MHD Advanced Power Train

Phase I Final Report

Volume 2
Development Program Plan

Prepared For

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

Contract DE-AC22-83PC60575

AUGUST 1985

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Government Technical Project Officer:

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AUGUST 1985

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1.0 INTRODUCTION AND SUMMARY

1. INTRODUCTION AND SUMMARY

This development program plan has been prepared by the Westinghouse team in partial completion of the Task III Work Scope, "Definition of a Program Plan for MHD Advanced Power Train Development." The contract expresses the requirement as follows:

"Using the information generated in Tasks I and II as a basis, the contractor shall define a program plan for the development of an MHD Advanced Power Train. This will be accomplished by demonstrating the required performance at the 50-100 MW(t) level and having developed the framework of performance requirements, scaling relations, and the design basis to proceed to the 200 MW(e) power plant with confidence".

MHD/steam power plant studies performed in Task I indicated that the performance goal for a power train of a 200 MW(e) power plant would be 70 MW(e) dc output, and the MHD channel lifetime goal would be at least 4000 hours. A related evaluation of the state of technology revealed that, to date, demonstrated performance has been limited to 2 - 3 MW(e) dc output from a 50 MW(t) power train, and demonstrated MHD channel lifetime is less than a thousand hours. Further, these studies showed that significant channel cost reductions will be required to meet an economic breakeven goal between a coal fired MHD/steam power plant and a modern coal/steam power plant.

These results led to the judgment that two scale-up steps are required, i.e. the 50 MW(t) power train and an additional higher powered advanced power train, before the 200 MW(e) power plant could be designed and constructed with reasonable risk. Scale-up in lifetime also is extended further at each step.

The development program plan, described herein, is constructed to respond to these three needed program elements: a) The design, and demonstration test of a 50 MW(t) power train that verifies channel life, b) The design, development

and demonstration of an advanced power train in a 250 MW(t) plant facility, and c) The development of the technology for advanced MHD generators that are economic of magnet warm bore, reliable for at least 4000 hours of operation, and are amenable to automated production to meet the low cost goal. An implicit program element, Base Technology provides support, as appropriate, to the three aforementioned major program elements.

The sum of the results of these elements is judged to be adequate to: a) demonstrate the required performance including lifetime, and b) provide the design basis to proceed to the 200 MW(e) power plant with confidence, by creation of the needed engineering data base.

The development program plan uses a systems engineering approach that has been proven repeatedly as a cost effective methodology for executing of large and complex development programs. In summary, this approach proceeds to expand, in successive levels of detail, the development program requirements and directives from top level objectives established for early commercial power plants.

The plan for management and technical execution places major emphasis on integration of the three elements into a single synergistic project, which is the most effective approach to complete the development of MHD in the shortest schedule and at the lowest cost. Opportunities to utilize each test facility to the fullest practical extent have been and will continue to be identified.

The overall program, leading to the delineation of the engineering data base for the design of the power train for the 200 MW(e) MHD/steam power plants, requires 11 years. Key milestones include: a) The proof-of-concept power train system integration including 500 hours life at the 50 MW(t) level, b) demonstration of high power and high enthalpy extraction in a special test device, c) demonstration of a 50 MW(t) power train, with a superconducting magnet, d) demonstration of power train integration in the 250 MW(t) total plant, and e) delineation of the engineering data base, that includes a low cost and reliable channel design. It can be seen that the development program plan is focussed, compressed, and hardware oriented. Although the schedule is

based on a successful program, there are decision points identified that will prevent costly phases from being initiated without an adequate basis. The integrated plan that has, as its foundation, the MHD R & D programs that have been conducted up to the present time, and it utilizes those MHD development organizations, test facilities and equipment that exist in the U. S. This results in a cost effective program and continues to build the industrial base needed for commercial MHD power.

Innovative approaches to the design and development of the MHD generator (the integrated MHD channel and power conditioning systems) are factored into the development plan. These approaches were identified in the course of the Task II effort. They offer the potential for significant reduction in the cost of the superconducting magnet (the major cost component in the MHD topping cycle), and for enhancing the lifetime and reliability of the power train components, especially the channel.

Innovative approaches to the technical integration effort also have been identified and will be applied. A typical example is the use of computer aided design (CAD). This versatile tool has found extensive use in the aerospace industry in complex design and development programs, can reduce the cost of drawings, and has many more potential cost saving uses. CAD can take the place of expensive mock-ups and models, resulting in significant savings and allowing almost instantaneous illustration of alternatives in design approaches. It can also be an effective communication tool where design and development activities are underway at more than one location.

The management plan for the direction and control of the program makes full use of the total U.S. MHD capability and provides for active participation by the utility community. The plan can utilize the extensive Westinghouse experience in participating with foreign organizations in power systems development programs to implement potential international cooperation agreements.

The cost estimate, for the three element, 11 year, power train development program is \$278 million in 1984 dollars, excluding test facilities operation. The elements are estimated to cost: A) 50 MW(t) power train - \$78 million,

b) retrofit power train - \$122 million, and c) advanced channel development and demonstration - \$78 million. In addition to these three elements for the engineering development program, the actual testing hours are estimated to cost \$10 million, modification of existing test facilities is estimated at \$40 million and the cost of the retrofit facility exclusive of the power train components, which were given above, is estimated at \$242 million. The development plan is presented in the following sections: 2.0 - Background, 3.0 - Work Breakdown Structure to the fourth level, 4.0 - Program Management Plan, and 5.0 - Cost Estimate.

2.0 BACKGROUND

2.0 BACKGROUND

2.1 NATIONAL NEED

During the first half of CY-84, a consensus developed within the U. S. Department of Energy, the U.S. Office of Management and Budget and the MHD Industrial Forum that engineering and technology development of coal fired MHD energy conversion should go forward with specific goals. This consensus was evidenced by a series of public meetings sponsored by the DOE's Office of Fossil Energy. The results of the consensus are manifested by an agreement on the budgeted level of DOE funding for MHD development in FY-85 and by the outline of long range goals intended to lead to commercialization of MHD power plants.

MHD has the potential for solving some of the nation's pressing problems associated with the production of electricity. As a topping stage on a conventional steam turbine generator plant, MHD increases plant efficiency and decreases environmental intrusion and can be an effective way to convert oil or gas fired units to coal firing. Thusly, resource (coal) conservation and cleaner air simultaneously can be gained by the use of combined cycle, coal fired plants that use MHD as the topping stage.

2.2 MHD PLANT SYSTEMS

A schematic diagram of the major systems in an MHD power plant is shown in Figure 2-1. As indicated on the figure, engineering development is needed on three of these major systems: the MHD power train and magnet, the heat recovery/seed recovery (HRSR) system and the seed reprocessing system. The remaining plant systems use established technology commonly used by electric utilities (e.g., coal handling equipment and steam turbine generators) or other industrial concerns (e.g., air separation plants). The development program plan defined in this report is confined by contractual provisions to the MHD Advanced Power Train (APT). Similar plans for the HRSR and seed

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Figure 2-1. MHD Plant — Major Systems

reprocessing systems will be needed to completely define the needed development efforts for MHD Power Plants. The superconducting magnet will require engineering development also and should be included with the power train.

2.3 MHD PROGRAM PHASES

Over this century, our nation's experience in power, aerospace, and electronic industries has established a pattern in the overall development of new technologies. This pattern follows through several logical program phases as depicted in Figure 2-2. Though the time scale for each stage is technology dependent, the phases have common features as follows: 1) basic and applied research where feasibility is established through scientific analysis and research, and the study of engineering concepts; 2) preliminary engineering includes the development of a technology base and testing of components and "breadboard" systems; 3) engineering development includes selection of materials with specific and well defined properties, compiling of detailed engineering and production data and information, determination of scaling bases, integration of components and systems, and development of instrumentation and controls; 4) large system experiments confirm viability of the engineering approach, provide initial operating experience and strengthen scaling and economic bases; 5) a commercial demonstration prototype or preproduction version of the plant is built and final assurance (to the market) that commercialization is attractive is gained; 6) commercial application occurs only after the earlier phases have transpired.

MHD technology is now largely ready to move into the third or engineering development phase. As stated earlier, this report is intended as a roadmap for the power train portion of this engineering development. In addition, this report will outline some key power train related aspects of the plant integration phase.

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Figure 2-2. MHD Program Phases

2.4 PERSPECTIVES FOR PROGRAM PLANNING

It is important to supplement the APT plan with broader perspectives so that it can be viewed properly as part of a larger national endeavor. Accordingly, we have highlighted herein a set of eight points that are intended to provide this broader perspective:

1. MHD offers the potential for response to national needs, including direct combustion of coal, clean air, balance of payments, and low cost electric energy.
2. Engineering concepts for all power train components have been demonstrated.
3. A key element in developing an MHD program is the demonstration of component durability (lifetime).
4. Engineering development must be pursued including:
 - Development and producibility of durable and cost effective components, and
 - Integration of components into proof-of-concept systems, and
 - Integration of systems into the prototype plant design.
5. The goals and objectives for the plant integration phase, along with the base-line conceptual design of the proof-of-concept integration facility, are needed to define specific requirements for the engineering development efforts.
6. Three key systems must be developed and integrated:
 - The MHD power train, including the superconducting magnet,
 - The heat recovery/seed recovery (HRSR), and
 - The seed regeneration

Specific interface definitions, among these three systems, are required as part of the design and development of the power train and its components. These three systems should be developed on the same time schedule because they are so intimately interrelated.

7. The steam bottoming plant and the oxygen enrichment system do not require development, but interfaces with these systems must be considered.

8. Engineering studies and development are required for:

- Operation with various coals
- Off-Design operation
- Transient analysis
- Plant control systems
- Total plant integration
- Maintainability
- Availability
- Permitting
- Operability
- Cost of plant and energy

From these eight points, none is more important to ultimate viability of MHD than the demonstration of component durability. As a result, the APT development plan stresses the attainment of successful life tests of major components, especially the channel.

3.0 PROGRAM PLAN FOR MHD DEVELOPMENT

3.0 PROGRAM PLAN FOR MHD DEVELOPMENT

3.1 OVERVIEW AND SCOPE

To reach a point of technology readiness so that early or near commercial MHD power plants can be designed and built, there will be a period of several years where engineering development has a dominant role. Thereafter, a second period that can be called the plant integration phase dominates. Of course, some level of engineering development will transpire during the plant integration phase and visa versa. These phases are shown schematically in Figure 3-1. Both phases need to focus on providing system requirements and the engineering data base that must be gained before the nation is ready to make use of early commercial MHD plants.

The major elements that need to be included in an overall MHD development program are listed in Table 3-1. Within each of these general elements are a number of subelements that are specific to MHD technology or the integration of the MHD topping stage within a power plant. As discussed earlier in Section 2.4, the development plan described herein is confined to defining the R&D efforts needed on APT only. Companion plans will be needed on other aspects of MHD related technology e.g., heat recovery/seed recovery. Preparation of those documents, however, is outside the scope of the present APT contract.

The development program, detailed herein, is provided in accordance with the contract and work scope directives. In that context, it has been assumed that the power train program will be conducted as an independently managed program rather than as part of an overall MHD plant development program. This assumption results in several significant impacts on the plan. It requires the inclusion of studies of the total plant along with scale-down studies, setting of goals and objectives for the retrofit plant, and establishment of power train and channel engineering data bases. It requires the establishment of tentative interfaces with the remainder of the plant, including vital components such as the magnet and the HRSR systems.

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Figure 3-1. Engineering Development and Plant Integration Program Phases — MHD Aspects

TABLE 3-1
MHD ENGINEERING DEVELOPMENT PROGRAM ELEMENTS

PLANT AND SYSTEM STUDIES

- COMMERCIAL PLANT REQUIREMENTS
- TEST SPECIFICATIONS
- UP-GRADE OF DATA BASE

SUPPORTING TECHNOLOGY

- SLAG AND SEED CHEMISTRY
- MATERIALS ENGINEERING (PROCESSES & SPECIFICATIONS)
- DIAGNOSTIC DEVELOPMENT
- COMPUTER SIMULATION AND ANALYSIS

COMPONENTS

- COMBUSTOR
- CHANNEL
- DIFFUSER
- POWER MANAGEMENT AND INVERTER
- HEAT RECOVERY, HEAT EXCHANGERS
- SEED RECOVERY EQUIPMENT
- SEED REGENERATION EQUIPMENT

COMMERCIAL PROTOTYPE SYSTEMS

- POWER TRAIN
- HEAT RECOVERY/SEED RECOVERY
- SEED REPROCESSING

FACILITIES

- OPERATION
- MAINTENANCE
- MODIFICATION

INTEGRATED PLANT DESIGN

- CONCEPTUAL
- PRELIMINARY
- DETAIL

Several of the activities shown in this plan are logically and more efficiently carried out in the plant prime contractor scope, because the results apply beyond the power train scope. Westinghouse, therefore recommends (see Section 4) that when a prime plant contract is put in place, that the work scopes be adjusted accordingly.

A Work Breakdown Structure (WBS) has been selected, for the Power Train Program, to facilitate the correlation of the WBS elements with the anticipated project management organization. This approach provides for the clear delineation of authority and responsibility for technical results, within assigned schedules and resources.

The contract work scope, for Task III, directs that development be considered at specific power levels - 20, 50, 80 and 250 MW(t). This was done, and the resulting plan describes activities at 20 MW(t), 50 MW(t) and retrofit (probably 250 MWt) ratings. There are no plans to test at 80 MW(t). Ready cross correlation between the WBS elements and these ratings is provided. Activities within the WBS tasks are subdivided to show the plans at each rating.

3.2 WORK BREAKDOWN STRUCTURE

To accomplish the work required on APT during the engineering development phase and a portion of the plant integration phase, a Work Breakdown Structure (WBS) has been defined in considerable detail. The first and second levels of this WBS are shown graphically in Figure 3-2. In addition, a tabular listing of the WBS through the fourth level is shown in Table 3-2. In Figure 3-3, an overall schedule is shown for the APT Development Program when structured by the three major program elements described earlier.

A detailed schedule for the program is shown in Figure 3-4 by WBS to the fourth level. A legend on Figure 3-4 indicates the correlation of the program elements with each task or subtask in the WBS. The Base Technology efforts shown in Figure 3-4 support each of the three major program elements as required throughout the entire program.

Figure 3-2. Work Breakdown Structure
First and Second Level

TABLE 3-2

DETAILED WORK BREAKDOWN STRUCTURE
(Through Fourth Level)

WBS

1000 APT ENGINEERING DATA BASE

1100 POWER TRAIN INTEGRATION

- 1110 PLANT STUDIES
 - 1111 200 MW(e) Analyses
 - 1112 Retrofit and Test Power Train Analyses
- 1120 RETROFIT POWER TRAIN CONCEPTUAL DESIGN
 - 1121 Definition of Goals and Objectives
 - 1122 System Description & Specification
 - 1123 Component Specifications
- 1130 50 MW(t) POWER TRAIN CONCEPTUAL DESIGN
 - 1131 Endurance Power Train
 - 1132 Power Train in Superconducting Magnet
- 1140 50 MW(t) POWER TRAIN INTEGRATION
 - 1141 Endurance Power Train
 - 1142 Power Train in Superconducting Magnet
- 1150 RETROFIT POWER TRAIN INTEGRATION
 - 1151 Title I
 - 1152 Title II
 - 1153 Title III
- 1160 POWER TRAIN TECHNOLOGY DEVELOPMENT
 - 1161 Assembly/Disassembly
 - 1162 Operation and Maintenance Studies
 - 1163 Thermal/Mechanical Forces Analyses
- 1170 ENGINEERING DATA BASES
 - 1171 Plant Engineering Data Base
 - 1172 Power Train Engineering Data Base

1200 MHD GENERATOR INTEGRATION

- 1210 ANALYSIS AND MODELING
 - 1211 Numerical Simulation of Generator Experiments
 - 1212 Plasmadynamics, Physics, Scaling, Critical Experiments
 - 1213 Numerical Design Support

TABLE 3-2 (Continued)
DETAILED WORK BREAKDOWN STRUCTURE
(Through Fourth Level)

- 1220 DESIGN AND INTEGRATION
 - 1221 Endurance Generator
 - 1222 Development Generators
 - 1223 Retrofit Generators

1300 CHANNEL DEVELOPMENT

- 1310 TECHNOLOGY DEVELOPMENT
 - 1311 Plasmadynamics
 - 1312 High Interaction and Power Experiments
 - 1313 Materials Engineering
 - 1314 Electrical/Mechanical Development
- 1320 ENDURANCE CHANNEL
 - 1321 Design
 - 1322 Construction
 - Channel 1
 - Channel 2
 - 1323 Installation and Test Support
 - 1324 Data Analysis
- 1330 DEVELOPMENT CHANNELS
 - 1331 Design
 - 1332 Construction
 - 1333 Installation and Test Support
 - 1334 Data Analysis
- 1340 RETROFIT CHANNELS
 - 1341 Conceptual Designs
 - 1342 Design
 - 1343 Construction
 - Channel 1
 - Channel 2
 - Channel 3
 - Channel 4
 - 1344 Installation and Test Support
 - 1345 Data Analysis
- 1350 FABRICATION AND ASSEMBLY DEVELOPMENT
 - 1351 Electrodes
 - 1352 Insulation
 - 1353 Box Structure
 - 1354 Cable and Connectors
 - 1355 Instrumentation
 - 1356 Overall Assembly

TABLE 3-2 (Continued)
DETAILED WORK BREAKDOWN STRUCTURE
(Through Fourth Level)

1400 POWER CONDITIONING DEVELOPMENT

1410 TECHNOLOGY DEVELOPMENT

- 1411 Channel Interface Characterization
- 1412 High Power Experiment
- 1413 Materials Tests

1420 50 MW(t) POWER MANAGEMENT

- 1421 Design
- 1422 Build and Factory Test
- 1423 Installation
- 1424 Subsystem Test
- 1425 Integrated Test

1430 RETROFIT POWER MANAGEMENT

- 1431 Conceptual Design
- 1432 Design
- 1433 Build and Factory Test
- 1434 Installation
- 1435 Subsystem Test
- 1436 Integrated Test

1440 50 MW(t) DC/AC CONVERTER DESIGN AND SUPPLY

- 1441 Design Review
- 1442 Design Modifications
- 1443 Utility Interface Review
- 1444 Utility Interface Equipment
- 1445 Build and Factory Test Converter Modification
- 1446 Installation
- 1447 Subsystem Test
- 1448 Integrated Test

1450 RETROFIT DC/AC CONVERTER DESIGN AND SUPPLY

- 1451 Conceptual Design
- 1452 Design
- 1453 Utility Interface Definition
- 1454 Utility Interface Equipment
- 1455 Build and Factory Test Converter
- 1456 Installation
- 1457 Subsystem Test
- 1458 Integrated Test

TABLE 3-2 (Continued)
DETAILED WORK BREAKDOWN STRUCTURE
(Through Fourth Level)

XXXX MAGNET DEVELOPMENT

1500 COMBUSTOR DEVELOPMENT

- 1510 20 MW(t) COMBUSTOR
 - 1511 Design and Fabrication
 - 1512 Component Testing
 - 1513 Integrated Power Train Testing
 - 1514 Materials Testing with Downstream Components
 - 1515 Data Reduction and Analysis
- 1520 50 MW(t) DEVELOPMENT COMBUSTOR
 - 1521 Design and Fabrication
 - 1522 Check-out Testing
 - 1523 Integrated Power Train Testing
 - 1524 Data Reduction and Analysis
- 1530 50 MW(t) PROTOTYPE COMBUSTOR
 - 1531 Design and Fabrication
 - 1532 Component Testing
 - 1533 Endurance Testing
 - 1534 Tests with Superconducting Magnet
 - 1535 Data Reduction and Analysis
- 1540 RETROFIT COMBUSTOR
 - 1541 Conceptual Design
 - 1542 Design and Fabrication
 - 1543 Instrumentation
 - 1544 Facility Modification
 - 1545 Component Testing
 - 1546 Installation and Integrated Testing
 - 1547 Data Reduction and Analysis

1600 DIFFUSER DEVELOPMENT

- 1610 TECHNOLOGY DEVELOPMENT
 - 1611 Cold Flow Tests
 - 1612 High Power Experiment
- 1620 50 MW(t) DEVELOPMENT DIFFUSER
 - 1621 Design and Fabrication
 - 1622 Integrated Power Train Tests
 - 1623 Data Reduction and Analysis

TABLE 3-2 (Continued)

DETAILED WORK BREAKDOWN STRUCTURE
(Through Fourth Level)

- 1630 50 MW(t) PROTOTYPE DIFFUSER
 - 1631 Design and Fabrication
 - 1632 Component Testing
 - 1633 Endurance Testing
 - 1634 Test with Superconducting Magnet
 - 1635 Data Reduction and Analysis
- 1640 RETROFIT DIFFUSER
 - 1641 Conceptual Design
 - 1642 Design and Fabrication
 - 1643 Check-out Tests
 - 1644 Installation and Integrated Testing
 - 1645 Data Reduction and Analysis

1700 INSTRUMENTATION AND CONTROL DEVELOPMENT

- 1710 TEST INSTRUMENTATION
 - 1711 Test Instrument Data Base
 - 1712 Test Plan Instrument Reviews
 - 1713 Instrument Development
 - 1714 Test Experience Documentation
- 1720 OPERATIONAL INSTRUMENTATION
 - 1721 Measurement Requirements Lists
 - 1722 Test Instrument Design Upgrades
 - 1723 New Instrument Qualification
 - 1724 New Instrument Application Data
 - 1725 Improved Data Display Development
 - 1726 Retrofit Plant Instrumentation
- 1730 RETROFIT CONTROL SYSTEM
 - 1731 Conceptual Design
 - 1732 Design
 - 1733 Control System Performance Studies
 - 1734 Retrofit Plant Control System Procurement
 - 1735 Installation, Operation and Test Support

1800 COORDINATION OF TESTING FACILITIES (GFE & OTHERS)

- 1810 20 MW(t) TESTS
 - 1811 Integrated Power Train
 - 1812 Materials Testing in Downstream Components

TABLE 3-2 (Continued)
DETAILED WORK BREAKDOWN STRUCTURE
(Through Fourth Level)

1820 50 MW(t) TESTS
1821 Development Combustor and Diffuser
1822 Endurance Power Train
1823 Development Power Trains
1824 Interface Liaison

1830 RETROFIT TESTS
1831 Combustor
1832 Power Conditioning
1833 Integrated Power Train

1840 OTHER INTEGRATION AND LIAISON
1841 High Power Experiment
1842 Technology Liaison

1900 PROGRAM MANAGEMENT

1910 PROJECT PROGRESS REVIEWS

1920 ORAL REPORTING

1930 TECHNICAL AND FINANCIAL REPORTING

1940 PROJECT MANAGEMENT

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Figure 3-3. Program Schedule

Figure 3-4. Detailed Schedules

MHD POWER TRAIN

Figure 3-4. Detailed Schedules

MHD POWER TRAIN

Figure 3-4. Detailed Schedules

Figure 3-4. D

Both Figure 3-3 and Figure 3-4 indicate three sets of major program milestones. The first these major milestones (A) occurs at the end of the third year and has two related parts: the retrofit power train conceptual design is to be complete, and this design package is to be submitted to DOE along with a request for DOE to initiate cost and facilities funding (CFF) submittals to the Congress.

The second set (B) of major milestones occurs at the end of the fourth year and is made up of five items. Four of these items must be satisfied before Title I design of the retrofit power train can be initiated: (1) the prototype (50 MWt) combustor and diffuser will have been demonstrated, (2) the durability of the channel wall will have been shown via the 500 hour endurance test, (3) the power management system will have been demonstrated (via the same test) and (4) power train scale up effects will have been experimentally verified via the high enthalpy extraction test. The fifth item in this set is not required to initiate Title I, but is vital to proceed with the next generation of channels. In this fifth item, the first of the developmental channels will have been built for subsequent testing in the SCM at CDIF.

The third set (C) of major milestones has two related parts and occurs at the end of the eleventh year: at that point, the retrofit plant will have been demonstrated by power plant operation and, a commercial prototype MHD generator will have been validated via tests in the retrofit power train.

In addition to these three sets of major program milestones, Figure 3-4 shows a number of significant technical milestones and the normal (contractural related) reports and deliverable items.

3.3 SUMMARY DESCRIPTIONS OF WORK BREAKDOWN STRUCTURE

This section contains summary descriptions of the WBS shown in Figure 3-2 and Table 3.2. These summary descriptions provide pertinent background and an overview of the WBS at the second level. Appendix D provides detailed work statements written to the WBS fourth level. In some cases, the detailed work statements are carried to an additional WBS level (level five) beyond the four levels listed in Table 3-2.

WBS 1100 POWER TRAIN INTEGRATION

A system engineering approach will be used in the execution of the MHD Advanced Power Train Development Program. The power train integration task will: (1) integrate all the power trains to be designed; (2) provide system engineering support for the management and direction of power train construction and testing; and (3) analyze the power train development and test results by assembling the results into an engineering data base.

The reference 200 MW(e) MHD/steam plant has been designed and analyzed using a Westinghouse proprietary computer code package. Additional analyses of the plant will be performed to insure that the plant (and especially the power train) can be operated in all of the necessary off-design conditions to meet the needs of the utility application. These analyses will be performed using modified versions of the code package.

The technical goals and objectives, for the retrofit power train, will be delineated and submitted for customer approval. The 200 MW(e) plant design will be scaled down to the Retrofit rating and off-design operating conditions will be considered to insure that the test program can provide the requisite operational data.

The retrofit conceptual design will be documented in a Retrofit Power Train System Description and Specification, similar to that already prepared for the 200 MW(e) Power Train. The internal and external interfaces of the power train components will be delineated in this document. Equipment Specifications, for each power train component will be prepared, consistent with the

retrofit power train system descriptions and specifications. This process will be continued for each power train to be built and tested in the program. The resulting specifications will be modified as required by results obtained in the development activities.

The component design and development activities will be integrated to insure that each properly reflects specifications and correctly interfaces with other power train and plant/facility activities. This will be accomplished by establishing liaison with other programs and participation in the project progress review and change control processes.

WBS 1100 will work closely with the Coordination of Testing Facilities task (WBS 1800). It also will support the Program Management task (WBS 1900) in project reviews, change control, technical documentation control and report preparation.

WBS 1100 is structured in seven tasks: WBS 1110, Plant Studies; WBS 1120, Retrofit Power Train Conceptual Design; WBS 1130, 50 MW(t) Power Train Conceptual Design; WBS 1140, 50 MW(t) Power Train Integration; WBS 1150, Retrofit Power Train Integration; WBS 1160, Power Train Technology Development; and WBS 1170, Engineering Data Bases.

WBS 1200 MHD GENERATOR INTEGRATION

The MHD generator is an assembly, consisting of the channel, the power conditioning subsystem, and the superconducting magnet. Most aspects of this assembly must be taken into consideration, essentially as a unit, to realize optimum MHD generator designs.

The magnet should be included in Phase II of the Advanced Power Train (APT) contract. The exclusion of the magnet from the scope of the power train, as defined in Phase I of the contract, made it necessary to assume characteristics, including the configuration of the magnet, in order to carry out the Phase I APT effort. While this information, along with calculations and conceptual design effort, has been sufficient to date, the execution of

the development program will require definitive specifications on the magnet. The optimum MHD generator can be realized only by engineering tradeoffs among the channel, magnet and power conditioning. The importance of including the power conditioning subsystem as a component of the MHD generator, arises from the potential advantages in channel design associated with close integration of these components. One example is the possibility that the channel may be shortened by ~ 20 per cent if the anode-to-anode voltage can be properly controlled through the power management subsystem.

There are two broad tasks included in WBS 1200, Analysis and Modeling (WBS-1210) and Design Integration (WBS-1220). The analyses and modeling in WBS 1210 also will support the channel and power conditioning development tasks. The analytical efforts require consideration of most of the aspects of the generator assembly. The development plan is organized to reflect this requirement since it applies both to the design and performance of power train test equipment and to the design and performance of MHD plants.

The tasks in WBS-1220 provide overall direction for MHD generator component design and integration of the generator components into the power train. Information that must flow from the combustor design to the MHD generator subsystem design and from the MHD generator design to the diffuser design will be processed within WBS 1220. Also, there will be interaction of the MHD generator design integration with Power Train Integration (WBS-1100) and Coordination of Test Facilities (WBS-1800).

The design, fabrication, installation, and testing of generator components have been placed in other WBS elements; channels in WBS-1300, and power conditioning in WBS-1400. The magnet is a yet unspecified WBS element.

WBS 1300 CHANNEL DEVELOPMENT

Development of the channel is vital to successful establishment of the engineering data base for MHD/power trains and the ultimate commercialization of MHD steam power plants. The nozzle, which serves as a transition component between the combustor and channel, is being treated as part of the channel. Channel development efforts, to date, have been conducted along two parallel

paths--demonstration of performance (rating) and demonstration of life (endurance). WBS-1300 will continue and extend this approach to bring the two results together to demonstrate the achievement of performance and life. WBS 1300 will implement the development of rugged, reliable and cost effective channels that will be necessary for power trains to meet the requirements of the utility application.

"Proof-of-concept" channels will be based largely on state-of-the-art technology. These proof-of-concept channels do not require the economy of warm bore, ease of installation, or low cost that ultimately must be provided in commercial channels. WBS 1300 does include the fabrication and assembly development efforts needed to obtain the complete engineering data base for the commercial channels. WBS 1300 will be closely coordinated with the power conditioning development task (WBS 1400) via the MHD generator integration efforts described under WBS-1200.

WBS 1300 is predicated on the research and preliminary design phases of channel development that have been essentially completed and on the extensive capability for channel development that exists in the U.S. This capability will be utilized to reduce the cost and time of the remaining channel development efforts.

Channel development has been structured into five tasks: WBS 1310, Technology Development; WBS 1320 Endurance Channel; WBS 1330 Development Channels; WBS 1340 Retrofit Channels; WBS 1350 Fabrication & Assembly Development.

WBS 1400-POWER CONDITIONING DEVELOPMENT

The power conditioning system provides the interface equipment to combine the electric output from the hundreds of MHD channel electrode pairs, and condition this DC output into three phase AC power (at the voltage required) for interfacing with the utility grid.

An approach to power conditioning has been devised by Westinghouse that performs these functions and offers additional advantages. This approach has

the potential to control either the voltage or the current of each electrode, and has the flexibility to modify these controls in response to the operating mode of the MHD generator or to the local condition of channel electrodes. These advantages are expected to enhance performance, and especially lifetime, of MHD channels and to allow significant reductions in cost of channels and magnets. The portion of the power conditioning designed to perform both the current collection and the control of the channel power is designated the "power management system" to distinguish it from the less versatile concept of current consolidation and control.

WBS 1400 will encompass the efforts required to define and develop the power management system and the efforts to provide power conditioning equipment for expected power train tests. These tests will use a power management system except in the case of the high power/high enthalpy extraction experiment where the resistive dissipation network type will be used since the tests will be of short duration.

WBS 1400 is structured into five subtasks: WBS 1410, Technology Development; WBS 1420, Power Management for 50 MW(t) power train; WBS 1430, Retrofit Power Management, WBS 1440 - 50 MW(t) DC/AC Converter Design and Supply, and WBS 1450, Retrofit DC/AC Converter Design and Supply.

WBS 1500 COMBUSTOR DEVELOPMENT

Critical performance requirements of slagging MHD combustors include: generation of a high, and uniform, plasma electrical conductivity through efficient combustion with low heat losses; maintaining a high overall system efficiency through the minimization of pressure drops; and controlling slag deposition and flow to achieve high slag rejection rates.

Major issues related to combustor development are design and construction to utilize high pressure - high temperature boiler feedwater for shell cooling; design of a continuous slag removal system and, electrical isolation of the combustor system at the high voltages generated by the power channel. Other combustor development issues include operation with a variety of coals,

sensitivity to coal moisture, effects of the fringe magnetic field on combustor life and plasma velocity and conductivity profiles at the combustor exit.

Cost effective development of the combustor dictates that existing test facilities should be utilized with modifications as required. Information obtained from early tests will provide the data base for the design of larger combustors. Development work leading to acceptable combustors for integration into commercial plants encompasses tests at nominal levels of 20, 50, and a nominal 250 MWt. WBS 1500 has been structured into four major tasks: WBS 1510, 20 MWt development combustor; WBS 1520, 50 MWt development combustor; WBS 1530, 50 MWt prototype combustor; and WBS 1540, retrofit combustor. Each of these tasks is intended to demonstrate, via tests, the adequacy of designs at the various power levels.

Under WBS 1510, a continuous slag removal system with provision for electrical isolation will be designed and fabricated. An external voltage will be applied to simulate MHD operation, and different isolation techniques will be investigated. The combustor will be tested with an integrated MHD channel for at least 100 hours. This system will consist of the same type hardware as was used in the CFC/channel testing in 1982, with the addition of the continuous slag removal system. The combustor will then be integrated with a materials test channel and the downstream heat recovery system at CFFF and tested.

WBS 1520 will verify the tubular-membrane wall design concept utilizing high pressure - high temperature boiler feedwater for cooling, select the proper design approach for the second stage section operating under a fringe magnetic field, evaluate performance and verify computer model predictions. A spool section of tubular-membrane wall design, a second stage with appropriate design for the section under the magnetic field, and an electrically isolated continuous slag removal system will be integrated with the slagging combustor first stage at CDIF. Power train testing with the existing CDIF channel will be performed to evaluate performance of the combustor and slag removal system and flow diagnostics.

The objectives of WBS 1530 will be to design and fabricate a 50 MW(t) prototype coal combustor and to perform endurance testing in an integrated power train. The prototype combustor will be designed based on commercial practice satisfying the safety, life and operational requirements. This combustor will consist of the coal feed hopper system, preheater, first stage, second stage and slag rejection system (with redundancy). It will undergo development testing at nominal and off-nominal operating conditions as part of the endurance tests. The combustor system will be tested for over 500 hours with the endurance generator to verify the integrity of the fabrication technique. The erosion effects due to current in the fringe field areas and the long term operation of the slag removal system will be further investigated in subsequent testing with development generators.

Under WBS 1540 a 250 MW(t) retrofit combustor will be designed and built for operation in a retrofit power plant facility. This power level is large enough to obtain specific details and to generate an adequate data base for later manufacture of commercial MHD combustors. The 5:1 scale up from the 50 MW(t) prototype combustor will verify scaling laws and aid in refining computer models. Integrated testing will provide information on performance and response of the combustor to load variations typical of a power plant. The experience gained during this task will provide the engineering data base to commercialize the MHD combustor technology.

WBS 1600-DIFFUSER DEVELOPMENT

The MHD diffuser has to operate under stringent fluid mechanical conditions, under the fringe magnetic field and at elevated temperatures. The main fluid mechanics issues associated with MHD diffusers are inlet Mach numbers very close to transonic, high inlet boundary layer blockages, possibility of separated boundary layers at the electrode walls and velocity overshoots at the side walls. These conditions are not typical of conventional diffuser practice. Therefore, the design of MHD diffusers requires that a data base be defined for these conditions. As a component of a power plant, the MHD diffuser should be able to operate at off design conditions without appreciable performance penalty. Further issues related to the diffuser design are:

(1) use of high pressure, high temperature boiler feed water as the coolant, (2) operation under the fringe magnetic fields high enough to produce currents that can cause wall erosion, (3) allowances for thermal expansion of components downstream of the combustor and (4) removal of the MHD channel for replacement or refurbishment.

The development of the diffuser has to encompass both fluid mechanical characterization and design/development. The former involves integrated testing, and cold flow modeling to verify the behavior of the diffuser under simulated MHD conditions. The diffuser cannot be tested completely as an independent component since its operation depends strongly on the inlet gas stream conditions. Whenever the MHD channel is tested, the diffuser also will be tested in the power train. By instrumenting the diffuser for wall pressure measurements and pitot pressure measurements in the core flow (preferably a pressure traverse), performance information will be obtained. Total heat rejection to the diffuser wall will be obtained by calorimetry (cooling water flow rate and temperature rise) without interfering with power train testing.

Four tasks are planned under WBS 1600. The first of these is WBS 1610, technology development. This task includes cold flow studies the effects of thick and separated boundary layers and velocity overshoots on diffuser pressure recovery, and the effects of high inlet Mach numbers on diffuser performance. Testing is to be conducted with a one-half scale model of a 20 MW(t) diffuser using hot air. The effect of Mach number on diffuser performance also will be investigated. Testing of the diffuser for the high power extraction generator will provide detailed information to aid in scaling to larger size diffusers.

Under WBS 1620, 50 MW(t) Development Diffuser, the main objectives will be to verify performance and computer model predictions at 50 MW(t) and, to verify the tubular-membrane wall design concept using high pressure, high temperature boiler feed water for wall cooling.

WBS 1630, 50 MW(t) Prototype Diffuser, will permit life testing in an integrated power train and the erosion and corrosion due to the magnetic field and

the integrity of fabrication to be investigated. This diffuser will have a tubular-membrane wall construction and will include the replaceable section under the magnetic field. This diffuser will represent a small scale version of the design planned for the retrofit plant.

WBS 1640, Retrofit Diffuser, will involve the design, fabrication, and testing of a larger diffuser in a retrofit plant. The power level, nominally 250 MW(t), is large enough to obtain specific details to commercialize the MHD diffuser technology. Further, the 5:1 scale up from the 50 MW(t) diffuser will permit scaling verification and refining of computer predictions. The design of this diffuser will be based on the previous experience with the 50 MW(t) prototype diffuser. The tubular-membrane wall diffuser will employ boiler feed water for cooling. The specific details of this testing will depend upon the site and facility location of the retrofit plant. Integrated testing will provide information on performance and response to load variations typical of power plant operation.

WBS 1700 INSTRUMENTATION AND CONTROL DEVELOPMENT

Each power train will require instrumentation to monitor performance and controls to assure proper operation. Data processing and the generation of control signals will take place in a number of distributed microprocessors. The microprocessors will be interconnected by a data highway to allow information exchange with each other, with data logging facilities and with central control room. Analytical studies will be performed to develop control strategies that will be verified during integrated power train tests. Non-operational test instrumentation also will be required during both component and power-train testing. Test and operational instrumentation will be provided as required for operations at development facilities and a complete set of instrumentation and control equipment will be provided for the power train in the retrofit plant.

WBS 1700 has been structured into three major tasks: WBS 1710, test instrumentation development; WBS 1720, operational instrumentation development and WBS 1730, retrofit control systems development.

WBS 1710 will assure that appropriate diagnostic instrumentation is identified or developed for use during APT development testing. This instrumentation will permit the performance of power train equipment and systems to be characterized so that an adequate engineering data base can be obtained for the design of commercial MHD power trains.

A body of prior experience in making the anticipated kinds of measurements is available from work done in MHD and related fields. This experience will be utilized to the maximum extent possible, but much of the future experimental work will be at higher power levels and will involve the use of a superconducting magnet. Established sensing and signal transmission techniques will be evaluated for use under these magnetic field conditions. Alternative methods of sensing parameters and transmitting and processing this information will be investigated. New hardware to meet program needs will be developed where neither industrial nor laboratory equipment can be identified.

Integrated power train testing will involve the collection of data of interest to more than one group of designers, particularly where the data are being taken to define interfaces and interactions between major components or systems. Meeting this need could involve special measurements that may not be required for a power train in a commercial plant. Similarly, instrumentation hardware performance will be evaluated following each test. In this manner, a data base experimental instrument technology as applied to MHD will be established.

The objectives of WBS 1720 will be to assure that: (1) appropriate instrumentation is identified or developed to provide the sensory inputs to the operational control, protection and monitoring systems, (2) functional data displays and operational instruments are available for the retrofit power train, and (3) the engineering data base for the design of operational instrumentation for commercial MHD power trains is obtained.

Many measuring instruments available as standard items are now in use in industry and utility applications. These state-of-the-art instruments will meet many conventional measurement needs and will require no further

development other than the normal evolutionary improvements that occur in the competitive marketplace. Due to the strong magnetic field, high DC voltages and magnet bore space limitations associated with MHD power trains, development of some new operational instruments is anticipated. The performance of these new instruments will be demonstrated to provide a sound technical basis for their application in the retrofit and ultimately in commercial MHD power plants.

The objectives of WBS 1730 will be (1) to develop control strategies and logic for the integrated power trains, (2) to provide control system equipment for a power train in a retrofit plant, and (3) to demonstrate that a sound engineering basis exists for the integration of power train control systems into commercial MHD power plants.

A conceptual design subtask of WBS 1730 will identify the controls required to operate power train components and supporting systems. Operating descriptions will be prepared outlining the functions and anticipated performance of major components and systems during manual and automatic control configurations.

A power train simulation and analysis will be performed under WBS 1110. The predictions from the mathematical models of the power train control system developed in that task will be exercised to show how the power train control system will respond under a full range of steady state and, transient, conditions. Different control system configurations and adjustments will be used until acceptable operation and a satisfactory control system design has been achieved. A final design description, drawings, and specifications will be prepared describing the design and detailing the requirements for the hardware with which it will be implemented.

WBS 1800 COORDINATION OF TESTING FACILITIES (GFE & OTHER)

The objective of this task is to coordinate the APT work with pertinent testing and other activities at component developers, National laboratories, and government owned MHD facilities. A good understanding of the results of these tests is essential to the APT development and the engineering data base

for MHD/power trains. The various tests required in GFE facilities will be identified by the cognizant engineers for all of the WBS elements. Test description packages, including justification, requirements, desired schedules and anticipated results will be established in this cooperative effort. These packages will be provided for required approvals and will be implemented through the appropriate GFE facility. Coordination between facility operators and cognizant engineers will be provided under WBS 1800, and timely production and delivery of test hardware will be coordinated. Coordination will be provided to the facility operator in modification of facilities, preparation of test plans and other test related activities. Technical assistance will be provided to the facility operators during installation, check out, start up and operation of the tests.

Tests are anticipated in MHD facilities at several performance levels. Studies performed during Phase I of the contract have confirmed that tests needed at 20MW(t) include the slag rejection combustor, integrated power train, and materials tests for downstream components. APT studies also have confirmed that developmental tests should be performed at a nominal 50MW(t). These tests include development and prototype combustors; endurance and development generators. Interface data also will be obtained as a product of these testing programs.

The performance and lifetime potential of the retrofit power train in a total integrated facility will be verified. The facility for the retrofit will be identified and the facility design and power train requirements and specifications will be obtained. In the planning for these tests, a specific definition of durability will be established, including selection of number and character of the cycles to which the power train is to be subjected during an anticipated 2000 hour test goal. WBS 1800 will serve as the focus for establishing contacts and cooperation with the facility operators.

WBS 1900 PROGRAM MANAGEMENT

The overall approach to program management of the APT program is presented in Section 4.0 of this Development Plan. To effectively manage the program, the

WBS presented here is structured into four elements: WBS 1910 Project Progress Reviews; WBS 1920 oral reports; WBS 1930, technical and financial reports; and WBS 1940 project management.

WBS 1910 will insure that the project is being carried out in full compliance with the contract and work plan. Oral reporting under WBS 1920 provide detailed progress reviews at which experts may question project participants and comment on approaches and progress. WBS 1930 will provide written records of progress against milestones, schedule and budget.

WBS 1940 will provide the management function for the overall direction of the APT portion of the engineering development and retrofit phases of the MHD program. The Project Office will accomplish the contract effort, using the AESD matrix organization and a system engineering approach. Support services such as purchasing and project schedule and control also will be provided to the project office. As appropriate, standing and ad hoc committees of senior personnel will be established for oversight review of progress, consistency with Westinghouse practice and procedure, and resolution of problem areas.

4.0 MANAGEMENT PLAN

The management plan and rationale are presented in this section. It consists of subsections that cover MHD overall program assumptions, organization and reporting structure, prime and subcontractor responsibilities, methods for overall program control, lines of communication, interfaces, Project Management Organization.

4.1 MHD OVERALL PROGRAM ASSUMPTIONS

The basis for the management plan described herein are as follows:

- The overall national MHD program is presently at an early stage of the engineering development phase. The engineering development phase consists of the development of prototypical components and the proof-of-concept integration of systems.
- Both the engineering development and the plant integration phases will be initiated, as appropriate, at this time. The integration phase includes retrofitting an MHD topping stage onto an existing coal fired plant. The portion of the plant integration that should be initiated now includes the definition of the goals and objectives for the retrofit and its conceptual design. These results can be used to delineate specific requirements for development of prototype components.
- The facility for the retrofit plant will be either a new unit or an existing utility unit. The unit will be of a size to accommodate a MHD topping cycle having a nominal 250 MW(t) rating.
- The necessary retrofit plant goals and objectives, plant studies and baseline conceptual design will be agreed upon early in the Power Train program.
- Programs will be established for the design development and production of the major MHD topping cycle systems that need significant engineering development. These systems include the power train, the HRSR, and the seed regeneration systems. The HRSR and seed regeneration data and information will be needed in the power train program since the interfaces between the three systems must be defined before final prototypical components can be designed. Considering the

state-of-technology of the HRSR and seed regeneration systems, it is assumed that the development program for these systems will be conducted in parallel with the power train.

- Some development, primarily scale-up, remains to be performed in the case of the superconducting magnet. The magnet was not included in the scope of the current MHD/APT contract, but it is a logical major element of the MHD generator, and the design of the power train and magnet are intimately intertwined. It is therefore assumed, and recommended, that the magnet will be included in the power train program in future effort.
- The existing MHD developmental facilities, such as AEDC, CDIF and CFFF will be provided as GFE facilities (including the cost of modification, operation, maintenance and supplies) to the power train program.
- A project organization for the power train program is shown (in heavy line) in Figure 4-1. The elements of this organization correlate with the Work Breakdown Structure. Assumptions for and interrelations within the overall program are also suggested (in light line). Reporting of the APT Project to DOE-PETC, prior to activation of the Joint Management Office, is noted by heavy dotted line.
- Plant studies are indicated in the power train program for the evaluation of, and trade-off between, options and alternatives in the development of the power train. If the power train development effort reveals situations where changes in power train specification would simplify development or improve the results, the impact of the change on the performance of the integrated plant will be evaluated.
- The nozzle has been included in the channel development function (WBS 1300) since the effect of the fringe field of the superconducting magnet is expected to require that the nozzle be of the same construction as the channel. If this proves to be the case, the logical approach is to make the nozzle as an integral part of the channel.

4.2 ORGANIZATIONAL AND REPORTING STRUCTURE, based on Westinghouse management of the APT project team, is shown in Table 4-1. This plan is based on the assumption that the Government will desire the program to utilize the full MHD capability of the nation in the effort. In addition to the indicated subcontracts, Westinghouse, in cooperation with DOE, will make every effort to bring other national resources, such as the universities and the national

Figure 4-1. Proposed Project Organization for Power Train Proof-of-Concept (Related Activities Shown in Light Time)

TABLE 4-1 APT ORGANIZATIONAL RESPONSIBILITIES

<u>RESPONSIBILITY</u>	<u>ASSIGNMENT</u>
Prime Contract & Program Management	Westinghouse
Generator Analysis & Modeling	Subcontract
Generator Design	Joint w/Subcontract
Power Conditioning	Westinghouse
Combustor Development	Subcontract
Diffuser Development	Subcontract
Instrumentation & Control	Westinghouse
Power Train System Development	Westinghouse
Coordination of Test Facilities	Westinghouse

laboratories into the program. The coordination of testing facilities will be expanded (as the plant phase unfolds) to provide the technical support to the design, construction, check-out and operation of the retrofit plant. This service will be provided by Westinghouse with assistance from each of the component subcontractors in their area of expertise.

All reports to Customer will be provided by Westinghouse, with proper input by each subcontractor.

4.3 PRIME AND SUBCONDUCTOR RESPONSIBILITIES as presently anticipated, are also indicated in Table 4-1. The prime contractor is responsible for the successful completion of the project, including portions that are subcontracted.

4.4 METHODS FOR OVERALL PROGRAM CONTROL are illustrated in Figure 4-2. The two activities to be initiated immediately upon contract approval are the completion of the work plan and the preparation of the technical requirements document. Once approved by the customer, these provide the specific direction for the organization and direction of the contract effort. It may be found necessary to revise these, from time to time, as the work progresses. In such cases, customer approval of the revisions will be obtained.

Figure 4-2. Methods for Program Control

The work plan includes the WBS along with the management approach. It provides estimates of schedule and resources allotment to each element of the WBS and establishes the milestones against which technical progress is to be measured and controlled.

The technical effort direction is provided to the various Westinghouse groups, that will perform the effort, by the issuance of work orders to intradivisional groups and interworks requisitions to interdivisional groups. These are standard Westinghouse procedures and are viewed as binding contracts between the Project Office and the performing group.

The technical effort direction is provided to the various subcontractors as part of the formal subcontracts, executed between Westinghouse purchasing (at the direction of the Project Office) and the subcontractors. The Project Office direction to purchasing is provided in the form of completed purchase requisitions that spell out the desired effort milestones, schedule and budget. Any subsequent change in these subcontracts is accomplished by purchasing in compliance with a purchase requisition change notice issued by the Project Office. Purchasing is responsible for securing customer approval of each subcontract, in accordance with government purchase regulations.

Control to maintain visibility of performance against direction, is obtained through regular project review meetings, required technical reports and cost reports provided by Westinghouse accounting. The budget detail, as spelled out in the work plan, is provided to accounting and entered into a computerized system. Weekly effort (in person-hours) reports are provided by the system. Monthly cost reports, compared to the budgets on a line by line basis, are provided by the system. The assistance of the project schedule and control function is made available to the Project Office to assist in preparation of progress reports in the required format and detail.

The first project review meeting is scheduled after a suitable period of performance under the direction of the work orders, IWR's and subcontracts. The frequency of these meetings depends on the project complexity and pace and may be monthly, bimonthly or quarterly. The results of these review meetings, along with the cost reports, provide the input for several actions:

- a) They form the basis of the required reports of progress against schedule and budget, to the Customer;
- b) They form the input from which variance reports are prepared to alert the Project Office and Westinghouse management to deviations from the plan and to potential problems that require attention. The value of the variance report lies in its focus on problems and potential problems resulting in assistance in concentrating management attention on high priority concerns;
- c) The project review meetings also identify any need for change in the technical direction. Such need, when identified, is recorded in a change request - which spells out the need, justification and possible impact on other group activities.

The resolution of a change request depends on its character. It may impact the work of only one group, or it may impact the work of two or even more groups in a project as complex as the power train. The impacts must be identified, considered and commented on by the affected parties, before the change request is approved. The effect of a proposed change may be direct (across an immediate interface) or indirect (influencing components that do not have an obvious and immediate interface).

A change control board, consisting of senior technical personnel, provides final project consideration of the change request. When they approve, and the impacts are judged to be limited to the power train, the change is implemented by revision of the appropriate work order or subcontract. When they approve, and the impacts are judged to extend beyond the power train, Customer approval is sought. When obtained, it is recorded in appropriate revisions to contract work plan or group direction documents.

This methodology, which may be described as a form of mini-PMS, has been applied successfully to many Westinghouse projects. It provides not only clear and current direction to all working groups, but also a clear and traceable history of the progress of the project.

4.5 LINES OF COMMUNICATION throughout the program must be a balanced compromise between efficient performance, clear understanding, and consistent contract management. The concept, as practiced by Westinghouse is illustrated

in Figure 4-3. The solid lines indicate the only allowed paths of communication concerning matters that impact the contractual and overall project relationships. The lighter dashed lines indicate the freedom allowed to the working groups to communicate as required for efficient performance of their assigned responsibilities. Each participant is responsible for providing, to the Project Office, confirmation of the results of each such communication. This requirement must be rigidly enforced to insure against agreements that inadvertently impact other parties or the contractual relationships.

4.6 INTERFACES between the group activities must be defined at the outset of the project. In the current Advanced Power Train efforts, considerable attention has been given to the preparation of a Power Train System Description and Specification. These efforts recognized the necessity for clear definition of the scope of, and interface relationships between, each of the groups working on the power train. This document also calls out the interfaces between the power train and other parts of the MHD/steam plant--so far as they may be determined at this point.

The APT System Description and Specification will be entrusted to the power train integration function, to be maintained current with progress in the development of the power train and its components. This function also will be assigned the responsibility for maintenance of the interfaces between the power train and other MHD/steam plant elements. For the interfaces with test facilities, the power train integration function (with assistance from the coordination of testing facilities function) will be directed to maintain an appropriate version of the System Description and Specification pertaining to the projected test activity.

The APT System Description and Specification is a "living" document that provides the current framework for project control. It will be maintained, up-dated, and reissued at intervals throughout the development and later plant design program.

Figure 4-3. Lines of Communication

4.7 THE WESTINGHOUSE PROJECT MANAGEMENT ORGANIZATION, for the Engineering Development phase, is illustrated in Figure 4-4. The organization will be modified as required by contractual and program needs.

Personnel with extensive experience and pertinent qualifications will be assigned to each management responsibility. Senior management and technical personnel will be assigned to the advisory and review committees. These personnel will be drawn from the subcontractor organizations as well as from Westinghouse. Experienced utility personnel will also be invited to participate in these committees.

Figure 4-4. Westinghouse Project Management Organization

5.0 PRELIMINARY COST ESTIMATES

5.0 PRELIMINARY COST ESTIMATES

The preliminary cost estimates, for the power train development program, are presented in this section. The estimates are presented in a number of formats. The overall program is defined in the Work Breakdown Structure (WBS) shown in Figure 5-1. The cost estimate breakdown that corresponds to these second level WBS elements is shown in Table 5-1.

The overall program is based on the eleven (11) year schedule shown in Figure 5-2. This figure also illustrates the three (3) major efforts that are considered in the overall program: a) The retrofit power train, b) The 50 MW(t) power train, and c) channel development. The cost estimate breakdown that corresponds to these three major efforts is shown in Table 5-2.

The cumulative cost curves for the three major efforts and the total program, are shown in Figure 5-3. The annual cost breakdown is shown in Figure 5-4. The detailed cost data are shown in Table 5-3.

Figure 5-1. Work Breakdown Structure
First and Second Level

TABLE 5-1
POWER TRAIN PROGRAM
COST ESTIMATE - BY WBS ELEMENT

	\$'s - Mil.	%
1100 PT Integration	13.6	4.9
1200 MHD Generator	21.6	7.8
1300 Channel	114.3	41.1
1400 Pow. Conditioning	59.1	21.3
1500 Combustor	26.7	9.6
1600 Diffuser	10.3	3.7
1700 Instr. & Control	9.5	3.4
1800 Coord. Facility Test'g	12.2	4.4
1900 Program Management	10.7	3.8
	<hr/> 278	<hr/> 100

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Figure 5-2. Program Schedule

TABLE 5-2
POWER TRAIN PROGRAM
COST ESTIMATE - BY OBJECTIVE

	\$'s - Mil
Retrofit Power Train	122
Development & Test Equipment	
50 MW_t Power Train	78
Generator Development	78
Total to produce PT	<hr/>
Engineering Data Base	278

Facilities, modifications, operation and escalation
are not included.

YEARS

Figure 5-3. Power Train Program Cost — Cumulative

Figure 5-4. APT Program Cost Estimate

TABLE 5-3
PROGRAM COST ESTIMATE

TASK		1	2	3	4	5	6	7	8	9	10	11	TOTAL
1100	RET PT	0.71	0.43	0.38	0.45	1.38	1.00	0.66	0.51	0.76	1.14	1.31	8.73
PWR TRIM	SOMM PT	1.00	1.00	1.00	1.00	0.50	0.39	0.00	0.00	0.00	0.00	0.00	4.89
INT	CHNL DEV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL	1.71	1.43	1.38	1.45	1.88	1.39	0.66	0.51	0.76	1.14	1.31	13.62
1200	RET PT	0.67	0.10	2.24	2.43	2.98	1.97	0.17	0.17	0.07	0.09	0.20	9.59
MHD GEN	SOMM PT	2.51	2.47	0.26	0.17	0.07	0.00	0.00	0.00	0.00	0.00	0.00	5.48
	CHNL DEV	0.00	0.00	0.02	0.11	0.18	1.57	2.16	0.80	0.79	0.63	0.07	6.53
	TOTAL	2.58	2.57	2.52	2.71	3.23	2.64	2.33	0.97	0.86	0.92	0.27	21.60
1300	RET PT	1.40	1.80	1.80	1.87	3.95	5.33	4.97	9.94	6.02	0.60	0.60	38.28
CHANNEL	SOMM PT	2.90	2.92	3.14	2.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.77
	CHNL DEV	5.22	8.84	14.00	14.75	5.92	2.74	5.02	5.83	0.70	0.60	0.60	64.22
	TOTAL	9.52	13.56	18.94	19.43	9.87	8.07	9.99	15.77	6.72	1.20	1.20	114.27
1400	RET PT	0.98	7.20	7.20	0.42	0.69	9.69	2.77	1.52	0.07	0.00	0.00	30.54
PWR COND	SOMM PT	1.39	16.75	8.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.44
	CHNL DEV	0.69	1.25	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.09
	TOTAL	3.05	25.20	15.65	0.42	0.69	9.69	2.77	1.52	0.07	0.00	0.00	59.06
1500	RET PT	0.00	0.00	0.00	0.00	1.38	1.38	3.32	3.32	0.30	0.13	0.13	9.96
COMBUSTOR	SOMM PT	6.23	7.27	2.77	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.69
	CHNL DEV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL	6.23	7.27	2.77	0.42	1.38	1.38	3.32	3.32	0.30	0.13	0.13	26.65
1600	RET PT	0.60	0.00	0.00	0.00	0.42	0.42	1.38	1.38	1.53	0.60	0.00	5.13
DIFFUSER	SOMM PT	1.80	1.94	1.11	0.29	0.00	0.30	0.00	0.00	3.00	0.60	0.00	5.13
	CHNL DEV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	TOTAL	1.80	1.94	1.11	0.29	0.42	0.42	1.38	1.38	1.53	0.60	0.00	10.26
1700	RET PT	0.27	0.80	2.05	2.12	0.85	0.21	1.23	1.23	0.49	0.20	0.10	9.46
INST&CONT	SOMM PT	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
	CHNL DEV	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.60
	TOTAL	0.27	0.80	2.05	2.12	0.85	0.21	1.23	1.23	0.49	0.20	0.10	9.46
1800	RET PT	0.10	0.10	0.10	0.00	0.90	0.75	0.20	0.20	1.25	1.25	1.25	6.10
COORD	SOMM PT	1.00	1.00	1.00	1.00	0.10	0.10	0.00	0.00	0.00	0.00	0.00	4.20
TEST FAC	CHNL DEV	0.00	0.00	0.00	0.10	0.10	0.10	0.50	0.50	0.20	0.20	0.20	1.90
	TOTAL	1.10	1.10	1.10	1.10	1.10	0.95	0.70	0.70	1.45	1.45	1.45	12.20
1900	RET PT	0.13	0.38	0.50	0.27	0.45	0.71	0.67	0.90	0.43	0.12	0.13	4.69
PROJECT	SOMM PT	0.52	1.25	0.72	0.25	0.02	0.20	0.00	0.00	0.00	0.00	0.00	3.06
MGMT	CHNL DEV	0.25	0.42	0.54	0.46	0.40	0.40	0.19	0.13	0.06	0.06	0.03	2.94
	TOTAL	1.30	2.05	1.76	0.99	0.87	1.31	0.86	1.03	0.49	0.18	0.16	10.69
TOTAL	RET PT	3.66	10.81	14.27	7.56	13.00	20.56	15.37	19.17	10.83	3.53	3.72	122.48
	SOMM PT	17.44	34.60	18.31	5.93	0.69	0.69	0.00	0.00	0.00	0.00	0.00	77.66
	CHNL DEV	6.16	10.51	14.70	15.42	6.60	4.91	7.87	7.26	1.75	1.69	0.90	77.67
	TOTAL	27.26	55.92	47.28	28.91	20.29	26.06	23.24	26.43	12.58	5.22	4.62	277.81