MHD Advanced Power Train

Phase 1 Final Report

**Volume 6
Special Studies-Evaluation Of Program Options**

**Prepared For
THE UNITED STATES DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER**

Contract DE-AC22-83PC60575

AUGUST 1985

Westinghouse

Advanced Energy Systems Division

Large, P.O. Box 10864, Pittsburgh, PA 15236

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Government Technical Project Officer:

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by

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1.0 INTRODUCTION AND SUMMARY

1.0 INTRODUCTION AND SUMMARY

Under contract to the Department of Energy, Westinghouse has prepared the definition of a program plan for the development of an MHD Advanced Power Train (APT). The scope of work of this contract includes conceptual designs of early commercial MHD/steam electric plants (topping/bottoming) ranging from 200 to 1000 MW(e). These plant designs were prepared during 1982 and made use of a system analysis model that provides performance and design information and economic estimates.

In early April 1984, DOE requested Westinghouse to perform special studies under the existing APT contract to aid the Department in evaluating MHD program options. Two tasks were defined by DOE: the first task was to evaluate an 80 MW(t) integrated test system (with steam electric bottoming cycle) for installation at the CUIF in Butte, Montana; the second task was to investigate placing a 50 MW(e) MHD topping stage onto an existing steam electric plant (as a retrofit).

This volume of the final report documents the results of these special studies. Highlights of the studies were presented orally to DOE on May 15, 1984.

1.1 Highlights of Task I Results

For the Integrated Test System at CUIF, systems rated at both 50 and 80 MW(t) (combustor heat) were evaluated. We found that standard ASME turbine generators of appropriate ratings could be placed as bottoming cycles in either case. The overall cycle efficiencies for these two cases were conservatively calculated to be 27 and 29% and the net plant power output levels would be 14 and 23 MW(e), respectively.

Westinghouse and Burns and Roe (a subcontractor) personnel visited the CUIF to review the facilities and assess capabilities and limitations for extended system testing. Subsequently, a preliminary plot plan was prepared to illustrate the needed site and facility modifications to accommodate an

Integrated Test System. In addition a design and construction schedule was prepared. Sixty-three months--from initiation of Title I design through system checkout and calibration--was estimated for the overall schedule. This period allows for 43 months of Title III construction management that would start in the sixth quarter.

For the 50 and 80 MW(t) cases, capital costs of \$112 million and \$138 million respectively were estimated; the costs of the MHD topping stages represented approximately 1/3 of the total capital costs. A qualitative risk assessment was prepared highlighting those component technologies where substantial engineering development remains to be done. These technologies were primarily in the MHD equipment and related components, (e.g. channel, power consolidation and control, HRSR and seed handling). The associated development requirements primarily relate to the need to demonstrate extended operation of the MHD topping cycle equipment.

1.2 Highlights of Task II Results

These two cases differed in the way that oxidant compressors were powered; steam turbines were used for compressor drives in the 50 MW(e) retrofit and electric motors were used in the nominal 40 MW(e) retrofit. Performance evaluations revealed that the overall plant efficiencies for the two cases were not significantly different, 32-33%. However, the net power output values were 106 and 89 MW(e) and the capital cost estimates were \$319 million and \$283 million respectively.

Westinghouse and Burns and Roe personnel also visited the Bird plant site during the study and reviewed suitability of new buildings and facilities with the Montana Power Co.'s personnel. The retrofit plot plan and construction schedule reflected the judgments formed during this visit. A nominal five year schedule for the retrofit program was estimated from the start of Title I design.

The qualitative risk assessment for the retrofit cases was similar to that of the CDIF cases. However, because of the need to scale to higher power levels compared to the CDIF cases, the extent of development work needed on the MHD equipment was judged to be somewhat greater.

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2.0 BASIS FOR STUDIES

2.0 Basis For Studies

This section presents the work scope of the study; key assumptions, and the study approach used by Westinghouse.

2.1 Scope of Work

The scope of work as defined by DOE required the definition and evaluation of two basic conceptual designs of integrated MHD systems followed by evaluation of the conceptual designs as potential program options. The work scope and deliverables are summarized as follows:

- CONCEPTUAL DESIGNS OF TWO INTEGRATED MHD TEST SYSTEMS
 - TASK I - 80 MW THERMAL SYSTEM WITH MAXIMUM AND COST EFFECTIVE USE OF GOVERNMENT OWNED EQUIPMENT
 - TASK II - RETROFIT SYSTEM WITH 50 MW ELECTRICAL OUTPUT FROM MHD GENERATOR
- DELIVERABLES FOR TASKS I AND II
 - CONCEPTUAL DESIGN CHARACTERISTICS
 - COSTS AND CONSTRUCTION SCHEDULES
 - RESOURCE/RISK ASSESSMENTS
 - PRELIMINARY MANAGEMENT PLANS
 - ORAL BRIEFINGS AND FINAL REPORT

Two cases were examined in each of the two conceptual design tasks. A 50 MW_t case was added to Task I and compared with the original 80 MW_t case to explore differences in: capital cost, affected components and the impact on consumables. The retrofit study of Task II based on the Frank E. Bird station lead to two different configurations for integrating the MHD topping cycle with the existing steam plant. In the first of these two configurations, the extra steam in excess of that necessary to match the existing turbine-generator from the exhaust of the MHD topping cycle is used to drive the coal combustor oxidant compressor through a steam turbine. In the second

configuration, the MHD topping cycle is sized such that the steam produced matches the input requirements of the existing turbine generator. All of the above conceptual design cases are discussed in detail in Section 3.0.

2.2 Key Assumptions

Key assumptions were developed early in the study and reviewed with DOE in the first oral briefing. These key study assumptions are summarized as follows:

1. ALL PLANTS WILL GENERATE ELECTRICITY DELIVERED TO THE UTILITY GRID.
2. A STEAM INTERCONNECTION WILL BE USED BETWEEN ALL TOPPING AND BOTTOMING CYCLES.
3. I&C AND OAS WILL BE THAT REQUIRED FOR PLANT OPERATION, NOT MHD EXPERIMENT OR TEST PROGRAMS.
4. THE ASSUMED STATUS OF MHD TECHNOLOGY VERSUS DESIGN AND CONSTRUCTION SCHEDULES IS:
 - THE 50MW_e COMBUSTOR/CHANNEL WILL HAVE RUN 50 HRS.
 - ALL OTHER COMPONENTS AND SYSTEMS WILL BE BASED ON CURRENT TECHNOLOGIES.
5. SUPERSONIC MHD CHANNELS.
6. THE RETROFIT SYSTEM IS BASED ON THE FRANK E. BIRD PLANT OWNED BY MONTANA POWER COMPANY.
7. DESIGN AND CONSTRUCTION SCHEDULES WILL BE EXPRESSED IN YEARS FROM A COMMON START DATE.
8. CAPITAL COSTS WILL BE EXPRESSED IN 1986 DOLLARS, AND WILL REFLECT ESCALATION DURING CONSTRUCTION.

2.3 Study Approach

The study approach was based in part on the methodologies used in previous Westinghouse MHD/steam plant system engineering studies. Previous Westinghouse team members including Applied Energetics, Burns & Roe, TRW, SeiTec, and HMJ Corporation also contributed to the present study. Visits to the DOE-CDIF and Montana Power Company Frank E. Bird sites and organizations were made by Burns & Roe and Westinghouse team members to assess construction schedules and to develop plant layouts. Candidate developers and suppliers of major components including the MHD combustor, channel, diffuser, magnet, power conditioning, and the HR SR were consulted to evaluate costs, schedules, and development status. Previous CDIF uprating and expansion studies and MHD retrofit studies listed in the references were reviewed. Information from the above subtasks was used as input data for the Westinghouse System Performance Analysis (SPA/SUMARY) code. This model has been used in previous Westinghouse MHD studies and its application is illustrated in Figure 2-1.

This code package accepts fuel data compiled by the NASA TRANS 72 code. In the SPA code, algorithms of up to 100 integrated plant elements can be analyzed simultaneously. The SUMARY code accepts the SPA output and presents tabulated data on performance, cost and physical features. Data for the total plant and also each component are presented. The cost data are also presented in the Uniform Code of Accounts format that includes component costs, balance of plant cost, installation costs, indirects, and contingencies. A significant amount of effort during the present study was expended in modifying and validating system and component cost algorithms to accurately represent the Task I and II integrated MHD systems. This effort was necessary because the Task I and II systems are scaled down significantly from the 200 MWe-1000MWe systems of previous studies. Burns & Roe assisted Westinghouse in the modification and validation of the cost algorithms. During the present study, SPA/SUMARY was utilized in the following analysis steps:

- A representative MHD topping/Rankine bottoming cycle plant configuration was used to evaluate performance and cost data throughout the plant size range.

Figure 2-1. Westinghouse SPA/SUMARY

- Performance and cost algorithms were modified where necessary and validated.
- Cycle and configuration alternatives were evaluated for Tasks I and II.
- Specific cycles and configurations were selected for Tasks I and II and were subjected to further analyses using the SPA/SUMARY code package.

The final configurations selected and analyzed included the following:

TASK I	A	80 MW _t @ CDIF
	B	50 MW _t @ CDIF
TASK II	A	50 MW _e MHD RETROFIT
	B	~ 40 MW _e MHD RETROFIT

These system configurations are described in detail in Section 3.0 of this report. The capital cost estimates, resources/risk assessments, and preliminary management plans are described in Sections 4.0, 5.0 and 6.0.

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3.0 CONCEPTUAL DESIGN DESCRIPTIONS

3.0 Conceptual Design Descriptions

A general concept expected to be used in early commercial coal-fired MHD/steam power plants has evolved through a series of U. S. Government sponsored studies such as CSPEC¹ and APT². Figure 3-1 illustrates, schematically, the commercial plant concept. As illustrated, the MHD power train (topping cycle) is fed a mixture of pulverized coal and ionizable seed such as potassium carbonate, which is combusted with moderately preheated air enriched in oxygen as the oxidant. Electric power is extracted from the plasma. The heat remaining after the MHD electric power extraction is then utilized in the steam cycle to generate additional electric power.

Concepts similar to the early commercial coal-fired MHD/steam power plants, utilizing intermediate temperature preheating of oxygen enriched air, were used for both the Task I and II systems.

3.1 Task I - Integrated CDIF/MHD Test Systems

The objective, of this portion of the study effort, was to develop preliminary conceptual designs of 80 Mwt and 50 Mwt integrated MHD test systems to the level of detail necessary to provide performance characteristics of the systems and to provide the basis for cost, schedule, and resource/risk assessments.

Important general design requirements and constraints were as follows:

- Incorporate government owned components and facilities, where cost effective, into the designs. More specifically, at a minimum, create designs suitable for use of: the CDIF, the superconducting magnet at ANL; TRW 50 Mwt coal combustor and the CDIF DC/AC inverter subsystem. The government owned equipment may be modified to enhance its suitability for use in or with the conceptual designs.
- The designs shall be substantially complete, small scaled simulations of early commercial coal-fired MHD/steam power plants. The designs shall be capable of generating and supplying electricity to an electric utility grid.

Figure 3-1. Representative Early Commercial MHD/Steam Power Plant Schematic

3.1.1 Concept Description

In the arrangement of Figure 3-1, the oxygen for air enrichment is obtained from an electrically driven air separation plant and MHD oxidant compressor. An alternate arrangement is to use steam turbines to power the air separation plant and oxidant compressor. The use of steam turbines to drive the oxidant subsystem is more energy efficient than using electric motors. However, if steam turbine drive is used for the oxidant subsystem, a large supply of steam is required to start up the plant. This steam supply is not available at the CDIF. Even if such a steam supply were available, the flexibility of electric motor drive would probably make it the design choice at the CDIF.

Currently, the CDIF is equipped to carry out MHD power train testing, for short periods of time (~ 50 hours) up to about 50 MWt using batch type consumables supply. There have been a number of prior studies carried out^{3,4,5} directed towards uprating CDIF MHD power train testing capabilities to 100 MWt and 1000 or more hours continuous operation. These prior studies provided useful input to this study as to the modifications required at the CDIF for the continuous operation of the MHD power train portion of an integrated MHD/steam test system at either 80 MWt or 50 MWt heat input. The prior studies also provided the basis for scoping calculations of the steam cycle conditions, arrangements, and turbine sizes needed to match the MHD power trains and form integrated MHD/steam test systems of 80 MWt and 50 MWt input.

Using the scoping calculations, two standard ASME commercial/turbine-generators were picked to provide a basis for the steam cycle portion of the integrated test systems concepts. Use of standard turbine characteristics, plus steam system design practice allowed a rapid convergence to matching steam cycle conditions, arrangements, and flow rates during later design efforts.

At both 80 and 50 MWt, the design constraint of using the ANL magnet, plus the need for the power train diffuser exit static pressure into the HRSR to be nearly local ambient pressure, sharply curtails the number of design point condition options available for use in the MHD power train. The options available are proscribed further by design practice limits such as maximum allowable Faraday current density ($\leq 1 \text{ A/cm}^2$) and Hall voltage gradient ($\leq 2000 \text{ V/m}$).

If the current construct of TRW combustor is used, the design options would be further constrained. However, based on conversation with Dr. Gabriel Roy of TRW, the TRW coal combustor was assumed to be a later version, now under development, that uses a coal-fired rather than an oil fired vitiating preheater, and can accommodate up to 50 mol % oxygen content in the oxidant.

A series of trial calculations were carried out on the power train portion of the system varying combustor inlet stagnation pressure, oxidant oxygen concentration, and channel plasma Mach. No. and Mach No. variation along the channel. From these calculations, a set of design point conditions in terms of these variables was found that satisfied design constraints for both the 80 Mwt and 50 Mwt systems. The values are:

System Size (Mwt)	Oxidant Oxygen Concentration (Mol %)	Combustor Inlet Stagnation Pressure (ATM)	Channel Mach No. Inlet	Exit
80	50	3.0	1.3	1.0
50	50	2.6	1.3	1.0

To provide major component sizing information and system performance, the 80 Mwt and 50 Mwt integrated test systems were modeled as shown in the schematic of Figure 3-2. The model was incorporated into the Westinghouse SPA/SUMARY code for further analyses. Designs satisfying design requirements and constraints for 80 Mwt and 50 Mwt CDIF integrated test systems were obtained from these analyses.

To summarize, the resulting design is based on the intermediate temperature oxygen preheat, oxygen enriched system for early commercial coal-fired MHD/steam power plants of 200 MW_e output and above. In the test system concept, unlike the larger plant concepts, the oxidant compressor and air separation subsystems are motor driven rather than steam turbine driven. Use of steam turbine drive for these auxiliaries at the CDIF would require a relatively large source of startup steam.

The two steam bottoming cycles are based on standard ASME turbine-generators. The turbines are non-reheat, have a single case and four extraction points for bleeding steam to the steam cycle feedwater train. The major water-side elements of the steam cycle are: a condenser, deaerator, four feedwater heaters and required drip and feed pumps. Nominal turbine-generator design conditions are as follows:

<u>Test System Size (Mwt)</u>	<u>Turbine-Generator Rating (Mwe)</u>	<u>Steam Inlet Temperature (°F/°K)</u>	<u>Steam Inlet Pressure (PSIA)</u>	<u>Condenser Exhaust Pressure (°HgA)</u>
50.	12.7	825/714	615.	1.5
80.	22.0	900/755	865.	2.5

State point data at the locations shown in Figure 3-2 is summarized in Table 3-1 for the 80 Mwt case and Table 3-2 for the 50 Mwt case.

3.1.2 System Performance

Tables 3-3 and 3-4 provide overall parameter values for the proposed CDIF 80 and 50 Mwt MHD/steam integrated test systems. The values given are for the concept outlined in the previous CDIF MHD/steam test system schematic. The values assume the use of the existing Argonne National Laboratory superconducting magnet, a non-reheat four feedwater heater steam cycle, and on-site air separation plant to provide enrichment oxygen.

The systems performance values are set, essentially, by the specified heat inputs, the effective central field length of the Argonne Magnet of three (3) meters, and the necessity of near ambient static pressure in the plasma (12.2 psia) at the entrance to the heat recovery seed recovery subsystem. To maximize the MHD generator outputs within these constraints, the plasma Mach No. through the MHD channel is made supersonic. Even so, as can be observed, an unusually high oxygen concentration of 50 mol percent is required to overcome high combustor, nozzle and channel heat losses and achieve operable levels of plasma electrical conductivity.

Figure 3-2. CDIF 80 & 50 Mwt MHD/Steam Integrated Test System Schematic

Table 3-1. CDIF 80 Mwt Case State Point Data

State* Point	Pressure		Temperature	Flow Rate	Composition
	N/m ²	psi	°K	kg/s	
1	304,064	44.2	375	3.10 0.31	Coal Coal Carrier Gas
2	304,064	44.2	375	0.08 0.18	K ₂ CO ₃ K ₂ SO ₄
3	304,064	44.2	922	6.08 3.94	Air Oxygen
4	294,942	42.8	2861	13.49	Combustion Gas
5	122,062	17.7	2560	13.49	"
6	61,375	8.9	2400	13.49	"
7	84,053	12.2	2518	13.49	"
8	81,531	11.9	1867	13.49	"
9	313,186	45.4	436	6.08 3.94	Air Oxygen
10	5,963,974	865.0	755	24.17	Steam
11	8,469	1.4	316	19.50	Steam
12	6,668,650	967.0	450	24.17	Water
13	81,531	11.9**	477	17.36	Combustion Gas
14	N/A		N/A		21.015 MW A.C. Electricity
15	N/A		N/A		6.64 MW A.C. Electricity

*As indicated in Figure 3-2.

**An Induced Draft Fan is Required Upstream of Stack

Table 3-2. COIF 50 Mwt Case State Point Data

State* Point	Pressure N/m ²	psi	Temperature °K	Flow Rate kg/s	Composition
1	263,519	38.4	375	1.93 0.194	Coal Coal Carrier Gas
2	263,519	38.4	375	0.05 0.11	K ₂ CO ₃ K ₂ SO ₄
3	263,519	38.4	922	3.80 2.46	Air Oxygen
4	255,613	37.1	2849	8.43	Combustion Gas
5	107,075	15.5	2492	8.43	"
6	61,450	8.9	2358	8.43	"
7	84,240	11.2	2482	8.43	*
8	81,713	11.9	1867	8.43	*
9	271,425	39.4	417	3.80 2.46	Air Oxygen
10	4,240,305	615.0	714	15.25	Steam
11	5,081	0.8	306	12.70	Steam
12	4,741,320	687.7	427	15.25	Water
13	8,240	11.9**	477	10.85	Combustion Gas
14	N/A		N/A		10.978 MW A.C. Electricity
15	N/A		N/A		3.134 MW A.C. Electricity

*As indicated in Figure 3-2.

**An Induced Draft Fan is Required Upstream of Stack

Table 3-3. CVIF 80 Mwt MHD/Steam Integrated Test System Performance

Coal Thermal Input (Mwt)		80.0
MHD Oxidant Preheat Temperature (°K)		922.0
MHD Oxidant Oxygen Concentration (Mol %)		50.0
Power Generated (MWe)		27.6
MHD	6.6	
Turbine-Generator	21.0	
Power Consumed (MWe)		4.4
Magnet/Transformers/Pumps/etc.	0.2	
Oxidant Compressor	3.0	
Oxygen Plant	1.2	
Net Plant Power Output (MWe)		23.2
Total Heat Input to Steam (Mwt)		63.3
Plant Efficiency (%)		29.0

Table 3-4. CDIF 50 Mwt MHD/Steam Integrated Test System Performance

Coal Thermal Input (Mwt)		50.0
MHD Oxidant Preheat (°K)		922.0
MHD Oxidant Oxygen Concentration (Mol %)		50.0
Power Generated (MWe)		16.2
MHD	3.1	
Turbine-Generator	13.1	
Power Consumed (MWe)		2.7
Magnet/Transformers/Pumps/etc.	0.2	
Oxidant Compressor	1.9	
Oxygen Plant	0.6	
Net Plant Power Output (MWe)		13.5
Total Heat Input to Steam (Mwt)		40.3
Plant Efficiency (%)		27.0

More detailed state point and performance data for both the 80 and 50 MWt systems are given in Appendices B.1 and B.2. A detailed schematic, representative of both 80 and 50 MW_t systems, for CDIF is also included in Appendix B.

3.1.3 Plant Layout

The possibility of placing the 80/50 MWt MHD topping cycle in the "B" bay location was considered. But in the judgment of our facility and operation engineers, the location shown in Figure 3-3 will facilitate both construction and operation. A dedicated overhead crane can be included in the MHD building so that the magnet, diffuser, and channel can be readily handled. This arrangement also provides for handling the concerns about the fringe magnetic field resulting from the superconducting magnet. Finally, it allows for the greatest use of the "A" bay, both during construction and operation of the new test facility. The other side of the coin is the cost. This layout may cost more than an arrangement where the maximum use is made of the existing building. More detailed study, on this and other questions would be required to increase the precision of the cost estimates.

A summary of the CDIF modifications required is as follows:

- New air separation plant (physical isolation from the coal storage area by topsoil mounds to keep coal dust out of air separation plant area is recommended)
- Additional coal storage capacity, unloading and reclaiming capability, thaw shed and second railroad spur
- Additional coal preparation capacity with capability for continuous operation and recycling to achieve improved moisture control
- New building to house power train with blast walls on four sides, magnetic shielding and connections to existing slag handling system
- New steam generation and steam turbine buildings
- New power management (electronics) building which could include a new bulk power inverter if one is required
- New baghouse and/or precipitator and stack
- New compressor building

Figure 3-3. CDIF 80/50 MW_t Integrated Test System Plant Layout

- New seed reprocessor if on-site reprocessing is used
- Cryogenic equipment for superconducting magnet will be located in existing B test bay
- Control room will be in existing experimenters' area and office area adjacent to existing control room
- New instrument and control system will include integral data acquisition system

3.1.4 Design and Construction Schedule

Figure 3-4 is the design and construction schedule for the 80 Mwt integrated test system at CDIF. The 50 Mwt alternative would not be significantly different. This roughly five year schedule may be slightly impacted by winter weather primarily in the activities of modification, site preparation, and building construction. The actual start date could change this impact. With a more refined schedule, ways to work around this potential problem could be explored. The critical path flows through design, ordering and production of the MHD channel, installation, and check-out.

The assumptions and considerations used in developing the schedule are as follows:

- Specifications for long lead items will require priority attention during title II design.
- Obtaining permits and approvals should not produce a scheduler impact.
- The winter conditions are significant only when outside construction is involved; namely site preparation and building construction. The net effect of winter conditions at Butte is estimated to cause a 4-5 month extension to the overall schedule.
- System buy-off would proceed on an "area" basis rather than wait for completion of all construction/installation activities.
- The present CDIF control room would be expanded.
- Upon completion of system calibration, CDIF would be functionally ready for the start of test activities.

Figure 3-4. Construction Schedule CDIF 80 MW_t Integrated Test System

3.2 Task II - Integrated Retrofit MHD System

The objective, of this portion of the study effort, was to develop a preliminary conceptual design of retrofit integrated MHD test system to the level of detail necessary to provide performance characteristics of the system and to provide the basis for cost, schedule, and resource/risk assessments.

A 50 MWe MHD concept and a 40 MWe variation on the MHD concept were developed that are appropriate for use as retrofit integrated MHD test systems for the Montana Power Company's Frank E. Bird plant. As for the CDIF systems, the concepts are similar to the intermediate temperature preheating of oxygen enriched air system expected in early commercial coal-fired MHD/steam power plants. The considerations that led to the selection of the Bird plant and the MHD retrofit system selection are described in the following paragraphs.

Important general design requirements and constraints were as follows:

- Use of a representative plant consistent with a retrofit system configuration in which 50 MWe is produced by the MHD generator.
- Use of government-owned equipment where practical and cost effective.
- Major technical risk is acceptable.
- Concept shall be a substantially complete simulation of early commercial coal-fired MHD/steam power plants.
- Concept shall be capable of generating and supplying electricity to an electric utility grid.
- Maximum use shall be made of existing plant equipment.
- Retrofit should not interfere with steam bottoming plant operation.

In addition, a retrofit program should have the following goals, at a minimum, in order to make a significant contribution towards the commercialization of MHD:

- The MHD retrofit plant combination should be economically dispatchable by the host electric utility.
- Demonstrate MHD power train operation at a significantly larger size than CDIF and close to or at commercial size.
- Develop service and operating experience with a MHD/ steam power plant system.
- Establish control and power conversion characteristics of the MHD power train and its feed systems.
- Demonstrate emission control and characteristics.
- Demonstrate seed recovery and seed/slag handling.
- Demonstrate integrated MHD/steam power plant operation.
- Demonstrate MHD electric interfacing with steam turbine-generator output and net electrical dispatching.
- Demonstrate MHD topping cycle coupling to a steam bottoming cycle.
- Establish cost and operating/service requirements for a MHD/steam power plant.

Alternate MHD Integration Concepts

Previous MHD retrofit studies addressing considerations similar to those above have resulted in three broad approaches for a retrofit to an existing steam plant as in the earlier studies by Westinghouse⁶ and Gilbert/Commonwealth⁷.

The first approach envisions a MHD unit capable of producing the total full load steam rate required by the turbine generator utilizing the existing hot gas heat transfer equipment. Physical changes to the existing plant are held to a minimum. The concept is depicted in Figure 3-5. A comparison of the relative advantages and disadvantages for Approach No. 1 is given in Table 3-5.

The second approach utilizes a MHD unit with complete independence of the existing boiler fired plant. Feedwater is received from the existing plant and converted to steam and fed back to the main steam line to the existing turbine generator. The MHD unit may be of any desired size, supplying all of the steam

Figure 3-5. Approach No. 1 Integration Concept, Gas Connection (From Ref. 7)

Table 3-5. Advantages and Disadvantages - Approach No. 1,
Gas Connection Integration Concept

<u>Advantages</u>	<u>Disadvantages</u>
<ul style="list-style-type: none"> Maximum use of existing plant equipment. 	<ul style="list-style-type: none"> Directly impacts existing downstream components and must be capable of isolating MHD system with a shut-off "door."
<ul style="list-style-type: none"> Demonstration of full system of topping cycle using matched MHD coal fired system with steam generation and steam bottoming plant. 	<ul style="list-style-type: none"> The effects of introduction of MHD combustion products and seed into existing steam boiler systems have not been demonstrated. The risks to the existing steam plant steam generator equipment could be very high.
<ul style="list-style-type: none"> Meets goals (if successful). 	
<ul style="list-style-type: none"> Maximizes power output of plant. 	<ul style="list-style-type: none"> Compromises continued operation of the original steam plant firing system if the MHD plant shuts down.
<ul style="list-style-type: none"> Demonstrates downstream components with coal burning gas products and seed recovery/effects. 	<ul style="list-style-type: none"> Requires substantial modification of existing system to meet NO_x standards and recover seed.
<ul style="list-style-type: none"> Truly meets a topping cycle-configuration. 	<ul style="list-style-type: none"> Requires maximum space utilization and re-arrangements to interface existing boiler.

or only a portion of it. The concept is depicted in Figure 3-6. A comparison of the relative advantages to disadvantages for Approach No. 2 is given in Table 3-6.

The third approach was selected to assess the impact of selected system integrations with a MHD power plant of less than full steam rate capability and with simultaneous operation of the fossil boiler to produce a total steam rate compatible with the turbine generator. This approach would provide a parallel MHD system sufficient for demonstration, integrated in such a way that a maximum thermodynamic performance and benefits might be realized. Again, the guideline was to provide a minimal interference with the operation of the existing plant in its normal mode. This approach attempts to minimize the risk but includes the more significant thermodynamic integrations of the MHD system with the existing power plant systems. The concept is depicted in Figure 3-7. A comparison of the relative advantages and disadvantages for Approach No. 3 is given in Table 3-7.

As can be seen, Approach No. 1 and No. 3 are more advantageous from a purely MHD "point of view" than Approach No. 2. However, Approach No. 2 offers two very practical advantages. These are: (1) minimum interference with a host utility's existing steam system and (2) the MHD demonstration stage size can be somewhat independent of the existing steam system size. Because of these two practical advantages, Approach No. 2 was that selected for retrofit preliminary conceptual design.

Selection of Retrofit Steam Plant

Assuming current state-of-art design capabilities (Ref. 8), a scoping calculation indicates that a MHD power train of 50 MWe gross output will provide waste heat to generate about 700,000 pounds of steam per hour. If the electrical power from the MHD power train is used to power motors driving the main MHD cycle auxiliaries (the air separation plant and the oxidant compressor) then all the steam generated is available for steam bottoming plant use. On the other hand, if the main MHD cycle auxiliaries are steam turbine driven,

Figure 3-6. Approach No. 2. Integration Concept, Steam Connection (From Ref. 7)

Table 3-6. Advantages and Disadvantages - Approach No. 2,
Steam Connection Integration Concept

Advantages

- Can be of any size from full matching the existing plant steam conditions to minimal MHD demonstrated size.
- would allow reaching many, but not all program goals.
- would permit location of the MHD train in an area amenable to most effective maintenance, service, and component replacement.
- Does not interfere in the operation of the existing plant. Minimal integration provides flexibility in operation of both systems.
- It allows sizing the MHD plant at a rating where boiler firing and MHD are used simultaneously.

Disadvantages

- Does not demonstrate completely integrated systems.
- Does not provide maximum efficiency performance that would result from fully integrated plant heat system.

Figure 3-7. Approach No. 3. Parallel Integrated MHD System (From Ref. 6, Modified)

Table 3-7. Advantages and Disadvantages - Approach No. 3,
Parallel Integration Concept

<u>Advantages</u>	<u>Disadvantages</u>
<ul style="list-style-type: none"> • will allow for realizing most of the top level goals of a demonstration program. • Integration through low temperature gas lines, steam and water lines should allow location of MHD in an area amenable to most effective maintenance, service, and component replacement. • Could be constructed with minimal interference in the operation of the existing plant. • Thermodynamically superior system. • Existing boiler would be operational at all times. Part power when MHD operational. • Because existing boiler is operational at all times it can be escalated to full power rapidly to pick up loss from MHD system. • Maintains the simplicity of non-critical integration with the existing steam plant and provides for flexibility therefore in operation of both systems. 	<ul style="list-style-type: none"> • The approach will be most realistic using quite large steam plants, say 600 MWe or more. • Some risk associated with the integration of gas streams and feedwater train.

about 200,000 pounds of steam per hour will have to be diverted to the drive turbines. This leaves about 500,000 pounds per hour available for steam bottoming plant use.

In past studies^{6,7} three different plants have been considered for an MHD retrofit. These are: the Etiwanda plant of the Southern California Edison Co. and Corrette and Bird plants of the Montana Power Co. Nominal steam flow requirements* of the turbine generators for these plants are as follows:

<u>Plant</u>	<u>Nominal Steam Flow (pound per hour)</u>
Etiwanda	920,000
Corrette	1,170,000
Bird	530,000

Using retrofit Approach No. 2, previously outlined, any of the plants are suitable for MHD retrofit. However, it is obvious that the Bird Plant is the best choice if the retrofit MHD cycle is to provide all the heat required to operate the plant. This arrangement is closest to that of prospective early commercial MHD/steam power plants. Therefore, the Bird plant was selected as the representative plant for MHD retrofit conceptual design.

3.2.1 Concept Description

The Frank E. Bird plant owned by Montana Power Company has a turbine generator nameplate rating of 66 MW electric and its other characteristics are listed in Table 3-8.

The Bird plant is capable of operating over a wide range of steam flows and conditions from about 33% of nominal rating¹⁰ to about 125% of nominal rating¹¹. This offered the opportunity to use near optimum MHD parameters based on past studies⁹ with the steam plant conditions departing only slightly from nominal design conditions for electric power output and steam

*Other characteristics of the Bird and Etiwanda Plants are given in Table 3-8.

Table 3-8. Performance Characteristics of Existing Plants for Potential MHD Retrofits

	Frank E. Bird		Etiwanda Unit 1	
	Coal Fired	Existing Oil Fired	Coal Fired	Existing Oil Fired
POWER OUTPUT				
Gross Steam Power, MWe	68.2	68.2	124.4	124.4
Steam Cycle Losses, MWe	-6.8	-3.1	-11.4	-8.3
Net Plant Output, MWe	61.4	65.1	113.0	116.1
STEAM CONDITIONS				
Pressure/Main Steam Temp./ Reheat Temp. (psia/°F/°F)	865/900/-	865/900/-	1815/1000/1000	1815/1000/1000
Condenser Pressure, in. Hga	2.5	2.5	2.5	2.5
HEAT INPUT				
Fuel Type in Boiler	Coal	Oil	Coal	Oil
Existing Boiler Input, Mwt	230.8	225.6	341.4	333.7
Total Heat Input, Mwt	230.8	225.6	341.4	333.7
PERFORMANCE				
Net Plant Efficiency, %	26.6	28.9	33.1	34.8
Net Plant Heat Rate, Btu/KWH	12,816	11,811	10,311	9,807

flow while still holding design values of turbine inlet throttle pressure (850 psig) and temperature (900°F). Values selected for some important MHD parameters were:

Combustor Stagnation Pressure	5 ATM
Oxidant Oxygen Concentration	36 Mol %
Channel Inlet Mach No.	1.3
Channel Outlet Mach. No.	1.0

Per the previous discussion, a Bird plant arrangement using steam turbine drives on the main MHD cycle auxiliaries would provide the closest match to the nominal Bird plant steam cycle design point and a nominal 50 MWe gross from the MHD generator. This is a feasible arrangement at the Bird plant because the existing plant boiler could provide startup steam. However, based on past studies⁹, Westinghouse recommends that the main MHD cycle auxiliaries be electric motor driven in MHD/steam plants of this size. Both configurations were investigated at the preliminary conceptual design level even though using motor drives reduces the gross electric MHD generator output below 50 MWe for a matched MHD retrofit to the Bird plant. The two selected configurations of Bird plant MHD retrofit were modeled as shown in Figure 3-8.

In summary, the schematic of Figure 3-8 presents the two concepts for a MHD retrofit to Montana Power Co.'s Frank E. Bird Plant. The two concepts differ, primarily, in the means used to drive the oxidant compressor. In the "A" configuration, the oxidant compressor has a steam turbine drive. In the "B" configuration, the oxidant compressor is motor driven.

For the "A" configuration the existing Bird Plant boiler could be used as a source of startup steam. Once the MHD topping cycle has been started and stabilized, the Bird Plant boiler could be put on standby and the steam provided from the topping cycle to the bottoming cycle through the steam/feedwater interconnecting circuits. The steam/feedwater interconnections can be configured so as not to disturb the existing Bird Plant steam turbine, condenser, and feedwater heating subsystem relationships.

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Figure 3-8. Frank E. Bird Plant MHD Retrofit

The existing Bird Plant turbine is a single case, non reheat type, with four extraction points for feedwater heating steam. Inlet steam conditions are 865 psia, 900°F. The turbine nameplate rating is 66 MWe at a condenser pressure of 2.5" Hga.

Statepoint data at the locations shown in Figure 3-8 is summarized in Table 3-9 for the 50 MWe "A" configuration and in Table 3-10 for the 40 MWe "B" configuration.

3.2.2 System Performance

Overall performance values for the two alternate configurations proposed for Bird Plant MHD retrofit are given in Tables 3-11 and 3-12. Table 3-11 provides values for the "A" configuration. Table 3-12 provides values for the "B" configuration. Except for the change which results in an "A" configuration MHD topping cycle of slightly larger size than the "B" configuration, common assumptions were used for the two performance estimates. The common assumptions were:

- Supersonic MHD channel plasma Mach No.
- Superconducting magnet peak field strength of 6.5 Tesla
- Montana Rosebud coal dried to 5 percent moisture
- MHD/Power train diffuser outlet static pressure of 0.83 ATM
- Combustor inlet stagnation pressure of 5. ATM

More detailed statepoint and performance data for both of the retrofit configurations is given in Appendices B.3 and B.4. A detailed schematic of the "A" configuration is included in Appendix B.

3.2.3 Plant Layout

Figure 3-9 is the retrofit plant layout developed for the Frank E. Bird station. This arrangement was discussed with the operating personnel at the Bird station but it has not been reviewed with Montana Power Company management. An

Table 3-9. Retrofit 50 MWe "A" Configuration State Point Data

State* Point	Pressure N/m ²	psi	Temperature °K	Flow Rate kg/s	Composition
1	506,739	73.5	375	12.08 0.12	Coal Coal Carrier Gas
2	506,739	73.5	375	0.42 0.92	K ₂ CO ₃ K ₂ SO ₄
3	506,739	73.5	922	42.26 11.12	Air Oxygen
4	491,537	71.3	2782	67.19	Combustion Gas
5	197,862	28.7	2508	67.19	Combustion Gas
6	61,500	8.9	2199	67.19	Combustion Gas
7	84,708	12.3	2360	67.19	"
8	82,167	12.0	1867	67.19	"
9	521,941	75.7	530	42.26 11.12	Air Oxygen
10	5,963,974	865.0	755	61.03	Steam
11	82,167	12.0**	477	82.30	Combustion Gas
12	N/A		N/A		58.00 MW A.C. Electricity
13	N/A		N/A		48.371 MW A.C. Electricity

*As indicated in Figure 3-8.

**An Induced Draft Fan is Required Upstream of Stack

Table 3-10. Retrofit 40 MWe "B" Configuration State Point Data

State* Point	Pressure N/m ²	psi	Temperature °K	Flow Rate kg/s	Composition
1	506,739	73.5	375	10.55 1.05	Coal Coal Carrier Gas
2	506,739	73.5	375	0.37 0.80	K ₂ CO ₃ K ₂ SO ₄
3	506,739	73.5	922	36.91 9.71	Air Oxygen
4	491,537	71.3	2783	58.68	Combustion Gas
5	198,268	28.9	2504	58.68	Combustion Gas
6	61,500	8.9	2193	58.68	"
7	84,719	12.3	2355	58.68	"
8	82,177	11.9	1867	58.68	"
9	521,941	75.7	530	36.91 9.71	Air Oxygen
10	5,963,974	865.0	755	74.92	Steam
11	82,177	11.9**	477	77.88	Combustion Gas
12	N/A		N/A		66.00 MW A.C. Electricity
13	N/A		N/A		41.426 MW A.C. Electricity

*As indicated in Figure 3-8.

**An Induced Draft Fan is Required Upstream of Stack

TABLE 3-11
BIRD PLANT RETROFIT PERFORMANCE
("A" CONFIGURATION)

COAL THERMAL INPUT (MW_t)		316.4
OXIDANT PREHEAT TEMPERATURE ($^{\circ}K$)		922.0
OXYGEN CONCENTRATION (MOL %)		36.0
POWER GENERATED (MW_e)		114.9
MHD	48.4	
TURBINE-GENERATOR	66.5	
POWER CONSUMED (MW_e)		9.1
MAGNET/TRANSFORMERS/PUMPS/ETC.	0.6	
OXYGEN PLANT	8.5	
NET PLANT POWER OUTPUT (MW_e)		105.8
TOTAL HEAT INPUT TO STEAM (MW_t)		225.6
PLANT EFFICIENCY (%)		33.4

TABLE 3-12
BIRD PLANT RETROFIT PERFORMANCE
("B" CONFIGURATION)

COAL THERMAL INPUT (MW_t)		276.3
OXIDANT PREHEAT TEMPERATURE ($^{\circ}K$)		922.0
OXYGEN CONCENTRATION (MOL %)		36.0
POWER GENERATED (MW_e)		107.4
MHD	41.4	
TURBINE-GENERATOR	66.0	
POWER CONSUMED (MW_e)		18.8
MAGNET/TRANSFORMERS/PUMPS/ETC.	0.6	
OXYGEN PLANT	7.4	
OXIDANT COMPRESSOR	10.8	
NET PLANT POWER OUTPUT (MW_e)		88.6
TOTAL HEAT INPUT TO STEAM (MW_t)		196.9
PLANT EFFICIENCY (%)		32.1

Figure 3-9. Retrofit Integrated MHD Test System/Frank E. Bird Plant Layout

alternative arrangement, on the other side of the existing units, is a possibility that would not require modification of the switchyard, but it is our impression that the Figure 3-9 arrangement is more satisfactory to Montana Power. The choice of either alternative would have a minimal effect on the present capital cost estimate. Further study of the effect of the superconducting magnet fringe field on the power electronics, is necessary to settle on the final location of the power conditioning building. This location could affect the cost of cabling but this would be well within the uncertainty of the overall retrofit cost estimate.

A summary of the Bird Station modifications required for the retrofit is as follows:

- New air separation plant physically separated from coal, gas lines and oil tanks
- Provisions for coal feed from existing conveyor at top of west side of Unit No. 2 to the MHD combustor
- New coal preparation building with recycling and moisture control capability
- New compressor building with electric or steam turbine drives
- New MHD building to house power train with blast walls on four sides and magnetic shielding
- New cryogenics building for superconducting magnet
- New steam generation building
- New economizer, induced draft fan, precipitator (or baghouse) and stack
- New power electronics building--transformer may be in switchyard
- New control room to be added on top of existing structure west of Unit No. 1 with access cut through wall to existing control room
- Relocate existing road closer to railroad tracks
- Rework northwest corner of switchyard ring bus and relocate fence
- Remove or replace existing construction office, warehouse and garage buildings

- New instrument and control system including an integral data acquisition system

3.2.4 Design and Construction Schedule

Figure 3-10 is the design and construction schedule for the integrated retrofit test system at the Bird Station. This schedule is slightly shorter than the one for the integrated test system at the CUIF site. One reason is the assumption that the existing bottoming cycle equipment and systems at Bird will require very little time for modification and will also require less time for check-out. However, it also appears that the superconducting magnet is on the critical path. One can say that both schedules are about five years in length unless more detailed studies are carried out and correlated with the winter impact on construction.

Other assumptions and considerations used in developing the schedule are as follows:

- Specification for long lead items will require priority attention during Title II design.
- Obtaining permits and approvals requires priority attention in order to preclude scheduler impacts.
- Winter conditions at Billings are less severe than Butte. The next effect of winter conditions at Billings is estimated to cause a 2 month extension to the overall schedule.
- The retrofit project will not cause any significant interruption in the adjacent Corrette plant operation or utility customer service.
- System buy-off would proceed on an "area" basis rather than wait for completion of all construction/installation activities.
- Upon completion of system calibration, the retrofit Bird Plant system would be functionally ready for the start of test activities.

Figure 3-10. Retrofit Integrated MHD Test System Frank Bird Plant

4.0 CAPITAL COST/CONSUMPTION
ESTIMATES

2

-

2
1

1

1
2
1

4.0 CAPITAL COST/CONSUMABLE ESTIMATES

Capital cost estimates for the CDIF cases and the two alternate BIRD retrofit configurations were developed based on the conceptual designs described in Section 3.0. The basic cost estimates were prepared by exercising MHD/steam plant system codes which consisted of the NASA code TRANS 72 and two proprietary Westinghouse code packages (SPA and SUMARY).

The range of plant ratings in the present study extended beyond that examined in previous tasks under the MHD/APT Contract. As a result many component cost algorithms had to be modified and validated. Adjustments were also applied to represent the costs of first-of-a-kind plants. The cost data, for major components such as the magnet, channel, combustor, diffuser, power conditioning, and HRSR were adjusted based on communications with potential component suppliers.

A summary of the capital costs, in 1986 dollars, is given in Table 4-1. Detailed cost estimates, in the code of accounts format used in previous MHD studies, are shown in Table 4-2.

One question concerning the comparison between the 80 MW_t and 50 MW_t integrated test systems at CDIF was that of consumable costs. The consumable cost is proportional to the thermal rating of the system. However, the credit of power delivered to the utility system grid is also proportional to the overall test system efficiency. Therefore the ratio of power credit to consumable cost will be slightly higher for the larger 80 MW_t test system. The consumable costs and power credits per 1000 hours of operation for both CDIF systems is shown in Table 4-3.

TABLE 4-1. CAPITAL COST SUMMARY

	INTEGRATED TEST SYSTEM AT CDIF		RETROFIT WITH COMPRESSOR DRIVEN BY	
			STEAM	ELECTRIC
MW_t	80	50	316	276
MW_e (NET)	23	14	106	89
TOTAL CAPITAL COST* OF MODIFICATIONS AND NEW CONSTRUCTION	138	112	319	283

*DOLLARS IN MILLIONS, 1986 DOLLARS

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TABLE 4-2. CAPITAL COST ESTIMATES BY CODE OF ACCOUNTS,
THOUSANDS OF 1986 DOLLARS

	Integrated Test System At CUIF		Retrofit With Compressor Driven By	
			Steam	Electric
Nominal MWe (Net)	23 MWe	14 MWe	50 MWe	40 MWe
310 Land & Land Rights	6	6	-	-
311 Structures & Improvements	17450	11900	32437	30022
312 Boiler Plant Equipment	30000	25000	69000	60000
314 Turbine - Generator Units	7150	5210	6000	5020
315 Accessory Electric System and Equipment	3960	2260	7394	7009
316 Miscellaneous Power Plant Equipment	423	300	987	956
317 MHD Topping Cycle Equipment				
.1 Combustion Equipment	2580	2300	6700	5900
.2 MHD Generator System	6000	5000	17000	15000
.3 Magnet System	2000	2000	50000	40000
.4 Power Conditioning System	8000	7000	20000	18000
.5 Oxidizer System	3000	2800	5165	5000
.6 Seed System	5000	4000	20000	18000
.7 Oxygen Enrichment System	8730	6800	19800	18000
.8 Misc. MHD Support Equipment	3	3	-	-
350 Transmission Plant	4	3	1212	1114
Engineering & Integration	33000	29000	38000	36000
Owners Cost	3000	2280	10000	8000
Check out and Start up	8000	6000	15000	15000
<hr/>				
TOTALS	138306	111856	318695	283021

TABLE 4-3. CDIF CONSUMABLE COSTS PER 1000 HOURS OF OPERATION

	<u>Integrated CDIF Test System</u>	
MW_t	50	80
MW_e (Net)	14	23
<hr/>		
Coal @ 1.75 \$/MMBtu	299	478
Seed @ 6.80 \$/ton	144	230
Lime @ 6.50 \$/ton	11	17
<hr/>		
Total Consumable Cost	454	725
<hr/>		
Power Produced, 10^6 kWh	14	23
<hr/>		
Power Credit @ 50 Mill/kWh	699	1150
<hr/>		
Power Credit/Consumable Cost	1.54	1.59
<hr/>		

Note: All costs are in \$000 at current (1984) CDIF rates

5.0 RESOURCE/RISK ASSESSMENTS

5.0 RESOURCE/RISK ASSESSMENTS

The resource and risk assessments address the availability of major components and the degree of technical risk involved in their use for the CUIF or retrofit systems. The approach used for these assessments consisted of identifying the major components or equipment required for each system by the MHD plant code of accounts format. For the resource assessment, each equipment item required was evaluated and categorized as follows:

Equipment on site

- use without modification
- modification required

Equipment requiring procurement

- potential of used equipment
- standard equipment
- design/development required

The qualitative technology status rating criteria previously used by Westinghouse for MHD plant risk assessments was then applied to the CUIF and retrofit equipment items. The equipment risk categories for this technique can be summarized as follows:

- A - Established technology commercially available with no technical risk
- B - Confirmatory testing and minimal R & D required, minimal technical risk
- C - Data base incomplete and R & D is required but probability of success is good to excellent.
- D - Major uncertainties exist, extensive R & D is required, and success probability is fair to poor.

Further definition of the technology status ratings is given in Table 5-1.

TABLE 5-1
TECHNOLOGY STATUS RATING CRITERIA

TECHNOLOGY RATING	TECHNOLOGY STATUS	REQUIREMENTS FOR APPLICATION AT (A) TECHNOLOGY RATING LEVEL			R & D PROGRAM CHARACTERISTICS	
		PERFORMANCE DATA BASE	EXTRAPOLATION FROM PERFORMANCE DATA BASE	APPLICATION OR DEVELOPMENT PROGRAMS REQUIREMENTS	RATIONALE	SUCCESS PROBABILITY
ESTABLISHED (A)	FIRM SELECTIONS CAN BE MADE. EQUIPMENT IS COMMERCIALY AVAILABLE IN FORM REQUIRED.	SUFFICIENT	NONE	MINIMAL, ROUTINE APPLICATIONS ENGINEERING.	NOT APPLICABLE	NOT APPLICABLE
NEAR TERM (B)	A NUMBER OF EQUIPMENT CANDIDATES ARE IDENTIFIED. CANDIDATES ARE COMMERCIAL OR NEAR COMMERCIAL.	INCOMPLETE	SHORT EXTRAPOLATIONS FROM EXISTING DATA BASE ARE INVOLVED.	CONFIRMATORY TESTING AND MINIMAL R & D.	STRAIGHT-FORWARD	VIRTUALLY CERTAIN
DEVELOPMENTAL (C)	EQUIPMENT NOT PREVIOUSLY DESIGNED, BUT ENGINEERING DATA BASE EXISTS FOR DESIGN.	INCOMPLETE; IMPORTANT GAPS EXIST.	LARGE EXTRAPOLATIONS FROM EXISTING DATA REQUIRED.	CONSIDERABLE R & D IS REQUIRED.	A CREDIBLE RATIONALE EXISTS. ALTERNATIVE AVENUES ARE EVIDENT.	GOOD TO EXCELLENT
SPECULATIVE (D)	EQUIPMENT NOT PREVIOUSLY DESIGNED WITH MAJOR MATERIALS, DESIGN, OR MANUFACTURING UNCERTAINTIES.	SPARSE OR ABSENT	HIGHLY SPECULATIVE OR NOT POSSIBLE.	EXTENSIVE R & D IS REQUIRED.	RATIONALE IS NOT CLEAR, OR REQUIRES A BREAK-THROUGH OR SERENDIPITY.	FAIR TO POOR

For the purposes of the present study, the technical risk ratings of the key development components address both the performance levels required and the operating duration required to meet CDIF or retrofit system goals. Duration of the equipment is one of the most serious concerns in proceeding with the proposed systems designs given the present engineering data base and status of MHD technology. This concern is exemplified by the lack of design information and experience with components that are prototypical of commercial power plant equipment. The anticipated use of rubber hoses for high voltage isolation for long duration MHD operation is an example. Such equipment may be adequate for experiment and test purposes, but the adequacy for reliable long term utility plant operation is questionable. Table 5-2 summarizes the performance and duration risk assessments for the key developmental components of both the CDIF and retrofit systems. The complete resource and risk assessments for the all the major equipment items in both systems are given in Tables 5-3 and 5-5. The following paragraphs describe the resource/risk assessments in detail.

5.1 CDIF SYSTEM ASSESSMENT

An evaluation of the existing equipment and the additional equipment needed to construct 80 MW_t and 50 MW_t integrated MHD/steam test systems at the CDIF was carried out. The examination was done at the major component level using the FERC code of power plant accounts. In addition, for each major component identified, a qualitative assessment of its technology risk status was made.

80 MW_t Integrated MHD/Steam Test System

A set of component assessments, presented in qualitative form, of the needs and status of equipment for constructing an 80 MW_t integrated MHD/steam test system at the CDIF are given in Table 5-3. As can be seen, each major component required has been evaluated as to both its current presence or absence at the CDIF and its technology status rating. Further, existing CDIF components are divided into those that can be used without modification and those requiring modification. The additional equipment needed at the CDIF is categorized as either "used" or "new" equipment. The "used" category covers

TABLE 5-2
KEY COMPONENTS RISK RATING

	80/50 MW _{th} CDIF		50/40 MW _e RETROFIT	
	PERFORMANCE	DURATION	PERFORMANCE	DURATION
BOILER PLANT EQUIPMENT				
COAL & SEED FEED SYSTEM	C	C	C	C
SLAG & ASH HANDLING	C	C	C	C
STEAM GENERATING EQUIPMENT	B	C	C	C
MHD TOPPING CYCLE EQUIPMENT				
COMBUSTOR	B	C	C	D
COAL & SEED INJECTION SYSTEM	B	D	C	D
SLAG COLLECTION SYSTEM	C	D	D	D
NOZZLE	B	B	B	B
CHANNEL	B	D	C	D
DIFFUSER	B	C	C	C
MAGNET SYSTEM	B	B	C	C
POWER CONDITIONING & CONTROL				
CONSOLIDATION & CONTROL	C	D	D	D
CABLING	B	B	C	C
INVERTER	A	A	B	B
SEED REGENERATION	C	D	D	D
SEED INJECTION SYSTEM	B	D	C	D
PLANT CONTROL	D	B	D*	B*

*The design and development of the power train control system will be extensive. Conversely the anticipated use of proven components lends confidence that lifetime (duration) can be realized.

equipment which might be obtained from U. S. Government sources such as the U. S. Navy or a Public Utility participant in the program. The only specifically identified component in the "used" category is the superconducting magnet at the Argonne National Laboratory.

The "new" category indicates whether the additional equipment required at the CDIF is of a standard design nature or is a developmental item. A finer breakdown of the "used" category would require identification of the specific used components. In general, as implied by the technical status ratings assignments, it has been assumed that "used" equipment is of a standard design nature and can be installed essentially "as is." An exception to this is the superconducting magnet at Argonne National Laboratory (ANL) where a "C" technology rating has been applied.

There are at least two factors to consider when evaluating the technology rating. These factors are performance and duration. The lowest technology rating of either of the two factors is that given in Table 5-3. For example the ANL superconducting magnet has been tested; so its performance is not in question, only its life expectancy or duration.

In some component categories the existing CDIF equipment plus additional equipment will be required for a complete installation. Multiple check marks are used to indicate a mixed equipment situation of the foregoing or other mixed nature.

50 MW_t Integrated MHD/Steam Test System

The qualitative assessments of equipment status and technology ratings given in Table 5-3 for the 80 MW_t system apply equally well to 50 MW_t system except as follows:

TABLE 5-3

CDIF 80 MW_t INTEGRATED MHD/STEAM TEST SYSTEM EQUIPMENT STATUS AND TECHNOLOGY RATING

ACCT. NO.	ACCOUNT DESCRIPTION	EQUIPMENT ON SITE		EQUIPMENT FOR PROCUREMENT			FACILITY & EQUIPMENT RATING CLASSIFICATION				COMMENT
		USE WITHOUT MODIFICATION	MODIFICATION REQUIRED	USED	NEW		A	B	C	D	
					STANDARD EQUIPMENT	DESIGN & DEVELOPMENT REQUIRED					
310.0.0	LAND AND LAND RIGHTS	✓					✓				
311.0.0	STRUCTURES & IMPROVEMENTS										
311.1.0	IMPROVEMENTS TO SITE		✓				✓				
311.2.0	MAIN BUILDING						✓				
311.2.1	MHD BUILDING				✓		✓				
311.2.2	HR SR BUILDING				✓		✓				
311.2.2	POWER CONDITIONING SYSTEM BLDG.				✓		✓				
311.2.4	MAGNET REFRIGERATION BLDG.				✓		✓				
311.3.0	STEAM TURBINE BUILDING						✓				
311.3.1	GENERATOR BUILDING				✓		✓				
311.3.2	COMPRESSOR BUILDING				✓		✓				
311.4.0	COAL BUNKER/PROCESSING AREA		✓				✓				
311.5.0	SERVICE BUILDINGS		✓				✓				
311.6.0	OTHER PRCS BLDG. AND STRUCTURES				✓		✓				
311.7.0	CRANES AND HOISTS		✓	✓		✓	✓				SPECIAL HANDLING OF MHD CHANNEL
312.0.0	BOILER PLANT EQUIPMENT										
312.1.0	COAL HANDLING & PROCESSING		✓				✓				
312.1.1	UNLOAD/STORE/RECLAIM SYS.		✓				✓				
312.1.2	PULVERIZING & DRYING SYS.		✓			✓	✓	✓			CONTINUOUS DRY SYSTEM REQUIRES MODEST DEV. EFFORT
312.1.3	FEED SYSTEM					✓			✓		SPECIAL TO MHD COMBUSTORS
312.2.0	SLAG & ASH HANDLING					✓			✓		SPECIAL TO MHD COMBUSTORS
312.3.0	LIMESTONE HANDLING				✓		✓				
312.4.0	STEAM GENERATOR EQUIPMENT										
312.4.1	RADIANT BOILER					✓			✓		
312.4.2	SUPERHEATER					✓			✓		
312.4.3	OXIDANT PREHEATER					✓			✓		
312.4.4	ECONOMIZER/SECONDARY AIR HEATER					✓			✓		
312.4.5	SECONDARY AIR COMBUSTOR					✓		✓			
312.4.6	INSTRUMENTATION AND CONTROLS				✓		✓				
312.4.7	AUXILIARIES				✓		✓				
312.4.8	AUXILIARY BOILER				✓						

TABLE 5-3 (Continued)

CDIF 80 MW_t INTEGRATED MHD/STEAM TEST SYSTEM EQUIPMENT STATUS AND TECHNOLOGY RATING

ACCT. NO.	ACCOUNT DESCRIPTION	EQUIPMENT ON SITE		EQUIPMENT FOR PROCUREMENT			FACILITY & EQUIPMENT RATING CLASSIFICATION				COMMENT
		USE WITHOUT MODIFICATION	MODIFICATION REQUIRED	USED	NEW		A	B	C	D	
					STANDARD EQUIPMENT	DESIGN & DEVELOPMENT REQUIRED					
312.5.0	OTHER BOILER PLANT EQUIPMENT										
312.5.1	CONDENSATE AND FEED WATER SYSTEMS										
	MAIN CONDENSATE PUMPS & MOTORS			✓			✓				USED EQUIP. POSSIBILITY
	FEED WATER BOOSTER PUMPS & MOTORS			✓			✓				USED EQUIP. POSSIBILITY
	MAIN BOILER FEED PUMPS & DRIVES			✓			✓				USED EQUIP. POSSIBILITY
	BOILER FEED WATER PIPING			✓			✓				USED EQUIP. POSSIBILITY
	FEED WATER HEATERS				✓		✓				
	DEAERATORS				✓		✓				
312.5.2	WATER TREATMENT SYSTEM				✓		✓				
312.6.0	EFFLUENT CONTROL										
312.6.1	ELECTROSTATIC PRECIPITATORS				✓			✓			SEED COULD CAUSE CORROSION
312.6.2	FANS/DUCTING/STACK			✓	✓			✓			USED FANS, UTILITY OR NAVY SURPLUS
312.7.0	OTHER BOILER PLANT SYSTEMS										
312.7.1	PIPING/VALVES/TANKS			✓			✓				USED EQUIP. POSSIBILITY
312.7.2	MISC. BOILER PLANT				✓						
314.0.0	TURBOGENERATOR UNITS										
314.1.0	STEAM TURB-GEN. & ACCESSORIES			✓			✓				USED EQUIP. POSSIBILITY
314.2.0	CONDENSERS/AUXILIARIES				✓		✓				
314.3.0	CIRCULATING WATER SYSTEM			✓			✓				USED EQUIP. POSSIBILITY
314.4.0	STEAM PIPING SYSTEMS										
314.4.1	FEED WATER PIPING			✓			✓				USED EQUIP. POSSIBILITY
314.4.2	STEAM PIPING			✓			✓				USED EQUIP. POSSIBILITY
314.4.3	OTHER STEAM PLANT PIPING			✓			✓				USED EQUIP. POSSIBILITY
314.5.0	OTHER TURBINE PLANT & MECH. EQUIP.			✓			✓				USED EQUIP. POSSIBILITY
315.0.0	ACCESSORY ELECTRIC EQUIP.				✓		✓				MOTORS, SWITCHGEAR, CONDUIT, ETC
316.0.0	MISC. POWER PLANT EQUIP.				✓		✓				SAFETY SYSTEMS, OIL SYSTEMS, ETC
317.0.0	MHD TOPPING CYCLE EQUIP.										
317.1.0	COMBUSTION EQUIPMENT										
317.1.1	COMBUSTOR					✓			✓		
317.1.2	COAL & SEED INJECTION SYS.					✓				✓	
317.1.3	SLAG COLLECTION SYS.					✓				✓	

TABLE 5-3 (Continued)

CDIF 80 MW_t INTEGRATED MHD/STEAM TEST SYSTEM EQUIPMENT STATUS AND TECHNOLOGY RATING

ACCT. NO.	ACCOUNT DESCRIPTION	EQUIPMENT ON SITE		EQUIPMENT FOR PROCUREMENT			FACILITY & EQUIPMENT RATING CLASSIFICATION				COMMENT
		USE WITHOUT MODIFICATION	MODIFICATION REQUIRED	USED	NEW		A	B	C	D	
					STANDARD EQUIPMENT	DESIGN & DEVELOPMENT REQUIRED					
317.2.0	MHD GENERATOR SYSTEM										
317.2.1	NOZZLE					✓			✓		
317.2.2	CHANNEL					✓				✓	
317.2.3	DIFFUSER					✓			✓		
317.3.0	MAGNET SYSTEM			✓				✓			EXISTING AAL MAGNET
317.4.0	POWER CONDITIONING & CONTROL SYSTEM										
317.4.1	CONSOLIDATION & CONTROL					✓				✓	
317.4.2	CABLING					✓			✓		
317.4.3	INVERTER		✓					✓			SUBSTANTIAL MOD
317.4.4	XPMRS		✓				✓				MORE OR NEW
317.5.0	OXIDIZER SYSTEM										
317.5.1	OXIDANT COMPRESSOR				✓		✓				
317.5.2	OXIDANT DUCTING				✓		✓				
317.5.3	STEAM TURBINE DRIVE/ACCESS			✓			✓				USED EQUIP. POSSIBILITY
317.5.4	STEAM CONDENSATE SYSTEMING			✓			✓				USED EQUIP. POSSIBILITY
317.6.0	SEED SYSTEM										
317.6.1	SEED REGENERATION SYSTEM					✓				✓	
317.6.2	LIME STORAGE				✓		✓				
317.6.3	SLUDGE PUMP		✓				✓				
317.6.4	SEED INJECTION SYSTEM					✓				✓	
317.7.0	AIR SEPARATION PLANT			✓			✓				USED EQUIP. POSSIBILITY
317.8.0	MISC. MHD TOPPING CYCLE SUP. EQUIP.				✓		✓				
317.8.1	PUMP CONDENSER SYS.			✓			✓				USED EQUIP. POSSIBILITY, START UP EQUIP
317.8.2	PLANT CONTROL & DISPLAY					✓		✓		✓	DISPLAY "B" RATING, PLANT CONTROL "D" RATING
360.0.0	TRANSMISSION PLANT		✓				✓				

50 MW_t Exceptions to Table 5-3

<u>Account No.</u>	<u>Description</u>	<u>Equipment Status</u>	<u>Technology Rating</u>
311.2.1	MHD Building	Modification Required	A
311.2	Power Conditioning Building	Modification Required	A
311.3.2	Compressor Building	Use Without Modification	A
317.1.1	Combustor	Modification Required	C
317.1.2	Coal & Seed Injection System	Modification Required	C
317.1.3	Slag Collection System	Design & Development Required	D
317.5.1	Oxidant Compressor	Minor Modification Required	A
317.5.2	Oxidant Ducting	Minor Modification Required	A

A further comparison of the 80 and 50 MW_t CDIF options is given in Table 5-4.

5.2 RETROFIT SYSTEM ASSESSMENT

An evaluation of the existing equipment and the additional equipment necessary to make an integrated MHD/steam power plant of the Frank E. Bird Steam Power Plant of Montana Power Company was carried out. This modification would be done by retrofitting an MHD topping cycle to the existing Bird Plant steam bottoming cycle plus use of the adjacent coal handling facilities of the Corrette Steam Power Plant on the same site.

The assessment procedures and formats are the same as those used in the CDIF integrated MHD/steam test systems evaluation of Section 5.1.

Two sizes of MHD topping cycle were considered. They are: (1) an approximate 50 MWe MHD output and (2) an approximate 40 MWe MHD output. In the qualitative terms of this resource assessment there is no difference between the two sizes. The evaluation results for each of the major components of the retrofit MHD/steam power plant are given in Table 5-5.

TABLE 5-4
AFFECTED COMPONENTS FOR CDIF SYSTEM OPTIONS

COMPONENT	DELTAS DUE TO REDUCED RATING (80 TO 50 MW _t)
COMBUSTOR	CAN CONCENTRATE ON MODIFYING EXISTING DESIGN TO INCORPORATE FEATURES FOR HIGH TEMPERATURE COOLING, SLAG MANAGMENT AND DURATION
NOZZLE	NO DIFFERENCE IN RISK
CHANNEL	INCREASED STRUCTURAL SPACE EASES DEVELOPING FEATURES TO ENHANCE DURATION
DIFFUSER	NO DIFFERENCE IN RISK
POWER MANAGEMENT	NEGLIGIBLE DIFFERENCE IN RISK
INVERTER	CAN USE AS IS
HRSR	NEGLIGIBLE DIFFERENCE IN RISK
SEED SYSTEM	NEGLIGIBLE DIFFERENCE IN RISK
FACILITY	SLIGHTLY REDUCED COST OF MODIFICATION
GENERAL	50 MW _t ADEQUATE FOR DURATION TESTING. SCALE UP (PERFORMANCE) ISSUES NOT ADDRESSED. TOPPING/BOTTOMING INTERACTIONS ARE WEAKER

TABLE 5-5

BIRO PLANT MHD RETROFIT EQUIPMENT STATUS AND TECHNOLOGY RATING

ACCT. NO.	ACCOUNT DESCRIPTION	EQUIPMENT ON SITE		EQUIPMENT FOR PROCUREMENT			FACILITY & EQUIPMENT RATING CLASSIFICATION				COMMENT	
		USE WITHOUT MODIFICATION	MODIFICATION REQUIRED	USED	NEW		A	B	C	D		
					STANDARD EQUIPMENT	DESIGN & DEVELOPMENT REQUIRED						
310.0.0	LAND AND LAND RIGHTS	✓					✓					
311.0.0	STRUCTURES & IMPROVEMENTS											
311.1.0	IMPROVEMENTS TO SITE		✓				✓					ROADS, UTILITIES, AND BLOC REMOVAL CHANGES
311.2.0	MAIN BUILDING											
311.2.1	MHD BUILDING				✓		✓					SPECIAL DESIGN FEATURES
311.2.2	WHR BUILDING				✓		✓					SPECIAL DESIGN FEATURES
311.2.3	POWER CONDITIONING SYSTEM BLDG.				✓		✓					SPECIAL DESIGN FEATURES
311.2.4	MAGNET REFRIGERATION BLDG.				✓		✓					SPECIAL DESIGN FEATURES, N ₂ , H ₂ STORAGE
311.3.0	STEAM TURBINE BUILDING											
311.3.1	GENERATOR BUILDING		✓				✓					
311.3.2	COMPRESSOR BUILDING				✓		✓					
311.4.0	COAL BUNKER/PROCESSING AREA		✓				✓					MINOR "LIVE" STORAGE CHANGES
311.5.0	SERVICE BUILDINGS	✓			✓		✓					NEED MHD INSPECTION & REPAIR SHOP
311.6.0	OTHER PRCS. BLDG. AND STRUCTURES	✓			✓		✓					NEED SEED PROC. & AIR SEP. BLDGS.
311.7.0	CRANES AND HOISTS	✓		✓		✓	✓	✓				SPECIAL HANDLING MHD CHANNEL
312.0.0	BOILER PLANT EQUIPMENT											
312.1.0	COAL HANDLING & PROCESSING											
312.1.1	UNLOAD/STORE/RECLAIM SYS.	✓					✓					
312.1.2	PULVERIZING & DRYING SYS.				PULVERIZING	DRYING	✓	✓				DRYING SYS. REQ. MODEST DEV. EFFORT
312.1.3	FEED SYSTEM								✓			SPECIAL TO MHD COMBUSTION
312.2.0	SLAG & ASH HANDLING				✓		✓		✓			SPECIAL TO MHD COMBUSTION
312.3.0	LIMESTONE HANDLING				✓							
312.4.0	STEAM GENERATOR EQUIPMENT											
312.4.1	RADIANT BOILER						✓			✓		
312.4.2	SUPERHEATER						✓			✓		
312.4.3	OXIDANT PREHEATER						✓			✓		
312.4.4	ECONOMIZER/SECONDARY AIR HEATER						✓			✓		
312.4.5	SECONDARY AIR COMBUSTOR						✓		✓			
312.4.6	INSTRUMENTATION AND CONTROLS			✓			✓					
312.4.7	AUXILIARIES			✓			✓					
312.4.8	AUXILIARY BOILER	✓										

TABLE 5-5 (Continued)
BIRD PLANT MHD RETROFIT EQUIPMENT STATUS AND TECHNOLOGY RATING

ACCT. NO.	ACCOUNT DESCRIPTION	EQUIPMENT ON SITE		EQUIPMENT FOR PROCUREMENT			FACILITY & EQUIPMENT RATING CLASSIFICATION				COMMENT
		USE WITHOUT MODIFICATION	MODIFICATION REQUIRED	USED	NEW		A	B	C	D	
					STANDARD EQUIPMENT	DESIGN & DEVELOPMENT REQUIRED					
312.6.0	OTHER BOILER PLANT EQUIPMENT										
312.5.1	CONDENSATE AND FEED WATER SYSTEMS										
	MAIN CONDENSATE PUMPS & MOTORS	✓		✓			✓				MHD PORTION IS NEW/USED EQUIP. POSS.
	FEED WATER BOOSTER PUMPS & MOTORS	✓		✓			✓				MHD PORTION IS NEW/USED EQUIP. POSS.
	MAIN BOILER FEED PUMPS & DRIVES	✓		✓			✓				MHD PORTION IS NEW/USED EQUIP. POSS.
	BOILER FEED WATER PIPING	✓		✓			✓				MHD PORTION IS NEW/USED EQUIP. POSS.
	FEED WATER HEATERS	✓					✓				
	DEAERATORS		✓				✓				ADDITIONAL DEAERATION REQUIRED
312.5.2	WATER TREATMENT SYSTEM		✓				✓				ADDITIONAL CAPACITY REQUIRED
312.6.0	EFFLUENT CONTROL										
312.6.1	ELECTROSTATIC PRECIPITATORS				✓			✓			SEED COULD CAUSE CORROSION
312.6.2	FANS/DUCTING/STACK			✓	✓			✓			USED FANS, UTILITY OR NAVY SURPLUS
312.7.0	OTHER BOILER PLANT SYSTEMS										
312.7.1	PIPING/VALVES/TANKS			✓			✓				
312.7.2	MISC. BOILER PLANT	✓			✓						MHD PORTION IS NEW
314.0.0	TURBOGENERATOR UNITS										
314.1.0	STEAM TURB.-GEN. & ACCESSORIES	✓					✓				
314.2.0	CONDENSERS/AUXILIARIES	✓					✓				
314.3.0	CIRCULATING WATER SYSTEM		✓				✓				REQUIRES LARGER PUMPS/INTAKES/ DISCHARGES
314.4.0	STEAM PIPING SYSTEMS										
314.4.1	FEED WATER PIPING		✓	✓			✓				MHD PORTION IS NEW
314.4.2	STEAM PIPING		✓	✓			✓				MHD PORTION IS NEW
314.4.3	OTHER STEAM PLANT PIPING		✓	✓			✓				MHD PORTION IS NEW
314.5.0	OTHER TURBINE PLANT & MECH. EQUIP.	✓		✓			✓				MHD PORTION IS NEW
315.0.0	ACCESSORY ELECTRIC EQUIP.	✓			✓		✓				MOTORS, SWITCHGEAR, CONDUIT, ETC.
316.0.0	MISC. POWER PLANT EQUIP.	✓			✓		✓				SAFETY SYSTEMS, OIL SYSTEMS, ETC.
317.0.0	MHD TOPPING CYCLE EQUIP.										
317.1.0	COMBUSTION EQUIPMENT										
317.1.1	COMBUSTOR					✓			✓		
317.1.2	COAL & SEED INJECTION SYS.					✓				✓	
317.1.3	SLAG COLLECTION SYS.					✓				✓	

0.0 PRELIMINARY MANAGEMENT PLANS

6.0 PRELIMINARY MANAGEMENT PLAN

Characteristics of a proposed Management Plan for an integrated MHD/steam system program are discussed in the following order: 1) major management responsibilities, 2) DOE management options, 3) contract organization, and 4) management plan logic (flow of work). Important points about the Management Plan are then summarized.

6.1 MAJOR MANAGEMENT RESPONSIBILITIES

The major management objective (and responsibility) is the successful design construction, checkout, and initial operation of an integrated MHD/steam power plant system at acceptable cost and within a reasonable time. Such a plant system, in work breakdown format, is illustrated in Figure 6-1 for an integrated MHD/steam plant to be constructed at the CDIF (Study Task I). A work breakdown structure for an MHD/steam system by retrofit to an existing utility steam plant (Study Task II) would differ only slightly from the CDIF structure. The differences would be largely in the degree of effort required in each of the major categories. Both systems are most complex and this complexity must be incorporated into the detail of the Management plan.

To achieve the major objective, it will be most important to select and implement an overall management concept that will effectively direct the engineering, fabrication, modification, erection, installation, personnel training, and facility operation to the common goal. It is recommended that the management concept be a minimized version of PMS (Program Management System) where form is selectively sacrificed without sacrificing function by delegating responsibility for implementation at the lowest practical level with rigorous discipline of line management.

Whatever overall management concept is implemented must be organized to effectively carryout such responsibilities as:

- Work planning and budgeting

Figure 6-1. CDIF MHD/Steam System Work Breakdown Structure

- Preparation of designs and design specifications for plant, systems, and components
- Quality Assurance
- Safety
- Preparation of bid packages and purchasing
- Cost and schedule control
- Program variance analysis/change control
- Support to Facility Management
- Follow/support to subcontractors and vendors

6.2 DOE MANAGEMENT OPTIONS

Creating a first of a kind integrated MHU/steam system is a major engineering project. A review of the major engineering projects from the pyramids of Inhotep to NASA's Space Shuttle might turn up almost as many engineering management styles as projects. However, for the MHU project there are three pertinent options. These are:

- DOE lets a single prime contract
- DOE lets multiple contracts including a Technical Integrator contract
- DOE lets multiple contracts and retains Technical Integrator responsibility

Of the above, it is recommended that DOE use the single prime contract approach. The single prime contract approach minimizes parallel and temporary DOE staffing. It also encourages strong and disciplined line management which can be held accountable for both omissions and commissions. The system integration function is built into the contractual relationship with the single prime contract approach.

However, if the multiple contract approach must be used, because of an absence of suitable prime contractors or other reasons, a strong separate Technical

Integrator function and contract should be employed. This recommendation is based on the (W) CDIF Engineering and Integration experience. The CDIF was designed and equipped via the multiple contract route. It proved necessary to put a technical integration contract in place to insure plant completeness and satisfactory resolution of interface problems. The merit of the technical integration contract was demonstrated by the early identification of plant items that were not in fabrication, or even under contract, in the amount of four million dollars. Had these items not been identified, the CDIF schedule would have suffered and costs increased.

6.3 CONTRACT ORGANIZATION

A prime contract type organization suitable for producing integrated MHD/steam systems either at the CDIF or at utility retrofit site is given in Figure 6-2. Under this arrangement the prime contractor scope includes design, modification of existing facilities, production or procurement of new equipment, construction of new facilities, and the check out of new and modified systems plus the responsibility of carrying out these efforts in a timely and cost effective manner. The responsibilities of the Facility Operator, either a utility or Mountain States Energy (MSE) at the CDIF, would be to: support the project as required; maintain the existing facility; and to operate the integrated MHD/steam system when completed.

The Figure 6-2 Program Organization shown is of a conventional type. The Project Manager reports directly to the contractor's General Manager who in a large company would most likely be a Division General Manager. The Project Manager has a staff Program Control group that prepares, plans and budgets, directives and project releases, and monitors cost and schedule against project progress.

In this diagram the Project Manager has dotted line responsibility for Services, Safety and Product Assurance. Services include Contract Administration, Accounting, Purchasing, Traffic and Shipping, etc. As this MHD program will be a fairly large one, particularly in the construction stage, the

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Figure 6-2. Program Organization

Project Manager might have direct line responsibility for most services, but probably should not have direct line responsibility for Accounting, Safety, or Product Assurance because of possible "conflict of interest."

The engineering aspects of the program are the responsibility of the Project Engineer who reports directly to the Project Manager. Reporting to the Project Engineer are the organizational elements shown in Figure 6-2.

Typical activities under Plant Engineering are preparation and maintenance of the plant design, preparation and maintenance of the system specification, preparation and maintenance of the interface control document, presentations at design reviews, and preparation of input to technical and progress reports.

Typical activities of Component Engineering are preparation and maintenance of equipment specifications, preparation of technical input to requests for proposals for equipment, technical evaluation of proposals for equipment, technical liason with equipment suppliers, liason with Architect Engineer personnel regarding specific equipment, input to Plant Engineering or components, and technical input to technical and progress reports. It is customary to assign each component to a specific cognizant engineer so that lines of responsibility and authority are clearly defined.

As the MHD Program is a fairly large one with specification, interface control documents, and plant and equipment descriptions originating in diverse groups and sites, a centralized Document Control group is advisable. In Figure 6-2 it is shown as a "line" group but could be equally well a "staff" group reporting to the Project Engineer. The Document Control group would also be responsible for the preparation of technical and progress reports and making arrangements for Design Reviews and making sure that Design Review "actions" are cleared thereafter. The actual conduct of the Design Reviews would be under the control of Product Assurance as would the final "say" as to the resolution of Design Review "actions".

Typical activities of the Architect Engineer and Constructor (depending upon the selection of a firm, these activities may be conducted by the same organization) are modifications of the structures of the existing facility, modification of existing equipment, design and installation of small piping and valves, installation of wire and cable and equipment, and checkout of the finished equipment, systems, and plant with the assistance of the Facility Management and the Contractor's Technical Site Representative.

The Technical Site Representative, with support from the Contractor's organization and vendors as required, provides a ready source of expert consultation to the Contractor during installation and checkout of equipment and systems.

6.4 MANAGEMENT PLAN LOGIC

The Management Plan Logic outlined is based on the single Prime Contractor approach. It is applicable to either a Utility retrofit program or to a CUIF program when the term "By DOE" is defined as "By Joint Management" where appropriate. The logic diagram of the Plan is illustrated in Figure 6-3, as is typical of such programs it is to be conducted in three phases:

Figure 6-3a, Phase I, The Preparatory or Initiation Phase

Figure 6-3b, Phase II, The Design Phase

Figure 6-3c, Phase III, The Construction and Checkout Phase

As can be seen specific points for DOE action, such as review and approval of plans and designs, are called out during Phases I and II. Such specific DOE actions during Phase III would be required only if severe technical problems or major technology changes occur and can be handled on a "case by case" basis.

Figure 6-3a. Management Plan Logic - Phase I

Figure 6-3b. Management Plan Logic - Phase II

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Figure 6-3c. Management Plan Logic - Phase III

In addition to the items shown in the logic diagram there are many more activities that are to be carried out as a part of the Management Plan. Some of the more important of these are:

- Prepare and submit technical, programmatic and financial reports as required by contract.
- Support facility management in plans and preparation for visitor facilities as required by contract
- Provide presentations to DOE, and others, as required by contract
- Maintain project records, including as-built drawings
- Support facility management in establishing and maintaining technical interface with a utility, if required

6.5 MANAGEMENT PLAN SUMMARY

The overriding Management Plan responsibility is to provide for the successful design, construction, checkout, and initial operation of an integrated MHD/steam power plant. The MHD/steam system has many complexities and interfaces as well as being of a developmental nature. In addition to general conventional plan responsibilities, these complexities and interfaces result in a great number of detail management responsibilities. Each of these must be incorporated into the Management Plan for prompt and orderly execution.

The work (Management Plan Logic) of the program divides naturally in to three phases. These are:

Phase I - Initiating or Preparatory Phase

Phase II - Design Phase

Phase III - Construction and Checkout Phase

Because of the program size, a mini-PMS (Program Management System) should be used to control the work.

These are three prominent options of overall management approach to the program that need to be considered by the DOE. These are:

- DOE lets a single prime contract
- DOE lets multiple contracts including a Technical Integrator contract
- DOE lets multiple contracts and retains Technical Integrator responsibility

The single prime contract approach is recommended as that most likely to result in program success. This is because:

- It promotes the use of strong and disciplined line management
- It minimizes the DOE management staffing required at all levels of the program but particularly at the lower program levels
- The System Integrator function is built into the prime contractual relationship
- It facilitates prompt and effective action on problems and problem areas

7.0 REFERENCES

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