02

MHD TECHNOLOGY TRANSFER, INTEGRATION AND REVIEW COMMITTEE

**Seventh Semi-Annual Status Report
April 1991 through September 1991**

**MHD Integrated Topping Cycle Project
Report No. MHD-ITC-93-017**

RECEIVED

SEP 15 1993

OSTI

**Date Submitted:
February 1993**

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

**By:
Applied Technology Division
TRW Space and Technology Group
One Space Park
Redondo Beach, California 90278**

**Contract Number:
DE-AC22-87PC90274**

MASTER

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Contents

	<u>Page</u>
Abstract	iv
1. INTRODUCTION	1
2. EXECUTIVE COMMITTEE MEETING	2
3. GENERAL COMMITTEE MEETING AND ACTIONS	3
4. TECHNOLOGY TRANSFER	4
5. INTEGRATION AND REVIEW	5
6. PLANNED ACTIVITIES	6
7. DISTRIBUTION LIST	7
APPENDIX A: TTIRC CHARTER AND RESPONSIBILITIES	A-1
APPENDIX B: MINUTES OF JUNE 1991 GENERAL COMMITTEE MEETING	B-1
APPENDIX C: STATUS REPORT - MHD INTEGRATED TOPPING CYCLE	C-1
APPENDIX D: STATUS REPORT - CDIF OPERATIONS	D-1
APPENDIX E: STATUS REPORT - HRSR DEVELOPMENT	E-1
APPENDIX F: STATUS REPORT - CFFF OPERATIONS	F-1
APPENDIX G: STATUS REPORT - SEED REGENERATION, PHASE II	G-1
APPENDIX H: STATUS REPORT - MISSISSIPPI STATE UNIVERSITY	H-1
APPENDIX I: STATUS REPORT - MHD HEAT AND SEED RECOVERY TECHNOLOGY	I-1

Abstract

This seventh semi-annual status report of the MHD Technology Transfer, Integration and Review Committee (TTIRC) summarizes activities of the TTIRC during the period April 1991 through September 1991. It includes a summary and minutes of the General Committee meeting, 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 seventh semi-annual status report covers the period April 1991 through September 1991. 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

There was no scheduled meeting of the Executive Committee during this reporting period. The next Executive Committee meeting is tentatively scheduled for January or February 1992, in conjunction with the annual DOE MHD Contractors' Review Meeting in Pittsburgh, PA.

3. GENERAL COMMITTEE MEETING AND ACTIONS

A meeting of the General Committee was held on June 17, 1991 at the OMNI Royal Orleans Hotel in New Orleans, Louisiana, preceding the 29th Symposium on Engineering Aspects of Magnetohydrodynamics (SEAM). Business included updates on the three POC programs with an emphasis on the bottoming cycle test plan with Western coal, seed regeneration economics, and power management for the integrated topping cycle. In addition, a status on the Clean Coal Technology Proposal activities was presented by Dr. W. Owens of Gilbert/Commonwealth. The meeting concluded with an open discussion regarding utility concerns/issues, moderated by Dr. Fred Walter of Montana Power Co. The agenda and minutes of this meeting are presented in Appendix B.

4. TECHNOLOGY TRANSFER

The primary technology transfer activities of the TTIRC consist of the holding of 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 C through I are summaries of technical progress on the major POC projects. Items of note include the following:

- The prototypical second stage combustor was delivered to the CDIF and installed as part of the workhorse test series.
- The anode current consolidation diode enclosure (part of the backup resistive consolidation network) was delivered to the CDIF and installed as part of the workhorse test series.
- Fabrication and assembly of the prototypical channel cathode wall is complete. Fabrication of the anode and sidewall gas-side elements is in progress.
- Four tests were completed at the Coal Fired Flow Facility during the current reporting period. One test was with an Illinois No. 6 coal and three tests were with a Montana Rosebud coal. The Western coal tests are focused on establishing conditions for the 2000-hour POC test.
- Construction and equipment installation for the potassium formate POC is complete and shakedown testing has been initiated.
- Fabrication of the high pressure calcium formate reactors has been completed.
- Diagnostic instruments for MHD applications continue to be tested by MSU's DIAL at both the CDIF and the CFFF. The Potassium Emission/Absorption System (PE/AS) was used to measure gas stream temperature and potassium/electron densities in the recent Western coal test at the CFFF (Test LMF5-13) and during the 91-SEED tests at the CDIF.

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 ITC program office formed the Power Management Working Group as an ad hoc committee to the POC Integration Task Force. The scope of the Working Group's effort will be limited to the integration and testing of the four major subsystems of channel power management: current controls, power takeoff region, current consolidation, and inverter. In addition, issues involving the High Voltage Room (HVR) will be addressed since it is the functional interface of the power management system.

The Working Group also approaches their integration function from two perspectives: 1) a top level system perspective, analyzing POC and retrofit power management requirements to determine specific data needs from the POC program, and 2) a specific subsystem perspective, evaluating engineering interface issues to ensure the successful performance and integration of the individual components within channel power management.

During this reporting period, the Power Management integration activities have focused on the design verification testing of the Westinghouse forward (anode) current consolidation system.

An update on Power Management activities is included in Appendix B, the minutes of the General Committee meeting.

6. PLANNED ACTIVITIES

The following TTIRC activities are planned for the eighth semi-annual reporting period (October 1, 1991 through March 31, 1992):

- Final distribution of the fifth and sixth semi-annual status report activities of the TTIRC.,**
- Issuance of the draft seventh semi-annual status report on the TTIRC.**
- Hold meeting of the Executive Committee in conjunction with the annual DOE MHD Contractors' Review Meeting in Pittsburgh, PA.**

7. MHD TTIRC DISTRIBUTION LIST

Required U.S. Department of Energy Distribution

Dr. Harold Chambers
Technical Project Officer
PM-40, MS 922-206
U.S. Department of Energy
Pittsburgh Energy Technology Center
P.O. Box 10940
Pittsburgh, PA 15236

Mr. David Hunter
Contracting Officer
AD-22, MS 921-118
U.S. Department of Energy
Pittsburgh Energy Technology Center
P. O. Box 10940
Pittsburgh, PA 15236

Dr. Victor Der
U. S. Department of Energy
Office of Fossil Energy
FE-32
Washington, DC 20545

General Counsel for Patents
U.S. Department of Energy
Chicago Operations Office
9800 South Cass Avenue
Argonne, IL 60439

U.S. Department of Energy *
Office of Technology Transfer
P. O. Box 10940, MS 922
Pittsburgh, PA 15236

* First obtain clearance from Office of Patent Counsel, Chicago, then mail copies to OTT with statement, "Patents Cleared by Chicago Office of Patent Counsel on _____ (Insert Date) _____".

Additional Distribution

Dr. William Swift
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Dr. R. Kessler
Textron Defense Systems
2385 Revere Beach Parkway
Everett, MA 02149

Mr. S. Petty
Textron Defense System
2385 Revere Beach Parkway
Everett, MA 02149

Mr. John Rackley
Babcock & Wilcox
1562 Beeson Street
Alliance, OH 44601

Dr. J. L. Bates
Battelle Pacific Northwest Labs
PSL Building 3000 Area
Box 999
Richland, WA 99352

Dr. Bert Zauderer
Coal Tech Corporation
P. O. Box 154
Merion Station, PA 19066-0154

Mr. R. King
U.S. Department of Energy
Butte Project Office
P.O. Box 3462
Butte, MT 59702

Mr. G. Staats
U.S. Department of Energy
Pittsburgh Energy Technology Center
P.O. Box 10940, PM-20/MS 922-208
Pittsburgh, PA 15236

Dr. R. Rosa
Montana State University
Department of Mechanical Engineering
Bozeman, MT 59715

Mr. Norm Swift
U.S. Department of Energy
Chicago Operations Office
9800 South Cass Avenue
Argonne, IL 60439

Dr. R. A. Carabetta
U.S. Department of Energy
Pittsburgh Energy Technology Center
P.O. Box 10940
Pittsburgh, PA 15236

Mr. Leo Makovsky
U.S. Department of Energy
Pittsburgh Energy Technology Center
P. O. Box 10940, MS 922-206
Pittsburgh, PA 15236

Dr. A. Cohn
Electric Power Research Institute
P.O. Box 10412
3412 Hillview Avenue
Palo Alto, CA 94303

Mr. A. C. Dolbec
Electric Power Research Institute
P. O. Box 10412
3412 Hillview Avenue
Palo Alto, CA 94303

Dr. William Owens
Gilbert/Commonwealth, Inc.
19664 Club House Road, Suite 820
Gaithersburgh, MD 20879

Dr. Peter Marston
MIT/Plasma Fusion Center
175 Albany Street
NW17-207
Cambridge, MA 02139

Dr. W. S. Shepard
Mississippi State University
D.I.A.L.
P.O. Drawer MM
Mississippi State, MS 39762

Dr. C. Kruger
Stanford University
Terman Mech. Eng., Room 214
Stanford, CA 94305

Mr. L. Farrar
Montec Associates
P.O. Box 4182
Butte, MT 59702

Mr. Stephen Myrick
TRW
P.O. Box 3767
Industrial Park
Butte, MT 59702

Mr. G. Funk
MSE, Inc.
P.O. Box 3767
Industrial Park
Butte, MT 59702

Mr. J. Sherick
Montana Technologies Corp.
220 N. Alaska Street
Butte, MT 59702

MSE, Inc.
P.O. Box 3767
Industrial Park
Butte, MT 59702
Attn: Librarian

Dr. W. Thielbahr
U.S. Department of Energy
Idaho Operations Office
785 Doe Place
Idaho Falls, ID 83402

Mr. L. Kovalsky
Westinghouse Electric Corp.
Science and Technology Center
1310 Beulah Road
Pittsburgh, PA 15235

Mr. M. Tuck
MSE, Inc.
P.O. Box 3767
Industrial Park
Butte, MT 59702

Dr. Bob Wright
U. S. Department of Energy
Office of Fossil Energy
FE-32
Washington, DC 20545

Mr. S. Demetriades
STD Corporation
P.O. Box "C"
Arcadia, CA 91006

Mr. C. Maxwell
STD Corporation
P.O. Box "C"
Arcadia, CA 91006

Mr. N. Johanson
University of Tennessee Space
Institute
Tullahoma, TN 37388

Dr. Susan Wu
Engineering Research and
Consulting, Inc.
P. O. Box 417
Tullahoma, TN 37388

Mr. L. Van Bibber
Westinghouse Electric Corporation
Advanced Energy Systems Division
P.O. Box 10864
Pittsburgh, PA 15236

Mr. W. Irving
WMI, Inc.
236 N. Falmouth Highway
North Falmouth, MA 02556

Dr. Carl C. P. Pian
Textron Defense Systems
2385 Revere Beach Parkway
Everett, MA 02149

Mr. J. M. Bauer
TRW Space and Technology Group
One Space Park, 01/1160
Redondo Beach, CA 90278

Dr. Joel Muehlhauser
Univ. of Tennessee
Space Institute
Tullahoma, TN 37388

Dr. A. Solbes
TRW Space and Technology Group
One Space Park, 01/1181
Redondo Beach, CA 90278

Dr. R.A. Meyers
TRW Space and Technology Group
One Space Park, 01/2270
Redondo Beach, CA 90278

Dr. Robert Aurora
Houston Lighting and Power
12301 Kurland Drive
Houston, TX 77034

Mr. Robert P. Johnson
Pennsylvania Power and Light Co.
Two North Ninth Street
Allentown, PA 18101

Mr. Sky Younger, P.E.
Arizona Public Service Co.
P.O. Box 53999
Phoenix, AZ 85072

Mr. Charles Linderman
Edison Electric Institute
1111 19th Street NW
Washington, DC 20036

Mr. N.S. Egan
MSE, Inc.
P.O. Box 3767
Butte, MT 59702

Dr. M. Petrick
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439

Mr. Sam Guro1
General Dynamics Space Systems
Mail Zone 92-8260
P.O. Box 85990
San Diego, CA 92138

Dr. Fred Walter
Montana Power Co.
40 East Broadway
Butte, MT 59701

Mr. Finn Hals
Avco Research Laboratory
2385 Revere Beach Parkway
Everett, MA 02149

Mr. Bruce Pote
TRW
c/o Textron Defense Systems
2385 Revere Beach Parkway
Everett, MA 02149

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 May 1991. 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
Arizona Public Service
Textron Defense Systems (TDS)
Babcock & Wilcox
DOE
Edison Electric Institute
EPRI
General Dynamics
Gilbert/Commonwealth
Houston Lighting and Power Co.
MHD Development Corporation
Mississippi State University

MIT (Plasma Fusion Center)
Montana Power Company
Montana State University (Rosa)
MSE, Inc.
Pennsylvania Power & Light Co.
Southern Services Co.
TRW Inc.
UTSI
Westinghouse, AESD
Westinghouse, R&D Center
WMI, Inc.

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

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 1991 GENERAL COMMITTEE MEETING

Presented in this Appendix are the agenda and minutes of the General Committee meeting held at the OMNI Royal Orleans Hotel in New Orleans, Louisiana on June 17, 1991. The meeting preceded the 29th Symposium on Engineering Aspects of Magnetohydrodynamics (SEAM). Included in this appendix is a reproduction of the presentation material used by the various presenters.

List of Attendees

<u>Organization</u>	<u>Name</u>
Argonne National Laboratories	Greg Berry
Babcock & Wilcox	Bob McIlroy
Brown and Co.	David Brown
Busek	Vlad Hruby
Consortio MHD (Italy)	Francesco Negrini
Consultant	Finn Hals
DOE/PETC	Harold Chambers
DOE/PETC	Robert Carabetta
DOE/PETC	Leo E. Makovsky
DOE/PETC	Nick Oliver
DOE/PETC	Gary Staats, Co-chairperson
DOE/PETC	Chuck Thomas
DOE/HDQ	Robert Wright
EPRI	David Gauntlett
General Dynamics	Lee R. Patterson
Gilbert/Commonwealth	William Owens
Gilbert/Commonwealth	Jack Hirschenhofer
HMJ	William D. Jackson
MHD Development Corp.	Neal Egan
MHD Development Corp.	Robert Labrie
MHD Ind. Forum	Vincent Coates Jr.
MIT	Peter Marston
Montana Power Co.	Fred Walter
MSE	Gerry Funk
MSE	Allan D. Miller
MSE	Jack Sherick
MSE	Michael R. Tuck
Mississippi State Univ./DIAL	Robert L. Cook
Mississippi State Univ./DIAL	W. Steve Shepard
Pennsylvania Power and Light	Robert P. Johnson
TDS	Robert Kessler
TRW	Marty Bauer
TRW	Edward Barrish
TRW	Loren McClanathan
TRW	Robert Meyers
TRW	Bruce Pote

Organization

UNI BO
Univ. of Sydney
UTSI
UTSI
UTSI
UTSI
UTSI
Westinghouse AESD
WMI, Inc.

Name

Antonio Manarius
Hugo K. Messerle
Lloyd W. Crawford
Jeff Holt
Norm Johanson
John Lineberry
Joel W. Muehlhauser
Joe Lance
William Irving

**MHD TECHNOLOGY TRANSFER,
INTEGRATION AND REVIEW COMMITTEE**

GENERAL COMMITTEE MEETING

June 17, 1991

OMNI Royal Orleans Hotel, New Orleans, LA

AGENDA

1:00 PM	Welcome and Introduction	B. Pote - TRW
1:05 PM	Opening Remarks and Call to Order	G. Staats - DOE
1:15 PM	Seed Regeneration Economics	L. McClanathan - TRW
2:00 PM	Channel Power Management for the ITC Program	B. Pote - TRW
2:30 PM	Western Coal Test Plan at CFFF - Compatibility with ITC and Retrofit (ϕ, K_2/S, FeO)	N. Johanson - UTSI
***** B R E A K *****		
3:15 PM	Utility Concerns/Issues	F. Walter - Montana Power
4:00 PM	Status of DOE Action on POC Task Force Recommendations	G. Staats - DOE
4:15 PM	Clean Coal Technology Update	W. Owens - Gilbert/ Commonwealth
4:30 PM	Other Business - TBD	
5:00 PM	Adjourn	

TECHNOLOGY TRANSFER, INTEGRATION AND REVIEW COMMITTEE

Minutes of the June 1991 General Committee Meeting

A meeting of the General Committee of the MHD Technology Transfer, Integration and Review Committee (TTIRC), held on June 17, 1991 at the OMNI Royal Orleans Hotel in New Orleans, was brought to order by co-chairman Mr. Gary Staats of the U.S. Department of Energy, Pittsburgh Energy Technology Center.

Minutes of Previous Meeting

Reading of the minutes of the previous meeting was dispensed with. Members were referred to the minutes in the TTIRC Fifth Semi-annual Report (TRW Report No. MHD-ITC-91-021). Since this report was approved for publication and distribution by the DOE and the Executive Committee, no motion for acceptance was necessary.

MHD Program Highlights

As an introduction to the meeting, Mr. Bruce Pote of TRW highlighted the national MHD program accomplishments over roughly the past 12 months. A copy of Mr. Pote's presentation slides are included as Figure B-1 with these minutes.

Of particular note was the completion of the 2000-hour POC testing with an Illinois No. 6 coal at the Coal Fired Flow Facility (CFFF). This included an approximately 191-hour continuous operation on coal, representing the longest continuous duration of any MHD facility to date.

Seed Regeneration Economics

Mr. Loran McClanathan of TRW made a presentation regarding seed regeneration economics for an MHD power plant. As has been discussed previously, the costs associated with seed regeneration have been identified as deleterious to the commercial/economic competitiveness of MHD technology. (See Figure B-3 of Sixth Semi-Annual Status Report - EPRI summary paper from the MHD utility colloquium.) Mr. McClanathan's presentation focused on various seed regeneration processing options that are being studied in an effort to reduce costs, in particular for low sulfur coals (i.e. Montana Rosebud). A copy of Mr. McClanathan's presentation material is included as Figure B-2 with these minutes.

The presentation began with a brief overview of the basic seed regeneration processing steps. The associated process flow schematics describing the Econoseed process are included with Figure B-2. Of particular note is the difference in the nature of the material that enters the seed regeneration plant depending on the sulfur content of the coal. For high sulfur coals, the incoming product to the seed regeneration plant is primarily potassium sulfate (K_2SO_4), while for low sulfur coals, the incoming product is a mixture of potassium carbonate (K_2CO_3) and potassium sulfate. (At 1.5% potassium loading, the spent seed contains approximately 2.5 times more K_2CO_3 than K_2SO_4 for a typical Montana Rosebud.) In order to take advantage of the

latter spent seed composition, a pre-separation of K_2CO_3 from K_2SO_4 should be made, followed by processing only the K_2SO_4 portion through the seed regeneration process. The cost savings primarily result from a reduction in the amount of calcium formate that must be produced. The major expense of the process is involved in calcium formate production. When this pre-separation step is factored into the process economics (thereby only processing the portion containing potassium sulfate), the seed regeneration costs are reduced by a factor of two. To a first approximation, both capital and operating costs contribute equally to the cost reduction.

Western Coal Test Plans of the CFFF

Co-chairman Mr. Gary Staats of DOE informed the committee of a slight change in the order of the agenda and requested that Mr. Norman Johanson discuss the Western coal test plans at the CFFF. This change would provide better continuity and insight into the issues discussed in the seed regeneration presentation, in particular, excess carbonate.

Mr. Johanson of UTSI presented a summary of the CFFF test plans with Western coal and reviewed the inputs and comments he received from the MHD community. A copy of Mr. Johanson's presentation material is included with these minutes as Figure B-3. The plan presented by Mr. Johanson showed four tests (designated LMF5-A, B, C and D), each approximately 100 hours in duration. The purpose of the tests is to vary key parameters in order to establish the actual process conditions for the bottoming cycle 2000-hour testing with Western coal. After clarification relating to some subtle details, there was general agreement with the test plan presented by Mr. Johanson. The tests conditions are summarized in the presentation slides included with these minutes (Figure B-3).

Mr. Johanson concluded his presentation indicating that the last test in calendar 1991, a 250-hour test, is the beginning of the POC testing and is going to be based on the results from the tests presented herein. A meeting will be scheduled with the bottoming cycle and topping cycle organizations to establish the actual test conditions and ensure consistency in bottoming-topping cycle test conditions.

During his presentation, Mr. Johanson suggested that the TTIRC adopt a standard for emissions in the form of pounds of effluent per million BTU as opposed to a percent removal. This measure is more commonly used in the utility industry and avoids misinterpretation when discussing, for example, different sulfur content coals. Mr. Johanson recommended that SO_2 removal should be 0.1 pound of SO_2 per million BTU (1/6 of current NSPS) as opposed to a percent removal. The General Committee was in agreement with this recommendation. His recommendation will be formally addressed at the next Executive Committee meeting.

Channel Power Management for the Integrated Topping Cycle

Mr. Bruce Pote of TRW presented the charter, organization, and accomplishments of the recently formed Power Management Working Group. The Working Group is an ad hoc committee to the POC Integration Task Force and is chartered with the integration and testing of the subsystems which comprise channel power management - current controls, power takeoff region, current

consolidation, and inverter. In addition, the CDIF high voltage room is considered since it is the functional interface. A description of the Working Groups's objectives and organizational structure was presented. Mr. Pote also presented the recent accomplishments and planned activities of the Working Group. Recent activities involved the inverter voltage transients, current control design verification testing at the CDIF, and current control testing as forward consolidators. The latter activity was addressed to verify the suitability of the current control devices as backup to the Westinghouse current consolidation subsystem. A copy of Mr. Pote's viewgraphs are included as Figure B-4 with these minutes.

Utility Concerns/Issues

Dr. Fred Walter of Montana Power Company shared with the committee the concerns and issues of the utility community regarding MHD. Mr. Walter indicated that in many instances the concerns are not definitive but come down to perceptions and, in that regard, the MHD community has not done an adequate job of "getting the message to the utilities". In broad terms, the utility feedback can be grouped into 4 to 5 categories:

- Engineering vs. R&D
- POC program
- Seed economics
- Who is the MHD supplier?
- Specific technology gaps

Regarding engineering vs. R&D, it is often perceived that when utilities come up with specific engineering questions, we in MHD (like other technologies) have brushed them aside and not addressed them, or if they were addressed, we have not let the utilities know about it. The concern is that we haven't let utilities become more directly involved-exposed to top data being collected and have relied on expecting the utilities to review our reports. To quote "the messenger is as important as the message" and right now the MHD community suffers as a creditable messenger.

Regarding the POC program, 1000 hours of topping cycle testing is not sufficient for utilities to make the type of investment decisions that go into the demonstration level in a full commercial facility. The POC program is not a fully integrated test of the whole system.

Regarding seed economics, although that has been discussed, the utility message also includes concerns about K_2/S ratio, particularly for low sulfur coals. Is the answer a chemical solution or is it a mechanical solution? From utility experience, they don't like sulfur in the gases and when we discuss the solution to the K_2/S ratio is to add sulfur in the front end for chemical reaction purposes (i.e. use sulfur to capture potassium), we need a good story if we want a positive response from utilities. The utility message: a mechanical solution better suits their needs.

Regarding the supplier of MHD, utilities have historically had strong component suppliers for the duration of a plant life cycle and for the system in general. It is not obvious that this is true with MHD. Will today's suppliers be there if utilities get involved with MHD tomorrow? Is the MHD supplier going to be there when the utilities need him?

The specific technology gap is primarily the high temperature air preheater. Utilities perceive it as brushed aside (for budgetary reasons); but because of the fact that we can't preheat, we will never look as attractive as natural gas.

Are we addressing the data requirements outlined by Dr. Robert Aurora from Houston Lighting and Power? (See Fifth Semi-Annual Status Report, Appendix C.) In addition to generating the life cycle analysis data, we must have it in a format that can be used by utilities.

Status of DOE Action on POC Task Force Recommendations

On 13 August 1990, the Executive Committee through the POC Integration Task Force formally transmitted its prioritized recommendations regarding aspects of the current POC program which could be modified or amended to better focus the program on consistent and commercially realistic specifications for a retrofit demonstration. (See Fifth and Sixth Semi-Annual Status Reports.)

Mr. Gary Staats of DOE provided a brief status of the DOE action regarding the TTIRC recommendations. Mr. Staats noted that several of the identified issues would be resolved during the review and approval of the various POC test plans, in particular, K_2/S ratio, combustor stoichiometry and additives. We are starting to see that integration process unfolding with the comments regarding the CFFF test plan. This process will continue when the topping cycle test plan is issued.

Regarding superconducting magnets, Mr. Staats indicated that the DOE would not be acting in this area directly. However, the superconducting magnet at Argonne is being used in a Navy/DARPA test and will be operational soon. We will be deriving a wealth of operational data from this testing.

Mr. Staats also noted that the DOE is addressing the recommendation for Western coal seed regeneration and integration of the seed regeneration process into the retrofit designs. Discussions are underway with the seed regeneration contractor (TRW). Mr. Staats did note that testing of multiple load will not be included in the POC program while the remaining recommendations are still under consideration.

Bruce Pote informed the meeting attendees of a document prepared by Westinghouse Energy Systems titled "Phase I Topical Report System Evaluation of POC Technology Integration Issues". This report covered from a systems perspective many of the aspects identified by the POC Integration Task Force. Interested individuals should contact J. Lance of Westinghouse for a copy of the report.

Clean Coal Technology Update

Dr. William Owens of Gilbert/Commonwealth gave an update on the activities of the MHD Development Corporation regarding CCT-V. As most everyone knows, the MHD Development Corp. (MDC) is planning to submit a clean coal proposal for an MHD power plant. Dr. Owens reported that the House Interior Subcommittee has passed a bill to approve a budget for CCT-V. It appears that the PON (Program Office Notification) will be released in mid-1992. Dr. Owens reported

that the MHD Development Corp. was successful in obtaining funding commitments from the State of Montana. Recently, the Montana state legislature met and passed essentially two bills: 1) \$250K to support MDC in the writing of the proposal for CCT-V, and 2) to provide for a \$25 million loan from the coal severance tax fund and to provide over \$25 million in tax exemptions to the project.

Other Business

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

FIGURE B-1

NATIONAL MHD PROGRAM HIGHLIGHTS

- 2000 hrs of POC testing with Eastern coal were successfully completed at CFFF
 - Gaseous and particulate environmental compliance
 - Material corrosion/erosion resistance
 - Part thermal load
 - Slagging and fouling characteristics
 - Seed recovery
- 191 hrs of continuous operation on coal achieved representing the longest duration of any MHD facility to date
- Recovered, collected and shipped approximately 40 tons of spent seed to TRW for seed regeneration in the TRW "Econoseed" process

FIGURE B-1

NATIONAL MHD PROGRAM HIGHLIGHTS

- 256 prototypical current control circuits delivered and installed at CDIF. Successfully tested with 1A1 workhorse channel
- Engineering prototype of the Westinghouse current consolidation system (forward and aft) successfully tested on Textron MKVII MHD test facility
- Engineering prototype section of the TRW combustor (pressure shell – cooling panel) successfully tested at CFFF with Illinois No. 6 coal for 250 hrs, 17 start-ups/shutdowns
- Proof of concept high temperature, high pressure boiler feed water electrical isolator was successfully tested for 50 hrs at 400 deg F – 1000 psi

FIGURE B-1

NATIONAL MHD PROGRAM HIGHLIGHTS

- Fabrication of the prototypical topping cycle hardware in progress. Delivery to the CDIF will be completed in May 1992
 - Anode (forward) current consolidation subsystem will be delivered in September 1991 for testing with the 1A1 workhorse channel
- Fabrication and assembly of the potassium formate reactor and calcium formate production unit for seed regeneration is underway
 - Plan to prepare 10 - 20 tons of regenerated seed for topping cycle testing at CDIF

FIGURE B-2

MHD Seed Regeneration Process for Eastern High Sulfur Coal

BASIS: 1 1/2 % K IN CHANNEL
 REGENERATION ONLY TO
 100% SULFUR CAPTURE
 SUPPORTS 300 MW_e

FIGURE B-2

PRIMARY REACTIONS OF THE ECONOSEED PROCESS

SPENT SEED REGENERATION:

CALCIUM FORMATE PRODUCTION:

FIGURE B-2

SEED REGENERATION WITH WESTERN VS. EASTERN COALS

- PRESENT POC SEED REGENERATION PROGRAM DIRECTED ONLY AT HIGH SULFUR EASTERN COAL
- DESIGN STUDIES INDICATE THAT CONSIDERABLE DIFFERENCES EXIST IN THE SEED REGENERATION PROCESS IF LOW SULFUR WESTERN COALS ARE USED. AT 1 1/2% K LOADING THERE IS A CONSIDERABLE EXCESS OF KCOOH FOR SULFUR CAPTURE. SPENT SEED CONTAINS MORE K_2CO_3 THAN K_2SO_4 [2.5:1]
- SEED REGENERATION FOR LOW SULFUR WESTERN COALS COULD COST ALMOST 50% LESS THAN THAT FOR HIGH SULFUR COALS IF CERTAIN NEW PROCESSING STEPS ARE TESTED AND PROVE SUCCESSFUL. REQUIRES A SEPARATION OF K_2CO_3 SOLUTION FROM THE K_2SO_4/K_2CO_3 SPENT SEED MIXTURE

FIGURE B-2

MHD Seed Regeneration Process for Western Low Sulfur Coal

**BASIS: 1 1/2 % K IN CHANNEL
REGENERATION ONLY TO
100% SULFUR CAPTURE
SUPPORTS 300 MW_e**

SEED REGENERATION OPTIONS

OPTION 1 – PROCESS ALL OF THE SPENT SEED TO KCOOH

ADVANTAGES:

Recycled seed contains only KCOOH – no K₂SO₄

DISADVANTAGES:

Expensive – Requires the production of calcium formate to regenerate both K₂CO₃ and K₂SO₄

OPTION 2 – PROCESS ONLY A PORTION OF SPENT SEED TO FORMATE BY LIMITING THE USE OF CALCIUM FORMATE TO THAT REQUIRED FOR SULFUR CONTROL.

ADVANTAGES:

Minimal cost – requires minimal production of calcium formate

DISADVANTAGES:

Seed feed from regeneration to MHD system contains a mixture of K₂SO₄ and KCOOH. Sulfate addition may prove harmful to channel hardware reducing channel life.

OPTION 3 – SEPARATE THE K₂CO₃ FROM THE K₂SO₄ ; PROCESS ONLY THE K₂SO₄ TO KCOOH. K₂CO₃ IS RECYCLED WITH MINIMAL PROCESSING.

ADVANTAGES:

Minimal cost – requires minimal production of calcium formate and reduced evaporation costs. No SO₄ addition.

DISADVANTAGES:

Spent seed now contains K₂CO₃ that affects performance, recovery and handling in bottoming cycle components.

FIGURE B-2
COMPARISONS OF PROCESS ECONOMICS FOR WESTERN
AND EASTERN COAL SEED REGENERATION

BASIS:
300 MWt MHD SYSTEMS @ 40% OVERALL EFFICIENCY
95% THEORETICAL COMBUSTION AIR
AIR ENRICHED TO 35% O₂
SLAG REJECTION- 70%
65% CAPACITY FACTOR

CASE	1	2	3	4	5
COAL:					
COAL TYPE	ILL #6	ILL #6	ILL #6	MONTANA	MONTANA
ASH CONTENT	12.52%	12.52%	12.52%	13.06%	13.06%
SULFUR CONTENT	3.62%	3.62%	3.62%	1.10%	1.10%
SEED:					
WT % K IN CHANNEL	1.5%	1.5%	1.17%	1.5%	1.5%
CO ₃ (equivalent) / S RATIO	1:1	1.29:1	1:1	3.95	3.95
SEED TYPE	FORMATE/ SULFATE	FORMATE	FORMATE	FORMATE	FORMATE/ CARBONATE
PROCESS ECONOMICS					
TOTAL CAPITAL REQMENT, (TCR) \$, millions	\$26.9	\$30.0	\$26.2	\$29.9	\$18.2
TCR - \$/KWe NAMEPLATE	\$224	\$250	\$218	\$249	\$152
OPERATING COSTS:					
DIR. OPER. COST, \$, Million	\$6.6	\$7.7	\$6.5	\$7.3	\$3.3
CAPITAL CHARGE- 15.5% TCR	\$4.2	<u>\$4.6</u>	<u>\$4.0</u>	<u>\$4.6</u>	<u>\$2.8</u>
TOTAL AMORTIZED OP COSTS	\$10.8	\$12.4	\$10.5	\$11.9	\$6.1
OPERATING COSTS, \$/LB K Based on total seed circ.	\$0.24	\$0.27	\$0.30	\$0.26	\$0.13
TOTAL OPERATING COST, mills/kwh	15.8	18.1	15.4	17.5	9.0

FIGURE B-2

TOTAL CAPITAL REQUIREMENT

300 MWt MHD SYSTEMS

FIGURE B-2

SEED REGENERATION COSTS vs COAL SULFUR

FIGURE B-2
FGD & SEED REGENERATION COST COMPARISON
MILLS/KWH VS SO₂ REDUCTION

FIGURE B-2

FGD & SEED REGENERATION COST COMPARISON MILLS/KWH vs BOILER SIZE

FIGURE B-2

REDUCING THE COST OF SEED REGENERATION

- PRESENTATIONS OF COSTS SHOULD BE BASED ON LARGER COMMERCIAL MHD SYSTEMS RATHER THAN A SMALL RETROFIT DESIGN BASIS
 - SHOW HIGHER MHD EFFICIENCY
 - LARGER CAPACITY THAN 300 MW_T (100 MW_E)
- USE HIGHER CAPACITY FACTOR FOR SEED REGENERATION
 - 80% MORE TYPICAL FOR CHEMICAL PLANTS
- MAXIMIZE INTEGRATION WITH TOPPING/BOTTOMING CYCLE
- OPERATE SEED REGENERATION IN A MODE TO MINIMIZE THE REQUIREMENT FOR CALCIUM FORMATE PRODUCTION
 - ADJUST SEED LOADING TO MINIMUM REQUIRED FOR SULFUR CAPTURE
 - ALLOW OPTIMUM RECYCLE OF K₂SO₄ WITHOUT INCURRING CHANNEL DAMAGE
 - DEVELOP METHOD FOR SEPARATING K₂SO₄ FROM K₂CO₃ IN SPENT SEED FOR LOW SULFUR COALS TO ALLOW FOR MINIMAL Ca(COOH)₂ PRODUCTION

FIGURE B-2

SEED REGENERATION COSTS VS EFFICIENCY WESTERN LOW SULFUR COAL

FIGURE B-2

OPTIONS TO SEED REGENERATION

- PURCHASE K_2CO_3 AND USE ON ONCE THRU BASIS:
 - PURCHASE COST ALONE IS PROHIBITIVE - MORE THAN 2X THE COST OF SEED REGENERATION OR ABOUT 50 MILS/KW
 - CREATES MASSIVE DISPOSAL PROBLEM FOR WATER SOLUBLE K_2SO_4 /ASH MATERIAL
 - REQUIRES ABOUT 80 MILLION LBS K_2CO_3 /YEAR FOR A SINGLE 300 MW_T MHD SYSTEM. US ANNUAL PRODUCTION IS ONLY ABOUT 100 MILLION LBS K_2CO_3
- USE K_2SO_4 AS SEED AND FGD SYSTEM FOR SULFUR CONTROL:
 - POTENTIAL FOR CHANNEL DAMAGE AND SHORTENED LIFE USING K_2SO_4 ONLY AS SEED - DOUBLES SULFUR LEVELS IN CHANNEL.
 - FGD SYSTEMS SHOW HIGHER COSTS THAN PRESENT SEED REGENERATION FORECASTS
 - NEED MEANS OF CONTROLLING CONTAINMENT BUILDUP FROM COAL ASH SO SOME REGENERATION REQUIRED UNDER THESE CIRCUMSTANCES

CONCLUSION - SEED REGENERATION OFFERS THE MOST ECONOMIC AND TECHNICAL VIABLE METHOD OF PROVIDING POTASSIUM IONS TO THE CHANNEL

FIGURE B-3

The 1991 CFFF Test Plan

TTIRRC Meeting
Presented by Norm Johanson
June 17, 1991

MEETING

LMF5-A - Western Coal Test

- July 15, 1991
- 100 hours
 - Start test at the same thermal input as the previous Eastern Coal POC tests
 - 3750 - 3800° F to Primary Furnace (may have to change thermal input to obtain)
 - 2250 - 2300° F to Superheater
 - Stoichiometry - 0.80, 0.85, 0.90
 - Same slag carryover as eastern coal POC tests ~ 50%
 - %K = 1
 - K₂/S ~ 1.12 (95% SO₂ Removal) mixture of K₂CO₃ and K₂SO₄

FIGURE B-3

LMF5-A Comments

**B & W, Westinghouse, AVCO
agree with our plan, TRW
recommended K₂/S higher ratio**

LMF5-B

Western Coal Test Corette Plant Conditions

- August, 1991
- 80 hours
- Western Coal (sulfur content less than 1%, moisture 8% or less)
- 3800 - 3850°F to Primary Furnace
- Oxidant Preheat - 1200° F
- Stoichiometry - 0.80, 0.85, 0.90, 0.95
- %K = 1
- 100% K_2CO_3 - $K_2/S = \sim 2.9$

MEETING

LMF5-B Comments

- B & W and Westinghouse agrees with the test plan.
- TRW agrees with the test plan except recommends operating at a $K_2/S = 2$ (which would include adding K_2SO_4 into the flow stream).
- AVCO agrees with the test plan in that the conditions we state above will result in a K_2/S ratio greater than 2.
- The above is true, actually 2.9

COAL-FIRED FLOW FACILITY

FIGURE B-3

New Stationary Sources Performance Standards

Environmental Protection Agency
June 11, 1979

Section (1) of SO₂ Standards:
Solid & Solid - Derived Fuels

FIGURE B-3

Coal and Analyses

PROXIMATE % AS RECORDED	ROSEBUD	ILLINOIS #6
Moisture	22.7	8.9
Volatile Matter	29.4	36.0
Fixed Carbon	39.2	11.4
Ash	8.7	11.4
ULTIMATE %		
Hydrogen	6.00	5.40
Carbon	52.10	62.40
Nitrogen	1.79	1.20
Oxygen	31.50	16.30
Sulfur	0.85	3.30
Chlorine	.03	0.04
ASH %		
SiO ₂	37.6	41.40
Al ₂ O ₃	17.3	19.30
Fe ₂ O ₃	5.1	22.30
TiO ₂	.7	.90
P ₂ O ₅	.4	.12
CaO	11.0	5.40
MgO	4.0	1.70
Na ₂ O	3.1	.60
K ₂ O	.5	2.10
SO ₃	17.5	7.50
Init. Deformation, F	2190 + - 230	1960 + - 70
Softening, F	2230 + - 240	2030 + - 70
Fluid, F	2280 + - 200	2260 + - 200

FIGURE B-3

Sulfur Removal Efficiency by Potassium Sorbent in an MHD System

SO₂ Removal

EASTERN COAL				
	ppm (dry)	# MMBTU	% SO	Removal
3.7% S	564	0.60		90
3% Moist	251	0.30		95
38% O Enrich	94	0.10		98
12,500 BTU / # Dry	56	0.06		99
WESTERN COAL				
	ppm (dry)	# MMBTU	% SO	Removal
1.0% S	504	0.57		70
6% Moist	267	0.30		84
38% O Enrich	89	0.10		95
11,000 BTU / # Dry	32	0.04		98
	16	0.02		99

* Current NSPS

** New Clean Air Act

*** Possible Now

LMF5-B Feedback

We will have the flexibility to run at 2 or 2.9. Operating at a $K_2/S = 2.9$ i.e. (100% K_2CO_3) is the worst case. In some future tests we will evaluate Western Coal fouling, gas clean up efficiencies and SO_2 removal with K_2/S from 1 to 2 after we obtain more experience with Western Coal.

LMF5-C

Iron Oxide with Western Coal

- **September, 1991**
- **~ 80 hours**
- **This test will be at the same conditions of LMF5-A except this test will be conducted with iron oxide addition. Iron oxide will be added to the coal to bring the total iron in the Western Coal to that contained in the Eastern Coal that we are currently using.**

LMF5-C Comments

- B & W, Westinghouse, and AVCO agree with the test plan. TRW recommends running the iron oxide test at $K_2/S = 2$. We selected to run at a condition where we have the most experience and the most data to identify quickly where we can expect significant changes in the operation of the HRSR.
- We intend to add enough iron oxide to the Western Coal to increase the iron level to 17-20% of the coal ash. 17% was suggested by TRW.

LMF5-D Western Coal POC Tests

- **October - November 1991**
- **250 hours**
 - **The test conditions will be established after the above tests are completed and in concurrence with DOE and their respective MHD contractors. These conditions will be the basis for 2000 POC hours on Western Coal.**
- **All agree with this plan or had no comment.**

Iron Oxide Injection

FIGURE B-3

Slag Layer Structure

FIGURE B-3

MHD Environmental Benefits

FIGURE B-4

POWER MANAGEMENT WORKING GROUP

**REPORT TO THE TTIRC
GENERAL COMMITTEE**

JUNE 17, 1991

FIGURE B-4

POWER MANAGEMENT INTEGRATION

OBJECTIVE

- Ensure the successful integration of the subsystems that comprise the power management system
 - Current Control Circuits
 - Current Consolidation Circuits
 - Inverter
 - High Voltage Room (Functional Interface)
- Error free design of the power take-off (PTO) and transition regions and successful implementation on the 1A4 prototypical power train

FIGURE B-4

POWER MANAGEMENT INTEGRATION

BACKGROUND

- The MHD channel, current control circuits, consolidation circuits and inverter represent interacting components within the power management system
- Present understanding and design methodology is largely empirical and not well established from a theoretical/analytical basis
- The performance and interactive affects (transients, faults etc.) must be analyzed, modeled and tested using the 1A1 channel to minimize problems during 1A4 operation
- A focused power management activity has been initiated to address these issues

FIGURE B-4

POWER MANAGEMENT WORKING GROUP

AREAS OF PRESENT EXPERIMENTAL ACTIVITY

- Avco 1A4 Current Controls
- Inverter Voltage Transients
- Avco Current Controls as Anode Consolidations (FWD PTO)

FIGURE B-4

POWER MANAGEMENT WORKING GROUP

1A4 CURRENT CONTROLS

- CC checkout test conducted in May 1990 (90-CC-1 and 90-CC-2)- determined several units not controlling, some working ok. Clock boards and driver cards determined to be non-functional
- Selected clock and driver boards returned to Avco (not a complete cabinet). "Noise" tests with welding machine conducted in attempt to affect clock boards - no effect. Boards run with MKVII channel - 16 amps 500-1500 VL - worked perfectly
- 90-CC-03 conducted with inverter off, under short circuit conditions. Current control operation was erratic and the degree a function of magnet power. Inverter eliminated as root cause

FIGURE B-4

POWER MANAGEMENT WORKING GROUP

1A4 CURRENT CONTROLS (cont.)

- CC operational problems traced to 480 vac supply voltage sag and line noise. CC worked perfectly during 90-CC-04 with clean, constant voltage supply power
- New power transformers installed in CC's to upgrade the transformer secondary side voltage from 18 to 20 volts to overcome voltage sag. Power line filter installed in original 480 vac supply line

POWER MANAGEMENT WORKING GROUP

FIGURE B-4

INVERTER VOLTAGE TRANSIENTS

- Inverter voltage transients identified as potential issue in 1984 – 1985 (Hruby–Wood)
- Inverter voltage measurements taken by MSE’s Schiller in 1985/1986; 1500 V spike, 3000 V peak to peak, freq. ~180Hz, 150 – 200 V/μsec (dv/dt)
- Investigation by Westinghouse conducted during August 1990
 - Confirmed Schiller measurements on the magnitude of spike
 - Identified cause of voltage transient
 - Implemented simple R–C filter from positive bus to ground to reduce magnitude and shape of transient waveform
- Further attenuation desired

FIGURE B-4

POWER MANAGEMENT WORKING GROUP

AVCO CURRENT CONTROLS AS CONSOLIDATORS

- In 1989 (1A1) current controls operating in consolidation mode suffered frequent GTO and diode failures in anode consolidation circuits. Inverter voltage transient suspected as possible cause
- 91-CC-01 and 91-CC-02 were conducted in November 1990 to identify the cause and implement corrective action for the component failures experienced
- Reverse voltage bias caused by different reduction in the VHALL and VLOAD when magnet is secured were the cause of past failures
- Approaches to mitigating the cause are being investigated
 - inverter/magnet interlock
 - circuit protection
 - operate inverter in current mode

FIGURE B-4

01M91040.01

*Busek Co.

Power Management Working Group Organization

FIGURE B-4

(1) Includes TDS consolidation system as backup
(2) Includes resistive load bank as backup

O1M 91.123.01

Power Management Subsystem Interfaces and Responsible Engineers

APPENDIX C

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:

October 1991

PRIME CONTRACTOR:

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

REPORTING PERIOD:

April 1991 to
September 1991

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_e 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

The focus of the systems engineering efforts during the reporting period was on updating and finalizing the interfaces between subsystems and between each of the subsystems and the CDIF. The interface package was expanded to include all of the instrumentation that is used for diagnostic and testing purposes even though most of the instruments are not a true interface. Additionally, four diagrams were prepared to show the process flows, the cooling water flows, the process instrumentation, and the facility instrumentation. At the end of this period, the various parts of the interface package were being cross-checked for consistency and accuracy.

To ensure timely design of the high voltage room (HVR) at the CDIF, a separate channel requirements document was prepared this quarter. This document contained all of the requirements that the 1A4 channel would place on the facility focusing on the configurations that would be tested and the instrumentation that would be required to accomplish these tests. The information contained in this document has been carried over into the Interface Document.

Task 2 - Combustion Subsystem (TRW)

The manufacturing activities for the combustion subsystem components were kicked off this period. Orders were placed for all of the major hardware which included the pressure shell components, the precombustor combustion can, both baffles, all of the cooling panels, and the transition ring. By the end of this period, the exit section pressure shell, the precombustor combustion can, the coal injector hot sleeve, and the exit section cooling panels had been received. The handling fixtures were also in place so that the assembly of the exit section was begun. The raw material (G-10) for the electrical insulating feet of the support stand was received. The fabrication and assembly of the insulators was completed by the end of September.

The procedure for the weld overlay process was completed prior to the delivery of the first cooling panels. The weld overlay was required because of the change to lower temperature cooling water which caused the cooling panel surfaces to operate below the dew point of sulfuric and nitric acid. The procedure for protecting the back sides of the panels with RTV was also finalized prior to the installation of the cooling panels into the exit section.

The design of the cooling water manifolds and the interconnecting lines between the manifolds and the cooling panels was finalized. The cooling water manifolds were ordered and about 80% had arrived by the end of the period.

A major milestone was achieved this reporting period with the completion of the prototypical second stage. The second stage assembly, along with the required adapter plates, was delivered to the CDIF in September, 1991. It will be installed for checkout during the upcoming workhorse test series. The prototypical second stage has a rectangular cross section instead of the workhorse square cross section to effect a better transition to the 1A4 channel nozzle.

Negotiations were completed with Ellis & Watts to design, fabricate, assemble, and test the low pressure cooling system (LPCS) that would be used to cool the precombustor and the slagging stage. The conceptual and final design reviews were held during this period and long lead procurements were made. The LPCS is scheduled for delivery in January 1992 which is consistent with the CDIF installation schedule for the prototypical hardware.

Task 3 - Channel Subsystem (Avco)

Sixteen (16) hours of testing was performed in the MK-VII facility this period to complete the Z-wall versus straight wall testing and to look at options for loading the rear power take-off region. These tests, in conjunction with previous testing, showed that the Z-wall configuration better matched the electric potential both in the plasma regions and at the slag boundary regions. This leads to lower inter-segment voltages and hence lower leakage currents as compared to the straight wall counterpart.

The waterside corrosion testing started during the last reporting period was completed. Requirements for the pH and dissolved oxygen of the cooling water were developed and given to MSE as part of the Channel Requirements Document.

A full scale plywood mock-up of the channel was completed. This mock-up was used to optimize the external wiring and hosing of the channel. With the use of the mock-up, the design of the wiring harnesses and cooling water manifolds was completed and the hardware ordered. The same mock-up will be modified to include the combustor second stage to ensure that there are no interferences between any of the consumable and cooling lines of the two subsystems.

The cathode wall was essentially completed with all of the elements installed onto the plastic backwall. The external wiring and hosing will be completed after the cathode wall is integrated with the other three walls. The final integration is scheduled for next February when the anode and sidewalls are completed. The strongback that will support the channel during assembly and shipping has been fabricated and delivered to TDS.

Two problems have surfaced during the fabrication and assembly phase of the sidewalls; tungsten cap cracking and brass cooling tube failures. Cracking of the tungsten caps on the tungsten-copper bases has occurred longitudinally along the slag retention groove. Stress buildup during the brazing process is the root cause of the cracks. Two methods to alleviate the stress buildup were investigated; the use of a compliant layer during the brazing process, and the cutting of a gap in the cap prior to brazing. The second method appears to work the best so coupons of this type were prepared for installation into the 1A1. These coupons will be evaluated during the upcoming test series.

The second problem is the failure of the brass cooling tubes during handling. The root cause appears to be embrittlement of the brass and not improper handling. Investigations into the type of brass being used, the braze procedure, and the braze material being used are ongoing. When a solution is found, coupons will be installed into the 1A1 for confirmation.

Task 5 - Current Consolidation Subsystem (Westinghouse)

Full scale GTO and SCR gate drive boards were successfully tested at the beginning of this reporting period. Parts for the remaining boards were ordered and at the end of this period these boards were essentially complete. The cabinets were received and the internal structure was installed including the high voltage insulators. All of the filter assemblies were installed and successfully hi-pot tested to 12 kV. Late deliveries from one of the printed circuit board suppliers coupled with funding problems have delayed the delivery of the entire anode consolidation system until early December. However, the diode stack, which allows the channel to be run in the resistive consolidation mode, was delivered on schedule to the CDIF in September, 1991. This was an important milestone as it allows power operation of the channel even without the complete anode consolidation hardware.

Task 6 - CDIF Test Support

During this period there were 36.1 thermal hours devoted to the checkout of the slag rejector system which transfers slag from the combustor tank at high electric potential to the facility tank at ground potential. These tests successfully debugged the operating logic under thermal operating conditions. Unfortunately, because of the unavailability of the magnet, the system was not able to be tested under full power, i.e., operated with the combustor at 6 kV. A 1000 volt power supply was connected to the combustor during one of the tests and the slag rejector successfully cycled at this voltage.

Channel coupons were installed into the 1A1 for testing in the upcoming fall test series. Several anode and cathode coupons were reinstalled after they were examined for material wear from previous testing. Additionally, seventy-five sidewall coupons were installed to evaluate the tungsten cap on tungsten-copper and tungsten cap on copper designs. TDS personnel were on hand at the CDIF during the installation of these coupons.

Task 8 - Technology Transfer/Integration

TRW issued to the DOE and Executive Committee the draft version of the Fifth Semi-Annual Status Report of TTIRC activity for review and approval. The report covers the period October 1990 through March 1991.

A meeting of the TTIRC General Committee was held in June 1991 in conjunction with the 29th Symposium on Engineering Aspects of Magnetohydrodynamics in New Orleans, Louisiana.

4: PLANNED ACTIVITIES (October 1991 - March 1992)

- Complete prototypical combustion subsystem hardware fabrication
- Deliver prototypical combustor to the CDIF
- Deliver the anode current consolidation cabinet to the CDIF
- Initiate the fabrication of the cathode consolidation hardware

- Complete channel subsystem hardware fabrication and initiate final assembly and testing
- Complete fabrication and assembly of the Low Pressure Cooling System and deliver to CDIF

5. SCHEDULE

The overall project schedule is shown in Figure 1 and the corresponding milestone log in Table 1.

DOE Form CR-535 (1-78)

1. Contract Identification MHD INTEGRATED TOPPING CYCLE		2. Reporting Period April 1991 to September 1991		3. Contract Number DE-AC22-87PC90274	
4. Contractor TRW INC. ONE SPACE PARK REDONDO BEACH, CA 902786.				5. Contract Start Date 9/30/87	
				6. Contract Completion Date 11/28/92	

7. ID # (TASK)	8. REPORTING CATEGORY	9. FISCAL YEARS/MONTHS/QUARTERS																												10. % COMPL.			
		88	89	90	91	O	N	D	J	F	M	A	M	J	J	A	S	92	O	N	D	Q2	Q3	Q4	93	Q1	Q2	Q3	Q4	94	Q1	Q2	a. PLAN

Activities on Tasks 1, 6, 7, 8, 9 and 10 are planned beyond the official 11/28/92 contract end date.

13. Signature of Government Technical Representative and Date

TABLE 1
STATEMENT OF WORK TECHNICAL MILESTONES

ID	DESCRIPTION	PLAN	BASLINE	ACTUAL	COMMENTS
Task 1 - SYSTEM 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	Final CDIF Test Plan	Feb-92	May-92		
1D	System Integration at CDIF	Sep-91	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	Deliver User's Manual to CDIF	Apr-91	Dec-91		
2D	Complete Prototypical Fabrication	Dec-90	Jan-92		
2E	Ship Combustor to CDIF	Jun-91	Jan-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	Feb-92		
3D	Deliver User's Manual to CDIF	Apr-91	Apr-92		
3E	Complete Non-Operating Tests	Apr-91	May-92		
3F	Ship Channel to CDIF	Jun-91	May-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	Mar-92		
4D	Deliver User's Manual to CDIF	Apr-91	Apr-92		
4E	Complete Non-Operating Tests	Apr-91	May-92		
4F	Ship Diffuser to CDIF	Jun-91	May-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	Feb-91	
5C	Anode Hardware Fabrication	Jan-91	Sep-91		Diode stack only delivered
5D	Ship Anode Hardware to CDIF	Feb-91	Sep-91		
5E	Cathode Hardware Fabrication	Jan-91	May-92		
5F	Ship Cathode Hardware to CDIF	Feb-91	May-92		
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 D
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 1, 1991

CONTRACT TITLE AND NUMBER:

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

Contract No. DE-AC07-88ID-12735

CONTRACTOR:

MSE, Inc.

REPORTING PERIOD:

April 1991 - September 1991

PROJECT MANAGER:

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

PERIOD OF PERFORMANCE:

April 1991 - September 1991

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 the 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.

PROGRESS SUMMARY:

(1) Facility ES&H Compliance Issues

Throughout this reporting period, emphasis continued on our obligation to operate the DOE-owned facility within all ES&H legal and regulatory guidelines. Significant events during this period included:

- The CDIF conduct of operations matrix was submitted to DOE-ID for approval. A recent audit showed that the CDIF is essentially in compliance with this order.
- The critical self-assessment program is progressing. Two critical assessments were conducted on management and the CDIF environmental program.
- An environmental audit of the CDIF was conducted by the DOE Office of Environmental Audit (OEV). The scope of the audit was comprehensive, addressing environmental activities in the technical areas of air, surface water/drinking water, groundwater, waste management, toxic and chemical materials, quality assurance, inactive waste sites, environmental management, and environmental self-assessment.

(2) Facility Support

Preparing the CDIF for the required extended runs for POC equipment testing entails substantial modifications to many systems. Each of the major modifications is being treated as an independent project. These projects have been budgeted and scheduled as appropriate to meet the POC testing schedule. The project accomplishments achieved during the last reporting period are outlined below:

- Completed the installation of the stack gas/environmental compliance upgrade, performed system start up procedures, and turned system over to operations.
- Completed installation and system operating test procedures for the TRW slag rejector system.
- Initiated preconstruction subcontract for the installation of oxygen system upgrade to support prototypic MHD duration testing.
- Completed Title II design for the ITC kurrent consolidators and completed the installation of the building to house the anode KC cabinets.
- A leak in the west half of the CDIF iron core magnet was discovered in February 1991. During the investigation of the leak in the west half, it was discovered that the east half had a very low resistance to ground. Further investigation revealed a likely cause of the low resistance. The epoxy insulation was cracked and moisture had worked into the cracks. A lengthy period of heating to 60 °C successfully returned the coil resistance to acceptable values. After analysis of the leak in the west half, its probable cause, methods of repair, and qualification of the vendor for proposed repair, the repair was effected in August 1991. No MHD testing using the ICM was conducted during this reporting period.

(3) Testing and Evaluation

The test program at the CDIF during the second half of FY91 was defined to support additional fine coal testing, steady-state duration power testing, checkout testing of the slag rejector, tailored coal testing and continued coupon testing of designs and materials. The magnet failure during this FY preempted power generation; therefore, test emphasis was switched and alternative test goals including seed utilization testing and E+H calibration testing were defined. Tailored coal testing was cancelled due to the inability to obtain tailored coal.

Testing during the second half of FY 91 resulted in the following:

- 15 test starts
- 30:17 hours of coal burn (thermal) time
- 00:00 hours of power generation time
- 00.00 MWhrs of total energy generated

Major technical accomplishments during the second half of FY91 were:

- Completed a series of special project testing to address multiple objectives that could be accomplished without power generation capability, which included the following:
 - Checked the slag rejector installation under thermal and conductivity operation.
 - Initiated seed utilization testing by running with various seed hot spot velocities.
 - Addressed slag tank plugging by altering test conditions and configurations.
 - Obtained data for the E+H meter calibration by altering line configuration to the Blue Vessel.
- Supported efforts to assess variations/new hardware designs including the coupon filler section, the slag rejection system grinder, and alternate cooling procedures.
- Montana State University, Electrical Engineering Department completed subcontracted research to investigate the interaction of external power extraction networks, both passive and active, with internal MHD channel gasdynamics. This work involved developing a computer program to implement a quasi one-dimensional model of an MHD channel including supersonic/subsonic shocks. A presentation at the CDIF was made during which results from several runs were presented which demonstrated the computer model's capabilities. The mechanical (non-MHD) aspects of the code have been validated against shock tube data. The MHD portions have not been validated, but were examined for correct behavior under a variety of conditions.

This model will be useful in the analysis of existing MHD generators, the design of future generators, the design and specification of power conditioning equipment, and the study of integrated combined-cycle plant control strategies.

- Prepared a detailed explanation of the advanced, one-dimensional, electrical model (ELECID) developed during the previous reporting period and used this model to analyze several CDIF tests. This new model accounts for boundary/slag layer power losses via a pair of nonuniformity factors and appropriate weighted averages of the gas dynamic variables. Using only CDIF test data taken over a load sweep, the model calculates the average conductivity, the average Hall parameter, the axial and transverse resistances per pitch, and the nonuniformity factors--all under power generation conditions (the calculation of some of these quantities requires, in addition, an estimate of the average plasma velocity). A detailed explanation of the model and its application to CDIF tests 90-CC-4 and 91-CC-1, respectively, can be found in papers 'Estimating Plasma/Slag Properties from CDIF Electrical Measurements,' AIAA 22nd Fluid Dynamics, Plasma Dynamics, and Lasers Conference, Honolulu, June 1991 and 'CDIF Plasma/Slag Calculations,' 29th SEAM, New Orleans, June 1991.
- Energy Research Consultants, Incorporated (ERCI) of Tullahoma, TN--on subcontract to MSE--continues to work closely with MSE personnel to identify and quantify the probable power loss mechanisms at work in the

CDIF generator, and recommend ways to ameliorate the situation. Currently, MSE and ERCI are investigating CDIF test 90-DIAG-3, one of the last high-power tests run at the CDIF, with the channel still using ballast resistors to reduce interanode voltage spikes and current densities on the electrodes (both major causes of electrode failure). A primary goal of this effort is to see how channel nonuniformities and power loss mechanisms scale with the level of MHD interaction in an MHD channel. A secondary goal is to determine how well MSE's one-dimensional model ELEC1D (described above) handles higher interaction MHD flows and to establish limits on its applicability. These goals will be accomplished by comparing plasma/slag properties computed by ERCI's gas-dynamics codes with those computed by ELEC1D, which uses only electrical data generated over a load sweep. One of the crucial assumptions needed by ELEC1D to calculate plasma/slag properties--that these properties remain essentially invariant over moderate load sweeps--may not be justified for higher interaction MHD flows such as those encountered during test 90-DIAG-3. The results of this investigation will be reported at the AIAA winter meeting (January 1992) in Reno, Nevada.

- Statistically modeled CDIF tests 91-SREJ-3 and 91-SREJ-4 using the SAS statistical package. These two tests, taken together, represent a Φ_1 sweep and a seed fraction sweep. In addition, several other 'control' variables--primarily Φ_0 , Φ_2 , combustor pressure, and total thermal input--varied sufficiently during these tests to be included in the statistical models. The response variables studied in this investigation were the combustor heat loss, the channel heat loss, and the channel bulk conductivity. In order to reduce the autocorrelation in the data and to allow time for changes in the control variables to be felt by the response variables, it was necessary to first average the data over five-minute intervals before attempting to fit any statistical models. This averaging technique reduced the original data set to 19 (averaged) data points or conditions. With so few degrees of freedom available for modeling, only linear terms in the control variables were considered, except for the seed fraction where a quadratic term was needed to cover the wide range of this variable. Due to a high degree of multicollinearity among the control variables in these experiments, it was necessary to drop the total thermal input from further consideration as a control variable. Among the remaining control variables, it was found that the dominant factors affecting combustor heat loss were Φ_1 , seed fraction, and Φ_2 (in order of diminishing significance). The dominant factors affecting channel heat loss were found to be Φ_1 and Φ_2 . As for the bulk conductivity, the dominant factors were found to be seed fraction and Φ_1 . Interestingly, the maximal bulk conductivity appears to occur at a seed slurry flow equal to 1.7% of the total mass flow. Due to the nature of the experimental designs chosen for these tests, some of the control variable effects could not be estimated reliably from the data. In order to accurately estimate all main effects and first-order interactions, MSE would like to see appropriate experimental designs employed in future MHD tests.
- A Power Management Integration Committee meeting was held at the CDIF on May 30. The POC Channel Requirements Document was reviewed and various aspects of power management were also discussed in relation to POC duration testing requirements.

(4) Test Hardware Support

Channel Assembly and Refurbishment

- Rebuilt four sidewall sections to incorporate copper/tungsten top caps.
- Rebuilt channel consisting of walls 27, 28, 49, 58, 29, 30, 31, and 32 for fall test series.
- Installed a series of 8 ft/sec flow bars in aft left sidewall for fall test series channel.
- Reinstalled Z-wall section in right and left forward sidewalls for fall test series channel.

MSE-supported CFC Repairs and Modifications

- OFV
 - Reinstalled cleaned 8-port oil burner.
 - Installed relined oil-fired vitiator chamber and elbow.
- CFPC
 - Installed new precombustor screen.
- CFC
 - Installed new coal injector assembly on head end plate.
 - Repinned slag dump section to increase slag retention.
 - Removed coupon filler section.
 - Reinstalled smooth-wall filler section.
 - Performed a series of slag grinder optimization tests.
 - Rebuilt the slag grinder using hard faced teeth.
 - Installed prototypic rectangular second stage with MSE nozzle.
 - Installed Phase II of slag rejection system which automated system.

PLANNED ACTIVITIES:

Testing at the CDIF for the next reporting period is projected to include:

- Complete checkout testing following extended shutdown, including new installation checkout of the new DAS, slag removal system, etc.

- Continue workhorse testing to accomplish/assess:
 - Power Management testing, including checkout of the new anode KC, rectangular second stage checkout,
 - duration testing (30-50 continuous hours),
 - seed utilization testing,
 - and fine coal testing (with baghouse fines reintroduced into the normal coal product).
- Complete prototypical combustor characterization testing.
- Initiate prototypical channel testing.

Test hardware support planned for the next reporting period includes:

- Channel
 - Fabricate back-up anode walls 65 and 66.
 - Install 1A₄ channel.
- CFC
 - Install slag removal portion of slag rejection project.
 - Prepare facility to accept prototypic combustor, low pressure cooling system, and channel.
 - Install low pressure cooling skid to cool prototypic combustor.
 - Install prototypic combustor.

Facility Upgrades for the next reporting period are projected to include:

- Finalize preparations for the acceptance of the anode KC cabinets which are tentatively scheduled for delivery early in December and preparation for the construction of the building to house the cathode KC cabinets.
- Complete instrumentation tie-ins and the system operating test procedure for the 50-hour oxygen system upgrade and complete the design for the 100-hour oxygen system upgrade.
- Complete evaluation of the low resistivity of the ICM East coil and return the ICM to operational readiness.
- Complete the subcontracts for installing the CDIF slag removal equipment and finalize the system operating test procedure.
- Complete Title II design for the test train/A-Bay modifications.
- Complete design for the 1A₄ channel electrical modifications.
- Complete installation of the two 16,000-gallon temporary nitrogen storage trailers to accommodate POC test durations.
- Initiate activities for the installation of the SSI system upgrade.

- Complete modification to convert the fly ash storage bin to a seed system dust collector.
- Complete construction subcontract to replace seed storage silo discharge piping modifications as recommended by the Seed System Task Force.
- Initiate activities to award construction subcontract to install the coal fines modification.

APPENDIX E

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 1, 1991

CONTRACTOR:

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

REPORTING PERIOD:

April 1, 1991 to
September 30, 1991

PROJECT MANAGER:

Robert A. McIlroy
(216) 829-7634

PERIOD OF PERFORMANCE:

July 2, 1979 through
September 30, 1991

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 - SO_2 , 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 has continued to review the test plans, express data reports and the results contained in the reports of the CFFF tests. Comments on these have been forwarded to DOE and UTSI. B&W will continue to advise DOE and UTSI of a additional data needs.

The task of extracting data for steady state periods from the mass of data for each run stored within the UTSI Data Acquisition System (DAS) continues. The raw data will be extracted, sorted by area, cleaned up, and refiled in a format that is readily available for a commercial plant designer. Inconsistencies in the data will be identified and attempts will be made to rectify them. Specific areas of interest are:

- o Heat transfer in the diffuser, radiant furnace and secondary combustion zone and variations with load, seed to coal ratio primary stoichiometry, and water and CO₂ content of plasma.
- o Heat transfer to the Superheater Test Sections (TS1, TS2, TS3), the cooling sections and the air heater. This includes the influence of sootblowing frequency and method. K₂/S ratio secondary stoichiometry, gas temperature at the inlet to each test section.
- o Gaseous emissions under various operating conditions such as primary and secondary combustor stoichiometry, temperature decay rates, potassium concentrations in the gas and potassium to sulfur ratio.
- o Electrostatic precipitator and baghouse performance under various operating conditions including gas flow, solids loading, SO₃ and water content of the gas, and particle size.
- o Environmental conditions in areas of high potential corrosion such as the radiant furnace and the Superheater Test Sections.
- o Operating conditions of corrosion and deposition probes and composition and temperatures of the gas environment surrounding the probes.
- o Dense phase pneumatic transport system including means of measuring the flow rate, coal/seed mixture flow rate, water content of the mixture.

Cleanup of the raw data includes identification of steady state periods, elimination of spikes caused by calibration checks and standardizations, adjustments for time delays between upstream events and downstream measurements, and identification of discrepancies between values of key variables determined by different measurement systems.

Samples of corrosion specimens exposed for 1500 and 2000 hours at the CFFF were selected. The samples were polished and photomicrographs were prepared.

4. PLANNED ACTIVITY

A plan and cost estimate for continuation of the effort during GFY 1992 was submitted to the U.S. Department of Energy. The plan includes examinations of additional specimens already exposed and specimens to be exposed during the tests with Montana Rosebud coal, and the review, cleanup and organization of the data.

APPENDIX F
STATUS REPORT - CFFF OPERATIONS

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

Tullahoma, TN 37388-8897
(615) 455-0631

September 27, 1991

Mr. Bruce Pote
TRW, Inc.
Deputy Chairman for Operations, TTIRC
c/o Textron Defense Systems
2385 Revere Beach Parkway
Everett, MA 02149

**SUBJECT: SEMI-ANNUAL STATUS REPORT:
OPERATIONS OF THE CFFF - APRIL 1991-SEPTEMBER 1991
CONTRACT NO. DE-AC02-79ET10815**

Dear Mr. Pote:

The subject status CFFF report for the seventh semi-annual report on the MHD Technology Transfer, Integration and Review Committee is attached.

If you have any questions, please call me at (615) 455-0631 extension 286.

Sincerely,

A handwritten signature in black ink, appearing to read 'Joel'.

Joel W. Muehlhauser, PhD
Administrator
Energy Conversion R&D Programs

JWM:mmn
Enclosure: a/s

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

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 26, 1991

CONTRACTOR

The University of Tennessee
Space Institute
Tullahoma, Tennessee 37388

REPORTING PERIOD

April 1991 through
September 1991

PRINCIPAL INVESTIGATOR

Joel W. Muehlhauser
(615) 455-0631

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

BACKGROUND

The Department of Energy's Coal Fired Flow Facility (CFFF), located at the University of Tennessee Space Institute, was dedicated in October 1980 and shakedown of the facility was completed in early 1981. During 1991, 271 POC hours of coal firing were accumulated on the test train components, increasing the total time on coal to 2543 hours, of which 2344 hours are testing with Eastern Coal (including 2004 Hours of POC testing), and 199 hours of testing on Western Coal.

Several important considerations guided the design of the MHD Low Mass Flow (LMF) heat recovery, seed recovery (HRSR) (steam bottoming cycle) components. A decision was made to use existing boiler technology wherever possible. Materials would be commercially available, and metals would be selected 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 and thus avoid recertification of non coded materials. Successful commercialization will provide

opportunities for future research in improvements, refinements, and increases in boiler efficiency.

The work at UTSI is directed toward simulating gas side conditions in projected MHD systems, including gas temperature, residence time and composition, among others. Development of technology that could be used for scale up was emphasized. Components were developed sequentially and added to the flow train over a period of time. Finally, 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. UTSI, in cooperation with B&W, ANL, and MSU have been continually reviewing and defining the goals and conditions needed for the POC testing of the HRSR system. As they become available, inputs from proposed retrofit designs are being factored into the goals and conditions.

The emphasis at UTSI has been to provide technology needed for scale up of HRSR components, including:

- Corrosion and erosion
- Slagging and fouling of heat transfer surfaces
- Seed recovery
- Control of gaseous (NO_x , SO_2 , CO), priority pollutants, and, particulate emissions
- System integration
- Waste management and environmental concerns

Data on these subject technology areas are being developed for both eastern and western coals.

DOE has initiated conceptual design studies for two potential MHD retrofit plants: (1) The Scholz plant of the Gulf Power Company, and (2) the Corrette plant of the Montana Power Company. The results of these studies have helped to better define conditions that need to be simulated at the CFFF to prove the concept and to obtain the necessary data to proceed with the preliminary design. The current tests at the CFFF are being conducted at conditions which closely match those expected for the Scholz plant and are relatively close to those initially proposed for the Corrette plant.

WORK COMPLETED

Operation of the CFFF at partial loads was completed to determine the effect of thermal input to NO_x and SO_2 reductions. NO_x exit levels were not effected appreciably. However, SO_2 was found to be sensitive to temperature at various thermal inputs. SO_2 was found early

in the series of POC testing to be sensitive to stoichiometry (decreased stoichiometry increases temperature, and we now know that temperature effect SO₂ absorption).

The modifications to the CFFF Coal Processing system to handle high moisture Montana Rosebud was completed and checked out during this reporting period. The system works better than predicted as far as moisture removal. The actual moisture level of the coal to the combustor has averaged $4.4\% \pm 0.5\%$. The target was to be 8% or less. The coal fineness for the finest grind was 93% through 200 mesh, 50% through 400 mesh. After adjustments toward the courser grind, we are now at 78-79% through 200 mesh. We are conferring with B&W to adjust to 70% through 200 mesh. At all the above grinds, the CFFF dense phase flow systems works very smoothly.

In previous tests, the oxidizing air compressors had shut down occasionally because of false surge indications. To eliminate false indications, compressor surge protection systems were modified as recommended by the Ingersoll Rand Company. The modified system uses a pressure reading at the compressor inlet as an indication of surge. A positive pressure, which indicates reverse flow, shows that the compressor is surging. The modification was completed prior to LMF4-W. No compressor tripping shutdowns were experienced during the 1991 testing.

Ambient Air Monitoring

A Quality Assurance audit was conducted by the State of Tennessee Division of Laboratory Quality Assurance. All instrumentation was within EPA guidelines prior to starting LMF4-W.

Data collected prior to the LMF4-W test indicated a baseline condition for both SO₂ and NO_x with ambient concentrations between 4-10 ppb for each parameter (Figure 1). During this same period (May 2-7, 1991) there was a slight elevation in SO₂ concentrations at the Impact 1 sampling site for the early morning period of May 2, 1991 (Figure 2). This elevation is thought to be the direct result of inversion formation during the night with an eventual destruction of the inversion conditions by mid morning. Figure 1 also illustrated the different solar intensities associated with clear and cloudy days. May 2 was clear, May 3 partially cloudy, May 4 and 5 cloudy, May 7 clear in the morning and partially cloudy by late afternoon.

Data from the May 7-8 period of LMF4-W indicates a slight elevation in ambient SO₂ and NO_x concentrations (Figure 3). The elevations were observed only in the early morning hours of May 7. By noon May 7 the CFFF had shut down to correct coal flow calibrations. The next period of CFFF impact data occurred on May 10 at the Impact 1 monitoring location (Figure 4). On May 10 the ambient SO₂ and NO_x concentrations deviated from previously established baseline conditions (4-10 ppb) by as much as 10 ppb.

Industrial Hygiene

Noise Exposure

Two noise dosimeter measurements were performed during LMF4-W. Both measurements were intended to give worse case cumulative exposures due to noise contributed by the coal pulverizing operation. The first was collected inside the CFFF weld shop. The total collection time was approximately 18 hours and yielded a 69% reading of total OSHA allowable reading of 100% at 90 dBA in an eight hour period. This data indicates that there is a low risk of violating the OSHA standard. However, ear plugs are recommended for this area.

The second was collected outdoors near the south side of the coal tower, this is in close proximity to the position of the outside observer during CFFF testing. This measurement yielded a 31% reading of OSHA allowable reading of 100% at 90 dBA with total time of sampling of 1.3 hours. Although this data indicates that there is no risk of violating the OSHA standard by the pulverizer, ear protection for anyone entering the general CFFF downstream area during testing is required.

SUMMARY OF TEST

Four tests were completed during the last six months, one firing Illinois Seam 6 coal and three with Montana Rosebud coal. Current testing is to emphasize establishing POC conditions, as well as, ash deposition and pollution control.

LMF4-W

A CFFF test (LMF4-W) was completed on May 11, 1991. A total of 86 hours on eastern coal was achieved. Two of the three primary objectives as listed below were successfully accomplished:

- Operate the CFFF for 80 hours minimum and 100 hours maximum using eastern U.S. coal, with potassium carbonate seed mixed with the coal to give a K_2/S ratio of 1.1, and with no fuel oil used in the primary combustor.
- Determine NO_x levels at all available gas sampling locations when the stoichiometry is varied at 0.80, 0.85, and 0.90.
- Determine SO_2 concentrations at the secondary combustor inlet and outlet at primary stoichiometries of 0.80, 0.85, and 0.90, and at secondary stoichiometries between 1.05 and 1.20. This objective was not accomplished because of high secondary combustor outlet temperatures.

Heat transfer data which shows the ash buildup profile between sootblowings from all of the TS and CS sections are very similar (Figures 5-8). The rate of change in the coefficient of heat transfer, does not appear to be very dependent on either position in the flow train or

cooling medium for most of the SHTM heat exchangers. TS1 was not sootblown at all but has a similar average coefficient of heat transfer to several of the other sections. The water cooled CS1 section, which has the highest delta-T, does have a higher heat flux than other CS sections, but the coefficient of heat transfer curves generated by the ash build-up and sootblowing is still very similar to the other sections. Heat transfer was also affected by staggered sootblowing cycles which would affect the heat transfer of adjoining sections. During LMF4-W, steam flow was kept constant and sootblowing was limited to a narrow time period to minimize effects on heat transfer.

Ash in CS1 is generally a very light, powdery material and is easily removed by standard sootblowing equipment. For LMF4-W, the surface of the CS1 ash was slightly harder than the other cooling sections due to molten seed which survives past the TS1 tubes, but these deposits were removed by the sootblowers. Ash characteristics may have changed from previous tests by the lack of the oil in primary combustion resulting in a higher dust loading or other factors such as the K_2/S ratio change at the end of the test, the seed tap modifications, changes in the sootblowing sequence, or interruptions in coal flow. However, they appear to be representative of ash deposits observed in past tests.

LMF5-A

LMF5-A, the first test on Montana Rosebud Coal during 1991 ran for 75 hours July 30th through August 3rd using the modified coal handling system. All of the following primary objectives were achieved.

Objectives:

A. Primary

1. Operate CFFF for 60 hours minimum, 80 hours maximum. (After 75 hours we had achieved all the other primary and secondary objectives.)
2. Evaluate operation of new Rosebud coal handling system.
3. Evaluate operation of new primary combustor potassium carbonate solution injection system.

B. Secondary

1. Determine SO_2 and SO_3 concentrations at the baghouse outlet.
2. Determine relative accuracy of secondary air flow measurements at orifice plate and new pitot probe.
3. Determine heat transfer and pressure characteristics of bayonet HTAH tube without convection enhancement to be used as a baseline for future convection enhancement studies.

4. Evaluate performance of Lanxide Dimox SiC/Al₂O₃ composite tube to include sealing ability of preformed Grafoil gaskets and resistance to corrosion and erosion in primary furnace. Document rate of slag accumulation on tube.
5. Determine characteristics of SHTM fouling using heat transfer measurements, video documentation, and post test inspections.
6. Evaluate performance of spent seed tap to include sampling of holding tank overflow solution to determine the saturation versus time on coal.
7. Determine source of ash deposition probe (ADP) thermocouple output signal noise. Determine if noise is being generated by the probe thermocouples or being picked up somewhere in the wiring to the data acquisition system.

The carbonate slurry system and the coal processing system worked very well, however, an oil cooler will be needed for long term operation of the pulverizer. Overall test results are not available at this time however, coal samples are being sent to B&W to determine melting temperatures and viscosity with and without seed.

LMF5-B

LMF5-B on Montana Rosebud Coal ran for 60 hours August 25 through August 29, 1991. All of the following objectives were achieved.

Objectives:

A. Primary

1. Operate the CFFF flow train with 1% potassium in the primary flow for 60 hours minimum. Potassium carbonate will be added to the primary combustor as a 47% solution. Potassium sulfate will not be added to the coal during pulverizing, but approximately 25,000 pounds of previously pulverized potassium sulfate seeded coal will be burned initially.
2. Characterize fouling of the superheater test module heat transfer surfaces.
3. Evaluate the performance of the flow train baghouse and electrostatic precipitator.
4. Determine NO_x and SO₂ concentrations at the secondary combustor outlet and upstream NO at primary stoichiometries of 0.8, 0.85, and 0.90.
5. Determine the effect on secondary combustor outlet NO_x and SO₂ of varying secondary stoichiometry to values of 1.05 and 1.12 at primary stoichiometries of 0.8, 0.85, and 0.90.

B. Secondary

1. Identify individual waste water streams from the CFFF during testing and measure flow, pH, and temperature.
2. Monitor holding pond #2 discharge rate and correlate with process activities.
3. Monitor inlet conditions for holding pond #1 and correlate with process activities.
4. Determine operating conditions required to obtain requisite SHTM inlet temperature of 2275°F and outlet temperature of 300-450°F.

We had considerable problems during this test. The BH reverse air fan failed. All flue gas dampers froze when in closed position, tube deposits encompassed the SH & AH tubes decreasing heat transfer, etc. Our recommendation is that we need to make adjustments to the system and repeat this test in November, as we cannot attribute these failures to excess carbonate. Overall test results are not yet available.

LMF5-C

The LMF5-C test was operated for 50 hours at the same conditions as LMF5-A with the addition of Iron Oxide to bring the total iron content up to 20% of the ash. The objectives were as follows:

A. Primary

1. Operate for 60 hours minimum, 80 hours maximum.
2. Evaluate difference in performance of ESP, BH, ash deposition, and heat transfer coefficients.

All objectives were met however, we had problems with the BH (not related to Iron Oxide) and problems with the ESP which we do not know at this time what the cause was. Ash deposits, heat transfer coefficients, etc., appeared to be the same as LMF5-A tests which were the same conditions without iron oxide. Overall tests results are not yet available.

FUTURE PLANS FOR THE NEXT 6 MONTHS

1. As a result of difference in heat transfer coefficients the Superheater and Air heater modules will have to be rearranged and additional cooling surface added to assure that the gas temperature to the BH is less than 450°F. (Note: This problem was present during the Illinois #6 coal tests also.)
2. Fix equipment that failed.

3. Establish POC run conditions for Montana Rosebud tests and obtain DOE approval.
4. Start first 250 hours of 2, 000 hours of Western coal POC tests.

FIGURE 1. Impact 1 Observed Conditions, LMF4-W Pretest

FIGURE 2. Impact 1 Observed Conditions, Inversion Effects on SO_2 and NO_x Concentrations

FIGURE 3. Impact 1 Observed Conditions, AM Elevation of SO_2 and NO_x

MAY 10-12, 1991

FIGURE 4. Impact 1 Observed Conditions, Elevation in SO_2 and NO_x Concentrations

FIGURE 5. Test Section 2 Overall Heat Transfer Coefficient

**Spikes are
deposit build u
and valleys are
sootblowing.**

FIGURE 6. Cooling Section 3 Overall Heat Transfer Coefficient

FIGURE 7. Cooling Section 5 Overall Heat Transfer Coefficient

FIGURE 8. Cooling Section 6 Overall Heat Transfer Coefficient

APPENDIX G

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:

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

DATE

10/14/91

CONTRACTOR:

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

REPORTING PERIOD

4/1/90 to
9/30/91

PROJECT MANAGER:

Robert A. Meyers
(213) 813-9439

PERIOD OF PERFORMANCE

5/1/89 to
10/31/91
(to be extended
to 10/31/93)

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 the 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 a 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 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 construction and equipment installation for the potassium formate POC plant has been completed. All major equipment and utility systems are now in place including the evaporator system. Final installation of the piping, instruments and electrical systems is complete. Checkout of the facility has been completed. Operating procedures were written, a Test Readiness Review was held, and approval for operations was granted. Plant shakedown to demonstrate operation and to trouble shoot potential problem areas has commenced. The major pieces of equipment for the calcium formate system have been ordered. Fabrication of the two high pressure calcium formate reactors is complete. Two proposals were prepared and submitted to the DOE for approval. The first proposal is for extension of the period of performance for the current base program for Eastern coal by two years. The second proposal is for addition of Western coal seed testing to the current program in order to evaluate proposed separation methods that could lead to a significant reduction in the cost of seed regeneration.

4. Planned Activities

Shakedown of the potassium formate plant will continue. Installation of the major equipment in the calcium formate POC system will begin. Shakedown operations for the calcium formate POC unit will commence in 1992 along with test operations for the KCOOH POC unit. The test operations to obtain scaleup data on the calcium formate unit are planned for June 1992. Following test operations, a new design for a 300 MW_t seed regeneration plant will be prepared.

5. Schedule

A revised schedule is attached reflecting overall project schedule slip due to fiscal year funding shortfalls. The planned project completion date is now the end of FY 1993.

MHD SEED REGENERATION

PROGRAM SCHEDULE

CY 1989				CY 1990				CY 1991				CY 1992				CY 1993			
2	3	4		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4

TASK DESCRIPTION

YEAR
QUARTER

TASK 1 DESIGN, REFURBISH, OPERATE

1.1 DESIGN/REFURBISH KCOOH POC

1.1.1 DESIGN

1.1.2 PROCUREMENT

1.1.3 REFURBISH/INSTALL POC

1.2 SHAKEDOWN POC UNIT

1.2.1 SHAKEDOWN TEST PLAN

1.2.2 SHAKEDOWN

1.3 TEST OPERATIONS

1.3.1 TEST PLANNING

1.3.2 OPERATIONS

1.3.3 DATA ANALYSIS/EVALUATION

TASK 2 DESIGN/BUILD OPERATE

CA FORMATE POC UNIT

2.1 DESIGN/CONSTRUCT CA FORM POC

2.1.1 DESIGN

2.1.2 PROCUREMENT

2.1.3 REFURBISH/INSTALL

2.2 SHAKEDOWN CA FORM POC

2.2.1 SHAKEDOWN TEST PLAN

2.2.2 SHAKEDOWN OPERATIONS

2.3 SCALEUP/PROD OPERATIONS

2.3.1 PLANNING

2.3.2 OPERATIONS

2.3.3 DATA ANALYSIS/EVALUATION

TASK 4 DESIGN 300 MWt SEED PLANT

4.1 TRW DESIGN INTERFACE

4.2 FLUOR DANIEL DESIGN SUBCONTRACT

TASK 5 MANAGEMENT AND REPORTING

APPENDIX H

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 15, 1991

REPORT PERIOD: April 1991 - September 1991

CONTRACT TITLE: Diagnostic Development and Support of MHD Test Facilities

CONTRACT NUMBER: DF-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 (MSU) 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. Measurements with this instrumentation also provide 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. Many of these diagnostic systems can provide the basis for MHD power plant control and performance monitoring instruments.

TECHNICAL APPROACH:

The computer-controlled, optical diagnostic instruments being developed and used for support of the MHD component engineering development are summarized in Table 1. They provide in-situ measurements of the following parameters:

Gas Temperature • Temperature Profiles
Coal Slag Wall Temperatures • Gas Velocity & Turbulence Profiles
Potassium Atom Number Density • Electron Number Density
Average Particle Size • Particle Size Distribution
Concentrations of Certain Molecular Species

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 validate analytical models.

Table 1.
Diagnostic Systems for Characterization of High Temperature Flows

Sodium Line Reversal System (average gas temperature)	Particle Size Distribution System (particle size distribution)
Potassium Emission/Absorption System (time-resolved temperature, K-atom density, electron density)	Coherent Anti-Stokes Raman Spectroscopy System (local gas temperature and species concentration, temperature and concentration profiles)
Multi-Color Pyrometer System (wall temperature and emissivity)	Multi-Purpose Imaging System (K-atom density, pressure profile)
Two-Color Laser Transmissometer System (average particle size and particle number density)	Faraday Rotation System (electron density)
Laser Doppler Velocimeter System (local velocity, velocity profile and turbulence level)	Cross Correlation System (flow velocity)
Gas Analysis System (gas composition, e.g., CO, NO, etc.)	Differential Absorption Laser Spectroscopy System (species concentrations, SO ₂ , NO ₂ , NO, H ₂ O, OH)
Intrusive Multi-Probe System (optical temperature probes - wall and gas temperature)	Laser Optogalvanic Spectroscopy System (average gas temperature, qualitative species identification)

Figure 1. Potassium concentration data from LMF5-B CFFF test run.

Support for the national MHD program is provided with six field-ready instruments (see Table 1). To provide diagnostic measurements and support to the national MHD program, DIAL also has two mobile instrument laboratories which are used to house the diagnostic equipment for transportation to, and for use at, a particular MHD facility. These mobile laboratories have on-board computers for on-line data acquisition and control of the diagnostic systems.

PROGRESS SUMMARY:

In order to aid in the performance and operation of MHD facilities, MSU diagnostics have been used at various DOE facilities. One of the field proven instruments that has probably seen the most use is the Potassium Emission/Absorption System (PE/AS) which is used in determining the gas stream temperature and potassium/electron densities of the gas stream. This system has not only provided useful measurements, but has also demonstrated its usefulness as a control/monitor instrument.

In a recent test (LMF5-B) at the Coal-Fired Flow Facility operated by the University of Tennessee Space Institute, Tullahoma, the PE/AS was used in making measurements in the diffuser. Post run analysis of the potassium concentration data revealed some interesting information with regard to the relationship of topping cycle operation and bottoming cycle diagnostics. Test LMF5-B involved injection of seeded coal with a transition to unseeded coal after which seed slurry injection was begun. A study of the data taken by the PE/AS for this transitional time period is shown in Figure 1. A full description of the UTSI coal feed facility is not included here, but briefly, pulverized coal is fed from either of two reservoirs into a feed tank. The coal from the feed tank is then pneumatically carried to the combustor. In the first part of the test, pre-mixed seed/coal was fed from the first reservoir to the feed tank. The coal supply to the tank was then switched to the second reservoir which contained unseeded coal. The potassium atom density measurements of Figure 1 show this transition. The potassium atom concentration in the gas stream falls as the remaining seeded coal in the feed tank is used up. The potassium concentration then levels off indicating that there is only unseeded coal burning in the combustor.

This data was compared with the secondary combustion SO_2 measurements made by UTSI personnel who were using conventional gas analysis apparatus. When there is sufficient potassium seed injected into the gas stream to cover the molar concentration of sulfur in the coal, then in the downstream post secondary combustion region, all the sulfur deposits out as potassium sulfate and the SO_2 gas concentration in this regime is minimal, as was the case in the first part of the test when seeded coal was being injected. As the unseeded coal started flowing into the combustor, the downstream SO_2 concentration should have started to go up shortly thereafter. However there were two time delays that influenced the gas concentration measurements:

- 1) the residual seed deposition on surfaces in the test facility that were absorbed into the gas stream and continued to form potassium sulfate,
- 2) the inherent time lag of a conventional gas sampling technique where the gas has to be sucked over some distance to the point of measurement.

In any case, as Figure 1 shows, the PE/AS system saw a drop in the potassium atom concentration about 17 minutes before the gas sampling system saw a rise in the SO_2 concentration. This time lag is due to a combination of the above two factors and is something inherent to a facility and the particular technique used at the sampling location.

Field Operations at CDIF

The PE/AS was installed on the middle pair of optical ports of the diffuser test section for temperature and potassium number density measurements. A collimated beam was used and the lamp-side optics were on the east side of the facility while the detector-side optics were on the west side. The window changer and slag buster with nitrogen purge were used on the optical ports for all of the tests. Extreme fluctuations in the white light transmission from one data frame to the next were observed for all of the tests at various times.

The flickering could be caused by lamp misalignment due to beamsteering in the flow or vibrations in the optical mounts, slag drips across the optical access ports, or sudden increases in particle loading. Examining recorded potassium spectra when the white light transmission is very low reveals that these data frames also have next to no potassium D-line emission. This indicates that the most likely cause for the flickering is slag dripping across the detector-side port which would obscure not only the white light but also the gas stream emission.

In the analysis routine, data frame rejection criteria are included to reject data frames during flickering. The criteria for rejection are: (1) off-line white light transmission of less than 10% and (2) optical depth difference between off-line and on-line of less than 0.3, i.e. a change of less than 74% in transmission from the off-line to the on-line wavelength.

The analysis routine reduced the anomalous swings to high temperatures that occurred with noise when the optical depth difference was too low because of a poor choice of wavelength. Some bias to erroneous high temperatures could still remain if data frames were kept when the lamp-side window is blocked by slag or with misalignment of the lamp image. To put this in perspective, all of the temperatures for the six tests were generally between 2200 K and 2500 K. An error of 100 K out of 2400 K is a 4% error which would introduce only a 2% underestimation in the atomic density determination. However this would lead to a 44% overestimation in the electron density. So, although electron density results have been plotted, because of the fluctuations in white light transmission the results should be viewed with skepticism. Of course, the Saha calculation is only an indirect measure of the electron density and is subject to error if significant sources or sinks of electrons other than potassium atoms are present in the flow.

Along with all of the test results, a figure has been included to show the retained data frames from each set of 50 as well as the selected on-line wavelength position. The different regions with low or high retained frames may indicate different slag behavior or changes in the gas flow characteristics, so this figure may be of interest by itself. Large standard deviation in the selected wavelength indicates wide fluctuations in the potassium linewidth and hence large fluctuations in the seed atom density.

Noticeable on the seed atom density plots are occasional downward spikes for the uncertainty limit. These are where the standard deviation is larger than the average value, which are typically when the transitions to stop or start the seed flow occurred during a one minute, 50-frame data set interval. This is not a problem with the instrument. The data set could be reanalyzed in subsets to correctly show the transition. However, occasionally this is seen at other portions of the tests and most likely indicates real fluctuations in the flow, not a problem with the instrument.

Plots of seed atom density compared to the facility seed loading are included to show the close correlation. Without a comparable facility parameter for temperature, no comparison plots are included. For several tests though there did seem to be a rough correlation between the temperature trends and the first stage heat loss, notably SREJ-4 and COAL-1. Because of the heat losses along the facility from the combustor to the diffuser and such possible complications as a moving shock wave, purging of the upstream optical ports or recirculation regions involving the quench flow, there may be no simple explanation for the observed temperature fluctuations. Extensive measurements have been made but only a few illustrative results are given below.

Test objectives for 91-SEED-1 that may be supported by the PEAS measurements of temperature and number density include:

- 1) Check out the slag rejector system with the conductivity power supply by completing three continuous slag collection tank cycles,
- 2) Obtain data for a thorough evaluation of the baseline seed injection method.

Only a test condition of 1% potassium seed was established before system shutdown. Results shown in Figures 2.a, b, c, and d show stable operation. The computer system clock board failed during this test and accurate times were not recorded; however, file 43 was at approximately 11:48, file 45 at 11:54, and file 46 at 11:57 with the files spaced by nearly one minute. The break in the data occurred when the operator reset the system clock. The one data set towards the end of the test with lower temperatures gives lower number density results that appear consistent with chemical equilibrium expectations.

91-SEED-3 test results are shown in Figures 3.a, b, c, and d. The break in the data collection was due to a stuck ram in one of the optical ports. The first nominal 1% seed loading condition showed slightly higher density results after test resumption at about 22:50. The 2.2% and 1.7% loadings do show higher seed atom densities in the diffuser but not significantly different from each other.

Comparisons between the density results and the seed loading versus time are seen in Figures 3.c and d. A plot of the density versus temperature is shown in Figure 3.e. This shows that at the diffuser there is not significantly higher seed atom density for the higher loadings, except that for the case of the 1.7% load from the main rather than

Figures 2.a,b. PE/AS results of temperature and neutral potassium number density for CDIF 91-SEED-1 on 3 May 91. Average is heavy line and crosshatch is the uncertainty limit for plus or minus one standard deviation.

Figures 2.c,d. PE/AS results of electron number density and sample size/measurement wavelength for CDIF 91-SEED-1 on 3 May 91.

Figures 3.a,b. PE/AS results of temperature and neutral potassium number density for CDIF 91-SEED-3 on 10 May 91. Average is heavy line and lighter lines are the uncertainty limits for plus or minus one standard deviation.

Figure 3.c. Comparison of PE/AS results of potassium number density and percent seed loading vs time for CDIF 91-SEED-3 on 10 May 91.

Figure 3.d. Comparison of PE/AS results of potassium number density and percent seed loading vs time for CDIF 91-SEED-3 on 10 May 91.

Figure 3.e. PE/AS results of potassium number density vs temperature for CDIF 91-SEED-3 on 10 May 91.

blue vessel there is a significant higher temperature excursion. The plot indicates a reasonably constant gas temperature at the diffuser with the decay in the seed atom density.

Considerable effort has been expended toward the objective of using laser Doppler velocimetry (LDV) to measure a particle velocity profile in the diffuser section of the MHD test train at the Component Development and Integrating Facility (CDIF). Attempts during the tests of 1989 and 1990 were essentially unsuccessful, primarily because of a lack of sustained optical access to the measurement point. Window and purge configurations that had been successful at the Mississippi State University (MSU) and University of Tennessee Space Institute (UTSI) test facilities were found to be totally unsatisfactory at CDIF. Several on-site modifications were tried regarding window placement and purge rates, but the incident laser beams were consistently blocked by either dirty windows or slag buildup at the port opening in the diffuser wall. All attempts at making LDV measurements under these conditions were futile.

The hope for overcoming the optical access problems at CDIF was rekindled as a result of the design and construction of two unique mechanical components. One was an automatic window changer that allowed up to four different windows to be used during a single test. The other was the so-called "slag buster" which mechanically punched away slag deposits at the port opening. Even though these devices added considerable bulk at the external measurement site, their combined capabilities made the critical difference between success and failure.

The configuration of the LDV experiment was designed to minimize the adverse affects of the hostile environment which included strong electrical and magnetic fields. Optical fibers were used exclusively for transmitting incident beams as well as for receiving signals. Double-walled metal boxes and Mumetal sheaths were constructed to cover the sensitive photodetectors and signal processor. Independent AC power was supplied by generators having a ground separate from the CDIF facility.

All of the LDV measurements were performed in a backscatter configuration. The results indicated that the flow in the diffuser section had a dual character. There was a slow mode with peak velocities of about 500 m/s. The velocity profile in this mode was characterized by unimodal histograms, skewness toward the east wall and flow reversal near the west wall. There is a definite transition to a fast mode with peak velocities near 1500 m/s. The histograms show a distinctive bimodal feature and the corresponding velocity profile is skewed towards the east wall. Reasons for the dual character of the flow are under consideration. Measurements described here were taken during the 91-SREJ-3 tests at CDIF on 15 May 1991.

Figure 4 shows the histogram at 0.5 inches from the east wall of the diffuser. The number of validated bursts is given in the small square just under the histogram, 4971 in this case. The mean velocity, 632 m/s, and the rms deviation, 115 m/s, are shown to the upper right of the small square. Note that the histogram appears to cut off somewhat on the lower velocity side. This was due to a particular filter in the signal processor that could not be changed in the field. Thus, the mean velocity of 632 m/s is probably a little too high, but not by much.

As we begin to move across the diffuser, the histogram shows a small but measurable shift to higher velocities at 1 inch. At 2 inches the histogram begins to show distinct changes. The mean velocity is up to 793 m/s, and there is also the appearance of the bimodal shape. It is important to note as we consider the various histograms that nothing is being changed except the measurement position. All of the settings on the signal processor are exactly the same.

For positions 2 inches to 3.5 inches there is a general shift of the histograms to higher velocities as one proceeds into the gas stream. The velocity distributions become progressively broader. The turbulence intensity (rms divided by mean) is about 29% for the histogram at 3.5 inches, shown in Figure 5.

Something very interesting happens at 4 inches. This histogram has become unimodal at very high velocities. The lower velocity component of the histogram has essentially disappeared. The turbulence intensity has dropped to about 12%. The mean value for the particle velocity is nearly 1500 m/s. That's fast, folks! A similar result was obtained at 4.5 inches. Note that there was over an hour difference in time between the measurements indicating that the flow had retained its properties over this time period.

The histogram at 5 inches from the east wall begins to show the reappearance of particles at the lower velocity component. This transition back to a bimodal distribution is clearly evident at 5.5 inches. The turbulence intensity has jumped to about 32% at this position. At the centerline position (6 inches) shown in Figure 6, the bimodal feature of the flow is fully evident. Note that the lower velocity component peak is dominant here, just the opposite compared to that found at 5.5 inches. Proceeding into the diffuser towards the west wall (6.5 to 11.5 inches), the mean velocities continue to drop as the high velocity peak of the bimodal distribution fades. The bimodal feature has essentially

Velocity Setup			Date: 15 MAY 1991 — Time: 20:25:39	
A) Dist from Wall (in.)	0.500	C) User 3	3.000	
B) User 2	3.000	D) User 4	3.000	
	Ch1	Ch2	Ch3	Volts
E) High Voltage	0	0	0	
F) Frequency Shift	N/A	0.00	On	MHz
G) DC Offset	20.3	19.1	8.5	mv
H) Mixer Frequency	Off	40	40	MHz
I) Low Pass Filter	80.000	10.000	10.000	MHz
J) Burst Filter	All Pass	All Pass	50 MHz LP	
K) Threshold	58.8	200.0	200.0	mv
L) Envelope Filter	100 ns	3.3 us	None	
M) Peak Detection	Off			
N) % After Peak	40			
O) # Of Samples	128			
P) Sampling Rate	160.000	40.000	10.000	MHz
Q) Channel Enabled	On	Off	Off	
Available Range	464.0 - 1855.9	252.8 - 189.6	-26.1 - 26.1	m/s
R) Vel Minimum	450.0	0.0	-100.0	m/s
S) Vel Maximum	2000.0	20.0	50.0	m/s
Meas. Range	464.0 - 1855.9	252.8 - 146.3	-26.1 - 26.1	m/s

Figure 4. Velocity measurement for SREJ-3 test at CDIF 15 May 91,
0.5 inches from east wall of diffuser.

DATA ACQUISITION 15 MAY 1991 20:17:39

CH1 Velocity Mean = 1218.820 m/s
RMS = 347.545 m/s

Attempts = 9418
Validations = 2002
Corrected Count =
Run Time = 1.58 sec

D:\DSADATA\CDIF\TEST2\RUN05

Velocity Setup Date: 15 MAY 1991 Time: 20:17:39

A) Dist from Wall (in.)	3.500	C) User 3	3.000
B) User 2	3.000	D) User 4	3.000
E) High Voltage	0	Ch1	Ch2
F) Frequency Shift	N/A	0	0.00
G) DC Offset	20.3	19.1	8.5
H) Mixer Frequency	Off	40	40
I) Low Pass Filter	80.000	10.000	10.000
J) Burst Filter	All Pass	All Pass	50 MHz LP
K) Threshold	58.8	200.0	200.0
L) Envelope Filter	100 nS	3.3 uS	None
M) Peak Detection	Off		
N) % After Peak	40		
O) # Of Samples	128		
P) Sampling Rate	160.000	40.000	10.000
Q) Channel Enabled	On	Off	Off
Available Range	464.0 - 1855.9	252.8 - 189.6	-26.1 - 26.1
R) Vel Minimum	450.0	0.0	-100.0
S) Vel Maximum	2000.0	20.0	50.0
Meas. Range	464.0 - 1855.9	252.8 - 146.3	-26.1 - 26.1

Figure 5. Velocity measurement for SREJ-3 test at CDIF 15 May 91, 3.5 inches from east wall of difuser.

Velocity Setup				Date: 15 MAY 1991 Time: 19:00:20			
A) Dist from Wall (in.)	6.000	C) User 3	3.000				
B) User 2	3.000	D) User 4	3.000				
	Ch1	Ch2	Ch3				
E) High Voltage	0	0	0	Volts			
F) Frequency Shift	N/A	0.00	On	MHz			
G) DC Offset	20.3	19.1	8.5	mv			
H) Mixer Frequency	Off	40	40	MHz			
I) Low Pass Filter	80.000	10.000	10.000	MHz			
J) Burst Filter	All Pass	All Pass	50 MHz LP				
K) Threshold	58.8	200.0	200.0	mv			
L) Envelope Filter	100 ns	3.3 uS	None				
M) Peak Detection	Off						
N) % After Peak	40						
O) # Of Samples	128						
P) Sampling Rate	160.000	40.000	10.000	MHz			
Q) Channel Enabled	On	Off	Off				
Available Range	464.0 - 1855.9	252.8 - 189.6	-26.1 - 26.1	m/s			
R) Vel Minimum	450.0	0.0	-100.0	m/s			
S) Vel Maximum	2000.0	20.0	50.0	m/s			
Meas. Range	464.0 - 1855.9	252.8 - 146.3	-26.1 - 26.1	m/s			

Figure 6. Velocity measurement for SREJ-3 test at CDIF 15 May 91,
5.5 inches from east wall of diffuser.

disappeared at about 10 inches. Once again, for those positions towards the west wall, the histograms are cut off on the low velocity side, so the mean values are somewhat artificially high. We had no way to remedy this problem during the test. A more complete analysis of this data is underway and a complete profile of the mean axial velocity component across the diffuser will be reported later.

Field Operations at CFFF

DIAL's Particle Size Distribution (PSD) instrument uses the light scattered from single particles to determine particle size. The light source is a laser and the scattered light is collected in the near forward region (less than 2 degrees for this particular instrument). Mie scattering calculations are used to determine the instrument's calibration curves and finally to assign a diameter scale to the particle size data collected.

The instrument has been used to aid in determination of the efficiency of an electrostatic precipitator at the CFFF. Measurement of size distribution can show the effect of the precipitator on various size particles as well as the effect on the total particle density. The ESP at CFFF has four vibrators which switch on and off in a predetermined sequence. Figure 7 shows the change in measurements of particle size distribution taken before, during, and immediately after a vibrator has operated. The vibrator ran during the final moments of data collection for the second test. The change in the number of smaller particles is clearly seen in the test done immediately after the vibrator had completed its sequence.

The rate at which particles are registered by the instrument can also be useful as it indicates either velocity or particle density variations. The velocity can also be measured when using the two beam mode of operation which uses the ripple deconvolution method for particle size determination. Figure 8 shows count rate data taken at UTSI at a time when the ESP was apparently erratic in its operation.

The mobile CARS instrument was aligned at the CFFF diffuser exit (penetration 1542 and 1543) during the LMF4-W test run. N_2 CARS spectra were taken at the center and also off the center of the gas stream to measure the temperature of the gas stream. The ratio of the N_2 CARS signal and non-resonant background is much smaller than that of the LMF4-T test run. This is due to the much higher particle density present in 100% carry over coal combustion. The broad nonresonant particle background is illustrated in Figure 9. In addition, the increased particle density leads to laser-induced production of C_2 radicals, which have an absorption near the N_2 fundamental band. Therefore, the accurate determination of the temperature from the observed CARS spectra will be more difficult in 100% carry over coal combustion.

N_2 -CO CARS spectra were also recorded to test the technique to measure the temperature and CO concentration simultaneously. Unfortunately, the N_2 signal is mostly buried in the huge background in these spectra and it is very hard to fit the data for simultaneous temperature and CO concentrations. Various analysis techniques are being studied to determine the CO concentrations. It is clear from these studies that application of optical control and monitoring instruments in a large-scale power plant will require operation at less than 100% slag carry over.

The Visible/Infrared Emission Spectroscopy (VIES) system extracts temperatures and emissivity values from emission spectra. This system is being developed by DIAL in order to assist CFFF evaluation of ceramic tubes for use in their high temperature air heater (HTAH) by providing them with determinations of the value of the emissivity for use in their heat transfer calculations. The VIES system can record emission spectra from 200 nm in the ultraviolet to 4800 nm in the infrared. Figure 10 shows the raw data emission spectrum of the 650 to 1200-nm region recorded during LMF5-C on September 23, 1991, between 21:19 and 21:32 at insertion 2218 of the third level of the radiant furnace. At that time CFFF had been continuously operating on coal for approximately 11 hours so the HTAH ceramic tube was still relatively clean although slag buildup had begun. The strong, broad transition near 760 nm is due to potassium atoms. Figure 11 shows the spectrum of Figure 10 corrected for the wavelength-dependent response sensitivity of the VIES system. The response sensitivity function is obtained by using the VIES system to record the spectrum of a blackbody radiation source operating at a known temperature. The strong emission near 1177 nm is also due to potassium atoms. It is known that least squares fitting of spectral emission data produces a significantly more reliable determination of emissivity than traditional multi-color pyrometry methods. However, to obtain reliable determinations of temperature and emissivity, it is necessary to omit regions of strong atomic or molecular emission or absorption from the least squares fit. Figure 12 shows the corrected data from Figure 11 in the 900 to 1100-nm region and the least squares fit of the data to the Planck function. The least squares determinations are temperature = $1429 \text{ K} \pm 20 \text{ K}$, and emissivity = 0.615 ± 0.088 .

Figure 7. Change in particle size distribution measurements before, during and after vibrator operation at CFFF/ESP.

Figure 8. Count rate data taken at CFFF/ESP during erratic operation.

Figure 9. CARS data during CFFF LMF4-T showing broad nonresonant particle background.

Figure 10. VIES raw data emission spectrum of the 650 to 1200-nm region recorded during LMF5-C at CFFF radiant furnace, September 23, 1991.

Figure 11. Spectrum of Figure 10 corrected for wavelength-dependent response sensitivity of the VIES system.

Figure 12. Corrected data from Figure 11 in the 900 to 1100-nm region and the least squares fit of the data to the Planck function.

The Two-Color Laser Transmissometer (TCLT) was located directly upstream of the electrostatic precipitator (ESP) and baghouse (BH) components. In order to handle the very large particle loading at this location, an optical probe was designed as shown in Figure 13. This probe is inserted into the gas stream and the visible radiation, which now travels a shorter path to the opposite optical port, is detected in the usual fashion. The purpose of the experiment was to monitor changes in the Sauter mean diameter (D_{32}) with variations in the ratio K_2/S . Previously we have noted that this ratio exerts considerable influence on the performance of the ESP with higher K_2/S values leading to decreased efficiency. One possible explanation for this behavior is that the particle sizes entering the ESP would decrease with an increase in K_2CO_3 concentration, i.e. that K_2CO_3 particles would nucleate to smaller average diameters than K_2SO_4 . The figures which follow do not support this contention.

Data is shown for selected periods covering the entire test. Similar results were obtained for other data collection periods. Of interest in all the data is the near-constant behavior of the average particle size (D_{32}). Particle number densities did not, within experimental error, change over the duration of the test. In some cases, however, increases in D_{32} were observed (Figures 14 and 15). These increases are thought to be due to sootblowing in the platen superheater. A comparison to facility records to identify the particular K_2/S ratio for each figure will be performed as soon as possible. In passing, it is noted that all of the results discussed above were also observed for the earlier LMF4-W test where Illinois #6 fuel with $K_2/S \approx 1.1$ was used. Based on the results of Figures 14 and 15, it appears that a change in the molar ratio, K_2/S , does not affect the average Sauter diameter of the particles entering the ESP. Thus, other possible mechanisms for decreased ESP performance should be investigated.

To further evaluate the application of some of DIAL's monitoring and controlling instrumentation systems in the topping cycle, and to characterize the plasma flow from the UTSL combustor, a new diagnostic port has been installed in the aerodynamic duct. The location of the optical port and its design are illustrated in Figure 16. At this location, the pressure will be about 1.5 atm, the temperature about 2600 K, and the gas flow on the order of 1000 m/s with a gas stream diameter of 3.75 inches. Because of the above gas stream properties, a different type "slag buster" than employed in the diffuser must be used. Moreover, the knife gate valve must be water cooled. The remote window changer, described previously, however, will still be used. The layout of the optical port is shown in Figure 17. To remove any slag buildup, the gate valve is closed and the nitrogen tank is rapidly opened to create a large gas flow blowing out slag in the port.

Figure 13. TCLT visible fiber optic beam delivery system.

Figure 14. Increases in average particle size during LMF4-W at CFFF.

Figure 15. Increases in average particle size during LMF4-W at CFFF.

Figure 16. Location and design of optical port.

Figure 17. Remote window changer and optical location on CFFF combustor.

APPENDIX I

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 was not available at the time of publication.

END

**DATE
FILMED**

10/5/93