TRW Applied Technology Division
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MHD Technology Transfer, Integration and Review Committee

Fifth Semi-annual Status Report

Period of Performance:
April 1990–September 1990

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Prepared for
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Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania 15236

Contract No. DE-AC22-87PC90274

MHD Integrated Topping Cycle

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MHD TECHNOLOGY TRANSFER, INTEGRATION AND REVIEW COMMITTEE

Fifth Semi-Annual Status Report
April 1990 through September 1990

MHD Integrated Topping Cycle Project
Report No. MHD-ITC-91-021

Date Submitted:
January 1992

Prepared For:
U.S. Department of Energy
Pittsburgh Energy Technology Center

By:
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Contract Number:
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Abstract

This fifth semi-annual status report of the MHD Technology Transfer, Integration and Review Committee (TTIRC) summarizes activities of the TTIRC during the period April 1990 through September 1990. It includes summaries and minutes of committee meetings, progress summaries of ongoing POC contracts, discussions pertaining to technical integration issues in the POC program, and planned activities for the next six months.

1. INTRODUCTION

As part of Task 8 of the MHD Integrated Topping Cycle (ITC) project, TRW was given the responsibility to organize, charter and co-chair, with the Department of Energy (DOE), an MHD Technology Transfer, Integration and Review Committee (TTIRC). The Charter of the TTIRC, which was approved by the DOE in June 1988 and distributed to the committee members, and the responsibilities and procedures of the committee are included as Appendix A. The TTIRC consists of an Executive Committee (EC) which acts as the governing body, and a General Committee (GC), also referred to as the main or full committee, consisting of representatives from the various POC contractors, participating universities and national laboratories, utilities, equipment suppliers, and other potential MHD users or investors. As stated in the Charter, the purpose of the TTIRC is to: (a) review all Proof-of-Concept (POC) projects and schedules in the national MHD program; to assess their compatibility with each other and the first commercial MHD retrofit plant; (b) establish and implement technology transfer formats for users of this technology; (c) identify interfaces, issues, and funding structures directly impacting the success of the commercial retrofit; (d) investigate and identify the manner in which, and by whom, the above should be resolved; and (e) investigate and assess other participation (foreign and domestic) in the U.S. MHD Program.

The Committee's activities related to "technology transfer" include holding and attending meetings, which provide a forum for the dissemination of technical and programmatic information within the MHD community and to the potential end users, and by publishing this semi-annual report, which presents summaries of technical progress for all DOE Proof-of-Concept MHD contracts and major test facilities.

The Committee's "integration and review" role encompasses all the major projects in the POC program, i.e., the Integrated Topping Cycle, Integrated Bottoming Cycle, Seed Recovery/Regeneration Process, and Retrofit Conceptual Designs, which are compiling the technical data base needed to scale MHD to retrofit power plant sizes. TRW and the TTIRC Executive Committee review schedules, test plans, test results, design requirements, and system studies for POC program activities to identify technology "gaps" and incompatibilities among the various POC projects which could lead to collection of an incomplete technical data base. Under the auspices of the committee, engineering studies are performed, technical and programmatic evaluations are conducted, and recommendations are made to the DOE on ways to enhance the effectiveness and efficiency of the integrated Proof-of-Concept program so as to minimize the risks of proceeding with an MHD plant retrofit.

This fifth semi-annual status report covers the period April 1990 through September 1990. The report is organized into seven sections, the first of which is this introduction. Sections 2 and 3 summarize Executive Committee and General Committee activity during this reporting period. Section 4 describes the committee activities related to technology transfer. Section 5 summarizes the ongoing POC integration activities being performed under the auspices of the Executive Committee. Planned activities for the next six months are listed in Section 6. Section 7 is a distribution list for this report.

2. EXECUTIVE COMMITTEE MEETING AND ACTIONS

A meeting of the Executive Committee was held on June 13, 1990 at the Boston/Cambridge Guest Quarters Suite Hotel. At the meeting, Mr. Bruce Pote of TRW presented the POC Integration Task Force's conclusions and recommendations. These recommendations were evaluated by the Executive Committee and will be passed on to the DOE. The recommendations regard aspects of the POC program which could be modified and/or expanded to better focus the program on commercially realistic goals for the retrofit demonstration. During the meeting, an agenda was formulated for the General Committee meeting to be held in conjunction with the 28th Symposium on Engineering Aspects of Magnetohydrodynamics in Chicago. Other business included a brief update on the Clean Coal Technology Solicitations and a summary of the EPRI-MHD Utility Colloquium. The agenda and minutes of this meeting are presented in Appendix B.

The transfer of Mr. Lou Scinto to another project within TRW created a vacancy on the Executive Committee. Lou's duties as Deputy Chairman of Operations have been assumed by Mr. Bruce Pote of TRW.

3. GENERAL COMMITTEE MEETING

A meeting of the General Committee was held on June 25, 1990 preceding the 28th Symposium on Engineering Aspects of Magnetohydrodynamics at the Chicago Westin Hotel. The agenda and minutes of the meeting are provided in Appendix C.

The meeting in Chicago primarily focused on the activities of the POC Integration Task Force. This included a presentation of the "open technical issues" and Executive Committee recommendations. Sixteen issues were identified by the Task Force, and from these issues fifteen sets of recommendations were formulated by the Executive Committee for transmittal to the DOE for implementation within the National MHD POC program. Open discussions were held regarding each of the issues/recommendations. A presentation was also made by Robert Aurora of Houston Lighting and Power regarding "Utility Data Requirements for Candidate Technologies for New Capacity Additions", and Dr. William Owens of Gilbert/Commonwealth provided the General Committee with a status on the Clean Coal Technology Solicitations.

4. TECHNOLOGY TRANSFER

The primary technology transfer activities of the TTIRC consist of the holding of semi-annual meetings of the General Committee and the publishing of this semi-annual report, which summarizes progress on the major POC program activities.

Presented in Appendices D through J are summaries of technical progress on the major POC projects. Items of note include the following:

- The Integrated Topping Cycle (ITC) project completed a major milestone as the Critical Design Reviews and Preliminary Design Reviews were held for the combustor/channel subsystems and current consolidation subsystem, respectively.
- A duration test of the prototypical combustor spool section (pressure shell and cooling panels) was performed at the University of Tennessee Space Institute (UTSI) in the Coal Fired Flow Facility (CFFF). The test, conducted with a 3.5% sulfur Illinois No. 6 coal, was 250 hours in duration with 17 start-ups and showed no signs of cracking, panel deformation or coal migration.
- The 1A4 current controls were installed and successfully tested at the CDIF on the 1A1 channel.
- Breadboard units of the Westinghouse consolidation subsystem were successfully tested on the Avco Mark VII channel (with current controls) under steady-state and transient conditions.
- Over 400 hours of testing on Illinois No. 6 coal was performed at the CFFF during tests LMF4T and LMF4U. There were a number of important test objectives all of which were completed successfully. These included:
 - Evaluation of the newly installed High Pressure Soot Blower and Ash Handling System
 - Evaluation of the effect of primary stoichiometry and K_2S ratio on NO_x decomposition and SO_x capture, respectively
 - Support of TRW prototypical spool section testing
 - Preparation and shipment of spent seed to TRW for regeneration in the seed regeneration POC test plant.
- Final design of the potassium formate reactor and conceptual design of the calcium formate test unit for the seed regeneration POC plant at TRW have been completed.
- To date, approximately 35 tons of Illinois No. 6 derived spent seed have been packaged and shipped to TRW by the CFFF with plans to provide CDIF with 10 to 20 tons of regenerated seed for workhorse combustor/channel

testing in June, 1991. This milestone will comprise the first sequential linkage between the three facilities which comprise an MHD-steam plant: combustor/channel testing at CDIF, seed regeneration at TRW and spent seed production/collection at CFFF.

- Diagnostic instruments for MHD applications continued to be tested at both the CDIF and the CFFF. Diagnostic measurements have supported the effect of K_2/S ratio on ESP performance, the temperature profile at the diffuser exit at CFFF, and temperature, potassium and electron number density in the diffuser at the CDIF.
- Combustion modeling studies of the second stage combustion process are ongoing at ANL using a 3-D hydrodynamic computer code and 2-D combustion code.

5. INTEGRATION AND REVIEW

The second major function of the TTIRC is to review the technical activities of the POC program to ensure that the individual projects are consistent with the overall program goal of developing a usable MHD data base, and that the entire POC program is consistent with the goal of supporting the design of a commercial retrofit plant. The committee is approaching this "integration and review" function from both a top-down perspective, analyzing retrofit requirements to determine the specific data required from the POC program, and a bottoms-up perspective, looking at individual issues that involve integration of the various MHD systems being developed within the POC program. The Executive Committee of the TTIRC is responsible for investigating these key technical integration issues and retrofit requirements.

The TTIRC Executive Committee formed the POC Integration Task Force to ensure continued coordination of the various POC contract activities and the integration of these efforts with the requirements/specifications for the first MHD-steam retrofit demonstration. During the previous reporting period, the Task Force performed the following activities:

- Reviewed the Corette and Scholz retrofit design final reports
- Reviewed General Electric and Westinghouse Advanced Power Train Studies
- Reviewed other early-commercial conceptual design studies
- Identified generic (non-site specific) retrofit requirements and formulated a Retrofit Reference Design Basis (RRDB)
- Evaluated POC program requirements and plans for topping cycle, bottoming cycle, and seed regeneration projects
- Identified areas where the POC program does not address retrofit requirements
- Distributed for review the RRDB and a questionnaire on the areas where the POC program does not conform to the RRDB
- Evaluated responses to the questionnaire
- Updated the RRDB based on reviewer and Task Force inputs
- Formulated conclusions and recommendations

During this reporting period, the Task Force performed the following activities:

- Distributed the Task Force report to the TTIRC Executive Committee with recommendations on identified issues.
- Presented the RRDB and Task Force recommendations to the Executive Committee and formulated consensus recommendations to be passed on to

the DOE regarding aspects of the current POC which could be modified or amended to better focus the program on commercially realistic goals and specifications for a retrofit demonstration.

- Presented the Task Force activities and Executive Committee recommendations to the TTIRC General Committee.
- Identified potential MHD commercialization issues based on the EPRI-MHD Utility Colloquium relating to high temperature direct-fired air heater (HTAH) development.
- Solicited input from the Task Force members on HTAH development.
- Continued to monitor the POC programs to ensure focus and integration.

The POC Integration Task Force identified sixteen issues as a result of their comparison of retrofit specifications/requirements with the existing POC plans. These recommendations were prioritized, by a cross-section of TTIRC Executive Committee members and POC program participants, in order of importance to demonstrate as part of the POC testing. Three groups emerged from the ranking process and for convenience were identified as: first, second and third priority, respectively. Table 5-1 summarizes the ranking of issues while the accompanying recommendations can be found in Appendix B.

It should be noted that the rankings within the second priority list are quantitatively indistinguishable and are considered of equal importance. The rankings and recommendations were formally transmitted to the DOE for their consideration on 13 August 1990.

TABLE 5-1. PRIORITIZED TASK FORCE ISSUES

FIRST PRIORITY	SECOND PRIORITY	THIRD PRIORITY
K ₂ /S	Additives	Scalability
ESP/Baghouse	Multiple Load	Integrated Plant Control
Seed Regeneration	Performance/Reliability	Strategy
Combustor Stoichiometry	Part Load	Seed Impurities
	Second Stage Oxidant	Superconducting Magnets
		Second Stage Cooling

6. PLANNED ACTIVITIES

The following TTIRC activities are planned for the sixth semi-annual reporting period (October 1, 1990 through March 30, 1991):

- Issuance of the fifth semi-annual status report on the activities of the TTIRC
- Hold semi-annual meeting of the Executive Committee in conjunction with the Contractors Review meeting in Pittsburgh, PA in early February 1991.

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APPENDIX A

TTIRC CHARTER AND RESPONSIBILITIES

The current version (approved by DOE in May 1988) of the TTIRC Charter is reproduced on the following pages. The organization chart has been updated to show the committee membership as of June 1990. Also included in this appendix is a list of the responsibilities and procedures for the Executive and General Committees, as approved by the Executive Committee in March 1988.

CHARTER FOR THE MHD TECHNOLOGY TRANSFER,
INTEGRATION AND REVIEW COMMITTEE

This Charter has been prepared under Contract No. DE-AC22-87PC90274 for the U.S. Department of Energy (DOE), Pittsburgh Energy Technology Center (PETC) by TRW Inc., the prime contractor for MHD Integrated Topping Cycle (ITC) Project.

CHARTER - ARTICLES

The purpose of the MHD Technology Transfer, Integration and Review Committee (MHD TTIRC) is to:

1. Review all Proof-of-Concept (POC) projects and schedules to assess their compatibility with each other and the first commercial MHD Retrofit Plant.
2. Establish and implement an appropriate technology transfer format for potential future users of MHD technology.
3. Identify integration interfaces, technical issues, and funding structures that have direct impact on the success of the first commercial MHD retrofit plant and successful MHD entry into the commercial marketplace.
4. Investigate and identify the manner in which and by whom, the above interfaces, issues and structures should be resolved.
5. Investigate and assess the potential for other participation, both foreign and domestic, in the U.S. MHD program, including the first commercial MHD retrofit plant.

CHARTER - MEMBERSHIP

The MHD Technology Transfer, Integration and Review Committee is comprised of:

The Department of Energy
Prime contractor for the MHD Integrated Topping Cycle
Prime contractor for the MHD Integrated Bottoming Cycle
The contractor for the MHD Combustor
The contractor for the MHD Channel
The contractor for the MHD Power Conditioning
The contractor for the MHD Seed Regeneration
The contractors for the MHD Retrofit Conceptual Design
Operating contractor for CDIF
Operating contractor for CFFF
Other equipment suppliers to the utility industry
Potential users of MHD technology
Investors in MHD technology
Participating universities
Participating national laboratories

CHARTER - OPERATION

ORGANIZATION

The organizational structure of the TTIR Committee shall be in accordance with Figure A-1. The General Committee participants include the organizations involved in the MHD Topping Cycle, Bottoming Cycle, Seed Regeneration, Retrofit Conceptual Design, potential future users of MHD, Universities and other parties cost sharing in the program. Proposed changes to the listed Committee Charter Membership or organizational participants of Figure A-1 will be accomplished only as discussed herein.

GENERAL COMMITTEE MEETINGS

The frequency of the General Committee meetings will be semi annually, with a single participant from each organization attending, plus Executive Committee members. The MHD TTIR General Committee shall meet at alternate U.S. east or west locations, beginning with the June 1988 SEAM meeting in Tennessee, at a location to be determined. The meeting dates and locations will be selected by the Executive Committee members.

The meetings will be cochaired (presiding alternately) by Gary E. Staats of DOE/PETC and William M. Irving of WMI, Inc. Each participating organization shall submit a person's name and an alternate to be responsible to the Committee for accomplishment of the Charter Articles. The TRW Deputy Chairman for Operations, in conjunction with the Committee Cochairmen, will schedule the meetings, arrange for the accommodations, prepare the agenda, distribute the minutes and action items, inform the Committee members of the planned Charter operation and will essentially manage the day-to-day operations of the TTIR Committee. The agenda for the first Committee meeting will emphasize themes, vectors and goals. The subsequent meetings will emphasize program accomplishments, schedule status, interface issues and other appropriate matters as defined in the Articles of this Charter.

Listed below are the specific organizations that are Charter Members in the TTIR Committee:

Argonne National Laboratory	MIT (Plasma Fusion Center)
Arizona Public Service	Montana Power Company
Avco/Textron	Montana State University (Rosa)
Babcock & Wilcox	MSE, Inc.
DOE	Pennsylvania Power & Light Co.
Edison Electric Institute	Southern Services Co.
EPRI	TRW Inc.
General Dynamics	UTSI
Gilbert/Commonwealth	Westinghouse, AESD
Houston Lighting and Power Co.	Westinghouse, R&D Center
MHD Development Corporation	WMI, Inc.
Mississippi State University	

The Executive Committee will act as the Membership Committee and will take care of any changes proposed.

Revised May 1991

O1M.90.546.04

Figure A-1. MHD Technology Transfer, Integration and Review Committee Organization

EXECUTIVE COMMITTEE MEETINGS

The Executive Committee is comprised of the industry and DOE Cochairmen, the Deputy Chairman for Operations, and Committee members (see Figure A-1). Election to the Executive Committee may be accomplished by a simple majority including one Cochairman constituting a quorum. This Committee will convene to plan the activities of the semi-annual General Committee meetings, discuss salient technical integration and technology transfer issues, and resolve other issues covered by the Articles of this Charter. The Executive Committee is empowered to appoint subcommittees from the General Committee membership to help resolve any specific issues covered by this Charter. The meeting dates and locations will be selected by the Committee Cochairmen and the Deputy Chairman for Operations will again make all arrangements, etc.

SEMI-ANNUAL CONTRACTUAL REPORTS

TRW will prepare semi-annual progress reports based on inputs from MHD contractors. The semi-annual contractual report inputs shall be in rough draft format, together if possible with a MultiMate Word Processing Disk (or compatible equivalent) and all original art work suitable for reproduction. All report inputs will be due at TRW within 30 days after the General Committee meetings. These semi-annual progress reports, including a collation of the MHD TTIR Committee meeting minutes, will be combined and distributed.

RESPONSIBILITIES AND PROCEDURES
TTIR EXECUTIVE COMMITTEE AND MAIN COMMITTEE

A. Executive Committee

The TTIR Executive Committee shall:

1. Act as the governing body of TTIRC.
2. Input to DOE and TRW creative ways to improve the MHD Program by:
 - Improving effectiveness and efficiency of MHD Program
 - Recommending increased or less involvement by parties in the TTIRC
 - Utilizing services of its members or others as required in performing Executive Committee assignments
3. Respond to requests by DOE and TRW.
4. Develop plans to efficiently incorporate end users in the MHD Program and prepare for them to install future MHD plants.
5. Prepare minutes of Executive Committee and Main Committee meetings for use in the Semi Annual Report and for distribution to the TTIR Main Committee prior to its next meeting. Present Executive Committee actions to the Main Committee at its meeting and obtain comments.
6. Use Roberts Rules of Order at all meetings.
7. Vote by simple majority of Executive Committee Members present (and) welcome substitutes for Executive Committee Members to meetings, but they will have no voting power.

B. TTIR Main Committee

1. The Committee is made up of a single representative from each of the Charter Member organizations.
2. Members shall be advised by the Cochairmen of the Executive Committee (who are also Cochairmen of the Main Committee) of all activities of the Executive Committee and will have the opportunity to comment on Executive Committee decisions and recommendations. Minutes of immediately previous Executive Committee Meetings will have been distributed to Main Committee members prior to the Main Committee Meeting.

APPENDIX B

MINUTES OF THE JUNE 1990 EXECUTIVE COMMITTEE MEETING

Presented in this Appendix are the agenda and minutes of the Executive Committee meeting held at the Boston/Cambridge Guest Quarters Suite Hotel on June 13, 1990. The list of attendees for the meeting is provided below. Included in this appendix is a reproduction of the Retrofit Reference Design Basis presented by Bruce Pote and a summary of the recommendations adopted by the TTIRC Executive Committee as a result of the POC Integration Task Force's findings.

List of Attendees

Committee Members

WMI - Bill Irving, Co-chair
Avco - Bob Kessler
TRW - Albert Solbes
TRW - Bruce Pote (replacing
Lou Scinto)
UTSI - Norm Johanson

Invited Guests

B/W - Bob McIlroy (substituting
for John Rackley)
Consultant - Finn Hals
DOE - Harold Chambers (substituting
for Gary Staats)
G/C - Jack Hirschenhofer (substituting
for Bill Owens)
TRW - Marty Bauer

MHD TECHNOLOGY TRANSFER
INTEGRATION AND REVIEW COMMITTEE

EXECUTIVE COMMITTEE MEETING
JUNE 13, 1990
BOSTON/CAMBRIDGE GUEST QUARTERS SUITES HOTEL

AGENDA

9:00am	Welcome and Introduction	B. Pote - TRW
9:10am	Call to Order and Approval of Previous Executive Committee Meeting Minutes	G. Staats - DOE W. Irving - WMI
9:20am	POC Integration Task Force: Presentation of Recommendations	B. Pote - TRW F. Hals - Avco
10:00am	Discussion of POC Task Force Recommendations	
12:00pm	Catered Lunch	
1:00pm	Executive Committee Actions on POC Task Force Recommendations	
	- Report Revisions and Distribution	
	- Committee Action and Recommendations to DOE	
	- Future POC Task Force Activities	
1:45pm	Agenda for General Committee Meetings June 25, 1990 - Chicago Westin Hotel	G. Staats - DOE W. Irving - WMI
2:30pm	TTIRC Reports	B. Pote - TRW
	- 3rd Semi-Annual (Final Report)	
	- 4th Semi-Annual (Draft)	
3:00pm	Other Business	
	- TTIRC Charter Revisions	
	- Clean Coal Technology Solicitation Update	W. Owens - GC
	- Summary of MHD Utility Colloquium, March 28, 1990	R. Kassler - Avco
	- High Temperature Air Heaters	F. Hals - Avco
4:30pm	Adjourn	

TECHNOLOGY TRANSFER, INTEGRATION AND REVIEW COMMITTEE

Minutes of the June 1990 Executive Committee Meeting

A meeting of the Executive Committee of the MHD Technology Transfer, Integration and Review Committee (TTIRC), held on June 13, 1990 at the Boston/Cambridge Guest Quarters Suite Hotel, was brought to order by co-chairman Mr. William Irving of WMI. Mr. Irving informed the Executive Committee members that Mr. Bruce Pote of TRW had been appointed by the ITC Project Manager to replace Mr. Lou Scinto as Deputy Chairman for Operations. Since this is an appointed position, no action by the committee members was necessary.

Minutes of Previous Meeting

Minutes of the previous Executive Committee meeting in January 1990 were distributed to members prior to the meeting. Mr. Irving asked if there were any additions and/or comments to the minutes. There were no comments. A motion was made by Mr. Irving to approve the minutes as distributed; there was a second to the motion and it carried by unanimous voice vote.

Presentation by Bruce Pote - POC Integration Task Force

Mr. Bruce Pote of TRW presented the status of the POC Integration Task Force. The presentation focused on the Retrofit Reference Design Basis (RRDB) and recommendations for additions and/or amendments to the POC program which would be beneficial to meeting the requirements of the RRDB.

The Task Force was formed in September 1989 by TRW, at the DOE's request, under Task 8 of the MHD Integrated Topping Cycle contract to ensure that the POC program remains focused on commercially realistic goals for the first MHD retrofit. Representatives from each of the POC program elements as well as from the utility sector were part of the Task Force. The members of the Task Force are included with these minutes as Figure B-1.

The approach to ensuring the integration of the POC program elements and their compatibility with a retrofit demonstration project utilized a 5-point plan:

- Review POC program requirements and progress
- Identify requirements from the two retrofit conceptual design studies
- Define a consensus retrofit reference design basis (RRDB)
- Using the RRDB, identify POC program needs to satisfy the RRDB requirements
- Issue recommendations to the TTIRC Executive Committee where changes/additions to the POC program are required to satisfy the RRDB

The preliminary findings of the Task Force were summarized by Mr. Gil Ogle of TRW during the previous reporting period. Mr. Pote's presentation focused on the Retrofit Reference Design Basis (RRDB) and the recommendations/conclusions from the Task Force's findings.

Figure B-1. POC Integration Task Force Members

BRUCE POTE, TRW, CHAIRMAN

FINN HALS, CONSULTANT

BILL OWENS, GILBERT/COMMONWEALTH

JOE LANCE, WESTINGHOUSE

JOHN CUTTING, SAIC

LOREN McCLANATHAN, TRW

Retrofit Reference Design Basis (RRDB)

The RRDB is a generic set of common specifications and requirements for an MHD-steam retrofit power plant. It was formulated using primarily the specifications from the two retrofit conceptual designs (Corette and Scholz) but also the GE and Westinghouse Advanced Power Train studies. Mr. Pote emphasized that the RRDB was not a design but a set of specifications that the Task Force utilized to evaluate the planned testing and focus of the POC programs.

The requirements/specifications for the RRDB were divided into nine sections:

- General plant
- Combustor
- Nozzle/channel assembly
- Inverter
- Magnet
- Diffuser
- Heat recovery (including particulate control)
- Seed regeneration
- Feed system (specific/unique to MHD)

The committee reviewed, in detail, each of the specifications from the nine RRDB sections. Several modifications and format changes to the specifications were adopted. At the conclusion of the RRDB review, Mr. Pote motioned that the RRDB be released for publication with the changes as noted by the committee. The motion was seconded and carried by unanimous voice vote. The approved RRDB (Rev. A) is included with these minutes as Figure B-2.

Integration Issues and Recommendations

Review of the POC programs in relation to the RRDB identified many areas of agreement but a number of inconsistencies that need to be further addressed within the POC programs before advancing to the retrofit demonstration.

Sixteen issues were identified:

Scalability	Seed regeneration integration
Performance and reliability	Multiple load operation
Superconducting magnets	Active current controls
Part load operation	Additives
Overall MHD combustor stoichiometry	K ₂ /S ratio
Second stage combustor oxidant	ESP/baghouse operation
Second stage combustor cooling	Slag rejection
Seed impurities	Integrated plant control strategy

It was noted by the committee that these issues are not "show stoppers" to the MHD program, just areas where further agreement with the RRDB specifications and an enhancement to the MHD engineering data base can be obtained.

In addition it was noted during Mr. Pote's presentation that the issues fall into three categories: 1) issues that were recognized during the initial formulation of the national MHD program (superconducting magnets), 2) issues that can only be fully addressed during the retrofit demonstration (integrated plant control, part load, seed regeneration integration), and 3) those issues which can be addressed within the POC program.

The Task Force's recommendations, resulting from these issues, were presented to the Executive Committee. After the presentation of each issue/recommendation, a motion was made to adopt the recommendation as presented or with slight modifications per the committee discussions. A summary of the recommendations adopted by the TTIRC Executive Committee is presented in Table B-1 at the end of these minutes.

General Committee Meeting Agenda

The committee suggested that the General Committee agenda include a presentation of the Task Forces's activities and Executive Committee recommendations and a presentation relating to an MHD bid for CCT-5. In addition, Mr. Irving stated that Dr. Aurora of Houston Lighting and Power requested 10 to 15 minutes at the meeting regarding utility data requirements for candidate technologies for new capacity additions.

Mr. Bruce Pote took the action to formulate the General Committee agenda and inform Dr. Aurora his request was accepted.

TTIRC Reports

Mr. Pote noted that the draft of the third semi-annual TTIRC status report was approved by the DOE and publication and distribution was completed.

Mr. Pote noted that the draft of the fourth semi-annual TTIRC status report had been sent to the Executive Committee members for review on 26 April 1990. Dr. Chambers noted that the DOE had completed their review and the report was accepted for publication subject to the changes/corrections provided with the annotated copy. The committee members were asked to provide their review comments to Mr. Pote by 6 July 1990.

Other Business

Due to the limited time remaining, no formal presentations were made on the remaining items on the agenda.

Mr. Hirschenhofer briefly discussed the status of the Clean Coal Technology solicitations for Dr. Owens. He indicated the activities were on hold until a congressional resolution on the impact of the pending acid rain bill. Dr. Owens will provide a more in-depth summary at the General Committee meeting.

The committee noted that there had been no feedback from EPRI on the MHD Utility Colloquium. Mr. Pote noted that Dr. Art Cohn and Dr. Heinz Pfeiffer were presenting a paper on that subject at the 28th SEAM. None of the committee members or invited guests had seen the paper.

Finn Hals briefly mentioned some recent work he performed relating to direct fired air heaters at the request of the POC Task Force. A copy of Mr. Hals summary paper was distributed to the committee attendees and is included in this document as Appendix K. The work related to an issue which surfaced at the EPRI Utility Colloquium. The issue involves the use of the exhaust gases exiting the channel to preheat the incoming oxygen enriched air. This type of system integration is necessary for MHD to reach its ultimate potential in overall thermal efficiency.

Mr. Hirschenhofer took the action to attempt publication of the Kessler/Hals paper titled "Coal-Burning Magnetohydrodynamic Power Generation". Possibilities included the Pittsburgh Coal Conference and other related periodicals and journals to provide a wider exposure to MHD.

The committee also noted the need for additional, updated and ongoing systems engineering studies.

Adjournment

There being no further time for business, a motion to adjourn was heard and seconded. Mr. Irving adjourned the meeting.

Figure B-2.

RETROFIT REFERENCE DESIGN BASIS

Design Basis/ Requirement	POC	Retrofit Reference Design Basis	Rationale*
General			
Plant Capacity Factor	Not applicable	0.65 min.	Goals based on existing utility operations
MHD Operational Availability	Not applicable	0.85 min.	Goals based on existing utility operations
MHD Operational Range	Normal design conditions	50 to 100%	Adequate for base load applications; provides adequate demo of operational aspects
Fuel	Rosebud and Illinois No. 6; pulverized	Western or Eastern (Site Specific)	
Fuel Moisture	Rosebud < 8%; Eastern coal < 4% as fired	Western < 8% as fired; Eastern < 4% as fired	Should be as dry as possible. Goals are within standard PC drying practice for these coals
Oxidant	60% oxygen enriched air	Oxygen enriched air, 35 to 40%; Same as first stage	35-40% O ₂ is suitable for a commercial retrofit with regard to plasma temperature and conductivity
First Stage	100% oxygen @225 psia	1000 to 1500°F	Range selected to allow economic integration using a metallic recuperative heat exchanger
Second Stage	1200 - 1500°F (vitiated) None	1000 to 1500°F	
MHD Thermal Input	Nominal 50 MW	Nominal design point, 200 to 300 MW _t	Range selected to provide for representative topping/bottoming integration and reasonable scaling to 500 MW _t
Seed	1 to 2% K	1 to 2% K	1 - 2% range selected based upon plasma electrical conductivity, sulfur removal and seed economics
Environmental	Must meet NSPS	1/6 to 1/10 current NSPS	Below NSPS projected to the year 2000

N9950

REV A

Figure B-2 (Continued)

RETROFIT REFERENCE DESIGN BASIS (CONTINUED)

Design Basis/ Requirement	POC	Retrofit Reference Design Basis	Rationale*
Combustor Type	Two-stage Slagging (TRW) (vitrified) > 60%	Two-stage Slagging > 60%	Increased ash carryover makes seed recovery and economics problematic
Slag Rejection			
Seed	K ₂ CO ₃ , 1-2% K dry (have tested K ₂ CO ₃ /H ₂ O solution; plan to test KCOOH/H ₂ O solution	KCOOH, molten or in solution; regenerated; K ₂ /S > 1; 1%K min	KCOOH most economic from regeneration plant;
Operational Availability	Not applicable	0.975	
Operational Range	Nominal design conditions	50 to 100%	
MTBF	Not applicable	20,000 hours	
Useful Equipment Life	2000 hrs; 500 cycles; design	30 years	Utility industry norm
Stoichiometry			
First Stage	0.55	Overall = 0.8 to 0.9	Necessary for compromise between projected future NOx emission limits and powertrain performance
Second Stage	0.95 nominal (test range 0.80 to 0.95)		
Heat Loss	7%	5%	
Operating Pressure	6 atm	4 to 8 atm	
Combustor Pressure Drop		< 4%	
Materials	Scalable materials and construction thermal panels/pressure shell	Based on POC	
Voltage Standoff	10 kV	20 - 30 kV	
Cooling			
1st Stage	450°F/1200 psia	High temperature/pressure boiler feedwater	Provides most attractive MHD process integration
2nd Stage	250°F/300 psia	High temperature/pressure boiler feedwater	Provides most attractive MHD process integration
Injectors	70-110°F	High pressure boiler feedwater if possible	Provides most attractive MHD process integration but may be precluded by high heat fluxes

N9955

REV A

Figure B-2 (Continued)

RETROFIT REFERENCE DESIGN BASIS (CONTINUED)

Design Basis/ Requirement	POC	Retrofit Reference Design Basis	Rationale*
Channel/Nozzle Assembly Exit Velocity Standoff Voltage Construction	Supersonic 10 kV Segmented to prevent current flow from fringe field	Supersonic 20 to 30 kV Segmented to prevent current flow from fringe field. Scalable design	Match channel design
Coolant	PCW at 70 to 110°F, 300 psia	Low pressure cooling water	High heat flux precludes HP boiler feedwater. Nozzle likely to be integral with channel
Enthalpy Extraction Velocity	Not applicable Supersonic	> 10% Supersonic	Supersonic operation selected based upon experience is less sensitive to combustion instabilities
Terminal Configuration	Diagonal, consolidated into a sin- gle load	Diagonal with multiloading configuration	Diagonal loading is selected since it is more reliable, greater fault tolerance, lower power conditioning losses and lower system cost than Faraday loading. Multiloading configuration is selected because it is more efficient than simple two terminal configuration
Isentropic Efficiency Maximum Transverse Field Maximum Axial Field Maximum Current Density Maximum Hall Voltage Maximum Hall Parameter Maximum Wall Heat Flux Electrode/Insulator Design	Not applicable 2.2 - 4.8 1.2 - 3.3 1.0 - 1.5 10 kV 2.02 300 W/cm ² Scalable to retrofit	> 50% 4 kV/m 2.5 kV/m 1 Amp/cm ² 30 kV 4 300 W/cm ² Electrode/insulator wall design based on POC to provide fault, arc protection and reliability Based on POC	Similar to constraint projected for commercial MHD Similar to constraint projected for commercial MHD Similar to constraint projected for commercial MHD Similar to constraint projected for commercial MHD Similar to constraint projected for commercial MHD Based on operating experience Maximize electrode life, and reliability
Power Management	Active current consolidation in PTO region and current controls in remainder of channel Existing Avco state of the art	Maximize magnet bore utiliza- tion and rapid channel replace- ment	Minimize magnet cost and maximize plant availability
External Packaging	PCW at 70 to 110°F, 300 psia Not applicable 2000 hours/500 cycles; design scalable to retrofit Not applicable	Low pressure cooling water 2000 hours	High heat flux precludes HP boiler feedwater Based on high sulfur concentration in the channel
Cooling			
MTBF			
Useful Equipment Life			
Operational Availability		0.96	Use of "stand-by" spare channel/nozzle assembly

N9952

Figure B-2 (Continued)

RETROFIT REFERENCE DESIGN BASIS (CONTINUED)

Design Basis/ Requirement	POC	Retrofit Reference Design Basis	Rationale*
Inverter Operational Availability MTBF	Existing single inverter Not applicable Not applicable	Multiple inverters to match multiload configuration 0.998 for inversion equipment; 0.998 for electrode consol/cont 10,000 hours	
Magnet Type	Iron core	Superconducting with stabilized NbTi windings	
Maximum Field	2.94 Tesla	4.0 to 6.0 Tesla	
Operational Availability MTBF	Not applicable Not applicable	0.998 10000 hours	Range is projected for early commercial MHD units
Diffuser Operation	Slagging	Slagging	
Inlet Velocity	Supersonic (Mach 1.9)	Supersonic	Supersonic to match channel design
Inlet Velocity to Radiant Furnace		< 300 fps	Velocity selected to meet boiler requirements
Pressure Inlet Outlet	0.4 atm 1.0 atm	0.7 atm 1.0 atm	Inlet pressure selected to match channel design Outlet pressure selected to meet boiler requirements including overpressure protection
Coolant Maximum Heat Flux, w/cm ² MTBF	PCW at 70 to 110°F, 300 psia 80 Not applicable	High pressure boiler feed water 40 4000 hours	Economic integration with boiler feedwater circuit Can use high pressure boiler feedwater
Useful Equipment Life Availability	2000 hours/500 cycles Not applicable	30 years 0.99	

N9953

REV A

RETROFIT REFERENCE DESIGN BASIS (CONTINUED)

Figure B-2 (Continued)

Design Basis/ Requirement	POC	Retrofit Reference Design Basis	Rationale*
Heat Recovery			
Radiant Boiler Residence Time	1.5 - 3 seconds	> 2 seconds with refractory lined radiant section	Residence time, cooling rate and lining selected for control of NO _x emissions, cooldown rate based on POC program
Radiant Boiler Inlet Temp.	3750 - 3800°F	3750 - 3840°F	
Radiant Boiler Cooling Rate	600 - 800°F/sec	Minimize NO _x based on POC	NO _x emissions below projected future NSPS
Afterburner Inlet Temp.	1900 - 2100°F	Based on POC	Design dependent; based on above rationale
Afterburner Outlet Temp.	2300 - 2400°F	Based on POC	Design dependent; based on above rationale
Afterburner Outlet Stoichiometry	1.0 - 1.3 (1.05 nominal)	Based on POC	Design dependent; based on above rationale
Convective Section Inlet Temperature	2300 - 2350°F	2250°F, nominal; based on POC	Higher temperatures require greater surface area to compensate for fouling
ESP/Baghouse	Both	Based on POC	
ESP Inlet Temperature	300 - 750°F	350-750°F, nominal based on POC	
Baghouse Inlet Temperature	Max. 400°F	Max. 400°F	
Materials	TS1 - 310, 316H, 253MA, 304H (inlet T = 2300 - 2350°F) TS2 - 321H, T22, 310, 253MA, 304H, 316H, 335P5 (inlet T = 1600 - 1700°F) TS3 - T22, SA - 192, T11, 335P5 (inlet T = 1200°F)	Based on POC	Materials selected for longest life at design condition
Useful Equipment Life	Not applicable	30 years	
MTBF	Not applicable	8000 hours	
Operational Availability	Not applicable	0.975	

N9954

REV A

Figure B-2 (Continued)

RETROFIT REFERENCE DESIGN BASIS (CONTINUED)

Design Basis/ Requirement	POC	Retrofit Reference Design Basis	Rationale*
Seed Regeneration			
Regeneration Plant Feed	CFFF ESP and superheater spent seed/ K_2SO_4 plus flyash	Convective boiler bottom ash and flyash	Radiant furnace slag discarded due to low K concentration and poor leaching quality
Product Seed Form	Potassium Formate ($KCOOH$)	Potassium Formate ($KCOOH$)	
Seed Loading	1 to 2% K as K_2CO_3	1 to 2% K; seed regeneration required	All sulfur is to be captured as K_2SO_4 ; little conductivity improvement and higher cost with K > 2%
K_2/S Ratio	> 1	> 1	> 95% sulfur removal from the gas stream
Product Seed Concentration	Ranging from dry anhydrous to 85% aqueous solution.	Molten potassium salt	Seed regeneration economics and generator performance
Impurity Levels	2% max impurities (K_2SO_4 , ash) chloride TBD	TBD based on elemental partitioning in ash and seed regeneration	Minimize impurities based on plasma performance, hardware corrosion, and regeneration economics
MTBF	Not applicable	10000 hours	
Useful Equipment Life	Scalable to retrofit	30 years	
Operational Availability	Not applicable	0.996	
Feed Systems			
Coal	Dual feed from single injection vessel using pinch valves for flow control. Measurement with load, cells, P, capacity/velocity and Coriolis type devices; nitrogen carrier	Pneumatic injection. Best available technology at the time of installation	Maximize reliability, controllability and turnaround
Seed	Basically same as coal system without the pinch valve	Formate as a liquid feed (molten or solution)	
Additives	Fe_2O_3 /gear oil slurry; diaphragm type metering pump injected at nozzle entrance	Additive TBD based upon POC results	Additives if required to control cathode wall non-uniformities

*The Rationale for selection of most parameters relates to efficiency of the integrated MHD facility.

**Balance of plant equipment including feed materials receipt, coal pulverizing, oxygen production and water treatment are not included in this table.

N9956

TABLE B-1

TTIRC

RECOMMENDATIONS FOR POC PROGRAM INTEGRATION

K₂/S RATIO

It is recommended that the following activities be addressed.

- Document and investigate, analytically and experimentally, the sulfur level and K₂/S ratio corrosion relationship for the components exposed to sulfur containing gases.
- Technical and economic analysis of seed regeneration operation for low sulfur Western coal incorporating K₂CO₃-K₂SO₄ separation prior to regeneration or seed by-pass at conditions which still fulfill the requirements for projected NSPS sulfur removal.
- Continue to study the effects of K₂/S ratio on HRSR, ESP and baghouse performance and costs.

ESP/BAGHOUSE OPERATION

It is recommended that ESP and baghouse performance continue to be investigated and over the range of gas temperatures (250-750°F) and K₂/S ratios (1-3).

Other relevant industrial and DOE experience should be investigated.

SEED REGENERATION INTEGRATION AND SLAG REJECTION

It is recommended that the seed regeneration process be integrated into both of the retrofit conceptual designs.

The feeding of molten salt or an aqueous salt solution (transport and injection methods) should be investigated within the POC program.

It is recommended that seed recovery efficiency and economics be evaluated to establish a lower limit for slag rejection.

OVERALL MHD COMBUSTOR STOICHIOMETRY

It is recommended that testing be performed at the lowest stoichiometries possible, and still meet performance and reliability requirements, sufficient to develop performance maps within the 0.80 to 0.95 range.

ADDITIVES

It is recommended that the impact and economics of iron oxide addition on the HRSR and seed regeneration process be assessed if iron oxide is selected for MHD channel operation.

Other methods for alleviating cathode wall shorting, should be continued.

TABLE B-1 (CONTINUED)

TTIRC

RECOMMENDATIONS FOR POC PROGRAM INTEGRATION

SINGLE LOAD VERSUS MULTIPLE LOAD OPERATION

It is recommended that multiple load operation be investigated as part of the POC program because it is necessary for efficient retrofit operation.

PERFORMANCE AND RELIABILITY

It is recommended that the POC program build a reliability data base by operating the power train at projected retrofit channel stresses.

RAM (Reliability, Availability, Maintainability) analysis should be incorporated into the test programs.

PART LOAD OPERATION

It is recommended that analytical design efforts be performed to establish part load operating conditions, integrated control strategies and information on test requirements.

SECOND STAGE OXIDANT

It is recommended that testing of low pressure second stage preheated oxidant injection be performed.

SCALABILITY

It is recommended that the basic design selected for testing of critical components and equipment should be capable of scale-up and applied to early commercial systems. Discrepancies between the POC programs, the projected retrofit components and early commercial systems should be investigated and resolved.

INTEGRATED PLANT CONTROL STRATEGY

It is recommended that integrated plant control strategies be studied in the POC programs. Studies should include plant control, fault analysis, dynamic modeling, part load, start-up/shut-down.

SEED IMPURITIES

Once the levels of impurities are known, after POC seed regeneration plant demonstration, the effects on various components should be evaluated in conjunction with methods for controlling buildup to acceptable levels.

SUPERCONDUCTING MAGNETS

It is recommended that previous experiences with SCM's from both MHD technology and other technologies be catalogued and specific design parameters compared with SCM requirements for a retrofit facility and early commercial plant.

TABLE B-1 (CONTINUED)

TTIRC

RECOMMENDATIONS FOR POC PROGRAM INTEGRATION

SECOND STAGE COOLING

It is recommended that the impact of the second stage cooling on an early commercial facility be assessed.

APPENDIX C

MINUTES OF THE JUNE 1990 GENERAL COMMITTEE MEETING

Presented in this Appendix are the agenda and minutes of the semi-annual General Committee meeting held at the Chicago Westin Hotel on June 25, 1990. The list of attendees for the meeting is shown below. Included in this appendix are reproductions of the presentations by Mr. Bruce Pote of TRW and Dr. Bob Aurora of Houston Lighting and Power.

List of Attendees

Argonne National Laboratories	Mike Petrick
Avco	Bob Kessler
Babcock & Wilcox	Bob McIlroy
Consultant	Finn Hals
Department of Energy	Ralph Carabetta
Department of Energy	Harold Chambers
Department of Energy	Bob Wright
Department of Energy	Nick Oliver
Department of Energy	Chuck Thomas
Department of Energy	Leo Makovsky
Department of Energy	Gary Staats
Department of Energy	Victor Der
General Dynamics	Sam Gurof
Gilbert/Commonwealth	Bill Owens
Gilbert/Commonwealth	Jack Hirschenhofer
Houston Lighting and Power	Bob Aurora
MHD Development Corp.	Neal Egan
MHD Development Corp.	Bob Labrie
Mississippi State Univ.	Bob Cook
MIT	Peter Marston
Montana Power Company	Fred Walter
Montana State University	Dick Rosa
MSE, Inc.	Jack Sherick
MSE, Inc.	Jerry Funk
Pennsylvania Power and Light	Bob Johnson
SAIC	John Cutting
TRW, Inc.	Marty Bauer
TRW, Inc.	Bruce Pote
TRW, Inc.	Bob Meyers
TRW, Inc.	Lou Scinto
STD Research Corp.	Craig Maxwell
STD Research Corp.	Martin Brouillette
UTSI	Norm Johanson
UTSI	Joel Muelhauser
UTSI	Marvis White
UTSI	Richard Attig
Westinghouse AESD	Joe Lance

**MHD TECHNOLOGY TRANSFER
INTEGRATION AND REVIEW COMMITTEE
MEETING OF THE GENERAL COMMITTEE
June 25, 1990
CHICAGO - WESTIN HOTEL**

1:00 PM	Welcome and Introduction	B. Pote - TRW
1:05 PM	Call to Order and Approval of Previous General Committee Meeting Minutes	W. Irving - WMI G. Staats - DOE
1:15 PM	POC Integration Task Force - Organization, Objectives and Approach - Retrofit Reference Design Basis - Open Technical Issues - Recommendation to the TTIRC Executive Committee	B. Pote - TRW F. Hals - Avco
4:00 PM	Utility Data Requirements for Candidate Technologies for New Capacity Additions	R. Aurora Houston Lighting and Power Co.
4:15 PM	Clean Coal Technology Update	W. Owens Gilbert/Commonwealth
4:30 PM	Other Business	

ADJOURN

TECHNOLOGY TRANSFER, INTEGRATION AND REVIEW COMMITTEE (TTIRC)

Minutes of the Semi-Annual General Committee Meeting

A meeting of the General Committee of the MHD Technology Transfer, Integration and Review Committee (TTIRC), held on June 25, 1990 at the Chicago Westin Hotel, was brought to order by co-chairman Gary Staats of DOE.

Minutes of Previous Meeting

Reading of the minutes, which were distributed prior to the meeting, was dispensed with. Members were referred to the minutes published in the committee's third semi-annual report (TRW Report No. MHD-ITC-90-133). Since this report has been published and distributed, no motion for acceptance was necessary.

Presentation by Bruce Pote - POC Integration Task Force

Mr. Bruce Pote of TRW made a lengthy presentation on the POC Integration Task Force activities. A copy of Mr. Pote's presentation slides are included as Figure C-1 with these minutes with the exception of the Retrofit Reference Design Basis (RRDB) which is reprint in Appendix B as Figure B-2.

Mr. Pote's presentation covered the origins, organization, objectives, approach and status of the POC Task Force. This was followed by a brief overview of the RRDB with the primary emphasis on areas of departure between the POC program and the RRDB. A copy of the RRDB (Rev. A) was provided to the members and guests in attendance.

The open technical issues and resulting recommendations were covered in detail. The presentation was structured such that an open discussion on each issue followed Mr. Pote's formal presentation. Many of the issues resulted in lively debate and technical interchange, with much of the open discussions focusing on marketing of MHD for grassroots and retrofit demonstrations.

The TTIRC General Committee was in agreement with all of the conclusions and recommendations presented by Mr. Pote with the exception of seed impurities. The POC Task Force and Executive Committee felt that seed impurities were not a major issue at this time and would be better addressed once impurities levels were better quantified after seed regeneration POC testing. Many General Committee members felt that seed impurities were indeed an important issue. This subject will be further discussed at subsequent TTIRC meetings.

NOTE: The write-up provided here makes no attempt to reiterate the lengthy open discussions during Mr. Pote's presentation. However, since the meeting was recorded on audio tape, a more rigorous transcript can be provided if desired. Committee members can contact Mr. Pote if interested.

Presentation by Bob Aurora - Utility Data Requirements for Candidate Technologies for New Capacity Additions

Dr. Bob Aurora of Houston Lighting and Power presented a perspective of utility data expectations required to market a new technology. A copy of Dr. Aurora's presentation slides are included as Figure C-2 with these minutes.

Dr. Aurora's presentation opened by posing the following question, "What is required from the MHD community to make this technology (MHD) the technology of choice for new or retrofit power plants"? The answer from a utility perspective is that the technology must be a "candidate technology" for utility resource planning. There are a number of data requirements that must be fulfilled in order to make the list of candidate technologies for utility resource planning. To even be considered, the technology must be on the list of applicable technologies and to get on the list the following data must be provided:

- Heat rate
- Planned outage rate
- Equivalent unplanned outage rate
- Lead time (commitment → operation)
- Unit life
- Capital costs
- Capital additions
- Land costs
- Direct non-fuel operating and maintenance costs (fixed and variable)

Dr. Aurora noted the source of the data is as important as the data itself. The source must be unbiased (i.e. no vested interest in the technology selection). EPRI was noted as the most logical source but other sources can be considered.

Dr. Aurora shared with the committee some of the steps Houston Lighting and Power utilized in the selection of a candidate technology for their new capacity addition in the 1998 to 1999 time frame. The planning cycle began in 1989.

In assessing a new technology, where quantitative data on unplanned outages, etc., are unknown, a technology composite is constructed. This composite lists all of the major pieces of equipment (pumps, valves, etc.) where operating data is available, plus equipment unique to the new technology where MTBF/MTTR is unknown. A conservative estimate is then made on the unknown data with an appropriate contingency to arrive at a quantitative estimate for the technology list.

Each technology has a "technology profile" constructed of tangible factors such as:

- Supplier
- Parameters
- Expected value (low and high range)
- Source of data
- Cycle capability
- Operating range
- Etc.

These are the input data required to operate systems models which perform life cycle cost analysis (levelized mils/kwh). The "best" technology is selected based on the output of the model.

Intangible factors are then assessed by management, some of which can be a go/no-go decision on the technology. These intangibles include environmental aspects, performance aspects (base load-load following), size compatibility, and level of technical development. These are all evaluated by management to select the technology for a new capacity addition.

Presentation by Bill Owens - Clean Coal Technology Update

Dr. Bill Owens of Gilbert/Commonwealth provided a status of the MHD Forum activities relating to a Clean Coal Technology proposal. As everyone is probably aware, CCT-4 and 5 are currently on indefinite hold pending resolution on the acid rain bill by Congress. There have been rumors that CCT-4 and 5 will die and the money be allocated to retrofitting utility plants with state-of-the-art scrubbers. In contrast, the impending global warming initiative may cause utilities to take a long-range approach to emissions as a package problem.

Gilbert/Commonwealth expects to play a major role in the Clean Coal activities as they relate to MHD. Gilbert/Commonwealth met with Assistant Secretary for Fossil Energy (Joe Gentile) concerning the status of CCT Rounds 4 and 5. Top DOE officials are confident that CCT-4 and 5 will be issued and will stress the repowering of utility power plants as opposed to retrofitting.

The net result will be the delay in the issue of the Clean Coal solicitations by about one year. Initially the CCT-5 proposal was due in November 1991 with a likely delay to November 1992.

This delay will benefit MHD from two perspectives: 1) the proposal activities will kick-off after the start of the POC long duration power train testing, and 2) it gives the MHD Forum another year to obtain the 50 percent cost sharing required under the Clean Coal program.

The challenge is for the MHD technical community to complete the POC program on schedule and to be in a position (technically and financially) to compete for a CCT-5 award.

Other Business

Mr. Gary Staats opened the floor to any other business. There being no further business, Mr. Staats formally adjourned the meeting.

Figure C-1.

POC INTEGRATION TASK FORCE

**REPORT TO THE TTIRC
GENERAL COMMITTEE**

**JUNE 25, 1990
CHICAGO - WESTIN HOTEL**

Figure C-1.

POC INTEGRATION TASK FORCE

BRUCE POTE, TRW, CHAIRMAN

FINN HALS, CONSULTANT

BILL OWENS, GILBERT/Commonwealth

JOE LANCE, Westinghouse

JOHN CUTTING, SAIC

LOREN McCLANATHAN, TRW

Figure C-1.

POC Integration Task Force Organization

POC Integration Approach

Figure C-1.

01M.90.227.00

Figure C-1.

POC INTEGRATION TASK FORCE

OBJECTIVE

TO FOCUS THE POC PROGRAM EFFORTS ON COMMERCIALY REALISTIC GOALS FOR THE FIRST
MHD-STEAM RETROFIT POWER PLANT

TO INTEGRATE THE POC PROGRAM ELEMENTS (TOPPING CYCLE, BOTTOMING CYCLE & SEED
REGENERATION) WITHIN THESE COMMON GOALS

Figure C-1.

POC INTEGRATION TASK FORCE

APPROACH

REVIEW POC PROGRAM REQUIREMENTS AND PROGRESS

IDENTIFY REQUIREMENTS FROM THE TWO RETROFIT CONCEPTUAL DESIGN STUDIES

DEFINE A CONSENSUS RETROFIT REFERENCE DESIGN BASIS (RRDB)

USING THE RRDB, IDENTIFY POC PROGRAM NEEDS TO SATISFY THE RRDB REQUIREMENTS

ISSUE RECOMMENDATIONS TO THE TTIRC EXECUTIVE COMMITTEE WHERE CHANGES/ADDITIONS TO THE POC PROGRAM ARE REQUIRED TO SATISFY THE RRDB

MONITOR THE POC PROGRAM TO MAINTAIN SYSTEMS INTEGRATION

Figure C-1.

POC INTEGRATION TASK FORCE

PROGRESS (AS OF JANUARY 1990)

REVIEWED CORETTE AND SCHOLZ RETROFIT DESIGNS

REVIEWED GE AND WESTINGHOUSE ADVANCED POWER TRAIN STUDIES

REVIEWED OTHER EARLY COMMERCIAL CONCEPTUAL DESIGNS (CSPEC, NASA COMPARATIVE ANALYSIS, AVCO/CE/C.T.MAIN, ETC.)

IDENTIFIED RETROFIT REQUIREMENTS AND FORMULATED A RETROFIT REFERENCE DESIGN BASIS (RRDB)

EVALUATED POC PROGRAM REQUIREMENTS AND PLANS

IDENTIFIED AREAS WHERE POC PROGRAM DOES NOT ADDRESS REQUIREMENTS

DISTRIBUTED RRDB AND A QUESTIONNAIRE ON THE IDENTIFIED ISSUES WHERE POC DOES NOT CONFORM TO THE RRDB

Figure C-1.

POC INTEGRATION TASK FORCE

PROGRESS

EVALUATED RESPONSES TO THE QUESTIONNAIRE UPDATED RRDB BASED ON REVIEWER AND TASK
FORCE INPUTS FORMULATED CONCLUSIONS/RECOMMENDATIONS

DISTRIBUTED TASK FORCE REPORT TO THE TTIRC EXECUTIVE COMMITTEE WITH
RECOMMENDATIONS ON IDENTIFIED ISSUES

IDENTIFIED POTENTIAL MHD COMMERCIALIZATION ISSUE BASED ON EPRI MHD UTILITY
COLLOQUIUM RELATING TO HIGH TEMPERATURE DIRECT FIRED AIR HEAT DEVELOPMENT

Figure C-1.

POC INTEGRATION TASK FORCE

RETROFIT REFERENCE DESIGN BASIS

THE RRDB IS A GENERIC SET OF COMMON SPECIFICATIONS AND REQUIREMENTS FOR A
MHD-STEAM RETROFIT POWER PLANT

THE TASK FORCE UTILIZED THE RRDB TO EVALUATE THE PLANNED TESTING AND FOCUS OF
THE POC PROGRAMS

THE REQUIREMENTS FOR RRDB ARE DIVIDED INTO NINE SECTIONS:

GENERAL PLANT

COMBUSTOR

NOZZLE/ CHANNEL ASSEMBLY

MAGNET

DIFFUSER

HEAT RECOVERY (INCLUDING PARTICULATE CONTROL)

INVERTER

SEED REGENERATION

FEED SYSTEM (SPECIFIC/UNIQUE TO MHD)

Figure C-1.

POC INTEGRATION TASK FORCE

OPEN TECHNICAL ISSUES

REVIEW OF THE POC PROGRAMS IN RELATION TO THE RRDB IDENTIFIED MANY AREAS OF AGREEMENT BUT A NUMBER OF INCONSISTENCIES THAT NEED TO BE FURTHER ADDRESSED WITHIN THE POC PROGRAMS BEFORE ADVANCING TO THE RETROFIT DEMONSTRATION

SIXTEEN ISSUES WERE IDENTIFIED:

SCALABILITY
PERFORMANCE AND RELIABILITY
SUPERCONDUCTING MAGNETS
PART LOAD OPERATION
OVERALL MHD COMBUSTOR STOICHIOMETRY
SECOND STAGE COMBUSTOR OXIDANT
SECOND STAGE COMBUSTOR COOLING
SEED IMPURITIES

SEED REGENERATION INTEGRATION
MULTIPLE LOAD OPERATION
ACTIVE CURRENT CONTROLS
ADDITIVES
K₂/S RATIO
ESP/BAGHOUSE OPERATION
SLAG REJECTION
INTEGRATED PLANT CONTROL STRATEGY

Figure C-1.

POC INTEGRATION TASK FORCE

RECOMMENDATIONS

THE RECOMMENDATIONS PROVIDED HEREIN ARE BASED PRIMARILY ON TECHNICAL NEEDS TO SATISFY THE RRDB SPECIFICATIONS; BUDGETARY AND SCHEDULE CONCERNS WERE NOT A SIGNIFICANT PRIORITY WITHIN THE EVALUATION PROCESS

Figure C-1.

POC INTEGRATION TASK FORCE

SCALABILITY

THE FIRST MHD-STEAM RETROFIT DEMONSTRATION PLANT IS ENVISIONED AT 200-300 MW_T WHILE THE TOPPING CYCLE BOTTOMING CYCLE AND SEED REGENERATION POC PROGRAMS ARE SIZED AT 50, 28 AND 5 MW_T, RESPECTIVELY

WITH THE EXCEPTION OF THE EXTERNAL DESIGN OF THE MHD GENERATOR, SCALABILITY OF THE MAJOR COMPONENTS TO THE RETROFIT SIZE IS BEING ADDRESSED WITHIN THE POC PROGRAM

IT IS RECOMMENDED THAT THE BASIC DESIGN SELECTED FOR TESTING OF CRITICAL COMPONENTS AND EQUIPMENT SHOULD BE CAPABLE OF SCALE-UP AND APPLIED TO EARLY COMMERCIAL SYSTEMS. DISCREPANCIES BETWEEN THE POC PROGRAMS AND THE PROJECTED RETROFIT COMPONENTS SHOULD BE INVESTIGATED AND RESOLVED

- BASIC DESIGN
- METHOD OF CONSTRUCTION
- MATERIALS

Figure C-1.

POC INTEGRATION TASK FORCE

PERFORMANCE AND RELIABILITY

WITHIN THE NATURAL LIMITATIONS OF THE POC TESTING, IT IS DIFFICULT TO SIMULATE ALL PARAMETERS SIMULTANEOUSLY THAT WOULD MAKE THE TEST OPERATION TOTALLY PROTOTYPICAL

EXAMPLE: MAXIMUM POWER vs. RETROFIT CHANNEL STRESSES

IT IS RECOMMENDED THAT THE POC PROGRAM SHOULD BUILD A RELIABILITY DATA BASE BY OPERATING THE POWER TRAIN AT PROJECTED RETROFIT CHANNEL STRESSES

RAM (RELIABILITY, AVAILABILITY, MAINTAINABILITY) ANALYSIS SHOULD BE INCORPORATED INTO THE TEST PROGRAMS

Figure C-1.

POC INTEGRATION TASK FORCE

SUPERCONDUCTING MAGNETS

THE POC TEST PROGRAM WILL BE PERFORMED WITH THE EXISTING IRON CORE MAGNET, AT A PEAK FIELD OF 2.93 TESLA. RETROFIT AND COMMERCIAL MHD POWER PLANTS WILL REQUIRE SCM'S AND PEAK FIELDS OF 4.5 TESLA OR GREATER

WITH THE EXCEPTION OF SPECIFIC MHD ENGINEERING NEEDS, THE TECHNOLOGY CURRENTLY EXISTS TO BUILD SCM'S AT THE RETROFIT SCALE.

IT IS RECOMMENDED THAT PREVIOUS EXPERIENCES WITH SCM'S FROM BOTH MHD TECHNOLOGY AND OTHER TECHNOLOGIES BE CATALOGUED AND SPECIFIC DESIGN PARAMETERS COMPARED WITH SCM REQUIREMENTS FOR A RETROFIT FACILITY AND EARLY COMMERCIAL PLANT

DESIGN/OPERATING EXPERIENCE

COST
DELIVERY
RELIABILITY

DESIGN PARAMETERS

PEAK FIELD
STORED ENERGY
PHYSICAL SIZE
ACTIVE FIELD LENGTH
TOTAL WEIGHT
BORE DIMENSIONS

Figure C-1.

POC INTEGRATION TASK FORCE

PART LOAD OPERATION

CURRENT PLANS DO NOT REQUIRE THE POC POWER TRAIN TO ADDRESS OPERATION AT PART LOAD WHILE RETROFIT AND COMMERCIAL FACILITIES WILL HAVE A REQUIREMENT TO OPERATE AT PART ELECTRICAL LOAD; 50% OF THE NOMINAL OPERATING RATING IS TYPICAL

IT IS RECOMMENDED THAT ANALYTICAL DESIGN EFFORTS BE PERFORMED TO ESTABLISH PART LOAD OPERATING CONDITIONS, INTEGRATED CONTROL STRATEGIES AND INFORMATION ON TEST REQUIREMENTS

Figure C-1.

POC INTEGRATION TASK FORCE

OVERALL MHD COMBUSTOR STOICHIOMETRY

OVERALL STOICHIOMETRY OF THE MHD COMBUSTOR DICTATES THE FORMATION OF NO_x AND WILL BE DETERMINED IN A RETROFIT DEMONSTRATION FROM CONSIDERATION TO NO_x EMISSION COMPLIANCE WITH NEW SOURCE POLLUTION STANDARDS (NSPS)

IT IS RECOMMENDED THAT TESTING BE PERFORMED AT THE LOWEST STOICHIOMETRIES POSSIBLE, AND STILL MEET PERFORMANCE AND RELIABILITY REQUIREMENTS, SUFFICIENT TO DEVELOP PERFORMANCE MAPS WITHIN THE 0.80 TO 0.95 RANGE.

Figure C-1.

POC INTEGRATION TASK FORCE SECOND STAGE OXIDANT

PURE, HIGH PRESSURE, OXYGEN AT NEAR AMBIENT TEMPERATURE IS PLANNED FOR THE POC TESTING WHILE THE RETROFIT DEMONSTRATION PLANT WILL USE PREHEATED, LOW PRESSURE, OXYGEN ENRICHED AIR ANALYSES HAVE SHOWN THAT HIGH PRESSURE, PURE OXYGEN CAN ADEQUATELY SIMULATE COMMERCIAL OXIDANT CONDITIONS

LOW PRESSURE INJECTION WILL PRESENT DESIGN AND ENGINEERING ISSUES WHICH NEED TO BE RESOLVED BEFORE SCALING TO A RETROFIT. A DEVELOPMENT PROGRAM SHOULD BE INITIATED WHICH INCLUDES ANALYTICAL EVALUATIONS, COMPUTER AND COLD FLOW MODELING AND DESIGN VERIFICATION TESTING

IT IS RECOMMENDED THAT TESTING OF LOW PRESSURE SECOND STAGE PREHEATED OXIDANT INJECTION BE PERFORMED

Figure C-1.

POC INTEGRATION TASK FORCE

SECOND STAGE COOLING

THE SECOND STAGE OF THE COMBUSTOR WILL BE COOLED WITH 250 F OR CHANNEL COOLING WATER WHILE THE RETROFIT DEMONSTRATION WOULD IDEALLY USE BOILER FEEDWATER FOR THE MOST ATTRACTIVE PROCESS INTEGRATION

NOT TESTING THE SECOND STAGE WITH BOILER FEEDWATER IS NOT AN IMPORTANT ISSUE SINCE THE CHOICE HAS LITTLE IMPACT ON A RETROFIT DESIGN AND EFFICIENCY

IT IS RECOMMENDED THAT THE IMPACT OF A SECOND STAGE COOLING ON A EARLY COMMERCIAL FACILITY BE ASSESSED

Figure C-1.

POC INTEGRATION TASK FORCE

SINGLE LOAD VERSUS MULTIPLE LOAD OPERATION

THE POC GENERATOR WILL BE OPERATED IN A SINGLE TERMINAL CONFIGURATION WHEREAS RETROFIT AND LARGER SCALE FACILITIES WILL UTILIZE A MULTIPLE LOAD OPERATION TO MAXIMIZE THE OVERALL RELIABILITY AND PERFORMANCE OF THE CHANNEL

IT IS RECOMMENDED THAT MULTIPLE LOAD OPERATION BE INVESTIGATED AS PART OF THE POC PROGRAM BECAUSE IT IS NECESSARY FOR EFFICIENT RETROFIT OPERATION

SMALLER SCALE TESTING, INDEPENDENT OF THE 1000 HOUR POC TEST COULD BE PERFORMED IF THIS IS CONSIDERED MORE COST EFFECTIVE AND TIMELY

Figure C-1.

POC INTEGRATION TASK FORCE

K_2/S RATIO

THERE EXISTS A DICHOTOMY OF OPINION BETWEEN THE RECYCLE OF SULFUR BACK INTO THE POWERTRAIN AND EXCESS POTASSIUM CARBONATE IN THE GAS

THE K_2/S ISSUE HAS EVOLVED INTO A HIGH SULFUR VERSUS LOW SULFUR COAL ISSUE

FOR EASTERN, HIGH SULFUR, COAL THERE IS SUFFICIENT SULFUR IN THE GAS TO COMBINE WITH ALL OF THE SEED MATERIAL REQUIRED FOR PLASMA IONIZATION AND THE K_2/S RATIO IS APPROXIMATELY ONE (1)

FOR WESTERN, LOW SULFUR, COAL THE SULFUR LEVEL IN THE GAS IS DEPENDANT ON THE OPERATION OF THE SEED REGENERATION PROCESS

THE ISSUE BECOMES A TRADE-OFF BETWEEN SEED REGENERATION COSTS AND EQUIPMENT LIFETIME, RELIABILITY AND PERFORMANCE

Figure C-1.

POC INTEGRATION TASK FORCE

K₂/S RATIO

IT IS RECOMMENDED THAT THE FOLLOWING ACTIVITIES BE ADDRESSED

- DOCUMENT AND INVESTIGATE, ANALYTICALLY AND EXPERIMENTALLY, THE SULFUR LEVEL AND K₂/S RATIO CORROSION RELATIONSHIP FOR THE COMPONENTS EXPOSED TO SULFUR CONTAINING GASES
- TECHNICAL AND ECONOMIC ANALYSIS OF SEED REGENERATION OPERATION FOR LOW SULFUR WESTERN COAL INCORPORATING K₂CO₃-K₂SO₄ SEPARATION PRIOR TO REGENERATION OR SEED BY-PASS AT CONDITIONS WHICH STILL FULFILL THE REQUIREMENTS FOR PROJECTED NSPS SULFUR REMOVAL
- CONTINUE TO STUDY THE EFFECTS OF K₂/S RATIO ON HRSR, ESP AND BAGHOUSE PERFORMANCE AND COSTS

Figure C-1.

POC INTEGRATION TASK FORCE

SLAG REJECTION

SLAG REJECTION RATES REQUIRED FROM THE MHD COAL COMBUSTOR IS PRIMARILY DRIVEN BY SEED RECOVERY ECONOMICS

IT IS RECOMMENDED THAT SEED RECOVERY EFFICIENCY AND ECONOMICS BE EVALUATED TO ESTABLISH A LOWER LIMIT FOR SLAG REJECTION

Figure C-1.

POC INTEGRATION TASK FORCE SEED REGENERATION

THE SEED REGENERATION SYSTEM DESIGN DOES NOT PRESENTLY INTEGRATE WITH A TOTAL FACILITY DESIGN WHICH IS NECESSARY TO CONSOLIDATE THE POC PROGRAM AND RRDB REQUIREMENTS INTO AN INTEGRATED SYSTEM

IT IS RECOMMENDED THAT THE SEED REGENERATION BE INTEGRATED INTO BOTH OF THE RETROFIT CONCEPTUAL DESIGNS

THE FEEDING OF MOLTEN SALT OR A AQUEOUS SALT SOLUTION (TRANSPORT AND INJECTION METHODS) SHOULD BE INVESTIGATED WITHIN THE POC PROGRAM

Figure C-1.

POC INTEGRATION TASK FORCE

ESP/BAGHOUSE OPERATION

ESP PERFORMANCE IS A FUNCTION OF INLET GAS TEMPERATURE AND PARTICULATE COMPOSITION

BAGHOUSE PERFORMANCE IS AFFECTED BY THE K_2/S RATIO

IT IS RECOMMENDED THAT ESP AND BAGHOUSE PERFORMANCE CONTINUE TO BE INVESTIGATED AND OVER THE RANGE OF GAS TEMPERATURES (250-750 F) AND K_2/S RATIOS (1-3).

OTHER RELEVANT INDUSTRIAL AND DOE EXPERIENCE SHOULD BE INVESTIGATED

Figure C-1.

POC INTEGRATION TASK FORCE

SEED IMPURITIES

POC TESTING WILL BE PERFORMED WITH COMMERCIALY PROCURED POTASSIUM CARBONATE WHILE THE RETROFIT DEMONSTRATION WILL UTILIZE A REGENERATED SEED CONTAINING IMPURITIES

INCREASED LEVELS OF SODIUM AND CHLORINE ARE EXPECTED TO DECREASE PLASMA ELECTRICAL CONDUCTIVITY

ONCE THE LEVELS OF IMPURITIES ARE KNOWN, AFTER POC SEED REGENERATION PLANT DEMONSTRATION, THE EFFECTS ON VARIOUS COMPONENTS SHOULD BE EVALUATED IN CONJUNCTION WITH METHODS FOR CONTROLLING BUILDUP TO ACCEPTABLE LEVELS

SEED IMPURITIES DO NOT APPEAR TO BE A MAJOR ISSUE AT THIS TIME

Figure C-1.

POC INTEGRATION TASK FORCE

ADDITIVES

USING ADDITIVES, SUCH AS Fe_2O_3 , HAS BEEN DEMONSTRATED AS AN EFFECTIVE SHORT TERM MEANS IN REDUCING CATHODE WALL SLAG POLARIZATION AND THE RESULTING HIGH VOLTAGE GAPS BETWEEN SHORTED GROUPS OF ELECTRODES. THE HIGH VOLTAGE GAPS ACCELERATE MATERIAL WEAR RATES AND REDUCE ELECTRODE AND SIDEWALL LIFE. THE USE OF ADDITIVES ADDS UNDESIRABLE COST AND COMPLEXITY TO A RETROFIT OR COMMERCIAL FACILITY THAT RENDERS IT UNATTRACTIVE

IT IS RECOMMENDED THAT THE IMPACT AND ECONOMICS OF IRON OXIDE ADDITION ON THE HRSR AND SEED REGENERATION PROCESS BE ASSESSED IF IRON OXIDE IS SELECTED FOR MHD CHANNEL OPERATION

OTHER METHODS FOR ALLEVIATING CATHODE WALL SHORTING, SHOULD BE CONTINUED

Figure C-1.

POC INTEGRATION TASK FORCE

INTEGRATED PLANT CONTROL STRATEGY

THE POC TEST PROGRAM IS STRUCTURED TO ADDRESS INTEGRATED SUBSYSTEMS OF AN MHD-SEAM POWER PLANT. AS A RESULT INTEGRATED PLANT CONTROL STRATEGY IS NOT ADDRESSED

IT IS RECOMMENDED THAT INTEGRATED PLANT CONTROL STRATEGIES BE STUDIED IN THE POC PROGRAMS. STUDIES SHOULD INCLUDE PLANT CONTROL, FAULT ANALYSIS, DYNAMIC MODELING, PART LOAD, START-UP/SHUT DOWN

SUMMARY OF 1989 RESOURCE PLAN ALTERNATIVES

[illegible]

Figure C-2. Utility Data Requirements for Candidate Technologies

TECHNOLOGY PROFILE

SUPPLIED BY	PARAMETER	EXPECTED VALUE	LOW VALUE	HIGH VALUE	SOURCE
_____	Net Generating Capacity (# units x MW)		—	—	
_____	Fuel Type				
_____	Expected Heat Rate - Full Load (8BTU/kWh)				
	- 75% Load (BTU/kWh)				
	- 50% Load (BTU/kWh)				
	- 25% Load (BTU/kWh)				
_____	Planned Outage Rate (%)				
_____	Equivalent Unplanned Outage Rate (%)				
_____	Cycling Capability (cycles/year)				
_____	Minimum Load (%)				
_____	lead Time (months)				
_____	Unit Life (years)				
_____	Capital Cost (\$/kW) (w/o AFUDC)				
_____	Post-COD Capital Additions (\$000/unit-yr)				
_____	Land Cost (\$/kW)				
_____	Direct Non-Fuel Fixed O&M (\$/kW-yr)				
_____	Direct Non-Fuel Variable O&M (mill/kWh)				

Figure C-2. Utility Data Requirements for Candidate Technologies (Continued)

APPENDIX D

STATUS REPORT - MHD INTEGRATED TOPPING CYCLE

The semi-annual status report for the ITC project is presented in this appendix.

CONTRACT TITLE:

MHD Integrated Topping Cycle
DE-AC22-87PC90274

DATE:

September 1990

PRIME CONTRACTOR:

TRW Space & Technology Group
One Space Park; Redondo Beach, CA 90278

REPORTING PERIOD:

April 1990 to
September 1990

MAJOR SUBCONTRACTORS:

Avco Research Laboratory/Textron
Westinghouse Science and Technology Center

PROJECT MANAGER:

J.M. Bauer
(213) 814-0245

PERIOD OF PERFORMANCE:

9/30/87 to
12/30/93

1. CONTRACT OBJECTIVE

The objectives of this effort are to design, construct and deliver all prototypical hardware necessary to conduct long-duration integrated MHD topping cycle proof-of-concept tests at the Component Development and Integration Facility in Butte, Montana, and to complement the existing engineering data base so as to allow scale-up of the MHD power train to an early-commercial scale retrofit MHD power plant.

2. TECHNICAL APPROACH

In order to achieve the program goal of demonstrating the durability and reliability of critical MHD topping cycle components at the 50 MW₊ scale, prototypical hardware will be operated at the CDIF for over 1000 hours. In general, the approach capitalizes on the existing R&D data base to design, fabricate, check out, deliver, integrate and test new prototypical power train components. Specifically, the following tasks will be performed:

- Task 1 - Systems Engineering Studies
- Task 2 - Prototypical Combustor Design, Fabrication, and Delivery
- Task 3 - Prototypical Channel Design, Fabrication, and Delivery
- Task 4 - Diffuser Section Design, Fabrication, and Delivery
- Task 5 - Power Conditioning Design, Fabrication, and Delivery
- Task 6 - Test Engineering Activities at the CDIF
- Task 7 - Hardware Repair/Replacement
- Task 8 - MHD Technology Transfer, Integration, and Review Committee
- Task 9 - Quality Assurance
- Task 10 - Integrated Project Management

3. PROGRESS SUMMARY

Task 1 - Systems Engineering

Part of the systems engineering efforts during the reporting period focused on the detailed definition of the interfaces between subsystems and between each subsystem and the CDIF. The interfaces for the Combustion Subsystem and the Channel subsystem were completed as part of the CDR process and the High Pressure Cooling Subsystem and the Current Consolidation Subsystem interfaces were identified as far as flow rates, line sizes, and quantities. The final definition of the mechanical interfaces remains open until the final design of these subsystems, currently planned for the next reporting period, is completed.

As part of the interface document, process flow diagrams, instrumentation diagrams, and cooling water flow diagrams were prepared.

Also prepared during this reporting period was a Facility Impact Report that identifies all of the changes required in progressing from the workhorse hardware to the prototypical hardware. This includes facility modifications, changes in process flow rates, operational changes, and identifies all of the interfaces and required instrumentation. This document is used as the major vehicle for transmitting information to the CDIF site operator.

A Systems Overview Report was also prepared as part of the formal CDR documentation as a guide through the many volumes of documentation provided for the Critical Design Review process. This report contains the system level requirements, a brief description of each of the subsystems, discusses power train integration and ends with a discussion of the integrated power train capabilities versus system requirements and shows the method of verification for each requirement.

Additional systems engineering effort was directed at investigation of key technical issues related to the integration of the prototypical topping cycle hardware at the CDIF. A summary of the status of these investigations is presented in Table 1.

Task 2 - Combustion Subsystem (TRW)

The detailed design was completed during this reporting period including all of the required thermal and stress analyses. The detailed drawings were prepared and presented at the Critical Design Review. The manufacturing procedures were also prepared during this period and will be finalized prior to the manufacturing kick-off scheduled for October.

The detailed design was reviewed in July in an in-house review and formally with the customer (DOE) in September. Tentative approval was given by DOE pending the completion of the CDR action items.

There were two major areas of testing to support the CDR during this period. The first was a duration test of a prototypical spool section (shell and cooling panels) performed at the University of Tennessee Space Institute (UTSI) in the Coal Fired Flow Facility (CFFF). This test duration was over 250 hours with 17 start-ups. Post-test inspection did

TABLE 1. SUMMARY OF SYSTEMS ENGINEERING ANALYSES

Issue	Analysis Summary	Resolution
Oxidant Preheat (*)	Does vitiated air as currently used at the CDIF sufficiently simulate preheated oxygen enriched air which would be used in a retrofit?	Analytical study demonstrated that preheated oxygen enriched air can be simulated by the use of an oil-fired vitlator. Additional oxygen is required in vitlator to combust fuel oil.
Oxidant Composition (*)	Oxidant for the second stage of a retrofit plant has been proposed to be 40% oxygen enriched air preheated to 1200°F.	Higher oxygen enrichment levels are required during POC testing relative to projected retrofit operation to account for the use of an oil-fired vitlator, room temperature secondary oxidizer, higher coal moisture (8% vs. 5%), higher throat conductivity requirement (8.0 vs. 7.0 mho/m) and higher combustor heat losses (7.0% vs. 5-6%).
Prototypical Test Conditions (*)	Define test conditions for CDIF testing that are prototypical of a retrofit operation.	Reference operating conditions have been defined for both Western and Eastern coal. Actual duration test conditions will be determined following Design Verification Testing.
Combustor Coolant Temperature	The compatibility of combustor cooling water with boiler feed water was evaluated.	For cooling water to be efficiently used as boiler feed water, temperature exiting combustor should exceed 450°F. Therefore, the combustor will be designed for 450°F cooling. Need for 250°F loop being assessed.
Electrical Isolation (*)	High Pressure Cooling Water Subsystem Slag Rejector	High temperature isolation is the baseline approach. Studies of the electrical isolation of the slag rejection system have been completed.
Seed Material	Seed material can be regenerated to formate at a lower cost than to carbonate. Can formate be used as seed?	Formate has higher theoretical performance than carbonate, but is not available commercially. Some testing will be performed with dry or aqueous KCOOH using regenerated formate. Baseline will remain dry carbonate.
Coal System (*)	Fine coal may enhance performance in terms of carbon utilization and will simplify operation at the CDIF. Coal flow at the CDIF is not controllable in the ranges requested for POC testing. Coal grind size affects slag recovery, and CDIF grinder does not supply correct coal grind to achieve >60% slag recovery (SOW requirement). Major cost impact to replace grinder.	Coal fines were tested on the workhorse hardware; The CDIF system was not modified to produce a finer coal since the coal fines adversely affected slag recovery without improving power performance. The coal system was tested and was modified to improve control and measurement by improvement of the flow control valve operation. Theoretical grind size to achieve SOW requirement was defined, and tests are planned with classified coal to demonstrate >60%. After confirmation, duration tests will be run with out-of-spec coal from existing coal system at reduced recovery.
Magnet	Magnet is a critical piece of hardware. Its failure could result in long delays in CDIF test program.	Spare coils were recommended; a dry (Halon) fire control system is recommended for the magnet power supply.
Start-up/Shutdown	The fast starts and stops that are currently performed at the CDIF are very stressful on the power train hardware.	Reduced stress start-up and shutdown procedures are being developed.
Oxygen Storage	There is insufficient oxygen capacity at the CDIF to perform more than 8 hours of testing more than once a week.	Additional temporary oxygen storage is being installed at the CDIF.
Power Train Anchor Point (*)	Stresses due to thermal growth of the power train are applied at different points, depending on the anchor point of the power train. Alignment of combustor/channel requires new procedures due to fixed anchor point and higher cooling water temperature.	The anchor point will be at the slagging stage/slag tank interface. Study underway to determine channel alignment requirements.

(*) Indicates a change from the previous semi-annual report, or a study in progress.

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not reveal any signs of cracking or panel deformation. The other test was performed at the CDIF to simulate the precombustor filler section at the higher temperatures which will be seen when cooled with the high temperature cooling water. This testing was successful in that no fouling was observed during the test or in the post test inspection.

The High Pressure Cooling Subsystem (HPCS) specification was prepared and reviewed at the CDR. The specification was sent out to eight (8) prospective bidders, four of which returned proposals. The specification breaks the procurement into two phases; phase 1 which covers the final design, and phase 2 which covers the procurement, installation, and final testing of the equipment. The proposals will be evaluated and it is expected that the purchase order for the phase 1 (final design) will be placed late in October.

Because of the decision to ground the high pressure cooling subsystem (see Table 1), an electrical isolator must be placed in the line between the combustion subsystem and the high pressure cooling subsystem. A design was completed this reporting period and a test section was assembled and put through a series of tests to simulate the conditions that will be present during operation. The insulator material of choice, Vespel, showed signs of hydrolysis (cracking) at 450 °F, 600 psi. Alternate materials will be tested during October.

Tasks 3 and 4 - Channel Subsystem (Avco)

The Critical Design Review for the Channel Subsystem was held this reporting period. Manufacturing procedures, including ultrasonic braze inspection, were completed to support the CDR. Approval was given for the cathode and sidewalls gas side designs and the anode design will be reviewed in January 1991.

The current controls were tested at the CDIF during which some noise problems caused them to malfunction. The problem was traced to a poorly regulated supply voltage to the current control cabinets. When the proper voltage was supplied to the control devices, they worked as expected.

Testing in the Mk-VII was carried out to evaluate the 0.7 pitch which was proposed for the prototypical channel versus the 0.6 pitch which was being used in the workhorse channel. The test results confirmed that the 0.7 pitch did not adversely affect performance or lifetime.

Also during this period, considerable testing was performed to evaluate the materials of choice for waterside corrosion. The testing was completed in September and the test samples have been sent out for metallurgical analysis.

The materials for the 1A4 supersonic diffuser section have all been procured and delivered. The diffuser section is currently undergoing final assembly.

Task 5 - Current Consolidation Subsystem (Westinghouse)

The damage to the anode consolidation cabinet which occurred during the testing at Avco during the last reporting period was repaired during

this period. Additional automatic protection was added to the control system to prevent a reoccurrence and the units were extensively retested both at Westinghouse and at Avco. The Avco testing was performed with the units installed on the Mk-VII channel. The testing was very successful. The PDR was held in September and the design was approved by the DOE. The CDR is scheduled for December.

Task 6 - CDIF Test Support

One of the major areas of emphasis was the testing of the current controls provided by Avco. Initial testing showed problems with noise interfering with the operation of the control devices. Considerable effort was spent to determine the cause of the noise which was originally thought to be a problem with the inverter. However, it was finally determined that a poorly regulated voltage was being supplied to the current control devices and when corrected, the devices worked as expected. The current control devices performed properly even in the presence of the inverter spike.

The initial facility readiness tests were run during this period with the goal of reaching a continuous 24 hour run. The longest test was over 21 thermal hours. These long duration tests also verified that the precombustor does not have any fouling problems. During this, and all other testing during this period, the slag rejector assembly checkout continued. Several minor problems related to plugging in the funnel section were detected and are being corrected.

The duration tests (50 hour goal) for the prototypical channel elements were started during this period but the current control problems forced them to be postponed until later this year.

Task 8 - Technology Transfer/Integration

TRW issued to the DOE the final versions of the third and fourth semi-annual status reports on TTIRC activity for the periods April 1989 through September 1989 and October 1989 through March 1990 respectively.

A meeting of the TTIRC Executive Committee was held in June 1990. A new executive committee member was appointed to replace Lou Scinto as Deputy Chairman for Operations.

A meeting of the TTIRC General Committee was held in June 1990 in conjunction with the 28th Symposium of Engineering Aspects of Magnetohydrodynamics (SEAM).

The POC Integration Task Force completed its investigation and findings into ways of ensuring the integration of the various POC program efforts and compatibility with a retrofit demonstration. A consensus retrofit reference design basis (RRDB) was formulated and from the Task Force's review, sixteen issues were identified along with recommendations for additions and/or amendments to the POC program which would be beneficial to meet the requirements of a MHD Steam Retrofit demonstration. These recommendations were prioritized and forwarded to the DOE for their consideration.

4. PLANNED ACTIVITIES (October 1990 - April 1991)

- Critical Design Review by DOE for the Current Consolidation Subsystem
- Initiation of the Manufacturing/Fabrication cycle for the Combustion, Channel and Current Consolidation Subsystem hardware
- Placement of the subcontract for the final design, fabrication, and testing of the High Pressure Cooling Subsystem hardware
- Continuation of the CDIF duration test series

5. SCHEDULE

Near term milestones in the Critical Design Review process are shown in Figure 1. The overall project schedule is shown in Figure 2 and the corresponding Milestone Log of Table 2.

	DATE	1990											
		MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
DELIVER PDR ACTION ITEM RESPONSES	4/9	▼											
HPCS PRESENTATION/PDR CLOSEOUT	4/25	▼											
TRW PROJECT INTERNAL CDR	5/23			▼									
AVCO PROJECT INTERNAL CDR	6/21				▼								
FINAL AVCO SYSTEM INPUTS TO TRW	7/16					▼							
TRW INTERNAL CDR DATA PACKAGE	6/11				▼								
TRW INTERNAL CDR (SYS/COMB/HPCS)	6/18				▼								
AVCO CDR DATA PACKAGE TO TRW	8/3						▼						
AVCO CDR DATA PACKAGE TO DOE	8/10						▼						
AVCO WORKSHOP WITH SOLBES	7/27					▼							
CHANNEL CDR WITH TRW (AT AVCO)	8/16,17						▼						
TRW CDR DATA PACKAGE TO DOE	7/27					▼							
COMB/HPCS/SYSTEM CDR WITH DOE	9/5,6							▼					
AVCO ADDENDUM TO DOE (IF NEEDED)	8/30							▼					
CHANNEL CDR WITH DOE (AT AVCO)	9/18,19								▼				
COMBUSTOR/CHANNEL FINAL DESIGN REP	11/12									▼			
WESTINGHOUSE PDR DATA PACKAGE TO TRW	8/3						▼						
WESTINGHOUSE PDR WITH TRW (AT WESTINGHOUSE)	8/15						▼						
WESTINGHOUSE PDR DATA PACKAGE TO DOE	8/30							▼					
CURRENT CONSOL PDR WITH DOE (AT WESTINGHOUSE)	9/20								▼				
WESTINGHOUSE CDR DATA PACKAGE TO TRW	11/12									▼			
WESTINGHOUSE CDR WITH TRW (AT WESTINGHOUSE)	11/21										▼		
WESTINGHOUSE CDR DATA PACKAGE TO DOE	12/5											▼	
CURRENT CONSOL CDR WITH DOE (AT WESTINGHOUSE)	12/19												▼
CURRENT CONSOL CRITICAL DESIGN REPORT	2/21												
TRW MANUFACTURING READINESS REVIEW	10/2										▼		
AVCO MANUFACTURING READINESS REVIEW	10/4											▼	

01M.90.431.01

Figure 1. Milestone Schedule

MILESTONE SCHEDULE STATUS REPORT

Page 1 of 1

D-9

TABLE 2. STATEMENT OF WORK TECHNICAL MILESTONES

ID	DESCRIPTION	9/89 PLAN	3/90 BASELINE	ACTUAL	COMMENTS
TASK 1 - SYSTEMS ENGINEERING STUDIES					
1A	System Preliminary Design Document	Sep-88	Sep-88	Sep-88	
1B	Preliminary CDIF Test Plan	Jun-89	Aug-89	Aug-89	
1C	System Integration at CDIF	Sep-91	Sep-92		
1D	Final CDIF Test Plan	Feb-92	Sep-92		
TASK 2 - COMBUSTOR DESIGN/FABRICATION/SHIPMENT					
2A	Combustor PDR	Jan-90	Jan-90	Jan-90	
2B	Combustor CDR	Apr-90	Aug-90	Sep-90	
2C	Complete Prototypical Fabrication	Dec-90	Jul-91		
2D	Deliver User's Manual to CDIF	Apr-91	Feb-92		
2E	Complete DVT at TRW	May-91	Feb-92		
2F	Ship Combustor to CDIF	Jun-91	Mar-92		
TASK 3 - CHANNEL DESIGN/FABRICATION/SHIPMENT					
3A	Channel PDR	Jan-90	Jan-90	Jan-90	
3B	Channel CDR	Apr-90	Aug-90	Sep-90	
3C	Complete Channel Fabrication	Mar-91	Jan-92		
3D	Deliver User's Manual to CDIF	Apr-91	Feb-92		
3E	Complete Non-operating Tests	Apr-91	Mar-92		
3F	Ship Channel to CDIF	Jun-91	Mar-92		
TASK 4 - DIFFUSER DESIGN/FABRICATION/SHIPMENT					
4A	Diffuser PDR	Jan-90	Jan-90	Jan-90	
4B	Diffuser CDR	Apr-90	Aug-90	Sep-90	
4C	Complete Diffuser Fabrication	Dec-90	Jan-92		
4D	Deliver User's Manual to CDIF	Apr-91	Feb-92		
4E	Complete Non-operating Tests	Apr-91	Mar-92		
4F	Ship Diffuser to CDIF	Jun-91	Mar-92		
TASK 5 - CURRENT CONSOLIDATION DESIGN/FABRICATION/SHIPMENT					
5A	Current Consolidation PDR	Jan-90	May-90	Sep-90	
5B	Current Consolidation CDR	May-90	Sep-90		New date Dec-90
5C	Complete Hardware Fabrication	Jan-91	May-91		
5D	Deliver User's Manual to CDIF	Feb-91	Dec-91		
5E	Complete Prelim. Tests (if req'd)	Feb-91	Dec-91		
5F	Deliver Hardware to CDIF	Feb-91	Dec-91		
TASK 8 - TTIR COMMITTEE					
8A	Submit Draft TTIRC Charter	Dec-87	Dec-87	Dec-87	
TASK 9 - PRODUCT INTEGRITY (QA)					
9A	Complete Preliminary QA Plan	Sep-88	Sep-88	Sep-88	

APPENDIX E

STATUS REPORT - CDIF OPERATIONS

The semi-annual status report for the CDIF operating contract is presented in this appendix.

TTIRC SEMI-ANNUAL REPORT
Prepared by G. D. Funk
October 12, 1990

CONTRACT TITLE AND NUMBER:

Operation of the Department of Energy's Component Development and Integration Facility.

Contract No. DE-AC07-88ID-12735

CONTRACTOR:

MSE, Inc.
P.O. Box 3767
Butte, MT 59701

REPORTING PERIOD:

April 1, 1990
September 30, 1990

PROJECT MANAGER:

J. M. Sherick
(406) 494-7300 or FTS 587-7300

PERIOD OF PERFORMANCE:

April 1, 1990 to
September 30, 1990

CONTRACT OBJECTIVE:

The Component Development and Integration Facility (CDIF) is an engineering scale, development test facility for magnetohydrodynamic (MHD) topping cycle components operated for the U.S. Department of Energy by MSE, Inc. The major objective of the CDIF is to obtain MHD test results that will provide the design basis for larger scale MHD components, which is in support of DOE's commitment to MHD development and proof-of-concept program. Included is support for the National MHD Environmental Program that provides research on environmental issues specific to MHD, evaluation of environmental test data from the CDIF and the Coal-Fired Flow Facility (CFFF), support for the development of an MHD technical data base, and ambient air quality monitoring at the CDIF.

TECHNICAL APPROACH:

MSE, Inc. has been under contract to the U.S. Department of Energy since October 1, 1978 to perform MHD component testing. The first system turnover from construction was December 1979 and initial turnover of the facility by the construction contractor occurred in February 1980.

MHD component testing began in December 1980 with initial power generation being achieved in April 1981. Maximum power to date, 2.3 MWe, was achieved in September 1982. In December 1983, 3.3 MWhrs of electricity were transmitted to the commercial power grid using the EPRI-supplied inverter.

From December 1983 through July 1984 preparations for and installation of the TRW-designed coal-fired combustor (CFC) occurred. CFC first-stage characterization testing was completed January 30, 1985. Installation of the second stage and an upgraded channel/diffuser was completed on May 17, 1985. The first checkout firing was accomplished on July 17, 1985 and coal-fired power generation tests on the workhorse components were initiated. On October 2, 1986 an 8-hour duration test was completed. In May and July of 1988 record peak power levels (coal generated) were attained in the diagonal and Faraday modes, respectively. After October 12, 1988, instrumentation and plant systems were modified and the TRW coal-fired precombustor (CFPC) was installed in February of 1989. Plant systems were modified to accommodate this new equipment. Checkout testing of the new combustor configuration was completed and the channel was installed. On September 6, 1989, a record peak power level of 1.89 MWe (coal generation) was attained in the diagonal mode. Again on September 28, 1989, a peak power of 1.89 MWe was attained. Duration testing efforts during FY90 resulted in surpassing the previous record for continuous test length of 8 hours 29 minutes of coal-fired MHD testing and 7 hours 10 minutes of power production, which was established October 2, 1986. This record was surpassed twice and the final record established for continuous power generation testing at the CDIF was achieved February 6, 1990 with 12 hours 50 minutes coal-burn time and 12 hours 36 minutes of continuous power run time. On August 14, a thermal test resulted in 21 hours 12 minutes of continuous coal burn time. Tests with these workhorse components will continue until delivery of the next generation (prototypic) hardware.

Specific tasks to support the above include:

1.0 Test Support

- Channel refurbishment and repair
- Design, installation and checkout of plant modifications to support the testing program
- Plant maintenance

2.0 Major Plant Modifications

- Design, installation, and checkout of major plant modifications required to support the Integrated Topping Cycle (ITC) and DOE Multi-Year Program Plan

3.0 Upgrade Plant Systems in Support of ITC and DOE Multi-Year Plan in the Areas of:

- Reliability
- Availability
- Maintainability
- Operability

PROGRESS SUMMARY:

During this reporting period, the shutdown effort was completed and testing at the CDIF was initiated. Checkout and power testing were initiated and included materials/coupon testing, current control checkout testing, slag grinder testing, second-stage oxygen injection variations, and diagonal steady-state and duration operation. Dedicated testing to address the inverter voltage spike and to support on-line current control troubleshooting were also completed. Successful diagnostic measurements, performed by Mississippi State University, were continued. Test time for the reporting period included a total of 70 hours 16 minutes on coal and 34 hours 54 minutes of power generation. The facility was shutdown at the beginning of this reporting period to install the new channel for materials testing and complete installation of the AVCO-supplied current controls. The Materials Test Channel was placed into service during the reporting period. This channel contains materials test coupons and electrode elements that were of the proposed prototypic designs. This channel was made up of new and used wall sections. Two short shutdowns were also completed during the reporting period for channel repair/replacement. During one of the short shutdowns, a new hot-walled filler section for the combustor was installed.

Considerable progress was made on channel refurbishment, fabrication and assembly during the reporting period.

PLANNED ACTIVITIES:

Test plans for the next reporting period include completing checkout of the initial stages of the slag rejector system installation and completion of channel testing for POC hardware. Completion of a 22-hour duration test using Rosebud coal is also planned.

APPENDIX F

STATUS REPORT - HRSR DEVELOPMENT

The semi-annual status report for the HRSR development work at Babcock & Wilcox is presented in this appendix.

SEMI-ANNUAL REPORT TO THE TTIRC

CONTRACT TITLE AND NUMBER:

MHD Heat Recovery Seed Recovery
Development
DE-AC02-79CH10018

DATE:

October 10, 1990

CONTRACTOR:

Babcock & Wilcox Co.
1562 Beeson St., Alliance, Ohio 44601

REPORTING PERIOD:

April 1, 1990 to
September 30, 1990

PROJECT MANAGER:

Robert A. McIlroy
(216) 829-7634

PERIOD OF PERFORMANCE:

July 2, 1979 through
September 30, 1990

1. CONTRACT OBJECTIVE

The objective of this project is to maximize the applicability of the data from bottoming cycle related programs to commercial MHD plant design and operation.

2. TECHNICAL APPROACH

The original plan called for the design, fabrication, installation and testing of a 20 MW(t) HRSR unit (i.e., a boiler) to obtain design data for commercial power plants. Several areas where adequate information was lacking were identified. These included:

1. Materials - corrosion and erosion resistance
2. Slagging and fouling - ash deposition
3. Heat transfer rates and distribution of surface
4. Emission control - SO₂, NO_x, particulate
5. Potassium recovery and reaction with coal ash
6. Interfaces with other systems.

The program was later redirected to review of bottoming cycle related projects including the CFFF at UTSI, corrosion and deposition studies at ANL, and the instrumentation development projects at Mississippi State University. Project plans and test data are reviewed to ensure that the information obtained can be used to design commercial units, particularly the MHD retrofit plants.

The user of the design data being developed must have an input to the planning and review of the development programs. This contract recognizes that need and is a vehicle to integrate commercial experience into the planning and execution of development work on the MHD bottoming cycle components.

3. PROGRESS SUMMARY

B&W began the task of arranging the data from the CFFF tests, stored in the UTSI data acquisition system, into groupings that would prove most friendly to potential users of the data. For some groupings initial attempts to isolate steady-state periods were made. Steady-state data related to radiant furnace heat transfer were obtained. This includes fuel and combustion air flows and temperatures of the flue gas at different elevations in the furnace.

Difficulty was experienced in obtaining steady-state data for components downstream of the secondary combustor. The major problem was the significant effect blowing of a single sootblower has on the total gas flow and the frequency of sootblowing. The sootblower air injection also significantly affects the temperature of the flue gas stream. Data relating to the bare thermocouple readings to true flue gas temperatures is also required. There can be a significant radiant heat loss from the unshielded T. C. to the surrounding refractory covered water jacket walls.

Some clean-up of the data is required before the data is stored for retrieval by future users. Data, when instruments such as the coal flow meter and thermocouples were malfunctioning or being calibrated, needs to be removed. In some cases time lags must be included for data calculated from two or more measurements.

The cleaned, steady-state data can be used to derive statistical data of critical parameters for furnace and superheater heat transfer, and baghouse and precipitator performance.

4. PLANNED ACTIVITIES

The HRSR performance data review will continue. B&W has submitted plans to examine the tube samples to be removed at the end of the eastern coal test program and do the part-load operations evaluation.

B&W has also submitted plans to design and fabricate a diffuser with prototypical cooling and construction. These plans also include the design and fabrication of a prototypical panel for installation in the area at which the diffuser outlet jet strikes the furnace wall.

APPENDIX G

STATUS REPORT - CFFF OPERATIONS

The semi-annual status report for the CFFF operating contract is presented in this appendix.

SEMI-ANNUAL REPORT TO THE TTIRC

CONTRACT TITLE AND NUMBER

MHD Bottoming Cycle Component Testing
at the Coal Fired Flow Facility
DE-AC02-79ET10815

DATE

September 30, 1990

CONTRACTOR

The University of Tennessee
Space Institute
Tullahoma, Tennessee 37388

REPORTING PERIOD

April 1990 to
through September 1990

PRINCIPAL INVESTIGATOR

Joel W. Muehlhauser
(615) 455-0631

PERIOD OF PERFORMANCE

October 1989 through
September 1990

1. CONTRACT OBJECTIVES:

Objectives established for the DOE sponsored program at UTSI are part of the DOE multi-year program targeted on the achievement of proof-of-concept (POC) testing which includes:

- A) To provide technology and resolve technical issues for scale up to larger systems including:
- Corrosion - gas side of radiant furnace, superheater, intermediate temperature air heater (ITAH), and low temperature air heater
 - Erosion - gas side of radiant furnace, superheater, ITAH
 - Slagging and Fouling of heat transfer surfaces
 - Seed Recovery
 - Gaseous pollutants and secondary combustion (NO_x, SO_x, CO)
 - Particulate characterization and removal
 - Heat transfer
 - Scale up
 - System Integration
 - Eastern and Western coal operational data
 - Waste management and environmental concerns

Semi-Annual Report To The TTIRC
Page Two

- B) To demonstrate system and component characteristics, such as, reliability, life, performance and failure modes.
- C) To build, operate and evaluate flow train components to meet objectives A & B.

2. TECHNICAL APPROACH:

The Department of Energy's Coal Fired Flow Facility (CFFF), located at The University of Tennessee Space Institute, was dedicated in October 1981 and shakedown of the facility was completed in early 1982. A total of 2031 hours of operation on coal has been accumulated on the test train components, of which 1764 POC hours have been on coal, (468 POC test hours during this reporting period).

Several important considerations guided the design of the MHD Low Mass Flow (LMF) heat recovery (steam bottoming cycle) components. A decision was made to use existing boiler technology wherever possible. Materials of construction should be commercially available, and metals would be selected almost exclusively from those approved by the ASME Codes for use in boiler pressure parts. This decision was based on the rationale that MHD, or any new technology, should be advanced to the market place as quickly as possible. Successful commercialization will provide opportunities for future research leading to improvements and refinements.

Last year, DOE completed conceptual design studies for two potential MHD retrofit plants: (1) The Scholz plant of the Gulf Power Company, and (2) the Corette plant of the Montana Power Company. The CFFF test conditions are based upon proposed retrofit conditions, i.e., gas side conditions including gas temperature, residence time and gas composition among others. Development of technology that can be used for scale up is being emphasized. For several reasons, including manpower loading and economic considerations, components were developed sequentially and added to the flow train over a period of time. The systems approach was emphasized, since it was felt that only through investigation involving interaction of all important aspects of the system could a thorough understanding be developed. The University of Tennessee Space Institute (UTSI), in cooperation with Babcock & Wilcox (B&W), Argonne National Laboratory (ANL), Westinghouse (W), and Mississippi State University (MSU) have been collectively reviewing and defining the goals and conditions needed for the proof-of-concept testing of the Heat Recovery Seed Recovery HRSR system.

3. PROGRESS SUMMARY

The first two months of this reporting period was to complete the installation of the High Pressure Sootblower System and the new Ash Handling System under the SH, AH, IH and ESP.

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Page Three

POC test - LMF4T was completed on June 12, 1990 with 225 hours planned. The actual hours were 217 hours. The objectives were to:

- 1) Evaluate operation of new automated ash handling system installed on the baghouse, ESP, and superheater test module.
- 2) Evaluate ability of superheater test module to maintain proper test section and downstream temperatures with new high pressure sootblower system and heat transfer surface modifications.
- 3) Evaluate performance of downstream components during 225 hours maximum on Illinois #6 coal.
- 4) Evaluate the affect of varying primary stoichiometry on NO_x decomposition at DFO, Rf1, SCI, and SCO sampling locations.
- 5) Evaluate the effect of varying K_2/S (ratios of 0.75, 1.00, and 1.25) on SO_2 removal (SCO, BH/ESP, and Stack locations).
- 6) Evaluate ESP performance as a function of specific collection area when K_2/S ratios are set at 0.75, 1.00, and 1.25. Time on each condition will be approximately 75 hours.
- 7) Identify source of audible pulsing and define relationship between plasma emission drop outs and system pressure fluctuations.
- 8) Assist in evaluation of HTAH tube materials by measuring spectral emission characteristics of a candidate tube.
- 9) Continue CARS performance evaluation and provide preliminary temperature profile data. (MSU)
- 10) Quantify particle size distributions or loading/Sauter mean diameter changes at the ESP outlet without interfering with contract obligations for ESP opacity readings. (MSU)
- 11) Continue evaluation of new stack instrumentation (O_2 analyzer, SO_2/NO_x analyzer, and Opacity).
- 12) Collect aspirated particulate samples at DFO, SCI, RF1, and SCO for sulfur analysis. Perform simultaneous analysis of the gas phase using analyzers.

All of the above objectives were completed successfully.

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Page Four

POC test LMF4U was completed on August 13, 1990. The actual test hours were 252 hours of a 250 hour test planned. All objectives of this test were completed successfully.

The objectives of this test were as follows:

- 1) Operate the Coal Fired Flow on Illinois #6 coal for 250 hours.
- 2) Evaluate ESP performance as a function of specific collection area when the K_2/S ratio is kept constant at 1.00.
- 3) Evaluate ability of superheater test module to maintain proper test section and downstream temperatures with variations in the sootblower system blowing frequency.
- 4) Evaluate the operation of the automated ash handling system with the order of priority of successful operation being the ESP, then the baghouse, then the superheater test module.
- 5) Reduce coal flow from about .9 lb/s to .7 lb/s and evaluate the Secondary Combustor Outlet (SCO) SO_2 changes along with corresponding temperature changes at the Secondary Combustor Inlet (SCI) and SCO.
- 6) Measure Industrial Hygiene particulate concentrations in areas frequented by personnel during testing.
- 7) Measure Total Suspended Particulate concentrations within the immediate CFFF area.
- 8) Test the 29 MW₁ prototype of the TRW slagging combustor first stage under actual coal conditions for 250 hours.
- 9) Characterize coal system baghouse exhaust for particulate and condensibles for design of Western coal handling system.

4. PLANNED ACTIVITIES AND SCHEDULE

Long duration Proof-of-Concept (POC) testing will be continued on Illinois #6 high sulfur coal during the period October 1990 through December 1990. During this period 2000 hours of testing will be concluded on this coal. Design, procurement and installation of the Western Coal Handling system was started in April 1990 and will be completed by April 1991.

Semi-Annual Report To The TTIRC
Page Five

Shakedown tests with the Rosebud Coal are planned to start April, 1991.

Attachment #1 is a schematic of the CFFF.

Attachment #2 is a summary and plan of the CFFF Testing Program.

Attachment #3 is the CFFF Goals and Schedules.

Attachment #4 is the CFFF Plan through FY 1993.

5. ISSUES IMPORTANT TO THE MHD-POC PROGRAM:

Several issues have been raised by members of the TTIRC Committee that could affect the bottoming cycle POC program.

- 1) Sulfur addition to topping cycle with Western Coal.
- 2) Potassium flow rate by weight of total flow, (1% or 1.5% for generator performance).
- 3) Primary Stoichiometry
- 4) Percent Oxygen enrichment
- 5) Impurities such as Na, Cl, S, and trace metals from the Seed Regeneration Process
- 6) Utility Input on operational ranges, day to night, turn down ratio, etc.
- 7) Future NSPS and more stringent state standards are being considered. It is expected that current NSPS emission limits may be modified. Examples are reducing NO_x from the current NSPS of 0.6#/MMBTU to 0.1#/MMBTU, and increasing sulfur removal from 90% to 95%.

These issues need to be addressed in order to ensure that the data being obtained in the POC program will be meaningful and useful in designing the first retrofit for minimum risk.

cc: N. Swift - DOE/CH
H. Chambers - DOE/PETC

Coal-Fired Flow Facility Test Train

A.	Vitiation Heater
B.	Combustor
C.	Supersonic Nozzle
D.	Circular Aerodynamic Duct
E.	Diffuser
F.	Radiant Furnace
G.	Secondary Combustor
H.	Superheater Test Module
I.	Air Heaters
J.	Venturi Scrubber
K.	Cyclone
L.	Baghouse
M.	Electrostatic Precipitator
N.	Stack

IL-0108 4/3/90

SUMMARY OF CFFF LOW MASS FLOW EXPERIMENTS

Test Configuration	Date of Completion	Total Hours on Coal	Test Objectives
LMF0 -	08-05-81	8	Facility shutdown with half flow rates
LMF1	08-08-82	7	Determine NO _x /SO ₂ effects, slag/seed interaction
LMF1A	Deleted	0	- Checkout test components
LMF1B	11-16-82	25	- Measure plasma conductivity
LMF1C	08-18-83	48	- NO _x behavior and decomposition mechanism
LMF1D	09-22-83	18	- Seed/slag interaction with slag screen
LMF1E			- Seed/slag interaction without slag screen
Subtotal -		98	
LMF2	08-01-85	4	Ran in conjunction with LMF4A, B, C, to study the effect of MHD generator interaction on the HRSR system under various conditions
LMF3			Evaluate superheater (air heater, characterize particulates)
LMF3A	08-01-84	2	- Cure refractory and check out SH/AH
LMF3B	12-06-84	18	- Evaluate deposits and sootblowing
Subtotal -		4	
LMF4			Evaluate particulate collection and duration testing
LMF4A	03-31-85	3	- Checkout additional cooling surfaces and sootblowing
LMF4B-C	08-01-85	22	- Checkout baghouse
LMF4D-E	12-11-85	14	- Checkout ESP
LMF4F	04-02-86	0	- Checkout compressors
LMF4G-H	06-05-86	16	- Western coal test
LMF4I	08-18-86	77	- Initiation of long duration test
LMF4J	07-28-87	6	- Checkout CFFF test train after installation of new aero duct
POC-LMF4K	09-05-87	198	- Long duration test - eastern coal
POC-LMF4L	12-02-87	63	- Long duration test - eastern coal
POC-LMF4M	02-17-88	57	- Long duration test - eastern coal
POC-LMF4N	05-07-88	185	- Long duration test - eastern coal
POC-LMF4O	09-02-88	252	- Long duration test - eastern coal
POC-LMF4P	11-12-88	101	- Long duration test - eastern coal
POC-LMF4Q	05-31-89	41	- Checkout SHTM modifications
POC-LMF4R	08-30-89	263	- Long duration test - eastern coal
POC-LMF4S	12-07-89	135	- Long duration test - eastern coal
POC-LMF4T	06-12-90	217	- Long duration test - eastern coal
POC-LMF4U	08-13-90	252	- Long duration test - eastern coal
POC-LMF4V (Projected)	10-90	240	- Long duration test - eastern coal (completes 2000 hrs on eastern coal)
LMF4W (Projected)	03-91	100	- Special test - eastern coal (separate seed injection)
LMF4X (Projected)	04-91	100	- Special test - western coal (FeO injection studies)
LMF4Y (Projected)	06-91	200	- Special test - western coal (K ₂ S) plus undefined
LMF4Z (Projected)	08-91	200	- Shutdown test - western coal
Subtotal -		2742	

Grand total through August 1990 is 2032 hours on coal and total test train operation time is 2322 hours (vitiation heater)
 POC = Proof-of-Concept

UTSI/CFFF MAJOR GOALS & SCHEDULE
AUGUST 1, 1990 - JULY 31, 1991

-----FY90-----FY 91-----
J A S O N D J F M A M J J

TASK 3 - CFFF FACILITY OPERATIONS

TASK 4 - TESTING

A. LONG DURATION PROOF-OF-CONCEPT TESTING

1. 240 POC Hours (previous contract period) &&&&
2. 240 POC Hours &&&&
3. 100 Hours (special test eastern or western coal) &&&&
4. 100 Hours " " " " &&&&
5. 200 Hours " " " " &&&&
6. 200 Hours POC (western coal) &&&&

B. TECHNICAL ANALYSES & REPORTS

TASK 5 - TESTING OF DOE COMPONENTS

1. IRW Combustor Materials Evaluation

TASK 6 - MODS/ADDITIONS TO CFFF

1. Western Coal Mods./Evaluation
2. Replace Tubes in TS1, TS2, TS3 For Western Coal Tests
3. HTAH Tube Evaluations
4. Evaluate Auto Ash/Seed Handling Sys.
5. Molten Ash Handling System
6. Install ITAH

TASK 7 - MHD TECHNOLOGY DEVELOPMENT PROGRAM

TASK 8 - TECHNICAL SUPPORT AND INTERFACE

TASK 9 - MANAGEMENT AND ADMINISTRATIVE SUPPORT

&&&& - SCHEDULED

Figure 4-2

10

APPENDIX H

STATUS REPORT - SEED REGENERATION, PHASE II

The semi-annual status report for the Phase II seed regeneration contract is presented in this appendix.

CONTRACT TITLE AND NUMBER:**DATE**

MHD Seed Recovery/Regeneration Phase II
DE-AC22-87-PC79672

10/18/90

CONTRACTOR:**REPORTING PERIOD**

TRW Applied Technology Division
One Space Park
Redondo Beach, CA 90278

4/1/90 to
9/30/90

PROJECT MANAGER:**PERIOD OF PERFORMANCE**

Robert A. Meyers
(213) 535-1457

5/1/89 to
10/31/91

1. Contract Objectives

- Design, procure and construct a proof of concept (POC) plant for the conversion of spent potassium sulfate seed (recovered from Illinois #6 coal) to potassium formate and potassium carbonate seed.
- Operate the plant using spent seed from CFFF at a rate producing 250 lb/hr of product seed and obtain operating data that will allow for scaleup to a 300 MW_t design.
- Produce tonnage quantities of potassium formate seed for testing at CDIF.
- Design, procure, and construct a POC plant to demonstrate the production of calcium formate reactant from carbon monoxide gas and lime slurry using technology previously developed at bench scale.
- Operate the POC calcium formate reactor system to obtain scaleup and operating data that will provide a design basis for a 300 MW_t retrofit plant.
- Assess the environmental acceptability of all waste streams.
- Update the design and cost estimate of seed regeneration system that will support a 300 MW_t MHD system.

2. Technical Approach

Modify TRW's existing test facility at San Juan Capistrano, CA to produce potassium formate from purchased calcium formate and spent seed.

Purchase and install any additional equipment necessary to obtain scaleup data for retrofit systems. Design, construct and operate two different size calcium formate pressure reactors that will provide scaleup data for a 300 MW_t system.

TRW's subcontractor Fluor Daniel will design and provide a cost estimate for a 300 MW_t retrofit seed regeneration plant based on the test data and engineering assessment generated from plant operations.

3. Progress Summary

The final design of the potassium formate reactor system has been completed and reviewed. A subcontract has been let for the fabrication of the evaporator system and delivery is expected in late January. About 35 tons of spent seed from UTSI has been delivered to TRW for use as feed material during test operations. Procurement and receiving of other materials and equipment is in progress. The refurbishment of the MEP and installation of equipment is presently underway. The conceptual design of the calcium formate test unit is complete and a review with DoE was held in September. The final design and equipment specification for that unit is now in progress.

4. Planned Activities

The construction and checkout of the potassium formate system will be completed and ready for shakedown in January of 1991 except for the evaporator system. That unit will undergo shakedown operations in February/March of 1991. The test operation and production of potassium formate seed for delivery to CDIF will commence in the spring of 1991 with delivery of recycled seed to CDIF expected in late June. The design and procurement of equipment for the calcium formate test system will proceed during the next two quarters with installation scheduled for completion at the end of the 3rd quarter 1991.

5. Schedule

See attached.

MHD SEED REGENERATION

PROGRAM SCHEDULE

	YEAR																		
	QUARTER				CY 1989				CY 1990				CY 1991				CY1992		
TASK DESCRIPTION	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	
<u>TASK 1 DESIGN,REFURBISH,OPERATE</u>																			
<u>1.1 DESIGN/REFURBISH KCOOH POC</u>																			
1.1.1 DESIGN																			
1.1.2 PROCUREMENT																			
1.1.3 REFURBISH/ INSTALL POC																			
<u>1.2 SHAKEDOWN POC UNIT</u>																			
1.2.1 SHAKEDOWN TEST PLAN																			
1.2.2 SHAKEDOWN																			
<u>1.3 TEST OPERATIONS</u>																			
1.3.1 TEST PLANNING																			
1.3.2 OPERATIONS																			
1.3.3 DATA ANALYSIS																			
<u>1.4 ENGINEERING ASSESSMENT</u>																			
1.4.1 FLOUR DANIEL ASSESSMENT																			
1.4.2 TRW ENGINEERING ASSESSMENT																			
<u>TASK 2 DESIGN/BUILD OPERATE</u>																			
<u>CA FORMATE POC UNIT</u>																			
<u>2.1 DESIGN/CONSTRUCT CA FORM POC</u>																			
2.1.1 DESIGN																			
2.1.2 PROCUREMENT																			
2.1.3 REFURBISH/INSTALL																			
<u>2.2 SHAKEDOWN CA FORM POC</u>																			
2.2.1 SHAKEDOWN TEST PLAN																			
2.2.2 SHAKEDOWN OPERATIONS																			
<u>2.3 SCALEUP/PROD OPERATIONS</u>																			
2.3.1 PLANNING																			
2.3.2 OPERATIONS																			
2.3.3 DATA ANALYSIS																			
<u>2.4 ENGINEERING ASSESSMENT</u>																			
2.4.1 FLOUR DANIEL ASSESSMENT																			
2.4.2 TRW ENGINEERING ASSESSMENT																			
<u>TASK 4 DESIGN 300 MWt SEED PLANT</u>																			
<u>4.1 TRW DESIGN INTERFACE</u>																			
<u>4.2 FLUOR DANIEL DESIGN SUBCONTRACT</u>																			
<u>TASK 5 MANAGEMENT AND REPORTING</u>																			

APPENDIX I

STATUS REPORT - MISSISSIPPI STATE UNIVERSITY

The semi-annual status report for the diagnostic instrumentation development and test support activities performed at MSU is presented in this appendix.

Diagnostic Instrumentation and Analysis Laboratory

SEMI-ANNUAL REPORT TO THE TTIRC

DATE: October 12, 1990

REPORT PERIOD: April - September, 1990

CONTRACT TITLE: Diagnostic Development and Support of MHD Test Facilities

CONTRACT NUMBER: DE-AC02-80ET-15601

CONTRACTOR NAME: Diagnostic Instrumentation & Analysis Laboratory
Mississippi State University

PROJECT DIRECTOR: W. Steve Shepard

CONTRACT PERIOD: March 1, 1980 - January 31, 1993

CONTRACT OBJECTIVES:

The Diagnostic Instrumentation and Analysis Laboratory (DIAL) at Mississippi State University is developing and applying advanced optical diagnostic techniques and instrumentation systems which provide nonintrusive, remote, real-time measurements and are designed to operate successfully in the industrial-like environment of large-scale facilities. Such diagnostic instrumentation provides the information required to more clearly characterize the various processes involved in the ash/seed-laden gas stream of the coal-fired MHD flow and necessary data to validate and further develop the analytical models required to minimize the technological risks associated with the ultimate construction of a commercial MHD power plant.

TECHNICAL APPROACH:

The following computer-controlled, optical diagnostic instrumentation is being developed for support of the MHD component engineering development:

- *Coherent Anti-Stokes Raman Spectroscopy System (CARS)* to measure local gas temperature and species concentrations, temperature and concentration profiles;
- *Particle Size Distribution System (PSD)* to determine particle size distribution;

- *Potassium Emission/Absorption System (PE/AS)* to determine time-resolved temperature, potassium atom density and electron density;
- *Intrusive Multi-Probe System (IMPS)* to determine wall and gas temperature;
- *Faraday Rotation System (FRS)* to measure electron density;
- *Multi-Purpose Imaging System (MPIS)* to measure potassium atom density and pressure profiles;
- *Differential Absorption Laser Spectroscopy System (DALAS)* to measure time-resolved, line-of-sight, average concentrations of atomic and molecular species (SO_2 , NO_2 , NO , H_2O , OH);
- *Laser Optogalvanic Spectroscopy System (LOGS)* to measure average gas temperature and to provide qualitative identification of atomic and molecular species; and
- *Cross Correlation System (CCS)* to measure flow velocity.

Dial has a computer-controlled, combustion test stand to simulate the combustion and thermal parameters present at various locations in a fossil-fueled MHD combustion system. Its versatility allows it to be used to simulate any type of combustion condition and effluent gas stream. The test stand is used for support of diagnostic instrumentation development, shake-down, and evaluation. As the need arises the test stand may also be used to gather data, systematically, under controlled conditions, to provide validation data for analytical models.

Support for the national MHD program is provided with six field-ready instruments. They include:

- *Sodium Line Reversal System (SLR)* to measure average gas temperature;
- *Multi-Color Pyrometer (MCP)* to measure wall temperature and emissivity;
- *Two-Color Laser Transmissometer (TCLT)* to determine average particle size and particle number density;
- *Laser Doppler Velocimeter (LDV)* to measure local velocity, velocity profiles and turbulence levels;
- *Potassium Emission/Absorption System (PE/AS)* to provide time-resolved temperature measurements; and
- *Gas Analysis System (GAS)* to determine gas composition.

Five instrumentation systems -- CARS, PSD, IMPS, PE/AS, and FRS -- are ready for field testing and instrument modifications.

DIAL has two mobile instrument laboratories with on-board computers for data acquisition and instrument control. These mobile labs are available to transport any diagnostic system to other MHD test facilities on an as-needed basis.

PROGRESS SUMMARY:

TCLT Measurements on CFFF's ESP

The TCLT system has been useful in studying the performance of the CFFF electrostatic precipitator (ESP). A major result of this work was the first observation of the effect of the ratio K_2/S on the Sauter diameter, D_{32} , measured downstream of the ESP. Figure 1 illustrates data for three representative time periods corresponding to three different K_2/S values. Clearly, as the seed percentage decreases the average particle diameter increases.

During these periods the facility conditions such as gas stream temperatures, soot blowing, total coal feed, etc., were reasonably constant. The mass flow rates to the ESP were approximately 6000 cfm for the data in panels A and B and 7800 cfm in panel C. Previous studies have indicated that the ESP performance is degraded as the amount of material entering the device is increased. For example, during baghouse cleaning cycles, when all of the mass flow normally entering the baghouse is diverted to the ESP, a drop in the Sauter mean diameters of about $0.75 - 1.0 \mu$ and a corresponding increase in C_v is observed. Based strictly on the increase in flow from panels A and B to the time frame of panel C, a decrease in the average value of D_{32} would be anticipated. The fact that D_{32} increases in going from panels A to B and then C illustrates that the percentage of K_2CO_3 not converted to K_2SO_4 , i.e. that fraction of K_2/S greater than 1.0, has a dramatic influence on ESP performance.

CARS Measurements in CFFF Diffuser Exit

A mobile CARS instrument has been developed and recently employed to measure the temperature profile in the diffuser exit at UTSI. Figure 2 shows schematically the layout of the mobile CARS system. To obtain good spatial resolution, folded BOXCARS phase matching geometry was used in aligning the laser beams. The laser beams were manipulated up to 35 feet inside the mobile instrument laboratory with prisms attached at the corners of the ceiling for fine adjustment. After tweaking the laser beams to peak the signal, the laser beams were then directed to the diffuser via a hole in the back of the trailer. A 43.5-inch focussing

lens was mounted on a 36-inch traverse which was used to focus the laser beams into the diffuser. A 24-inch focal length lens was used to collimate the laser beams and the CARS signal on the receiver side. The CARS signal was separated from the high intensity laser beams with low wave pass (LWP) filters and beam blocks and then coupled to a 200- μm , (NA = 0.12) optical fiber mounted on a computer controlled x-y-z translator. The other end of the fiber was coupled directly with the SPEX 500 M monochromator. This direct coupling method enhanced the CARS detection about six times. The emission from the laser-induced breakdown has produced a strong background on the CARS spectra. A reduced gate pulse width of the OSMA (Optical Spectrometric Multichannel Analyzer) detector and a proper aperture in front of the fiber has reduced this background effectively.

The N_2 CARS spectra were recorded at various points of the gas stream by moving the focus lens. All the spectra observed have the new feature observed during the LMF4-S run. The feature appeared on the N_2 CARS hot band and was more pronounced near the center of the gas stream. To eliminate the cold CARS signal generated near the wall, argon purge was used for the measurements near the boundary of the gas stream. The quality of the spectra was quite good. However, a small amount of cold CARS signal was still found on the spectra taken near the boundary of the gas stream due to cold nitrogen leaking from the slag buster during its operation. The CARS data were fit with DIAL's theoretical model to extract the temperature information. A typical fit from these measurements is shown in Figure 3. Part of the CARS spectrum containing the unknown feature was ignored in the fit.

The results of the profile measurements made between June 6 and June 7, 1990, are shown in Figure 4. The data were taken from the center of the gas stream up to 18 inches toward the west side of the gas stream and 11 inches toward the east side of the gas stream. The temperature gradients were small near the center of the gas stream and increased rapidly near the edge of the gas stream. N_2 CARS spectra taken during this test run were also consistent and reproducible at the same place from one day to the next.

These field measurements represent the first time that data like this have been obtained in such a hostile gas stream environment on a large-scale facility. Model calculations to predict this temperature profile are presently underway at UTSI.

CDIF Measurements

Early attempts to make measurements with DIAL's instruments at the CDIF diffuser were plagued with loss of optical access. This problem was exacerbated by being unable to physically approach the diffuser during the test.

The problem was solved by a redesign of the triple port wall by MSE. This removed a recessed portion which allowed slag to collect. The opening was reduced from a three to two-inch diameter. A remotely-controlled window changing mechanism, along with a remotely-controlled slag breaking mechanism, were designed and installed by MSU. The N₂ purge was also increased to the point where the diffuser pressure was balanced.

The result was that optical access was maintained and successful measurements were made during the tests in August and September. DIAL made both temperature and potassium number density measurements.

The measurements, which agreed very well with modeling calculations, were carried out throughout the test because optical access was maintained. We are now in a position to make other measurements when testing resumes at CDIF.

Plots of measured temperature as a function of time are shown in Figures 5 and 6 along with potassium and electron number densities. Based on flow rates and heat losses from the facility, preliminary calculations yield

$$T_{calc} \approx 2600 \text{ K}$$

$$e = 1.219 \cdot 10^{14} \frac{\text{atom}}{\text{cm}^3} \text{ (electron density)}$$

$$K = 1.822 \cdot 10^{16} \frac{\text{atom}}{\text{cm}^3} \text{ (potassium atom density) .}$$

These calculations assume complete combustion, and do not include frictional effects or energy losses through shock waves. Including these effects would lower the calculated temperatures to the measured temperatures. At a temperature $T = 2500 \text{ K}$ the concentrations are

$$e = 0.769 \cdot 10^{14} \frac{\text{atom}}{\text{cm}^3}$$

$$K = 1.652 \cdot 10^{16} \frac{\text{atom}}{\text{cm}^3} .$$

PLANNED ACTIVITIES:

DIAL will continue to support the national MHD research and development program with diagnostic measurements and data analysis at test facilities when requested.

ISSUES IMPORTANT TO MHD-POC PROGRAM:

It has been demonstrated that the TCLT system can be used as a real-time monitor of the ESP. Moreover, it has been found that the performance of the ESP degrades as the K_2/S ratio increases, and the TCLT system can also provide information on the K_2/S ratio.

The previous velocity profiles obtained in the diffuser and the furnace at UTSI, along with the recently measured temperature profile across the diffuser, provide important fundamental data to evaluate the existing predictive models used to characterize the thermal, chemical and flow properties of the MHD gas streams.

Figure 1

Arrangement of the beam delivery system and various components of the mobile CARS system.

Figure 2

UTSI DIFFUSER CARS DATA: P=4", T= 2673K
DATE: JUNE 6, 1990

Figure 3

Figure 4

Figure 5

CDIF 90-CC-4

30-AUG-90

POTASSIUM EMISSION ABSORPTION SYSTEM

Std. Plotted for every 15 points

DIAL- MISSISSIPPI STATE UNIVERSITY

Figure 6

APPENDIX J

STATUS REPORT - MHD HEAT AND SEED RECOVERY TECHNOLOGY

The semi-annual status report by Argonne National Laboratory for issues related to the integration of the MHD topping and steam bottoming cycles is presented in this appendix.

CONTRACT TITLE AND NUMBER:
MHD Heat & Seed Recovery Technology Project
AA-70/ANL 49745

DATE:
October 12, 1990

CONTRACTOR:
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

REPORTING PERIOD:
From: April 1, 1989
To: September 31, 1990

PROJECT MANAGER:
Dr. William M. Swift
(312)/972-5964

PERIOD OF PERFORMANCE:
From: July 1, 1976
To: September 30, 1991

1. Contract Objective

The objective of this project is to address technical issues related to the integration of the MHD topping and steam bottoming cycles. Through modeling and experimentation, design information will be obtained that can be used in conjunction with the proof-of-concept testing at the CFFF and CDIF to reliably integrate the MHD topping and bottoming cycles in the design of the first-generation MHD retrofit plant.

2. Technical Approach

Since 1976, Argonne National Laboratory (ANL) has been investigating problem areas related to the design of an MHD steam plant. Computer models of the important chemical and transport processes have and are continuing to be developed in support of experimental activities at ANL and other MHD test facilities to provide the necessary component and system design information for the design of the first-generation MHD plant. Work during the current reporting period focused on: (1) modeling the hydrodynamic and combustion characteristics of the MHD combustor second stage to investigate the effect of operating and design changes on combustor performance, (2) the testing of alloys for the air-heater convective section of the MHD steam plant, (3) the initiation of additional modifications to the ANL 3-D Multigrid MHD channel code (MGMHD) to model the effect of the channel slag layer on channel performance, and (4) the completion of design work on a bench-scale one-dimensional flow reactor for the study of NO_x kinetics and fouling deposits.

3. Progress Summary

Combustor Modeling. The objective of this task is to develop a computer simulation of the MHD slagging combustor. The simulation, which will include heat and mass transfer and combustion models, will be useful in helping investigate and evaluate the effect of design and operating parameters on overall combustor performance, which in turn may improve the downstream channel performance. The ANL modeling effort is currently focused on modeling the second stage of the combustor.

The current work is investigating both cold (or non-reacting) mixing patterns of gas and jet flows and combustion processes. A three dimensional hydrodynamics computer code (COMMIX) and a two-dimensional combustion computer code (GEMCHIP) are being used for the study. The COMMIX code is used to study

the three-dimensional effects due to the no-slip wall conditions, the distributed jet flows of oxidant, and the asymmetric inlet flow. The GEMCHIP code is used to simulate two-fluid mixing and combustion processes. The GEMCHIP code is also being extended to a three-dimensional combustion simulation.

Figure 1 shows the idealized rectangular combustor under investigation. The model second stage combustor consists of four solid side walls, the gas inlet (left), a number of jet holes on the top and bottom walls for the injection of oxidant to the combustor, and the combustor exit (right). Work has progressed in the following major areas: 1) a study of the degree of mixing between the oxidizer jet and main gas flows for various jet geometries (number and orientation of jets); (2) a study of the effects of asymmetric and swirl inlet flows on the mixing patterns of the oxidizer jets and main gas flows; and (3) the development of a two-dimensional combustion model, including sensitivity studies to investigate the effects of jet injection angle, grid point arrangement, and the size of the boundary nodes on numerical convergence of the two-dimensional combustion code and the predicted combustion performance.

The results of typical calculations of jet/gas mixing patterns are presented in Fig. 2. Figure 2 illustrates the mixing at four different axial locations (the jets are located at an X/D value of 0.66) for a symmetrical twelve-jet-port arrangement with a high jet inlet velocity (614 m/s). In this case, jet momentum is sufficient for the opposing jets (six on the top wall and six on the bottom wall) to impinge in the center of the channel. The jet flow blocks and pushes the incoming main gas flow away from the walls and causes a large axial velocity differential in the vertical (Y) direction. Further downstream, the velocity differential is reduced by turbulent mixing between the jet and gas flows.

The normalized deviation of axial velocity over a Y - Z cross section was used to quantify the degree of momentum mixing between the jet and main gas streams. The development of jet/gas stream mixing as the flow moves down the combustor was investigated for two 12-jet and three 8-jet arrangements. All cases indicated a region of rapid convective mixing where the jets penetrate the gas flow just downstream of the injectors. Once the jets have been turned in the downstream direction, mixing is slower and depends primarily on turbulent transport and diffusion between neighboring layers of fluid. The 8-jet arrangements have better downstream mixing because of the stretching of the high velocity core and vortices.

Calculations were also made to investigate the effects of asymmetric and swirl inlet flows on the mixing patterns of the main and gas jet flows. Two cases of asymmetric inlet flow were studied: one with an inlet flow profile constant in the Y -direction and increasing linearly in the Z -direction (or Z -asymmetric) and one with an inlet flow profile constant in the Z -direction and increasing linearly in the Y -direction (or Y -asymmetric). The inlet flow asymmetry was observed to persist throughout the combustor. The Z -asymmetric flow distorted the jet flow patterns more than the Y -asymmetric flow. Similarly, mixing patterns (temperature contours) were also affected by the asymmetric main flow.

The effect of inlet swirl flow on mixing of the main and jet flows was made using a three-dimensional 12 vertical-jet-port combustor with a 41 by 21 by 13 grid system to represent the computational domain. The combustor

geometry and flow conditions are summarized in Table 1. Simulation of the inlet swirl was made by introducing jets of main fluid from four corners of the side walls at the inlet to the combustor. The velocity vector plots of the secondary flow on four Y-Z planes at $X/D = 0.32, 0.73, 1.46,$ and 3.67 are shown in Fig. 3. In the plot at $X/D = 0.32$ (where the inlet swirl is shown), the outer tangential velocity is relatively higher than the inner tangential velocity because the swirl jets are injected from the four corners. In the plot at $X/D = 0.73$, the swirl flow interacts with the oxidizer jet flow from both the top and bottom walls ($Y/D = 0$ and 1). In this case, the jet flow is pushed by the strong swirl flow in the general swirl direction. In the plots at $X/D = 1.46$ and 3.67 , the swirl flow gradually dissipates.

A simplified one-step, integral combustion-kinetics model has been incorporated into the GEMCHIP combustion code to simulate combustion in the MHD second stage combustor. Typical results for the case of counterflow combustion (jet angle = 130°) are shown in Fig. 4. Figure 4a presents the computed velocity vectors and shows that (1) a parabolic velocity profile develops near the exit, (2) a pair of uneven vortices are formed downstream of the jet ports, (3) the top vortex is larger than the bottom vortex, and (4) the counterflow jets penetrate upstream near $X/D = 0.5$. The length of the velocity vectors represents the velocity magnitude and the arrow indicates the direction of flow. The inlet velocity at $Y/D = 0.5$ is 29 m/s .

The flow patterns in Fig. 4 are similar to those obtained for non-reacting flow cases. One major difference is the higher average exit velocity for combustion flow due to the lower density of the fluid. Figure 4b shows the calculated normalized temperature contours (T/T_{in} where $T_{in} = 1974 \text{ K}$). The normalized inlet gas temperature is 1.0 (1974 K), the normalized jet temperature is 0.15 (300 K), the average normalized exit temperature is about 1.4 (2760 K), and the normalized peak temperature in the flame zones is about 1.5 (2960 K). Two flame zones are evident between the temperature contour lines of 1.5 that extend from the jet port locations to the exit. Figures 4c, 4d, and 4e show the concentration contours for fuel, oxidizer, and product, respectively. Inlet fuel concentration is $Y_{fu} = 0.42$ and the oxidizer jet concentration is $Y_{ox} = 1$. Fuel and oxidizer are consumed in the flames where they meet as shown in Figs. 4c and 4d. At the exit, some fuel and oxidizer leave unreacted. The products are formed in the flame zones and diffuse into both the fuel and oxidizer streams as shown in Fig. 4e. High product concentrations (Y_{pr} above 0.5) are found in the flames.

Parametric studies to determine the effect of jet injection angle, boundary cell size, and number and arrangement of grid points on the convergence and computational results of the two-dimensional combustion code have also been completed. Based on the results to date with the use of the code, a grid system of 53 by 31 grid points and a convergence criterion of 10^{-9} maximum mass residual are considered adequate for numerical convergence of the second stage combustion calculations. Calculated results using this grid system and convergence criterion for a jet injection angle of 70° are shown in Fig. 5 for simulated TRW combustor conditions.

Materials Studies. Tests completed during previous reporting periods evaluated selected candidate alloys in a laboratory autoclave furnace at the anticipated conditions of the steam superheater (SSH) tubes and the intermediate-temperature air heater (ITAH) tubes in an MHD retrofit plant. The austenitic steels exposed at the SSH test conditions exhibited negligible

corrosion. The low- to medium-chromium steels tested under ITAH transition-region conditions and all of the austenitic alloys tested (except 310 steel) under ITAH conditions exhibited corrosion rates in excess of the assumed limit of 0.5 mm/yr assuming linear corrosion kinetics. As a result, a second round of tests at ITAH conditions was initiated. With input from UTSI, B&W, and Gilbert-Commonwealth, the alloys listed in Table 2 were selected for the tests. All the specimens were prepared by ANL with the exception of the two chromized specimens of 304 and 800 steels prepared by Combustion Engineering. For the tests, the specimens were coated with two different types of deposit material. Half of each specimen was coated with typical deposit material from the superheater test sections of CFFF (containing approximately 85 wt% K_2SO_4). The other half of each specimen was coated with the same deposit material mixed with 25 wt% iron oxide (Fe_2O_3). The latter mixture was included in this test to evaluate the possible influence of iron oxide addition to the topping cycle on the corrosion of downstream bottoming-cycle components. During the current reporting period, 500-h and 2000-h duration tests in the autoclave materials test facility were completed. The metallographic examination of the specimens is currently in progress. The results will be reported in the next semi-annual report in this series.

ANL is also providing support in the evaluation, testing and identification of alloys for the TRW slagging combustor. A specimen of AL-15 Glidcop material that was tested for 15 h in the exit section (reducing environment) of the TRW workhorse combustor was examined using electron microscopy (SEM) equipped with an energy dispersive X-ray analyzer (EDX). The results of that analysis have been reported to TRW.

3-D Channel Code. In November of 1989, the modified ANL 3-D channel code (MGMHD) based on a multigrid solution technique was made available to the MHD community through the National Energy Software Center (operated by Argonne National Laboratory for the U.S. DOE). The user's manual, "User's Manual for MGMHD: A Multigrid Three-Dimensional Computer Code for the Analysis of Magnetohydrodynamic Generators and Diffusers (ANL Report No. ANL/MHD-89/1)," was published and distributed. During the current semi-annual reporting period, work was initiated to make further modifications to the code to include the effect of the channel slag layer on the predicted channel performance. The planned approach to this task, which is just getting underway, is to model the electrochemistry of the slag layer to obtain an understanding of the polarization phenomenon by which potassium ions in the slag layer rearrange themselves and produce a medium to very high axial conductivity (that can sustain very large leakage currents in the axial direction degrading the generator performance). Details of this work will be presented in future reports in this series.

NO_x Kinetics. Work has been completed on the detailed design of a small-scale one-dimensional flow reactor. The system will be used to 1) obtain experimental data on NO_x decomposition for kinetic code validation and 2) study the chemistry of fouling deposits. Fabrication of the reactor and testing is scheduled for completion in FY1991.

4. Planned Activities

Future combustion modeling activities will focus on: (1) two-dimensional combustion calculations, (2) three-dimensional hydrodynamic calculations, (3) extension of the GEMCHIP code to three-dimensional combustion calculations,

and (4) comparison of the computational results against experimental data. Work will also continue on further modifying the ANL 3-D channel code to include channel slag layer effects on channel performance calculations. Work on the fabrication of a system for measuring NOx kinetics and the chemistry of fouling deposits will be expedited during FY1991. Work will continue on the evaluation of materials for the bottoming cycle and to support TRW in the evaluation and testing of alloys for the POC slagging combustor.

5. Schedule (attached)

Table 1. Combustor Geometry and Flow Conditions

Combustor Dimensions (L:D:H)	=	3.8:1:1
Jet Port Location (L_j/D)	=	0.66
Main Fluid Temperature	=	0 K
Jet Fluid Temperature	=	100 K
Pressure	=	1 atm
Bulk Jet Concentration	=	6.4 %
Jet Angle	=	90 deg.
Jet Velocity	=	614 m/s

Table 2. ITAH Candidate Materials

	C	Cr	Ni	Si	Mn	N	Ce	Fe	Other
253MA	0.08	21.0	11.0	1.7	0.6	0.17	0.04	Bal	-
RA85H	0.2	18.0	14.0	3.5	0.5	-	-	63	Al 1.0
CR35A	0.05	36.6	45.0	0.04	-	-	-	Bal	Nb 0.5; Al 0.12
CR30A	0.06	30.5	51.0	0.27	0.20	-	-	Bal	Al 0.14; Ti 0.18; Mo 2.1
HR-160	0.05	28	Bal	2.75	0.5	-	-	4.0	Co 27
HR-120	Experimental Alloy								
556	0.1	22.0	20.0	0.4	1.5	-	-	Bal	Co 20; Mo 3; W 2.5
310	0.06	25.0	20.2	0.68	1.71	-	-	52.2	
Chromized 304									
Chromized 800

Fig. 1. Idealized MHD second stage combustor (12-jet-port arrangement)

Fig. 2. Axial velocity contours for 12-jet-port arrangement
(D = channel width, jets located at $X/D = 0.66$)

(a) $X/D = 0.32$

(b) $X/D = 0.73$

(c) $X/D = 1.46$

(d) $X/D = 3.67$

Fig. 3. Combustor cross-sectional velocity vectors with inlet swirl; jet injection angle = 90 deg.

(a) Velocity vectors

Fig. 4. Computed axial profiles for second-stage flow with combustion; jet injection angle = 1300 deg.

(b) Normalized temperature

(c) Fuel concentration

(d) Oxygen concentration

(e) Product concentration

Fig. 4. Computed axial profiles for second-stage flow with combustion; jet-injection angle = 130 deg. (contd)

(a) Velocity vectors ($U_{in} = 22$ m/s)

(b) Normalized temperature contours ($T_{ref} = 1974$ K)

Fig. 5. Calculated flow and temperature profiles for a full-size TRW combustor.

Argonne National Laboratory
Heat and Seed Recovery Technology Project

Milestone Log
(Revised 10/01/90)

Milestone No.	Description	Completion Date	
		Planned	Expected Actual
1	Slagging Combustor Model Interim Report	12/31/90	03/31/91
2	Topical Report on Materials Tests	11/30/90	02/28/91
3	Fouling Topical (Thermal Properties)	05/31/90	12/15/90
4	Fouling Topical (K ₂ S Ratio)	12/31/90	09/30/91
5	Channel Model Topical Report	09/30/91	09/30/91
6	Complete NO _x Reactor Design	05/31/90	01/31/91
7	Complete Reactor Assembly	08/31/90	03/31/91
8	Complete NO _x Experiments	01/31/91	06/30/91
9	Report on NO _x Kinetic Studies	05/31/91	

Project Schedule FY 1989

Task	Description	FY 90												FY 91														
		O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
1	Combustor Modeling																											
2	Materials Studies																											
3	CFFF Support																											
4	Fouling																											
5	3-D Channel Model																											
6	NO _x Kinetics																											

APPENDIX K

CONSULTANT REPORT - HIGH TEMPERATURE AIR HEATERS

This appendix presents the text of a brief topical report prepared by Finn Hals for the TTIRC POC Integration Task Force relating to the use of high temperature air heaters for MHD applications. The contents of this paper were briefly discussed at the Executive Committee at the meeting in June 1990. Copies were provided to the members and guests in attendance.

HIGH TEMPERATURE AIR HEATERS

High temperature air heaters for MHD power systems are classified as directly fired or indirectly (separately) fired. Directly fired air heaters are part of the bottoming plant heat recovery system and utilize the heat energy of the MHD generator exhaust gas for preheating of the combustion air or fuel oxidant. An important criterion for directly fired air heaters is that they must be capable of operating with any seed, ash or other impurities contained in the exhaust gas of the MHD generator. Indirectly fired air heaters utilize a separate heat source and the heaters are in this case separately fired with a clean fuel. The principal reason for considering indirectly or separately fired air heaters is to circumvent the serious problems associated with the seed and ash content of the MHD generator exhaust gas. Various arrangements of MHD power systems with indirectly fired air heaters have been considered including balanced pressure heater operation with power production from the heater exhaust in a gas turbine. Directly fired high temperature air heaters offer the potential of significantly higher net cycle efficiencies than that which can be attained at the same preheat temperature by using indirectly fired heaters. Indirectly fired high temperature heaters are not part of this brief review of high temperature air heaters which are limited to directly fired heaters. For a comparison between projected power plant efficiencies and economics of different MHD power systems with the use of oxygen, indirectly and directly fired high temperature air heaters, I refer to results from MHD power system analyses conducted. Here it is only mentioned that high temperature air heaters are not considered necessary for early commercial MHD power plants and the planned retrofit demonstration plant, but the development of high temperature directly fired air heaters would be a great impetus for MHD power generation because it would make it possible to improve MHD power plant efficiencies and its economics substantially. Preheat temperatures from 1500°K to 2000°K or more are a desirable goal for directly fired high temperature MHD air heaters.

Air heaters or heat exchangers are classified into two categories, recuperators and regenerators. Recuperators transfer heat continuously from one fluid to the other through a solid wall that separates the two fluids. Regenerators operate on the principle of transferring heat by a medium which is heated for a certain time by the hotter fluid and subsequently cooled by the other cooler fluid which then is heated up. Common to all directly fired air heaters for MHD applications is that they must be capable of operating with the seed and ash impurities contained in the MHD generator exhaust gas and withstand corrosive attacks from such impurities. This is a specific important MHD power system requirement. Other system requirements are:

- Thermal effectiveness, including minimum heat and pressure losses.
- Continuous delivery of preheated air with minimum fluctuations in temperature, pressure and mass flow rate.
- Minimum leakage of air and minimum air contamination.
- Compatible with NO_x emission controls and seed recovery.
- Operability including controls, transient response and start-up and shutdown.
- RAM (reliability, availability, maintainability).
- Costs and constructibility.

Materials represent the governing and limiting factors for the preheat temperature which can be obtained. Major criteria and considerations for refractory materials and ceramics for use in high temperature heaters are:

- High temperature capability including thermal stability and thermal fracture resistance.
- Mechanical strength including creep and fatigue resistance.
- Chemical stability including corrosion resistance to seed and ash.
- Material availability, fabrication process and costs.

It is also pointed out that efficient power plant operation requires that attention is given both to the thermodynamic design and to the practical construction and operation of the air heater system. The air heater system may be divided into different temperature regimes for optimum performance and lowest cost and this division of the air heater system must be practical, thermodynamically feasible and arranged so that it results in efficient utilization of all of the heat absorbed in the heat recovery system of the bottoming plant.

Recuperative heat exchangers are in many ways simpler than regenerative ones. Special gas fired ceramic recuperators have been built for preheating of air close to 1500°K , but these were essentially for clean combustion gases and balanced pressure operation between the heat exchanging fluids. Development of a coal fired high pressure ceramic recuperator with unbalanced pressure operation for gas turbine applications is underway and I recommend that this development work as well as any other development work of high temperature heat exchangers be closely followed by the MHD community. Besides the severe problems associated with seed and coal ash, other problems for ceramic recuperators problems are related to fabrication, mechanical strength including thermal fracture resistance and fatigue, joints sealing and fluid leakage.

Regenerative heat exchangers can broadly be divided into two categories: fixed-bed and moving bed. The fixed or stationary bed regenerator operates intermittently through cycling. The geometry of the heater bed or matrix considered are generally: cored bricks or checkers with internal flow passages, standard bricks laid in a variety of patterns, pebbles or particles. The fixed bed heater system will consist of several regenerators arranged in parallel with switch-over valves in order to deliver a continuous flow of preheated air. Fixed bed regenerators have been used for many years within the steel and glass industries to preheat air in the range 1475°K to 1675°K , but they operate in a much less corrosive and hostile environment than MHD heaters. Moving bed regenerators have a matrix that moves continuously. The heater bed can be a rotating matrix, moving pebbles, falling clouds of particles or a fluidized bed. Moving bed regenerators deliver the heated fluid at constant temperature and do not require switch-over valves. However, they must have provisions for preventing leakage between the two fluids operating at different pressure, e.g., inlet and outlet seals for rotating beds and valve-lock devices for beds in which pebbles or particles circulate from one chamber to another. Fluidized beds which are essentially isothermal are divided into several beds in series with connecting columns that provide adequate resistance against fluid leakage.

I also mention that a novel regenerator design utilizing liquid slag as the heat transfer medium was proposed some time ago by British MHD investigators who also conducted some initial experimental work of this interesting concept at that time.

Most of the development work conducted of high temperature air heaters for MHD applications have been associated with fixed bed regenerators. Although significant progress has been made, major problems remain to be resolved before directly fired high temperature air heaters can be considered practical for coal burning MHD power systems. The most severe problem is related to materials lifetime in the hostile MHD environment, but the problems to satisfy all of the heater requirements otherwise must not be overlooked. I personally consider the development of directly fired high temperature air heaters a formidable challenge which will require substantial time and resources to solve. However, I believe that MHD like any other new technology will continue to develop and advance after its commercial introduction and that high temperature air heaters can and will be developed.

END

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