicates that the optimum value of the channel load parameter is 0.80 or thereabout. A decrease of the diffuser recovery factor from 0.6 to 0.5 decreased the net plant efficiency with 0.3 percentage points. The use of Illinois #6 coal type instead of Montana Rosebud resulted in a slight increase of the plant efficiency to 42.7% or 0.2 percentage points. Combustion of Illinois #6 coal dried to 2% moisture as fired results in a slightly higher flame temperature than combustion of Montana Rosebud coal dried to 5% moisture as fired. This improved the performance of the MHD generator. However, the sulfur content of Illinois #6 coal is significantly higher than that of Montana Rosebud, 3.3% versus 0.85%. This increases the energy requirements associated with sulfur removal and seed regeneration. The overall result of these two opposing effects is that the difference in overall plant efficiency for the two coal types is relatively small and calculated to be 0.2 percentage points.

Drying of Illinois #6 bituminous coal to its assumed moisture content of 2% as fired is standard utility practice. The assumed basic moisture content of 5% of Montana subbituminous coal as fired is considered practical based on experience with conventional coal drying processes of high moisture content coals. This type of coal is now often dried to 10% moisture content during milling. Drying of Montana subbituminous coal to 10% instead of 5% as fired reduces the overall plant efficiency by 0.4 percentage points to 42.1% because of a reduction in flame temperature and hence MHD generator performance.

The selection of a carbon reduction process for seed regeneration instead of the assumed formate process as assumed in the base case reduces the plant efficiency also with 0.4 percentage points. It is emphasized that the design data used for the formate seed regeneration process are considered more reliable than those used for the carbon reduction process because the formate process is adapted from a proven industrial process whereas the carbon reduction process presently only is conceptual and therefore has a higher degree of uncertainty.

Figure 2-5 is a flow diagram of Reference Plant 1 with state point conditions for the gas and air sides identified for the base case. The state point conditions for the water and steam side for this case was identified in Fig. 2-3.

2.3 CASE II - REFERENCE PLANT 2

The power cycle configuration of Reference Plant 2 is shown in Fig. 2-6. It is based on the use of a separately fired high temperature air preheater as in Case I for Reference Plant 1. However, in this Case II, the fuel for firing of the high temperature air preheater is produced in an entrained bed LBtu gasifier of the advanced type. This type of gasifier is presently under development by Combustion Engineering, Inc. Figure 2-7 is a schematic block diagram of the C-E Gasifier Subsystem. It consists of an atmospheric pressure gasifier with heat recovery sections, particulate removal system and a cold gas Stretford type sulfur removal system. The gasifier is blown with preheater air. Roughly, 2/3 of the gasifier air is preheated to 1100°F in the base design case. The remaining 1/3 of the air which is utilized for transport and feed of coal to the gasifier is preheated to 300°F. The first part of the gasifier heat recovery system is utilized for production of main steam (2400 psi/1000°F) and it is integrated with the main steam generator of the bottoming steam plant.

Final heat recovery is attained by preheating of the LBtu gas produced to 900°F in the base design case after sulfur removal and before firing of the high temperature air preheater. This final heat recovery cools the gasifier product gas to 300°F at which temperature the product gas enters a scrubbing system for removal of particulate matter before sulfur removal. The dry char collected in the particulate removal systems is utilized as additional fuel for the MHD combustor. The char heating value represents roughly 10% of the heat input of coal feed to the gasifier or about 5.5% of the total fuel heat input to the MHD combustor for the base design case.

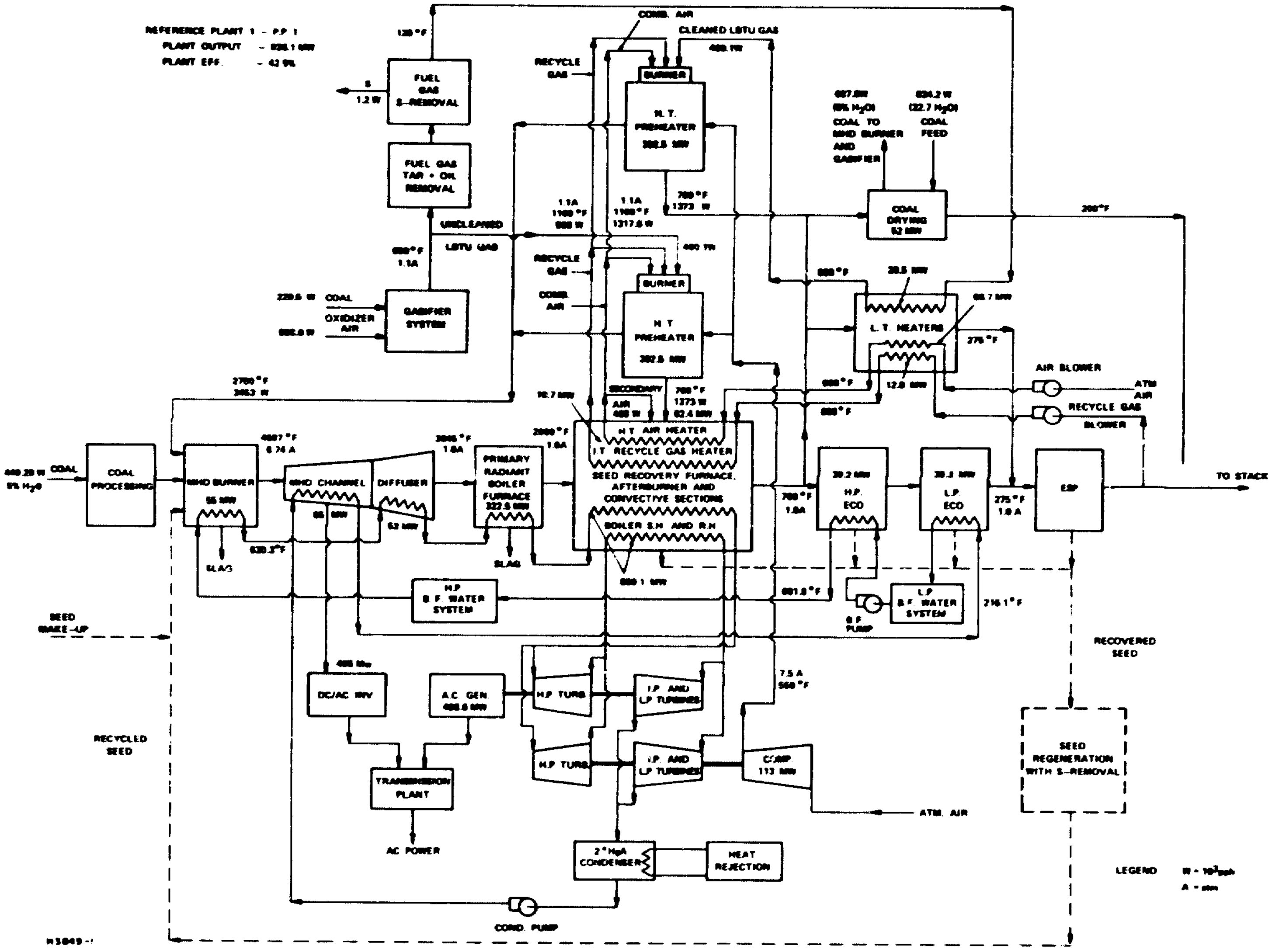

Fig. 2-5 Flow Diagram for Base Case of Reference Plant 1

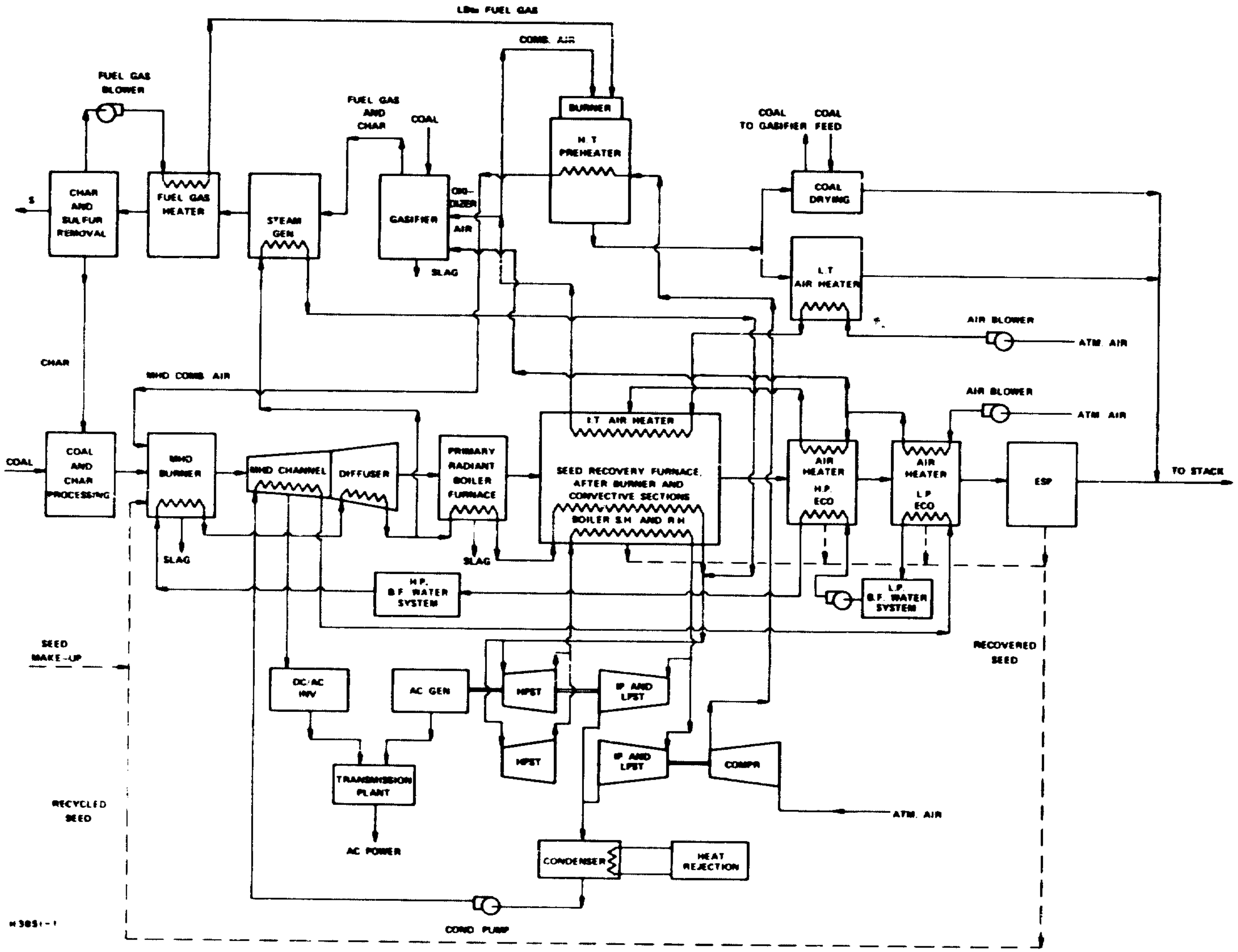

Fig. 2-6 Cycle Configuration for Reference Plant 2

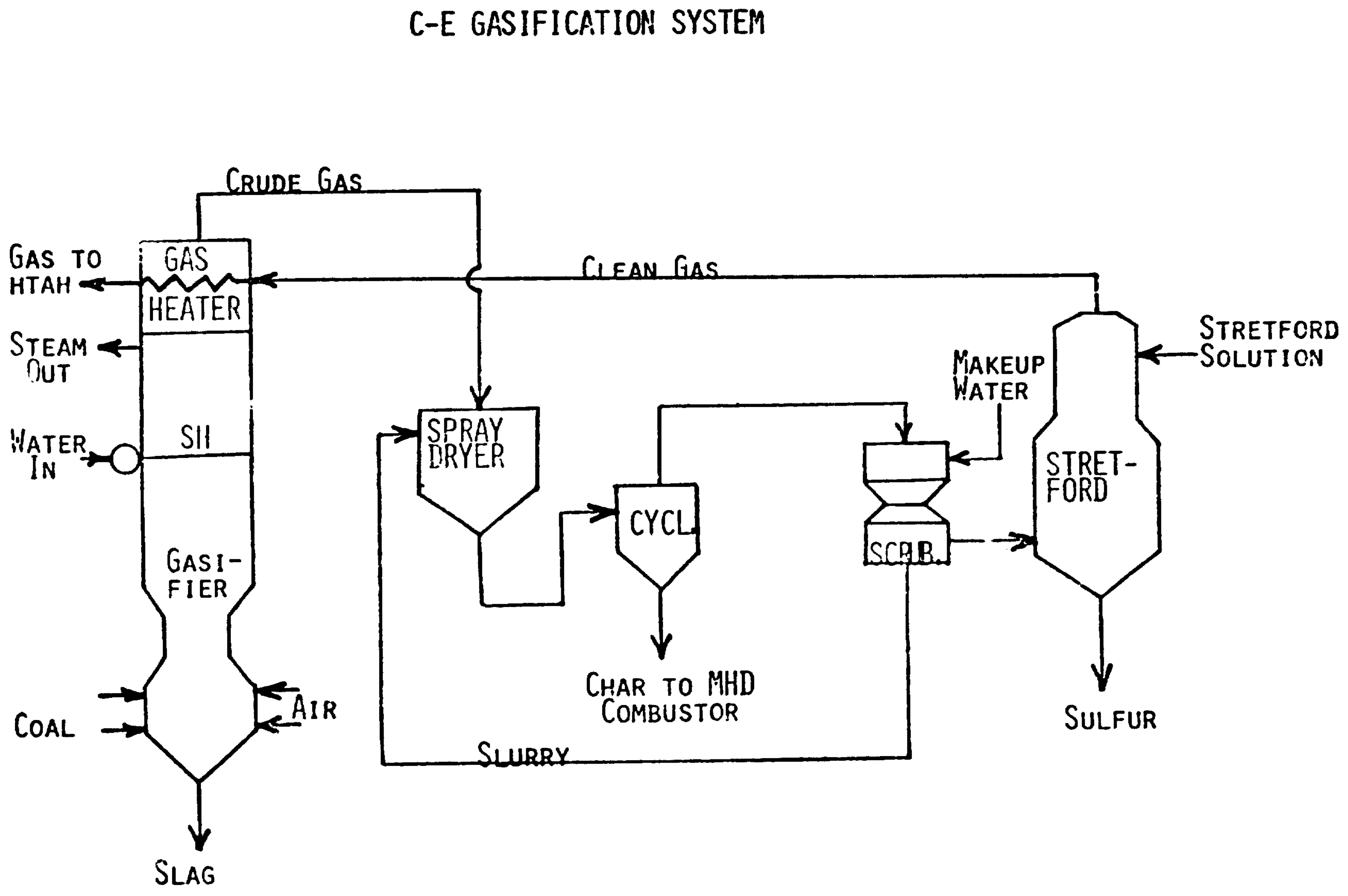

Fig. 2-7 C-E Gasification System for Reference Plant 2

The heating value of the clean LBtu fuel gas produced for separate firing of the high temperature air preheater is 140 Btu/scft for Montana Rosebud Coal feed at 5% moisture content and 148 Btu/scft for Illinois #6 coal feed at 2% moisture content. The fuel gas compositions for the two coal types are listed in Table II-10.

The parametric design case variations for Reference Plant 2 are listed in Table II-11. Corresponding calculated design and performance data for the MHD prime cycle of this reference plant including the MHD coal combustor and MHD generator channel are listed in Table II-12. Mass and energy balances for the high temperature air heater and gasifier subsystems and for the combined MHD/bottoming plant otherwise are listed in Tables II-13, II-14 and II-15, respectively.

Figure 2-8 is a flow diagram with a heat balance for the total steam and feed water cycle for the base case (p.p.1) of Reference Plant 2. The economizer duty is split in low pressure and high pressure sections and seven feed water heaters are utilized as in Reference Plant 1. The resulting calculated steam cycle efficiency $\left(\frac{\text{Total steam plant output}}{\text{Total heat absorbed steam plant}}\right)$ of 42.58% is practically identical to that for Reference Plant 1. Again, this calculated steam cycle efficiency for the base case is used for all other parametric points of Reference Plant 2 except for parametric point design Case 11 with the use of Illinois #6 coal in which case a slightly lower steam cycle efficiency of 42% has been used.

The overall energy balance of Reference Plant 2 is shown in Table II-16. Figure 2-9 is a bar chart showing the comparative calculated net plant efficiency values for the various design cases considered for Reference Plant 2. As in Case 1, a lower air preheat temperature results in a lower plant efficiency with 44.8% for the base design case with 3000°F preheat temperature and 44.3% for the parametric design case with 2700°F preheat temperature. Furthermore, similar to Case 1, increasing the preheat temperature of the combustion air and fuel gas to the high temperature air preheater increases the plant efficiency slightly. A variation of the channel load parameter from the base case value of 0.80 to 0.77 and 0.83 respectively, resulted in a slight decrease of the plant efficiency of 0.1 percentage point. This indicates that the optimum value of the channel load parameter is 0.80 or thereabout similar to Case 1. Again, a decrease of the diffuser recovery factor from 0.6 to 0.5 decreased the net plant efficiency slightly and with 0.2 percentage points. The increase of the diffuser recovery factor to 0.7 had the expected opposite effect and increased the plant efficiency with 0.2 percentage points.

TABLE II-10

C-E GASIFIER PRODUCT GAS

(NO CHAR RECYCLE)

Coal Type	Montana Rosebud	Illinois #6
Gas Composition (% by Volume)		
CO	27.1	30.0
CO_2	3.1	0.1
H_2	15.1	15.0
H_2O	5.6	5.4
N_2	49.1	49.5
H_2S	Trace	Trace
	100.0	100.0
Gas HHV (Btu/scf)	140.4	148.2

TABLE II-11. PARAMETRIC VARIATIONS FOR REFERENCE PLANT DESIGN #2 - CASE II

Parametric Point	1	2	3	4	5	6	7	8	9	10	11	12*	13*	14*	15*	16*	17*^	18*^	19*^
1. Plant Size - MW	900																		
2. Fuel Type	Mont. Subbit.										Ill. #6								
Moist. Cont. Dried Coal %	5																		
3. MHD Combustion:																			
Fuel	Pulv. Coal & Char																		
Oxidizer	Air																		
Combustor Type	Single Stage																		
Ash Removal - %	80																		
Oxidizer/Fuel Equiv. Ratio	0.92											0.85							
Combustor Coolant	HPBF Water																		
4. High Temp. Regenerative Preheater:																			
Oxidizer Preheat Temp. - °F	3000							2700											
Reheat Gas Pressure - atm.	1.0																		
Reheat Fuel Gas	LBTU Gas																		
5. Gasifier:																			
Type	Atmospheric Cold Gas Cleanup																		
Fuel Produced	LBTU Gas & Char																		
Oxidizer	Air																		
Fuel Gas Clean-up	Low Temp.																		
Fuel Gas Preheat After Cleanup	900	1300	1100																
6. MHD Generator:																			
Channel Type	Diag.																		Far.
Peak Magnetic Field - Tesla	6					7													
Gas Seed Conc. - %K	1.0						1.5												
Channel Gas Velocity	Subsonic													Supersonic: →	→	→	→	Subsonic	
Elect. Load Parameter	0.80								0.77	0.83				0.77	0.80	0.83	0.83	0.83	0.83
Diffuser Recovery Factor	0.60				0.70								0.50						
Diffuser Exit Pressure - atm.	1.0																		
Channel Coolant	LPBF Water			HPBF Water															
7. Bottoming Plant:																			
Main Steam	2400 psia/1000°F																		
Reheat Steam	1000°F																		
Final MHD Gas Ox/Fuel Equiv. Ratio	1.05																		
HT Preheater Comb Air Preheat - °F	1100	1300	1100																
8. Seed Regeneration Process:	Formate																		

Note: All blank spaces have same value for corresponding parameter as column #1

*Performance analysis only
^Half load operation

TABLE II-12. MHD PRIME CYCLE DESIGN DATA - REFERENCE PLANT #2

Parametric Point		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
		900 MW	1300°F PH Pre-heat	1100°F PH Pre-heat	HPBF	h_D=0.7	7T	1.5%k	2700°F Preheat	α=0.77	α=0.33	Ill #6	ρ =0.85	h_D=0.5	SS α=0.77	SS α=0.80	SS α =0.83	
MHD COMBUSTOR																		
FUEL THERMAL INPUT (HHV)	MW	1440.5	—	—	—	—	—	—	—	—	—	[illegible]	1541.1	1440.5	→	→	→	
EXIT PRESSURE	ata	8.3	→	→	→	8.3	9.6	8.8	7.3	9.1	7.5	6.6	8.0	8.3	8.5	7.8	7.0	
EXIT TEMPERATURE	°F	4727	→	→	→	4727	4746	4733	4602	4739	[illegible]	4751	4746	4727	4732	4719	4706	
HEAT LOSS	MW	62	→	→	→	→	→	→	53.0	62	[illegible]	63	57	62	→	→	→	
MHD GENERATOR																		
MAGNETIC FIELD STRENGTH	Tesla	6.0	→	→	→	6.0	7.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	4.5	4.5	4.5	
ELECTRICAL LOAD PARAMETER		0.8	→	→	→	0.8	0.8	0.8	0.8	0.77	0.83	0.8	0.8	0.8	0.77	0.8	0.83	
INLET MACH NO. (CONST. VEL.)		0.8	→	→	→	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.1	1.1	1.1	
MAX. AXIAL FIELD (E_x)	kV/m	2.3	→	→	→	2.4	3.2	2.2	2.6	2.7	2.0	2.2	2.3	2.3	2.8	2.4	2.0	
MAX. TRANSVERSE FIELD (E_y)	kV/m	4.2	→	→	→	4.2	4.9	4.2	4.1	4.1	4.3	4.2	4.2	4.2	4.1	4.2	4.2	
MAX. TRANSVERSE CURRENT (J_y)	amp/cm^2	1.1	→	→	→	1.1	1.2	1.2	0.9	1.2	1.0	1.1	1.1	1.1	1.3	1.2	1.0	
MAX. HALL PARAMETER ($\omega\tau$)		5.8	→	→	→	5.9	6.8	5.5	5.9	5.7	5.8	6.1	5.7	5.6	5.1	5.2	5.2	
CHANNEL INLET DIMENSION	mxm	1x1	→	→	→	1x1	1x1	0.9x0.9	1x1	0.9x0.9	1x1	0.9x0.9	0.9x0.9	1x1	0.9x0.9	1x1	1x1	
CHANNEL EXIT DIMENSION	mxm	2.6x2.6	→	→	→	2.7x2.7	2.7x2.7	2.6x2.6	2.6x2.6	2.6x2.6	2.5x2.5	2.6x2.6	2.6x2.6	2.6x2.6	2.5x2.5	2.5x2.5	2.5x2.5	
CHANNEL LENGTH	m	18.9	→	→	→	19.3	18.2	13.4	19.2	18.4	19.5	19.2	19.5	18.5	19.0	19.4	19.5	
DIFFUSER RECO. FACTOR		0.6	→	→	→	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.6	0.6	0.6	
CHANNEL HEAT LOSS	MW	82	→	→	→	83	82	81	79	82	82	88	85	82	86	85	83	
CHANNEL ENTHALPHY EXTRACTION	%	25.4	→	→	→	25.7	27.2	26.0	24.0	25.5	25.1	25.6	24.7	25.1	22.4	22.3	21.9	
MHD PRIME CYCLE																		
MHD POWER	MW	558	558	558	558	565	595	571	508	559	550	566	567	550	492	490	480	
CYCLE COMPRESSOR POWER	MW	130	130	130	130	130	142	135	120	137	122	134	132	130	131	125	116	
NET POWER	MW	428	428	428	428	435	453	436	388	422	428	433	434	420	361	365	364	
MHD CYCLE EFF.	%	18.7	→	→	→	19.0	19.7	19.0	18.1	18.5	18.5	18.9	18.2	18.3	15.7	15.9	15.8	

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TABLE II-13. REFERENCE PLANT 2 - HIGH TEMP. AIR HEATER SYSTEM

Parametric Point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mass Flow Rates-10^3pph															
Fuel Gas	1089.0	1000.0	1060.0			1071.9	1080.9	918.4	1079.0	1106.0	1009.0	1081.7			
Comb. Air	1408.0	1300.0	1369.5			1388.0	1399.0	1159.0	1399.0	1425.0	1408.0	1399.0			
Recycle Gas								520.0							
TOTAL	2497.0	2300.0	2429.5			2459.9	2480.9	2597.4	2478.0	2531.0	2417.0	2480.7			
Heat Inputs-MW															
Fuel Gas (HHV + Sensible)	764.2	743.8	764.0			752.2	759.0	644.8	757.7	776.7	763.0	759.0			
Comb. Air	105.5	118.2	102.8			104.0	104.8	87.0	104.8	107	105.5	104.8			
Recycle Gas								40.5							
TOTAL	869.7	862.0	866.8			856.2	863.8	772.3	862.5	883.7	868.5	863.8			
Heat Outputs-MW															
Cycle Air	687.0	687.0	687.0			675	682.4	602.2	680	695.0	693	682.4			
L.T. Air Heaters (600°F)															
Sec. Comb. Air	17.1	17.1	17.1			17.1	17.1	17.1	17.1	17.1	17.1	17.1			
Gasifier Air (64%)	19.7	18.2	19.2			19.4	19.6	**20.5	19.6	20.0	*53.4	19.6			
Coal Drying	56.9	55.3	56.3			56.1	56.8	52.9	56.8	57.0	17	57.5			
Stack Loss	62.9	58.2	61.2			61.9	62.5	51.8	62.5	63.9	61	62.5			
Heat Loss	26.1	26.2	26.0			26.7	25.4	27.8	26.5	30.7	27	24.7			
TOTAL	869.7	862.0	866.8			856.2	863.8	772.3	862.5	883.7	868.5	863.8			

**Includes heating of balance of gasifier air to 300°F

NOTE: All blank spaces have same parametric values as column #1

*H.T. Air Heater
Comb. Air

TABLE II-14. GASIFIER MASS AND ENERGY BALANCES - REFERENCE PLANT #2

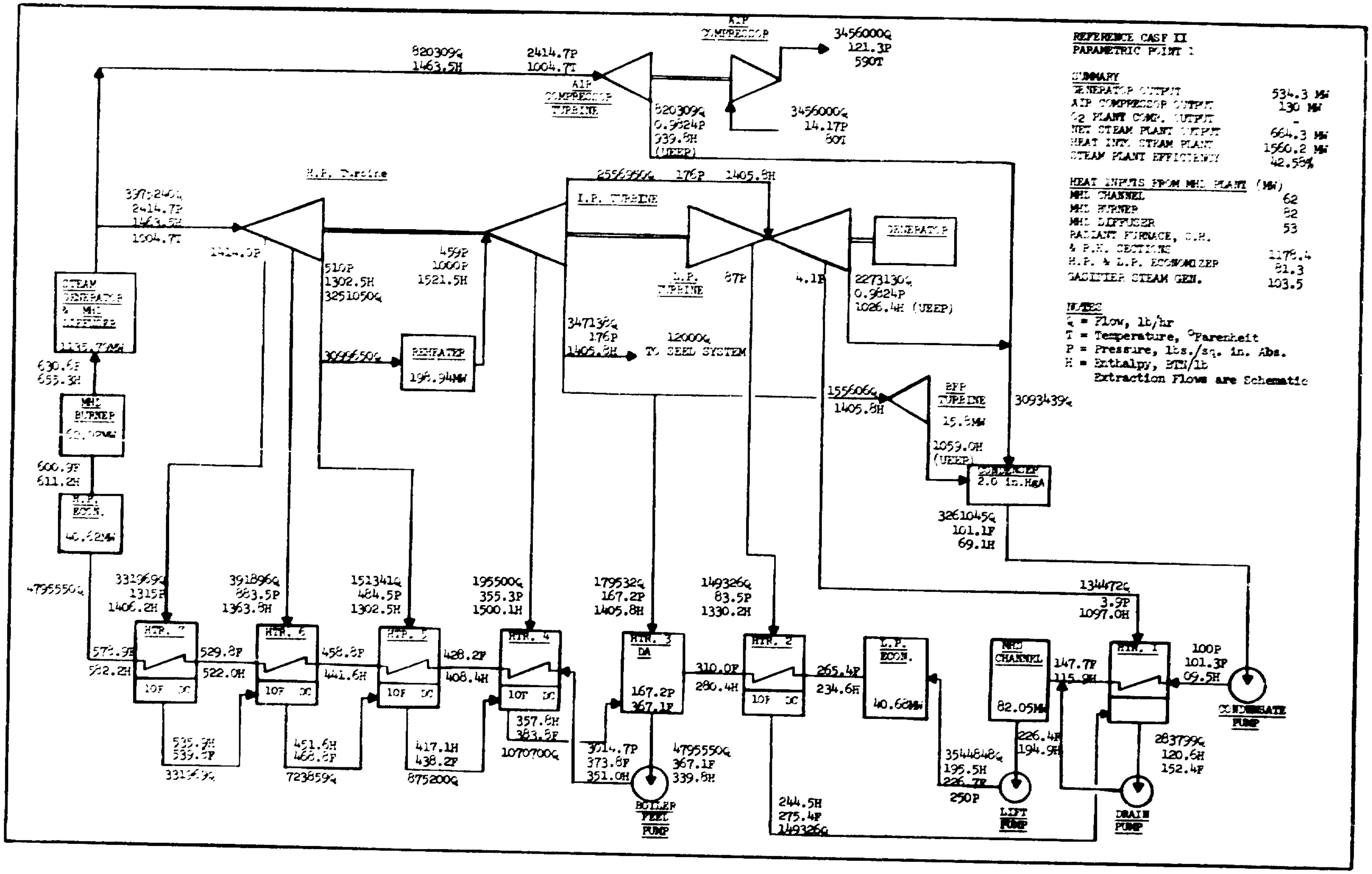
Parametric Point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	900 MW	1300°F PH Pre-heat	1100°F PH Pre-heat	HPB?	h_D=0.7	7T	1.5%k	2700°F Preheat	α=0.77	α=0.83	I1186	φ=0.85	h_D=0.5	SS α=0.77	SS α=0.80	SS α=0.83	
Mass Flow Rate-10^3 pph																	
Coal (5% Moisture)	290.9	267.1	282.9			286.4	289.0	245.3	288.2	295.4	267.7	289.0					
Air	817	750	794.5			804	811.5	689.0	809.5	829.8	776	811.5					
LBTU Gas Produced	1089	1000	1060			1071.9	1081	918.4	1079	1106	1009	1081.7					
Char Produced	40.6	37.4	39.5			40.0	40.0	34.2	40.2	41.2	48.9	40.4					
													NOTE:	All blank spaces have same parametric values as column #1			
Heat Inputs-MW																	
Coal	934.0	857.7	908.0			919.3	927.7	775.3	925.4	948.6	950.2	927.7					
Air (64% at 1100°F 36% at 300°F)	44.8	41.0	43.5			44.1	44.5	37.5	44.4	44.5	42.5	44.5					
TOTAL	978.8	898.7	951.5			963.4	972.2	812.8	969.8	993.1	992.7	972.2					
Heat Outputs-MW																	
LBTU Gas (HHV)	634.4	625.6	666.5			673.7	679.8	577.2	678.1	695.0	689.1	679.8					
LBTU Gas (Sensible)	79.8	118.2	97.5			78.6	79.3	67.3	79.1	81.1	73.9	79.3					
Char (HV)	80.5	74.2	78.3			79.2	80.0	67.9	78.8	81.7	104.1	80.0					
Steam Generation	103.5	50.7	77.7			99.9	100.7	73.4	101.3	102.3	100.4	100.7					
Losses	30.6	30.0	31.5			32.0	32.4	27.0	32.5	33.0	25.2	32.4					
TOTAL	978.8	898.7	951.5			963.4	972.2	812.8	969.8	993.1	992.7	972.2					

TABLE II-15. REFERENCE PLANT 2 - MHD/STEAM BOTTOMING PLANT

Parametric Point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	900 MW	1300°F PH pre-heat	1100°F PH pre-heat	HPBF	h_D=0.7	7T	1.5%k	2700°F preheat	α =0.77	α =0.85	Ill #6	φ=0.85	h_D=0.5	SS α =0.77	SS α =0.80	SS α =0.83
Mass Flow Rates-10^3pph																
Raw Coal (22.7% H_2O)																
Dried Coal (5% H_2O)	423.4	425.4	424.1			424.0	423.8	425.2	424.0	422.9	378.9	455.0				
Char	10.6	37.4	39.5			40	40.4	34.2	40.2	41.2	48.9	40.4				
Primary Air (92% of theor.)	3456.0	3456.0	3456.0			3456.0	3456.0	3456.0	3456.0	3456.0	3494.0	3449.0				
Secondary Air (5% excess)	484.6	484.6	484.6			484.6	484.6	484.6	484.6	484.6	484.0	484.6				
Seed (all as K_2SO_4)	89.7	89.7	89.7			89.7	89.7	89.7	89.7	69.7	89.7	80.0				
Heat Inputs																
Coal (HHV)	1360.0	1366.3	1362.2			1361.9	1361.2	1372.6	1361.7	1358.8	1346.5	1461.1				
Char	80.5	74.2	78.3			78.6	79.3	67.9	78.8	81.7	104.1	80.0				
Coal Drying	32.9	33.0	32.9			32.9	32.9	33.0	32.9	32.9	10.1	35.4				
Primary Air	817.0	817.0	817.0			817.0	817.0	718.0	817.0	817.0	826.0	815.4				
Secondary Air	17.1	17.1	17.1			17.1	17.1	17.1	17.1	17.1	17.1	17.1				
Seed Chemistry	12.0	12.0	12.0			12.0	12.0	12.0	12.0	12.0	35.0	12.0				
TOTAL	2319.5	2319.6	2319.5			2319.5	2319.5	2220.6	2319.5	2319.5	2338.8	2421.0				
Heat Outputs																
MHD Power	558.0	558.0	558.0		565.0	595.0	571.0	508.0	559.0	550.0	566.0	567.0	550.0			
MHD Heat Losses																
Burner	62.0	62.0	62.0		62.0	62.0	62.0	53.0	62.0	62.0	63.0	57.0	62.0			
Channel	82.0	82.0	82.0		83.0	82.0	81.0	79.0	82.0	82.0	88.0	85.0	82.0			
Diffuser	53.0	53.0	53.0		53.0	53.0	53.0	52.0	53.0	53.0	53.0	53.0	53.0			
Steam Generator	1178.4	1167.8	1182.0		1170.4	1143.6	1167.3	1134.9	1181.6	1184.6	1227.3	1273.8	1186.4			
I.T. Air Heaters (600°F-1100°F)																
H.T.A.H. Comb. Air	52.4	69.1	51.1			51.6	52.1	*63.3	52.0	53.2	52.4	52.1	52.1			
Gasifier Air (64%)	19.5	18.0	19.0			19.2	19.4	16.5	16.4	19.8	18.6	19.4	19.3			
L.T. Air Heaters																
H.T.A.H. Comb. Air (600°F)	53.1	49.1	51.6			52.3	52.8	*56.9	52.6	53.9	0	52.8				
Gasifier Air (300°F)	4.6	4.3	4.5			4.5	4.6	--	4.6	4.7	4.5	4.6				
Economizer	81.3	81.3	81.3			81.3	81.3	82.0	81.3	81.3	115.0	81.3				
Stack Losses	147.0	147.0	147.0			147.0	147.0	147.0	147.0	147.0	123.0	147.0				
Heat Losses	28.2	28.0	28.0			28.0	28.0	28.0	28.0	28.0	28.0	28.0				
	2319.5	2319.6	2319.5			2319.5	2319.5	2220.6	2319.5	2319.5	2338.8	2421.0				

NOTE: All blank spaces have same parametric values as column #1

*Includes recycle gas heating for high temp. air heater



REFERENCE CASE II
PARAMETRIC POINT 2

SUMMARY	
GENERATOR OUTPUT	534.3 MW
AIR COMPRESSOR OUTPUT	130 MW
O_2 PLANT COMP. OUTPUT	-
NET STEAM PLANT OUTPUT	664.3 MW
HEAT INP. STEAM PLANT	1560.2 MW
STEAM PLANT EFFICIENCY	42.55%

HEAT INPUTS FROM MHD PLANT (MW)	
MHD CHANNEL	62
MHD BURNER	82
MHD DIFFUSER	53
RADIANT FURNACE, S.H. & R.H. SECTIONS	1179.4
H.P. & L.P. ECONOMIZER	81.3
GASIFIER STEAM GEN.	103.5

NOTES
Q = Flow, lb/hr
T = Temperature, °Farenheit
P = Pressure, lbs./sq. in. Abs.
H = Enthalpy, BTU/lb
Extraction Flows are Schematic

Fig. 2-8 Steam and Feed Water Cycle for Reference Plant 2

TABLE II-16. OVERALL ENERGY BALANCE - REFERENCE PLANT #2

Parametric Point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	900 MW	1300°F PH Pre-heat	1100°F PH Pre-heat	HPBF	h_D=0.7	7T	1.5%k	2700°F Preheat	α =0.77	α =0.83	Ill #6	φ =0.85	h_D=0.5	SS α =0.77	SS α=0.80	SS α=0.85
Fuel Heat Inputs-MW																
MHD Burner	1360	1366.3	1362.2	1360	1360	1361.9	1361.2	1372.6	1361.7	1358.8	1376.5	1461.1	1360	1360	1360	1360
Gasifier for H.T. Air Heater	934	857.7	908	934	934	919.3	927.7	775.3	925.4	948.6	950.2	927.7	934	935	941	942
Gasifier for Seed Regen.	14	14	14	14	14	14	14	14.5	14	14	14	14	14	14	14	14
TOTAL	2308	2238	2284.2	2308	2308	2295.2	2302.9	2162.4	2301.1	2321.4	2340.7	2402.8	2308	2309	2315	2316
Gross Power Outputs-MW																
MHD Power	558	558	558	558	565	595	571	508	559	551	566	567	550	492	490	480
Steam Power	664.3	637.3	654.9	*671	661.4	648.0	658.0	627.8	664.8	666.5	*691.6	700	667.7	692.4	693.3	697.5
TOTAL	1222.3	1195.3	1212.9	1229	1226.4	1243.0	1229.0	1135.8	1223.8	1217.5	1257.6	1267	1217.7	1184.4	1183.3	1177.5
Auxiliaries and Losses-MW																
Compressor	130.0	130.0	130.0	130.0	130.0	142.0	135.0	120.0	137.0	122.0	134.0	132.0	130.0	131.0	125.0	117
Aux. and Other	46.7	45.8	46.3	46.7	46.5	46.0	46.4	45.8	46.3	46.4	56.1	46.7	46.7	48.0	48.0	48
Inverter and Transformer	11.7	11.6	11.7	11.7	11.7	12.2	11.8	10.8	11.7	11.6	12.0	12.0	11.7	11.0	11.0	11.0
TOTAL	188.4	187.4	188.0	188.4	188.2	200.2	193.2	176.6	195.0	180.0	202.1	190.7	188.4	190.0	184.0	176.0
Net Plant Output-MW	1033.9	1007.9	1024.9	1040.6	1038.2	1042.8	1035.8	959.2	1028.8	1037.5	1055.5	1076.3	1029.3	994.4	999.3	1001.5
Net Plant Efficiency-%	44.8	45.0	44.9	45.1	45.0	45.4	45.0	44.3	44.7	44.7	45.1	44.8	44.6	43.1	43.2	43.2
				*43%							*42%					

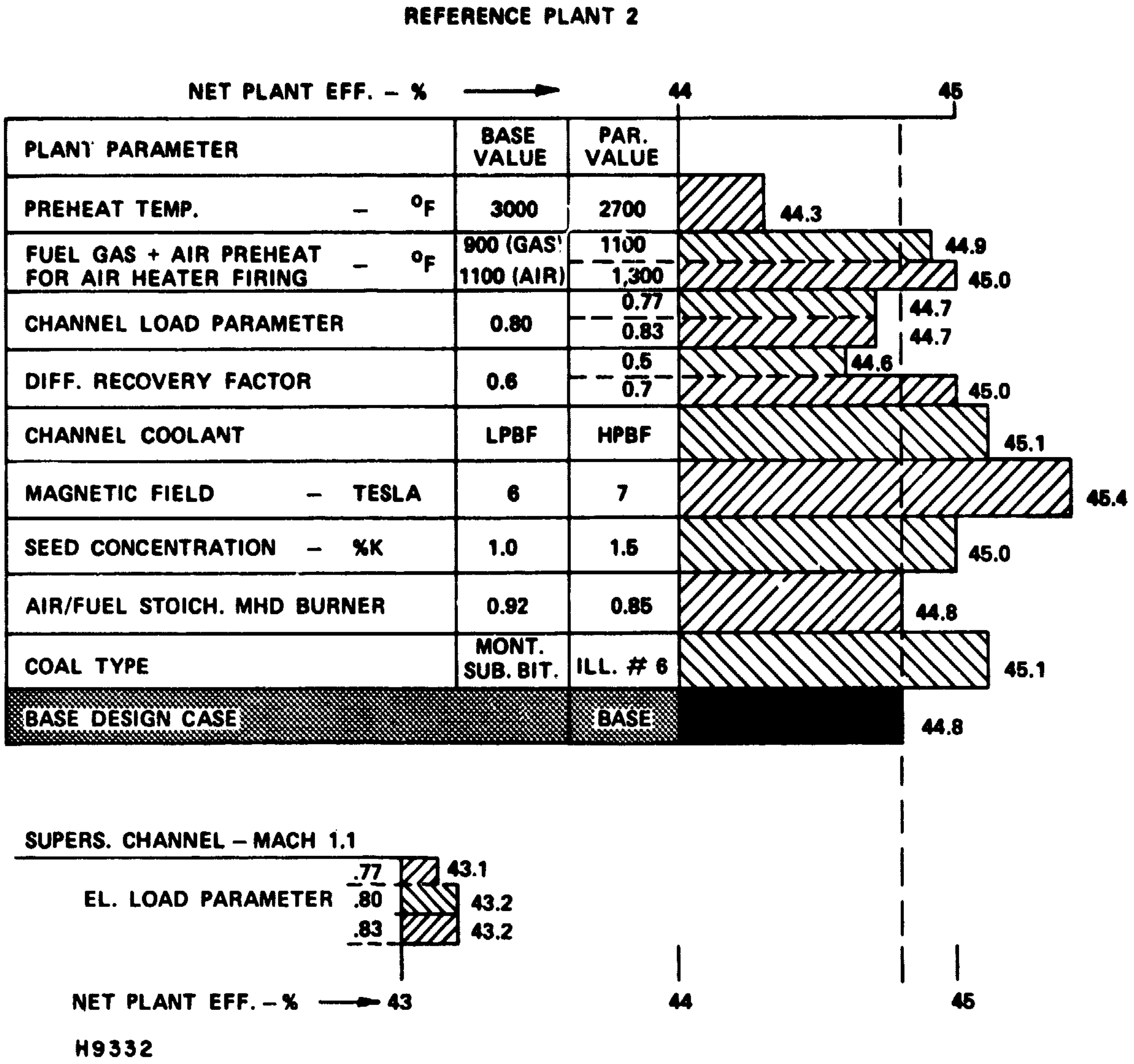


Fig. 2-9 Comparative Plant Efficiencies for Reference Plant 2

The parametric design variation considering high pressure boiler feed water as channel coolant instead of low pressure boiler feed water increased the calculated plant efficiency with 0.3 percentage point. The use of high pressure boiler feed water for cooling of the channel makes it possible to shift to and to increase the extraction of low pressure steam from the turbine for regenerative feed water heating. This improves the steam cycle efficiency which has been raised from the base case value of 42.6% (with low pressure feed water cooling) to 43.0% for this parametric design case with high pressure feed water cooling.

An increase of the magnetic field from the base case value of 6 Tesla to 7 Tesla raised the overall plant efficiency with 0.6 percentage points to 45.5% because of improved performance of the MHD generator.

An increase of the seed mass concentration from 1.0 to 1.5% improved the MHD generator performance somewhat with a resulting increase of the plant efficiency of 0.2 percentage points.

A reduction of the air/fuel equivalence ratio (ϕ) in the MHD burner from 0.92 of the stoichiometric value to 0.85 had no effect on the calculated plant efficiency which remained the same. Two-stage combustion with initial fuel rich MHD combustion conditions ($\phi < 1$) is employed for NO_x emission control. Initial design calculations indicate that an air/fuel equivalence ratio of 0.92 will provide the necessary NO_x emission control for satisfying NSPS. However, a further reduction of the equivalence ratio from 0.92 to 0.85 would enable to reduce the NO_x emission level to less than half of the specified NSPS NO_x emission limitations. Calculations show that this can be achieved without any penalty in plant efficiency if the MHD coal combustor performs properly under the assumed increased fuel rich combustion conditions.

The use of Illinois #6 coal type instead of Montana Rosebud resulted in a slight increase of the plant efficiency similar to that as previously explained for Reference Plant 2.

Supersonic operating conditions of the MHD generator channel with a Mach No. of 1.1 resulted in significant reductions of the plant efficiency as compared to subsonic operation. The plant efficiency was reduced to 43.1 and 43.2% or with 1.7 and 1.6 percentage points for assumed channel electric load parameters of 0.77, 0.80 and 0.83. The reduction in plant efficiency resulted from reduced power output from the MHD generator. As discussed later in Section 3.0 under the description of analytical channel calculations, it becomes necessary to reduce the magnetic field to a maximum value of 4.5 Tesla for supersonic operation in order to limit the critical electrical operating parameters of the channel to reasonable values comparable to subsonic operation.

Figure 2-10 is a flow diagram with base case state point conditions for air and gas. Corresponding water and steam side state point conditions are shown on the steam and feed water cycle diagram for Reference Plant 2 in Fig. 2-8.

The parametric variations of the preheat temperature to 2700°F for parametric point 8, and of the coal type to the use of Illinois #6 bituminous coal for parametric point 11 require different arrangements of low grade heat recovery from the combustion gases in order to maintain the same steam cycle efficiency as calculated for the base design case. The different arrangements of low grade heat recovery considered for the base case (p.p.1) and for the parametric variations with the use of 2700°F preheat temperature (p.p.8) and Illinois #6 coal (p.p.11) are shown in Figs. 2-11, 2-12 and 2-13, respectively.

2.4 CASE III - REFERENCE PLANT 3

The power cycle configuration of Reference Plant 3 is shown on Fig. 2-14. It employs oxygen enrichment of the combustion air. This eliminates the need for a high temperature preheater and thus also the need for a gasifier system for production of a fuel gas for separate firing of this preheater. The oxygen enriched combustion air is considered preheated to a more moderate temperature attainable with a metal recuperative type tubular heat exchanger which becomes part of the bottoming heat recovery plant. Preheat temperatures from 1000°F to 1400°F are considered with 1100°F selected as the preheat temperature for the base design case.

Three different degrees of oxygen enrichment of the combustion air are considered, namely, 29.2%, 34.1% and 39.1% by volume with the middle enrichment value selected for the base case. The oxygen required for enrichment of the combustion air is considered produced from an oxygen plant which is integrated with the power plant. For the degrees of oxygen enrichment involved high purity oxygen is not necessary. Our previous analysis of oxygen enrichment has indicated that an oxygen purity of around 80% is about the optimum for the oxygen plant production in order to minimize the associated power requirements and costs. Information provided by NASA for use in this study indicate that this concurs with initial results from recent parallel investigations of O_2 plants for MHD power plant applications conducted by Lotepro Corporation, a subsidiary of Linde, A.g., W. Germany. The information provided has been utilized in determining the power requirements and costs associated with the oxygen plants for Reference Plant 3. Pertinent O_2 plant data based on this information for the three degrees of oxygen enrichment considered are listed in Table II-17.

The parametric design case variations for Reference Plant 3 are listed in Table II-18. Calculated design and performance data

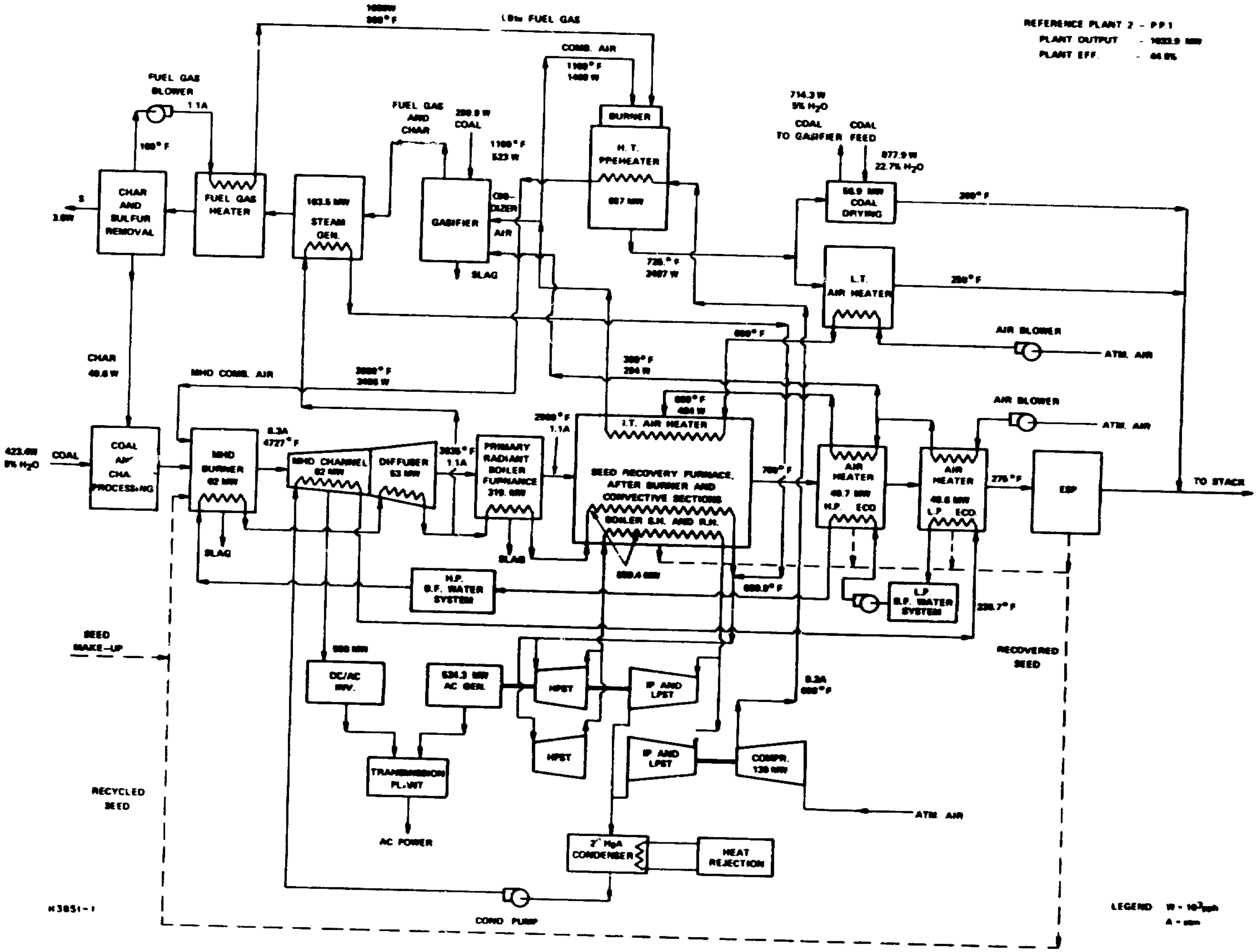


Fig. 2-10 Flow Diagram for Base Case of Reference Plant 2

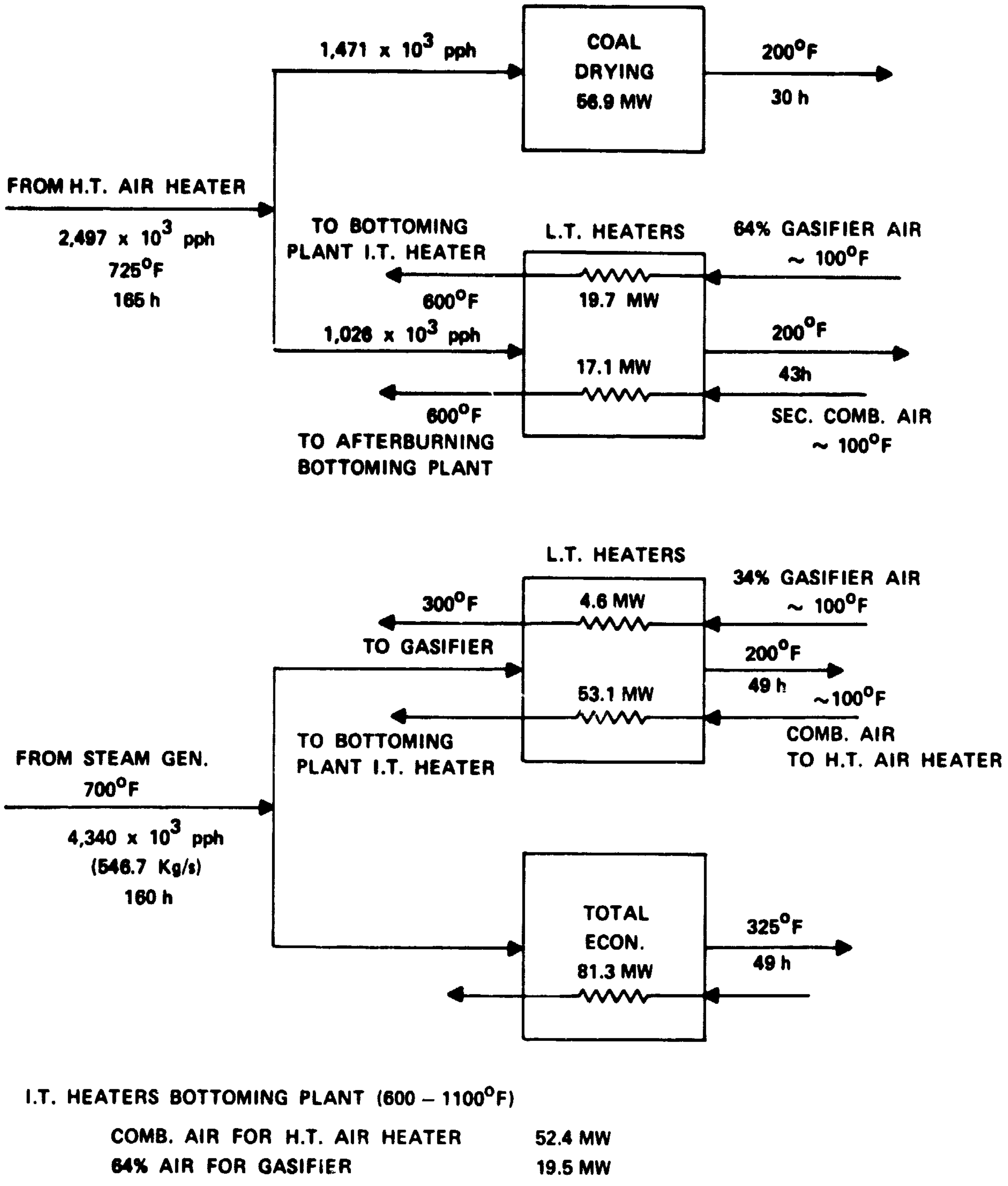


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Fig. 2-11 Low Grade Heat Recovery Arrangement from the Combustion Gases for the Base Design Case, Parametric Point 1, of Reference Plant 2.

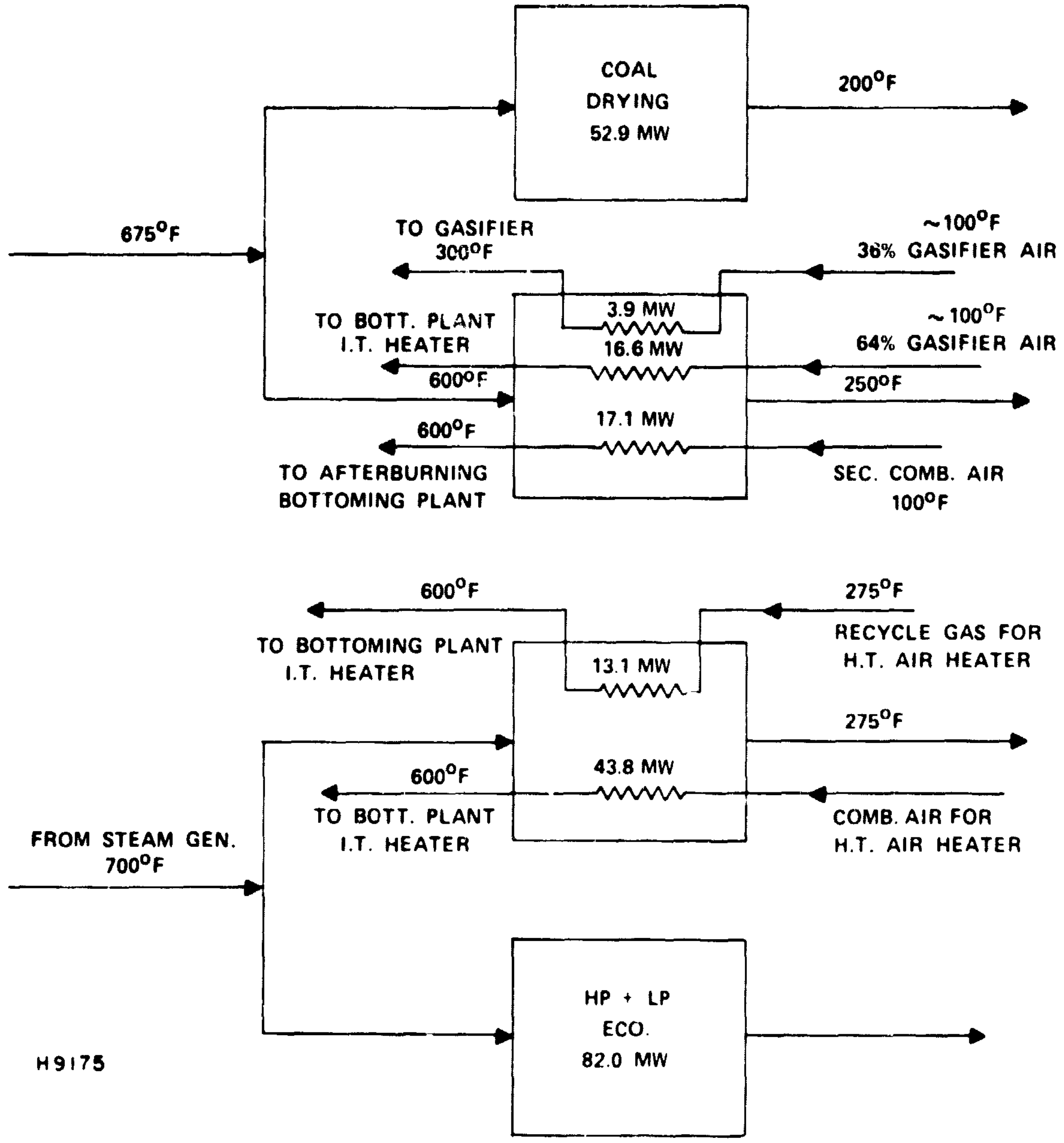

Fig. 2-12 Low Grade Heat Recovery Arrangement from the Combustion Gasses for the Base Design Case, Parametric Point 8, of Reference Plant 2

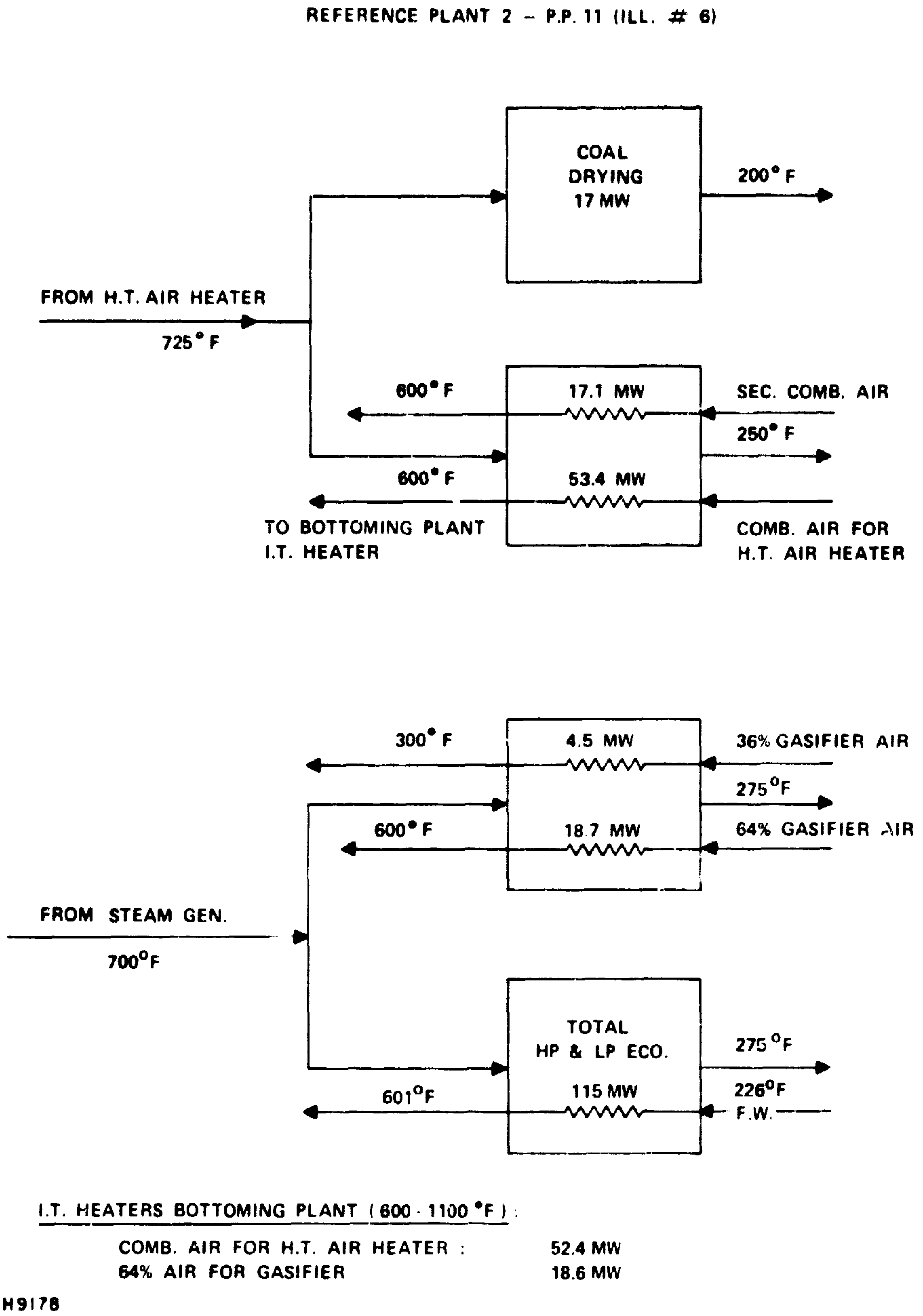

Fig. 2-13 Low Grade Heat Recovery Arrangement for the Parametric Design Variation (Parametric Point 11) with the use of Illinois #6 Bituminous Coal.

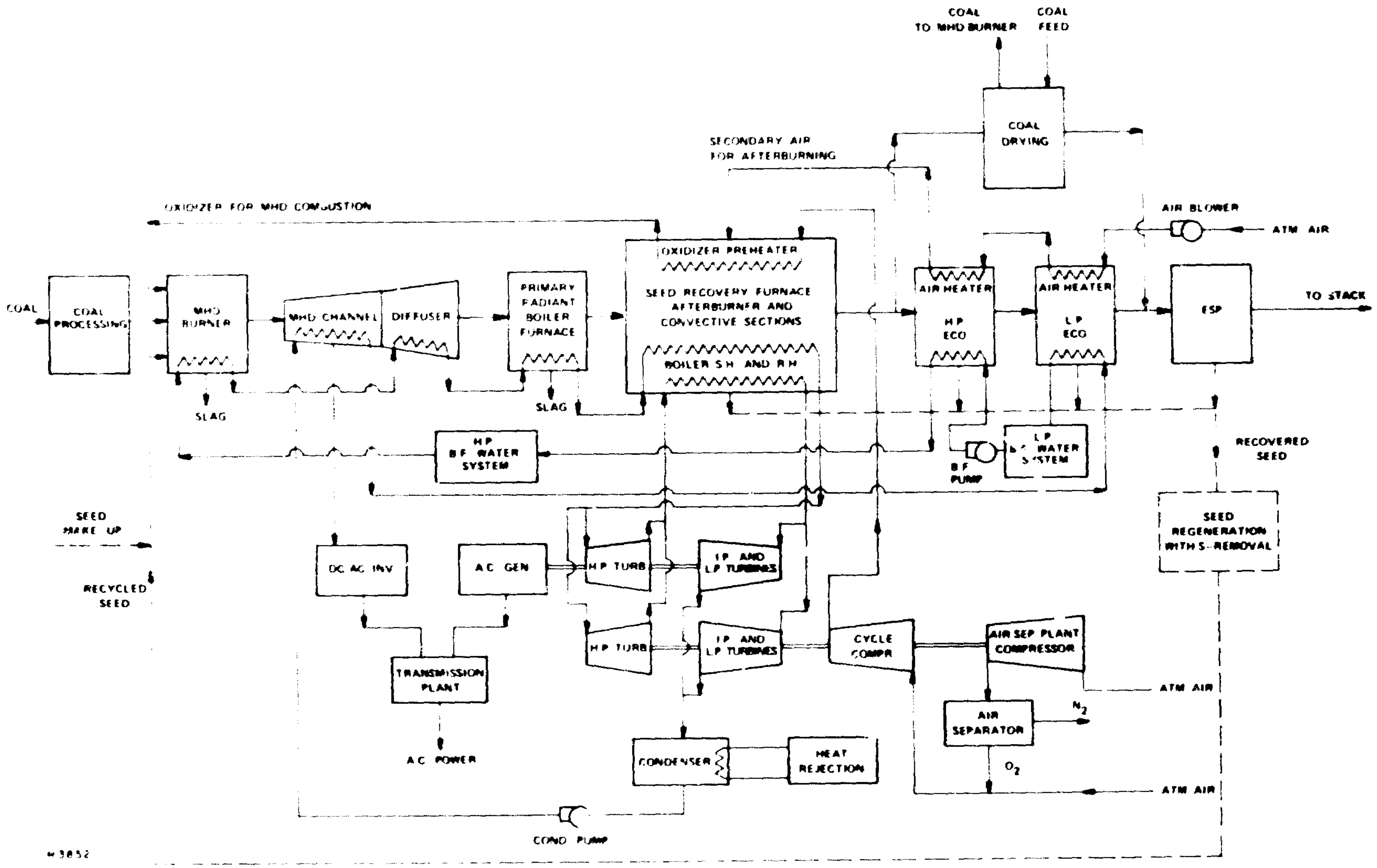

Fig. 2-14 Cycle Configuration for Reference Plant 3

TABLE II-17

O_2 - PLANT DATA

MHD - Power Plant Size	MW	900 (nominal)		
O_2 - Content of Comb. Air	% O_2 (vol.)	29.2	34.1	39.1
O_2 - Plant size (80% purity)	T/day	5570	7470	8900
O_2 - Plant Compr. Power (197 kWh/T prod.)*	MW	45.5	61.5	73.5
O_2 - Plant Cost (Turn key)*	10^6\$	46.3	62.1	73.9

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*Based on Lotepro Corp. Data for 3 x 2000 STD Air Separation Plants.

TABLE II-18. REFERENCE PLANT DESIGN #3

PARAMETRIC POINT	1	2	3	4*	5	6	7	8	9*
1. Plant Size - MW	900	600	900						
2. Fuel Type:	Mont. Subbit							III. #6	MontSub
3. MHD Comoustion:									
Oxidizer O_2 content -% Vol.	34		29	39	34				29
Fuel Moist. as fired - %	5							2	5
Combustor Type	Single Stage								
Ash Removal - %	80								
Oxidizer/Fuel Equiv. Ratio	0.92								
Combustor Coolant	HPBF Water								
4. MHD Generator:									
Channel Type	Diagonal								
Peak Magnetic Field - Tesla	6								
Gas Seed Conc. - %K	1.0								
Channel Gas Velocity	Subsonic								
Channel Elect. Load Parameter	0.79								
Diffuser Rec. Factor	0.50								
Diffuser Exit Press. - atm.	1.0								
Channel Coolant	LPBF water								
5. Bottoming Plant:									
Main Steam	2400 psia/1000°F								
Reheat Steam	1000°F								
Final MHD Comb. Gas. Ox/Fuel Eq. Ratio	1.05								
Oxidizer Preheat Temp - °F	1100				1000	1300	1400	1100	1400
Stack Gas Temp - °F	275								
nser Press - "HgA	2-3.5								
6. S eration Process:	Formate								

*Performance Analysis Only

for the MHD prime cycle with its MHD combustor and MHD generator are listed in Table II-19. Corresponding mass and energy balances for the combined MHD/steam power cycle are contained in Table II-20.

Figure 2-15 is a flow diagram with a heat balance for the total steam and feed water cycle for the base case (p.p.1) of Reference Plant 3. As in the two previous reference plant designs the economizer duty is split in low pressure and high pressure sections and again seven feed water heaters are utilized. The resulting calculated steam cycle efficiency $\frac{\text{Total steam plant output}}{\text{Total heat absorbed steam plant}}$ is 42.08%. This calculated steam cycle efficiency for the base case was used for all other parametric points of Reference Plant 3 including parametric point design case 8 with the use of Illinois #6 coal. As previously discussed under Reference Plants 2 and 3, a slightly lower steam cycle efficiency can be expected for the use of Illinois #6 because of less waste heat required for coal drying. However, for Reference Plant 3, the use of Illinois #6 coal requires a higher seed concentration ($\sim$1.2%K) than that assumed in all of the channel performance calculations (1.0%K) so as to satisfy the specified sulfur emission regulations. The seed regeneration process for this design case of Reference Plant 3 is based on the use of this higher seed concentration for necessary sulfur removal. The use of the same high seed concentration of 1.2%K would have improved the MHD generator performance slightly. Therefore, to compensate for the use of 1%K in the channel performance calculations, the same steam cycle efficiency as in the base case was also used for establishing the overall plant efficiency with the use of Illinois #6 coal for Reference Plant 3.

The overall energy balance of Reference Plant 3 is shown in Table II-21 and Fig. 2-16 is a bar chart showing the comparative calculated net plant efficiency values for the various design cases considered of this Reference Plant.

As in Case I, a decrease of the plant size decreases the plant efficiency. The calculated plant efficiency at a nominal capacity of 600 $\mathrm{MW_e}$ or 2/3 of the plant size for the base design case is reduced with 0.4 percentage points from the base case efficiency value.

A decrease of the preheat temperature from 1100°F for the base case to 1000°F decreases the calculated plant efficiency with 0.5 percentage points. An increase of the preheat temperature to 1300°F and 1400°F resulted in the expected opposite effect and increased the plant efficiency with 1.0 percentage point and 1.4 percentage points to 44.4% and 44.8% respectively.

TABLE II-19. MHD PRIME CYCLE DESIGN DATA - REFERENCE PLANT #3

PARAMETRIC POINT		1	2	3	4	5	6	7	8	9
		900 MW 34%	600 MW	900 MW 29%	900 MW 39%	1000°F	1300°	1400°F	Ill #6	1400°F
MHD COMBUSTOR										
Fuel Thermal Input (HHV)	MW	2123	1415	2123	2123	2123	2123	2123	2174	2123
Exit Pressure	ata	8.3	7.78	6.2	10.4	8.0	8.8	9.1	9.1	7.0
Exit Temperature	°F	4676	4656	4458	4850	4647	4726	4753	4762	4555
Heat Loss	MW	61	47	55	67	59	63	65	64	59
MHD GENERATOR										
Magnetic Field Strength	Tesla	6.0								→
Electrical Load Parameter		0.8								→
Inlet Mach No. (Const. Vel)		0.8								→
Max. Axial Field (Ex)	Kv/m	2.1	1.9	2.8	1.5	2.2	2.0	1.9	1.9	2.7
Max Transverse Current (Jy)	Amp/CM²	0.8	0.8	0.59	1.0	0.8	0.9	0.9	0.9	0.7
Max. Hall Parameter (Wτ)		5.0	4.9	5.1	4.8	4.95	5.0	5.0	5.0	5.2
Channel Inlet Dimension	MxM	0.9x0.9	0.8x0.8	1.1x1.1	0.8x0.8	1x1	0.9x0.9	0.9x0.9	0.9x0.9	1.1x1.1
Channel Exit Dimension	MxM	2.6x2.6	2.2x2.2	2.7x2.7	2.6x2.6	2.6x2.6	2.6x2.6	2.6x2.6	2.6x2.6	2.7x2.7
Channel Length	M	19.7	19.0	18.7	21.4	19.8	19.7	19.7	19.1	18.3
Diffuser Reco. Factor		0.5								→
Channel Heat Loss	MW	82	68	65	101	86	92	94	94	76
Channel Enth. Entr.	%	22.8	22.1	20.7	23.6	22.4	23.2	23.6	23.6	22.0
MHD PRIME CYCLE										
MHD Power	MW	523	339	485	533	510	543	559	554	533
Cycle Compressor Power	MW	114	73	111	113	111	118	120	123	120
O_2 Plant Compressor*	MW	61.5	41	45.5	73.5	61.5	61.5	61.5	62.5	45.5
Net Power	MW	347.5	227	328.5	346.5	337.5	363.5	377.5	368.5	367.5
MHD Cycle Eff.	%	16.4	15.7	15.5	16.3	15.9	17.1	17.7	16.9	17.3

* Based on 197 KWH/Ton AT 80% Purity

TABLE II-20. MASS AND ENERGY BALANCE - REFERENCE PLANT #3

PARAMETRIC POINT				1	2	3	4	5	6	7	8	9
Mass. Flow Rates (10^3 pph)												
Raw Coal				812.65	541.77	812.65					658.68	812.65
Dried Coal				661.24	440.83	661.24					612.30	661.24
Primary Oxidizer (92% of theor.)				3133.13	2088.75	3629.25	2748.14	3133.13			3186.63	3629.25
Secondary Air (5% Excess)				700.0	466.67	700.0					717	700.0
Seed				89.93	59.95	96.05	76.20	89.93			*110.0	96.05
Heat Inputs (MW)												
Coal (HHV)				2123	1415	2123					2174	2123
Coal Drying				51	34.0	51.0					16.1	51
Primary Oxidizer				232.6	155.1	270.5	203.3	208.5	281.5	306.3	236.4	356.1
Secondary Air				26	17.3	26					26.6	26
Seed Chemistry				25.0	16.6	25.0					69.0	25.0
	TOTAL			2457.6	1638.0	2495.5	2428.3	2433.5	2506.5	2531.3	2522.1	2581.1
Heat Outputs (MW)												
MHD Power				523	339	485	533	510	543	559	554	533
MHD Heat Losses												
Burner				61	47	55	67	59	63	65	64	59
Channel				82	68	65	101	86	92	94	94	76
Diffuser				53	37	57	53	53	54	53.8	53.8	57.6
I.T. Oxidizer Heater				118.6	89.1	159.5	90.3	97.5	163.5	186.3	110.9	236.1
L.T. Secondary Air Heater				26.0	17.3	26.0	26.0				26.4	26.0
Coal Drying				51.0	34.0	51.0	51.0				16.1	51.0
Stack Loss @ 275° F				192	129.3	200	187	197			160	197
Heat Losses				30.0	19.0	30.0					30	30.0
Steam Generator				1230	801.0	1264.0	1217.0	1238.0	1231.0	1213.2	1292.4	1229.4
Economizer				86	57.3	103.0	73	86	86	86	120.5	86
	TOTAL			2457.6	1638.0	2495.5	2428.3	2433.5	2506.5	2531.3	2522.1	2581.1

* This corresponds to roughly 1.2% K to provide for necessary sulfur removal. Channel calculations based on 1.0% K

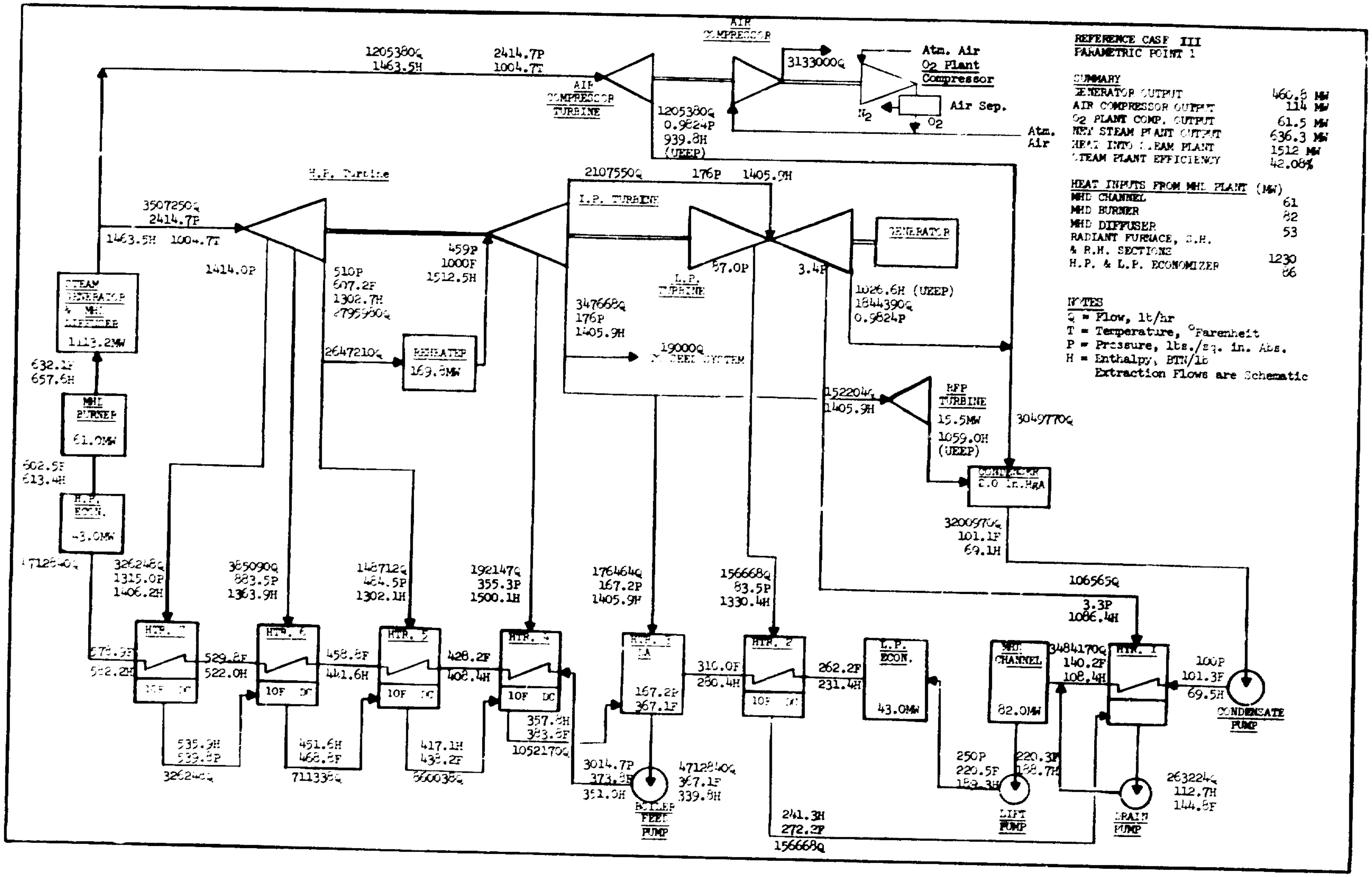
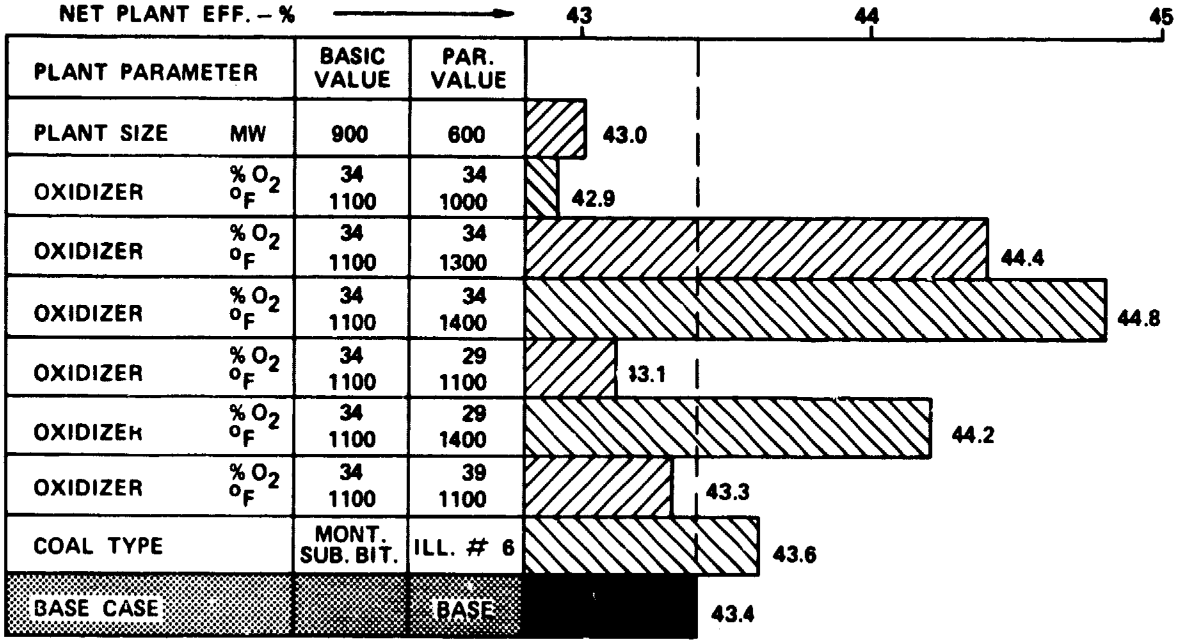


Fig. 2-15 Steam and Feed Water Cycle for Reference Plant 3

TABLE II-21. OVERALL ENERGY BALANCE - REFERENCE PLANT #3

Parametric Point		1	2	3	4	5	6	7	8	9
		900 MW 34%	600 MW	900 MW 29%	900 MW 39%	1000°F	1300°F	1400°F	Ill #6	1400°F 29% O_2
Fuel Inputs-MW										
MHD Burner		2123	1415	2123	2123	2123	2123	2123	2174	2123
Gasifier for Seed Regen.		24	16	24	24	24	24	24	71	24
TOTAL		2147	1431	2147	2147	2147	2147	2147	2245	2147
Gross Power Outputs-MW										
MHD Power		523	339	485.0	533	510	543.0	559	554	533
Steam Power		636.3	425.1	649.7	635.8	640.5	642.2	636.3	683.7	634.6
TOTAL		1159.3	764.1	1134.7	1168.8	1150.5	1185.2	1195.3	1237.7	1167.6
Auxiliaries and Losses-MW										
Cycle Compressor		114.0	73.0	111	113	111	118	120	123	120
O_2-Plant Compressor		61.5	41.0	45.5	73.5	67.5	61.5	61.5	62.5	45.5
Aux. and Other		42.1	28.6	42.7	41.6	41.9	42.1	41.8	62.0	42.5
Inverter and Transformer		11.0	7.1	10.6	11.2	10.9	11.4	11.5	11.7	11.2
TOTAL		228.6	149.7	209.8	239.3	231.3	233.0	234.8	259.2	219.2
Net Plant Output	MW	930.7	614.4	924.9	929.5	919.2	952.2	960.5	978.5	948.4
Net Plant Efficiency	%	43.4	43.0	43.1	43.3	42.9	44.4	44.8	43.6	44.2

REFERENCE PLANT 3



PLANT PARAMETER		BASIC VALUE	PAR. VALUE	NET PLANT EFF. – %
PLANT SIZE	MW	900	600	43.0
OXIDIZER	% O_2 ^oF	34 1100	34 1000	42.9
OXIDIZER	% O_2 ^oF	34 1100	34 1300	44.4
OXIDIZER	% O_2 ^oF	34 1100	34 1400	44.8
OXIDIZER	% O_2 ^oF	34 1100	29 1100	43.1
OXIDIZER	% O_2 ^oF	34 1100	29 1400	44.2
OXIDIZER	% O_2 ^oF	34 1100	39 1100	43.3
COAL TYPE		MONT. SUB. BIT.	ILL. # 6	43.6
BASE CASE			BASE	43.4

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Fig. 2-16 Comparative Plant Efficiencies of Reference Plant 3

A decrease of the degree of oxygen enrichment of the combustion air from 34.1 vol.% for the base case to 29.2% vol.% decreased the efficiency with 0.3 percentage points. An increase of the degree of oxygen enrichment to 39.1 vol.% resulted in a decrease of 0.1 percentage point only. This indicates that the optimum degree of oxygen enrichment of the combustion air is about 35% or slightly higher.

The use of Illinois #6 bituminous coal instead of Rosebud subbituminous coal increased the plant efficiency only slightly and with 0.2 percentage points. Thus, the difference in overall plant efficiency for these two coal types is also here for Reference Plant 3 calculated to be relatively small as for the two previous Reference Plants 1 and 2.

Figure 2-17 is a flow diagram of Reference Plant 3 with base case state point conditions for air and gas. Corresponding water and steam cycle state point conditions were shown on the previous Fig. 2-15.

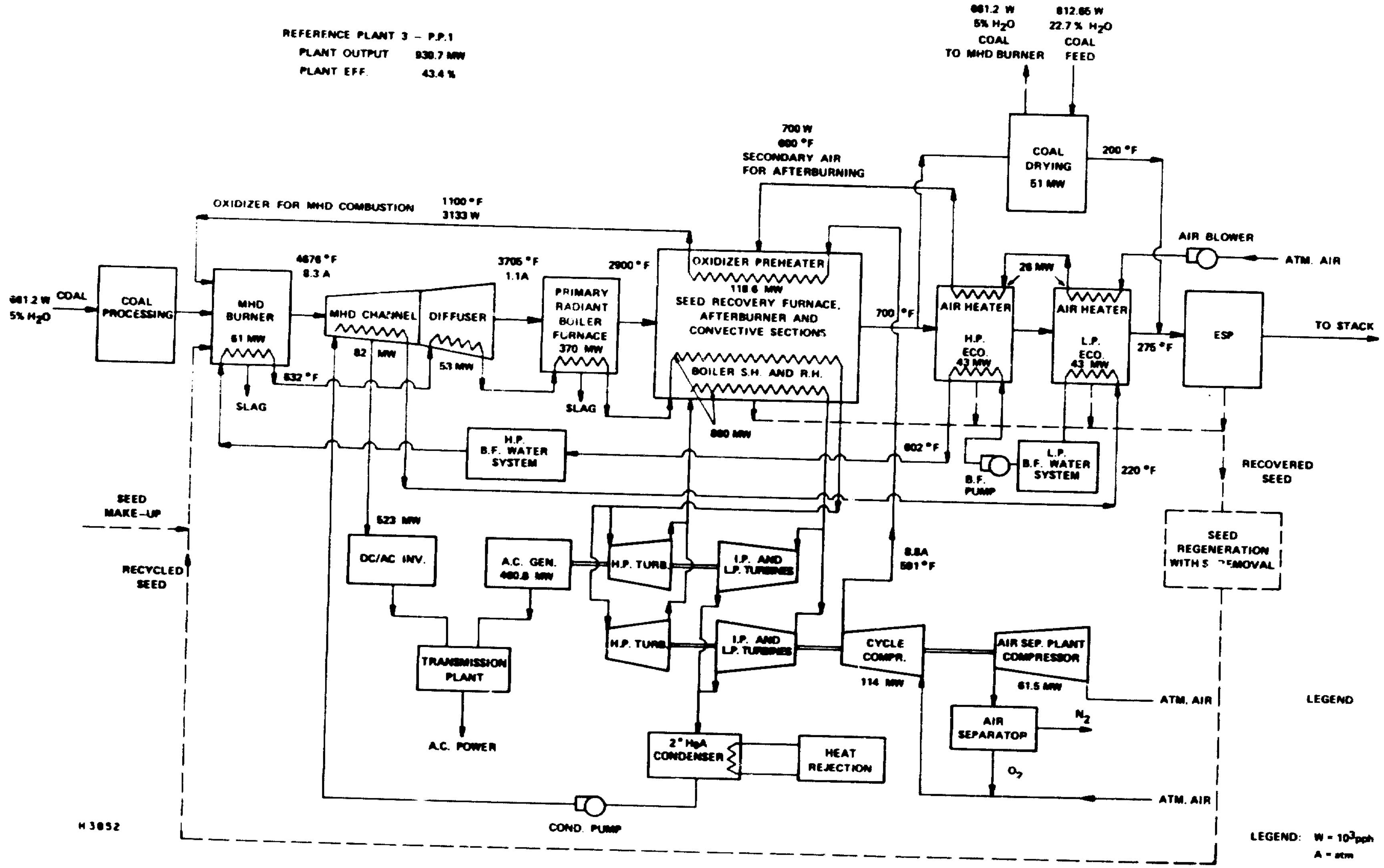


Fig. 2-17 Flow Diagram for Base Case of Reference Plant 3

3.0 SUBSYSTEMS/COMPONENTS DESIGN

3.1 MHD CHANNEL

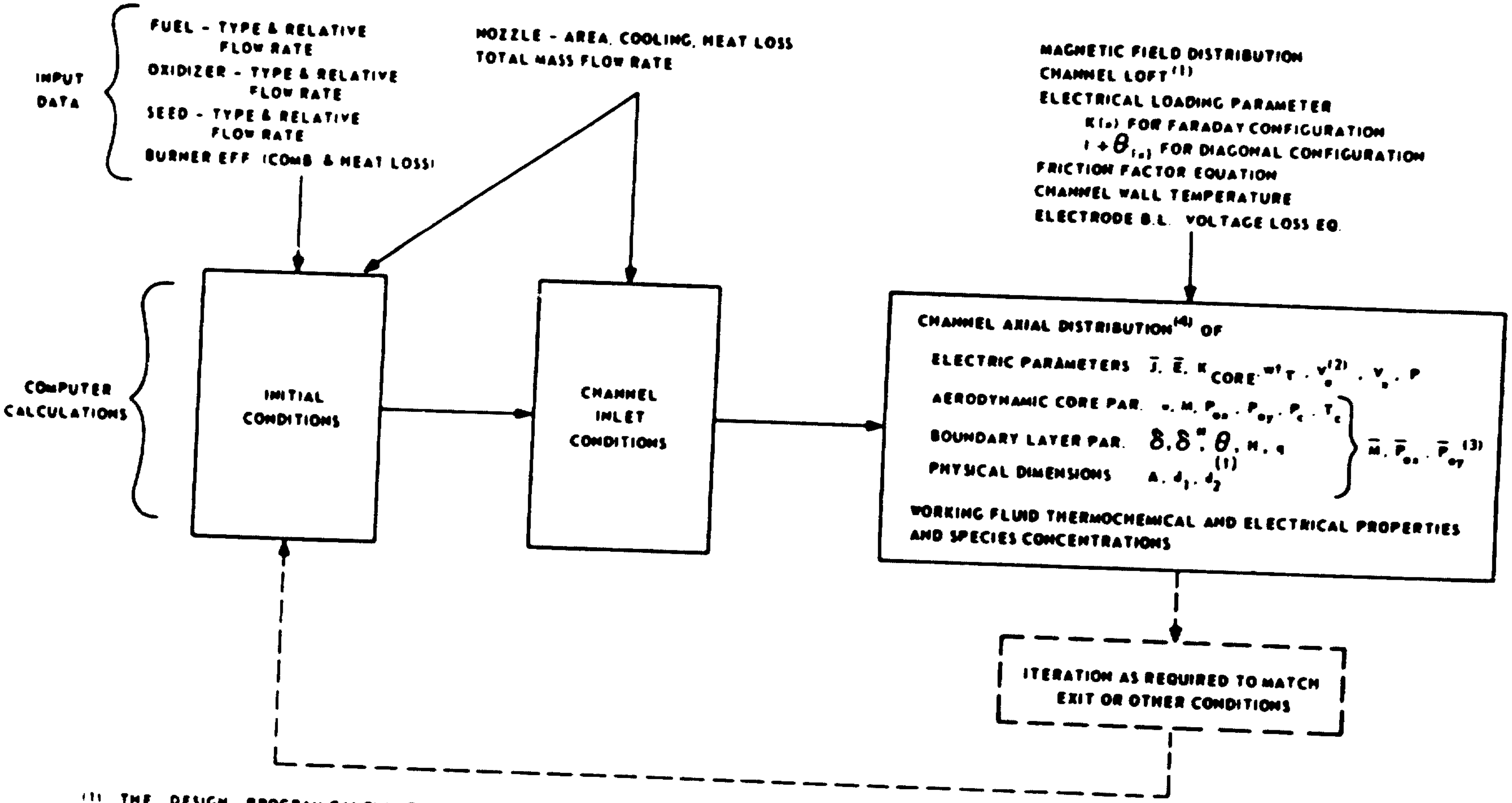
3.1.1 MHD Channel Calculations and Performance

The main computer program used for the channel calculations is referred to as the PDG 73 program. This program is used to calculate the channel loft and operating parameters for specified channel inlet conditions, axial velocity profile, magnetic field distribution, and electrical loading. It concentrates on the channel core flow, with a relatively crude treatment of the channel boundary layer. The program permits calculations of the basic channel loft and operating characteristics more readily than other channel programs which have a more sophisticated treatment of channel wall phenomena including slagging effects and boundary layer losses. Therefore, the PDG 73 program was utilized for the large number of channel design case calculations involved in the parametric analysis which served the main purpose of comparison between the various design cases considered.

The basic channel calculation procedure for the PDG series programs is schematically outlined in the diagram on Fig. 3-1. Both the electrical and gasdynamic calculation subroutines of the model separate the flow into a uniform core and a boundary layer. An additional subroutine calculates the composition of the plasma assuming chemical equilibrium at each step in the channel integration.

The inlet boundary conditions are established by the various selected system parameters for fuel, oxidizer, seed, etc., together with assumed combustion design conditions. These also define the thermodynamic, thermochemical, and electrical properties of the working fluid which were calculated for the various coal-oxidizer-seed mixtures involved for the three different Reference Plants considered. The exit pressure is determined by the diffuser performance and the downstream bottoming plant operating conditions.

The combustor pressure or MHD generator pressure ratio was sought optimized in each design case so as to maximize the net power output (MHD generator power minus compressor power) from the prime MHD cycle and to obtain this with acceptable values of the critical electrical and gasdynamic operating parameters of the MHD generator. (Axial and transverse electrical fields, transverse current, power density, Hall parameter, L/D ratio). As previously mentioned complete and final channel design optimization requires further design effort which was beyond the scope of the parametric analysis of Task I.



(1) THE DESIGN PROGRAM CALCULATES CHANNEL LOFT FOR A SPECIFIED VELOCITY DISTRIBUTION
THE OFF DESIGN PROGRAM CALCULATES VELOCITY, ETC FOR A GIVEN CHANNEL LOFT.

(2) ELECTRODE AND BOUNDARY LAYER VOLTAGE LOSS AS SPECIFIED BY AN EQUATION BASED ON EXPERIMENTAL MEASUREMENT AS WELL AS THEORETICAL CALCULATION.

(3) BARRED QUALITIES ARE AVERAGES OVER THE CHANNEL CROSS SECTION

(4) SEPARATE PROGRAMS ARE USED FOR THE CALCULATIONS OF THREE DIMENTIONAL CURRENT DISTRIBUTIONS AND END EFFECTS

Fig. 3-1 Basic MHD Channel Calculation Procedure

Calculated channel performance and design data for all of the various design cases considered for the three different Reference Power Plants 1, 2 and 3 were presented in the separate description of each Reference Plant in the previous Section 2.0, in Tables II-6, II-12, and II-19, respectively.

Channel performance characteristics for the base design case of each Reference Plant are summarized in Table III-1. Detailed design data for each of these three base case channel designs are plotted in Figs. 3-2 through 3-8. The magnetic field distribution from channel inlet to exit was kept constant and at a value of 6 Tesla for all of the channel calculations in order to simplify the numerous channel calculations involved in the parametric analysis. It is noted that the high values of the Hall parameter ($\omega\tau$) in particular and to a lesser degree of the transverse field (E_y) occur at the exit end of the channel. These high values of the Hall parameter specifically but also of the transverse field can be reduced by tapering of the magnetic field. Subsequent conceptual design work will consider this which also will conform to the real field distribution of the superconducting magnet.

Important MHD channel performance data developed for the base case channel designs of the Reference Plants in this study, from ECAS, our ETF Conceptual Design study, our CDIF #1B channel design work, and from the AVCO experimental Mark VI generator are summarized in Table III-2 for comparison. The values of the critical channel design parameters such as power density, axial field and current density for the early commercial plant channel designs developed in this study are of the same order as those projected for the channel designs of ETF and CDIF #1B. The experimental operation of the AVCO MK VI generator has already provided a good basis for operation of larger channels at the parametric values indicated. As previously mentioned, the Hall parameter ($\omega\tau$) and to a lesser degree the transverse field (E_y) can be reduced for the early commercial plant channel designs by tapering of the magnetic field.

The enthalpy extraction of the various channels listed in this table is plotted in Fig. 3-9 against the thermal input to the channels which is a measure of the channel capacity or its size. The isentropic efficiency of the various channels considered is also identified on this figure. It is clear that size plays an important role in establishing the attainable thermodynamic performance of the MHD generator channel (η_e, η_{is}) and of the MHD prime cycle (η_{MHD}) and thus of the overall net plant thermal efficiency.

Results from calculations of supersonic operation of the MHD generator for the parametric design points 14, 15 and 16 are listed in Table III-3. These channel calculations were conducted both with the original value of 6 Tesla of the magnetic field and

TABLE III-1

CHANNEL CHARACTERISTICS FOR BASE DESIGN CASE OF EACH REFERENCE PLANT

		Ref. Plant 1	Ref. Plant 2	Ref. Plant 3
Fuel		Mont. Sub.	Mont. Sub.	Mont. Sub.
Thermal Input	MW	2106	2195	2295
Mass Flow	kg/s	497	497	480
Inlet Stangation Pressure	atm	6.74	8.3	8.3
Inlet Stagnation Temp	°F	4597	4727	4678
Loading Parameter (Faraday)				
Inlet Mach No.		0.8	0.8	0.8
Channel Design Mode		Const. Vel.	Const. Vel.	Const. Vel.
Magnetic Field	Tesla	6	6	6
Power Output	MW	495	558	523
Enthalpy Extraction	%	23.5	25.4	22.8
Isentropic Efficiency	%	72.5	73.1	73.0
Diffuser Recovery Factor		0.6	0.6	0.6
Length	m	16	18.9	19.7
Inlet Cross Section	m x m	1.1 x 1.1	1.0 x 1.0	0.9 x 0.9
Exit Cross Section	m x m	2.6 x 2.6	2.6 x 2.6	2.6 x 2.6
Max. Transverse Current Density (J_y)	amp/cm^2	0.9	1.0	0.8
Max. Hall Field (E_x)	kv/m	2.7	2.3	2.[illegible]
Max. Transverse Field (E_y)	kv/m	4.0*	4.2*	4.0*
Max. Hall Parameter ($\omega\tau$)		6.0*	5.8*	5.0*
Average Power Density	MW/m^3	7.5	7.4	7.0

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*Can be reduced by tapering of magnetic field.

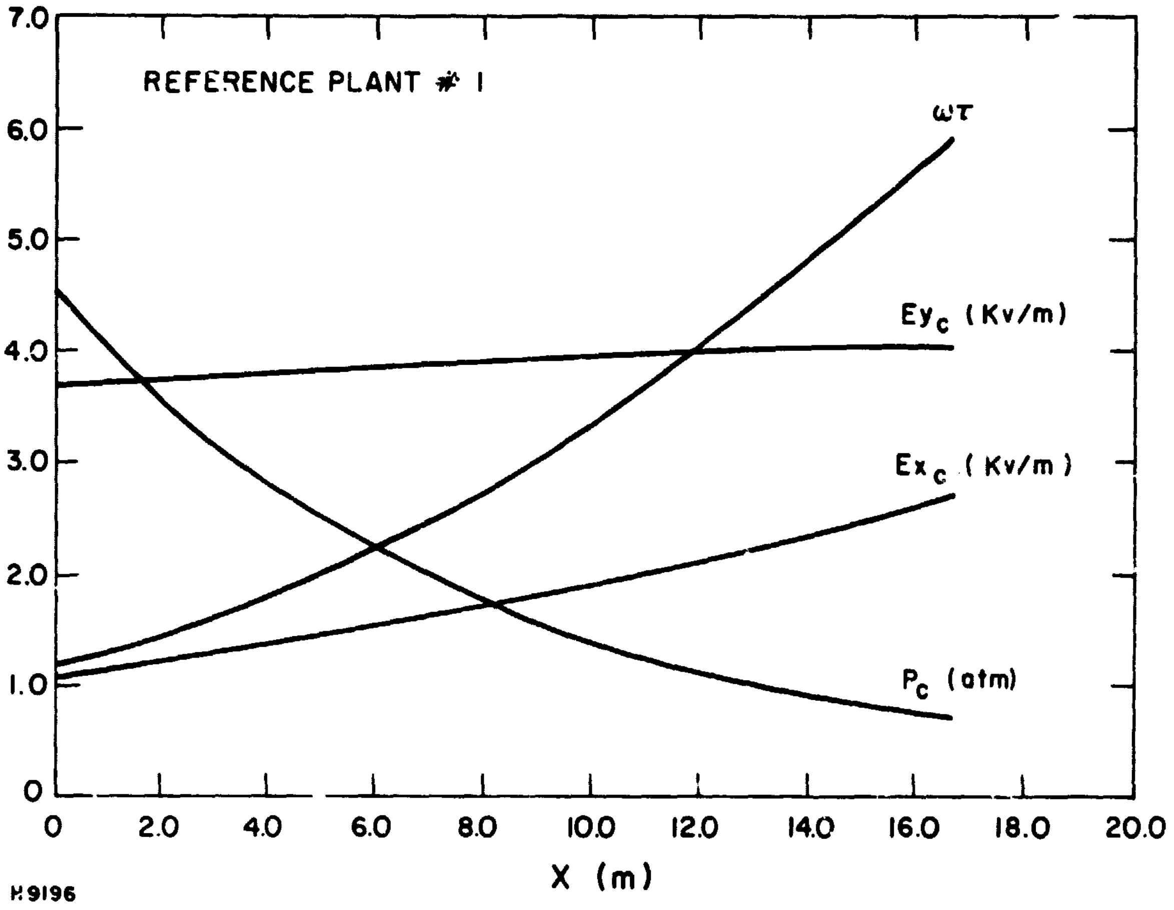

Fig. 3-2 Base Case Channel Operating Characteristics for Reference Plant 1

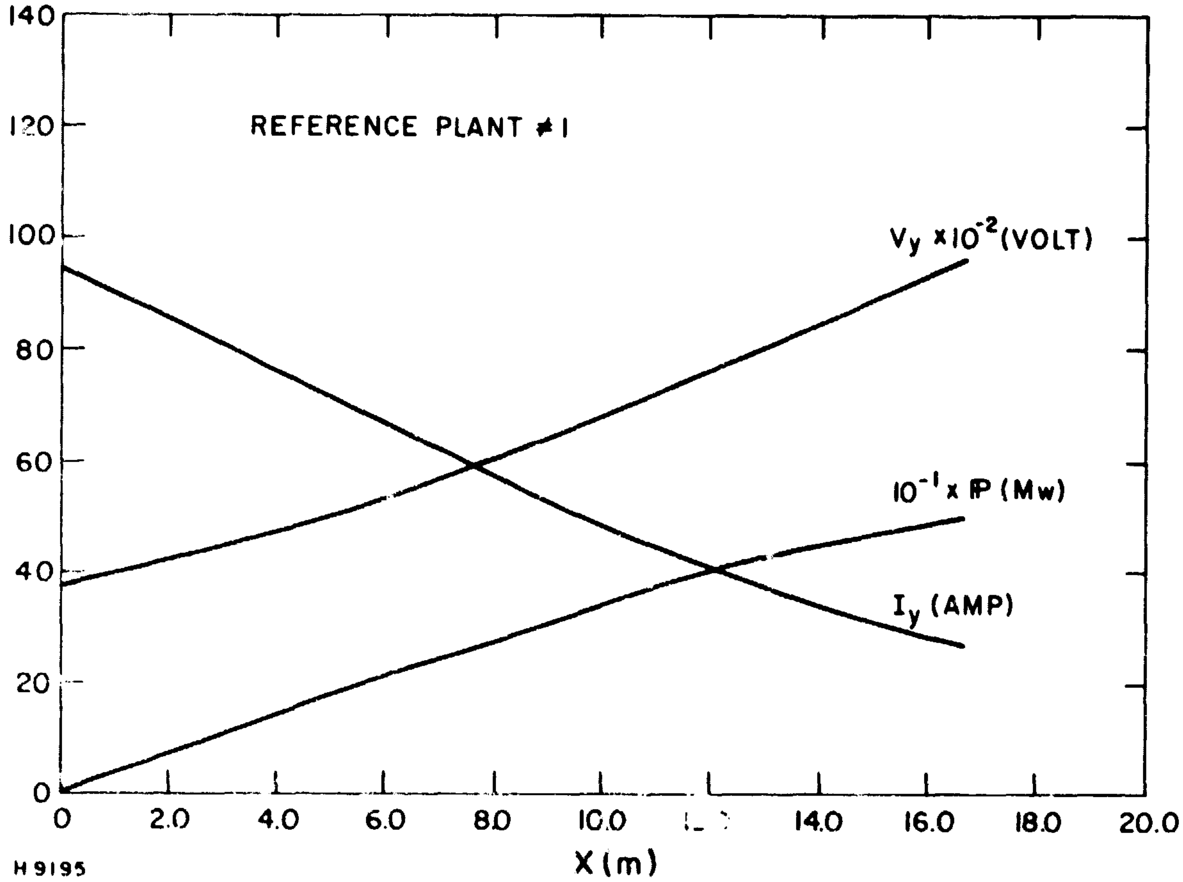

Fig. 3-3 Base Case Channel Operating Characteristics for Reference Plant 1

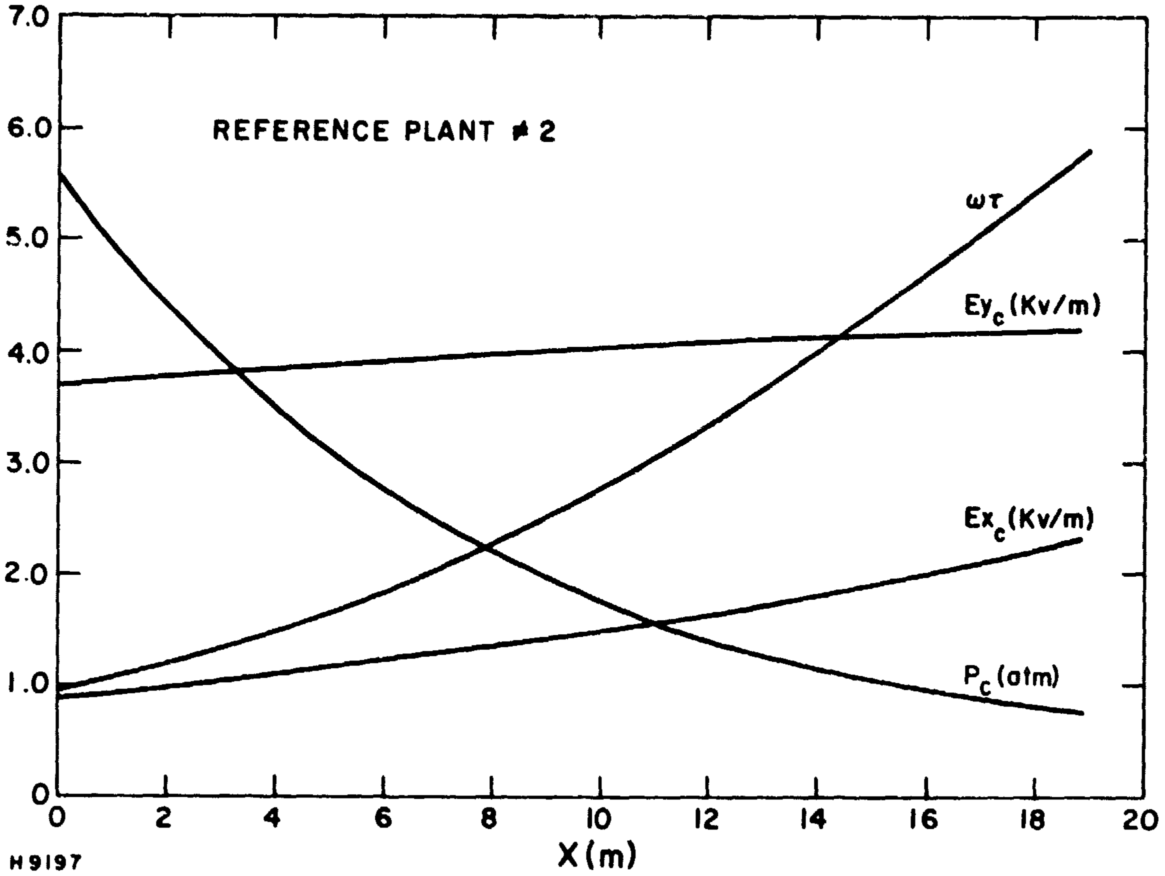

Fig. 3-4 Base Case Channel Operating Characteristics for Reference Plant 2

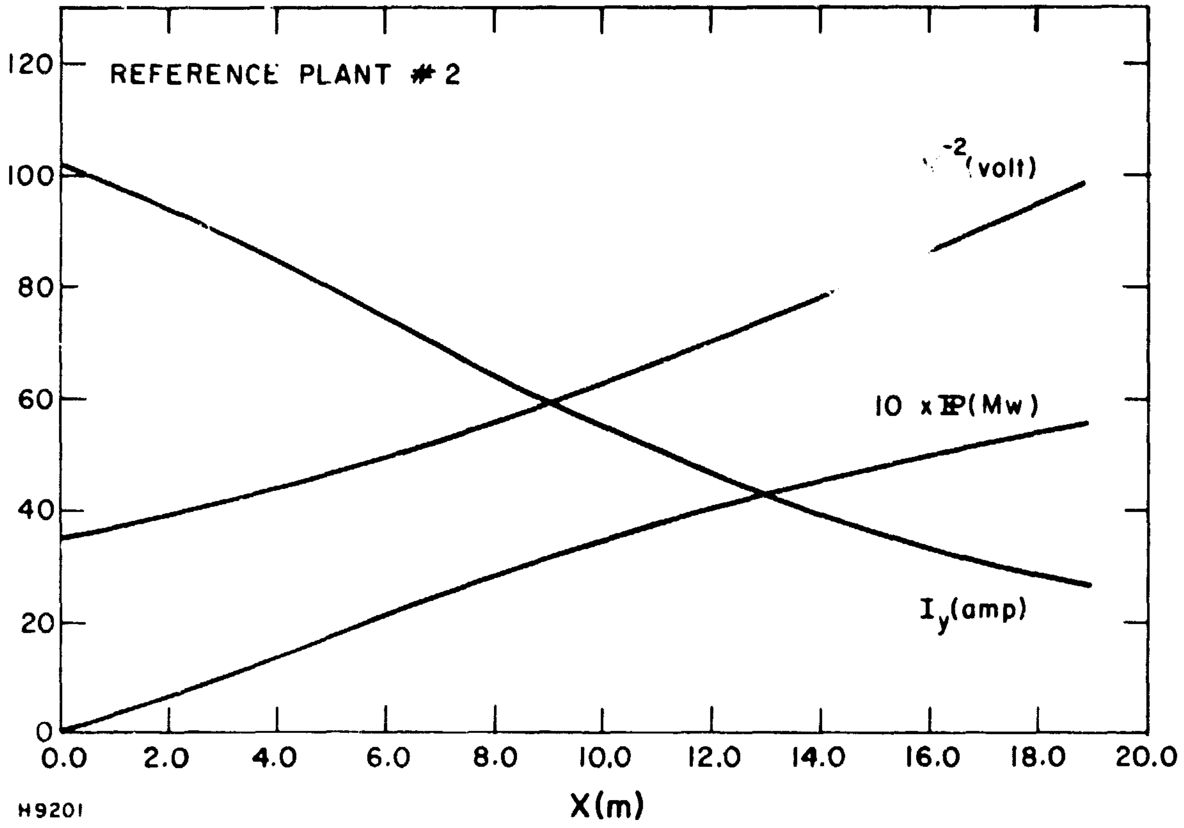

Fig. 3-5 Base Case Channel Operating Characteristics for Reference Plant 2

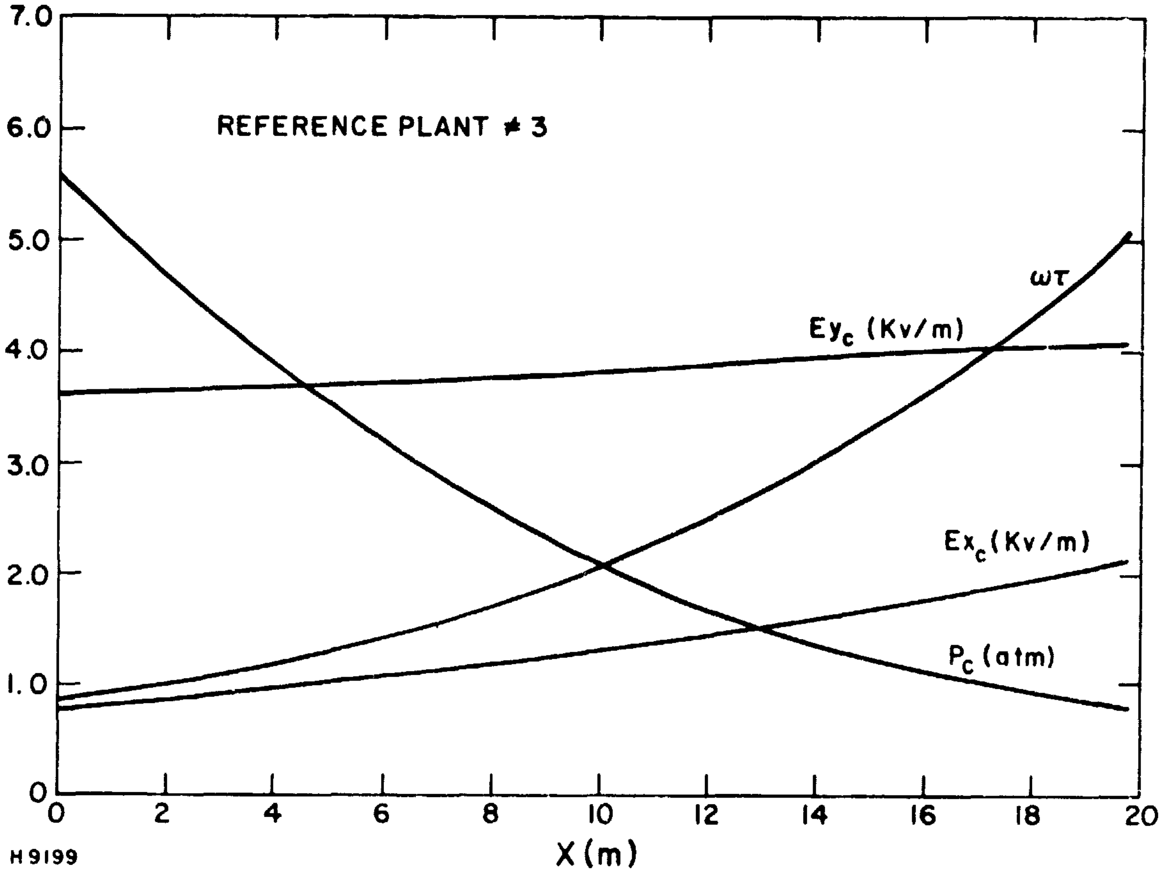

Fig. 3-6 Base Case Channel Operating Characteristics for Reference Plant 3

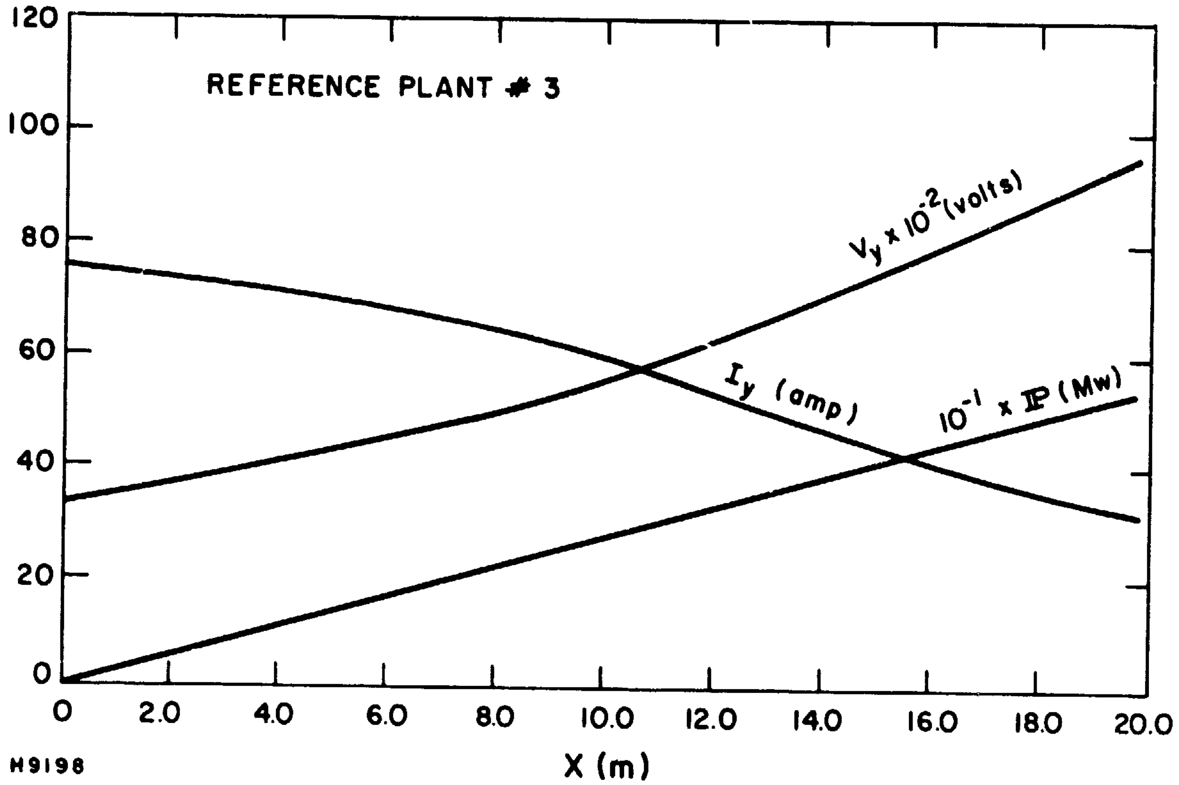

Fig. 3-7 Base Case Channel Operating Characteristics for Reference Plant 3

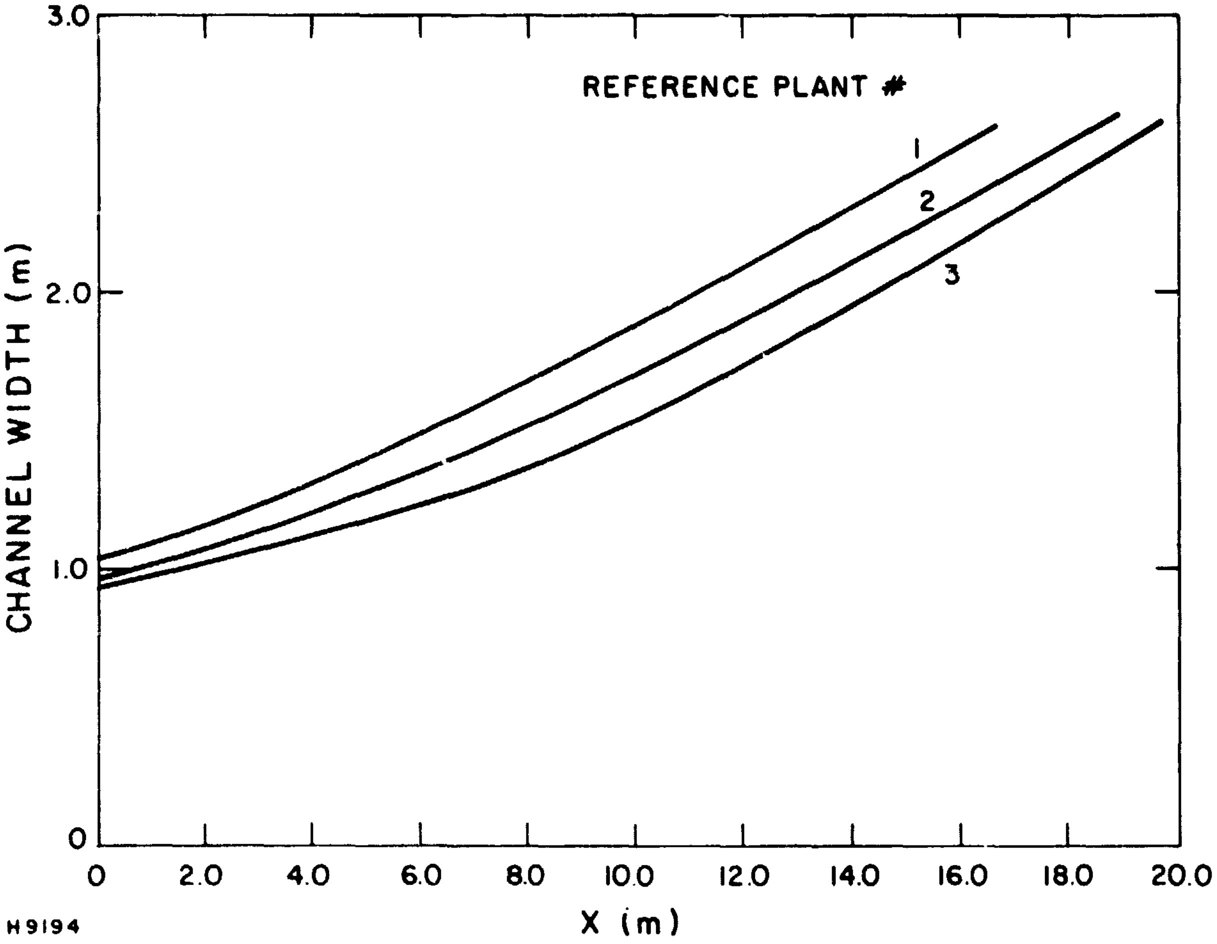

Fig. 3-8 Base Case Channel Loft of Each Reference Plant

TABLE III – 2

COMPARATIVE MHD CHANNEL PERFORMANCE DATA

						COMMERCIAL BASELOAD			
						EARLY			MATURE
		AVCO MK–VI	CDIF # 1B	ETF 2500°F PREHEAT	ETF 3000°F PREHEAT	PLANT 1 S.F.A.H. 2700°F PREHEAT	PLANT 2 S.F.A.H. 3000°F PREHEAT	PLANT 3 34% O_2 1100°F PREHEAT	ECAS D.F.A.H. 2500°F PREHEAT
THERMAL INPUT	MW_{th}	15	48	250	270	2106	2195	2295	5300
PRESSURE RATIO		2.9 – 3.5	3.5	4.0	5.4	6.74	8.3	8.3	8.3
INLET TEMP. (STAG.)	°K	2900	2860	2675	2794	2809	2882	2853	2830
MAX. MAGNETIC FIELD	TESLA	2.8	6	6	6	6	6	6	6
MASS FLOW RATE	kg/s	2.5	10	65	65	497	497	480	1270
GAS VELOCITY	MACH	1.2	0.8	0.8	0.8	0.8	0.8	0.8	0.8
POWER OUTPUT	MW	0.2 – 0.6	3.4	35.5	45.6	495	558	523	1420
MAX. TRANSV. CURRENT	$amps/cm^2$	0.8 – 1.5	1.0	0.65	1.1	0.9	1.0	0.8	1.0
MAX. AXIAL FIELD (E_x)	kV/m	1.0 – 3.0	2.2	2.5	2.4	2.7	2.3	2.1	2.7
MAX. TRANSV. FIELD (Ey)	kV/m	1.0 – 3.0	3.9	3.7	3.6	•4.0	•4.2	•4.0	
HALL PARAMETER	$\omega\tau$	1.5 – 2.5	2.8	4.4	4.4	•6.0	•5.8	•5.0	4.1
POWER DENSITY (AVG)	MW/m^3	5 – 15	~10	8.4	11.6	7.5	7.4	7.0	7.4
ENTHALPY EXTRACTION	%	1.5 – 4.0	7	14.2	16.9	23.5	25.4	22.8	26.5
ISENTROPIC EFFICIENCY	%		44	57.0	57.8	72.5	73.1	73.0	76.0
DIFFUSER EFFICIENCY	%		45	46	46	60	60	60	70

•CAN BE REDUCED BY TAPERING OF MAGNETIC FIELD

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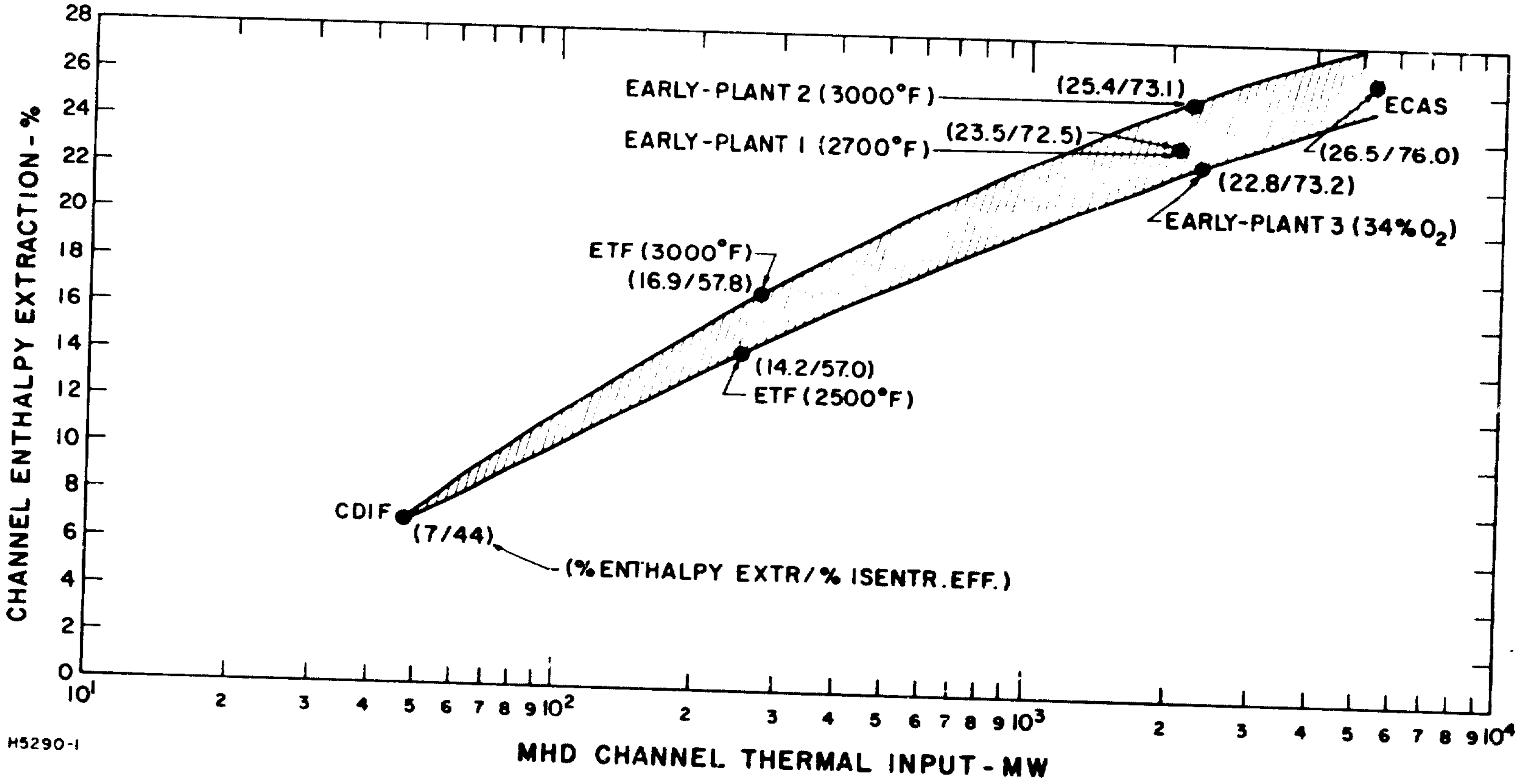

Fig. 3-9 Channel Enthalpy Extraction and Isentropic Efficiency Versus Thermal Input

TABLE III-3. SUPERSONIC MHD GENERATOR DESIGN DATA - REFERENCE PLANT #2

			PARAMETRIC POINT 14				PARAMETRIC POINT 15			PARAMETRIC POINT 16		
MAGNETIC FIELD STRENGTH	B	UNITS	6	6	4.5	4.0	6.0	6.0	4.5	6.0	6.0	4.5
INLET MACH NO. (CONT. VEL.)	M		1.2	1.1	1.1	1.1	1.2	1.1	1.1	1.2	1.1	1.1
ELECTRICAL LOAD PARAMETER	α		0.77	→	→	→	0.8	→	→	0.83	→	→
COMBUSTOR EXIT PRESSURE	Po	ata	8.5	→	→	→	8.3	8.3	7.8	8.1	8.1	7.0
COMBUSTOR EXIT TEMPERATURE	T_o	°F	4723	4723	4723	4723	4728	4728	4719	4724	4724	4706
MAXIMUM AXIAL FIELD	E_x	kV/m	7.0	5.5	2.8	2.1	5.9	4.7	2.4	4.8	3.8	2.0
MAXIMUM TRANSVERSE FIELD	E_y	kV/m	5.8	5.4	4.1	3.6	5.9	5.5	4.2	6.0	5.6	4.2
MAXIMUM TRANSVERSE CURRENT	J_y	amp/cm^2	1.4	1.5	1.1	0.9	1.2	1.2	1.0	0.9	1.0	0.9
MAXIMUM HALL PARAMETER	ωτ		7.8	7.1	5.1	4.4	7.7	7.0	5.2	7.5	6.9	5.2
CHANNEL INLET DIMENSION	S_{in}	m x m	0.9x0.9	0.9x0.9	0.9x0.9	0.9x0.9	0.9x0.9	0.9x0.9	1.0x1.0	1.0x1.0	1.0x1.0	1.0x1.0
CHANNEL EXIT DIMENSION	S_{ex}	m x m	2.4x2.4	2.4x2.4	2.5x2.5	2.5x2.5	2.4x2.4	2.4x2.4	2.5x2.5	2.4x2.4	2.4x2.4	2.5x2.5
CHANNEL LENGTH	L	m	9.5	10.5	19.0	24.3	11.0	12.2	19.4	13.0	14.6	19.5
MHD POWER	P	MW	492	506	492	488	502	515	490	508	524	480

with lower field strengths. The results from the calculations show that it became necessary to reduce the magnetic field strength from the original value of 6 Tesla to maximum 4.5 Tesla in order to obtain reasonable values of the channel critical electrical operating parameters.

Supersonic operation of the MHD generator resulted in reduced power output from the MHD generator and the MHD prime cycle as compared to subsonic operation. However, it should be noted that the cost of the MHD generator magnet becomes less because of a lower magnetic field (or a shorter channel length).

3.1.2 MHD Channel Mechanical Design

Mechanical Design - The mechanical design of the channel considered for all the cases investigated in the parametric study is similar to that developed for the channels in the ETF program. It is based on the channel development work conducted at AERL.

The mechanical construction of the channel is illustrated by the cross-sectional drawing in Fig. 3-10. It consists of a four-wall box structure made from glass-epoxy insulating material upon which the gas-side elements are mounted. This insulating box provides the principal structural support for the channel. It also serves as a pressure vessel to contain the high temperature gases. The channel will consist of a number of longitudinal sections fastened by flanged joints to facilitate fabrication and assembly. Due to the larger size of these commercial baseload channels as compared to those for the ETF, the thickness of the sidewall insulator material must be increased to provide additional structural strength. Initial design investigations show this to be feasible. Additional insulating structural members can also be incorporated on the outer walls of the channel if required. More detailed design analysis with stress calculations are necessary to establish the final design of the channel. These were beyond the scope of these parametric analyses.

The gas-side elements of the channel will be made from extruded copper segments with integral cooling water passages. These will be attached to the insulating walls with mechanical fasteners. The electrode pitch will be of the order of 1.5 cm. Inter-electrode insulators will consist of thin pre-formed boron nitride segments. The anode surface will be protected from electro-chemical attack by a 10 mil platinum cap.

For all the design case variations considered in this study except parametric point 4 of Case II (Reference Plant 2), it was assumed that channel cooling would be accomplished by employing low pressure and low temperature water from the boiler feed water circuit in order to comply with present state-of-the-art in channel technology. Parametric Point 4 of Case II considered the use of high pressure and high temperature boiler feed water as channel

CDIF CHANNEL 1A CONFIGURATION DETAILS

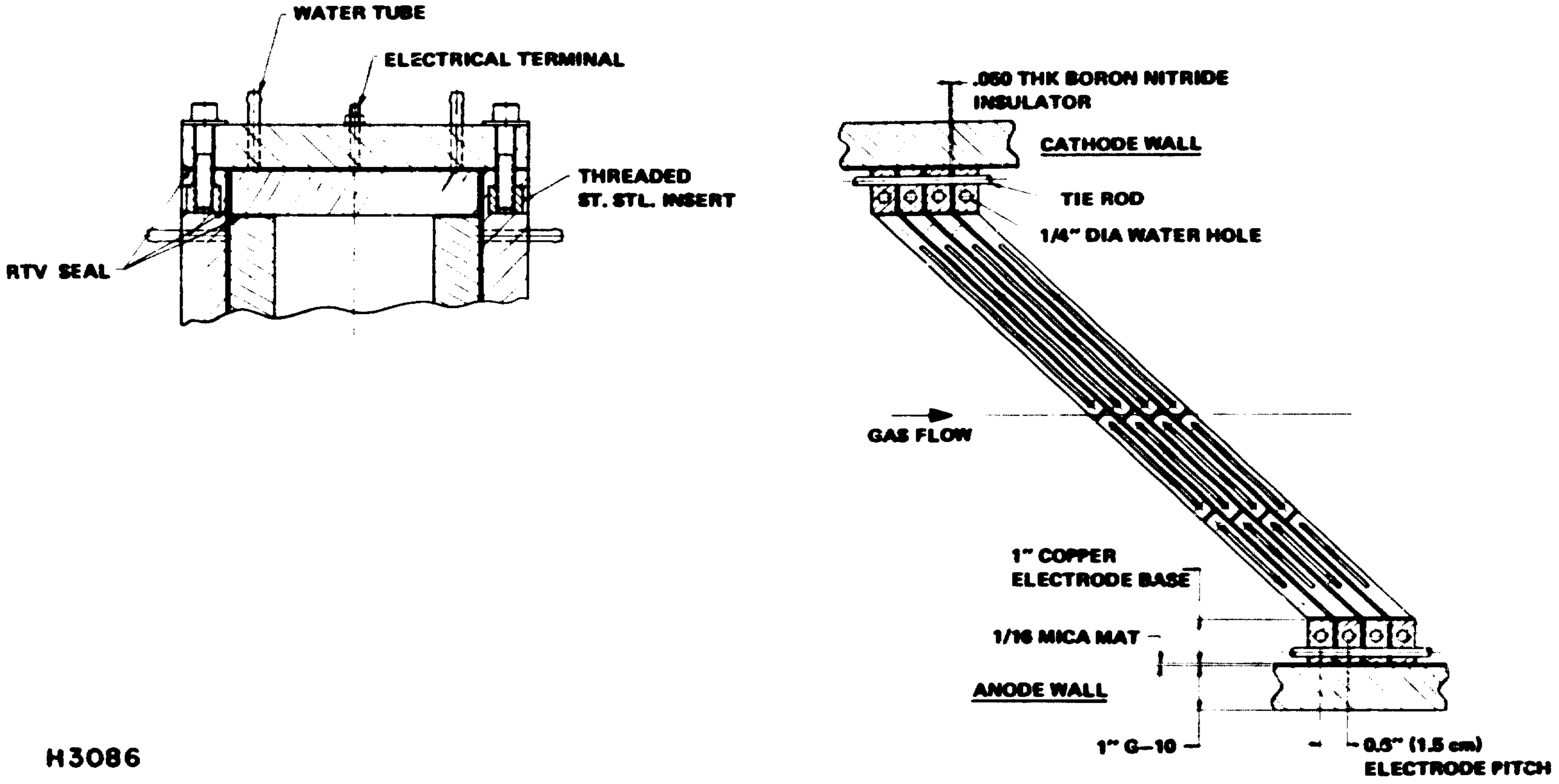

Fig. 3-10 Channel Construction - Typical

coolant. This requires advanced channel cooling design concepts such as those used in ECAS.

Channel costs were estimated by initially determining the cost of the base case channel of Reference Plant 1 including breakdown of the material, fabrication and channel assembly costs. The cost for all other channels was then obtained by applying a scaling factor assuming that cost was proportional to the total channel surface area raised to the 0.7 power. Relevant information gained from experience in building the MK VI and CDIF channels was utilized in generating the channel costs.

The total weight of the base case channel of Reference Plant 1 was estimated to be 130,000 lbs. The weight of the other channels varies roughly proportional to the channel surface area.

3.1.3 Loading and Consolidation Circuitry

For a large scale MHD generator, circuits interfacing with both the channel and the load inverters are contemplated. These circuits serve the dual function of controlling individual electrode currents, and consolidating power from several electrodes, each at a different potential, for conversion by a single inverter. The ultimate configuration of these control and consolidation networks will be determined by considerations of cost, efficiency, reliability, flexibility and effectiveness.

Consolidation and control circuits are applicable to both Faraday and diagonal generators. Representative circuitry for both types of generators is shown in Fig. 3-11. It is important to note that in addition to applications in regions of power takeoff, the consolidation and control circuits can be used to regulate the cross-connection currents in the diagonal channel, if this is necessary (experience on the Avco Mark VI diagonal generator indicates that severe electrode current nonuniformities will develop if no control is used).

A successful control circuit must satisfy the following criteria: (1) the circuit must be essentially nondissipative; (2) it must not short the Hall field in the generator; (3) it must not induce destructive arcing along the channel wall; and (4) it must provide control over individual electrode currents so that the channel can be trimmed (i.e., the process of adjusting the electrical loading of the channel to achieve a desired electrical and gasdynamic operating condition).

It is presently contemplated that the channel will be loaded in the multi-terminal diagonal mode. Typical circuits using five terminal connections are shown in Fig. 3-12 for a base load channel. Two types of circuit are shown, designated as independent connection and parallel connection. Other connections, combining these, are also possible.

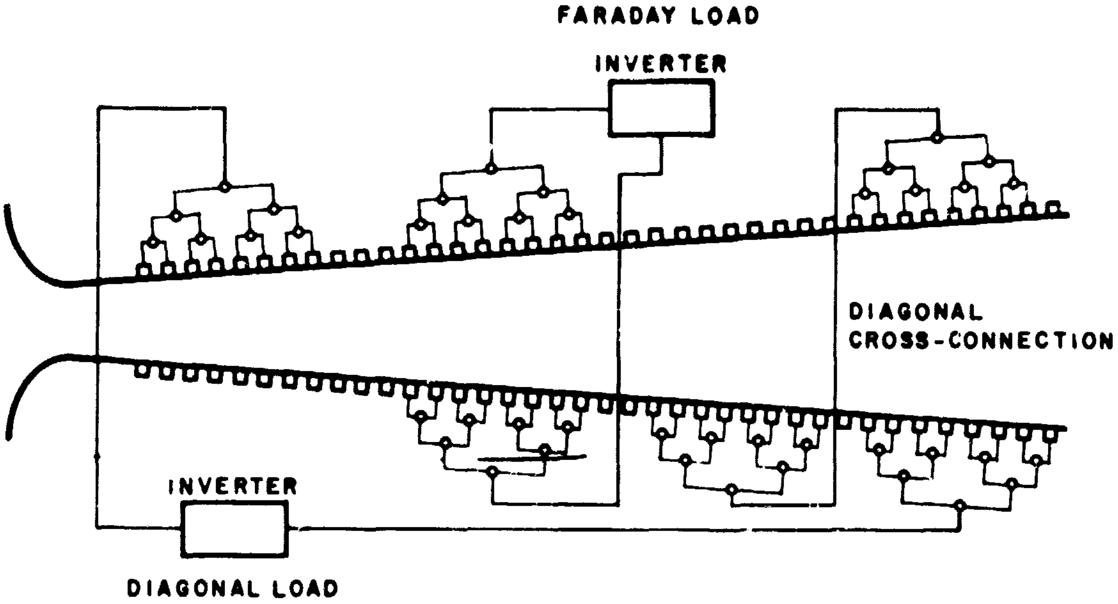

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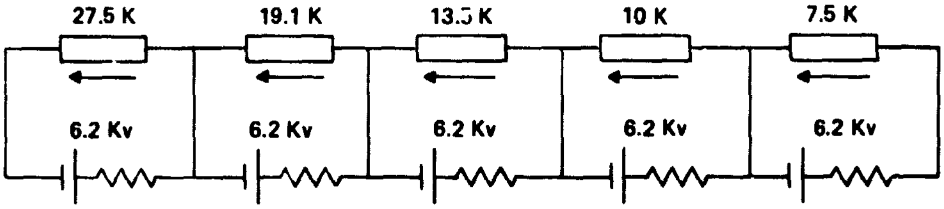
Fig. 3-11 Applications of Consolidation Networks to Both Faraday and Diagonally Loaded Channels

VOLTS	AMPS	Mw
INDEPENDENT CONNECTION		
6.2 Kv	27.6 Ka	173.9
6.2 Kv	19.1 Ka	120.3
6.2 Kv	13.5 Ka	85.1
6.2 Kv	10 Ka	63
6.2 Kv	7.5 Ka	47.3



PARALLEL CONNECTION		
6.3	8.5 Ka	53.6
12.6	5.6 Ka	70.6
18.9	3.5 Ka	66.2
25.2	2.5 Ka	63
31.5	7.5 Ka	236.3
		490

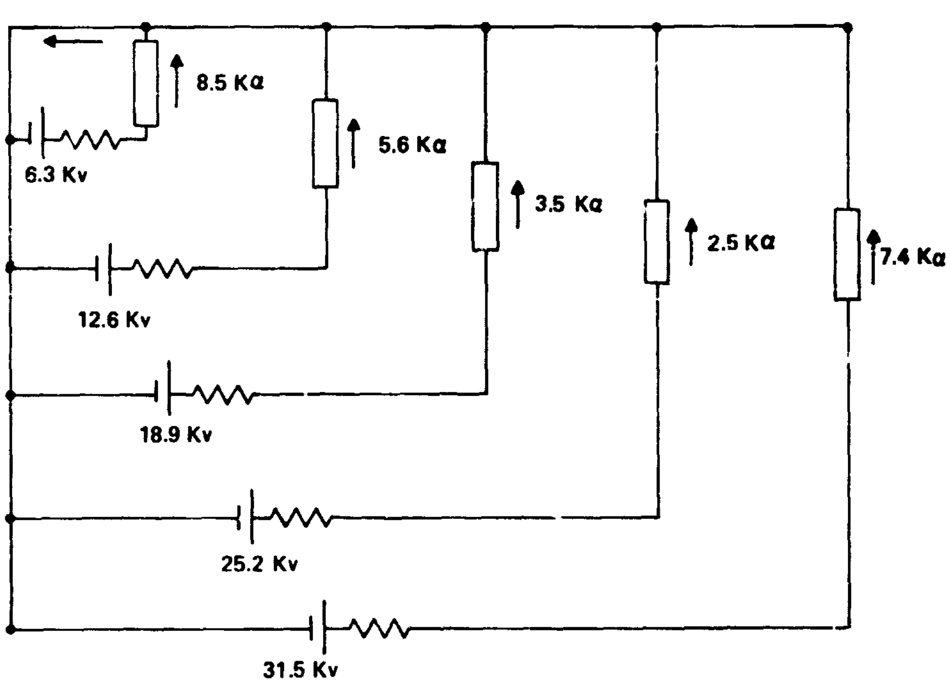


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Fig. 3-12 Typical Five Terminal Diagonal Load Connections

3.2 SUPERCONDUCTING MAGNET

The design and cost analyses of the superconducting magnet were based on the magnet design concept previously developed in the Conceptual Design of the ETF. Magnet size and estimated costs were initially developed for the base case of Reference Plant 1. Dimensions and estimated costs of the magnet for the various design cases of each Reference Plant were then obtained by scaling from this first design case.

Scaling from the ETF size to the commercial size considered here was possible because the peak magnetic field in both magnets was the same (6 Tesla) and the design principles used in estimating the cost, weight and dimensions of the magnet are equally applicable for both sizes. The dimensions of the warm bore were based on the channel designs developed. Comparative dimensions between the ETF size and commercial size magnets are listed in Table III-4. With this information, the required ampere turns could be estimated, leading to an evaluation of the forces and other pertinent data for the magnet.

It is important to point out that the ETF magnet conceptual design which formed the basis for the magnet design in this study represented a significant departure from earlier conceptual designs that had been made for both pilot scale and large scale base load MHD power plants. This new design concept offers the potential of a very significant reduction in the amount of labor and cost required for magnet construction and assembly.

In the current concept the magnet has been designed with modules which are small enough to be shipped to the site ready for assembly. Small size and light weight were not, in themselves, primary design objectives, but capital cost, and the need to conserve helium were considered important. It is noted that the magnet cost is a significant part of the overall MHD system cost. The magnet design objectives were:

1. All components (with the exception of the vacuum tank) should be of modular construction and of a size that permits shipment to the power plant site.

2. The most difficult and the largest single item to be shipped is the winding. Therefore the magnet design was aimed at shop prefabrication of the winding and for shipment of the winding in individual containers ready for final assembly.

3. The Lorentz forces originating within the windings should be transferred via a substructure within the winding container, to the container walls and then to a suitable superstructure.

TABLE III-4

COMPARATIVE MAGNET WARM BORE DIMENSIONS

		ETF	Commercial (Base Case of Ref. Plant 1)
Mean Cross Section	m^2	3.55	7.35
Channel Length	m	7.75	16.6

4. All forces except the weight should be contained within the support structure and not reacted either against the vacuum tank walls or the bore tube.

5. The conductor splices should be brought to a separate splice box located in the low field region of the winding container where the individual conductor ends and winding instrumentation could be accessible for inspection or repair.

6. All pressure and vacuum seals whether on the vacuum tank or on the helium container should be independent of the load transferring elements. In this way, the containers may be opened and resealed, without interferring with the structural integrity of the part.

7. The vacuum tank would have a single wall with an 80°K baffle and superinsulation. There would be removable covers that are large enough to permit magnet assembly or disassembly within the main frame of the tank.

The type of geometry chosen for the winding was a combination of a saddle coil and a race track coil. The saddle coil is an efficient type of winding, however, the maximum field in the winding can be significantly reduced by placing a portion of the ampere turns close to the symmetry axis of the magnetic field. This accounts for the "L" shaped winding space shown in the cross section view of the magnet in Fig. 3-13. The magnetic field profile is shown in Fig. 3-14. The magnetic field was for all design cases of the different reference plants in these parametric analysis specified without axial taper. As previously mentioned tapering of the magnetic field will be considered in subsequent design activities to match the channel requirements.

A plan view of the magnet, is shown in Fig. 3-15. It is housed in a cylindrical vacuum tank which has two large covers. It is assembled on its supports inside the tank. The central part of the tank is notched at the inlet side so that the combustor may be brought close to the channel. The magnet windings are housed in sealed helium containers which have a 45° rectangular saddle shape. The principal direction of the magnetic field is horizontal.

The force containment structure consisting of trusses and the tension plates is assembled from individual modules built up from flat aluminum plates without welding. In the mating faces of the trusses and tension plates, teeth are cut to transfer forces. As a result of this new design concept, significant savings in projected magnet costs are expected compared to other magnet designs that require extensive manufacturing and assembly at the power plant site.

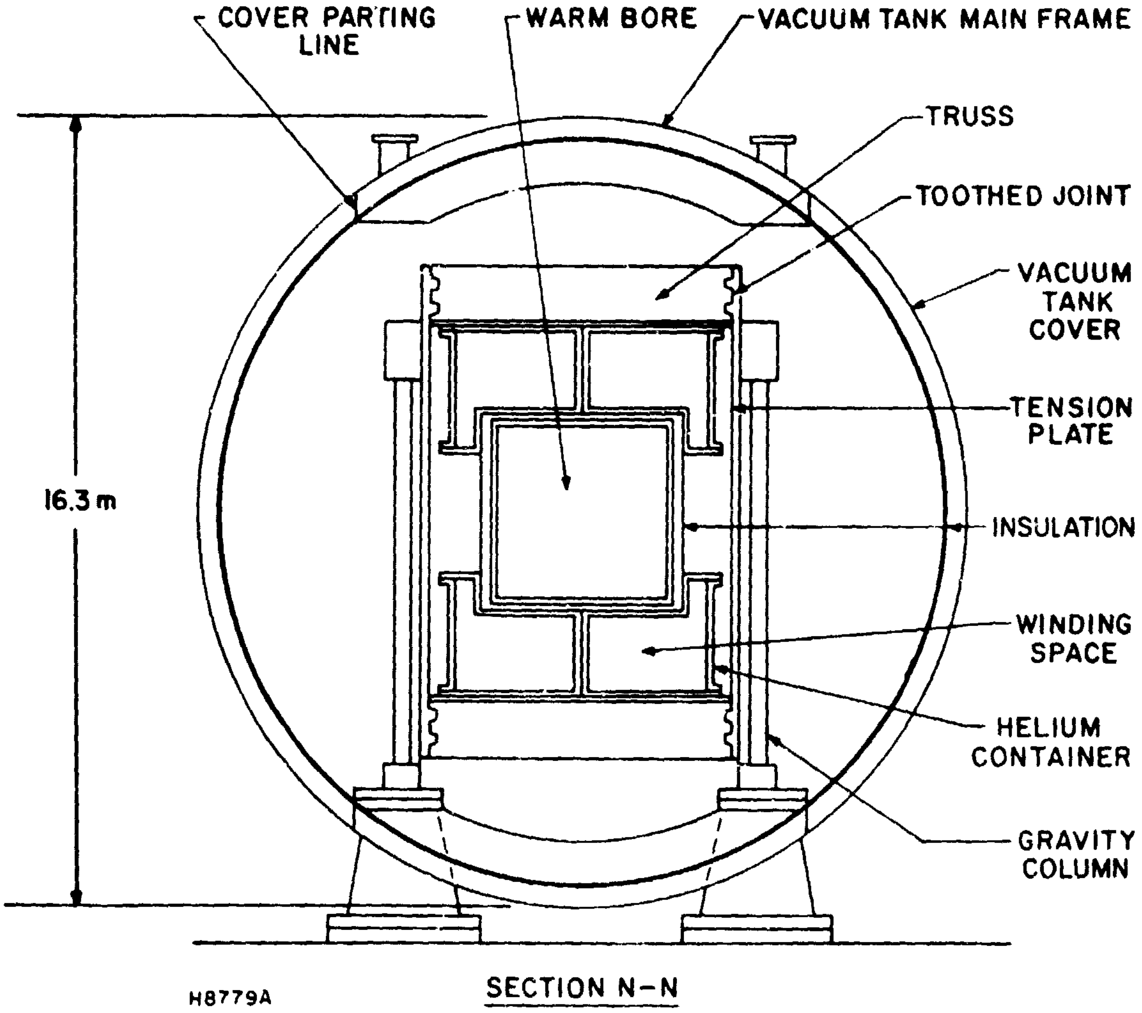

Fig. 3-13 Magnet Cross Section with Dimensions for Base Case Reference Plant 1

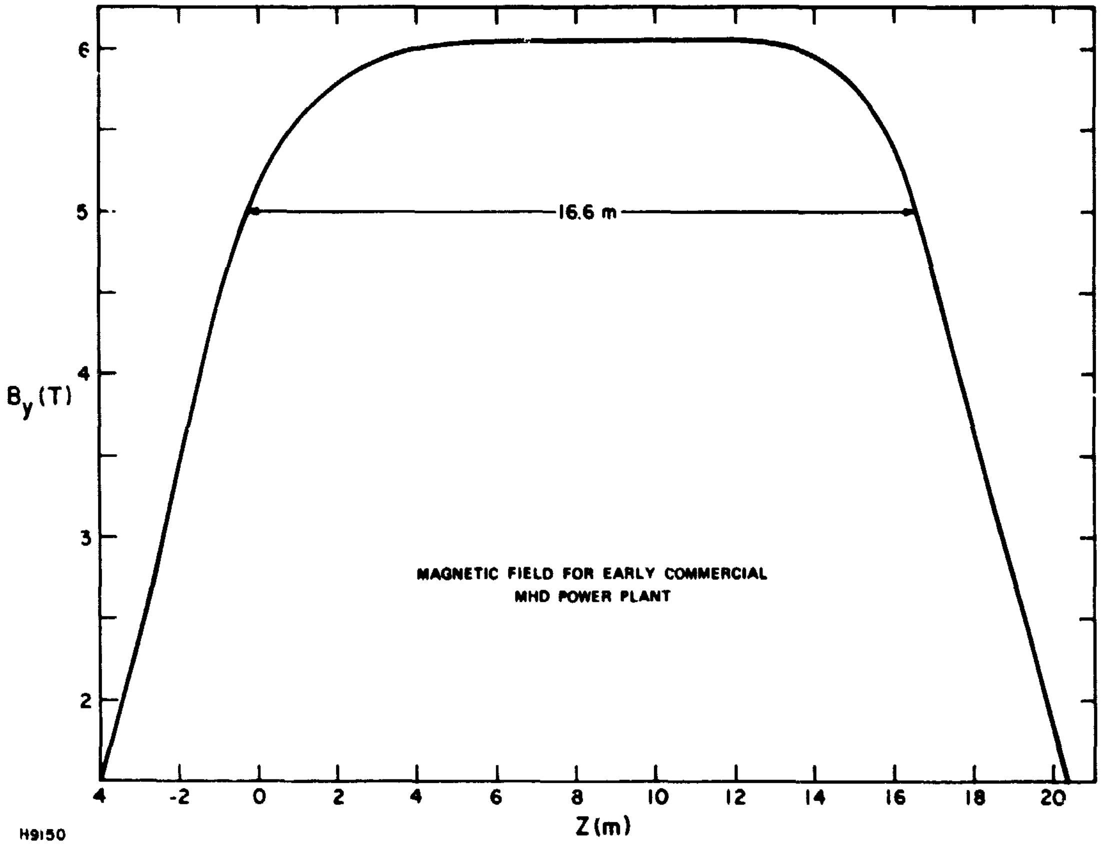

Fig. 3-14 Axial Magnetic Field Distribution for Base Case of Reference Plant 1

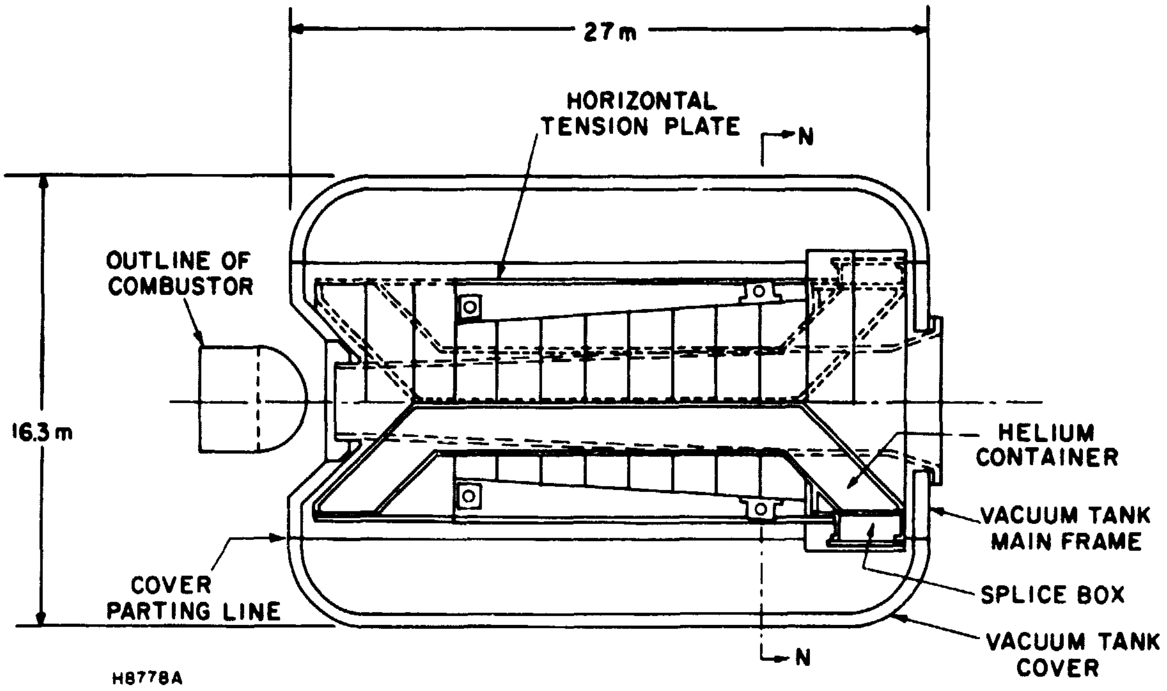

Fig. 3-15 Magnet Outline with Dimensions for Base Case of Reference Plant 1

A comparison of dimensions, stored energy and weights between the ETF size and commercial size magnets are listed in Table III-5. The estimated cost of the commercial size magnet was developed utilizing cost data from the ETF magnet and scaling in accordance with the weight and complexity of the relative parts. Estimated magnet costs in 1977 dollars are shown in Table III-6. These costs were subsequently escalated to 1978 dollars in establishing plant capital costs.

Table III-7 shows a comparison of pertinent data of magnets of different sizes designed for the CDIF, ETF and Early Commercial Plant here respectively. All magnets are designed for the same maximum magnetic field of 6 Tesla. The ratio of weights between the ETF size and CDIF size magnets is about 6 and between the commercial size and ETF size about 4. The corresponding stored energy ratios are about 10 and 4.5 respectively. The magnet is a significant cost item of an MHD power system. Therefore, it is important to develop reliable cost data which require a substantial larger design effort than that possible in these parametric analysis. Further magnet design and cost analysis would be an important item of subsequent design analysis. The commercial size magnet differs from the ETF size magnet in significant ways. For example, in order to improve the shipability of the windings, it is contemplated to manufacture the superconducting windings in four sealed modules. The ETF magnet winding consisted of two modules, both of which were of saddle shape. The commercial size magnet winding will consist of two saddle shape modules and two race track modules. The latter two are easier to wind and therefore expected to be less costly to fabricate. Additional analysis of the magnet winding and costs are important as well as of magnet structure and stresses.

3.3 COAL COMBUSTOR

The coal combustor employed for all of the design cases for the three Reference power plants considered is a single-stage combustor design. The main reasons for selection of a single-stage combustor were:

1. Relatively low heat loss.
2. Effective carbon utilization resulting from rapid particle heating and volatilization.
3. Mechanical simplicity and controls.

An outline schematic drawing of the combustor with dimensions for the base case of Reference Plant 1 is shown in Fig. 3-16. The combustor consists of a downward firing cylindrical chamber where the combustion and slag separation processes are performed and a side-mounted horizontal duct where the seed is introduced and through which the high temperature combustion products are delivered to the MHD channel.

Table III-5

COMPARISON OF MHD MAGNETS

		ETF	Commercial Size (Base Case Ref. Plant 1)
Magnet Height and Width	m	10.3	16.3
Height - Overall	m	11.0	17
Stored Energy	j	1.7×10^9	7.8×10^9
Winding Assembly Weight	kg	4.30×10^5	2.2×10^6
Structure Assembly Weight	kg	3.80×10^5	1.04×10^6
Tank Weight	kg	2.89×10^5	7.6×10^5
Total Weight	kg	1.1×10^6	4.0×10^6

Table III-6

MAGNET COST ESTIMATE FOR BASE CASE REFERENCE PLANT 1

1978 Dollars X 10^{-3}	Materials	Installation	Indirect	Total Cost
Magnet Subsystem				
Structure	3,662	93	46	3,801
Winding Assembly	24,110	22	11	24,143
Dewar	9,470	42	21	9,533
Refrigeration System	2,943	41	22	3,005
Power, Controls, etc.	1,352	290	145	1,787
TOTAL	41,537	488	244	42,269

TABLE III-7

COMPARISON OF MHD MAGNETS

		CDIF*	ETF**	EARLY*** COMM'L.
Peak magnetic field	T	6.	6.	6.
Warm bore area, average	m^2	0.86	3.57	7.34
Effective length of field	m	3.	9.	16.6
Stored energy	10^9 j	0.18	1.7	7.8
Weight	10^6 kg	.18	1.1	4.0
Length, overall	m	8.9	14.9	27.
Height, overall	m	4.8	11.0	17.
Method of construction		one piece sealed unit	modular	modular
Repairability		Difficult	Easy	Easy
Copper for conductor with niob. titan. superconductor		Yes	Yes	Yes
Full cryostatic stability		Yes	Yes	Yes

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*Gen. Elec. Preliminary Design

**Avco Conceptual Design

***Plant Reference Design #1

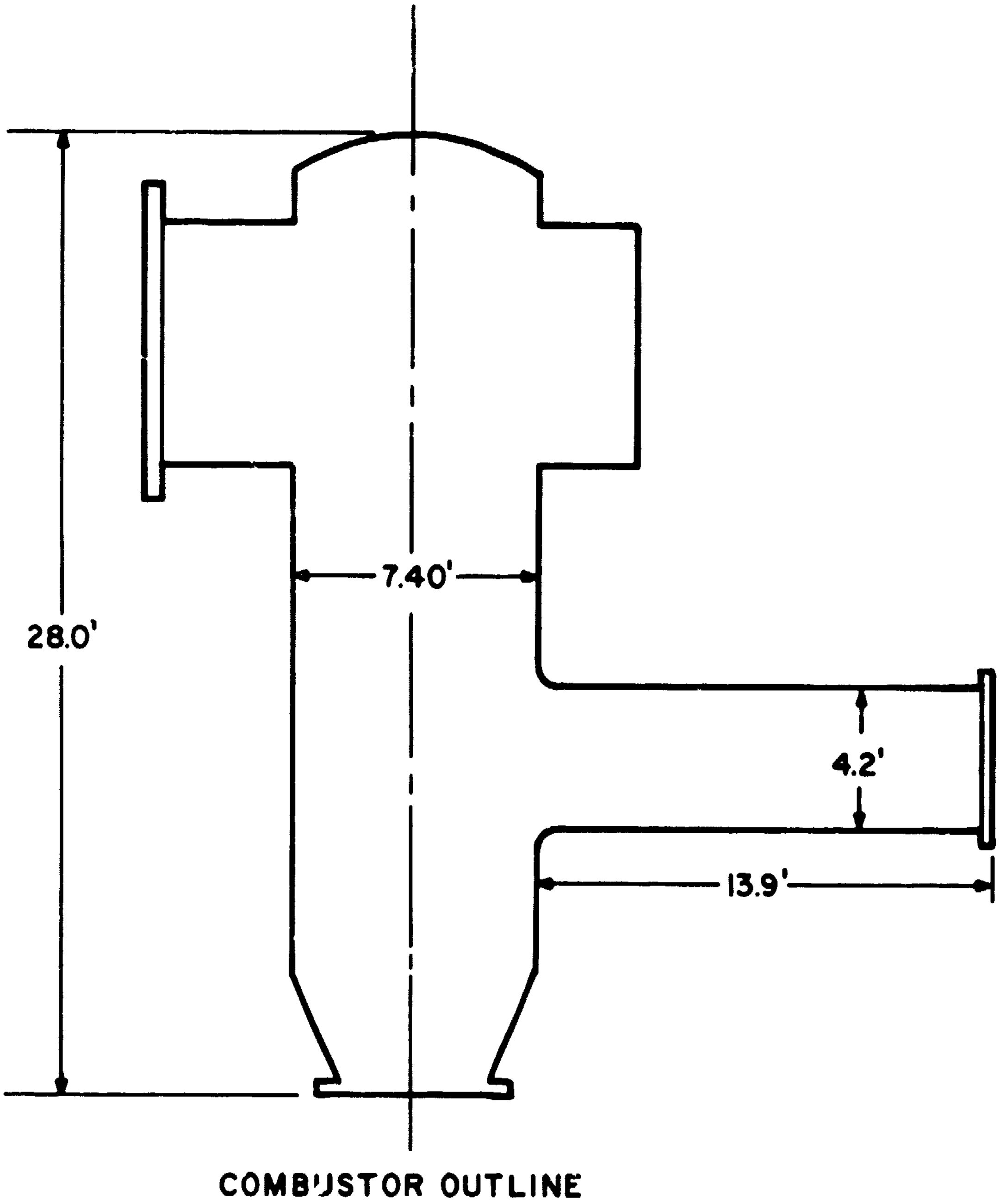

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Fig. 3-16 Coal Combustor Outline Schematic with Dimensions for Base Case of Reference Plant 1

The pulverized coal and high temperature primary air are introduced through a number of equally spaced coaxial injectors located near the top of the combustor. A refractory-lined toroidal shaped inlet manifold with equi-spaced ports supplies the primary air to the injectors. The rapid and intimate mixing of the fuel particles with high temperature preheated air results in a high release of volatiles and efficient utilization of carbon. The coal feed is dried coal pulverized to 70% through 200 mesh. The combustor was designed for a residence time of 50 ms. in all design cases. Variations in mass flow and operating temperature and pressure were taken into account in establishing the size of the combustor for each design case.

The combustor and its discharge duct are cooled by high pressure boiler feed water which flows through closely spaced welded tubes arranged at the inner wall of the combustor. No refractory material is used for lining of the combustor wall. It is anticipated, however, that a continuously replenished slag layer will be formed on the combustor walls which will reduce the wall heat loss.

The overall combustor heat loss for the various parametric design cases was calculated from the "best" analytical and experimental data presently available. Variations in combustor size, flame temperature, pressure and operating conditions otherwise, were accounted for in establishing the combustor heat loss for the different design cases involved. The combustor average wall heat flux for the range of cases considered varied from a high value of about 300,000 Btu/ft^2 - hr. to a low of about 200,000 Btu/ft^2 - hr.

The downstream end of the MHD generator channel is considered grounded. Therefore, the combustor will be operating at the full axial Hall potential developed by the generator. This required that the combustor including structural elements, all feed lines (primary air, fuel, seed, cooling water), instrumentation leads as well as the slag collection system were electrically isolated.

The total weight of the combustor for the base case of Reference Plant 1 is estimated to be 91,000 lbs..

3.4 MHD GENERATOR INLET NOZZLE

The MHD generator inlet nozzle considered for all the cases investigated in the parametric study is similar in aerodynamic and mechanical design to that developed for the nozzle in the ETF conceptual design. The nozzle assembly consists of water-cooled copper modules. These are contoured to provide the proper flow area for accelerating the gas flow to the prescribed channel inlet velocity.

The nozzle geometry is selected to provide a low pressure gradient (dp/dx) to facilitate the formation of a uniform slag coating on the nozzle walls which will reduce the wall heat loss. Grooves are machined in the nozzle wall and initially filled with castable zirconia ceramic to provide attachment points for the slag. Experience from operation of the AERL MK VI facility has shown that such an attachment scheme is essential to the formation of a slag coating in a high velocity region.

The nozzle has a modular design concept. This is shown in Fig. 3-17. The nozzle modules are made of OFHC copper materials. A modular design was selected to facilitate fabrication and assembly. It also allows for ready repair and maintenance by possible replacement of individual modules should any of these be damaged in service.

The nozzle is cooled by high pressure boiler feed water circulating through the machined water cooling passages. Total nozzle costs were estimated from a breakdown of material, fabrication and assembly costs. The estimated weight of the nozzle assembly for the base case of Reference Plant 1 is 10,000 lbs.

3.5 DIFFUSER AND TRANSITION SECTION

The geometry of the diffusers for all the parametric points of the three different Reference Plants was based upon the diffuser conceptual design in the ETF study. An outline drawing of the diffuser and transition section with dimensions for the base case of Reference Plant 1 is shown in Fig. 3-18. The diffuser consists of a two dimensional straight wall diverging duct. It has an exit to inlet area ratio of 4.0, and a wall half angle of 2.5°. This is consistent with present available data for obtaining proper MHD diffuser performance for the relatively thick boundary layer flow exiting from the channel.

The diffuser is composed of an outer pressure vessel made from 1/4" steel plate. It has an inner tube wall construction which is part of the bottoming heat recovery boiler circuitry and provides the necessary wall cooling. I-beams are welded to the outer surface of the diffuser to provide sufficient rigidity and support. The upstream section of the diffuser will be fabricated from non-magnetic stainless steel because of its close proximity to the high magnetif field. The remaining downstream section will be made from conventional carbon steel.

The diffuser is followed by a constant area transition section which further decelerates the gas to the proper conditions for entry into the radiant furnace. The area ratio of the transition section to the diffuser exit is 2.0. Construction of the transition section is essentially the same as that of the diffuser. The heat transfer rates to the walls of the diffuser and transition sections conform to incorporating wall cooling as

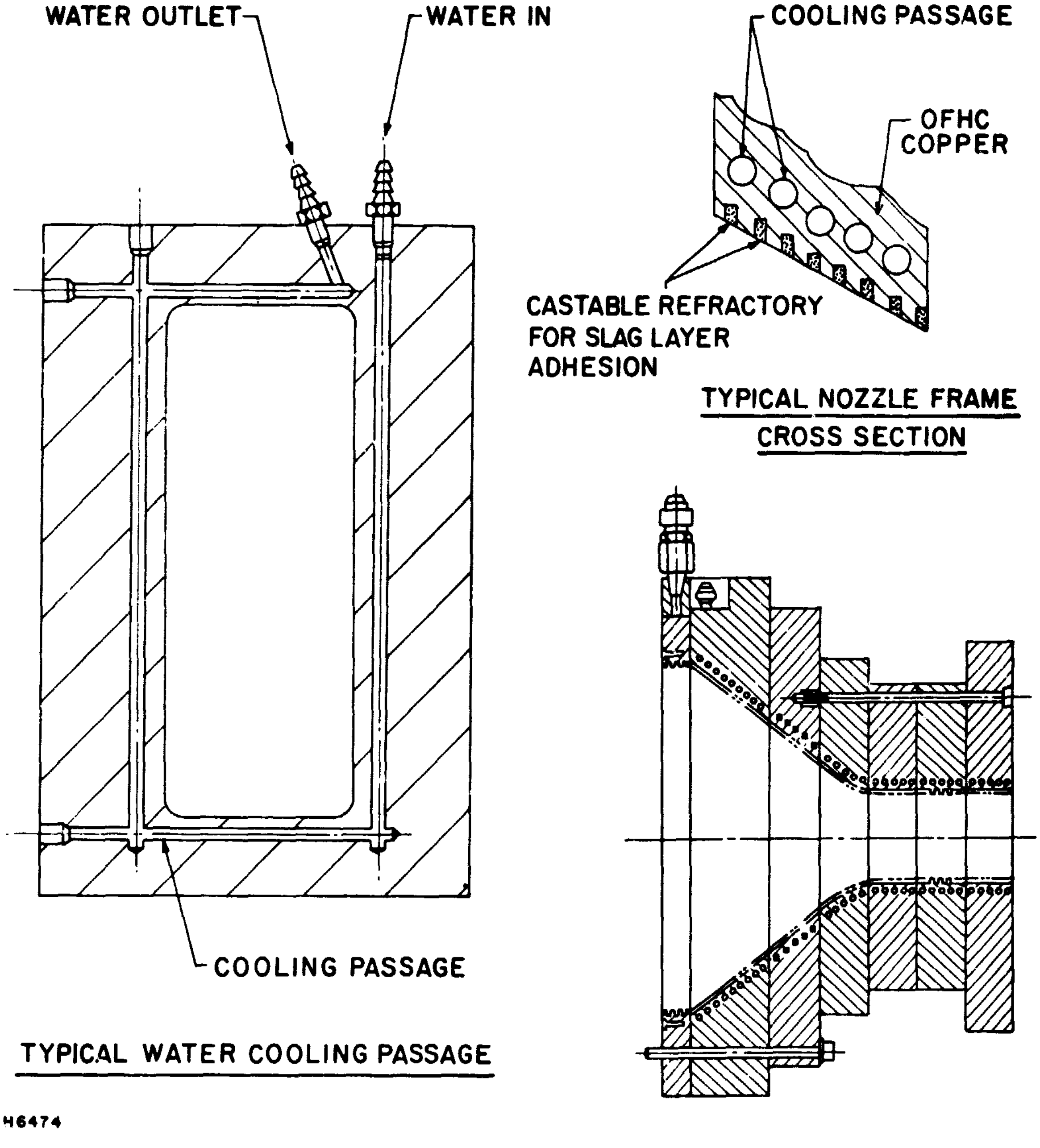

Fig. 3-17 Modular Nozzle Construction - Typical

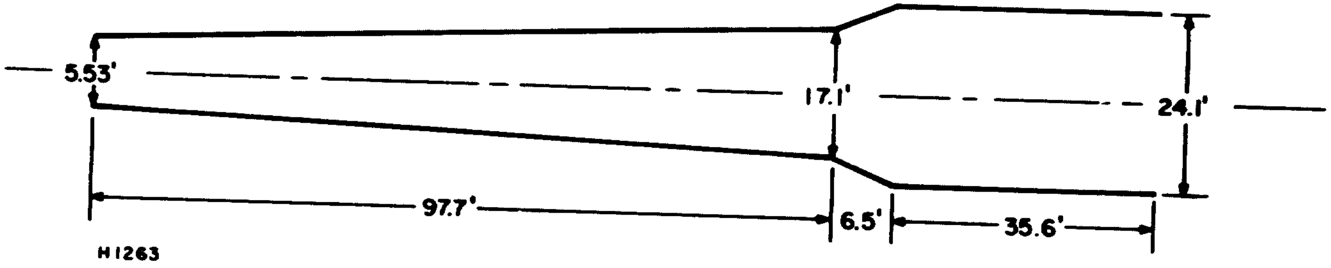

Fig. 3-18 Schematic Outline Drawing of Diffuser and Transition Section for Reference Plant 1, p.p.1

part of the evaporative boiler circuit for optimization of the bottoming steam and feed water cycle.

The cost of the diffuser and transition sections were estimated by initially estimating the cost of these for the base case of Reference Plant 1 including a breakdown of the material, fabrication, and assembly costs. The costs for all other design cases were obtained by assuming that the costs were proportional to the total surface areas raised to the 0.7 power.

3.6 AIR PREHEATER SYSTEM

The high temperature air preheater systems for Reference Plants 1 and 2 are of the regenerative type with stationary checker brick matrices. The preheaters are separately fired with a low Btu fuel gas produced from coal to avoid the serious operational problems related to seed and ash impurities. As described in Section 2.0, half of high temperature preheater system in Reference Plant 1 is fired with fuel gas delivered directly from the fixed bed gasifier system without prior sulfur removal and the other half is fired with fuel gas which has been cleaned of sulfur before firing. In Reference Plant 2, the total preheater system is fired with a fuel gas all of which has been cleaned both of particulate matter and sulfur. This fuel gas was produced in an entrained bed type gasifier.

The preheater systems are designed to provide continuous delivery of high temperature preheated air with minimum fluctuations in pressure, temperature, mass flow rate and oxidizer contamination at the inlet to the MHD generator. Further, the systems are designed for continuous flow of reheat combustion gas from the preheater system. Table III-8 summarizes major operational requirements. Reliability is a prime design objective and the preheater system design is based upon an extension and modification of current commercial state-of-the-art blast furnace stove systems. Initially, a checker matrix with 3/4" checker hole diameter and 0.4" web thickness was selected for design of the basic preheater system both for Reference Plants 1 and 2. Subsequently, an advancement of the preheater design was briefly investigated considering the use of more efficient checkers with a smaller hole size of 0.6" as matrix along with a shorter cycle time.

The preheater systems consists in all design cases of 6 regenerative heat exchanger units with their own external reheat combustion systems. Elevation plan views of the initial preheater system design for the base case of Reference Plant 1 with 2700°F air preheat is shown in Figs. 3-19 and 3-20. The matrices of checkers with 3/4" hole size are each 28 feet in diameter and 75 feet high. For the parametric variation with 3000°F air preheat, the preheater system design is the same. However, the

TABLE III-8

HIGH TEMPERATURE REGENERATIVE AIR HEATER SYSTEM MAJOR OPERATIONAL REQUIREMENTS

1. Continuous Delivery of High Temperature Preheated Air With Minimum Fluctuation in Pressure, Temperature and Mass Flow Rate at the Inlet to the MHD Combustor.

2. Continuous Flow of Reheat Combustion Gas from Preheater System.

3. High Thermal Effectiveness Including Minimum Heat Loss Through Vessel, Combustion Chamber, High Temperature Ducting and Valving.

4. Minimum Pressure Loss Through Matrix, Valving and High Temperature Ducting.

5. Minimum Leakage Between Fluids.

6. Low Oxidizer Contamination by Adequate Purge of Reheat Gas Prior to Switchover.

7. Capability of Part Load Operation at Reduced Temperature, Pressure and Flow Rates.

8. Controlled Startup and Shutdown.

9. For Reference Plant 1, Operation With Both Clean and Raw Fuel Gas.

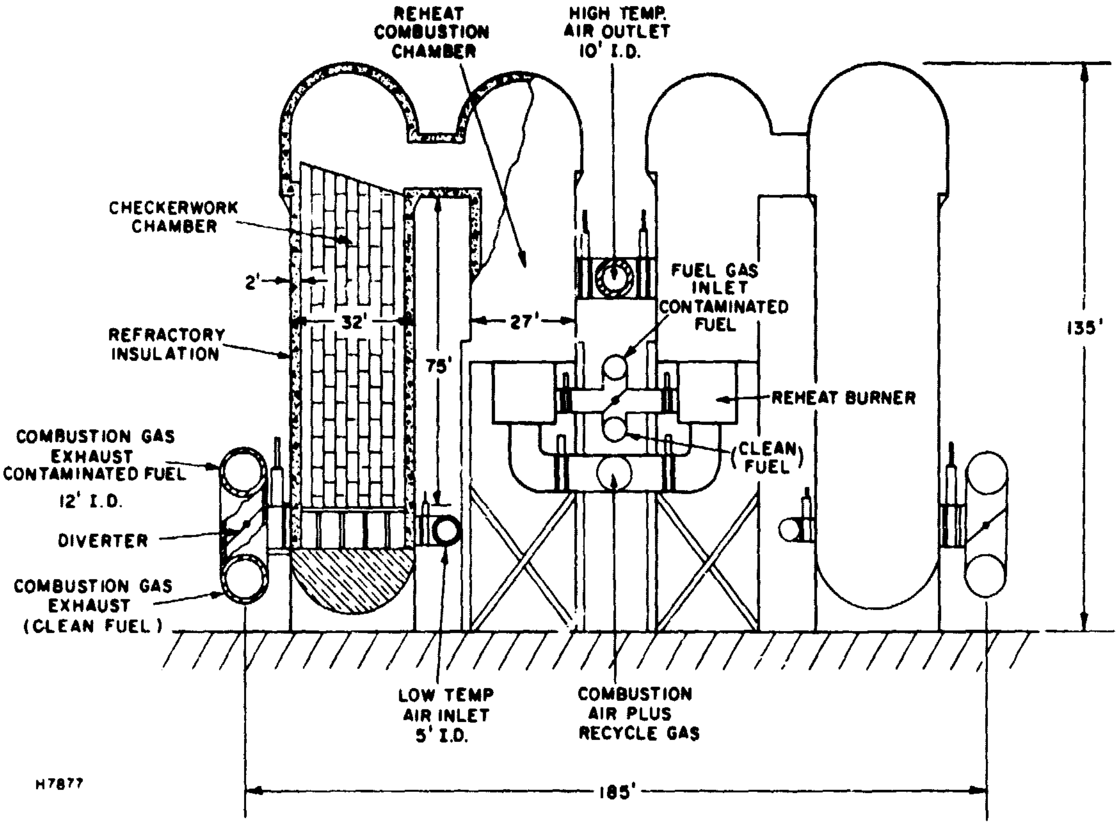

Fig. 3-19 Basic Design Case Reference Plant 1, 2700°F Air Preheat

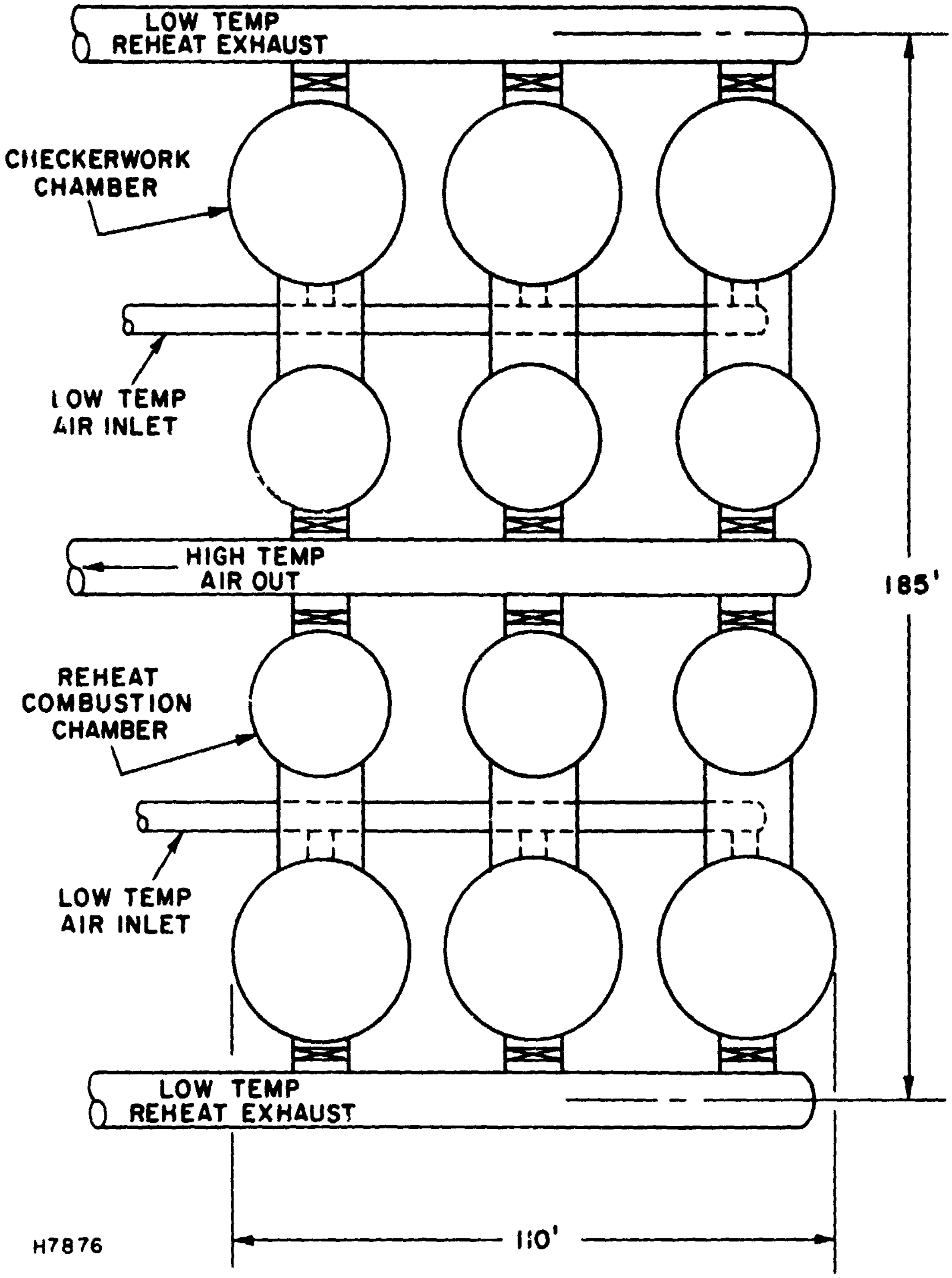

Fig. 3-20 Basic Design Case Reference Plant 1, 2700°F Air Preheat

matrix is for this case extended to 85 feet high. Table III-9 is a summary of design and operating data of the initial and basic preheater system design developed for 2700°F and 3000°F preheat temperature for Reference Plants 1 and 2.

During normal operation, the preheater system for Reference Plant 1 is designed for operation of all 6 units in a staggered parallel mode with 3 units on blowdown, 2 on reheat and 1 switching as shown in the sequencing diagram in Fig. 3-21. In this mode of operation, 3 heat exchanger units would be fired with clean fuel gas and 3 with raw sulfur laden fuel gas. Also staggering of the heat exchanger units operation in time and mixing of the preheated air streams from the units reduce the difference in overall air preheat temperature delivered. This again reduces the amount of bypass air required for control of a constant preheat temperature.

In the event one heat exchanger unit is inoperative because of regular maintenance or forced outage full operational capacity would still be available by operation with 2 units on blowdown, 2 on reheat and 1 switching as illustrated in the sequencing diagram in Fig. 3-22. Operation in this mode for Reference Plant 1 would require that each heater unit operate alternately with clean and sulfur laden fuel gas. This could be accomplished by diverter valves as shown in Fig. 3-20. For Reference Plant 2, the design and operation would essentially be the same as for Reference Plant 1. However, the diverter valves and their additional associated ducting are not required in this case because only clean fuel gas would be used in Reference Plant 2.

Table III-10 summarizes the estimated weights and costs of the initial basic air preheater system developed for 2700°F and 3000°F preheat temperature.

Advancement in the design of the high temperature preheater system was considered to the extent possible. This is now discussed in the parametric analysis.

In the design of a regenerative heater exchanger system consideration must be given to many design factors which effect the thermal performance, cost, reliability and availability of the system. Important design factors for high temperature regenerative preheaters are:

1. Matrix Volume
2. Matrix Material
3. Thermal and Mechanical Stresses
4. Checker Brick Hole Size and Geometric Porosity
5. Air Blowdown and Gas Reheat Cycle Time
6. Reheat Gas Pressure Drop
7. Matrix Aspect (L/D) Ratio

TABLE III-9

AIR PREHEATER SYSTEM
INITIAL AND BASIC PREHEATER SYSTEM DESIGN
6 HEAT EXCHANGER UNITS

		2700°F Air Preheat	3000°F Air Preheat
Matrix Geometry			
Hole Diameter	in	.75	.75
Geometric Porosity	%	39	39
Matrix Height	ft	75	85
Matrix Diameter	ft	28	28
Operating Units on Blowdown/Reheat/Switching		3/2/1 (2/2/1)	3/2/1 (2/2/1)
Matrix Material			
Composition		Al_2O_3	Al_2O_3
Porosity	%	18-21	18-21
Operating Conditions			
Blowdown/Reheat Cycle Period	min	22.5/15 (15/15)	22.5/15 (15/15)
Switchover Time	min	3.75	3.75
Blowdown/Reheat Specific Mass Flow Rate	$lbm/sec-ft^2$ (bed area)	.52/.62 (.78/.62)	.52/.59 (.78/.59)
Reheat Combustion Gas Inlet Temperature	°F	3100	3400
Air Inlet Temperature	°F	530	600
Air Outlet Temperature	°F	2930-2653	3199-2859
Reheat Combustion Gas Inlet Pressure	atm	1.2	1.2
Air Inlet Pressure	atm	7.0	7.0
Reheat Combustion Gas Pressure Across Matrix	atm	.057	.057
Air Pressure Drop Across Matrix		.005 (.012)	.006 (.014)
Matrix Thermal Stress			
2000°F	lb/in^2	666 (1000)	810 (1215)

Note: Values indicated are for either 5 or 6 units in active operation except those shown in parenthesis which are based on 5 units in operation with 1 unit down.

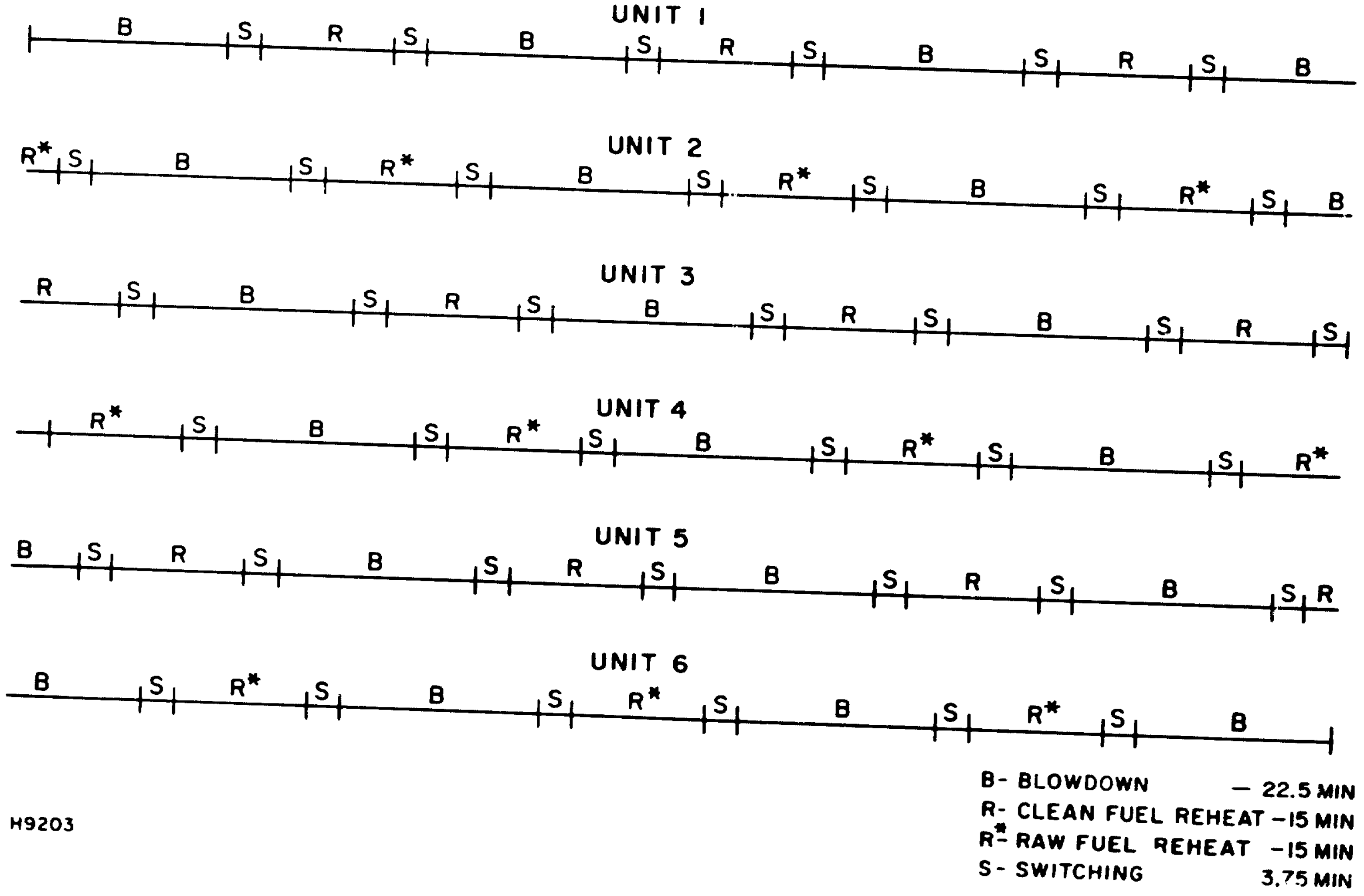

Fig. 3-21 Air Preheater System Cycle Sequence, 3 Blowdown, 2 Reheat, 1 Switching

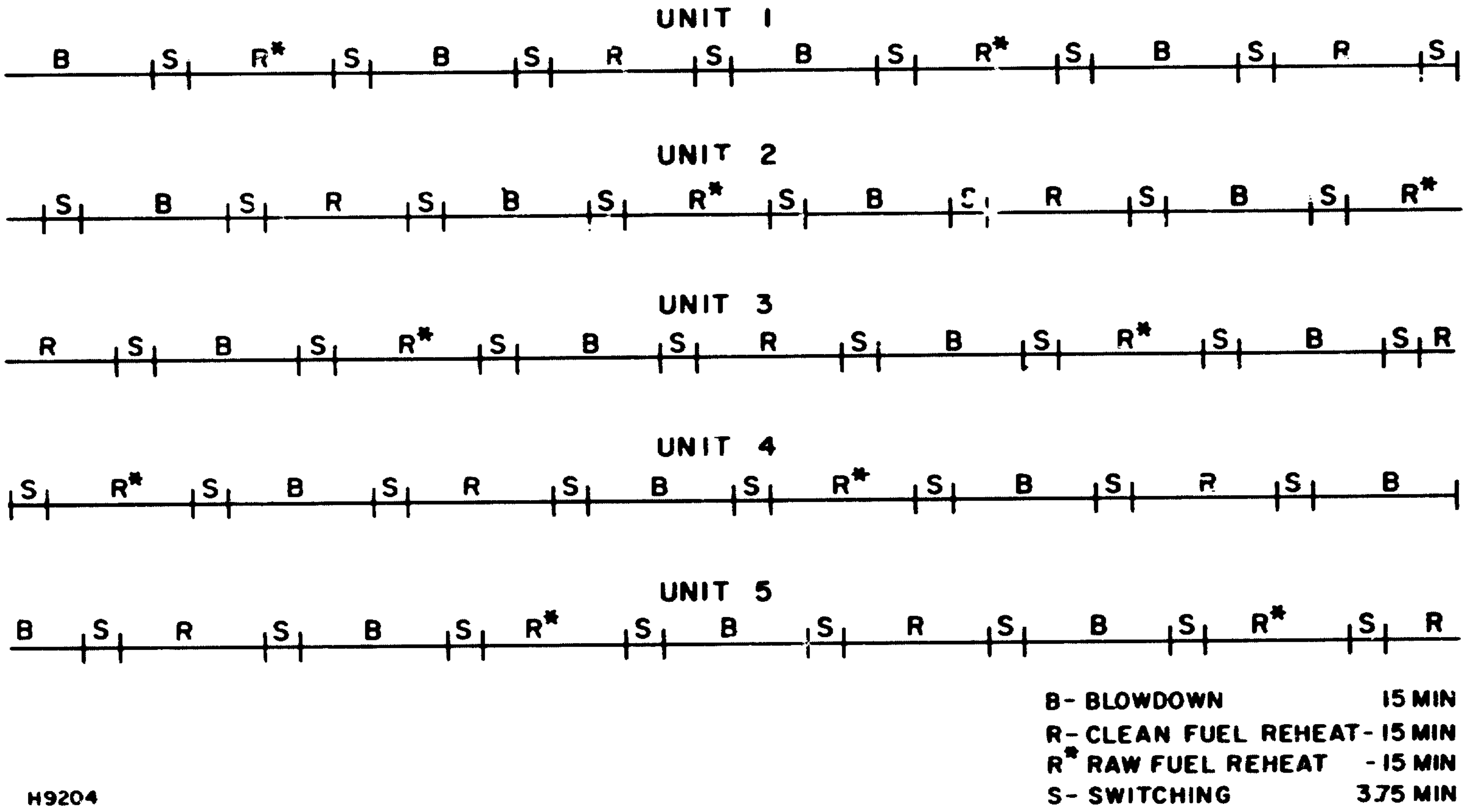

Fig. 3-22 Air Preheater System Cycle Sequence, 2 Blowdown, 2 Reheat, 1 Switching

TABLE III-10

INITIAL AND BASIC AIR PREHEATER SYSTEM WEIGHTS AND COSTS*

	2700°F - 6 Units		3000°F - 6 Units	
	Weight (tons)	Cost (1,000$)	Weight (tons)	Cost (1,000$)
HEAT EXCHANGER VESSELS				
Matrix	15,279	21,105	17,316	27,382
Insulation	8,320	9,942	8,936	11,557
Shell	2,909	9,428	3,124	10,125
Matrix Support	350	4,550	350	4,550
Sub Total	26,858	45,025	29,720	53,614
REHEAT BURNERS				
Insulation	3,284	3,809	3,284	4,137
Shell and Burner	1,000	3,241	1,000	3,241
Sub Total	4,284	7,050	4,284	7,378
DUCTING				
Insulation	1,872	2,297	1,872	2,484
Piping	500	2,900	500	2,900
Valves	1,200	6,000	1,200	6,000
Sub Total	3,572	11,197	3,572	11,384
INSTRUMENTATION AND CONTROLS		500		500
TOTAL	34,710	63,772	37,582	72,876

*Does not include combustion air blower, foundations, overhead cranes, building or manufacturing engineering.

Different heater matrix designs and operating conditions may satisfy the required thermal performance. Thus, other important design objectives become to optimize the preheater system in terms of cost, reliability and availability. The heater matrix volume required determines the size and hence the cost of the heater system. Therefore, it is important to minimize the heater matrix volume.

The use of high efficiency checkers of small hole size together with relatively short cycle times result in significant reductions in the required heater matrix volume. Table III-11 lists preliminary design data developed for an advanced commercial preheater system. It is mentioned that a decrease of the checker hole size from originally .75 in. to .60 in. and of the total cycle time from originally 45 min. to 35 min., has reduced the required matrix volume of the commercial preheater system by a factor of 2. Data for this advanced preheater system design is compared with data for the first basic high temperature preheater system design developed in this study in Table III-12. Also, for the purpose of comparison design data for a commercial modern blast stove furnace preheater system, for an experimental high temperature MHD preheater system, and for a conceptual ETF preheater system are listed in this Table.

A key parameter for comparison of the various preheater systems is the specific heat output defined as heat transferred per unit time and unit volume of matrix. The value of this parameter increases with advancement of the preheater design. Current commercial blast furnace stove systems have been built and operated with specific heat outputs of up to .98 Btu/sec-ft^3. The AERL experimental preheat system has operated successfully over longer periods of time with specific heat outputs of 5.58 Btu/sec-ft^3. The ETF preheater system was designed for a specific heat output to 1.48 Btu/sec-ft^3. For the early commercial plant design in this study a specific heat output at 2.08 Btu/sec-ft^3 was initially used for the design of the high temperature air preheater system. The subsequent advanced preheater design considered increased the specific heat output to 4.35 Btu/sec-ft^3 which is approaching that obtained with the AERL experimental preheater system.

Estimated weights and cost data for the preheater system of the more advanced design is shown in Table III-13. It is seen that the total cost of the preheater system can be reduced to roughly 2/3 of the cost of the initial basic preheater design.

3.7 LBTU GASIFIER

As previously described in Section 2.0, a state-of-the-art fixed bed gasifier of the Wellman Galusha type was selected for

TABLE III-11

ADVANCED AIR PREHEATER SYSTEM DESIGN
6 HEAT EXCHANGER UNITS

		2700°F Air Preheat	3000°F Air Preheat
Matrix Geometry			
Hole Diameter	in	.60	.60
Geometric Porosity	%	34	34
Matrix Height	ft	60	66
Matrix Diameter	ft	22	22
Operating Units On Blowdown/Reheat/Switching		2/3/1 (2/2/1)	2/3/1 (2/2/1)
Matrix Material			
Composition		Al_2O_3	Al_2O_3
Porosity	%	18-21	18-21
Operating Conditions			
Blowdown/Reheat Cycle Period	min	10/15 (10/10)	10/15 (10/10)
Switchover Time	min	2.5	2.5
Blowdown/Reheat Specific Mass Flow Rate	lbm/sec-ft^2 (bed area)	1.262/.668 (1.262/1.002)	1.262/.631 (1.262/.947)
Reheat Combustion Gas Inlet Temperature	°F	3100	3400
Air Inlet Temperature	°F	530	600
Air Outlet Temperature	°F	2945-2615	3210-2793
Reheat Combustion Gas Inlet Pressure	atm	1.2	1.2
Air Inlet Pressure	atm	7.0	7.0
Reheat Combustion Gas Pressure Across Matrix	atm	.086 (.194)	.084 (.189)
Air Pressure Drop Across Matrix		.042	.046
Matrix Thermal Stress			
2000°F	lb/in^2	1150	1315

Note: Values indicated are for either 5 or 6 units in active operation except those shown in parenthesis which are based on 5 units in operation with 1 unit down.

TABLE III-12

ADVANCED AIR PREHEATER SYSTEM WEIGHTS AND COSTS*

	2700°F - 6 Units		3000°F - 6 Units	
	Weight (tons)	Cost (1,000$)	Weight (tons)	Cost (1,000$)
HEAT EXCHANGER VESSELS				
Matrix	8,079	11,062	8,887	13,947
Insulation	5,196	6,209	5,454	7,063
Shell	1,608	5,210	1,700	5,508
Matrix Support	200	2,600	200	2,600
Sub Total	15,083	25,081	16,241	29,118
REHEAT BURNERS				
Insulation	3,284	3,809	3,284	4,137
Shell and Burner	1,000	3,241	1,000	3,241
Sub Total	4,284	7,050	4,284	7,378
DUCTING				
Insulation	1,872	2,297	1,872	2,484
Piping	500	2,900	500	2,900
Valves	1,200	6,000	1,200	6,000
Sub Total	3,572	11,197	3,572	11,384
INSTRUMENTATION AND CONTROLS		500		500
TOTAL	22,939	43,828	24,097	48,380

*Does not include combustion air blower, foundations, overhead cranes, building or manufacturing engineering.

TABLE III-13

COMPARISON OF HIGH TEMPERATURE AIR PREHEATER SYSTEMS

		Commercial Blast Furnace Stoves (Europe)	Avco Experimental Preheater System	ETF	Parametric Study of Early Commercial MHD Power Plants	
					Initial Basic Design	Advanced Design
Air Preheat Temperature	°F	2500	3100	3000	2700/3000	2700/3000
Air Inlet Temperature	°F	250	1000	500	530/600	530/600
Preheat Air Flow Rate	lb/sec	400	.7	126	960	960
Preheat Air Pressure	ata	6	1	6	7/8.5	7/8.5
Specific Heat Output	$\frac{\text{Btu}}{\text{sec-ft}^3}$ (matrix)	.98/.74	5.58	1.48	2.08/2.08	4.14/4.35
Number of Units		3/4	2	4	6	6
Total Cycle Time	min	80	12	80	45	30
Matrix Diameter	ft	30	1.2	15	28	22
Matrix Height	ft	120	15	85	75/85	60/66
Checker Hole Size	in.	1.18	.25	1.00	.75	.60
Refractory Material in Highest Temperature Region (Dome, Top Checkers)*		SiO_2-Al_2O_3	Al_2O_3	Al_2O_3	Al_2O_3	Al_2O_3

*In recent years, increased air preheat temperatures have resulted in a reduction in the use of firebrick in preference to alumina and high purity silica refractories in the high temperature regions of the preheater.

Reference Plant 1 and an entrained bed gasifier of the advanced type was selected for Reference Plant 2. This latter type of gasifier is presently under development by Combustion Engineering, Inc.

Design data for these two types of gasifiers have already been presented in the separate descriptions of Reference Plant 1 and 2, respectively, in Section 2.0. These descriptions include the operating characteristics and the arrangements of the two different gasifier subsystems, data of the fuel gas produced and of the methods used for fuel gas cleaning and sulfur removal.

In this section, some additional information for the two types of gasifiers are presented.

Table III-14 summarizes pertinent data for the state-of-the-art fixed bed gasifier of the Wellman Galusha type. The gasifier units are presently of 10' internal diameter bed size. For this bed diameter, the unit capacity varies between 3.5 - 5.0 T/hr with the higher value applicable to the more reactive subbituminous coal type. With this capacity, the total number o gasifier units required for the base case of Reference Plant 1 with 2700°F preheat temperature is 28. Correspondingly less or more units are required depending upon the plant size and level of preheat temperature and coal type for variations in these plant parameters. For all parametric design cases one spare gasifier unit has been added.

According to information obtained projections have been made for increasing the internal bed diameter of the gasifier unit from presently 10' to 25'. The unit capacity is roughly proportional to the gasifier cross sectional area. This means that the gasifier unit capacity would be increased with a factor of 6.25 and number of gasifier units required reduced correspondingly.

The estimated costs of the fixed bed gasifier system based on the present 10' gasifier unit bed diameter and including the necessary gas scrubbing and tar separation and removal systems, water treatment system and sulfur removal system are listed in Table III-15.

The C-E gasification system for Reference Plant 2 consists of an atmospheric pressure entrainment-type gasifier with heat recovery sections, a particulate removal system, and a Stretford sulfur removal system.

The gasifier will be air blown and tangentially fired, using conventional fuel supply and firing equipment. One gasifier unit will process roughly 150 short tons of coal per hour, producing fuel gas with a heating value of 140 Btu/scf (Montana coal). The gasifier will be approximately 180 feet tall with a maximum cross sectional dimension of about 30 feet. The reaction

TABLE III-14

SOA LBTU GASIFIER

Type	Fixed Bed (Wellman-Galusha)
Coal Feed	Bit., Sub. bit., Lignite
Commercial Operation	150 Plants Worldwide
Largest Plant in U.S.A.	3 Units (Hazelton, Pa.)
Unit Capacity	3.5 - 5.0 TPH (10' diam.)
Total # Units for 900 MW (nominal) MHD Plant	29 for 2700°F preheat (115 TPH) 32 for 3000°F preheat (132 TPH)
Prod. Gas Heating Value (HHV)	140 Btu/SCF (Mont. Sub.Bit.)
	149 Btu/SCF (Ill. #6)
Prod. Gas Dust Content	No reliable data*
Prod. Gas Tar + Oil Removal	Scrubber (alt. ESP)
Prod. Gas S-Removal	Stretford
Clean Gas S- Content	1 ppm
Stretford Unit Cap.	0.5 - 90 TPD

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*Dependent upon coal type, throughput and operation.

TABLE III-15. ESTIMATED COSTS GASIFIER SYSTEM - REFERENCE PLANT #1

Parametric Point	1			2			3			4			5			12		
	Mat. $\$10^6$	Inst. $\$10^6$	Total $\$10^6$	Mat. $\$10^6$	Inst. $\$10^6$	Total $\$10^6$	Mat. $\$10^6$	Inst. $\$10^6$	Total $\$10^6$	Mat. $\$10^6$	Inst. $\$10^6$	Total $\$10^6$	Mat. $\$10^6$	Inst. $\$10^6$	Total $\$10^6$	Mat. $\$10^6$	Inst. $\$10^6$	Total $\$10^6$
1. Gasifier Eq.	10.73	3.62	14.35	4.77	1.61	6.38	7.15	2.40	9.55	12.21	4.13	16.34	10.00	3.40	13.40	10.73	3.62	14.35
	(29 gasifiers)			(13 gasifiers)			(19 gasifiers)			(32 gasifiers)			(27 gasifiers)			(29 gasifiers)		
2. Gas Scrubbing and Cooling	1.10	0.50	1.60	0.60	0.30	0.90	0.83	0.37	1.20	1.15	0.55	1.70	1.05	0.47	1.52	1.10	0.50	1.60
3. Tar Separation and Removal (Battery Limit)	(2.80)	(0.96)	3.76	(1.60)	(0.55)	2.15	(2.10)	(0.72)	2.83	(3.13)	(1.07)	4.20	(2.66)	(0.91)	3.57	(2.80)	(0.96)	3.76
4. Phenalsolvan Unit and Wash Water Treatment (Battery Limit)	(2.00)	(0.66)	2.66	(1.15)	(0.35)	1.50	(1.50)	(0.50)	2.00	(2.18)	(0.72)	2.90	(1.90)	(0.63)	2.53	(2.00)	(0.66)	2.66
5. Stretford Unit and Sulfur Recovery (Battery Limit)	(4.00)	(1.50)	5.50	(2.25)	(0.35)	3.16	(3.00)	(1.14)	4.14	(4.40)	(1.60)	6.00	(3.80)	(1.42)	5.22	(5.15)	(1.95)	7.10
6. Additional Ductwork, etc.	0.62	0.31	0.93	0.30	0.15	0.45	0.45	0.20	0.65	0.68	0.34	1.02	0.60	0.30	0.90	0.62	0.31	0.93
7. Instrumentation (gasifier eq.)	1.10	0.30	1.40	0.50	0.15	0.65	0.73	0.27	1.00	1.20	0.40	1.60	1.00	0.30	1.30	1.10	0.30	1.40
TOTAL	22.35	7.85	30.20	11.17	3.96	15.13	15.76	5.60	21.37	24.95	8.81	33.76	21.01	7.43	28.44	23.50	8.30	31.80

NOTE: Parametric Points 6 through 11 have same costs as Parametric Point 1 chamber will consist of gas-tight, fusion welded tubular waterwalls supporting an inner refractory lining. The reaction chamber will be divided into lower and upper reaction zones separated by a reduced cross section throat, or diffuser zone, intended to minimize mixing of reactants between the two zones. The lower zone of the reaction chamber will be an oxidizing zone in which dried pulverized coal (5% moisture Montana coal, 70% through 200 mesh) will be completely burned in order to fuse the ash in the fuel and to produce the heat required for the endothermic reduction reactions which will occur in the upper chamber of the gasifier (reducing zone). The remainder of the pulverized coal feed to the gasifier will be injected into the lower part of the reductor, where devolatilization of the coal and initiation of the reduction reactions will occur. These reactions will continue throughout the height of the reductor.

The main combustor air (roughly two thirds of the total air flow) is preheated to 1100°F in the base case. The remaining air is preheated to 300°F and used to transport the coal to the various feed points. It is expected that the oxidizer gas temperature will be about 3200°F. Approaching the heat recovery sections, the gas will have cooled to about 1990°F.

The heat recovery sections will consist of a superheater and a fuel gas preheater. The superheater section will produce steam at 2400 psi/1000°F, which will be integrated with the steam produced by the main steam generator. The fuel gas preheater will heat the clean fuel gas to 900°F from the Stretford exit temperature of about 100°F. The gasifier product gas will be cooled to 300°F in the heat exchanger prior to entering the particulate removal system.

The particulate removal system will consist of two spray dryers, a multi-cyclone unit, a wet scrubber, and a thickener, all commercially available items currently used in the process industry. The dry char particles collected in the spray dryers and cyclones will be used as additional fuel for the MHD combustor. The remaining particulate will be removed in the scrubber and recycled to the spray dryers as a slurry. The fuel gas will be sent on to the Stretford system for removal of the H_2S.

The Stretford sulfur removal system will consist of two absorber reaction vessels, two solution tanks, two oxidizer tanks, plus several ancillary items. The system is commercially available and in current use in the process industry. The system is designed to remove sufficient H_2S to meet the EPA sulfur emissions limit of 85% total sulfur removal. The clean fuel gas will leave the Stretford system at about 100°F and proceed to the fuel gas heater in the gasifier convective section, where it will be preheated to 900°F in the base case. The preheated gas will then be sent on to the high temperature air heater.

3.8 HRSR

3.8.1 Steam Generator Including Air and Gas Heaters and Economizer

The steam generator is a balanced draft, controlled circulation multichamber design, divided into:

- Radiant Slag Furnace
- Seed Recovery Furnace
- Convective Section and Rear Pass
- Economizer/Low Temperature Air Heater

Key factors which were considered in the steam generator design included:

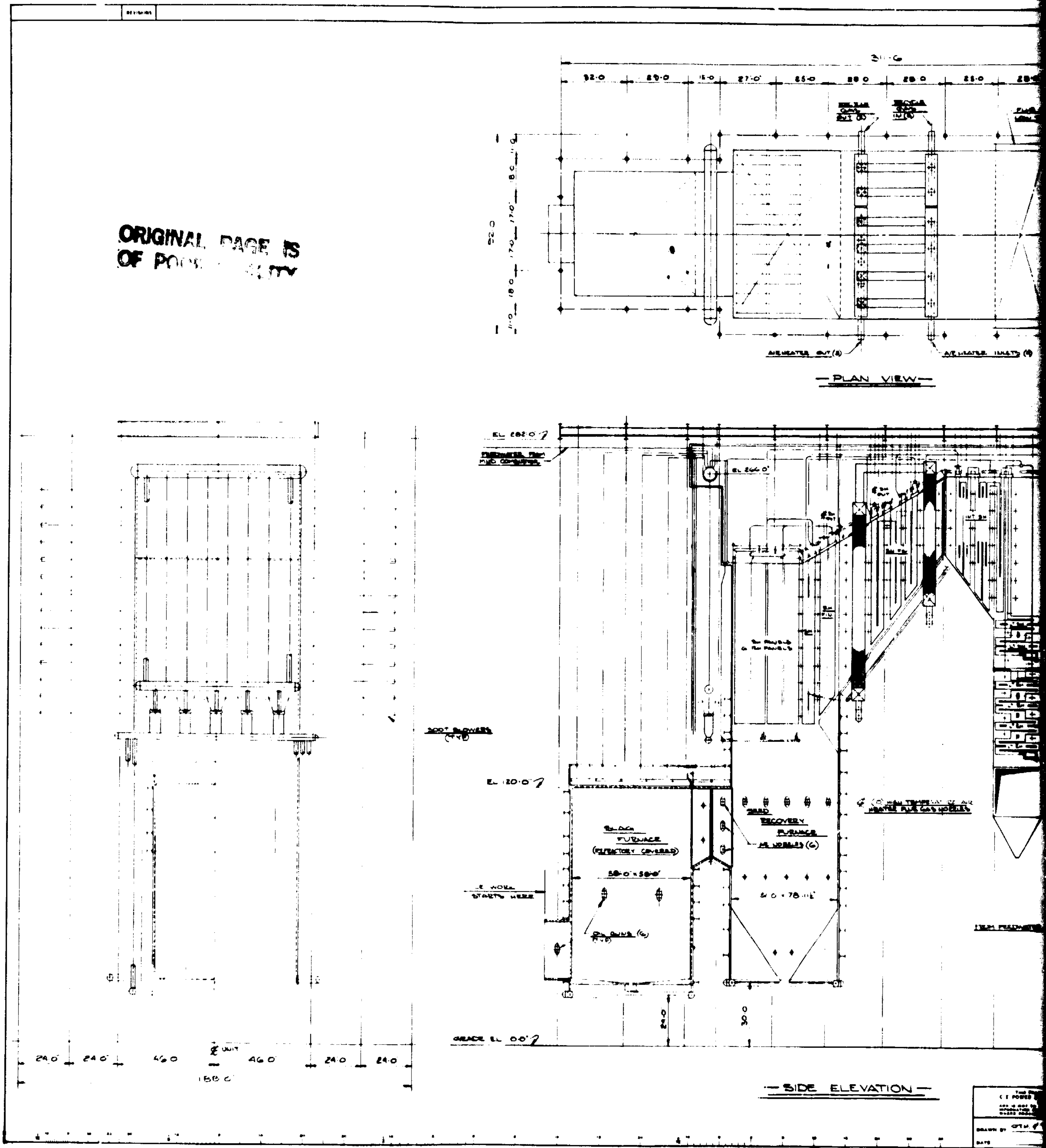
a) NO_x Control - A gas residence time of 2 seconds above 2900°F is provided in the primary furnace by reducing the gas velocity through the furnace and by lining the chamber walls with refractory to reduce heat transfer and the gas cooling rate.

b) Seed Recovery - Provision for seed condensation and recovery. The seed material which will deposit on the various surfaces is removed by incorporation of a large number of sootblowers, mostly in the convective pass. The seed material removed from the steam generator surfaces will be collected in the dry bottom hoppers provided in the Seed Recovery, Low Temperature Reheat/Superheat, and Economizer sections. It is expected that roughly one third of the total solids entering the steam generator will be removed in this manner. The collected material will be processed as necessary.

c) Final Combustion - Provision for final and complete combustion of the substoichiometric MHD generator exhaust gas with the introduction of preheated secondary (or burnout) air was included.

d) Steam Conditions - The design was based on steam conditions of 2400 psia/1000°F/1000°F. These steam conditions were considered preferable for early commercial MHD power plant applications to lessen the associated operational complexities of supercritical steam conditions.

The steam generator configuration for the Base Case design of Reference Plant 1 is shown in Fig. 3-23. This base case design of the steam generator was initially developed. It formed the basis for the steam generator designs for all other design cases of the three different Reference Plants including the Base Cases



FOLDOUT FRAME

Fig. 3-23 (Foldout)

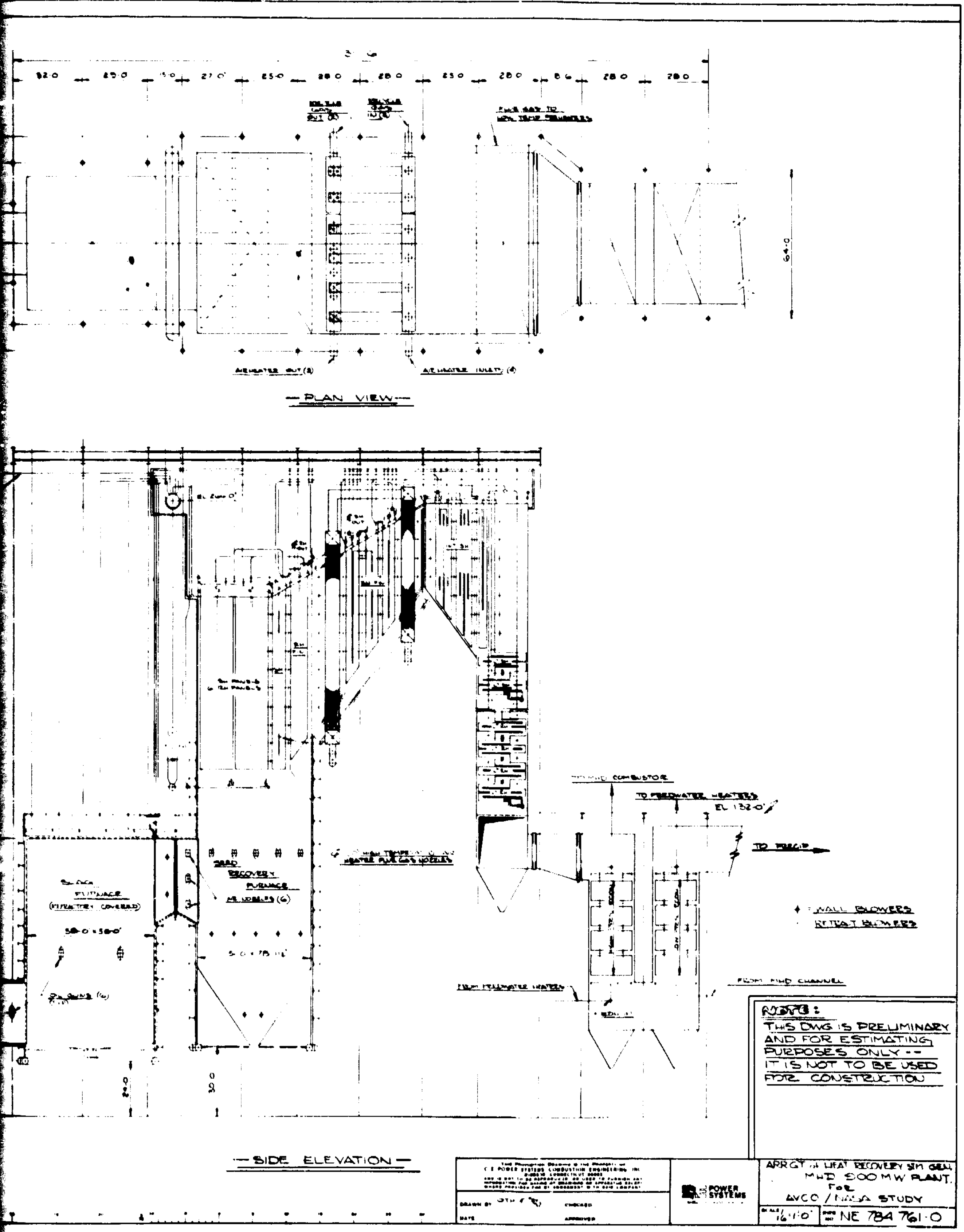


Fig. 3-23 (Foldout)

FOLDOUT FRAME

for Reference Plants 2 and 3. Data for the heat absorbing surfaces of the three Base Case steam generators for Reference Plants 1, 2 and 3 respectively, including materials and weights, are summarized in Table III-16. Surface assembly details for the Base Case steam generator for Reference Plant 1 are presented in Table III-17.

Radiant Slag Furnace

The Radiant Slag Furnace chamber is designed to cool the MHD gas in a controlled manner from the Diffuser outlet condition (typically 3650°F) to 2900°F. This chamber will be wet-bottomed and lined with a high alumina ram refractory (from 1" to 4" thick). The gas will enter horizontally through a single opening near the bottom of the chamber and move upward at a velocity of 30 ft/sec. The average uniform gas cooling rate will be less than 400°F/sec, which will provide a gas dwell time above 2900°F of about 2 sec. to ensure NO_x emission control.

Cooling tubes will be SA 210C 2" OD carbon steel fusion welded on 2 1/2" centers, with aluminizing on the furnace side for corrosion protection.

Six oil guns (rated at a total output of 1500×10^6 BTU/hr) will be located in the lower region of the slag furnace chamber. These guns will be used to provide sufficient heat input to the chamber during startup and shutdown to prevent excessive temperature gradients.

Seed Recovery Furnace

At the exit of the transition duct from the Slag Furnace, the 2900°F substoichiometric MHD gas will be mixed with preheated burnout air for the completion of combustion. The air will be introduced through six nozzles located on the side walls of the duct. With proper mixing, it is expected that burnout will be nearly instantaneous at these temperatures. The final flue gas composition will contain 5% excess air.

The gas mixture will enter the Seed Recovery Furnace at an elevation roughly one third from the bottom. In the Reference Plant 1 design, approximately one half of the High Temperature Air Heater exhaust gas will be sent to this chamber for sulfur removal. This gas will be introduced through ten nozzles located on the side walls roughly halfway up the chamber. As the gas mixture proceeds through the upper Seed Recovery Furnace, it will pass over the radiant reheat wall, the reheat and superheat panels, and the front superheat pendant before entering the convective pass. It is expected that some of the seed material will condense on the walls and surfaces in this region. Part of the seed condensed in the gas or removed by sootblowing will fall to the

TABLE III-16

STEAM GENERATOR BASE CASE DESIGN SUMMARY

Section	Surface Ft^2			Material
	I	II	III	
Superheater	477,528	478,986	496,431	210-A1, 213 T22, 213 TP347H
Reheater	207,919	277,597	195,822	192, 213 T11, 213 TP304H
Economizer	245,127	255,255	269,774	192
ITAH	164,910	135,085	196,529	213 T22, 213 TP310
Evaporator	60,000	58,980	62,540	210 C (70% Aluminized)
Total Weight (Tons)	22,650	23,450	25,900	

TABLE III-17

Steam Generator Assembly Details

Section	Location	Tube OD	Traverse Spacing	Longitudinal Spacing
SH-Low Temp.	RP	2"	6.75"	4.5"
SH-Internal	CP	2"	6.75"	4.5"
SH-Panel	USF	2"	4'5"	2.1"
SH-Front Plt.	USF	2"	27"	2.1"
SH-Finish	CP	2"	9"	4.5"
RH-Low Temp.	RP	2½"	6.75"	4.5"
RH-Rad. Wall	USF	2 11/32"	--	2 3/8"
RH-Panel	USF	2 1/4"	4'5"	2.5"
RH-Finish	CP	2 1/2"	22.5"	2.7"
ITAH-Air I	CP	3"	9"	4.5"
ITAH-Gas I	CP	3"	9"	4.5"
ITAH-Air II	CP	4"	11.25"	5.5"
ITAH-Gas II	CP	4"	11.25"	5.5"
HP-Econ	E	2"	4.5"	4"
LP-Econ	E	2"	4.5"	4"

USF - Upper Seed Recovery Furnace
CP - Convective Pass
RP - Rear Pass
E - Economizer Section

bottom and be collected in the hopper and sent to seed reprocessing as necessary.

Cooling tubes will be SA 210C 2" OD carbon steel fusion welded on 2 1/2" centers. The tubes will be aluminized for corrosion protection in the lower 70% of the furnace chamber.

Convective Section and Rear Pass

The Convective Section and Rear Pass will contain the bulk of the various hanging surfaces. As the gas passes through the Convective Section, it will pass over the finishing reheat, air preheat, and superheat surfaces, followed by the initial air preheat and intermediate superheat surfaces, prior to entering the rear pass. The roof is steam cooled, while the walls incorporate a combination of evaporative and steam cooling.

Additional seed material will fall out of the gas stream throughout this section, adhering to the walls and surfaces. Numerous retractable sootblowers will be used to remove the seed material, which will be collected in the hoppers for reprocessing.

As the gas passes through the rear pass, which contains the low temperature superheat and reheat sections, the gas temperature will be lowered to about 700-725°F. At this point, the designs for the three Reference Plants differ. In Reference Plant 1, roughly half of the MHD gas will be taken off at this point through ducts on both sides of the rear pass. This gas will be used to preheat the low BTU gas from the Wellman-Galusha gasifier and the air and recycle gas to the High Temperature Air Heater. The remaining MHD gas will be sent on to the Economizer section. In Reference Plant 2, with no gas taken off at the rear pass exit, the entire stream will be sent on to the Economizer/Low Temperature Air Heater section. In Reference Plant 3, approximately one third of the MHD gas will be taken off at the rear pass exit for coal drying and processing. The remaining MHD gas will be sent on to the Economizer/Low Temperature Air Heater section.

Economizer Section

The Economizer Section will contain the High Pressure and Low Pressure Economizers, and, in Reference Plants 2 and 3, the Low Temperature Air Heaters. Flue gas will enter this section at 725°F and will be cooled to the cleanup inlet temperature of 275°F.

In the Reference Plant 1 design, all of the MHD gas entering the Economizer Section will pass over the high and low pressure economizers. In the designs for Reference Plants 2 and 3, the entering 725°F gas flow will split, with part of the flow passing over the economizers and the reminaing flow passing through the low temperature air heater(s).

These sections will also include dry bottom hoppers and numerous sootblowers for removal and collection of the seed material which might adhere to the various surfaces.

Superheater Design

The superheater will be divided into several sections located throughout the upper seed recovery furnace, convective pass, and rear pass areas. The specific design details regarding number of banks, tube spacing, and total surface area will vary considerably among the various parametric points.

The saturated steam will leave the drum and flow through the roof tubes of the three sections. The walls of the convective pass will also be steam cooled, in parallel with the roof. The stream will then proceed, in sequence, to: the low temperature superheat sections, located in the rear pass; the intermediate superheat pendant, located in the rear of the convective pass; the superheat panels, located in the upper seed recovery furnace: the front superheat platens, located in the upper seed recovery furnace; and the finishing superheat pendants, located in the convective pass. For temperature control, two spray desuperheat nozzles in series will be provided at the exit of the front platens. The desuperheaters will be sized to provide up to 75° temperature control at design point conditions. The steam exit conditions from the finishing superheat section will be 2415 psia and 1005°F.

Reheater Design

The reheater, like the superheater, will be divided into several sections, located throughout the upper seed recovery furnace, convective pass, and rear pass areas. The specific design details regarding number of banks, tube spacing, and total surface area will vary considerably among the various parametric points.

Steam will enter the low temperature reheat sections from the exit of the high pressure turbine. The reheat inlet conditions will be 510 psia, 607°F. After leaving the low temperature sections, the steam will pass through the walls and hangers in the upper rear pass and rear convective pass areas. It will then go, respectively, to: the radiant reheat walls, located in the upper seed recovery furnace; the reheat panels, also located in the upper seed recovery furnace; and the finishing reheat sections, located at the inlet to the convective pass.

For temperature control, desuperheat capability will be provided at the inlet to the low temperature reheat section. The desuperheaters will be sized to provide up to 75°F temperature control at design point conditions. The steam exit conditions from the finishing reheat section will be 450 psia and 1000°F.

Intermediate Temperature Air and Gas Heaters

The intermediate temperature air and gas heaters, located in the convective pass, will be divided into two major sections: the low temperature section and the finishing section. The specific design details regarding the number of subsection assemblies, tube spacing, and total surface area will vary considerably among the various parametric points.

The composition of the preheated fluid will vary among the three Reference Plant designs. In Reference Plant 1, air and MHD recycle gas, both at 600°F inlet temperature, will be preheated to 1100°F (nominal outlet condition). The recycle gas plus most of the air will be sent to the High Temperature Air Heater. The balance of the air will be introduced through the air nozzles in the transition duct between the slag and seed recovery furnaces for the completion of combustion.

Each major section will be divided into two subsections, one for air and one for recycle gas. The low temperature air subsection will consist of four tube assemblies. The low temperature recycle gas subsection will consist of two tube assemblies. Air and recycle gas at 600°F will enter through manifolds at the bottom of the assemblies and flow upward, exiting at about 830°F. The air and gas will then pass on to the finishing subsections, entering through manifolds at the top and flowing downward, exiting at 1100°F (nominally). The finishing subsections will also consist of four air tube assemblies and two gas tube assemblies.

In the Reference Plant 2 design, recycle gas is not required for the High Temperature Air Heater. Air for this heater, plus combustion air for the Combustion Engineering entrained bed gasifier, will be preheated to 1100°F (nominally) from the 600°F temperature.

In the Reference Plant 3 design, oxygen-enriched main combustor air will be preheated from the compressor exit condition (591°F in the Base Case) to 1100°F (nominally).

While initial estimated surface requirements for the Reference Plants Base Cases are presented in Table III-16, additional conceptual design analyses in Task II are required for refinement of these.

Economizer Design

The economizer will be divided into high pressure and low pressure sections. The MHD gas at 700-725°F will first pass downward over the high pressure section and then upward over the low pressure section, exiting finally at 275°F. The tubes will be oriented horizontally, since particle loadings and temperatures are expected to be low enough to preclude deposition problems. Seed collecting hoppers will be located below each section.

Water conditions entering the high pressure economizer will be approximately 2800 psia and 579°F. Conditions into the low pressure economizer will be approximately 250 psia and 216°F. These conditions are for the Reference Plant 1 Base Case design. Conditions for the various parametric points will require additional analyses in Task II.

3.8.2 Stack Gas Cleaning

The particulate removal system was designed such that the total plant particulate emissions would be below the 0.03 lb/10^6 BTU total fuel input EPA limit. Since it is expected that a small amount of particulate material will be sent to the stack from the coal processing system, the clean-up equipment for the main MHD gas stream will be required to remove a very high percentage of the total solid material entrained in this stream.

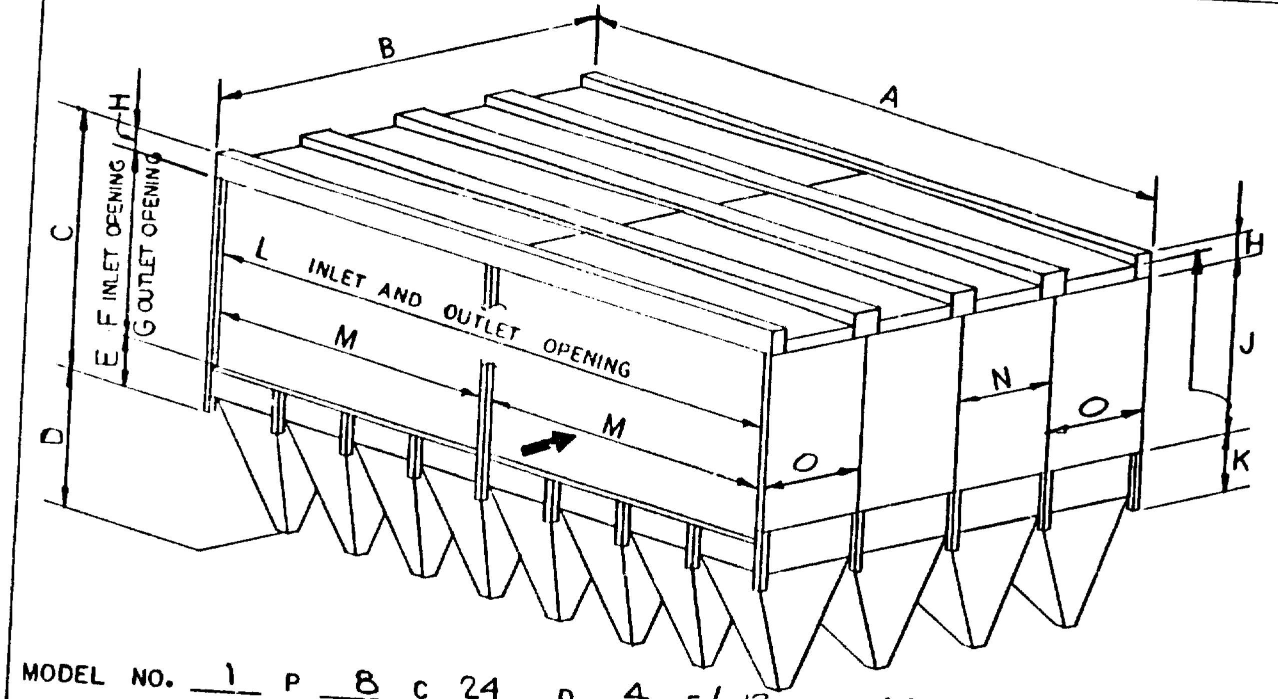
The selection of an electrostatic precipitator (ESP) was made, based upon required particulate removal efficiency, gas flow rates, compatibility with seed regeneration systems, and widespread use in utility power plants.

ESP Design - For the Reference Plant 1 Base Case, the ESP was designed for a particulate removal efficiency of 99.82%, with a gas flow of approximately 1.80 x 10^6 acfm. The particulate removal efficiencies and gas flows for the Reference Plants 2 and 3 Base Cases were 99.84% and 1.56 x 10^6 acfm, and 99.81 and 0.94 x 10^6 acfm, respectively. The reason for the considerably lower gas flow for Reference Plant 3 is that the gas taken off upstream of the economizer section for coal processing will be cleaned in the two-stage particulate removal system in that area. It will not be returned to the ESP for further cleaning.

A preliminary design for the Reference Plant 1 Base Base is presented in Fig. 3-24. The dimensions indicated are representative of European-type practice. Design details for the three Base Case precipitators are shown in Table III-18.

3.9 STEAM TURBINE GENERATOR

The steam turbine for the electric generator will share the boiler steam supply with the turbine drivers for the main air compressors. The steam turbine-generator for the base cases is rated at approximately 500 MW.



A = 205'-6±
B = 87'-4±
C = 56'-10±
D = 17'-11±
E = 6'-9¼±
F = 45'-8±
G = 45'-8±
H = 4'-4¾±
J = 46'-1±
K = 7'-6¼±
L = 203'-6±
M = 101'-3±
N = 21'-8±
O = 22'-0±

MODEL NO. 1 P 8 C 24 D 4 F/ 12 X 48 X 64 [4 @ 16.0]

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POLLUTION CONTROL-WALTHER, INC.
BIRMINGHAM, ALABAMA

CUSTOMER COMBUSTION ENGINEERING
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Fig. 3-24

TABLE III-18

Electrostatic Precipitator Design Details

	Base Case 1	Base Case 2	Base Case 3
Gas Volume	1.80×10^6 acfm @ 275°F	1.56×10^6 acfm @ 275°F	0.94×10^6 acfm @ 275°F
Efficiency	99.82%	99.84%	99.81%
Model Number	1P8C24D4F/12x48x64 (4@16.0)	1P8C21D4F/12x48x64.0(4@16.0)	1P4C26D4F/12x48x64.0(4@16.0)
No. of Precipitators	1	1	1
No. of Chambers/Precipitator	1	1	1
No. of Ducts/Precipitator	192	168	104
Duct Spacing	12"	12"	12"
No. of Fields	4 @ 16.0'L x 48'H	4 @ 16.0'L x 48'H	4 @ 16.0'L x 48'H
Total Collecting Plate Area	1,179,648 ft^2 = 36,864/T.R.	1,032,171 = 32,255 ft^2/T.R.	638,976 ft^2 = 39,936 ft^2/T.R.
Total Discharge Electrode Length	698,880	611,520 ft	378,560 ft
No. of T/R's	32 FW Sets @ 1400 Ma each	32 FW Sets @ 1250 Ma each	16 FW Sets @ 1500 Ma each
SCA	657	660	560
Migration Velocity	4.89 cm/sec	4.96 cm/sec	4.90 cm/sec
Gas Velocity	3.25 ft/sec	3.23 ft/sec	3.28 ft/sec
Total Expected T/R Power Consumption	1750 KW	1550 KW	1000 KW
Total Approximate Precipitator Weight	6,725,000 lbs	5,977,000 lbs	3,741,000 lbs

The turbine selected for all parametric points will be a tandem compound, multiflow, condensing, single reheat unit. Steam throttle conditions are 2400 psig, 1000°F. These conditions of pressure and temperature are typical of modern, central electric-generating stations and will allow high steam plant efficiencies to be attained.

As discussed in Section 3.14.1, the steam cycle performance has been calculated based on a turbine backpressure of 2 in. HgA. The steam cycle has been arranged for seven turbine extraction points. Steam to seven feedwater heaters, the heat losses from the MHD components, and the boiler high and low pressure economizers heat the feedwater to within 50°F of boiler drum saturation temperature. Steam to drive the boiler feed pump turbine is taken from the crossover between the intermediate and low pressure turbines. Steam to drive the main air compressors and oxygen plant air compressor is taken from the main steam line (see Section 3.10).

The extraction points from the turbine were chosen to make the best use of the available heat losses from the MHD components and the boiler economizer. The high temperature heat available from the MHD burner and one-half of the economizer was used to heat feedwater just prior to entering the boiler. The location of the MHD channel is dictated by the requirement for a maximum cooling water temperature of 225°F out of the channel. The low pressure economizer was located in the cycle such that boiler exhaust gases will be cooled to 275°F with a minimum temperature difference of 50°F between the feedwater to the economizer and exhaust gases out of the economizer. Since the MHD diffuser is incorporated in the radiant section of the boiler rather than in the feedwater cycle, more extraction steam can be used for feedwater heating.

The results of the cycle arrangement discussed above give steam plant efficiencies (steam turbine power/heat input to steam cycle) in the range of 42% to 42.67%.

3.10 AIR COMPRESSOR AND DRIVE

Axial flow air compressors will be provided, each with its steam turbine drive and inlet filter and silencer. This equipment is located on the operating floor with the main turbine-generator set.

For the base cases, the air compressor flow rate is approximately 3.2 (10^6) lb/hr. Pressure ratios vary within a range of 6 to 9, and power required to drive the compressor ranges from 110 to 140 MW. The compressors are multi-stage axial flow machines without intercooling.

The steam turbine drive is a multi-stage, condensing machine designed for a back-pressure of 2 in. HgA. The turbine throttle conditions are 2400 psig, 1000°F. Using main steam for the compressor drive turbine resulted in a better steam plant efficiency than if hot reheat steam used.

The flow rate from the compressor is controlled by varying the speed and stator vane angle on the compressor. To decrease the flow below design, the compressor stator vane angle is varied while maintaining rated speed. For flows less than 70% of design flow, the stator vane angle remains at the minimum setting while the speed is decreased.

3.11 COAL DRYING, PULVERIZING, AND FEEDING

The coal drying, pulverizing, and feeding system will be required to handle up to 812,000 pph of Montana Rosebud coal. The fuel will be transported from the raw coal storage bins in a partially crushed state. Analysis of the coals are contained in Appendix A.

The Montana coal will be thermally dried from 23% to 5% moisture using hot inert drying gas from either the high temperature air heater exhaust (Plants 1 and 2) or the MHD exhaust upstream of the economizer (Plant 3). The coal will be pulverized to 70% through 200 mesh.

For high pressure injection into the combustor, the Petrocarb^R lockhopper system will be used. This is considered the only proven commercially available injection system which can deliver controlled quantities of coal against the 5-10 atm combustor pressure used in the open cycle MHD system.

For low pressure coal injection into the C-E Gasifier (Reference Plant 2), Acrison-type gravimetric feeders will be used.

The system layout will be similar to that used in the ETF design. Crushed coal from the raw storage bins will be fed into the C-E supplied bowl mills (#1003 RP Bowl Mills with 600 hp/900 rpm motors) by gravimetric feeders. Flue gas from the HTAH at 700-725°F (MHD flue gas at 700°F for Reference Plant 3) will be used for drying. The gas with the entrained pulverized coal will be processed next to the cyclone filters where approximately 85% of the coal will be removed. The gas with the remaining coal will be sent to a baghouse filter where approximately 99.9% of the coal will be removed. The filtered gas, now at about 200°F and nearly dust-free, will be sent to the stack.

Pulverized coal from the cyclones plus the fines from the baghouse collection system will enter the prepared coal storage bins. Total capacity of the bins will be roughly equivalent to 2 1/2 hours of full load running to provide for temporary outages or overload operation.

For operation of the C-E gasifier, the coal will then be fed to Acrison gravimetric feeders which entrain the pulverized coal in 300°F delivery air at slightly above atmospheric pressure.

For operation of the MHD combustor, the coal will be fed from the storage bins on demand via bin activators and screw feeders to scalping screens and finally to the Petrocarb lockhopper system. When the upper hoppers of the Petrocarb system are filled, they will be sealed and pressurized to 200-250 psig using HTAH or MHD flue gas. With upper and lower lockhopper pressures equalized, the isolating valves will be opened, allowing the coal to drop into the lower bins. When the upper bins are empty, they will be depressurized, ready to be recharged. Coal will leave the lower bins via two 1 1/2 inch feed pipes per bin. Compressed air will be used in the pipes to convey the fuel and inject it into the combustor.

For the Reference Plant 1 Base Case design, four processing trains, from raw coal storage bin through the Petrocarb hoppers, with one spare mill, will provide the dried pressurized coal feed for the MHD combustor. The total flow of drying gas will be passed through a single large baghouse filter prior to being sent to the stack. The atmospheric Wellman-Galusha gasifier will operate on crushed coal which for Montana coal has been dried to 5%. Thus, no pulverizing or pressurizing equipment will be required for this gasifier.

For the Reference Plant 2 Base Case design, in addition to the four-train pressurized feed system described above, three additional trains feeding 5% moisture pulverized coal to the atmospheric C-E gasifier will be provided.

For the Reference Plant 3 Base Case design, seven pressurized feed trains, with one spare mill, will provide the required flow to the MHD combustor. It should be noted that the seed material entrained in the drying gas will be removed in the cyclone and baghouse and sent back to the combustor with the pulverized coal. This might result in unacceptable loss or feeding of this seed. Alternate arrangements, such as incorporating a high temperature electrostatic precipitator between the gas take-off point at the steam generator and the coal processing system, will be investigated in subsequent design work.

3.12 SEED PROCESSING

3.12.1 Ground Rules

The analysis assumes:

a. That the most recent proposed EPA SO_2 regulations must be met by the MHD facility, i.e., 85% SO_2 removal from the combustion gases and SO_2 emission not to exceed 1.2 lb/10^6 Btu fuel input.

b. That for Reference Plant 1, 50% of the combustion gases from the HTAH gasifier system is 100% desulfurized by methods other than seed regeneration.

c. That for Reference Plant 2, 100% of the combustion gases from the HTAH gasifier system is 100% desulfurized by methods other than seed regeneration.

d. That for Reference Plant 3, all desulfurization required must be effected by seed regeneration.

3.12.2 Methodology

The analytical rationale applied to generate the data reported includes:

a. The (potassium) Formate seed regeneration process reported in the AVCO ETF Final Report (1978) was the basis for comparison for all parametric points except one.

b. The Carbon Reduction seed regeneration process reported in the AVCO ETF Conceptual Design Report (1977) was the basis for comparison for Reference Plant 1, Parametric Point 11. (Other technical concepts, such as a Tomlinson process might also be possible.)

c. The seed regeneration requirement was computed for each parametric point and the corresponding process data was generated by comparison and scale up of data developed in the ETF analyses.

d. The scale factors (parametric analysis case ÷ ETF case) applied for the below listed items were directly proportional to seed regeneration quantity ratios:

recovered seed flow
lime feed

process chemical flow - output
process chemical flow - discharge
steam required
275°F. flue gas feed
auxiliary motors - HP
net energy requirement

e. The scale factor applied for plant area data was (seed regeneration quantity ratio)$^{2/3}$ to reflect the assumed volumetric relationship between plant size and plant capacity.

f. The scale factor applied for capital cost estimates was (seed regeneration quantity ratio)$^{0.7}$.

3.12.3 Discussion of Data

The parametric analysis data for Reference Plant 1, 2 and 3 are presented in Tables III-19, III-20, and III-21, respectively.

A. Formate Process

1. Per the AVCO ETF Study, the recovered seed flow is kept 20% above requirements for regeneration to help surpress double salt formation in the reactor, to help drive the basic chemical reaction to completion and to facilitate gypsum filtration.

2. For Reference Plants 1, and 2, the required supply of carbon monoxide (CO) is assumed integrated with the HTAH gasifier system. For Reference Plant 3 an independent gasifier for the seed regeneration facility is required.

3. The coal feed required for seed regeneration and sulfur removal is for all design cases and parametric points added to the plant coal input. The coal feed requirement was computed from raw coal analyses, gasifier efficiency and output gas analyses.

4. The parametric points which assume Illinois No. 6 coal feed (Reference Plant 1, Parametric Point 12; Reference Plant 2, Parametric Point 11; Reference Plant 3, Parametric Point 8) require much larger seed regeneration facilities because of the higher sulfur content in the coal. The data is particularly severe for Reference Plant 3 where there is no auxiliary desulfurization scheme and all required SO_2 removal must be effected by seed regeneration.

TABLE 3-19
SEED REGENERATION 1/
PARAMETRIC ANALYSIS - REF. PLANT I 2/

Para-metric Point	Regener-ation Process	Coal Type Used	PROCESS CHEMICAL FLOW: Input - lb/hr: Recovered Seed (K_2SO_4)	Input - lb/hr: Coal	Input - lb/hr: Unslaked Lime (CaO)	Output - lb/hr: Potassium Sulfate (K_2SO_4)	Output - lb/hr: Potassium Formate (KCOOH)	Output - lb/hr: Potassium Carbonate (K_2CO_3)	Discharge - ton/hr: Gypsum ($CaSO_4 \cdot 2H_2O$)	Discharge - ton/hr: Elemental Sulfur 3/ (S)	Steam Req'd. 4/ 10^6 Btu/hr	275°F Flue Gas 10^3 SCFM	Aux-iliary Motors HP	Plant Area SF	Energy Req't 5/ MW	Capital Cost 10^6 $
1	Formate	Montana Rosebud Sub. Bit. 5% H_2O	30,820	6170	8250	5100	24,770	-	12.7	-	22.8	399.7	9400	47,200	11.9	14.0
2	"		13,420	2750	3700	2230	10,010	-	5.4	-	9.9	174.4	4100	27,100	5.2	7.8
3	"		20,600	4120	5510	3410	16,550	-	8.5	-	15.2	267.1	6300	36,100	8.0	10.5
4	"	"	30,960	6200	8290	5130	24,890	-	12.7	-	22.9	401.6	9400	47,300	12.0	14.0
5	"	"	33,760	6770	9040	5590	27,140	-	13.9	-	24.9	437.9	10300	50,100	13.0	14.9
6	"	"	31,660	6360	8460	5240	25,450	-	13.0	-	22.4	410.6	9700	48,500	12.2	14.2
7	"	"	30,820	6170	8250	5100	24,770	-	12.7	-	22.8	399.7	9400	47,200	11.9	14.0
8	"	"	30,660	6160	8210	5080	24,660	-	12.6	-	22.6	397.1	9400	47,100	11.8	13.9
9	"	"	30,820	6170	8250	5100	24,770	-	13.2	-	22.8	399.7	9400	47,200	11.9	14.0
10	"	"	30,660	6160	8210	5080	24,660	-	12.6	-	22.6	397.1	9400	47,000	11.9	14.0
11	Carbon 9/ Reduction	"	32,170	10360	-	6460	-	20,390	-	2.37	14.0	123.2		92,000	25.6 7/	11.6
12	Formate	Illinois No. 6 2% H_2O	95,130 8/	18200	25460	15750	76,460	-	39.1	-	112.4 6/	992.1	29000	100,000	36.7	30.7

1/ To meet proposed EPA requirement of 85% SO_2 removal.
2/ Assumes 65% of gasifier combustion gas is 100% desulfurized by other methods.
3/ Product of Claus process conversion of H_2S discharged from seed regeneration.
4/ 10% above computed values.
5/ Includes credit for seed chemistry in channel and reactor off-gas combustion.
6/ Includes 42.2X10^6 Btu/hr for spray drier supplemental heat since insufficient 275°F flue gas available (multiple effect evaporator would reduce quantity of steam needed).
7/ Excluding auxiliary motor H.P. and Claus Plant.
8/ 5% above MHD channel requirement of 59,700 lb/hr.
9/ Based on Atomics International (Rockwell) molten salt reduction concept.

TABLE 3-20
SEED REGENERATION[1]
PARAMETRIC ANALYSIS - REF. PLANT II [2]

Para-metric Point	Regener-ation Process	Coal Type Used	PROCESS CHEMICAL FLOW Input - lb/hr Recovered Seed (K_2SO_4)	Coal	Unslaked Lime (CaO)	Output - lb/hr Potassium Sulfate (K_2SO_4)	Potassium Formate (KCOOH)	Discharge - ton/hr Gypsum ($CaSO_4 \cdot 2H_2O$)	Steam Req'd.[3] 10^6 Btu/hr	275°F Flue Gas 10^3 SCFM	Aux-iliary Motors HP	Plant Area SF	Energy Req't[4] MW	Capital Cost 10^6 $
1	Formate	Montana Rosebud [illegible]	21,350	4290	5720	3540	17,160	8.8	15.8	276.9	6500	36,900	8.2	10.8
2	"		21,660	4350	5800	3590	17,410	8.9	16.0	280.9	6600	37,300	8.4	10.9
3	"		21,440	4310	5740	3550	17,230	8.8	15.9	278.0	6500	37,000	3	10.8
4	"	"	21,350	4290	5720	3540	17,160	8.8	15.8	276.9	6500	36,900	[illegible]	10.8
5	"	"	21,350	4290	5720	3540	17,160	8.8	15.8	276.9	6500	36,900	8.2	10.8
6	"	"	21,370	4300	5730	3540	17,170	8.8	15.8	277.1	6500	36,900	8.3	10.8
7	"	"	21,370	4290	5730	3540	17,170	8.8	15.8	277.1	6500	36,900	8.3	10.8
8	"	"	21,910	4400	5870	3630	17,610	9.0	16.2	284.2	6700	37,600	8.5	11.0
9	"	"	21,350	4300	5720	3540	17,160	8.8	15.8	276.9	6500	36,900	8.2	10.8
10	"	"	21,280	4270	5700	3520	17,100	8.7	15.7	276.0	6500	36,500	8.2	10.8
11	"	[illegible]	65,670	12900	17400	10870	52,750	27.0	46.5	851.5	20000	75,100	25.4	23.7
12	"	Montana Rosebud [illegible]	21,350	4290	5720	3540	17,160	8.8	15.8	276.9	6500	36,900	8.2	10.8
13	"		21,350	4290	5720	3540	17,160	8.8	15.8	276.9	6500	36,900	8.2	10.8
14	"		21,350	4290	5720	3540	17,160	8.8	15.8	276.9	6500	36,900	8.2	10.8
15	"	"	21,350	4290	5720	3540	17,160	8.8	15.8	276.9	6500	36,900	8.2	10.8
16	"	"	21,350	4290	5720	3540	17,160	8.8	15.8	276.9	6500	36,900	8.2	10.8
17	"	"	21,350	4290	5720	3540	17,160	8.8	15.8	276.9	6500	36,900	8.2	10.8
18	"	"	21,350	4290	5720	3540	17,160	8.8	15.8	276.9	6500	36,900	8.2	10.8
19	"	"	21,350	4290	5720	3540	17,160	8.8	15.8	276.9	6500	36,900	8.2	10.8

1 To meet proposed EPA requirement of 85% SO_2 removal.

2 Assumes all gasifier combustion gas is 100% desulfurized.

3 10% above computed values.

4 Includes credit for seed chemistry in channel and reactor off-gas combustion.

TABLE 3-21

SEED REGENERATION[1]

PARAMETRIC ANALYSIS - REF. PLANT III

Para-metric Point	Regener-ation Process	Coal Type Used	PROCESS CHEMICAL FLOW: Input - lb/hr: Recovered Seed (K_2SO_4)	Input - lb/hr: Coal	Input - lb/hr: Unslaked Lime (CaO)	Output - lb/hr: Potassium Sulfate (K_2SO_4)	Output - lb/hr: Potassium Formate (KCOOH)	Discharge - ton/hr: Gypsum ($CaSO_4 \cdot 2H_2O$)	Steam Req'd.[3] 10^6Btu/hr	275°F Flue Gas 10^3SCFM	Aux-illiary Motors HP	Plant Area SF	Energy Req't[5] MW	Capital Cost 10^6 $
1	Formate	Montana Rosebud Sub Bit. 5% H₂O	39,090	7720	10,460	6470	31,420	16.1	28.9	506.9	11,900	55,300	15.1	16.5
2	"		25,640	5070	6,860	4250	20,610	10.5	18.1	332.5	7,800	41,700	9.9	12.3
3	"		38,530	7600	10,310	6380	30,970	15.8	28.4	499.7	11,700	54,700	14.9	16.3
4	"		38,530	7600	10,310	6380	30,970	15.8	28.4	499.7	11,700	54,700	14.9	16.3
5	"	"	38,530	7600	10,310	6380	30,970	15.8	28.4	499.7	11,700	54,700	14.9	16.3
6	"	"	38,530	7600	10,310	6380	30,970	15.8	28.4	499.7	11,700	54,700	14.9	16.3
7	"	"	38,530	7600	10,310	6380	30,970	15.8	28.4	499.7	11,700	54,700	14.9	16.3
8	"	Illinois [illegible]	125,000[2]	22000	33,490	20690	100,400	51.4	203.8[4]	997.9	38,100	120,000	48.3	37.2
9	"	Montana Rosebud Sub Bit. 5% H₂O	38,530	7600	10,310	6380	30,970	15.8	28.4	499.7	11,700	54,700	14.9	16.3

[1] To meet proposed EPA requirement of 85% SO_2 removal.

[2] 39% above MHD channel requirement of 89,930 lb/hr.

[3] 10% above computed values.

[4] Includes 110.0 x 10^6 Btu/hr for spray drier supplemental heat since insufficient 275°F flue gas available (multiple effect evaporator would reduce quantity of steam needed).

[5] Includes credit for seed chemistry in channel and reactor off-gas combustion.

With the use of high sulfur content Illinois #6 coal for Reference Plant 1, Parametric Point 12 and Reference Plant 3, Parametric Point 8, the required seed feed to the regeneration facility with 20% excess seed flow exceeds the assumed seed feed to the MHD channel for 1% seed in the gas by 6% and 39% respectively. Also, for these points the available 275°F. flue gas from the bottoming plant is insufficient to supply all of the heat required for the spray drier. In those cases supplemental heat for drying is assumed to be supplied by a steam/gas heat exchanger. Alternatively, higher temperature flue gas could be taken upstream from the ESP or a multiple effect evaporator could be introduced to reduce the supplemental steam quantity required. For all drying options, thermal energy used in excess of available 275° F. flue gas will reduce to some extent the thermal energy available for power generation.

B. Carbon Reduction Process

1. The carbon reduction process proposed by Atomics International Division (now Energy Systems Group) of Rockwell International, as evaluated in the AVCO ETF Conceptual Design Report, was applied to Reference Plant 1, Parametric Point 11.

2. For the conversion of hydrogen sulfied (H_2S) produced by the carbonation of potassium sulfide (K_2S) formed in the reduction step to elemental sulfur, a Claus Process facility is assumed. Other process options for this conversion, such as the Holmes-Stretford Process, are possible.

3. Estimated data for plant area and capital cost was generated from information reported in the literature.* Cost data was converted to mid 1978 basis using a 6.5% annual escalation rate.

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* Botts, W. V. & Gehri, D.C., "Regenerative Aqueous Carbonate Process for Utility and Industrial Sulfur Dioxide Removal", Advances in Chemistry Series, 1975, V. 139, pp. 164-179.

Aldrich, R. G. & Oldenkamp, R. D., "A 100 MW Second Generation SO_2 Removal Demonstration Plant for New York State Utilities", 39th Annual Meeting of Americal Power Converence, April, 1977.

3.13 INVERTER SYSTEM AND EQUIPMENT

3.13.1 Introduction and General Note

This section describes the inverter system for a commercial scale, entry level, coal fired MHD/Steam power plant.

In all major respects this system follows the design concepts presented in the Avco ETF Report. However, in the present report some innovations are suggested: use of water cooled thyristors, a single broad band filter for AC harmonics instead of individual sharp tuned filters for the major characteristics harmonics, a static continuously variable var supply instead of switched capacitors for reactive compensation, and additional inverter control for the MHD channel. It should be emphasized that the characteristics of the particular AC power/transmission system to which the MHD plant will be coupled will influence the final detail design of the inverter system.

3.13.2 Inverter Bridges

The inverter components are scaled to 495 MW of nominal MHD power, for Plant No. 1 base case. For the other two base plants with about 560 and 525 MW MHD power, small differences would exist in the number of internal components and in the sizing of other equipment for the system.

The plants considered herein operate with diagonal channels with five-terminal load circuit output. There are then two combinations of voltages and currents corresponding to the two possible external arrangements of the total load, namely the independent and parallel connections as shown in previous Fig. 3-12. The actual extraction points or consolidated from electrodes along the channel which determine the absolute values of the voltages and currents are chosen from the point of view of channel efficiency and other considerations. The voltage, current, and power levels for the five terminal independent connection and the five terminal parallel connection are given in Table III-22.

In the independent load connection a total of 80 kiloamps have to be processed for the total power into the AC system (grid); in the parallel loading connection only 28 or about one third as many. However, the index ratio of MW to KA (which is the voltage of the loads) is uniformly low in the first case, but increases in the second case with the largest block of power having also the highest voltage.

We can anticipate that the independent load connection will probably result in a less simple inverter system, with more components, higher losses, relatively more redundancy required for

TABLE III-22

VOLTAGE CURRENT AND POWER LEVELS FOR INDEPENDENT AND PARALLEL CONNECTIONS

Five Terminal Independent Connection			Five Terminal Parallel Connection		
KV	KA	MW	KV	KA	MW
6.2	28	173.6	6.2	8.5	52.7
6.2	19.5	120.9	12.4	5.5	68.2
6.2	14	86.8	18.6	3.5	65.1
6.2	10.5	65.1	24.8	2.5	62
6.2	8	49.6	31	8	248
	80	496		28	496

a given reliability and maintenance, and also a somewhat higher net cost. Also, more physical space is required. Hence, initial considerations appear to favor the parallel load connection scheme over the independent connection scheme, although more detailed consideration must be given to this question before a selection can be made.

The number of bridges and internal thyristor components are indicated in Tables III-23 and 24 for the two loading connections. Assumed component performance is representative of current experience or a modest extension thereof and does not require extensive development effort.

For industrial converters (medium power at low voltage) current ratings of about 2500 amperes are available but the blocking voltage capability is usually something less than 3000 volts, and usually only a modest number need be put in series.

We will assume that 2500 ampere ratings with inherent 10% continuous overload capacity will be available at a PIV of about 3000 volts.

In HVDC transmissions it has been possible to satisfy the current requirements with a single string per bridge leg, e.g., a 1000 MW, + and - 400 kV line is only 1250 amperes per pole. Only some few early solid state installations when thyristors were still relatively undeveloped, required at most two or three strings in parallel.

3.13.3 Converter Transformers

The converter transformer self-cooled (OA) ratings are shown in Tables III-25 and 26. For sake of uniformity some have slightly more capacity than actually needed by their connected bridges. In all cases the overload capacity for channel loadings above normal baseload power is taken by a suitable forced air (FA) rating of 120 or 125%.

3.13.4 Use of Water Cooled Thyristor Bridges

The total bulk power and the powers per bridge are large enough to recommend serious consideration to water cooled thyristors. This development is relatively recent, but there are now sufficient thyristor-years of HVDC experience that the net reliability may be considered equal to the previously prevalent forced air cooled installations.

3.13.5 Harmonic Filters

The power factor of the inverter, taking control modes into account, is about 0.84. That is, the 495 MW active power

TABLE III-23

FIVE TERMINAL INDEPENDENT CONNECTION

Load KA	KV Per Bridge of 12-p Group	No. of Groups In Parallel	KA Per Group	No. Parallel Strings/Leg	Total No. Thyristors	MW Per Bridge**
28	3.1	3	9.3	4 x 2500 A	720	29
19.5	3.1	2	9.75	4 x 2500 A	480	30.2
14	3.1	2	7	*4 x 2500 A	480	21.7
10.5	3.1	1	10.5	4 x 2500 A	240	32.6
8	3.1	1	8	4 x 2500 A	240	24.8
		9 Groups (18 Bridges)			2160	

*Allows use of one group for emergency spare with channel operation at reduced load.

**EX: From Table I, load MW of 173.6; 173.6 by three groups in parallel and two bridges per group = 29 MW per bridge.

TABLE III-24

FIVE TERMINAL PARALLEL CONNECTION

Load KA	KV Per Bridge of 12-p Group	No. of Groups In Parallel	No. Parallel Strings/Leg	Total No. Thyristors	MW Per Bridge
8.5	3.1	1	4 x 2500 A	240	26.4
5.5	6.2	1	2 x 2500 A	216	34.1
3.5	9.3	1	2 x 2000 A	288	32.6
2.5	12.4	1	1 x 2500 A	192	31
8	15.5	1	3 x 2500 A	720	124
		5 Groups (10 Bridges)		1656	

TABLE III-25

CONVERTER TRANSFORMER RATINGS FOR FIVE TERMINAL INDEPENDENT CONNECTION

Load KA	MW Per Bridge	No. of Groups In Parallel	3-Winding, 1-ph KV sec/22 KV	2-Winding, 3-ph KV sec/22 KV
28	29	3	3-2.65 KV, 75 MVA	6-2.65 KV, 35 MVA
19.6	30.2	2	2-2.65 KV, 75 MVA	4-2.65 KV, 35 MVA
14	21.7	2	2-2.65 KV, 60 MVA	4-2.65 KV, 30 MVA
10.5	32.6	1	1-2.65 KV, 75 MVA	2-2.65 KV, 35 MVA
8	24.8	1	1-2.65 KV, 60 MVA	2-2.65 KV, 30 MVA
		TOTAL INSTALLED MVA	630	600
		RATIO:MVA/BASELOAD MW	1.27	1.21

TABLE III-26

CONVERTER TRANSFORMER RATINGS FOR FIVE TERMINAL PARALLEL CONNECTION

Load KA	MW Per Bridge	No. of Groups In Parallel	3-Winding, 1-ph KV sec/22 KV	2-Winding, 3-ph KV sec/22 KV
8.5	26.4	1	1-2.65 KV, 65 MVA	2-2.65 KV, 35 MVA
5.5	34.1	1	1-5.3 KV, 80 MVA	2-5.3 KV, 40 MVA
3.5	32.6	1	1-7.96 KV, 80 MVA	2-7.95 KV, 40 MVA
2.5	31	1	1-10.6 KV, 75 MVA	2-10.6 KV, 40 MVA
8	124	1	Use 2-Winding	2-13.25KV, 150 MVA
		TOTAL INSTALLED MVA	600	610
		RATIO:MVA/BASELOAD MW	1.21	1.23

is 0.84 of the MVA; reactive power about 0.54 of the MVA, or 0.64 of the active power, i.e., 0.64 x 495 = 315 MVAR.

Of this, about half or 150 MVAR may be incorporated into the AC harmonic filters, as outlined in the ETF Report.

The conventional provisions for AC filters to date, as adopted for the ETF, is to provide sharply tuned, high-Q filters for the first two characteristic harmonics (the 11th and 13th) and a high-pass filter for the remainder. Recent developments in HVDC technology indicate that equally good filtering may be achieved with a high-pass, broad-band, low-Q filter to screen all the harmonics, from the 11th up. Such filters because of their wide resonance characteristic need no tuning during operation for temperature variations of the capacitor components, or for failure of capacitors.

An HVDC converter of 1800 MW, + and - 500 kV has been designed with such a new filter and experience with it should be available in the near future.

For the MHD plant of this report, the design would be facilitated since the filter will be at the intermediate 22 kV AC bus of the converter transformers. In the HVDC case mentioned above, the AC voltage is the system 230 kV.

3.14 BALANCE OF PLANT EQUIPMENT

3.14.1 Heat Rejection and Cooling Water Systems

The heat rejection system will condense steam from the main stream turbine-generator (STG) and the air compressor turbine drives. This system will include circulating water pumps, piping, a two pass vertically divided surface condenser and, as specified in the RFP, a counterflow mechanical-draft evaporative cooling tower.

Design conditions for the heat rejection system are 77°F wet bulb and 93°F dry bulb. Cycle performance is based on 51°F wet bulb and 59°F dry bulb. These conditions are such as to allow a turbine back-pressure of 2 in. HgA. to be specified for calculating cycle performance. The number of cooling tower cells required was determined such that 2 in. HgA back-pressure could be maintained at 51°F wet bulb, while less than 5 in. HgA back-pressure could be maintained at 77°F wet bulb. The most critical of these two conditions, in terms of sizing the cooling tower, is the case with the 2 in. HgA back-pressure condition.

A clean water holding pond is provided on-site to hold water for make-up to the cooling tower. Treated wastewater and/or river water is used to maintain a level in the clean water holding basin.

3.14.2 Waste Removal Systems

Waste collection systems are provided to collect solid and liquid wastes and transport them to the proper storage areas. Solid wasts include slag, ash, mill rejects and gypsum from the formate seed regeneration process. Liquid wastes come from demineralizers, boiler blowdown, cooling tower blowdown and miscellaneous floor drains and cooling water.

All liquid wastes are collected and pumped to the storm water and waste water holding basin. Water, deposited with the solid wasts, will run off into the storm water and waste water holding basin. The dirty water will be treated and stored or reused as required.

For Reference Plants 1, 2 and 3, mill rejects are collected dry from the bowl mill and sluiced to dewatering bins. For the coal delivered to the combustor, approximately 80% of the ash will be removed as slag from the combustor and the majority of the balance of the ash will be removed as slag from the radiant section of the boiler. The slag is sluiced to dewatering bins. The small amount of ash passing through the radiant section will be collected in the downstream sections of the boiler and precipitator with the seed. Dewatered slag is trucked to the on-site waste disposal area. When the formate process is used for seed regeneration, gypsum will be collected and trucked to the on-site waste disposal area.

For Reference Plant 1, ash will be collected dry from the Wellman Galusha gasifiers and trucked to the on-site waste disposal area.

For Reference Plant 2, slag will be collected from the entrained-bed slagging gasifier and sluiced to the dewatering bins.

The on-site waste disposal area is sized for 30 years of waste storage based on the plant operating at a 65% capacity factor. The final height of the waste disposal area and dikes will be 40 feet. The largest area is required when burning Illinois coal and using the formate process for seed regeneration.

The waste disposal system also includes a water treatment plant to clean liquid wastes prior to storing them in the clean water holding basin.

3.14.3 Coal Receiving, Storage and Reclaim

Coal is assumed to be delivered by unit train on a spur track which services the plant. The cars are of the bottom dump type. Coal will be dumped into a hopper from which it is moved by conveyor to a radial stacker. The live storage pile has a 3 day capacity. Coal can be moved by bulldozer from the live pile to the dead coal storage pile. The dead coal storage can provide the plant with coal for a 60 day period operating at a 65% capacity factor.

Coal reclaim can be accomplished from hoppers below the live storage pile or from hoppers adjacent to the dead storage pile. From the reclaim hoppers, conveyors transport the coal to the top of the crusher tower. In Reference Case 1, coal is transported from the crushers directly to the Wellman-Galusha gasifier and to the pulverizer silos for the combustor. For Reference Cases 2 and 3, all the crushed coal is transported directly to the pulverizer silos. Pulverized coal is transported pneumatically to the gasifier and combustor in Reference Case 2. In Reference Case 3, all the pulverized coal is pneumatically transported to the combustor as a gasifier is not used.

3.14.4 Feedwater, Condensate and Steam Systems

The condensate and feedwater systems incorporate six closed feedwater heaters, one open deaerating type heater, the MHD channel and the combustor. In addition, there are two half capacity condensate pumps and one full-size turbine driven boiler feed pump.

The condensate pumps discharge through heater No. 1 and the MHD channel. A lift pump takes suction from the channel outlet and pumps the condensate through the low pressure boiler economizer and heaters No. 2 and 3 to the deaerator. One full-size turbine-driven boiler feed pump takes suction from the deaerator and pumps the feedwater through heaters No. 4, 5, 6, and 7, the high pressure boiler economizer and the MHD burner to the boiler drum. The MHD diffuser has been incorporated into the radiant section water circuit of the boiler.

The MHD channel is located such that the condensate temperature is compatible with the electrical insulating material which has been used successfully, for connecting the generator electrodes to pipes carrying the cooling water supply. A deaerator and polisher are included in the condensate cycle to minimize oxygen and corrosion products in the feedwater.

A variation in the system described above was used in parametric point 4, Reference Case 2. For this point, the increase in steam plant efficiency was investigated by allowing high pressure and temperature boiler feedwater to cool the MHD channel.

In Reference Cases 1 and 3, all of the steam is raised in the steam generator using heat from the channel exhaust gases. In Reference Case 2, a portion of the feedwater is fed to the gasifier where steam is generated to main steam conditions, 2400 psig and 1000°F.

3.14.5 Miscellaneous Mechanical Systems and Equipment

A fuel oil storage and supply system will be provided for receiving, storing and forwarding the No. 2 distillate. The distillate will be primarily used for the house heating boiler, the diesel engine generator and start-up of the HTAH and boiler.

An auxiliary boiler will be provided for house heating steam and to provide steam for turbine warm-up, steam seals and other miscellaneous start-up functions.

Water treatment and chemical feed systems will be included to provide high purity demineralized water for boiler makeup, feedwater treatment, condensate polishing, cooling tower acid treatment, cooling water chlorination, and pH adjustment of recycled wastewater.

Other systems included are as follows: fire protection, condensate make-up including storage tank and pumps, service and instrument air compressors and driers, non-potable service water system and potable water system.

3.14.6 Electrical System

The electrical system includes the following:

Transmission Facilities
Auxiliary Power System
Control Panels and Monitoring Systems
Emergency Power System
Lighting Systems and Equipment
Communications System and Equipment
Cable, Raceways, Hardware, and Grounding Systems

Start-up power will be provided for the transmission facilities through a Start-up/Standby Transformer to the Medium Voltage Switchgear to provide electrical energy for the station auxiliaries. During operating conditions a Unit Auxiliary Transformer will provide auxiliary power from the Steam Turbine-Generator output bus, with the Start-up/Standby Transformer providing a backup source in the event of any power failure.

Controls for the entire station will be provided in panels in the Main Control Room with local operating panels as required for mechanical systems. The Main Control Room will also contain the primary alarm and monitoring systems which include a computer CRT and handwired solid state annunciator system.

An Emergency Power System will be provided to ensure safe and reliable shutdown of the station and power for blackout conditions. The emergency system will consist of battery banks, battery chargers, uninterruptible A-C control power system and a diesel generator for shutdown auxiliary power.

4.0 PLANT LAYOUTS

The Plant Island drawings for Reference Plants 1, 2 and 3 are shown in Figures 4-1, 4-2 and 4-3, respectively. Figure 4-4 is a section taken along the centerline of the MHD components of Reference Plant 1. It is representative also of Reference Plants 2 and 3.

The Plant Island arrangement is basically the same for each of the three Reference Plants. The major difference is that Reference Plants 1 and 2 have High Temperature Air Heaters and associated gasifiers whereas Reference Plant 3 has an O_2-plant instead which is located outside the Turbine-Generator building.

Buildings are shown to house the turbine generator and air compressors, the MHD components, the inverter equipment, the maintenance area and offices for administrative personnel. The arrangement of the buildings, location of overhead cranes, and the entrance of the railroad tracks into the buildings provide for accessibility and ease of maintenance for all the major components.

Figure 4-4 shows the relative elevations of the equipment along the centerline of the MHD components. The channel centerline is 45 ft above grade. The HTAH outlet is put at the elevation of the burner inlet to provide a direct and short refractory lined gas duct to the burner. As a result, the HTAH and burner slag collection equipment are in a pit. The channel centerline elevation was chosen to minimize excavation for the pit, keep the MHD components reasonably close to grade, and to provide adequate clearance below the boiler for slag and seed collection equipment.

Other pieces of auxiliary equipment are located suitably around the Plant Island. The coal and seed feed systems are as close as possible to the burner to minimize response times. The main steam turbine and the steam turbines for driving the air compressors are located in close proximity to the steam deaerator and the turbines share a common condenser. The stack is centrally located so as to be near both the ID fan and waste heat recovery equipment. Electrical leads from the inverter and main generator leave the plant on the same side. The control building is centrally located for convenience and ready access to all parts of the plant. The MHD building has as part of its equipment laydown area, a limited access area where the magnetic field is above 200 G. This space will be considered an unsafe work area when the unit is operating.

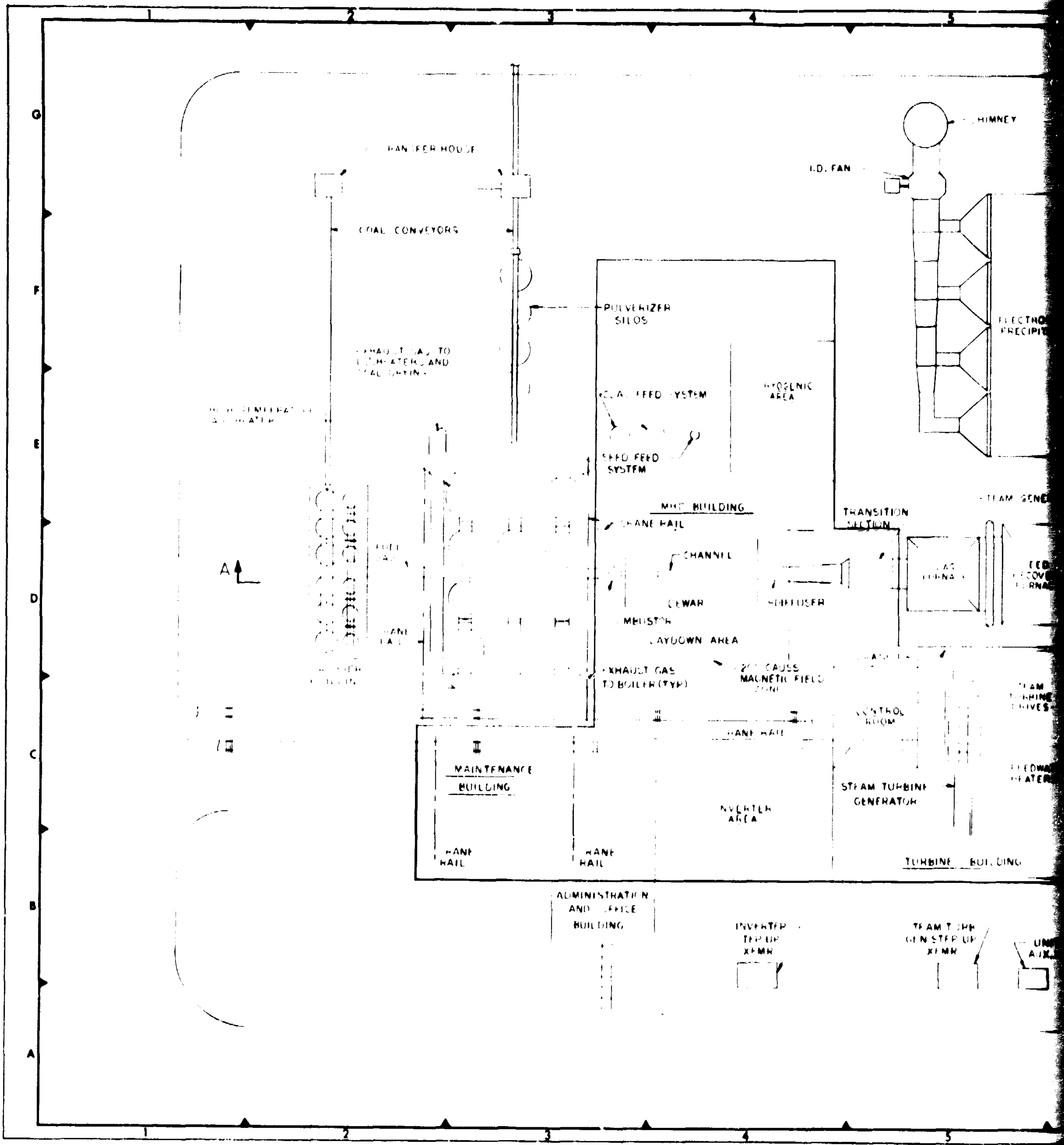

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Figure 4-1 Plant Island Arrangement of Referen

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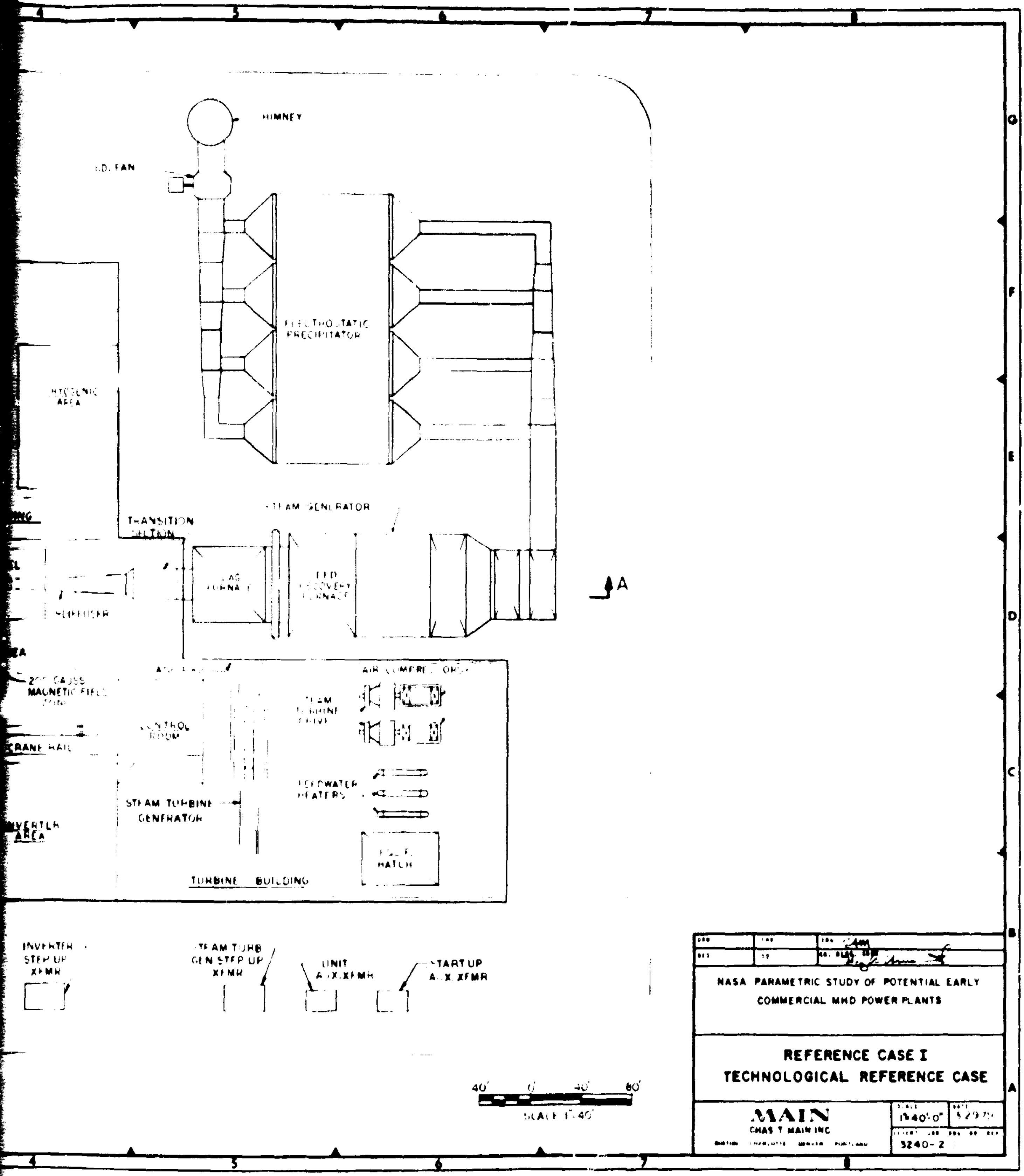

land Arrangement of Reference Plant 1

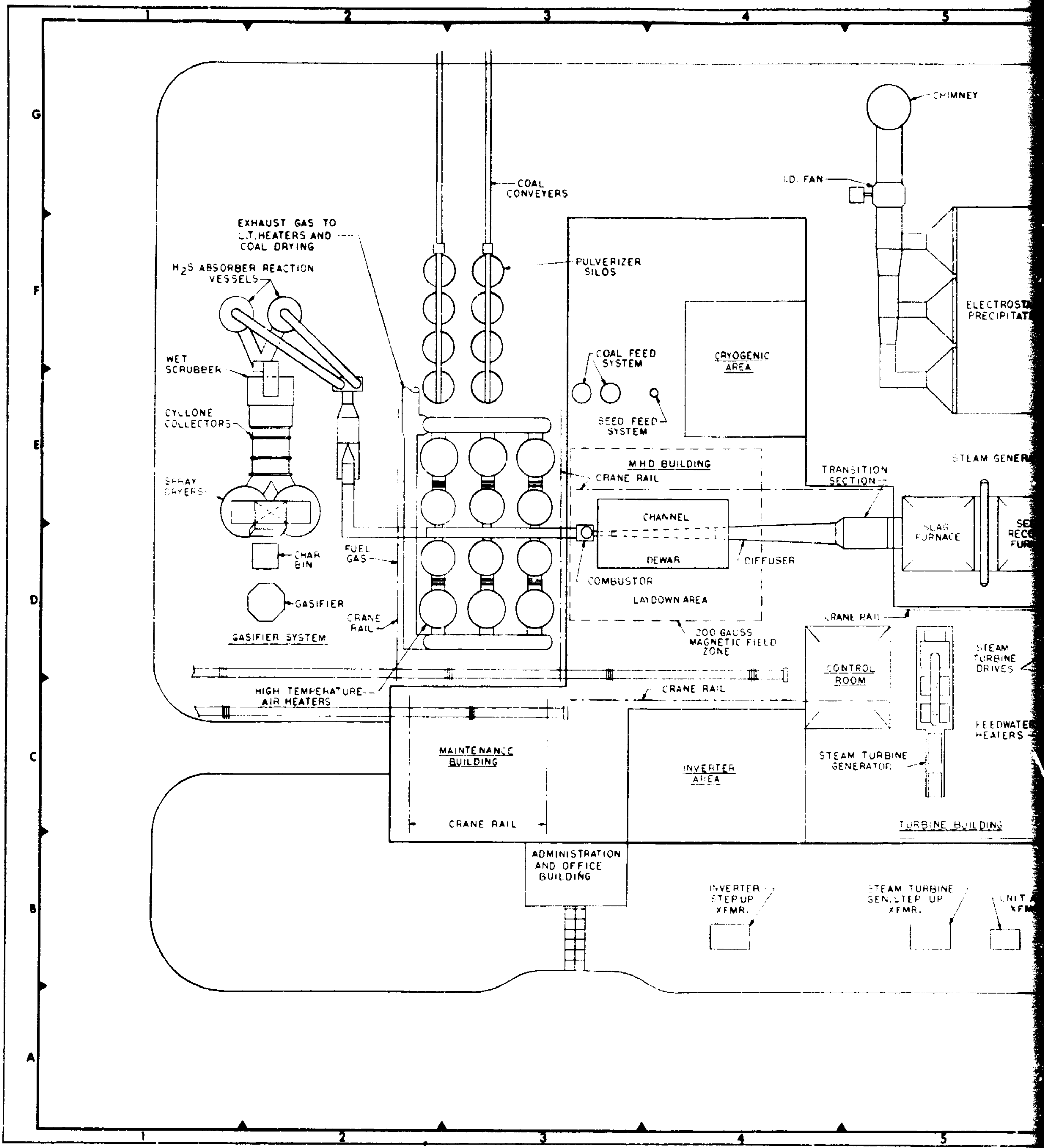

Figure 4-2   Plant Island Arrangement of

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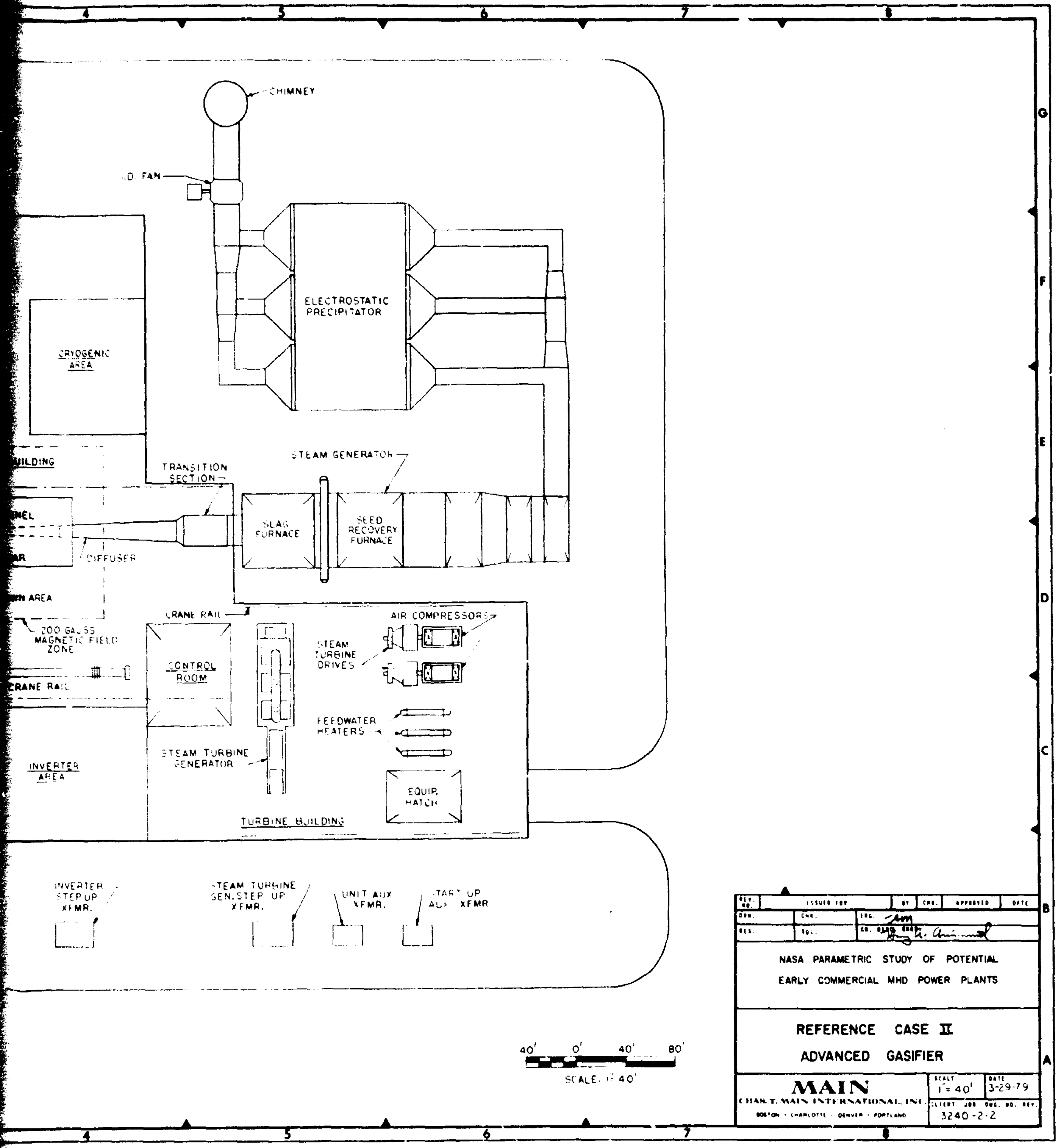

Plant Island Arrangement of Reference Plant 2

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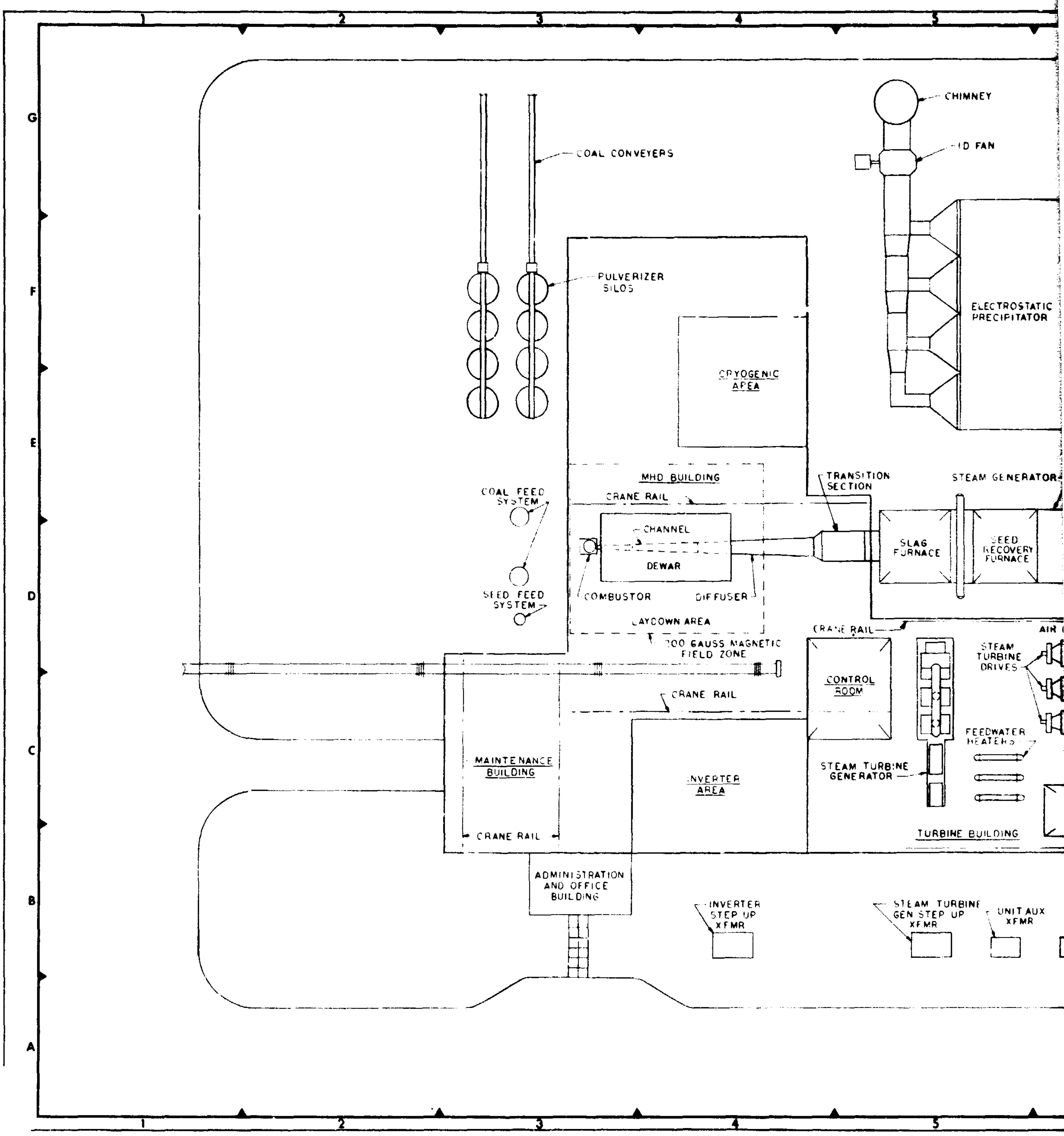

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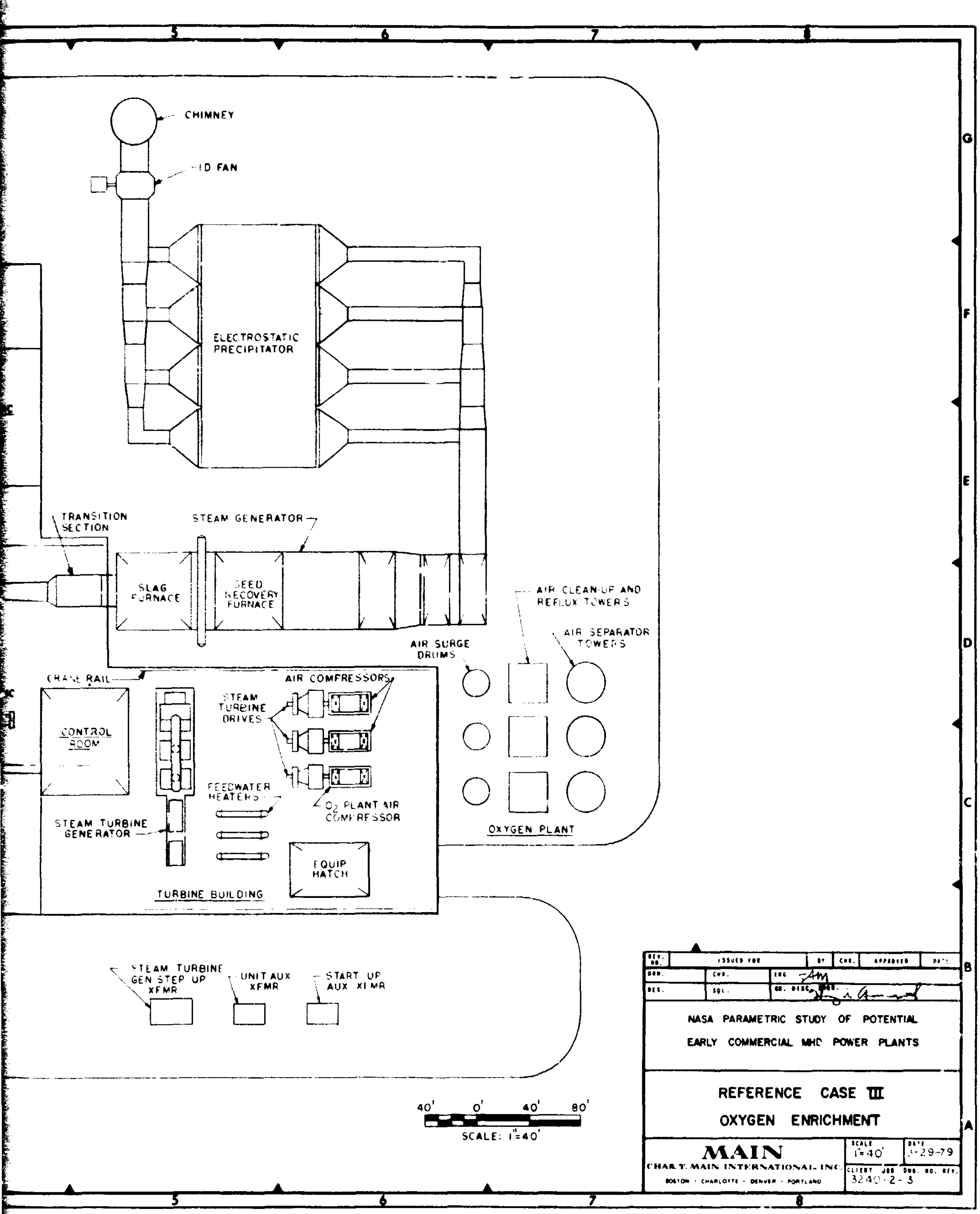
Figure 4-3   Plant Island Arrangement of Referen



d Arrangement of Reference Plant 3

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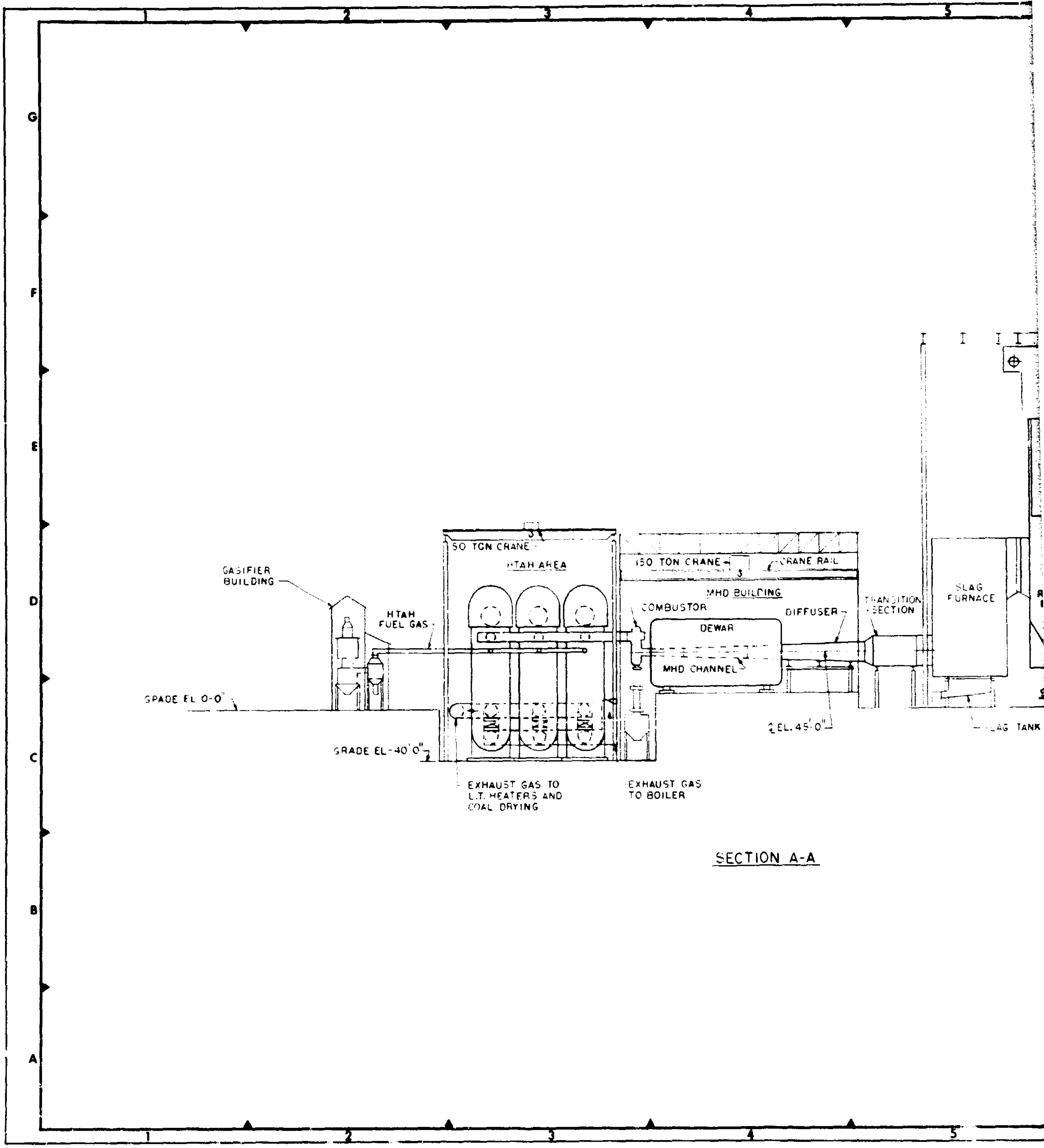
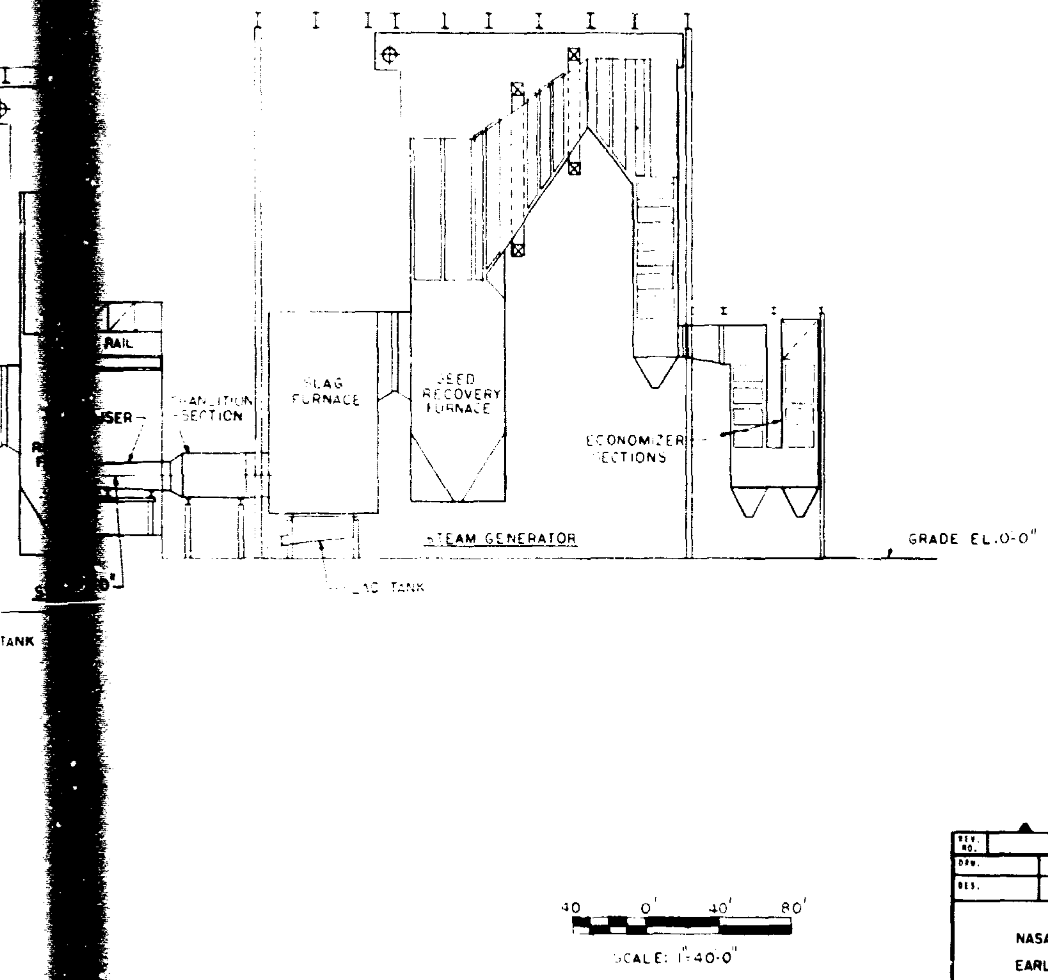


Figure 4-4 Plant Section of Reference



REV. NO.	ISSUED FOR	BY	CHK.	APPROVED	DATE

DRW.	CHK.	ENG.
DES.	SOL.	CH. DISC. ENGR.

NASA PARAMETRIC STUDY OF POTENTIAL
EARLY COMMERCIAL MHD POWER PLANTS

REFERENCE CASE I
SECTION A-A

MAIN
CHAS. T. MAIN INTERNATIONAL, INC.
BOSTON · CHARLOTTE · DENVER · PORTLAND

SCALE 1"=40'
DATE 3-29-79
CLIENT JOB 3240-2 DWG. NO. 4 REV.

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tion of Reference Plant 1

5.0 PLANTS ESTIMATED COSTS AND COST OF ELECTRICITY

5.1 CAPITAL COSTS

The summary estimate format and code of accounts supplied in this report has been developed in accordance with the Department of Energy's directives, and closely follows standard estimating practices. Detailed project cost estimates are shown in Tables 5-1, 5-2 and 5-3 for parametric point 1 of Reference Cases I, II, and III. Summary estimates are given on Tables 5-4 through 5-31 for all of the parametric points beginning with Reference Case I, parametric point 1. The cost elements identified for each line item are those costs for materials (divided into major components and balance of plant), costs for field installation, indirect costs, a specific contingency, and a total cost for that item. Costs are in mid-1978 dollars and are shown in thousands of dollars. "Major Components" have been identified as those items which are engineered, designed, fabricated, shipped, and in some cases erected, by one supplier. For the MHD facility, these costs are analogous with components of high technology and which are research oriented.

"Balance of Plant" items are normally designed, engineered, and purchased by the engineer. All material costs include charges for delivery to the site.

The "Installation" portion of the direct cost includes wage costs for all manual labor, foremanship, and all wage related benefits and costs mandated by labor agreement. Payroll taxes, payroll premium costs and workmen's compensation insurance costs are built into the wage rate of direct labor costs. Also included is special construction equipment associated with certain civil work items to which the costs can be charged directly, and also contractor fees. Auxiliary labor for unloading, storing, sorting materials and equipment, general and final cleanup, and other miscellaneous activities directly associated with the installation of the work area are also charged to the direct account.

"Indirect Costs" for construction are those cost items which include facilities, equipment and services that are required to directly support the construction operations, but which cannot be conveniently charged by the constructor or general contractor directly to a single estimating account. For conceptual estimates, indirect construction costs are expressed as a percentage of the direct cost. Field offices and temporary facilities, transportation, safety equipment, construction tools

Sheet 1 of 4

Case I   Parametric Point 1

TABLE 5-1
PARAMETRIC STUDY-PROJECT COST ESTIMATE

ACCOUNT NUMBER	ACCOUNT DESCRIPTION	UNIT	QUANTITY	MATERIAL		INSTALL-ATION COST	INDIRECT COST	CONTIN-GENCY	TOTAL COST
				MAJOR COMPONENT	BALANCE OF PLANT COST				
310.	Land and Land Rights	JOB	1	---	893	---	---	89	982
311.	Structures and Improvements	JOB	1	---	23,817	16,603	8,299	4,872	53,591
311.1	Improvements to Site	JOB	1	---	1,595	1,713	857	417	4,582
311.2	MHD Building			---	3,518	2,754	1,377	765	8,414
311.3	Bottoming Plant Building			---	3,417	2,675	1,338	743	8,173
311.4	Steam Generator Building			---	255	795	398	145	1,593
311.5	HTAH Building			---	823	2,067	1,034	392	4,316
311.6	Maint. Serv., Warehouse and Office Buildings			---	1,044	817	409	227	2,497
311.7	Other Buildings			---	2,014	2,768	1,379	616	6,777
311.8	Cranes and Hoists	JOB	1	---	8,137	904	452	949	10,442
311.9	On-site Waste Treatment	JOB	1	---	3,014	2,110	1,055	618	6,797
312.	Boiler Plant	JOB	1	---	123,680	36,290	18,149	17,811	195,930
312.1	Coal Handling	JOB	1	---	10,746	4,606	2,304	1,766	19,422
312.11	Unloading and Yard Storage	JOB	1	---	4,491	1,925	963	738	8,117
312.12	Reclaim and Delivery	JOB	1	---	6,255	2,681	1,341	1,028	11,305
312.2	Slag and Ash Handling	JOB	1	---	3,780	945	473	520	5,718
312.4	Steam Generator	JOB	1	---	94,718	25,258	12,631	13,260	145,867
312.41	Steam Generator	JOB	1	---	86,434	23,049	11,525	12,100	133,108
312.42	I.F. Air Heater	JOB	1	---	3,068	818	409	430	4,725
312.43	Instrumentation & Controls	JOB	1	---	2,092	558	279	293	3,222
312.44	Auxiliaries	JOB	1	---	3,124	833	418	437	4,812
312.5	Effluent Control	JOB	1	---	10,198	3,650	1,825	1,567	17,240
312.51	Precipitator and Breeching	JOB	1	---	9,798	2,858	1,429	1,408	15,493
312.52	Chimney	EA.	1	---	400	792	396	159	1,747
312.6	Auxiliary Boiler System	JOB	1	---	225	25	13	26	289
312.7	Other Boiler Plant System	JOB	1	---	4,013	1,806	903	672	7,394
312.71	Condensate and Feedwater Sys.	JOB	1	---	2,566	1,290	645	450	4,951
312.72	Water Treatment System	JOB	1	---	737	213	107	106	1,163
312.73	Water Supply System	JOB	1	---	710	303	152	116	1,281

Sheet 2 of 4

Case I **Parametric Point 1**

TABLE 5-1
PARAMETRIC STUDY-PROJECT COST ESTIMATE

ACCOUNT NUMBER	ACCOUNT DESCRIPTION	UNIT	QUANTITY	MATERIAL		INSTALL-ATION COST	INDIRECT COST	CONTIN-GENCY	TOTAL COST
				MAJOR COMPONENT	BALANCE OF PLANT COST				
314.	Steam Turbine Gen. and Aux.				33,537	7,431	3,717	4,468	49,153
314.1	Steam Turbine and Aux.				23,684	2,908	1,454	2,804	30,850
314.2	Condenser and Auxiliary				1,353	557	279	219	2,408
314.3	Circulating Water System				5,716	2,346	1,174	923	10,159
314.31	Pumps, Valves, Piping and Struct.				2,336	1,219	610	416	4,581
314.32	Cooling Towers				3,380	1,127	564	507	5,578
314.4	Steam Piping Systems				2,184	1,450	725	436	4,795
314.41	Main Steam				1,057	748	374	218	2,397
314.42	Auxiliary Steam				215	254	127	60	656
314.43	Misc. Piping Systems				312	278	139	73	802
314.5	Other Turbine Plant & Mech. Equip.				600	170	85	86	941
315.	Accessory Electric Equipment				12,054	10,485	5,243	2,933	30,715
315.1	Station and Aux. Transf.				500	30	15	82	627
315.2	Misc. Motors				2,000	378	189	385	2,952
315.3	S.G. and MCCs				1,741	800	400	294	3,235
315.4	Conduit Tray, Cable and Busswork				4,201	7,614	3,807	1,562	17,184
315.5	Misc. Electrical Equipment				351	540	270	116	1,277
315.6	Integrated Control System				1,900	683	342	292	3,217
315.7	Data Acquisition System				1,300	436	218	195	2,149
315.8	Emergency Power Systems				61	4	2	7	74
316.	Misc. Power Plant Equipment				1,773	1,215	608	360	3,956
316.1	Fuel Oil Handling System				686	885	442	201	2,214
316.2	Fire Protection System				587	305	153	105	1,150
316.3	Machine Shop and Maint. Shop				500	25	13	54	592

Sheet 3 of 4

Case I Parametric Point 1

TABLE 5-1
PARAMETRIC STUDY-PROJECT COST ESTIMATE

ACCOUNT NUMBER	ACCOUNT DESCRIPTION	UNIT	QUANTITY	MATERIAL		INSTALL-ATION COST	INDIRECT COST	CONTIN-GENCY	TOTAL COST
				MAJOR COMPONENT	BALANCE OF PLANT COST				
317.	MHD Topping Cycle			127,113	56,866	29,873	14,939	37,503	266,294
317.1	Combustion Equipment			5,999	5,622	2,839	1,420	1,688	17,568
317.11	Coal Drying			---	5,622	1,511	756	789	8,678
317.12	Coal Injection			4,586	---	1,223	611	642	7,062
317.13	Combuster			963	---	27	14	200	1,204
317.14	Slag Coll. System			450		78	39	57	624
317.2	MHD Generator			4,948	---	148	75	1,034	6,205
317.21	Nozzle			175	---	7	4	37	223
317.22	Channel (3000^{o}F)			3,820	---	101	51	794	4,766
317.23	Diffuser & Transition			953	---	40	20	203	1,216
317.3	Magnet Subsystem			41,537		488	244	8,454	50,723
317.31	Structure								
317.32	Winding Assembly								
317.33	Dewar								
317.34	Refrigeration System								
317.35	DC Power Instr. & Control, Other								
317.4	Inverters and Electrode Con.			4,500	28,000	5,630	2,815	4,639	45,584
317.41	Inverters			---	28,000	5,000	2,500	3,550	39,050
317.42	Electric Consolidation Circ.			4,500	---	630	315	1,089	6,534
317.5	Oxidizer Preheat System			52,829	11,824	12,781	6,392	15,308	99,134
317.51	Air Compressor and Drive			---	8,180	818	409	941	10,348
317.52	Comb. Air and Gas Piping, Fans			---	205	103	52	36	396
317.53	L.T. Air Heater			---	3,439	917	459	482	5,297
317.54	H.T. Air Heater			52,829	---	10,943	5,472	13,849	83,093
317.541	Vessels			36,673	---	8,119	4,060	9,770	58,622
317.542	Reheat Burner			5,284	---	1,692	846	1,564	9,386
317.543	Ducting			10,372	---	1,132	566	2,414	14,484
317.544	Auxiliary Equipment, I&C			500	---	0	0	100	600

Sheet 4 of 4

Case I Parametric Point 1

TABLE 5-1
PARAMETRIC STUDY-PROJECT COST ESTIMATE

ACCOUNT NUMBER	ACCOUNT DESCRIPTION	UNIT	QUANTITY	MATERIAL MAJOR COMPONENT	MATERIAL BALANCE OF PLANT COST	INSTALLATION COST	INDIRECT COST	CONTINGENCY	TOTAL COST
317.6	Seed Subsystem				11,420	4,120	2,060	1,760	19,360
317.61	Seed Regeneration Process			---	10,220	3,780	1,890	1,589	17,479
317.62	Seed Injection System			---	1,200	340	170	171	1,881
317.7	Other MHD Topping Equipment			---	---	---	---	---	---
317.72	Gasifier System			17,300	---	3,867	1,933	4,620	27,720
318.	Not Applicable								
319.	Not Applicable								
350.	Transmission Plant			---	3,744	533	267	453	4,997
350.1	Structures and Improvements			---	193	160	80	43	476
350.2	Main Transformers			---	3,000	75	38	311	3,424
350.3	Switchyard			---	551	298	149	99	1,097
	Subtotal - Direct Accounts			127,113	256,364	102,430	51,222	68,489	605,618
	Engineering Services								
	Preliminary Engineering								12,112
	Detailed Design								24,225
	Construction Management								12,112
	Other Costs								12,112
	Total Estimated Construction Cost								666,179

Sheet 1 of 4

TABLE 5-2

Case II Parametric Point 1

PARAMETRIC STUDY-PROJECT COST ESTIMATE

ACCOUNT NUMBER	ACCOUNT DESCRIPTION	UNIT	QUANTITY	MATERIAL		INSTALLATION COST	INDIRECT COST	CONTINGENCY	TOTAL COST
				MAJOR COMPONENT	BALANCE OF PLANT COST				
310.	Land and Land Rights				893	—	—	89	982
311.	Structures and Improvements				23,763	16,434	8,220	4,842	53,259
311.1	Improvements to Site				1,595	1,713	857	417	4,582
311.2	MHD Building				3,518	2,754	1,377	765	8,414
311.3	Bottoming Plant Building				3,417	2,675	1,338	743	8,173
311.4	Steam Generator Building				255	795	398	145	1,593
311.5	HTAH Building				823	2,067	1,034	392	4,316
311.6	Maint. Serv., Warehouse and Office Buildings				1,044	817	409	227	2,497
311.7	Other Buildings				1,960	2,599	1,300	586	6,445
311.8	Cranes and Hoists				8,137	904	452	949	10,442
311.9	On-site Waste Treatment				3,014	2,110	1,055	618	6,797
312.	Boiler Plant				125,814	36,873	18,439	18,112	199,238
312.1	Coal Handling			—	10,746	4,606	2,304	1,766	19,422
312.11	Unloading and Yard Storage			—	4,491	1,925	963	738	8,117
312.12	Reclaim and Delivery			—	6,255	2,681	1,341	1,028	11,305
312.2	Slag and Ash Handling			—	3,780	945	473	520	5,718
312.4	Steam Generator			—	97,633	26,036	13,018	13,668	150,355
312.41	Steam Generator			—					
312.42	I.T. Air Heater			—					
312.43	Instrumentation & Controls			—					
312.44	Auxiliaries			—					
312.5	Effluent Control			—	9,185	3,350	1,675	1,421	15,631
312.51	Precipitator and Breeching			—	8,785	2,558	1,279	1,262	13,884
312.52	Chimney			—	400	792	396	159	1,747
312.6	Auxiliary Boiler System				225	25	13	26	289
312.7	Other Boiler Plant System				4,245	1,911	956	711	7,823
312.71	Condensate and Feedwater Sys.				2,746	1,380	690	482	5,298
312.72	Water Treatment System				789	228	114	113	1,244
312.73	Water Supply System			—	710	303	152	116	1,281

Sheet 2 of 4

TABLE 5-2

Case II Parametric Point 1

PARAMETRIC STUDY-PROJECT COST ESTIMATE

ACCOUNT NUMBER	ACCOUNT DESCRIPTION	UNIT	QUANTITY	MATERIAL		INSTALL-ATION COST	INDIRECT COST	CONTIN-GENCY	TOTAL COST
				MAJOR COMPONENT	BALANCE OF PLANT COST				
314.	Steam Turbine Gen. and Aux.				34,925	7,659	3,829	4,641	51,054
314.1	Steam Turbine and Aux.			---	25,034	3,074	1,537	2,964	32,609
314.2	Condenser and Auxiliary			---	1,452	597	298	235	2,582
314.3	Circulating Water System			---	6,110	2,439	1,220	977	10,746
314.31	Pumps, Valves, Piping and Struct.			---	2,430	1,225	613	427	4,695
314.32	Cooling Towers			---	3,680	1,214	607	550	6,051
314.4	Steam Piping Systems			---	1,695	1,369	684	375	4,123
314.41	Main Steam			---	1,131	800	400	233	2,564
314.42	Auxiliary Steam			---	230	272	136	64	702
314.43	Misc. Piping Systems			---	334	297	148	78	857
314.5	Other Turbine Plant & Mech. Equip.			---	634	180	90	90	994
315.	Accessory Electric Equipment			---	12,054	10,485	5,243	2,933	30,715
315.1	Station and Aux. Transf.								
315.2	Misc. Motores								
315.3	S.G. and MCCs								
315.4	Conduit Tray, Cable and Busswork								
315.5	Misc. Electrical Equipment								
315.6	Integrated Control System								
315.7	Data Acquisition System								
315.8	Emergency Power Systems								
316.	Misc. Power Plant Equipment			---	1,773	1,215	608	360	3,956
316.1	Fuel Oil Handling System			---	686	885	442	201	2,214
316.2	Fire Protection System			---	587	305	153	105	1,150
316.3	Machine Shop and Maint. Shop			---	500	25	13	54	592

Sheet 3 of 4

TABLE 5-2 Case II Parametric Point 1

PARAMETRIC STUDY-PROJECT COST ESTIMATE

ACCOUNT NUMBER	ACCOUNT DESCRIPTION	UNIT	QUANTITY	MATERIAL		INSTALL-ATION COST	INDIRECT COST	CONTIN-GENCY	TOTAL COST
				MAJOR COMPONENT	BALANCE OF PLANT COST				
317.	MHD Topping Cycle			162,406	56,772	36,982	18,492	41,101	315,753
317.1	Combustion Equipment			5,724	8,785	3,848	1,924	2,116	22,397
317.11	Coal Drying			---	8,785	1,185	592	622	6,841
317.12	Coal Injection			4,442	---	2,558	1,279	1,262	13,884
317.13	Combuster			832	---	27	14	175	1,048
317.14	Slag Coll. System			450	---	78	39	57	624
317.2	MHD Generator			5,280	---	155	78	1,103	6,616
317.21	Nozzle			164	---	7	4	35	210
317.22	Channel (3000°F)			4,142	---	108	54	861	5,165
317.23	Diffuser & Transition			974	---	40	20	207	1,241
317.3	Magnet Subsystem								
317.31	Structure								
317.32	Winding Assembly								
317.33	Dewar								
317.34	Refrigeration System			44,480	---	491	246	9,043	54,260
317.35	DC Power Instr. & Control, Other								
317.4	Inverters and Electrode Con.			5,000	30,000	5,672	2,836	4,952	48,460
317.41	Inverters			---	30,000	5,000	2,500	3,750	41,250
317.42	Electric Consolidation Circ.			5,000	---	672	336	1,202	7,210
317.5	Oxidizer Preheat System			62,190	8,903	12,696	6,348	16,787	105,924
317.51	Air Compressor and Drive			---	8,500	850	425	978	10,753
317.52	Comb. Air and Gas Piping, Fans			---	210	105	52	37	404
317.53	L.T. Air Heater			---	193	51	26	27	297
317.54	H.T. Air Heater			61,190	---	11,690	5,845	15,745	94,470
317.541	Vessels								
317.542	Reheat Burner								
317.543	Ducting								
317.544	Auxiliary Equipment, I&C								
317.6	Seed Subsystem			---	9,084	3,256	1,628	1,397	15,365
317.61	Seed Regeneration Process			---	7,884	2,916	1,458	1,226	13,484
317.62	Seed Injection System			---	1,200	340	170	171	1,881
317.7	Other MHD Topping Equipment			40,732	---	10,864	5,432	5,703	62,731
317.72	Gasifier System			40,732	---	10,864	5,432	5,703	62,731

Sheet 4 of 4

Case II Parametric Point 1

TABLE 5-2

PARAMETRIC STUDY-PROJECT COST ESTIMATE

ACCOUNT NUMBER	ACCOUNT DESCRIPTION	UNIT	QUANTITY	MATERIAL MAJOR COMPONENT	MATERIAL BALANCE OF PLANT COST	INSTALL-ATION COST	INDIRECT COST	CONTIN-GENCY	TOTAL COST
318.	Not Applicable								
319.	Not Applicable								
350.	Transmission Plant			---	3,744	533	267	453	4,997
350.1	Structures and Improvements			---	193	160	80	43	476
350.2	Main Transformers			---	3,000	75	38	311	3,424
350.3	Switchyard			---	551	298	149	99	1,097
	Subtotal - Direct Accounts			162,406	259,738	110,181	55,098	72,531	659,954
	Engineering Services								
	Preliminary Engineering								13,199
	Detailed Design								26,398
	Construction Management								13,199
	Other Costs								13,199
	Total Estimated Construction Cost								725,949

Sheet 1 of 4

Case III Parametric Point 1

TABLE 5-3

PARAMETRIC STUDY-PROJECT COST ESTIMATE

ACCOUNT NUMBER	ACCOUNT DESCRIPTION	UNIT	QUANTITY	MATERIAL MAJOR COMPONENT	MATERIAL BALANCE OF PLANT COST	INSTALL-ATION COST	INDIRECT COST	CONTIN-GENCY	TOTAL COST
310.	**Land and Land Rights**			---	938	---	---	94	1,032
311.	Structures and Improvements				23,037	14,671	7,318	4,505	49,531
311.1	Improvements to Site			---	1,595	1,713	857	417	4,582
311.2	MHD Building			---	3,518	2,754	1,377	765	8,414
311.3	Bottoming Plant Building			---	3,417	2,675	1,338	743	8,173
311.4	Steam Genera Building			---	255	795	398	145	1,593
311.5				-					
311.6	Maint. Serv., Warehouse and Office Buildings			---	1,044	817	409	227	2,497
311.7	Other Buildings			---	2,057	2,903	1,452	641	7,053
311.8	Cranes and Hoists			---	8,137	904	452	949	10,442
311.9	On-site Waste Treatment			---	3,014	2,110	1,035	618	6,777
312.	Boiler Plant				120,314	35,286	17,646	17,324	190,570
312.1	Coal Handling			---	10,746	4,606	2,304	1,766	19,422
312.11	Unloading and Yard Storage			---	5,158	2,211	1,144	542	9,055
312.12	Reclaim and Delivery			---	5,588	2,395	1,160	1,224	10,367
312.2	Slag and Ash Handling			---	5,021	1,255	628	691	7,595
312.4	Steam Generator			---	94,019	25,072	12,536	13,162	144,789
312.41	Steam Generator			---	84,957	22,655	11,328	11,894	130,834
312.42	I.T. Air Heater			---	3,667	978	489	513	5,647
312.43	Instrumentation & Controls			---	2,092	558	279	293	3,222
312.44	Auxiliaries			---	3,303	881	440	462	5,086
812.5	Effluent Control			---	6,162	2,474	1,237	987	10,860
312.51	Precipitator and Breeching			---	5,762	1,682	841	828	9,113
312.52	Chimney			---	400	792	396	159	1,747
312.6	Auxiliary Boiler System			---	225	25	13	26	289
312.7	Other Boiler Plant System			---	4,141	1,854	928	692	7,615
312.71	Condensate and Feedwater Sys.			---	2,670	1,331	666	467	5,134
312.72	Water Treatment System			---	761	220	110	109	1,200
312.73	Water Supply System			---	710	303	152	116	1,281

Sheet 2 of 4

Case III Parametric Point 1

TABLE 5-3

PARAMETRIC STUDY-PROJECT COST ESTIMATE

ACCOUNT NUMBER	ACCOUNT DESCRIPTION	UNIT	QUANTITY	MATERIAL		INSTALL-ATION COST	INDIRECT COST	CONTIN-GENCY	TOTAL COST
				MAJOR COMPONENT	BALANCE OF PLANT COST				
314.	Steam Turbine Gen. and Aux.				31,912	7,225	3,613	4,235	46,985
314.1	Steam Turbine and Aux.				22,263	2,734	1,367	2,636	29,000
314.2	Condenser and Auxiliary			---	1,430	588	294	231	2,543
314.3	Circulating Water System			---	6,020	2,422	1,211	965	10,618
314.31	Pumps, Valves, Piping and Struct.			---	2,430	1,225	613	427	4,695
314.32	Cooling Towers			---	3,590	1,197	598	538	5,923
314.4	Steam Piping Systems			---	1,635	1,321	661	363	3,980
314.41	Main Steam			---	1,091	772	386	225	2,474
314.42	Auxiliary Steam			---	222	262	131	66	681
314.43	Misc. Piping Systems			---	322	287	144	72	825
314.5	Other Turbine Plant & Mech. Equip.			---	564	160	80	40	844
315.	Accessory Electric Equipment			---	12,054	10,485	5,243	2,933	30,715
315.1	Station and Aux. Transf.								
315.2	Misc. Motors								
315.3	S.G. and MCCs								
315.4	Conduit Tray, Cable and Busswork								
315.5	Misc. Electrical Equipment								
315.6	Integrated Control System								
315.7	Data Acquisition System								
315.8	Emergency Power Systems								
316.	Misc. Power Plant Equipment			---	1,773	1,215	608	360	3,956
316.1	Fuel Oil Handling System			---	686	885	442	201	2,214
316.2	Fire Protection System			---	587	305	153	105	1,150
316.3	Machine Shop and Maint. Shop			---	500	25	13	54	592

Sheet 3 of 4

TABLE 5-3 Case III Parametric Point 1

PARAMETRIC STUDY-PROJECT COST ESTIMATE

ACCOUNT NUMBER	ACCOUNT DESCRIPTION	UNIT	QUANTITY	MATERIAL MAJOR COMPONENT	MATERIAL BALANCE OF PLANT COST	INSTALLATION COST	INDIRECT COST	CONTINGENCY	TOTAL COST
317.	**MHD Topping Cycle**			68,315	50,343	15,596	7,801	19,890	161,945
317.1	Combustion Equipment			14,285	---	3,615	1,808	2,059	21,767
317.11	Coal Drying			7,506	---	2,002	1,001	1,051	11,560
317.12	Coal Injection			5,947	---	1,586	793	833	9,159
317.13	Combuster			832	---	27	14	175	1,048
317.14	Slag Coll. System			450	---	78	39	57	624
317.2	MHD Generator			5,300		155	78	1,106	6,639
317.21	Nozzle			157	---	7	4	34	202
317.22	Channel (3000°F)			4,190	---	108	54	870	5,222
317.23	Diffuser & Transition			953	---	40	20	202	1,215
317.3	Magnet Subsystem			44,030	---	491	246	8,953	53,720
317.31	Structure								
317.32	Winding Assembly								
317.33	Dewar								
317.34	Refrigeration System								
317.35	DC Power Instr. & Control, Other								
317.4	Inverters and Electrode Con.			4,700	29,000	5,651	2,826	4,785	46,962
317.41	Inverters			---	29,000	5,000	2,500	3,650	40,150
317.42	Electric Consolidation Circ.			4,700	---	651	326	1,135	6,812
317.5	Oxidizer Preheat System			---	8,098	889	445	943	10,375
317.51	Air Compressor and Drive			---	7,900	790	395	908	9,993
317.52	Comb. Air and Gas Piping, Fans			---	198	99	50	35	382
317.53	L.T. Air Heater			---	---	---	---	---	---
317.54	H.T. Air Heater			---	---	---	---	---	---
317.541	Vessels			---	---	---	---	---	---
317.542	Reheat Burner			---	---	---	---	---	---
317.543	Ducting			---	---	---	---	---	---
317.544	Auxiliary Equipment, I&C			---	---	---	---	---	---
317.6	Seed Subsystem			---	13,245	4,795	2,398	2,044	22,482
317.61	Seed Regeneration Process			---	12,045	4,455	2,228	1,873	20,601
317.62	Seed Injection System				1,200	340	170	171	1,881
317.7	Other MHD Topping Equipment								
317.72	Gasifier System			0	---	0	0	0	0

Sheet 4 of 4

TABLE 5-3

Case III Parametric 1

PARAMETRIC STUDY-PROJECT COST ESTIMATE

ACCOUNT NUMBER	ACCOUNT DESCRIPTION	UNIT	QUANTITY	MATERIAL		INSTALL-ATION COST	INDIRECT COST	CONTIN-GENCY	TOTAL COST
				MAJOR COMPONENT	BALANCE OF PLANT COST				
318.	Not Applicable								
319.	Not Applicable								
350.	Transmission Plant								
350.1	Structures and Improvements			---	3,744	533	267	453	4,997
350.2	Main Transformers			---	193	160	80	43	476
350.3	Switchyard			---	3,000	75	38	311	3,424
				---	551	298	149	99	1,097
	Subtotal - Direct Accounts			68,315	244,115	85,011	42,496	49,794	489,731
	Engineering Services								
	Preliminary Engineering								9,793
	Detailed Design								19,589
	Construction Management								9,795
	Other Costs								9,795
	Total Estimated Construction Cost								538,705
	O_2 System								62,100
									600,805

(x 1000 $)

CASE 1 PARA. PT. 1

TABLE 5-4

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights	---	893			89	982
311.0	Struct. & Improvements	---	23,817	16,603	8,299	4,872	53,591
312.0	Boiler Plant	---	123,680	36,290	18,149	17,811	195,930
312.1	Coal Handling	---	10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling	---	3,780	945	473	520	5,718
312.4	Steam Generator	---	94,718	25,258	12,631	13,260	145,867
312.5	Effluent Control	---	10,198	3,650	1,825	1,567	17,240
312.6	Aux. Boiler System	---	225	25	13	26	289
312.7	Other Boiler Plant Sys.	---	4,013	1,806	903	672	7,394
314.0	Stm Turbine Gen.	---	33,537	7,431	3,717	4,468	49,153
315.0	Accessory Elec. Equip.	---	12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.	---	1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	132,213	56,866	33.806	16,906	39,703	279,494
317.1	Combustion Equip.	5,999	5,622	2,839	1,420	1,688 (1)	17,568
317.2	MHD Generator	4,948	---	148	75	1,034 (20%)	6,205
317.3	Magnet Subsystem	41,537	---	488	244	8,454 (20%)	50,723
317.4	Inverters	4,500	28,000	5,630	2,815	4,639 (2)	45,584
317.5	Oxidizer Preheat	52,829	11,824	12,781	6,392	15,308 (3)	99,134
317.6	Seed Subsystem	---	11,420	4,120	2,060	1,760	19,360
317.7	Other MHD Topping Equip.	22,400	--	7,800	3,900	6.820	40.920
350.0	Transmission & SWYD	---	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	132.213	256.364	106.363	53,189	70,689	618,818
	Engineering/Other Costs						61,882
	TOTAL COSTS						680,700

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $) CASE I PARA. PT. 2

TABLE 5-5

ACCT. #	DESCRIPTION	MATERIAL		LABOR		CONTINGENCY	TOTAL
		MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS		
310.0	Land & Land Rights	-	651	-	-	65	716
311.0	Struct. & Improvements	-	20,959	14,610	7,305	4,287	47,161
312.0	Boiler Plant	46,321	14,972	18,276	9,141	8,870	97,580
312.1	Coal Handling	-	5,010	2,147	1,074	823	9,054
312.2	Slag & Ash Handling	-	1,762	440	220	242	2,664
312.4	Steam Generator	46,321	-	12,352	6,177	6,485	71,335
312.5	Effluent Control	-	5,255	2,046	1,024	832	9,157
312.6	Aux. Boiler System	-	100	11	6	12	129
312.7	Other Boiler Plant Sys.	-	2,845	1,280	640	476	5,241
314.0	Stm Turbine Gen.	-	14,968	1,531	766	1,726	18,991
315.0	Accessory Elec. Equip.	-	8,550	2,140	1,070	1,176	12,936
316.0	Misc. Power Plant Equip.	-	1,070	565	282	192	2,109
317.0	MHD Topping Cycle	70,665	30,064	18,216	9,109	21,046	149,100
317.1	Combustion Equip.	3,177	2,939	1,469	735	895 (1)	9,215
317.2	MHD Generator	3,224	-	98	50	674 (20%)	4,046
317.3	Magnet Subsystem	21,764	-	342	171	4,455 (20%)	26,732
317.4	Inverters	2,500	14,000	4,340	2,170	2,614 (2)	25,624
317.5	Oxidizer Preheat	28,800	6,845	7,019	3,509	8,398 (3)	54,571
317.6	Seed Subsystem	-	6,280	2,281	1,141	970	10,672
317.7	Other MHD Topping Equip.	11,200	-	2,667	1,333	3,040	18,240
350.0	Transmission & SWYD	-	2,218	460	230	291	3,199
	SUBTOTAL DIRECTS	116,986	93,452	55,798	27,903	37,653	331,792
	Engineering/Other Costs						33,179
	TOTAL COSTS						364,971

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $) CASE I PARA. PT. 3

TABLE 5-6

ACCT. #	DESCRIPTION	MATERIAL		LABOR		CONTINGENCY	TOTAL
		MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS		
310.0	Land & Land Rights	-	752	-	-	75	827
311.0	Struct. & Improvements	-	22,388	15,607	7,804	4,580	50,379
312.0	Boiler Plant	-	86,663	25,742	12,872	12,528	137,805
312.1	Coal Handling	-	7,137	3,055	1,527	1,172	12,891
312.2	Slag & Ash Handling	-	2,510	627	314	345	3,796
312.4	Steam Generator	-	66,159	17,643	8,822	9,262	101,886
312.5	Effluent Control	-	7,357	2,892	1,446	1,170	12,865
312.6	Aux. Boiler System	-	150	17	9	18	194
312.7	Other Boiler Plant Sys.	-	3,350	1,508	754	561	6,173
314.0	Stm Turbine Gen.	-	26,027	4,782	2,391	3,320	36,520
315.0	Accessory Elec. Equip.	-	10,060	2,520	1,260	1,384	15,224
316.0	Misc. Power Plant Equip.	-	1,553	932	466	296	3,247
317.0	MHD Topping Cycle	59,273	81,588	22,979	11,491	26,774	202,105
317.1	Combustion Equip.	4,323	4,065	2,041	1,020	1,222(1)	12,671
317.2	MHD Generator	4,171	-	124	63	871(20%)	5,229
317.3	Magnet Subsystem	31,779	-	415	208	6,480(20%)	38,882
317.4	Inverters	3,200	20,000	4,095	2,047	3,333(2)	32,675
317.5	Oxidizer Preheat	-	49,622	9,489	4,745	11,415(3)	74,671
317.6	Seed Subsystem	-	8,501	3,082	1,541	1,313	14,437
317.7	Other MHD Topping Equip.	15,800	-	3,733	1,867	2,140	23,540
350.0	Transmission & SWYD	-	2,763	490	245	350	3,848
	SUBTOTAL DIRECTS	59,273	231,794	73,002	36,529	49,307	449,905
	Engineering/Other Costs						44,990
	TOTAL COSTS						494,895

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $) CASE I PARA. PT. 4

TABLE 5-7

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
313.0	Land & Land Rights	-	893	-	-	89	982
311.0	Struct. & Improvements	-	23,817	16,603	8,299	4,872	53,591
312.0	Boiler Plant	-	124,760	36,579	18,291	17,963	197,593
312.1	Coal Handling	-	10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling	-	3,780	945	473	520	5,718
312.4	Steam Generator	-	95,798	25,547	12,773	13,412	147,530
312.5	Effluent Control	-	10,198	3,650	1,825	1,567	17,240
312.6	Aux. Boiler System	-	225	25	13	26	289
312.7	Other Boiler Plant Sys.	-	4,013	1,806	903	672	7,394
314.0	Stm Turbine Gen.	-	33,862	7,480	3,740	4,508	49,590
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	147,635	57,166	35,587	17,796	44,359	302,543
317.1	Combustion Equip.	5,868	5,622	2,839	1,420	1,663(1)	17,412
317.2	MHD Generator	5,355	-	158	80	1,119(20%)	6,712
317.3	Magnet Subsystem	45,272	-	472	236	9,196(20%)	55,176
317.4	Inverters	5,000	28,000	5,630	2,815	4,739(2)	46,184
317.5	Oxidizer Preheat	61,190	12,124	13,558	6,780	18,249(3)	111,901
317.6	Seed Subsystem	-	11,420	4,120	2,060	1,760	19,360
317.7	Other MHD Topping Equip.	24,950	-	8,810	4,405	7,633	45,798
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	147,635	258,069	108,482	54,244	75,537	643,967
	Engineering/Other Costs						64,397
	TOTAL COSTS						708,364

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)　　　CASE I　　PARA. PT. 5

TABLE 5-8

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights		893	-	-	89	982
311.0	Struct. & Improvements		23,817	16,603	8,299	4,872	53,591
312.0	Boiler Plant		125,179	36,692	18,348	18,022	198,241
312.1	Coal Handling		10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling		3,780	945	473	520	5,718
312.4	Steam Generator		96,163	25,644	12,822	13,463	148,092
312.5	Effluent Control		10,252	3,666	1,833	1,575	17,326
312.6	Aux. Boiler System		225	25	13	26	289
312.7	Other Boiler Plant Sys.		4,013	1,806	903	672	7,394
314.0	St Turbine Gen.		34,442	7,583	3,791	4,582	50,398
315.0	Accessory Elec. Equip.		12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.		1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	130,382	57,692	33,251	16,631	39,215	277,171
317.1	Combustion Equip.	5,868	5,622	2,839	1,420	1,663 (1)	17,412
317.2	MHD Generator	5,049	-	151	76	1,055 (20%)	6,331
317.3	Magnet Subsystem	41,955	-	488	244	8,537 (20%)	51,224
317.4	Inverters	5,000	28,000	5,630	2,815	4,739 (2)	46,184
317.5	Oxidizer Preheat	51,500	11,993	12,350	6,179	14,928 (3)	96,950
317.6	Seed Subsystem	-	12,077	4,363	2,182	1,862	20,484
317.7	Other MHD Topping Equip.	21,010	-	7,430	3,715	6,431	38,586
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	130,382	259,594	106,362	53,187	70,526	620,051
	Engineering/Other Costs						62,005
	O_2 System						34,000
	TOTAL COSTS						716,056

(1) Combuster 20%　Balance 10%
(2) Inverters 10%　El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20%　Balance 10%

(x 1000 $)

CASE I PARA. PT. 6

TABLE 5-9

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights		893	-	-	89	982
311.0	Struct. & Improvements		23,817	16,603	8,299	4,872	53,591
312.0	Boiler Plant		124,146	36,414	18,209	17,876	196,645
312.1	Coal Handling		10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling		3,780	945	473	520	5,718
312.4	Steam Generator		95,245	25,400	12,700	13,334	146,679
312.5	Effluent Control		10,137	3,632	1,816	1,558	17,143
312.6	Aux. Boiler System		225	25	13	26	289
312.7	Other Boiler Plant Sys.		4,013	1,806	903	672	7,394
314.0	Stm Turbine Gen.		33,133	7,386	3,693	4,421	48,633
315.0	Accessory Elec. Equip.		12,054	10,485	5,243	2,933	30,715
316.0	sc. Power Plant Equip.		1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	131,644	56,941	33,896	16,950	39,617	279,048
317.1	Combustion Equip.	6,020	5,622	2,839	1,420	1,693 (1)	17,594
317.2	MHD Generator	4,924	-	148	75	1,029 (20%)	6,176
317.3	Magnet Subsystem	41,120	-	438	244	8,370 (20%)	50,222
317.4	Inverters	4,400	28,000	5,630	2,815	4,619 (2)	45,464
317.5	Oxidizer Preheat	52,830	11,753	12,767	6,384	15,298 (3)	99,032
317.6	Seed Subsystem	-	11,566	4,174	2,087	1,783	19,610
317.7	Other MHD Topping Equip.	22,350	-	7,850	3,925	6,825	40,950
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	131,644	256,501	106,532	53,269	70,621	618,567
	Engineering/Other Costs						61,857
	TOTAL COSTS						680,424

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)

CASE I PARA. PT. 7

TABLE 5-10

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights		893	-	-	89	982
311.0	Struct. & Improvements		23,817	16,603	8,299	4,872	53,591
312.0	Boiler Plant		125,009	36,646	18,325	17,998	197,978
312.1	Coal Handling		10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling		3,780	945	473	520	5,718
312.4	Steam Generator		96,047	25,614	12,807	13,447	147,915
312.5	Effluent Control		10,198	3,650	1,825	1,567	17,240
312.6	Aux. Boiler System		225	25	13	26	289
312.7	Other Boiler Plant Sys.		4,013	1,806	903	672	7,394
314.0	Stm Turbine Gen.		32,798	7,344	3,672	4,381	48,195
315.0	Accessory Elec. Equip.		12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.		1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	131,964	60,610	33,848	16,928	39,668	283,018
317.1	Combustion Equip.	5,799	5,622	2,834	1,420	1,649(1)	17,324
317.2	MHD Generator	4,948	-	148	75	1,034(20%)	6,205
317.3	Magnet Subsystem	41,537	-	488	244	8,454(20%)	50,723
317.4	Inverters	4,500	28,000	5,630	2,815	4,639(2)	45,584
317.5	Oxidizer Preheat	52,830	11,824	12,778	6,389	15,307(3)	99,128
317.6	Seed Subsystem	-	11,420	4,120	2,060	1,760	19,360
317.7	Other MHD Topping Equip.	22,350	-	7,850	3,925	6,825	40,950
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	131,964	260,698	106,674	53,342	70,754	623,432
	Engineering/Other Costs						62,343
	TOTAL COSTS						685,775

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)

CASE I PARA. PT. 8

TABLE 5-11

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights		893	-	-	89	982
311.0	Struct. & Improvements		23,817	16,603	8,299	4,872	53,591
312.0	Boiler Plant		124,238	36,439	18,222	17,890	196,789
312.1	Coal Handling		10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling		3,780	945	473	520	5,718
312.4	Steam Generator		95,276	25,407	12,704	13,339	146,725
312.5	Effluent Control		10,198	3,650	1,825	1,567	17,240
312.6	Aux. Boiler System		225	25	13	26	289
312.7	Other Boiler Plant Sys.		4,013	1,806	903	672	7,394
314.0	Stm Turbine Gen.		33,242	7,414	3,707	4,436	48,799
315.0	Accessory Elec. Equip.		12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.		1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	130,309	56,943	33,829	16,921	29,340	277,342
317.1	Combustion Equip.	5,950	5,622	2,834	1,420	1,679 (1)	17,505
317.2	MHD Generator	4,800	-	144	73	1,003 (20%)	6,020
317.3	Magnet Subsystem	39,879	-	485	243	8,121 (20%)	48,728
317.4	Inverters	4,500	28,000	5,630	2,815	4,639 (2)	45,584
317.5	Oxidizer Preheat	52,830	11,974	12,793	6,398	15,324 (3)	99,319
317.6	Seed Subsystem	-	11,347	4,093	2,047	1,749	19,236
317.7	Other MHD Topping Equip.	22,350	-	7,850	3,925	6,825	40,950
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	130,309	256,704	10[illegible]8	53,267	70,373	617,171
	Engineering/Other Costs						61,717
	TOTAL COSTS						678,888

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)　　　CASE I　　PARA. PT. 9

TABLE 5-12

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights		893	-	-	89	982
311.0	Struct. & Improvements		23,817	16,603	8,299	4,872	53,591
312.0	Boiler Plant		124,089	36,399	18,202	17,869	196,559
312.1	Coal Handling		10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling		3,780	945	473	520	5,718
312.4	Steam Generator		95,127	25,367	12,684	13,318	146,496
312.5	Effluent Control		10,198	3,650	1,825	1,567	17,240
312.6	Aux. Boiler System		225	25	13	26	289
312.7	Other Boiler Plant Sys.		4,013	1,806	903	672	7,394
314.0	Stm Turbine Gen.		34,119	7,481	3,741	4,534	49,875
315.0	Accessory Elec. Equip.		12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.		1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	133,020	56,766	33,840	16,925	39,867	280,418
317.1	Combustion Equip.	6,066	5,622	2,834	1,420	1,702(1)	17,644
317.2	MHD Generator	5,002	-	148	75	1,045(20%)	6,270
317.3	Magnet Subsystem	42,372	-	490	245	8,621(20%)	51,728
317.4	Inverters	4,400	28,000	5,630	2,815	4,619(2)	45,464
317.5	Oxidizer Preheat	52,830	11,724	12,768	6,385	15,295(3)	99.002
317.6	Seed Subsystem	-	11,420	4,120	2,060	1,760	19,360
317.7	Other MHD Topping Equip.	22,350	-	7,850	3,925	6,825	40,[illegible]50
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	133,020	257,255	106,556	53,235	70,977	621,093
	Engineering/Other Costs						62,109
	TOTAL COSTS						683,202

(1) Combuster 20%　Balance 10%
(2) Inverters 10%　El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20%　Balance 10%

(× 1000 $) CASE I PARA. PT. 12

TABLE 5-13

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights		1,077	-	-	108	1,185
311.0	Struct. & Improvements		24,072	17,398	8,698	5,017	55,185
312.0	Boiler Plant		124,474	36,502	18,253	17,923	197,152
312.1	Coal Handling		10,746	4,606	2,304	1,756	19,422
312.2	Slag & Ash Handling		3,780	945	473	520	5,718
312.4	Steam Generator		95,512	25,470	12,735	13,372	147,089
312.5	Effluent Control		10,198	3,650	1,825	1,567	17,240
312.6	Aux. Boiler System		225	25	13	26	289
312.7	Other Boiler Plant Sys.		4,013	1,806	903	672	7,394
314.0	Stm Turbine Gen.	-	32,648	7,307	3,654	4,361	47,970
315.0	Accessory Elec. Equip.		12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.		1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	131,565	69,227	38,821	19,417	41,637	300,667
317.1	Combustion Equip	5,950	5,622	2,834	1,420	1,679(1)	17,505
317.2	MHD Generator	4,806	-	148	75	1,006(20%)	6,035
317.3	Magnet Subsystem	39,879	-	485	243	8,121(20%)	48,728
317.4	Inverters	4,600	28,000	5,630	2,815	4,659(2)	45,704
317.5	Oxidizer Preheat	52,830	11,994	12,795	6,399	15,326(3)	99,344
317.6	Seed Subsystem	-	23,611	8,629	4,315	3,656	40,211
317.7	Other MHD Topping Equip.	23,500	-	8,300	4,150	7,190	43,140
353.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	131,565	269,069	112,261	56,140	72,792	641,827
	Engineering/Other Costs						64,183
	TOTAL COSTS						706,010

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $) CASE II PARA. PT. 1

TABLE 5-14

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights		893			89	982
311.0	Struct. & Improvements	---	23,763	16,434	8,220	4,842	53,259
312.0	Boiler Plant	---	125,814	36,873	18,439	18,112	199,238
312.1	Coal Handling	---	10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling	---	3,780	945	473	520	5,718
312.4	Steam Generator	---	97,633	26,036	13,018	13,668	150,355
312.5	Effluent Control	---	9,185	3,350	1,675	1,421	15,631
312.6	Aux. Boiler System	---	225	5	13	26	289
312.7	Other Boiler Plant Sys.	---	4,245	1,911	956	711	7,823
314.0	Stm Turbine Gen.	---	34,925	7,659	3,829	4,641	51,054
315.0	Accessory Elec. Equip.	---	12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.	---	1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	162,406	56,772	36,982	18,492	41,101	315,753
317.1	Combustion Equip.	5,724	8,785	3,848	1,924	2,116 (1)	22,397
317.2	MHD Generator	5,280	---	155	78	1,103 (20%)	6,616
17.3	Magnet Subsystem	44,480	---	491	246	9,043 (20%)	54,260
317.4	Inverters	5,000	30,000	5,672	2,836	4,952 (2)	48,460
317.5	Oxidizer Preheat	61,190	8,903	12,696	6,348	16,787 (3)	105,924
317.6	Seed Subsystem	---	9,084	3,256	1,628	1,397	15,365
317.7	Other MHD Topping Equip.	40,732	---	10,864	5,432	5,703	62,731
350.0	Transmission & SWYD	---	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	162,406	259,738	110,181	55,098	72,531	659,954
	Engineering/Other Costs						65,995
	TOTAL COSTS						725,949

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)

CASE II PARA. PT. 2

TABLE 5-15

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY		TOTAL
310.0	Land & Land Rights	-	893	-	-	89		982
311.0	Struct. & Improvements	-	23,763	16,434	8,220	4,842		53,259
312.0	Boiler Plant	-	125,388	36,370	18,382	18,053		198,583
312.1	Coal Handling	-	10,746	4,606	2,304	1,766		19,422
312.2	Slag & Ash Handling	-	3,780	945	473	520		5,718
312.4	Steam Generator	-	97,207	25,923	12,961	13,609		149,700
312.5	Effluent Control	-	9,185	3,350	1,675	1,421		15,631
312.6	Aux. Boiler System	-	225	25	13	26		289
312.7	Other Boiler Plant Sys.	-	4,245	1,911	956	711		7,823
314.0	Stm Turbine Gen.	-	39,944	11,167	5,584	5,670		62,365
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933		30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360		3,956
317.0	MHD Topping Cycle	121,674	107,855	39,816	19,909	43,592		332,846
317.1	Combustion Equip.	5,724	6,876	3,264	1,632	1,859	(1)	19,355
317.2	MHD Generator	5,280	-	155	78	1,103	(20%)	6,616
317.3	Magnet Subsystem	44,480	-	525	263	9,054	(20%)	54,322
317.4	Inverters	5,000	30,000	5,672	2,836	4,952	(2)	48,460
317.5	Oxidizer Preheat	61,190	8,710	12,645	6,322	17,765	(3)	106,632
317.6	Seed Subsystem	-	9,784	3,556	1,778	1,511		16,629
317.7	Other MHD Topping Equip.	-	52,485	13,999	7,000	7,348		80,832
350.0	Transmission & SWYD	-	3,744	533	267	453		4,997
	SUBTOTAL DIRECTS	121,674	315,414	116,410	58,213	75,992		687,703
	Engineering/Other Costs							68,770
	O_2 System							
	TOTAL COSTS							756,473

(1) Combustor 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)

CASE II PARA. PT. 3

TABLE 5-16

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights	-	893	-	-	89	982
311.0	Struct. & Improvements	-	23,763	16,434	8,220	4,842	53,259
312.0	Boiler Plant	-	125,641	36,827	18,416	18,088	198,972
312.1	Coal Handling	-	10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling	-	3,780	945	473	520	5,718
312.4	Steam Generator	-	97,460	25,990	12,995	13,644	150,089
312.5	Effluent Control	-	9,185	3,350	1,675	1,421	15,631
312.6	Aux. Boiler System	-	225	25	13	26	289
312.7	Other Boiler Plant Sys.	-	4,245	1,911	956	711	7,823
314.0	Stm Turbine Gen.	-	36,742	8,017	4,008	4,877	53,644
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	121,674	98,614	37,203	18,602	41,266	317,359
317.1	Combustion Equip.	5,724	6,876	3,264	1,632	1,859 (1)	19,355
317.2	MHD Generator	5,280	-	155	78	1,103 (20%)	6,616
317.3	Magnet Subsystem	44,480	-	491	246	9,043 (20%)	54,260
317.4	Inverters	5,000	30,000	5,672	2,836	4,952 (2)	48,460
317.5	Oxidizer Preheat	61,190	8,903	12,696	6,348	16,787 (3)	105,924
317.6	Seed Subsystem	-	9,084	3,256	1,628	1,397	15,365
317.7	CE Gasifier	-	43,751	11,669	5,834	6,125	67,379
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	121,674	303,224	110,714	55,364	72,908	663,884
	Engineering/Other Costs						66,388
	O_2 System						
	TOTAL COSTS						730,272

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $) CASE II PARA. PT. 4

TABLE 5-17

ACCT #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights	-	893	-	-	89	982
311.0	Struct. & Improvements	-	23,763	16,434	8,220	4,842	53,259
312.0	Boiler Plant	-	125,837	36,880	18,442	18,116	199,275
312.1	Coal Handling	-	10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling	-	3,780	945	473	520	5,718
312.4	Steam Generator	-	97,656	26,043	13,021	13,672	150,392
312.5	Effluent Control	-	9,185	3,350	1,675	1,421	15,631
312.6	Aux. Boiler System	-	225	25	13	26	289
312.7	Other Boiler Plant Sys.	-	4,245	1,911	956	711	7,823
314.0	Stm Turbine Gen.	-	33,623	7,336	3,667	4,463	49,089
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	121,764	95,595	36,394	18,200	40,844	312,707
317.1	Combustion Equip.	5,724	6,876	3,264	1,632	1,859 (1)	19,355
317.2	MHD Generator	5,280	-	155	78	1,103 (20%)	6,616
317.3	Magnet Subsystem	44,480	-	491	246	9,043 (20%)	54,260
317.4	Inverters	5,000	30,000	5,672	2,836	4,952 (2)	48,460
317.5	Oxidizer Preheat	61,190	8,903	12,692	6,348	16,787 (3)	105,920
317.6	Seed Subsystem	-	9,084	3,256	1,628	1,397	15,365
317.7	CE Gasifier	-	40,732	10,864	5,432	5,703	62,731
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	121,674	297,282	109,277	54,647	72,100	654,980*
	Engineering/Other Costs						65,498
	[illegible] TOTAL COSTS						720,478*

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)

CASE II PARA. PT. 5

TABLE 5-18

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY		TOTAL
310.0	Land & Land Rights	-	893	-	-	89		982
311.0	Struct. & Improvements	-	23,763	16,434	8,220	4,842		53,259
312.0	Boiler Plant	-	125,837	36,880	18,442	18,116		199,275
312.1	Coal Handling	-	10,746	4,606	2,304	1,766		19,422
312.2	Slag & Ash Handling	-	3,780	945	473	520		5,718
312.4	Steam Generator	-	97,656	26,043	13,021	13,672		150,392
312.5	Effluent Control	-	9,185	3,350	1,675	1,421		15,631
312.6	Aux. Boiler System	-	225	25	13	26		289
312.7	Other Boiler Plant Sys.	-	4,245	1,911	956	711		7,823
314.0	Stm Turbine Gen.	-	34,663	7,563	3,781	4,600		50,607
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933		30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360		3,956
317.0	MHD Topping Cycle	122,936	95,395	36,433	18,217	41,107		314,288
317.1	Combustion Equip.	5,724	6,876	3,264	1,632	1,859	(1)	19,355
317.2	MHD Generator	5,280	-	155	78	1,103	(20%)	6,616
317.3	Magnet Subsystem	45,742	-	526	263	9,306	(20%)	55,837
317.4	Inverters	5,000	30,000	5,672	2,836	4,952	(2)	48,460
317.5	Oxidizer Preheat	61,190	8,903	12,696	6,348	16,787	(3)	105,924
317.6	Seed Subsystem	-	9,084	3,256	1,628	1,397		15,365
317.7	CE Gasifier	-	40,732	10,864	5,432	5,703		62,731
350.0	Transmission & SWYD	-	3,744	533	267	453		4,997
	SUBTOTAL DIRECTS	122,936	298,322	109,543	54,778	72,500		658,079
	Engineering/Other Costs							65,808
	O_2 System							
	TOTAL COSTS							723,887

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)

CASE II PARA. PT. 6

TABLE 5-19

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights	-	893	-	-	89	982
311.0	Struct. & Improvements	-	23,763	16,434	8,220	4,842	53,259
312.0	Boiler Plant	-	126,204	36,977	18,491	18,167	199,839
312.1	Coal Handling	-	10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling	-	3,780	945	473	520	5,718
312.4	Steam Generator	-	98,023	26,140	13,070	13,723	150,956
312.5	Effluent Control	-	9,185	3,350	1,675	1,421	15,631
312.6	Aux. Boiler System	-	225	25	13	26	289
312.7	Other Boiler Plant Sys.	-	4,245	1,911	956	711	7,823
314.0	Stm Turbine Gen.	-	34,663	7,563	3,781	4,600	50,607
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	131,688	95,795	36,452	18,228	42,894	325,057
317.1	Combustion Equip.	5,644	6,876	3,264	1,632	1,851 (1)	19,267
317.2	MHD Generator	5,247	-	155	78	1,103 (20%)	6,583
317.3	Magnet Subsystem	54,607	-	525	263	11,079 (20%)	66,474
317.4	Inverters	5,000	30,000	5,672	2,836	4,952 (2)	48,460
317.5	Oxidizer Preheat	61,190	9,103	12,716	6,359	16,809 (3)	106,177
317.6	Seed Subsystem	-	9,084	3,256	1,628	1,397	15,365
317.7	CE Gasifier	-	40,732	10,864	5,432	5,703	62,731
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	131,688	298,889	109,659	54,838	74,338	669,412
	Engineering/Other Costs						66,941
	[illegible]						
	TOTAL COSTS						736,353

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)

CASE II PARA. PT. 7

TABLE 5-20

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights	-	893	-	-	89	982
311.0	Struct. & Improvements	-	23,763	16,434	8,220	4,842	53,259
312.0	Boiler Plant	-	125,717	36,848	18,426	18,099	199,090
312.1	Coal Handling	-	10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling	-	3,780	945	473	520	5,718
312.4	Steam Generator	-	97,536	26,011	13,005	13,655	150,207
312.5	Effluent Control	-	9,185	3,350	1,675	1,421	15,631
312.6	Aux. Boiler System	-	225	25	13	26	289
312.7	Other Boiler Plant Sys.	-	4,245	1,911	956	711	7,823
314.0	Stm Turbine Gen.	-	33,234	7,251	3,626	4,411	48,522
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	120,067	95,695	36,441	18,221	40,567	310,991
317.1	Combustion Equip.	5,689	6,876	3,264	1,632	1,852 (1)	19,313
317.2	MHD Generator	5,163	-	155	78	1,103 (20%)	6,499
317.3	Magnet Subsystem	43,025	-	524	262	8,762 (20%)	52,573
317.4	Inverters	5,000	30,000	5,672	2,836	4,952 (2)	48,460
317.5	Oxidizer Preheat	61,190	9,003	12,706	6,353	16,798 (3)	106,050
317.6	Seed Subsystem	-	9,084	3,256	1,628	1,397	15,365
317.7	CE Gasifier	-	40,732	10,864	5,432	5,703	62,731
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	120,067	296,873	109,207	54,611	71,754	652,512
	Engineering/Other Costs						65,251
	O_2 System						
	TOTAL COSTS						717,763

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)

CASE II PARA. PT. 8

TABLE 5-21

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights	-	893	-	-	89	982
311.0	Struct. & Improvements	-	23,763	16,434	8,220	4,842	53,259
312.0	Boiler Plant	-	125,353	36,750	18,377	18,048	198,528
312.1	Coal Handling	-	10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling	-	3,780	945	473	520	5,718
312.4	Steam Generator	-	97,172	25,913	12,956	13,604	149,645
312.5	Effluent Control	-	9,185	3,350	1,675	1,421	15,631
312.6	Aux. Boiler System	-	225	25	13	26	289
312.7	Other Boiler Plant Sys.	-	4,245	1,911	956	711	7,823
314.0	Stm Turbine Gen	-	33,234	7,251	3,626	4,411	[illegible],522
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	114,257	95,591	35,722	17,862	39,139	302,571
317.1	Combustion Equip.	5,802	6,876	3,264	1,632	1,873 (1)	19,447
317.2	MHD Generator	5,332	-	155	78	1,103 (20%)	6,668
317.3	Magnet Subsystem	45,293	-	526	263	9,216 (20%)	55,298
317.4	Inverters	5,000	30,000	5,672	2,836	4,952 (2)	48,460
317.5	Oxidizer Preheat	52,830	8,753	11,931	5,966	14,872 (3)	94,352
317.6	Seed Subsystem	-	9,230	3,310	1,655	1,420	15,615
317.7	CE Gasifier	-	40,732	10,864	5,432	5,703	62,731
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	114,257	296,405	108,390	54,203	70,275	643,530
	Engineering/Other Costs						64,353
	O_2 System						
	TOTAL COSTS						707,883

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)

CASE II PARA. PT. 9

TABLE 5-22

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY		TOTAL
310.0	Land & Land Rights	-	893	-	-	89		982
311.0	Struct. & Improvements	-	23,763	16,434	8,220	4,842		53,259
312.0	Boiler Plant	-	125,814	36,873	18,439	18,113		199,239
312.1	Coal Handling	-	10,746	4,606	2,304	1,766		19,422
312.2	Slag & Ash Handling	-	3,780	945	473	520		5,718
312.4	Steam Generator	-	97,633	26,036	13,018	13,669		150,356
312.5	Effluent Control	-	9,185	3,350	1,675	1,421		15,631
312.6	Aux. Boiler System	-	225	25	13	26		289
312.7	Other Boiler Plant Sys.	-	4,245	1,911	956	711		7,823
314.0	Stm Turbine Gen.	-	34,563	7,541	3,770	4,587		50,461
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933		30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360		3,956
317.0	MHD Topping Cycle	120,089	95,705	37,191	18,595	41,246		312,352
317.1	Combustion Equip.	5,672	6,876	3,264	1,632	1,848	(1)	19,292
317.2	MHD Generator	5,170	-	155	78	1,080	(20%)	6,483
317.3	Magnet Subsystem	43,057	-	1,273	636	8,993	(20%)	53,959
317.4	Inverters	5,000	30,000	5,672	2,836	4,952	(2)	48,460
317.5	Oxidizer Preheat	61,190	9,013	12,707	6,353	16,799	(3)	106,062
317.6	Seed Subsystem	-	9,084	3,256	1,628	1,397		15,365
317.7	CE Gasifier	-	40,732	10,864	5,432	5,703		62,731
350.0	Transmission & SWYD	-	3,744	533	267	453		4,997
	SUBTOTAL DIRECTS	120,089	298,309	110,272	55,142	72,149		655,961
	Engineering/Other Costs							65,596
	O_2 System							
	TOTAL COSTS							721,557

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $) CASE II PARA. PT. 10

TABLE 5-23

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights	-	893	-	-	89	982
311.0	Struct. & Improvements	-	23,763	16,434	8,220	4,842	53,259
312.0	Boiler Plant	-	125,814	36,873	18,439	18,113	199,239
312.1	Coal Handling	-	10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling	-	3,780	945	473	520	5,718
312.4	Steam Generator	-	97,633	26,036	13,018	13,669	150,356
312.5	Effluent Control	-	9,185	3,350	1,675	1,421	15,631
312.6	Aux. Boiler System	-	225	25	13	26	289
312.7	Other Boiler Plant Sys.	-	4,245	1,911	956	711	7,823
314.0	Stm Turbine Gen.	-	35,877	7,828	3,914	4,762	52,381
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	121,159	95,455	36,418	18,209	40,737	311,978
317.1	Combustion Equip.	5,789	6,876	3,264	1,632	2,791 (1)	20,352
317.2	MHD Generator	5,170	-	155	78	1,080 (20%)	6,483
317.3	Magnet Subsystem	44,010	-	525	262	8,960 (20%)	53,757
317.4	Inverters	5,000	30,000	5,672	2,836	4,952 (3)	48,460
317.5	Oxidizer Preheat	61,190	8,763	12,682	6,341	16,770 (2)	105,746
317.6	Seed Subsystem	-	9,084	3,256	1,628	1,397	15,365
317.7	CE Gasifier	-	40,732	10,864	5,432	5,703	62,731
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	121,159	299,373	109,786	54,900	72,289	657,507
	Engineering/Other Costs						65,750
	O_2 System						
	TOTAL COSTS						723,257

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $) CASE II PARA. PT. II

TABLE 5-24

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY		TOTAL
310.0	Land & Land Rights	-	1,056	-	-	106		1,162
311.0	Struct. & Improvements	-	23,763	16,434	8,220	4,842		53,259
312.0	Boiler Plant	-	125,058	36,536	18,269	17,986		197,849
312.1	Coal Handling	-	9,886	4,238	2,119	1,624		17,867
312.2	Slag & Ash Handling	-	3,591	898	449	494		5,432
312.4	Steam Generator	-	97,926	26,114	13,057	13,710		150,807
312.5	Effluent Control	-	9,185	3,350	1,675	1,421		15,631
312.6	Aux. Boiler System	-	225	25	13	26		289
312.7	Other Boiler Plant Sys.	-	4,245	1,911	956	711		7,823
314.0	Stm Turbine Gen.	-	34,663	7,563	3,781	4,600		50,607
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933		30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360		3,956
317.0	MHD Topping Cycle	121,830	103,861	39,581	19,791	42,183		327,246
317.1	Combustion Equip.	5,704	6,876	3,264	1,632	1,855	(1)	19,331
317.2	MHD Generator	5,306	-	155	78	1,109	(20%)	6,648
317.3	Magnet Subsystem	44,630	-	525	262	9,083	(20%)	54,500
317.4	Inverters	5,000	30,000	5,672	2,836	4,952	(3)	48,460
317.5	Oxidizer Preheat	61,190	8,953	12,701	6,351	16,792	(2)	105,987
317.[illegible]	Seed Subsystem	-	17,300	6,400	3,200	2,690		29,55[illegible]
317.[illegible]	CE Gasifier	-	40,732	10,864	5,432	5,702		62,730
350.0	Transmission & SWYD	-	3,744	533	267	453		4,997
	SUBTOTAL DIRECTS	121,830	305,972	112,347	56,179	73,463		669,79[illegible]
	Engineering/Other Costs							66,979
	O_2 System							
	TOTAL COSTS							736,770

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)　　　　CASE III　　PARA. PT. 1

TABLE 5-25

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights	---	938	---	---	94	1,032
311.0	Struct. & Improvements	---	23,037	14,671	7,318	4,505	49,531
312.0	Boiler Plant	---	120,314	35,286	17,646	17,324	190,570
312.1	Coal Handling	---	10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling	---	5,021	1,255	628	691	7,595
312.4	Steam Generator	---	94,019	25,072	12,536	13,162	144,789
312.5	Effluent Control	---	6,162	2,474	1,237	987	10,860
312.6	Aux. Boiler System	---	225	25	13	26	289
312.7	Other Boiler Plant Sys.	---	4,141	1,854	928	692	7,615
314.0	Stm Turbine Gen.	---	31,912	7,225	3,613	4,235	46,985
315.0	Accessory Elec. Equip.	---	12,054	10,485	5,243	2,933	30,715
316.0	Misc Power Plant Equip.	---	1,773	1,215	608	360	3,956
317 0	MHD Topping Cycle	68,315	50,343	15,596	7,801	19,890	161,945
317.1	Combustion Equip.	14,285	---	3,615	1,808	2,059 (1)	21,767
317.2	MHD Generator	5,300	---	155	78	1,106 (20%)	6,639
317.3	Magnet Subsystem	44,030	---	491	246	8,953 (20%)	53,720
317.4	Inverters	4,700	29,000	5,651	2,826	4,785 (2)	46,962
317.5	Oxidizer System	---	8,098	889	445	943 (3)	10,375
317.6	Seed Subsystem	---	13,245	4,795	2,398	2,044	22,482
317.7	Other MHD Topping Equip.	---	---	---	---	---	---
350.0	Transmission & SWYD		3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	68,315	244,115	85,911	42,496	49,794	489,731
	Engineering/Other Costs						48,973
	Oxygen System						62,100
	TOTAL COSTS						600,804

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $) CASE III PARA. PT. 2

TABLE 5-26

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights	---	812	---	---	81	893
311.0	Struct. & Improvements	---	21,616	15,067	7,534	4,422	48,639
312.0	Boiler Plant		85,171	24,028	12,015	12,122	133,336
312.1	Coal Handling	---	8,784	2,260	1,130	1,217	13,391
312.2	Slag & Ash Handling	---	3,012	752	376	414	4,554
312.4	Steam Generator	---	65,269	17,405	8,703	9,138	100,515
312.5	Effluent Control	---	4,606	2,086	1,043	774	8,509
312.6	Aux. Boiler System	---	150	17	9	18	194
312.7	Other Boiler Plant Sys.	---	3,350	1,508	754	561	6,173
314.0	Stm Turbine Gen.	---	26,100	4,795	2,398	3,329	36,622
315.0	Accessory Elec. Equip.	---	10,060	2,520	1,260	1,384	15,224
316.0	Misc. Power Plant Equip.	---	3,330	1,500	750	558	6,138
317.0	MHD Topping Cycle	47,346	41,774	12,401	6,201	15,336	123,058
317.1	Combustion Equip.	5,297	5,247	2,755	1,378	1,554 (1)	16,231
317.2	MHD Generator	4,502	---	840	420	1,152 (20%)	6,914
317.3	Magnet Subsystem	34,347	---	448	224	7,004 (20%)	42,023
317.4	Inverters	3,200	20,000	4,095	2,047	3,333 (2)	32,675
317.5	Oxidizer System	---	6,845	753	377	798 (3)	8,773
317.6	Seed Subsystem	---	9,682	3,510	1,755	1,495	16,442
317.7	Other MHD Topping Equip.	---	---	---	---	---	----
350.0	Transmission & SWYD	---	2,763	490	245	350	3,848
	SUBTOTAL DIRECTS	47,346	191,627	60,801	30,403	37,582	367,758
	Engineering/Other Costs						36,776
	Oxygen System						41,400
	TOTAL COSTS						445,934

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heat 20% Balance 10%

(x 1000 $) CASE III PARA. PT. 3

TABLE 5-27

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights	-	938	-	-	94	1,032
311.0	Struct. & Improvements		21,948	15,396	7,683	4,505	49,531
312.0	Boiler Plant	-	121,991	35,750	17,877	17,563	193,181
312.1	Coal Handling	-	10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling	-	5,021	1,255	628	691	7,595
312.4	Steam Generator	-	94,438	25,180	12,590	13,221	145,429
312.5	Effluent Control	-	7,5[illegible]3	2,878	1,439	1,187	13,052
312.6	Aux. Boiler System	-	225	25	13	26	289
312.7	Other Boiler Plant Sys.	-	4,013	1,806	903	672	7,394
314.0	Stm Turbine Gen.	-	33,756	7,519	3,760	4,504	49,539
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	64,897	57,130	15,695	7,849	20,600	166,171
317.1	Combustion Equip.	7,693	7,506	3,732	1,867	2,193 (1)	22,991
317.2	MHD Generator	5,456	-	158	79	1,139 (20%)	6,832
317.3	Magnet Subsystem	47,348	-	494	247	9,618 (20%)	57,707
317.4	Inverters	4,400	28,000	5,630	2,815	4,635	45,480
317.5	Oxidizer System	-	8,505	933	467	991 (3)	10,896
317.6	Seed Subsystem	-	13,119	4,748	2,374	2,024	22,265
317.7	Other MHD Topping Equip.	-					
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	64,897	253,334	86,593	43,288	51,012	499,122
	Engineering/Other Costs						49,912
	Oxygen System						46,300
	TOTAL COSTS						595,334

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)

CASE III PARA. PT. 5

TABLE 5-28

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights	-	938	-	-	94	1,032
311.0	Struct. & Improvements	-	21,948	15,396	7,683	4,505	49,531
312.0	Boiler Plant	-	120,311	35,261	17,633	17,321	190,526
312.1	Coal Handling	-	10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling	-	5,021	1,255	628	691	7,595
312.4	Steam Generator	-	94,144	25,095	12,548	13,179	144,966
312.5	Effluent Control	-	6,162	2,474	1,237	987	10,860
312.6	Aux. Boiler System	-	225	25	13	26	289
312.7	Other Boiler Plant Sys.	-	4,013	1,806	903	672	7,394
314.0	Stm Turbine Gen.	-	32,620	7,309	3,655	4,358	47,942
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	57,699	57,360	15,634	7,819	19,155	157,667
317.1	Combustion Equip.	7,454	7,506	3,732	1,867	2,144 (1)	22,703
317.2	MHD Generator	5,359	-	158	79	1,119 (20%)	6,715
317.3	Magnet Subsystem	40,286	-	485	243	8,203 (20%)	49,217
317.4	Inverters	4,600	28,700	5,630	2,815	4,729 (2)	46,474
317.5	Oxidizer System	-	8,055	888	444	939 (3)	10,326
317.6	Seed Subsystem	-	13,099	4,741	2,371	2,021	22,232
317.7	Other MHD Topping Equip.	-					
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	57,699	250,748	85,833	42,908	49,179	486,366
	Engineering/Other Costs	-	-	-	-	-	48,636
	Oxygen System	-	-	-		-	62,100
	TOTAL COSTS						597,102

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

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(x 1000 $)

CASE III PARA. PT. 6

TABLE 5-29

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights	-	938	-	-	94	1,032
311.0	Struct. & Improvements	-	21,948	15,396	7,683	4,505	49,531
312.0	Boiler Plant	-	121,083	35,501	17,753	17,444	191,881
312.1	Coal Handling	-	10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling	-	5,021	1,255	628	691	7,595
312.4	Steam Generator	-	96,016	25,335	12,668	13,302	146,321
312.5	Effluent Control	-	6,162	2,474	1,237	987	10,860
312.6	Aux. Boiler System	-	225	25	13	26	289
312.7	Other Boiler Plant Sys.	-	4,013	1,806	903	672	7,394
314.0	Stm Turbine Gen.	-	32,384	7,289	2,645	4,332	47,650
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	62,530	58,620	15,753	7,880	20,232	164,655
317.1	Combustion Equip.	7,400	7,506	3,732	1,867	2,133	22,638
317.2	MHD Generator	5,333	-	155	78	1,113	6,679
317.3	Magnet Subsystem	44,897	-	491	246	9,127	54,761
317.4	Inverters	4,900	29,500	5,736	2,869	4,888	47,893
317.5	Oxidizer System	-	8,155	898	449	950	10,452
317.6	Seed Subsystem	-	13,099	4,741	2,371	2,021	22,232
317.7	Other MHD Topping Equip.	-	-	-	-	-	-
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	62,530	253,373	85,447	43,079	50,353	494,417
	Engineering/Other Costs						49,442
	O_2 System						62,100
	TOTAL COSTS						605,959

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)　　CASE III　　PARA. PT. 7

TABLE 5-30

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights	-	938	-	-	94	1,032
311.0	Struct. & Improvements	-	21,948	15,396	7,683	4,505	49,551
312.0	Boiler Plant	-	125,525	36,657	18,331	18,[illegible]2	198,565
312.1	Coal Handling	-	10,746	4,606	2,304	1,766	19,422
312.2	Slag & Ash Handling	-	5,021	1,255	628	691	7,595
312.4	Steam Generator	-	99,358	26,491	13,246	13,910	153,005
312.5	Effluent Control	-	6,162	2,474	1,237	989	10,860
312.6	Aux. Boiler System	-	225	25	13	26	289
312.7	Other Boiler Plant Sys.	-	4,013	1,806	903	672	7,394
314.0	Stm Turbine Gen.	-	31,443	7,089	3,545	4,208	46,285
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	61,754	58,790	15,777	7,892	20,135	164,348
317.1	Combustion Equip.	7,383	7,506	3,732	1,867	2,129	22,617
317.2	MHD Generator	5,208	-	155	78	1,108	6,649
317.3	Magnet Subsystem	44,063	-	481	241	8,957	53,742
317.4	Inverters	5,000	29,900	5,757	2,879	4,955	48,941
317.5	Oxidizer System	-	8,285	911	456	965	10,617
317.6	Seed Subsystem	-	13,099	4,741	2,371	2,021	22,232
317.7	Other MHD Topping Equip.	-	-	-	-	-	-
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	61,754	256,215	87,152	43,569	50,650	499,429
	Engineering/Other Costs						49,943
	O_2 System						62,100
	TOTAL COSTS						611,472

(1) Combuster 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

(x 1000 $)

CASE III PARA. PT. 8

TABLE 5-31

ACCT. #	DESCRIPTION	MAJOR COMPONENTS	BOP	DIRECTS	INDIRECTS	CONTINGENCY	TOTAL
310.0	Land & Land Rights	-	1,250	-	-	125	1,375
311.0	Struct. & Improvements	-	22,182	16,128	8,064	4,637	51,011
312.0	Boiler Plant	-	120,860	35,625	17,813	17,429	191,725
312.1	Coal Handling	-	9,700	4,500	2,250	1,645	18,095
312.2	Slag & Ash Handling	-	4,782	1,228	615	663	7,288
312.4	Steam Generator	-	95,978	25,590	12,795	13,436	147,799
312.5	Effluent Control	-	6,162	2,474	1,237	987	10,860
312.6	Aux. Boiler System	-	225	25	13	26	289
312.7	Other Boiler Plant Sys.	-	4,013	1,806	903	672	7,394
314.0	Stm Turbine Gen.	-	32,657	7,336	3,668	4,366	48,027
315.0	Accessory Elec. Equip.	-	12,054	10,485	5,243	2,933	30,715
316.0	Misc. Power Plant Equip.	-	1,773	1,215	608	360	3,956
317.0	MHD Topping Cycle	61,087	74,211	21,399	11,701	22,403	190,801
317.1	Combustion Equip.	7,248	7,506	3,709	1,855	2,112	22,430
317.2	MHD Generator	5,226	-	155	78	1,092	6,551
317.3	Magnet Subsystem	43,613	-	490	245	8,870	53,218
317.4	Inverters	5,000	29,800	5,757	3,879	4,945	49,381
317.5	Oxidizer System	-	8,645	948	474	1,007	11,074
317.6	Seed Subsystem	-	28,260	10,340	5,170	4,377	48,147
317.7	Other MHD Topping Equip.	-	-	-	-	-	-
350.0	Transmission & SWYD	-	3,744	533	267	453	4,997
	SUBTOTAL DIRECTS	61,087	268,731	92,719	47,364	52,706	522,607
	Engineering/Other Costs						52,261
	O_2 System						62,100
	TOTAL COSTS						636,968

(1) Combustor 20% Balance 10%
(2) Inverters 10% El. Consol. Circ. 20%
(3) High Temperature Air Heaters 20% Balance 10%

and equipment, expendable supplies, non-manual labor, construction services and testing contracts, and insurance and bonds are all examples of indirect costs.

"Contingency" represents the total contingency that has been applied to each line item. As Owner commited monies for purchased material and negotiated contracts proceeds towards 100% of total project cost, necessary contingency factors may be reduced in a manner to reflect lessened possibilities of unforeseeable circumstances occurring before project completion. As project engineering nears completion, estimating may deal with more precise information and can more accurately predict material quantities and respective project costs. Items incorporated into contingency management considerations include:

Design (but not major scope) changes

Market conditions

Labor productivity

State of project definition

Unreliable and noncurrent estimating data

Unpredictable field conditions

Instabilities of material and labor markets

Uncertainties in project timing

Errors and omissions

Weather

Short term strikes, walkouts, and other labor disputes

Other unforeseeable occurrences and conditions which would delay or otherwise increase material and/or installation costs.

The contingency factors used in this report reflect varying degrees of development and uncertainty and reflect an increasing familiarity and competence for estimating these MHD facilities. In the case of Balance of Plant (BOP) structures, improvements and well defined mechanical systems, a 10% factor is used. For the higher technology components, a factor of 20% is used.

"Total Cost" represents the total for all material, installation, indirect and contingency costs for each account.

Professional services include project management, licensing and preliminary engineering, detailed design and engineering, construction management, procurement services, architectural design, shop inspection, expediting, and start-up and testing. For this project, professional services have been subdivided into preliminary engineering (2% of total direct and indirect costs), detailed design and engineering (4% of same costs), and construction management (2% of same costs).

The "Other Costs" category includes such items as the Owner's field staff, legal fees and ad valorum taxes. A factor of 2% of the Direct and Indirect Sub-Total costs was assumed for this category. As directed by DoE, no costs for escalation or allowance for funds during construction (AFDC) have been included in these capital cost estimates. However, for developing costs of electricity, escalation and interest during construction were added using DoE guidelines.

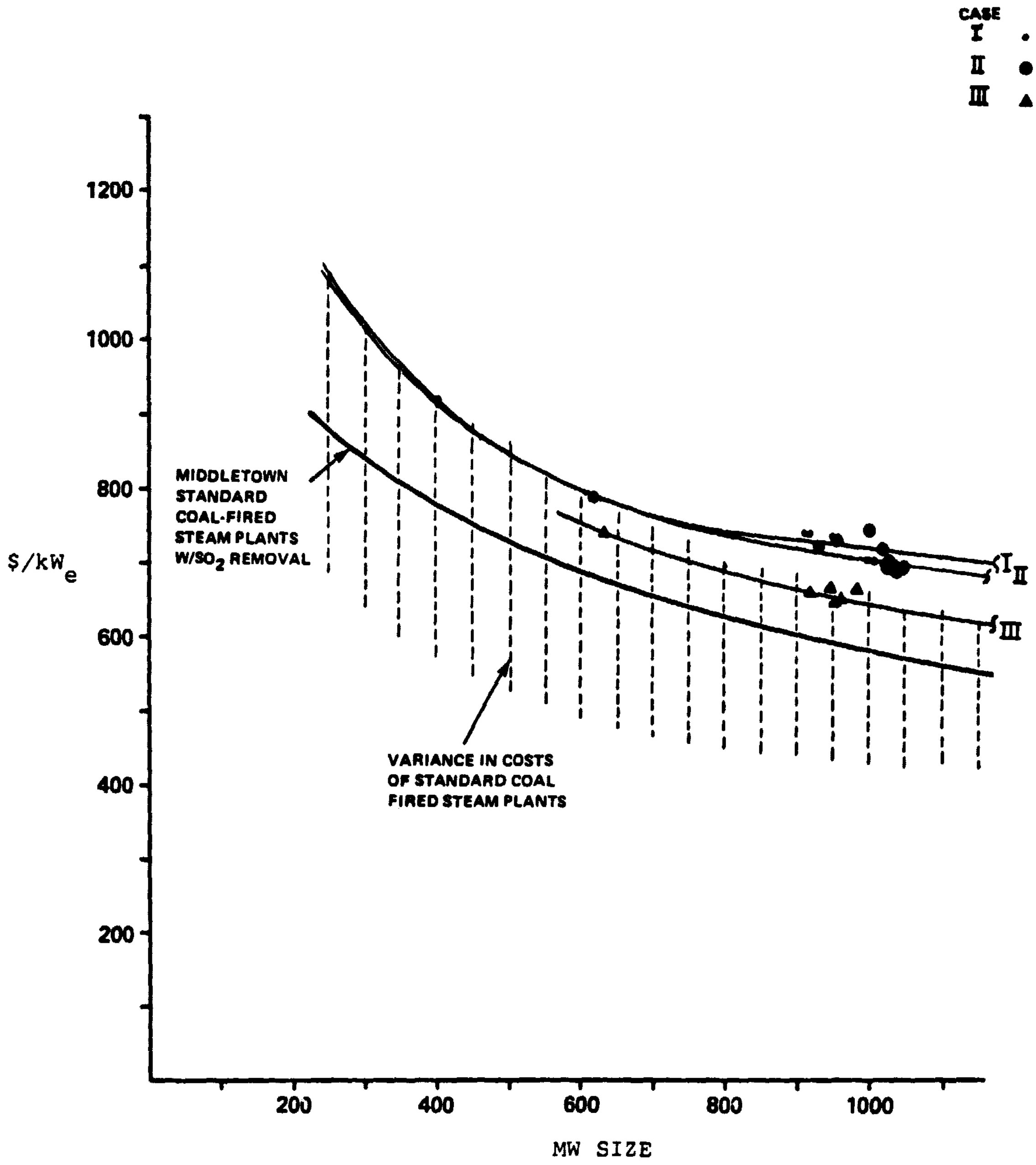
A Capital Cost Curve is presented, shown on Figure 5-0, which compares the cost per kilowatt of electricity vs the megawatt size of proposed unit. Each parametric point is plotted and curves developed for each of the three Reference Plant Cases. Another Capital Cost Curve is shown which indicates the average cost for a regular coal fired steam electric power plant located in Middletown, U.S.A. The dashed verticle lines represent the range in cost for standard coal-fired steam plants and options. In all cases, escalation and interest during construction are not included in the costs shown.

5.2 COST OF ELECTRICITY

The cost of electricity (COE) has been calculated for each parametric point. The economic parameters which are the basis for calculating the COE are shown on Table 5-32. Items 1 through 3, and 5 through 12 were specified by DoE. Item 4, the construction time, was developed by the contractor. Item 11, labor rates, were specified by DoE to be Middletown, U.S.A. labor rates. The range of labor rates given represents the high, low and average for the country. Item 13 is the levelizing factor for O&M and fuel. This was used for calculating the levelized COE. The specified escalation and interest during construction factors, which are the result of Item 6, 7 and 8 on Table 5-32, are shown on Table 5-33.

For Reference Plant 1, a summary of power output and capital costs is shown on Table 5-34. A summary for the COE is shown on Table 5-35. Tables 5-36 through Table 5-39 present similar data for Reference Plants 2 and 3. The cost summaries include interest and escalation during construction as calculated from the factors on Table 5-33. The COE has been calculated by three methods as indicated on Tables 5-35, 5-37 and 5-39, for Reference Plants 1, 2 and 3 respectively. Note that the COE shown on these tables corresponds to the average labor rate, $21/hr. Varying the labor rate will be discussed later. The levelized method of calculating COE is discussed first. The second two methods for calculating the COE were discussed in the NASA evaluation of ECAS, Phase 1 (See NASA TM X-71855).

AVCO / MAGNETOHYDRODYNAMIC ELECTRIC PLANT
CAPITAL COST CURVES
MHD PARAMETRIC STUDY



COSTS WITHOUT ESCALATION AND INTEREST
FOR FUNDS DURING CONSTRUCTION

Figure 5-0

MAIN

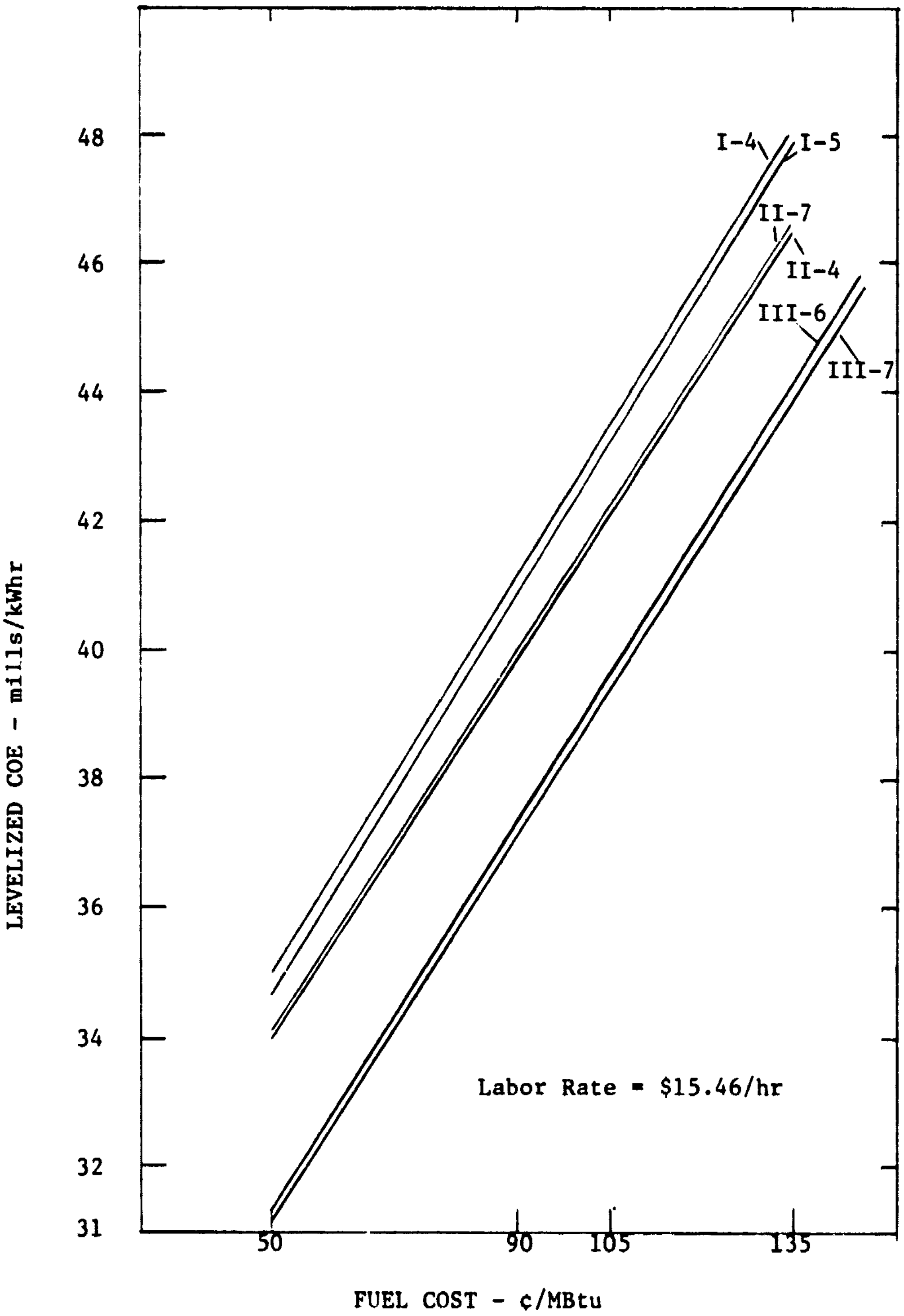


Figure 5-1 Levelized COE vs. Fuel Cost at Labor Rate = $15.46/hr

TABLE 5-32

ECONOMIC PARAMETERS

1.	PLANT LIFE	30 Years
2.	PLANT SITE	Middletown, USA
3.	CAPACITY FACTOR	65%
4.	CONSTRUCTION TIME	
	900 MW Plant	69 Months
	600 MW Plant	61 Months
	400 MW Plant	56 Months
5.	FIXED CHARGE RATE	18%
6.	ESCALATION DURING CONST.	6.5%
7.	INTEREST DURING CONST.	10%
8.	PERCENT EXPENDITURE VS TIME	Specified "s" Curve
9.	ECONOMIC BASE YEAR	Mid 1978
10.	FUEL COSTS (COAL)	
	High	135¢/MBtu
	Average	105¢/MBtu
	Low	50¢/MBtu
11.	LABOR RATES (1)	
	Base	$21.00 per hour
	Low	$15.46 per hour
	High	$25.35 per hour
12.	PLANT PERFORMANCE FOR COE	Full-Load Heat Rate
13.	FUEL AND O&M LEVELIZING FACTOR(2)	1.94

(1) Includes construction contractor's cost adders of 45%.

(2) G. R. Fox, Proc. Amer. Power Conf. 1978, pg 474.

TABLE 5-33 - ESCALATION AND INTEREST COST FACTORS

[Escalation + Interest = Total. Annual rates: escalation, 6.5 percent; interest, 10 percent.]

Time from start of design to powerplant completion, yr	Escalation	Interest on obligated funds	Total
	Cost factor		
0	1.000	1.000	1.000
.5	1.018	1.022	1.040
1.0	1.037	1.044	1.081
1.5	1.056	1.069	1.125
2.0	1.076	1.094	1.170
2.5	1.096	1.122	1.218
3.0	1.116	1.151	1.267
3.5	1.137	1.182	1.319
4.0	1.158	1.214	1.372
4.5	1.179	1.249	1.428
5.0	1.202	1.285	1.487
5.5	1.224	1.324	1.548
6.0	1.247	1.365	1.612
6.5	1.270	1.409	1.679
7.0	1.294	1.454	1.748
7.5	1.319	1.503	1.822
8.0	1.344	1.554	1.898
8.5	1.369	1.609	1.978
9.0	1.395	1.666	2.061
9.5	1.422	1.726	2.148
10.0	1.449	1.790	2.239

TABLE 5-34

REFERENCE CASE I

POWER OUTPUT AND CAPITAL COST SUMMARY

PARAMETRIC POINT		1	2	3	4	5	6	7	8	9	10[2]	11[2]	12
POWER OUTPUT SUMMARY	**UNITS**												
MHD Generator	(MW)	495	195	318	556	560	480	495	500	480	487	495	519
Steam Turbine Generator	(MW)	498.6	236.2	339.2	503	513	493	484	491	511	500.7	495	508
Cycle Air Compressor	(MW)	113	44.8	73.8	129	127	109	113	119	106	114.3	113	120
Oxygen Plant Compressor	(MW)	---	---	---	---	16	---	---	---	---	---	---	---
Auxiliary and Losses[1]	(MW)	57.5	26.6	38.4	58.2	60.7	57.3	56.6	57.3	57.6	57.4	57.5	71.8
Net Plant Power	(MW)	936.1	404.6	618.8	1000.8	1012.3	915.7	922.4	933.7	933.4	930.3	932.5	955.2
COST SUMMARY ($ × 10^{-3})[3]													
Direct Costs		494,940	272,623	362,760	514,186	496,338	494,677	499,336	493,531	496,831	---	---	512,895
Indirect Costs		53,189	29,785	35,960	54,244	53,187	53,269	53,342	53,267	53,285	---	---	56,140
Contingency Costs		70,689	38,497	49,117	75,537	70,526	70,621	70,754	70,373	70,977	---	---	72,792
Professional Costs		49,506	27,272	35,828	51,518	49,604	49,486	49,874	49,374	49,687	---	---	51,346
Owners Costs		12,376	6,818	8,957	12,879	12,401	12,371	12,469	12,343	12,422	---	---	12,837
Oxygen System		---	---	---	---	34,000	---	---	---	---	---	---	---
Subtotal		680,700	374,395	492,642	708,364	716,056	680,424	685,775	678,888	683,202	---	---	706,010
Escalation Cost		160,645	69,749	101,484	167,174	168,989	160,580	161,843	160,218	161,236	---	---	166,618
Interest During Const.		234,542	97,874	144,344	244,386	247,039	234,746	236,592	234,216	235,705	---	---	243,573
TOTAL CAPITALIZATION		1,076,187	542,618	738,470	1,119,924	1,132,034	1,075,750	1,084,210	1,073,322	1,080,143	---	---	1,116,201

1. Includes 1% inverter losses and .5% transformer losses.
2. Performance only.
3. Capital costs are in mid-1978 dollars.

TABLE 5-35
REFERENCE CASE I
COST OF ELECTRICITY

PARAMETRIC POINT	1	2	3	4	5	6	7	8	9	12
LEVELIZED COE (mills/kWhr) Labor = $21/hr										
COE - Capital	25.30	31.58	27.38	24.62	24.60	25.84	25.86	25.29	25.46	25.57
COE - O&M	4.52	6.36	5.24	4.60	4.35	4.58	4.56	4.54	4.52	5.61
COE - Fuel @ 50¢/10^6 Btu	7.78	7.99	7.84	7.64	7.72	7.86	7.74	7.80	7.82	7.78
COE - TOTAL	37.60	45.93	40.46	36.86	36.67	38.28	38.16	37.63	37.80	38.96
COE - Fuel @ 105¢/10^6 Btu	16.33	16.78	16.47	16.06	16.20	16.51	16.26	16.35	16.39	16.35
COE - TOTAL	46.15	54.72	49.[illegible]	45.28	45.15	46.93	46.68	46.18	46.37	47.53
COE - Fuel @ 135¢/10^6 Btu	21.01	21.57	21.18	20.66	20.84	21.22	20.89	21.03	21.09	21.03
COE - TOTAL	50.83	59.51	53.80	48.88	48.79	51.64	51.31	50.86	51.07	52.21

1) Parametric Points 10 and 11 were for performance only

TABLE 5-35 (cont'd)
REFERENCE CASE I
COST OF ELECTRICITY

PARAMETRIC POINT [2]	1	2	3	4	5	6	7	8	9	12
FIRST YEAR OF COMMERCIAL OPERATION COE (mills/kWhr) [1]										
Labor = \$21/hr										
COE - Capital	25.30	31.58	27.38	24.62	24.60	25.84	25.86	25.29	25.46	25.57
COE - O&M	2.33	3.28	2.7	2.37	2.24	2.36	2.35	2.34	2.33	2.89
COE - Fuel @ 50¢/10^6 Btu	4.01	4.12	4.04	3.94	3.98	4.05	3.99	4.02	4.03	4.01
COE - TOTAL	31.64	38.98	34.12	30.93	30.82	32.25	32.20	31.65	31.82	32.47
COE - Fuel @ 105¢/10^6 Btu	8.42	8.65	8.49	8.28	8.35	8.51	8.38	8.43	8.45	8.43
COE - TOTAL	36.05	43.5	38.57	35.27	35.19	36.71	36.59	36.06	36.24	36.89
COE - Fuel @ 135¢/10^6 Btu	10.83	11.12	10.92	10.65	10.74	10.94	10.77	10.84	10.87	10.84
COE - TOTAL	38.46	45.98	41.00	37.64	37.58	39.14	38.98	38.47	38.66	39.30
AVERAGE LIFE CYCLE COE (mills/kWhr) [1]										
Labor = \$21/hr										
COE - Capital	11.74	14.65	12.70	11.42	11.41	11.99	12.00	11.73	11.81	11.86
COE - O&M	2.33	3.28	2.7	2.37	2.24	2.36	2.35	2.34	2.33	2.89
COE - Fuel @ 105¢/10^6 Btu	8.42	8.65	8.49	8.28	8.35	8.51	8.38	8.43	8.45	8.43
COE - TOTAL	22.49	26.58	23.89	22.07	22.00	22.86	22.73	22.50	22.59	23.18

1. COE is in mid-1978 dollars.
2. Para. Pts. 10 and 11 were for performance only.

TABLE 5-36

REFERENCE CASE II

POWER OUTPUT AND CAPITAL COST SUMMARY

PARAMETRIC POINT		1	2	3	4	5	6	7	8	9	10	11
POWER OUTPUT SUMMARY	UNITS											
MHD Generator	(MW)	588	558	558	536	565	595	571	508	559	551	566
Steam Turbine Generator	(MW)	534.3	507.3	524.9	541	531.4	506	523	507.8	527.8	544.5	557.6
Cycle Air Compressor	(MW)	130	130	130	130	130	142	135	120	137	122	134
Auxiliary and Losses 1)	(MW)	58.4	57.4	58	58.4	58.2	58.2	58.2	56.6	58	58	68.1
Net Plant Power	(MW)	1,033.9	1,007.9	1,024.9	1,040.6	1,038.2	1,042.8	1,035.8	959.2	1,028.8	1,037.5	1,055.5
COST SUMMARY ($ x 10^{-3}) 2)												
Direct Costs		532,325	553,498	535,612	528,233	530,801	540,236	526,147	519,052	528,670	530,318	540,149
Indirect Costs		55,098	58,213	55,364	54,647	54,778	54,838	54,611	54,203	55,142	54,900	56,179
Contingency Costs		72,531	75,992	72,908	72,100	72,500	74,338	71,754	70,275	72,149	72,289	73,463
Professional Costs		52,796	55,016	53,110	52,398	52,646	53,553	52,201	51,482	52,477	52,600	53,583
Owners Costs		13,199	13,754	13,278	13,100	13,162	13,388	13,050	12,871	13,119	13,150	13,396
Subtotal		725,949	756,473	730,272	720,478	723,887	736,353	717,763	707,883	721,557	723,257	736,770
Esclation Cost		171,324	178,528	172,344	170,033	170,837	173,850	169,392	167,060	170,287	170,712	173,878
Interest During Const.		250,452	260,983	251,944	248,565	249,741	254,145	247,628	244,220	248,937	249,558	254,186
TOTAL CAPITALIZATION		1,147,725	1,195,984	1,154,560	1,139,076	1,144,465	1,164,648	1,134,783	1,119,163	1,140,781	1,143,627	1,164,834

1. Includes 1% inverter losses and .5% transformer losses.
2. Capital Costs are in mid-1978 dollars.

TABLE 5-37

REFERENCE CASE II

COST OF ELECTRICITY

PARAMETRIC POINT	1	2	3	4	5	6	7	8	9	11	12
LEVELIZED COE (mills/kWhr) Labor = $21/hr											
COE - Capital	24.42	26.11	24.78	24.08	24.25	24.57	24.10	25.67	24.39	24.25	24.28
COE - O&M	4.38	4.44	4.40	4.37	4.38	4.37	4.38	4.31	4.38	4.38	5.08
COE - Fuel @ 55¢/10^6 Btu	7.39	7.35	7.37	7.33	7.35	7.31	7.35	7.47	7.41	7.41	7.33
COE - TOTAL	36.19	37.90	36.55	35.78	35.98	36.25	35.83	37.45	36.18	36.04	36.69
COE - Fuel @ 105¢/10^6 Btu	15.52	15.44	15.50	15.42	15.46	15.38	15.44	15.68	15.56	15.56	15.42
COE - TOTAL	44.32	45.99	44.68	43.87	44.09	44.32	43.92	45.66	44.33	44.19	44.78
COE - Fuel @ 135¢/10^6 Btu	19.96	19.85	19.92	19.83	19.87	19.77	19.87	20.16	20.00	20.00	19.83
COE - TOTAL	48.76	50.40	49.10	48.28	48.50	48.71	48.35	50.14	48.77	48.63	49.19

TABLE 5-37 (cont'd)
REFERNECE CASE II
COST OF ELECTRICITY

PARAMETRIC POINT	1	2	3	4	5	6	7	8	9	10	11
FIRST YEAR COMMERCIAL OPERATION COE (mills/kWhr)[1]											
Labor = $21/hr											
COE - Capital	24.42	26.11	24.78	24.08	24.25	24.57	24.10	25.67	24.39	24.25	24.28
COE - O&M	2.26	2.29	2.27	2.25	2.26	2.25	2.26	2.22	2.26	2.26	2.62
COE - Fuel @ 50¢/10^6 Btu	3.81	3.79	3.80	3.78	3.79	3.77	3.79	3.85	3.82	3.82	3.78
COE - TOTAL	30.49	32.19	30.85	30.11	30.30	30.59	30.15	31.74	30.47	30.33	30.68
COE - Fuel @ 105¢/10^6 Btu	8.00	7.96	7.99	7.95	7.97	7.93	7.96	8.08	8.02	8.02	7.95
COE - TOTAL	34.68	36.36	35.04	34.28	34.48	34.75	34.32	35.97	34.67	34.53	34.85
COE - Fuel @ 135¢/10^6 Btu	10.29	10.23	10.27	10.22	10.24	10.19	10.24	10.39	10.31	10.31	10.22
COE - TOTAL	36.91	38.65	37.32	36.55	36.75	37.01	36.60	38.28	36.96	36.82	37.12
AVERAGE LIFE CYCLE COE (mills/kWhr)[1]											
Labor = $21/hr											
COE - Capital	11.33	12.12	11.50	11.17	11.25	11.40	11.18	11.91	11.32	11.25	11.27
COE - O&M	2.26	2.29	2.27	2.25	2.26	2.25	2.26	2.22	2.26	2.26	2.62
COE - Fuel @ 105¢/10^6 Btu	8.00	7.96	7.99	7.95	7.97	7.93	7.96	8.08	8.02	8.02	7.95
COE - TOTAL	21.59	22.38	21.76	21.37	21.48	21.58	21.40	22.21	21.60	21.53	21.84

1. COE is in mid-1978 dollars.

TABLE 5-38

REFERENCE CASE III

POWER OUTPUT AND CAPITAL COST SUMMARY

PARAMETRIC POINT		1	2	3	4 [2)]	5	6	7	8	9 [2)]
POWER OUTPUT SUMMARY	UNITS									
MHD Generator	(MW)	523	338	485	533	510	543	559	554	533
Steam Turbine Generator	(MW)	460.8	311.1	493.2	449.3	462	462.7	454.8	498.2	469.1
Cycle Air Compressor	(MW)	114	73	111	113	111	118	120	123	120
Oxygen Plant Compressor	(MW)	61.5	41	45.5	73.5	67.5	51.5	61.5	62.5	45.5
Auxiliary and Losses [1)]	(MW)	53.1	35.7	53.3	52.8	52.8	53.5	53.3	73.7	53.7
Net Plant Power	(MW)	930.7	614.4	924.9	929.5	919.2	952.2	960.5	978.5	948.4
COST SUMMARY ($ x 10^{-3}) [3)]										
Direct Costs		397,440	302,970	404,824	-	394,280	400,985	405,210	422,537	
Indirect Costs		42,496	31,059	43,284	-	42,908	43,079	43,569	47,364	
Contingency Costs		49,794	37,967	51,012	-	49,179	50,353	50,650	52,706	
Professional Costs		39,180	29,760	39,930	-	38,909	39,553	39,954	45,989	
Owners Costs		9,795	7,440	9,980	-	9,727	9,888	9,989	11,497	
Oxygen System		62,100	41,400	46,300	-	62,100	62,100	62,100	62,100	
Subtotal		600,805	445,934	595,334	-	597,103	605,959	611,472	636,968	
Escalation Cost		141,790	91,862	140,498	-	140,916	143,006	144,307	150,325	
Interest During Const.		207,278	130,658	205,390	-	206,001	209,055	210,958	219,755	
TOTAL CAPITALIZATION		949,873	668,274	941,222	-	944,020	958,020	966,737	1,007,048	

1. Includes 1% inverter losses and 0.5% transformer losses.
2. Performance only.
3. Capital costs are in mid-1978 dollars.

TABLE 5-39
REFERENCE CASE III
COST OF ELECTRICITY

PARAMETRIC POINT	1	2	3	4[1]	5	6	7	8	9[1]
LEVELIZED COE Labor = $21/hr									
COE - Capital	22.46	24.92	22.31		22.53	22.07	22.07	22.57	
COE - O&M	3.41	4.13	3.43		3.43	3.36	3.34	4.97	
COE - Fuel @ 50¢/10^6Btu	7.64	7.70	7.68		7.74	7.47	7.39	7.60	
COE - TOTAL	33.51	36.75	33.42		33.70	32.90	32.80	35.14	
COE - Fuel @ 105¢/10^6 Btu	16.04	16.16	16.14		16.24	15.68	15.54	15.95	
COE - TOTAL	41.91	45.21	41.88		42.20	41.11	40.95	43.49	
COE - Fuel @ 135¢/10^6 Btu	20.62	20.80	20.76		20.87	20.16	19.98	20.51	
COE - TOTAL	46.49	49.85	46.50		46.83	45.59	45.39	48.05	

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(1) Performance Only

TABLE 5-39 (Cont'd)
REFERENCE CASE III
COST OF ELECTRICITY

PARAMETRIC POINT	1	2	3	4[2]	5	6	7	8	9[2]
FIRST YEAR COMMERCIAL OPERATION COE (mills/kWhr)[1]									
Labor = $21/hr									
COE - Capital	22.46	24.92	22.31		22.53	22.07	22.07	22.57	
COE - O&M	1.76	2.13	1.77		1.77	1.73	1.72	2.56	
COE - Fuel @ 50¢/10^6 Btu	3.94	3.97	3.96		3.99	3.85	3.81	3.92	
COE - TOTAL	28.16	31.02	28.04		28.29	27.65	27.60	29.05	
COE - Fuel @ 105¢/10^6 Btu	8.27	8.33	8.32		8.37	8.08	8.01	8.22	
COE - TOTAL	32.49	35.38	32.40		32.67	31.88	31.80	33.35	
COE - Fuel @ 135¢/10^6 Btu	10.63	10.72	10.70		10.76	10.39	10.30	10.57	
COE - TOTAL	34.85	37.77	34.78		35.06	34.19	34.09	35.70	
AVERAGE LIFE CYCLE COE (mills/kWhr)[1]									
Labor = $21/hr									
COE - Capital	10.42	11.57	10.36		10.45	10.24	10.25	10.48	
COE - O&M	1.76	2.13	1.77		1.77	1.73	1.72	2.56	
COE - Fuel @ 105¢/10^6 Btu	8.27	8.33	8.32		8.37	8.08	8.01	8.22	
COE - TOTAL	20.45	22.03	20.45		20.59	20.05	19.98	21.26	

1. COE is in mid-1978 dollars
2. Performance only

In all cases the tables indicate the COE due to capital, O&M and fuel. The fuel portion of the COE is based on full load heat rates and a 65% capacity factor. The O&M portion of COE for all methods is based on the following items; station personnel, lime and seed makeup for the seed regeneration process, channel overhaul every 5000 hr, one HTAH matrix renewal per year, costs for on-site waste disposal, and fuel oil requirements.

The first method presented on the COE summary tables uses levelized costs. In this method, capital, fuel and O&M costs, in mid-1978 dollars, are levelized. The COE due to capital costs is calculated by applying the fixed charge rate of 18% to the total capitalization shown on the cost summary tables. Since interest and escalation during construction are included in the total capitalization, the fixed charge calculated must be deflated to mid-1978 dollars from end of construction dollars. These costs are deflated at 6.5% per year. Fuel and O&M costs are calculated in mid-1978 dollars and levelized by the factor shown in Item 13 on Table 5-32. The method described above for calculating the COE due to capital costs is as follows:

$$\text{COE - Capital} = \frac{\text{FCR (Total Capitalization in \$)}}{(1+e)^m \text{ (Net Plant Power in MW)}} \times \frac{1}{\text{CF} \times 8760 \frac{\text{hr}}{\text{yr}}}$$

where FCR = Fixed charge rate - 18%
e = Escalation rate - 6.5%/yr
m = Construction Period - yrs.
CF = Capacity Factor - 0.65

The second method presented on the COE summary tables uses the "First Year of Commercial Operation COE" approach. The COE due to capital costs is the result of applying the fixed charge rate of 18% to the total capitalization shown on the cost summary tables. Since interest and escalation during construction are included in the total capitalization, the fixed charge calculated must be deflated to mid-1978 dollars from end of construction dollars. As was done in the NASA review of ECAS, all costs are deflated at the general escalation rate of 6.5% per year. This results in the same COE due to capital costs as discussed above for the levelized cost method. Fuel and O&M costs are also escalated to the first year of commercial operation and then converted to mid-1978 dollars. Since each is deflated at the escalation rate, the actual values remain unchanged. These fuel and O&M costs are less than the corresponding levelized costs by a factor of 1.94, the levelizing factor.

The third method presented on the COE summary tables gives the "Average Life Cycle COE." The COE due to capital is found as follows: Determine the annual fixed charges in mid-1978 dollars by applying the fixed charge rate to the total capitalization and deflating this to mid-1978 dollars. Then calculate the average annual fixed charge over the life of the plant by deflating the fixed charge in mid-1978 dollars for each year of plant life, adding the deflated dollars for each year and dividing by 30 years, the plant life. This is equivalent to the following expression:

$$\text{COE - Capital} = \frac{\text{FCR [Total Capitalization - \$]}}{(1+e)^m\ (30)} \times \left[1 + \frac{1}{1.065} + \frac{1}{1.065^2} + .. + \frac{1}{1.065^{29}}\right] (\text{Net Plant Power - MW}) \times \frac{1}{\left(\text{CF } 8760\ \frac{\text{hr}}{\text{yr}}\right)}$$

where:

FCR = Fixed charge rate - 18%

e = Escalation rate - 6.5%/yr

m = Construction Period - yrs.

CF = Capacity Factor - 0.65

Fuel and O&M are also escalated to each year of plant operation, then each year is deflated to mid-1978 dollars, added and divided by 30 years, the plant life. Again, since costs are deflated at the general escalation rate of 6.5%, the actual values remain unchanged. This results in values of COE due to fuel and O&M being equal to those calculated in the "First Year of Commercial Operation COE" method.

The First Year of Commercial Operation COE" tends to make the capital cost portion of COE more significant than the fuel or O&M portions. The other two methods essentially consider the fact that, in present year dollars, the fuel and O&M escalate over the plant life while the capital portion stays constant and is therefore less significant than in the First Year of Commercial Operation COE method. The COE calculated by all methods is presented on Tables 5-34, 5-37 and 5-39 for Reference Cases I, II, and III respectively. As can be seen for the average labor rate of $21/hr, the parametric point with the lowest COE is the same for all methods. That is, for References Cases I, II, and III, parametric points 5, 4, and 7, respectively, have the lowest COE for all methods discussed above.

As specified by the RFP, the effect of varying the fuel cost and labor rate was investigated. Intuitively, one would expect that these changes would not affect the relative differences in the COE of the parametric points. This is due to the fact that the plants are of the same type and therefore equally capital intensive, so that a change in labor rates (thus capital costs) would have an equal effect on all parametric points. Also, the efficiencies of all parametric points are very close. Thus, a change in fuel cost would also affect all parametric points equally. To confirm the above, Figures 5-1, 5-2, and 5-3 show the levelized COE vs fuel cost for labor rates of $15.46/hr, $21/hr and $25.35/hr, respectively. This comparison was made for the two parametric points from each Reference Case with the lowest COE. As can be seen, varying the fuel cost with different labor rates does not change the difference in the COE for these parametric points.

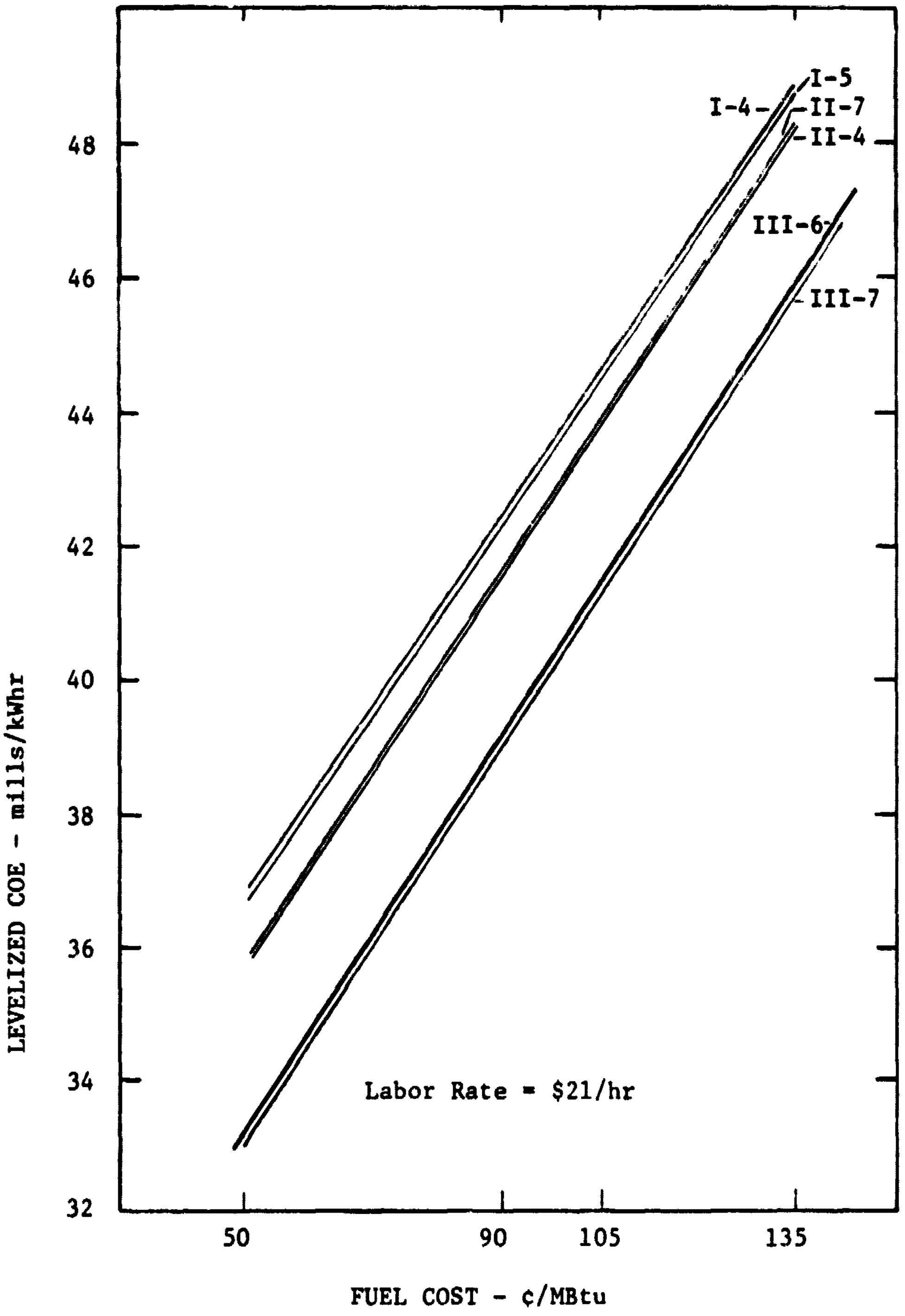

Figure 5-2 Levelized COE vs. Fuel Cost at Labor Rate = $21/hr

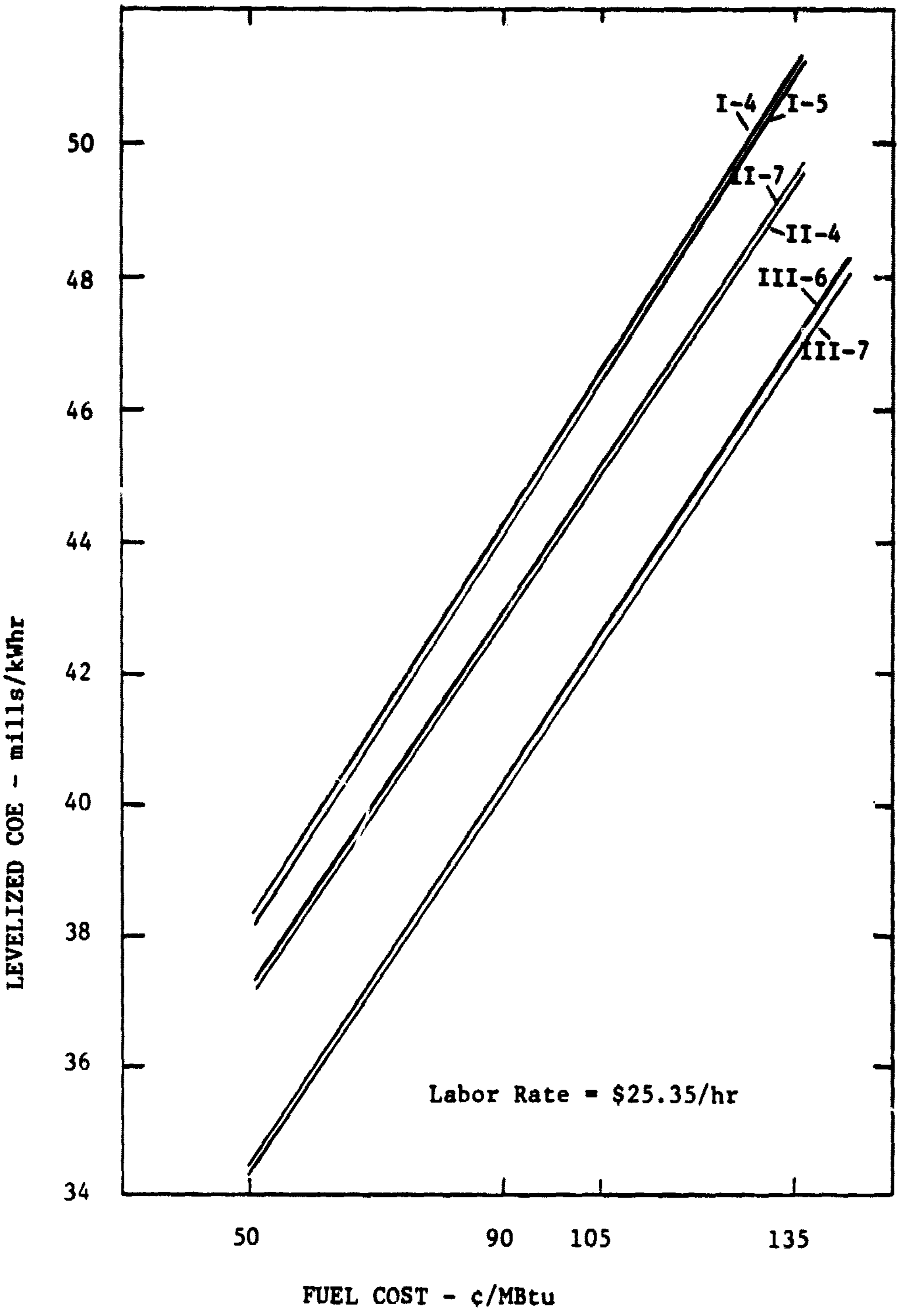

Figure 5-3 Levelized COE vs. Fuel Cost at Labor Rate = $25.35/hr

Another item which should be discussed is a comparison of the COE for the MHD-Steam plants considered in this study vs the COE for standard coal-fired plants. [Figure 5-4 shows the levelized COE vs Plant Size for coal-fired plants considered in Figure 5-0.] The COE for the parametric points corresponds to the mid-range labor rate of \$21/hr and therefore should be compared to the solid curve which represents the mid-range COE for coal-fired plants. As can be seen, all points for Reference Case I are equal to or greater than the COE for coal-fired plants. The COE for all other MHD plants is less than the mid-range COE for coal-fired plants.

The RFP also requested that a method for converting all costs from 1978 to 1976 dollars be presented. Using the cost summary sheets on Tables 5-4 through 5-31, the total capital cost of each parametric point can be converted to 1976 dollars by the following:

$$\text{Total Cost (1976 \$)} = \left[\frac{D + I}{(1 + e_L)^2} + \frac{MC + BOP}{(1 + e_M)^2}\right]$$

$$\left[1 + \frac{C}{MC + BOP + D + I}\right]^{1.1}$$

where from cost summary sheets:

MC = Major Component Cost

BOP = BOP Cost

D = Direct Cost

I = Indirect Cost

C = Contingency Cost

e_L = Labor Escalation Rate, 6%/yr

e_M = Material Escalation Rate, 7%/yr

The COE due to capital can then be calculated as dicussed in Section 5.2. The COE of O&M can be converted to 1976 dollars by deflating the values given on Table 5-35, 5-37 and 5-39 by the general escalation rate, 6.5%/yr. Fuel Costs for the last five months of 1976 supplied by NASA are: High = 125.8¢/MBtu, Average = 86.7¢/MBtu and Low = 36.8¢/MBtu. The 1978 fuel costs specified by NASA and used in this study represent the following yearly escalation over the above 1976 values; High = 3.6/yr, Average = 10%/yr and Low = 16.6%/yr. Therefore, these rates should be used to deflate the COE due to fuel given in this study.

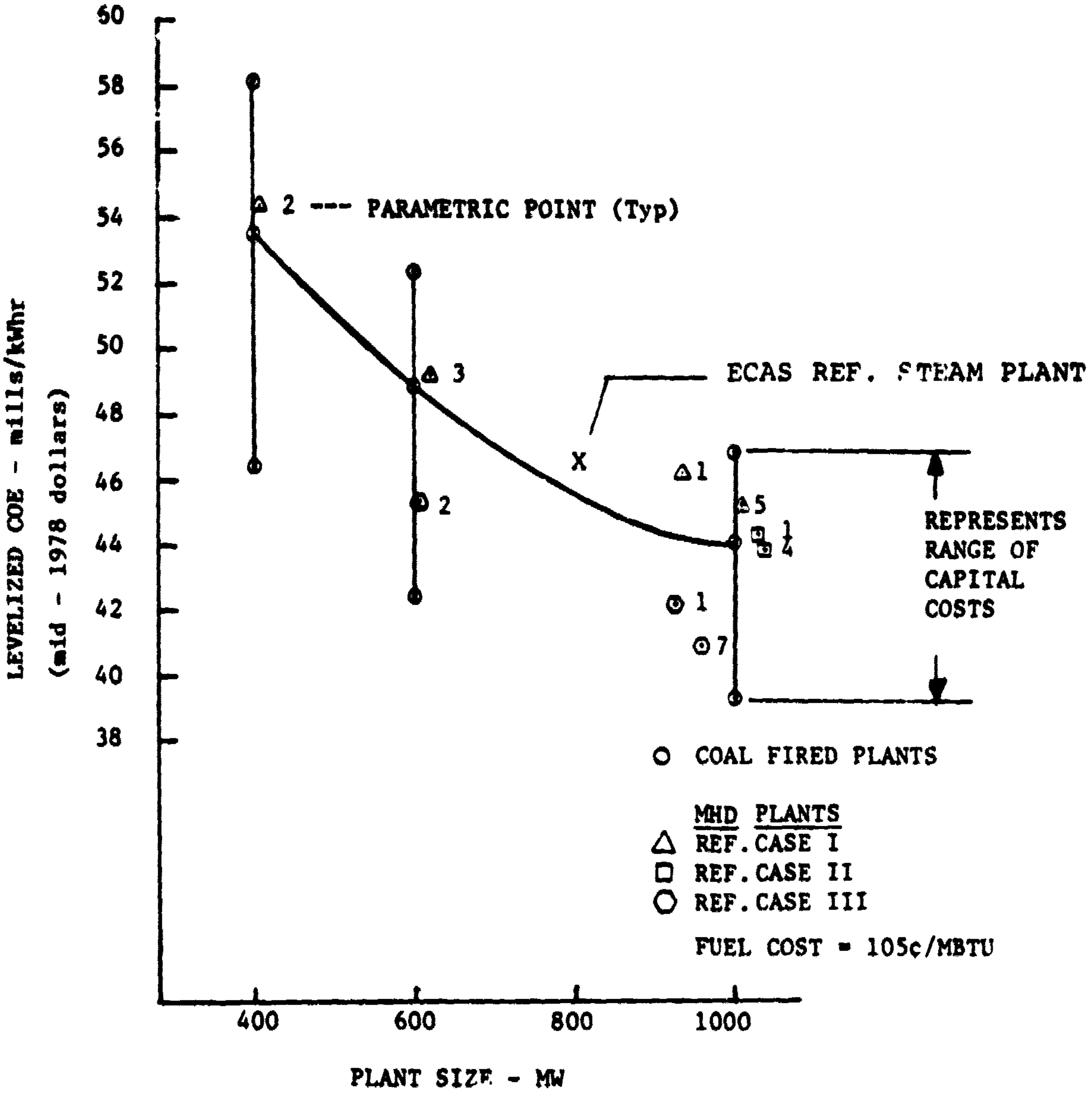

Figure 5-4 Levelized COE vs. Plant Size

For ease of comparison bar charts of plant capital costs, exluding escalation and interest, and of costs of electricity based on first year of commercial operation are shown in Figures 5-5 through 5-10 for the various parametric cost design cases considered for each of three different Reference Plants.

REFERENCE PLANT 1 – CAPITAL COST (EXCL. ESC. + INTEREST)

PLANT PARAMETER		BASE VALUE	PAR. VALUE
PLANT SIZE	MW	900	400 600
PREHEAT TEMP	°F	2700	3000
AIR PREHEAT FOR AIR HEATER FIRING	°F	1100	1300
OXIDIZER		AIR	AIR + O_2
CHANNEL LOAD PAR.		0.80	.77 .83
DIFF. RECOVERY FACTOR		0.6	.5
COAL TYPE		MONT. SUB. BIT.	ILL. # 6
MOISTURE DRIED COAL	%	5	10
SEED REGEN. PROCESS		FORMATE	CARB. RED
BASE DESIGN CASE			BASE

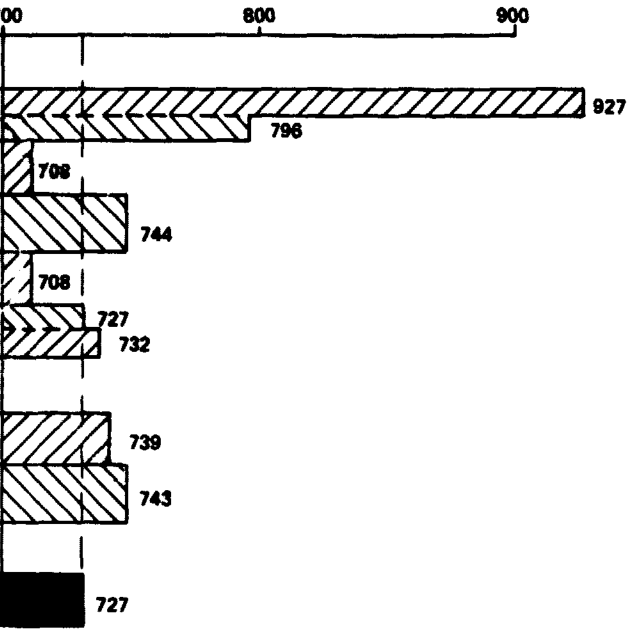

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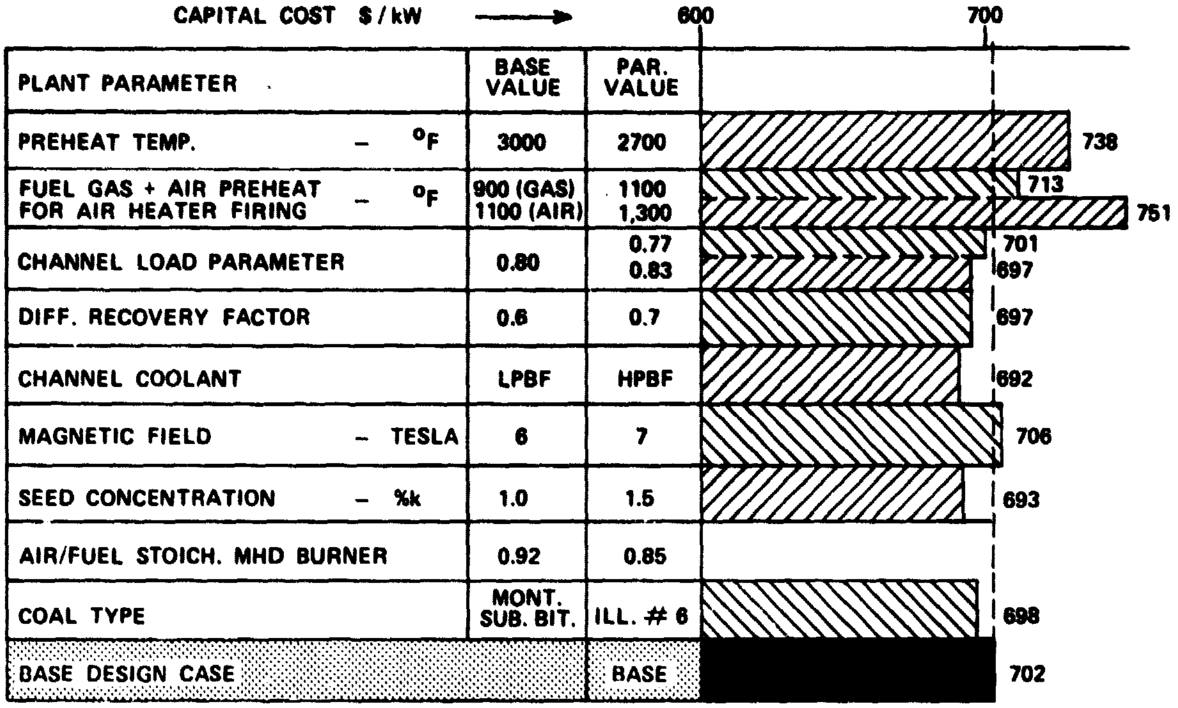
Figure 5-5 Plant Capital Costs of Reference Plant 1

REFERENCE PLANT 2 – CAPITAL COST (EXCL. ESC. + INTEREST)



PLANT PARAMETER		BASE VALUE	PAR. VALUE	CAPITAL COST $/kW
PREHEAT TEMP.	– °F	3000	2700	738
FUEL GAS + AIR PREHEAT FOR AIR HEATER FIRING	– °F	900 (GAS) 1100 (AIR)	1100 1,300	713 751
CHANNEL LOAD PARAMETER		0.80	0.77 0.83	701 697
DIFF. RECOVERY FACTOR		0.6	0.7	697
CHANNEL COOLANT		LPBF	HPBF	692
MAGNETIC FIELD	– TESLA	6	7	706
SEED CONCENTRATION	– %k	1.0	1.5	693
AIR/FUEL STOICH. MHD BURNER		0.92	0.85	
COAL TYPE		MONT. SUB. BIT.	ILL. # 6	698
BASE DESIGN CASE			BASE	702

H9369

Figure 5-6 Plant Capital Costs of Reference Plant 2

REFERENCE PLANT 3 – CAPITAL COST (EXCL. ESC. + INTEREST)

PLANT PARAMETER		BASIC VALUE	PAR. VALUE
PLANT SIZE	MW	900	600
OXIDIZER	% O_2 °F	34 1100	34 1000
OXIDIZER	% O_2 °F	34 1100	34 1300
OXIDIZER	% O_2 °F	34 1100	34 1400
OXIDIZER	% O_2 °F	34 1100	29 1100
OXIDIZER	% O_2 °F	34 1100	29 1400
OXIDIZER	% O_2 °F	34 1100	39 1100
COAL TYPE		MONT. SUB. BIT.	ILL. # 6
BASE CASE	% O_2 °F	34 1100	

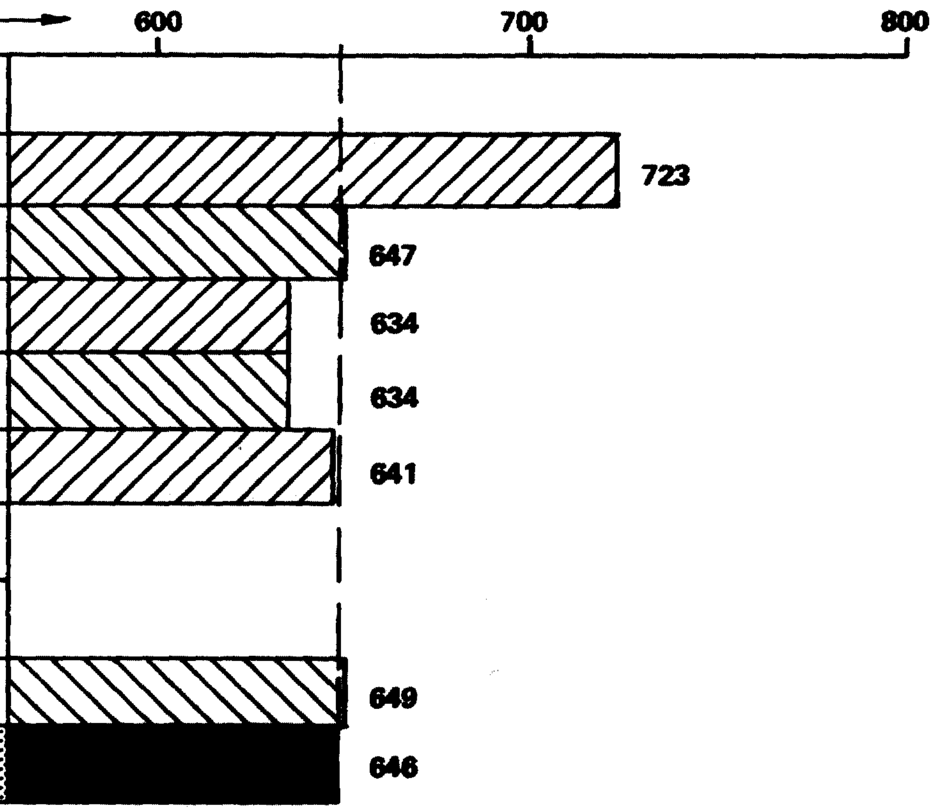


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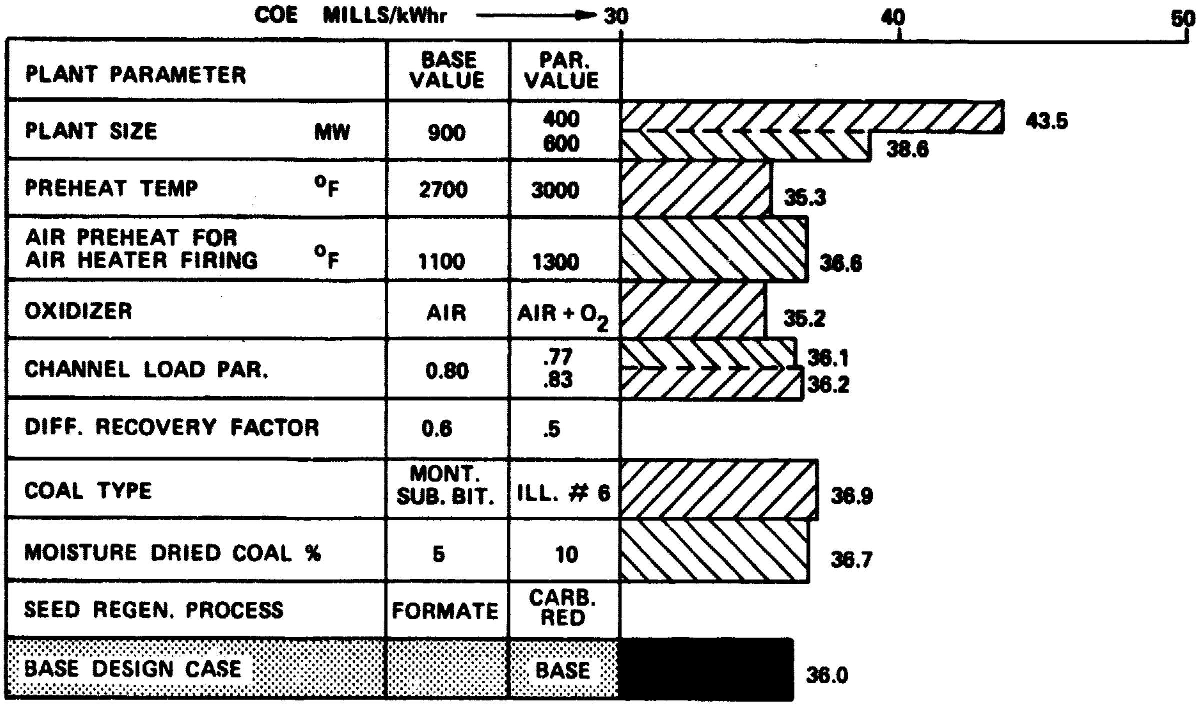
Figure 5-7   Plant Capital Costs of Reference Plant 3

REFERENCE PLANT 1 – COE IN CONSTANT MID 1978 DOLLARS



PLANT PARAMETER		BASE VALUE	PAR. VALUE	COE MILLS/kWhr
PLANT SIZE	MW	900	400 600	43.5 38.6
PREHEAT TEMP	°F	2700	3000	35.3
AIR PREHEAT FOR AIR HEATER FIRING	°F	1100	1300	36.6
OXIDIZER		AIR	AIR + O_2	35.2
CHANNEL LOAD PAR.		0.80	.77 .83	36.1 36.2
DIFF. RECOVERY FACTOR		0.6	.5	
COAL TYPE		MONT. SUB. BIT.	ILL. # 6	36.9
MOISTURE DRIED COAL %		5	10	36.7
SEED REGEN. PROCESS		FORMATE	CARB. RED	
BASE DESIGN CASE			BASE	36.0

H9367

Figure 5-8 COE (First Year of Commercial Operation) for Reference Plant 1

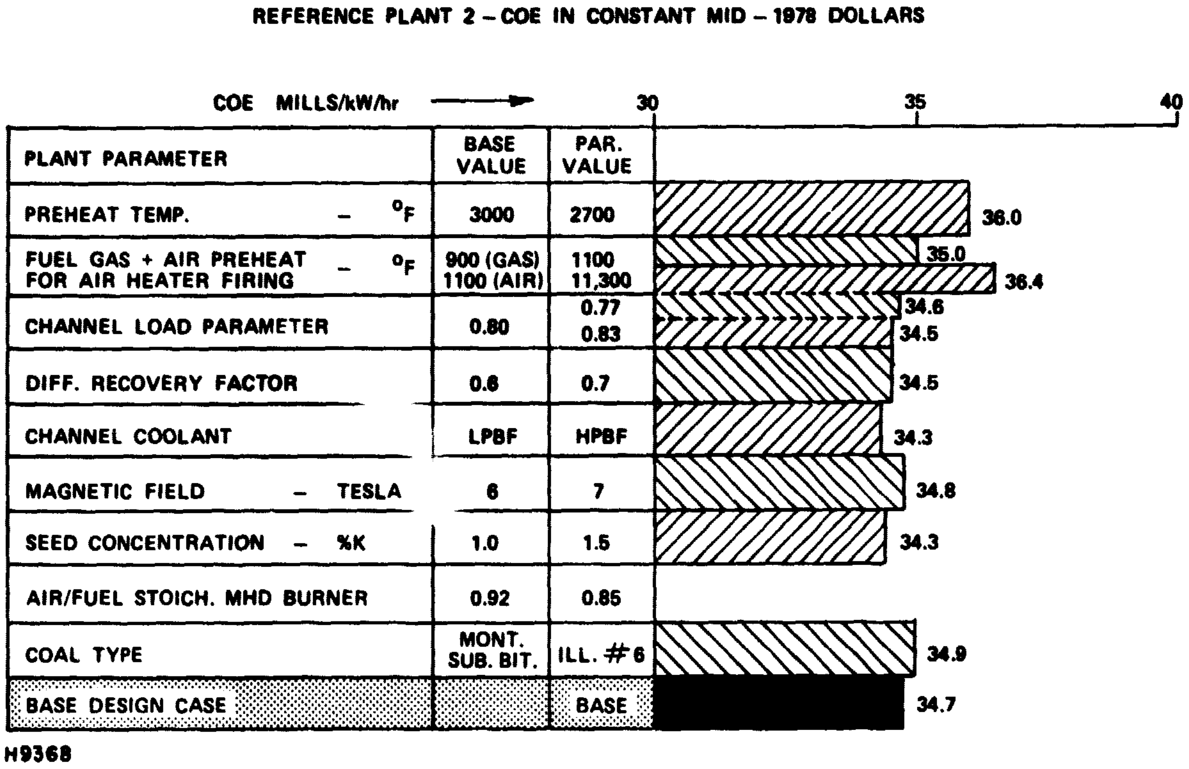
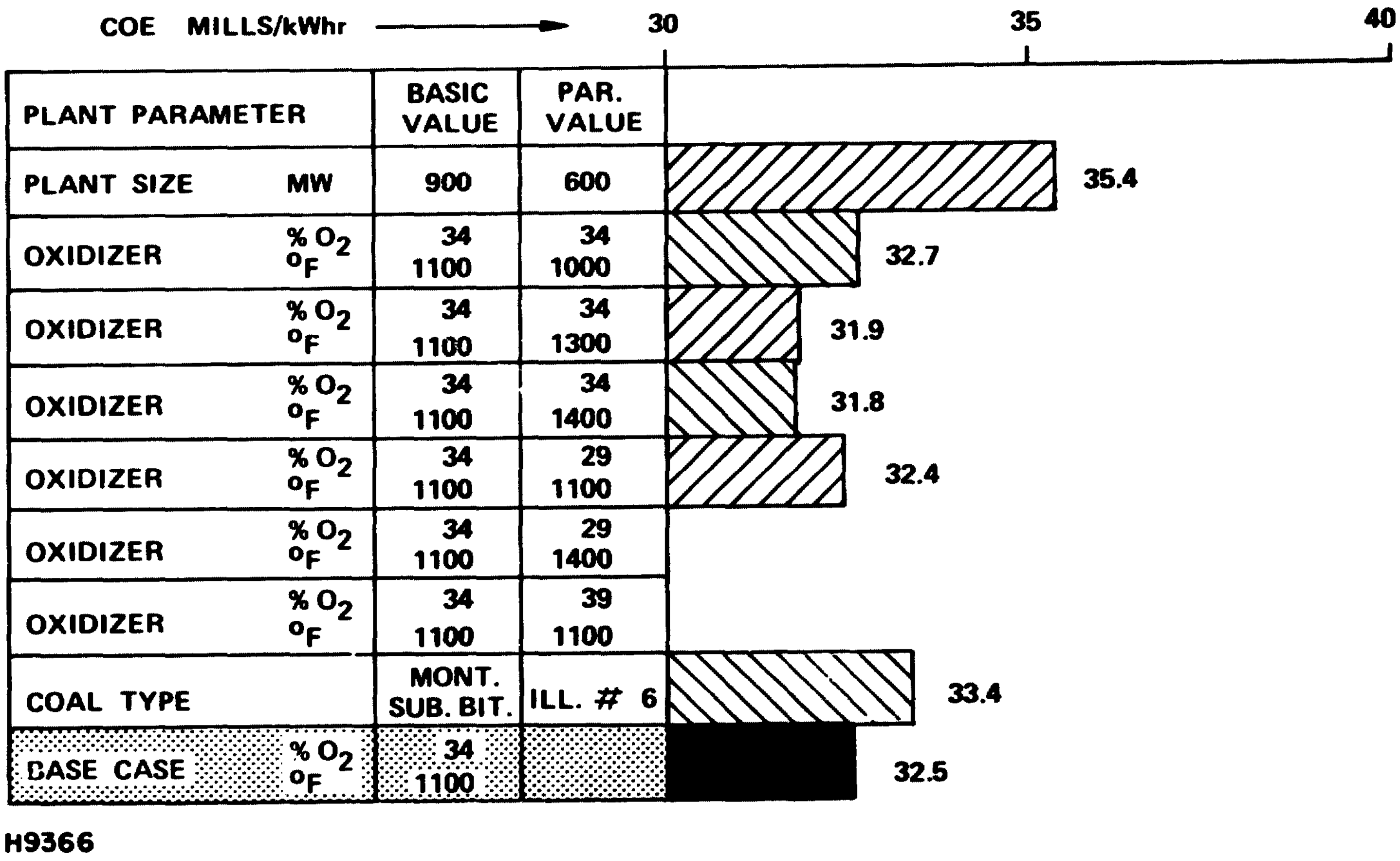


Figure 5-9 COE (First Year of Commercial Operation) for Reference Plant 2

REFERENCE PLANT 3 – COE IN CONSTANT MID – 1978 DOLLARS



PLANT PARAMETER		BASIC VALUE	PAR. VALUE	COE MILLS/kWhr
PLANT SIZE	MW	900	600	35.4
OXIDIZER	% O_2 °F	34 1100	34 1000	32.7
OXIDIZER	% O_2 °F	34 1100	34 1300	31.9
OXIDIZER	% O_2 °F	34 1100	34 1400	31.8
OXIDIZER	% O_2 °F	34 1100	29 1100	32.4
OXIDIZER	% O_2 °F	34 1100	29 1400	
OXIDIZER	% O_2 °F	34 1100	39 1100	
COAL TYPE		MONT. SUB. BIT.	ILL. # 6	33.4
BASE CASE	% O_2 °F	34 1100		32.5

H9366

Figure 5-10 COE (First Year of Commercial Operation) for Reference Plant 3

6.0 NATURAL RESOURCE REQUIREMENTS AND ENVIRONMENTAL INTRUSION

Tables 6-1 and 6-2 summarize the environmental intrusion and natural resource requirements for each of the parametric points. Each parametric point falls into one of the five categories shown on the two tables. The categories are designated according to plant nominal size, coal type and seed regeneration process. The data is reported separately for the three reference cases where significant differences occur between them.

Table 6-1 indicates the quantity of wastes products, heat rejection and emissions. The major differences occur as a result of the amount and type of sulfur removal. Reference Case III with Illinois coal, produces the greatest quantity of gypsum as a result of burning the high sulfur coal and removing the necessary sulfur by the formate process. On the other hand, Reference Case II with Montana coal, produces the least amount of gypsum. This is due to the lower sulfur content of Montana coal and the fact that a portion of the necessary sulfur removal is accomplished by removing elemental sulfur from the gasifier fuel gas. The quantity of elemental sulfur varies depending on the amount of gasifier fuel gas which is desulfurized. The plant emissions are all within the specified EPA guidelines. The SO_x emission corresponds to 85% sulfur removal.

Table 6-2 shows the use of coal, potassium sulfate, lime, water and land. With the exception of water, resource usage depends mainly on the type of coal burned and the method of sulfur removal. The seed makeup is 3.8% of the total seed flow. 2.6% is assumed lost in the boiler and MHD components, 1% in the seed regeneration process and 0.2% with stack gas. Seed makeup and lime consumption increase from Reference Case II to Case I to Case III as the formate process does more of the sulfur removal. The use of seed and lime also increases with the use of high sulfur Illinois coal. The land requirement includes 30 years storage of wastes. As a result, the land requirement is the greatest while burning Illinois coal and using the formate system which produces waste gypsum. The least land is required while burning Montana coal and using the carbon reduction process for seed regeneration.

The estimated usage of critical elements is shown on Table 6-3.

TABLE 6-1

ENVIRONMENTAL INTRUSION

Plant Nominal Size (MW)	900	900	900	600	400
Coal Type	Montana	Illinois	Montana	Montana	Montana
Seed Regeneration Process	Formate	Formate	Carbon Red.	Formate	Formate
Wastes (lb/kWhr)					
Ash					
Ref. Case I, II & III	.078	.079	.078	.078	.078
Gypsum					
Ref. Case I	.027	.081	0	.027	.027
Ref. Case II	.017	.051	-	-	-
Ref. Case III	.035	.105	-	.035	.035
Sulfur					
Ref. Case I	.00128	.00377	.00636	.0013	.00129
Ref. Case II	.0029	.00898	-	-	-
Ref. Case III	0	0	-	0	-
Heat Rejected (Btu/kWhr)					
Cooling Tower					
Ref. Case I	2980	2860	2980	3054	3164
Ref. Case II	2940	2940	-	-	-
Ref. Case III	3191	3170	-	3234	-
Chimney & Losses					
Ref. Case I	705	606	712	710	731
Ref. Case II	578	488	-	-	-
Ref. Case III	836	663	-	823	-
Emissions (lb/MBtu)					
SO_x					
Ref. Case I, II & III	.28	.88	.28	.28	.28
NO_x					
Ref. Case I, II & III	.5	.5	.5	.5	.5
Particulates					
Ref. Case I, II & III	.03	.03	.03	.03	.03

TABLE 6-2

NATURAL RESOURCE REQUIREMENTS

Plant Nominal Size (MW)	900	900	900	600	400
Coal Type	Montana	Illinois	Montana	Montana	Montana
Seed Regeneration Process	Formate	Formate	Carbon Red.	Formate	Formate
Coal (lb/kWhr)					
Ref. Case I, II & III	.87	.68	.85	.89	.91
K_2SO_4 Seed Makeup (lb/kWhr)					
Ref. Case I	.00367	.00374	.00366	.00367	.00367
Ref. Case II	.0033	.00323	-	-	-
Ref. Case III	.00367	.00485	-	.0037	-
Unslaked Lime (lb/kWhr)					
Ref. Case I	.0088	.0264	0	.0089	.0089
Ref. Case II	.0055	.0167	-	-	-
Ref. Case III	.0112	.034	-	.011	-
Water (gal/kWhr)					
Cooling Tower					
Evaporation					
Ref. Case I	.359	.345	.359	.368	.382
Ref. Case II	.355	.355	-	.39	-
Ref. Case III	.385	.382	-	.39	-
Blowdown					
Ref. Case I	.118	.113	.118	.121	.125
Ref. Case II	.116	.116	-	-	-
Ref. Case III	.126	.125	-	.128	-
Total Land (acres/100 MW_e)					
Main Plant					
Ref. Case I, II & III	30.5	30.5	30.5	47.2	72.2
Disposal Land					
Ref. Case I, II & III	30.2	50	23.4	32.8	33.7
Total					
Ref. Case I, II & III	60.7	80.5	53.9	80	105.9

TABLE 6-3

ESTIMATED USAGE OF CRITICAL ELEMENTS

(1000 lb)

	Cr	Ni	Mo	Mn	Nb	Ti	Cu	Al	Mg	Pt*
MHD Components										
Base Case I										
Combustor & Nozzle	5.7	5.3					28.5			
Channel							60.3			5.83
Diffuser	8.29	3.7								
Base Case II										
Combustor & Nozzle	4.9	4.7					24.2			
Channel							67.8			6.54
Diffuser	8.6	3.8								
Base Case III										
Combustor & Nozzle	4.9	4.7					24.2			
Channel							68.7			6.64
Diffuser	8.3	3.7								
Magnet										
Base Case I	1194	677	---	---	58	46	1240	2293	104	
Steam Generator										
Base Case I	485.7	246.5	37.8	76.4						
Base Case II	486	237	46.1	81.8						
Base Case III	465	250	30	66.3						
Gasifier										
Base Case II	131.1	60	26.6	24.1						

* (1000 oz)

7.0 REFERENCE PLANTS EVALUATION AND SUMMARY

The parametric analyses have shown that net MHD plant efficiency of the order of 45% can be reached for combustion of coal with air preheated to 3000°F in a high temperature air preheater system which is separately fired with a low Btu gas produced in an entrained bed gasifier. The use of a state-of-the-art fixed bed gasifier of the Wellman Galusha type gave net plant efficiency of about 1.5 - 2.0 percentage points lower than that attainable with the entrained bed gasifier, other plant parametric design assumptions being the same. The entrained bed gasifier has the advantage of delivering a fuel gas which is free of tars and which is thoroughly cleaned both of particulate matter and sulfur before firing in the preheater system. In this study only half of the fuel gas delivered from the fixed bed gasifier was cleaned before combustion in order to optimize the thermal efficiency of this gasifier system. Cleaning of all of the fuel gas produced from the fixed bed gasifier system would have resulted in a somewhat lower net plant efficiency and a correspondingly somewhat larger difference in the attainable plant efficiency between the use of the two gasifier types. The use of a C-E entrained bed type gasifier requires only a single gasifier unit for MHD base load power plant application because this type of gasifier has a projected large unit capacity. The present unit capacity of the Wellman Galusha fixed bed type gasifier requires the use of about 30 gasifier units for a 900 MW_e MHD power plant. The number of required fixed bed gasifier units could be reduced to about 5 considering the projected increase of the gasifier bed diameter from the present 10' to 25'.

The use of oxygen enrichment of the combustion air resulted in a calculated net plant efficiency in the range 43.5% - 45.0% for preheat temperatures in the range 1000°F - 1400°F. An oxygen enrichment of the combustion air to roughly 35 vol.% of oxygen appears optimum. The net plant efficiency attainable for an oxygen enrichment of 34.1% and 1400°F preheat temperature is calculated to be 44.8%, or the same as that attainable for the basic Reference Plant 2 design case with the use of a high temperature air preheater separately fired with a fuel gas produced from the entrained bed gasifier type. A preheat temperature of 1400°F for a metal heat exchanger is presently considered an upper limit for early commercial MHD power plant application and practical considerations may dictate the use of a lower temperature. However, the analysis shows that even a lower and more practical preheat temperature of around 1200°F would result in an attractive net power plant efficiency of around 44.0%. It is emphasised that the power requirement for O_2-production is an important factor in establishing the net plant efficiency which can be attained for MHD power plants with the use of oxygen enrichment of the combustion air. Therefore, it becomes very important to integrate the O_2-plant properly with the power plant and to optimize the oxygen plant both from the viewpoint of power requirements and capital costs. Preliminary investigations indicate that the optimum value of oxygen purity is about 80% for combustion with air enriched with oxygen to about 35% O_2 content.

The performance and cost data of the three different Reference Plants considered in this study are summarized in Table VII-1. For each Reference Plant, data for two design cases are tabulated; the first is the base design case and the second is the design case with lowest cost of electricity (COE) for the respective Reference Plant.

In addition, at the right side of the Table, data are listed for the mature MHD power plant of advanced design which uses directly fired high temperature air preheater as considered in ECAS, and for the conventional steam plant with scrubber used as reference by G.E. in ECAS. For comparison, the listed cost data for these two plants from ECAS have been converted from mid-1975 to mid-1978 dollars by applying an annual escalation of 6.5% and the fuel costs are based on 105 ¢/MBtu as for the other plants.

Reference Plants 2 and 3 offer lower COE than Reference Plant 1, and operate at higher efficiencies. Therefore, Reference Plants 2 and 3 are more attractive than Reference Plant 1. These plants do not offer the same high efficiency and low cost as the mature MHD power plant defined in ECAS, yet the efficiencies and COE are still considered attractive compared to conventional steam plants. It is noted that the emission regulations (NSPS) specified for this early MHD power plant study are more stringent than those specified in ECAS.

Regarding potential plant improvements significant cost reductions are considered possible for the high temperature preheater system of Reference Plant 2 and for the oxygen plant of Reference Plant 3. Our preliminary design and cost analysis of the high temperature preheater system have already indicated that the cost of the preheater system can be expected to be reduced to roughly 2/3 of the cost used in our parametric cost analysis.

The cost and performance data for the oxygen plant used in Reference Plant 3 are based upon estimated turnkey costs and performance data developed by Lotepro in a parallel DOE sponsored study. Improvements in this area have been indicated. Obviously, the use of oxygen eliminates the need for a a high temperature preheater system and its associated gasifier.

TABLE VII-1

POWER PLANT COMPARISON SUMMARY

	EARLY COMMERCIAL MHD PLANT STUDY						ECAS	
	PLANT 1		PLANT 2		PLANT 3		MATURE MHD PLANT WITH DIRECTLY FIRED HT AH	REFERENCE CONVENTIONAL STEAM PLANT
	BASE CASE	LOWEST COST CASE	BASE CASE	LOWEST COST CASE	BASE CASE	LOWEST COST CASE		
PARAMETRIC VARIATION	AIR 2700°F PREHEAT	*24.1% O_2 IN AIR 2700°F PREHEAT	AIR 3000°F PREHEAT LPBF	AIR 3000°F PREHEAT HPBF	*34.1% O_2 IN AIR 1100°F PREHEAT	*34.1% O_2 IN AIR 1400°F PREHEAT	AIR 2800°F PREHEAT HPBF	SCRUBBER 170°F STACK
OVERALL EFFICIENCY – %	42.5	42.9	44.8	45.1	43.4	44.8	48.3	38.8
**CAPITAL COST – $/kW	800	770	772	762	711	680	576	680
**COE – MILLS/kWhr								
CAPITAL	25.30	24.60	24.42	24.08	22.46	22.07	18.2	23.8
FUEL @ 165 ¢/MBtu	16.33	16.20	15.52	15.42	16.04	15.54	14.9	18.6
O & M	4.52	4.35	4.38	4.37	3.41	3.34	3.5	5.9
TOTAL	46.15	45.15	44.32	43.87	41.91	40.95	36.6	48.3

**CONSTANT 3RD 1978 DOLLARS LEVELIZED

*O_2 – PLANT 2120 TPD

*O_2 – PLANT 7470 TPD

H9370

In summary, two different "Moderate Technology" entry level MHD power plants have been identified in Task I as potentially attractive. These are:

1. Reference Plant 2 which considers the use of a high temperature regenerative air preheater separately fired with a clean fuel gas produced from an advanced entrained bed atmospheric type gasifier.

2. Reference Plant 3 which considers the use of oxygen enrichment of the combustion air.

The results from Task I are encouraging. However, further conceptual design work of the above two potential Reference Plants identified as most attractive in Task I is required to form a better basis for an assessment of their attractiveness and commercial viability. Such design work is also important to define the development requirements of MHD power system components and of the overall power system, and hence to structure a development program to meet the goal of commercial MHD power generation. MHD like any other technology is expected to advance and improve after its commercial introduction. Therefore, this study program which had as its prime objective the identification of early prospective MHD power plants, serves also to define the initial goal for the commercial development of MHD power generation and the requirements of a technical development program for meeting this goal.

EMISSION STANDARDS (NSPS)

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 (6-minute average)

SO_2: 1.2 #1/10^6 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.

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.

2. 0.6 #/10^6 Btu (260 ng/J)

   (a) With 65 percent reduction for bituminous, certain lignites and othr 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.

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.

APPENDIX A

COAL AND ASH ANALYSES OF SELECTED COALS

	Montana (Rosebud)	Illinois (No. 6)
Proximate Analysis, Coal as Rec'd, Percent		
Moisture	22.7	8.9
Volatile Matter	29.4	38.0
Fixed Carbon	39.2	41.7
Ash	8.7	11.4
Ultimate Analysis, Percent		
Hydrogen	6.0	5.4
Carbon	52.1	62.4
Nitrogen	.79	1.2
Oxygen	31.5	16.3
Sulfur	0.85	3.3
Heating Value, Wet, Btu/lb	8920	11265
Heating Value, Dry, Btu/lb	11560	12370
Coal Rank	Subbit B	HVCB
Ash Analysis, Percent		
SiO_2	37.6	41.4 ± 5.4
Al_2O_3	17.3	19.3 ± 6.8
Fe_2O_3	5.1	22.3 ± 6.8
T_1O_2	0.7	0.9
P_2O_5	0.4	0.12
CaO	11.0	5.4 ± 3.3
MgO	4.0	1.7 ± 1.3
Na_2O	3.1	0.6 ± 0.2
K_2O	0.5	2.1 ± 0.4
SO_3	17.5	7.5 ± 0.6
Initial Deformation Temp °F	2190 ± 230	1960 ± 70
Softening Temp °F	2230 ± 240	2030 ± 70
Fluid Temp °F	2280 ± 200	2260 ± 200

APPENDIX B

Summary of Auxiliary Power Requirements (KW)

	Ref. Plant I	II	III
Superconducting Magnet			
Cryogenic System	1000	1000	1100
Coal Gasifier System			
FD Comb. Air Blower	3838	2493	
HTAH System			
FD Comb. Air & Recycle Gas Blower	5927	6470	
Coal Handling & Proc.			
Feeders & Conveyors	1325	1357	1375
Pulverizors & Fans	4252	6650	6495
Coal & Seed Feeding			
Petrocarb Sys. Comp.	1385	1318	1985
Steam Generator			
Boiler Circ. Pumps	4800	4800	4800
Condensate Pumps	705	768	780
ID Fans & Sec. Air Blower	6056	5725	5895
Electrostatic Precipitator	1750	1550	1400
Seed Regen. Sys.	7425	5307	9400
Balance of Plant			
Circ. & cooling water pumps	4980	5610	5450
Cooling Tower Fans	2722	2963	2872
Misc.	305	250	300
Station Services			
HVAC, Lighting, Control Power, etc.	1110	1100	1100
TOTAL	47580	47361	42952

APPENDIX C

ETF ESTIMATE FORMAT

ACCT NO	ACCOUNT DESCRIPTION	UNIT	QUANTITY	MATERIAL COST		INST COST	INDIR COST	CONTIN	TOTAL COST
				MJR COMP	BOP				
	Direct Accounts (see attachment B)	xx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
	SUBTOTALS			xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
	ENGINEERING SERVICES			-	-	xxxx	-	xxxx	xxxx
	OTHER COSTS			xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
	TOTAL ESTIMATED COSTS			xxxx	xxxx	xxxx	xxxx	xxxx	xxxx

NOTES

1. Cost basis 1978 1/2 dollars.
2. Costs should be shown in thousands of dollars.
3. UNIT - Unit of measure for each account.
4. QUANTITY - Quantity for each account based on the unit of measure.
5. MATERIAL COST - Total material cost for each account.
   MJR COMP - Total major component material cost delivered to the site for each account. Major components are those major purchased items which are engineered, designed, fabricated, shipped, and in some cases erected by one supplier or manufacturer.
   BOP - Total balance of plant materials cost delivered to the site for each account. BOP materials are those items normally designed and purchased by an Architect - Engineer.
6. INST COST - Total direct installation cost for each account. Provide as part of the estimate backup a breakdown of those items included in the installation cost.
7. INDIR COST - Total indirect construction cost for each account. Provide as part of the estimate backup a breakdown of those items included in indirect construction cost and the procedure used in applying that cost to the estimate.
8. CONTIN - Total contingency cost for each account. Provide as part of the estimate backup the basis for the contingency costs and the procedure used in applying those costs to the estimate.
9. TOTAL COST - Total of all material, installation, indirect and contingency costs for each account.
10. ENGINEERING SERVICES - Total cost of all professional services. Provide as part of the estimate backup the basis for the engineering services cost and procedure used in applying that cost to the estimate.
11. OTHER COSTS - Total of other costs. Provide as part of the estimate backup a breakdown of those items included in other costs and the procedure in applying that cost to the estimate.

ETF CODE OF ACCOUNTS

ACCT NO		DESCRIPTION
310		Land and Land Rights
311	(1)	Structures and Improvements
311.1		Improvements to Site
311.2		Main Building
311.3		Steam Turbine Building
311.4		Coal Bunker/Processing Area
311.5	(2)	Service Buildings
311.6	(3)	Other Buildings and Structures
312		Boiler Plant Equipment
312.1	(4)	Coal Handing and Processing
312.2	(5)	Slag and Ash Handling
312.3		Radiant Section
312.4	(6)	Steam Generator Sections
312.5	(7)	Effluent Control
312.6		Auxiliary Boiler Systems
312.7	(8)	Other Boiler Plant Systems
313	(9)	Engines and Engine Driven Generators

ACCT NO		DESCRIPTION
314		Turbogenerator Units
314.1		Steam Turbine Generator and Auxiliaries
314.2		Condenser and Auxiliaries
314.3	(10)	Circulating Water System
314.4	(11)	Steam Piping Systems
314.5		Other Turbine Plant Equipment
315	(12)	Accessory Electric Equipment
316	(13)	Miscellaneous Power Plant Equipment
317		MHD Topping Cycle Equipment
317.1	(14)	Combustion Equipment
317.2	(15)	MHD Generator Subsystem
317.3	(16)	Magnet Subsystem
317.4	(17)	Inverters and Electrode Control
317.5	(18)	Oxidizer Preheater Subsystem
317.6	(19)	Seed Subsystem
317.7	(20)	Other Major MHD Topping Cycle Support Subsystems
317.8		Miscellaneous MHD Topping Cycle Support Equipment
318	(21)	Research Equipment
319	(22)	Simulation Equipment
350	(23)	Transmission Plant

ETF CODE OF ACCOUNTS

GENERAL NOTES

A. The modified FPC "ETF Code of Accounts" and these notes should be used as a guide in developing and utilizing the final code of accounts for the ETF cost estimate.

B. These notes should be used as a guide in subdividing accounts and additional subaccounts included in order to more accurately define the cost of the plant. Individual subaccounts should be included for each major component or subsystem.

C. If the total cost of an account or subaccount is greater than 5% of the total estimated plant cost the account or subaccount should be subdivided into its next lower level of detail.

D. Individual component or subsystem foundations, structural steel supports, access platforms, etc. should not be included in account 311, but are to be included as part of the BOP material cost and installation cost for the component or subsystem.

E. All piping; ducting; and electrical, mechanical and instrumentation & control equipment within a subsystem should be included in the cost of the subsystem.

SPECIFIC NOTES

(1) Subdivide the building accounts into subaccounts for each individual building or major building area. (Example: If subaccount 311.2 Main Building includes the heater, MHD, cryogenic system, invertor and control buildings provide separate subaccounts under 311.2 for each of these building.) All building services should be included in the cost of the building.

(2) Includes all office, shop, warehouse and maintenance buildings. Include a subaccount for each building provided.

(3) Includes all miscellaneous buildings such as the water treatment or seed system buildings. Include a subaccount for each building provided.

(4) Includes all equipment from the initial coal unloading point up to and including coal storage prior to final preparation (final preparation includes drying and pulverizing).

(5) Includes all equipment from the initial collection equipment up to the storage area.

(6) Include subaccount for each major steam generator section (examples: superheater, reheater, economizer, etc.).

(7) Includes all equipment from the steam generator outlet up to and including the chimney, with subaccounts for each seed and/or cleanup subsystem, and the chimney.

(8) Include subaccounts for the condensate system, boiler feedwater system, condensate pumps, boiler feed pumps, boiler plant related water treatment equipment and the secondary air system.

(9) Do not use account 313.

(10) Include a subaccount for the cooling towers.

(11) Include a subaccount for each of the major steam systems (examples: main steam, hot and cold reheat steam, extraction steam and bypass steam systems).

(12) Includes all accessory electric equipment such as the equipment from the MHD power conditioning equipment and steam turbine generator up to the main transformers, emergency or standby equipment, and wire and cable systems.

(13) Includes all equipment and subsystems not otherwise identified (examples: fire protection system, station maintenance equipment, fuel oil system, etc.).

(14) Includes all final coal preparation equipment not included in account 312.1, the combustor, all coal injection equipment, and initial slag collection equipment at the combustor.

(15) Include subaccounts for the nozzle, generator channel, and diffuser.

(16) Include a subaccount for the magnet and each support system.

(17) Includes all power conditioning and electrode control equipment.

(18) Includes all equipment from the outside inlet through the delivery piping to the combustor; Including the main air compressors, air compressor drives, low temperature air heaters, high temperature air heaters and hot gas piping.

(19) Includes all seed unloading, storage, preparation, injection, transport, separation, and reprocessing subsystems and equipment.

(20) Includes all other major support subsystems such as oxygen an system or a coal gasification system. Include a specific subaccount for each major support subsystem subdivided into its major components and subsystems.

(21) Includes all equipment or subsystems provided specifically for research purposes (example: instrumented generator channel). Include a subaccount for each major research component or subsystem.

(22) Includes all equipment or subsystems specifically provided to simulate equipment or subsystems which would normally be included in a commercial MHD power plant (example: heat rejection equipment used to simulate a steam bottoming plant). Include a subaccount for each major simulation component or subsystem.

(23) Includes all transmission plant equipment located at the facility including the main transformers and switchyard.