FOSSIL ENERGY

FE-15529-5

MHD ELECTRODE DEVELOPMENT

Quarterly Report, October—December 30, 1979

By
John W. Sadler
Jeff Bein
Laurence H. Cadoff
H. Dean Coe, Jr.
James A. Dilmore
Edsel W. Frantti
Dave Jacobs
Edgar L. Kochka
Jack A. Kuszyk
S. K. Lau
Joseph Lempert
Barry R. Rossing
James R. Schornhorst
Eugene E. Smeltzer

February 1980

Work Performed Under Contract No. AC01-79ET15529

Westinghouse Electric Corporation
Advanced Energy Systems Division
Pittsburgh, Pennsylvania

U. S. DEPARTMENT OF ENERGY

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James R. Schornhorst
Eugene E. Smeltzer*

*Westinghouse Research & Development Center
**Consultant

WESTINGHOUSE ELECTRIC CORPORATION
Advanced Energy Systems Division
P. O. Box 10864
Pittsburgh, Pa. 15236

February 1980

PREPARED FOR THE
UNITED STATES DEPARTMENT OF ENERGY

Under Contract No. DE-AC-01-79-ET-15529

APPROVED:

J. W. Sadler, Project Manager
Advanced Energy Systems Division

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I. ABSTRACT

Technical progress under DOE Contract DE-AC-01-79-ET-15529 during the October to December 1979 quarter is reported.

Platinum capped anodes and iron cathodes will be evaluated in a future WESTF test, WESTF Test 43. Results of bonding studies in support of this test are presented. In addition, an attachment technique has been developed for bonding the indium doped hafnia current leadout material to a compliant nickel mesh and results are reported.

Laboratory electrochemical corrosion tests have continued. Results reported herein indicate that major reductions in polarization, electrical resistivity and ionic transference number of the slag (Rosebud) can be achieved with moderate additions of cobalt which will produce a significant reduction in the electrochemical stress.

During this period, significant WESTF operations included WESTF D-10 (2 runs), WESTF D-11 and WESTF Test 45. This latter test was the first WESTF screening test of electrode materials which are candidates for use in the non-slagging super-hot operating mode.

Results of design and fabrication activities which are supportive of the up-coming WESTF tests are similarly presented. Status of design, procurement and modification activities in support of the installation of a conventional 3 tesla magnet in WESTF is presented. Facility shutdown to permit installation of the magnet is projected for March 1980.

II. OBJECTIVE AND SCOPE OF WORK

In continuation of the program to develop MHD power generation to commercial feasibility, Westinghouse is conducting a program to develop improved electrode designs for open-cycle coal-fired MHD generator applications. The program includes the link between basic and supportive materials development and testing in an engineering test rig that offers an adverse MHD environment for extended periods of time.

Specific development activities of this program are as follows:

(a) Laboratory screening tests to provide preliminary electrochemical stability data on selected advanced or modified ceramic candidate electrode and insulation materials.

(b) Laboratory screening tests to evaluate the resistance of selected candidate anode materials to simulated arc impingements under a representative range of chemical and thermal conditions.

(c) Engineering rig tests of preferred electrode designs, selected on the basis of the screening test results and/or pertinent outside data, under simulated open-cycle coal-fired MHD operating conditions.

(d) Preparation and fabrication of experimental electrode materials, as warranted by favorable laboratory screening test results, to provide samples for engineering rig tests.

In addition to these four main development activities, this project includes providing such laboratory, design, test and analytical support as necessary to characterize test materials, and to determine such essential physical and chemical properties as are required to properly design the test specimens and to interpret and analyze test data. Dependent on development results, preferred electrode materials will be prepared for advanced testing in other DOE contractor facilities.

These objectives are being pursued in accordance with a statement of work which is consistent with the National Plan for MHD development formulated by DOE.

The major elements of the program are presented in a Work Breakdown Structure which is presented in Table 1. The Level I effort is the MHD Electrode Development Contract, and Level II consists of the following four tasks.

WBS 1.1 ELECTRODE AND INSULATOR MATERIALS
WBS 1.2 ENGINEERING TESTS
WBS 1.3 WESTF MODIFICATION
WBS 1.4 PROJECT MANAGEMENT AND DOCUMENTATION

WBS 1.1 - ELECTRODE AND INSULATOR MATERIALS

The objective of this task is to provide for the development, laboratory evaluation and fabrication of electrode and insulator materials. All necessary experimental material preparation, as well as fabrication of test samples for laboratory screening tests, engineering rig tests in the Westinghouse Electrode System Test Facility, WESTF (WBS 1.2), or other tests will be completed under this task. This task also includes supporting pre-test material characterization and laboratory screening tests used to evaluate the relative performance of candidate materials. These screening tests include electrochemical and anode arc impingement tests.

WBS 1.2 - ENGINEERING TESTS

The objective of this task is to provide for the engineering tests of promising electrode/insulator materials resulting from the WBS 1.1 activity. In particular, this task provides for the supporting design, test and post-test analysis effort as well as maintenance and operation of the engineering test rig, WESTF. Table 2 summarizes WESTF test capabilities.

This task incorporates the elements of planning, experiment design, test operations and post-test analysis and provides the close engineering design and test discipline necessary to effect successful electrode/insulating wall system development. In addition, final fabrication and assembly operations necessary to incorporate electrode and interelectrode insulating elements fabricated under WBS 1.1 into a complete assembly ready for testing in WESTF

TABLE 1

WORK BREAKDOWN STRUCTURE

(SUBELEMENTS TO DOE WBS 2.2.2)

WBS 1.0 MHD ELECTRODE DEVELOPMENT

- WBS 1.1 ELECTRODE AND INSULATOR MATERIALS
  - WBS 1.1.1 EXPERIMENTAL MATERIALS FABRICATION
    - MATERIAL DEVELOPMENT
    - MATERIAL CHARACTERIZATION
    - MATERIAL FABRICATION
  - WBS 1.1.2 LABORATORY SCREENING TESTS
    - ELECTROCHEMICAL TESTS
    - ANODE ARC TESTS
- WBS 1.2 ENGINEERING TESTS
  - WBS 1.2.1 TEST ENGINEERING
    - DEVELOPMENT REQUIREMENTS
    - EXPERIMENT DESIGN
    - POST-TEST ANALYSIS
  - WBS 1.2.2 TEST ASSEMBLY FABRICATION
  - WBS 1.2.3 WESTF OPERATIONS
    - PRE-TEST ACTIVITY
    - TEST OPERATIONS
- WBS 1.3 WESTF MODIFICATION
- WBS 1.4 PROJECT MANAGEMENT AND DOCUMENTATION

I II III - SYSTEMS LEVEL

TABLE 2

WESTF TEST CAPABILITIES

Mass Flow	To 0.5 lb/sec
Combustion Temperature	To 2850°K
Combustor Pressure	1 to 5 atm
Channel Velocity	Subsonic, 500 to 800 m/sec
Seeding	K_2CO_3 or K_2SO_4 wet with ash or char additions (Rosebud)
B Field	3 tesla, nominal - 3.3 tesla, objective
Fuel	Toluene/#2 Fuel Oil
Oxidant	Preheated air with oxygen enrichment
Data Collection	240 channels coupled with minicomputer
Test Duration	Up to 100 hours
Test Frequency	Up to 2 per month
Channel Configuration	12.5 cm^2 flow cross section
Startup Ramp, Minimum	≈25°K/min

will be provided under this task. Required test documentation and facility operating procedures will also be prepared.

WBS 1.3 - WESTF MODIFICATION

This task has been established to provide for the planned modification of WESTF. The primary element of this task is the addition of a conventional 3.0 tesla magnet.

WBS 1.4 - PROJECT MANAGEMENT AND DOCUMENTATION

This centralized management task provides the focal point for directing the activities which comprise the full project effort. The Project Manager is responsible for the proper definition, integration and implementation of the technical, schedule, contractual, and financial aspects of the program. Coordination of the preparation of required documentation will also be completed under this task.

III. SUMMARY OF PROGRESS TO DATE

During the October to December 1979 quarter, the principal areas of activity were as follows:

- Continuation of electrode and insulator material development activities with emphasis on investigating electrode attachment techniques.
- Continuation of anode/slag interface polarization electrochemical corrosion tests.
- Completion of WESTF Tests D-10, D-11 and 45.
- Completion of design for WESTF Tests D-10, D-11, 44, 45, 46 and 47; completion of test section fabrication for WESTF Tests D-11, 42, 45 and 47.
- Continuation of the design of the modified WESTF Test Section for use with the magnet (WESTF II).
- Completion of the design and fabrication of the type II Materials Test Section (MTS II).
- Continuation of magnet modification activities.

Figure 1 summarizes the overall program schedule, based on the approved Project Management Summary Baseline Report, FY 80 Revision dated October 1979, and shows schedular status. As of the end of this quarter, the WESTF Operations (WBS 1.2.3) and WESTF Modification (WBS 1.3) activities are approximately one month behind schedule.

Failure to achieve the anticipated WESTF test schedule was due in part to the effect of year-end holidays and vacation schedules. With regard to WESTF testing, increased facility utilization has been achieved over the last quarter when compared to previous quarters. This trend of increased utilization is expected to continue until the facility is shut down for installation of the magnet since the supporting engineering and fabrication activities are on schedule, or even

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DOE Form CR-535 (1-78)

MILESTONE SCHEDULE AND STATUS REPORT

PAGE 1 OF 1

FORM APPROVED OMB NO 38-R-0190

1. Contract Identification: MHD ELECTRODE DEVELOPMENT PROGRAM	2. Reporting Period: through 12/79	3. Contract Number: DE-AC-01-79-ET-15529
4. Contractor (name, address): WESTINGHOUSE ELECTRIC CORPORATION, ADVANCED ENERGY SYSTEMS DIVISION, P. O. Box 10864 Pittsburgh, Pa. 15236		5. Contract Start Date: April 23, 1979
		6. Contract Completion Date: September 30, 1980

7. Identification Number	8. Reporting Category (e.g., contract line item or work breakdown structure element)	9. Fiscal Years and Months 79				80																				10. Percent Complete (a) Planned	(b) Actual
WBS		1Q	2Q	3Q	4Q	O	N	D	J	F	M	A	M	J	J	A	S										
1.1	ELECTRODE AND INSULATOR MATERIALS																										
1.1.1	EXPERIMENTAL MATERIALS FABRICATION																										
1.1.2	LABORATORY SCREENING TESTS																										
1.2	ENGINEERING TESTS																										
1.2.1	TEST ENGINEERING																										
1.2.2	TEST ASSEMBLY FABRICATION																										
1.2.3	WESTF OPERATIONS																										
1.3	WESTF MODIFICATION																										
1.4	PROJECT MANAGEMENT AND DOCUMENTATION																										

11. Remarks

12. Signature of Contractor's Project Manager and Date: John W. Sadler	13. Signature of Government Technical Representative and Date

Figure 1. Program Schedule and Status

a bit ahead of schedule, and a backlog of test sections which are ready for test is being maintained.

With regard to the magnet modification and subsequent installation in WESTF a schedule slip of approximately one month is projected. The magnet modification itself has been impacted by a slippage in completion of the design and subsequent fabrication of the coil final assembly fixture. Satisfactory progress has been maintained in all other areas of the magnet modification activity. The slippage in the WESTF Modification activity results primarily from changes in vendor delivery dates for major hardware items. The magnet power supply is now expected to be delivered in mid-March, a 6 week slip, and the load-interruptor switches in mid-February. All engineering activities in support of the WESTF modification are being completed on schedule.

In view of the above, it is planned to postpone the planned facility shutdown consistent with availability of the major hardware items which will also permit completion of further tests in WESTF. The shutdown for magnet installation is projected in March and is expected to take approximately 6 to 8 weeks.

1.0 WBS 1.1 - ELECTRODE AND INSULATOR MATERIALS

In addition to providing necessary test materials, for the laboratory screening tests and WESTF tests, and material characterization data required for the detail design activity, this task includes a number of electrode and insulator materials development and evaluation activities.

A number of candidate insulator materials have been evaluated on the basis of corrosion resistance in Western coal slag. On the basis of this immersion test (Reference 1), the following materials have been ranked as excellent:

Al_2O_3	Fused Cast	Carborundum
Al_2O_3-Cr_2O_3	Fused Cast	Carborundum
$MgAl_2O_4$-Cr_2O_3	Fused Cast	Carborundum
$MgAl_2O_4$	Fused Cast	Carborundum
$MgAl_2O_4$	Fused Cast	Trans-Tech
MgO	Fused Cast	Norton

Laboratory electrochemical corrosion tests and anode arc erosion tests have been conducted to evaluate the relative performance of candidate electrode materials. The following summarizes significant findings in these areas:

- A comprehensive model for understanding electrochemical reactions in slagging MHD channels has been developed (Reference 1).
- Zirconia based materials appear to be extremely promising candidate materials for use as anodes with Western slags under slagging hot and perhaps non-slagging super-hot conditions (Reference 2).
- Electrochemical corrosion is extremely sensitive to density and purity of electrode materials (Reference 2).
- Iron cathodes and platinum anodes form the most promising metal electrode combination identified to date for use under slagging hot conditions.
- Slag chemistry modification, through additions of transition metal ions, is effective in minimizing electrochemical corrosion and polarization (this report).
- Laboratory scale anode arc tests indicate that TiB_2 coated copper may be comparable to platinum clad copper in the slagging cold operating mode (Reference 3).

As reported in Section IV - 1.1.1, satisfactory attachment techniques were defined in support of WESTF Test 43 (Pt/Fe electrodes) and WESTF Test 44 (hafnia electrodes with integral oxide current leadout). Additionally, preliminary attachment trials have been successful in defining an attachment technique for use with the 0.5 $(SrZrO_3) \cdot 0.5 (Sr_{0.25}La_{0.75}FeO_3)$ electrode material to be supplied by MIT for WESTF Test 49. Continuing electrochemical corrosion test activity is reported in Section IV - 1.2.1. These studies indicate that major reductions in electrochemical stress can be achieved in Rosebud slags by doping the slag with moderate additions of cobalt. Results of further evaluation of the TiB_2 copper and Inconel anode arc erosion test samples are presented in Section IV - 1.2.2.

2.0 WBS 1.2 - ENGINEERING TESTS

This task is directed towards the design, fabrication, test and post-test analysis of those electrode/insulator materials which undergo testing in the Westinghouse Electrode System Test Facility (WESTF). In comparison with laboratory screening tests, which generally couple only one or two aspects of the MHD channel environment, WESTF provides a realistic simulation of the MHD channel environment. Inclusion of magnetic field effects is planned, see WBS 1.3 below.

Table 3 provides a summary of WESTF tests completed to date. Implicit in this test summary are the following accomplishments:

- Satisfactory operation of WESTF: in the clean firing super-hot mode; in the slagging cold mode with Eastern and Western slags, and in the non-slagging super-hot mode with Western slag.
- WESTF Tests 40 and 41, slagging cold electrodes, have established a correlation with laboratory and generator tests.
- Screening of non-slagging super-hot materials was initiated with WESTF Test D-9, September 1979.

During this quarter, as presented in Section IV - 2.1.2, the design of the Type II Materials Test Section (MTS II) has been completed. Results of supporting thermal analyses for WESTF Tests 43 through 47 are similarly presented. Section IV - 2.1.3 reports the results of the post-test analysis efforts completed this quarter. Fabrication activities are discussed in Section IV - 2.2.

WESTF operating time during this quarter was 33 hours which included WESTF Tests D-10, D-11 (2 runs) and 45. As of the end of this quarter the total WESTF operating time, defined as the cummulative time interval from combustor on to combustor off is 388 hours. Of this total time, 198 hours were accumulated under clean firing conditions and 190 hours were accumulated under slagging conditions.

TABLE 3

WESTF TEST HISTORY

OPERATING MODE	CLEAN	CLEAN COLD	CLEAN SH	CLEAN SH	CLEAN SH	CLEAN SH	SLAG COLD
Test ID	D-7	W-35	W-36	W-37(2)	W-38(2)	W-39(2)	D-8
Test Section	Dummy	WESTF	WESTF	WESTF	WESTF	WESTF	Dummy
Approx. Date	5/77-6/77	7/77-9/77	9/77	10/77	11/77	1/78	6/78-9/78
Electrode Material(1)	NA	Cu	$LaCrO_3$	MAFF 31 MAFF 41 HfO_2 Comp.	$LaCrO_3$(3) $LaCrO_3ZrO_2$ $LaCrO_3$	$LaCrO_3$-$LzAlO_3$ $LaCrO_3$-$SrZrO_3$ $LaCrO_3$ MAFF 31	NA
Insulator Material	NA	$MgAl_2O_4$	$MgAl_2O_4$ MgO	$MgAl_2O_4$	$MgAl_2O_4$ MgO	$MgAl_2O_4$ MgO	NA
T_E, °C	NA	400-100	1700	1700+	1700+	1700+	NA
J, amp/cm^2	NA	To 1.0	1.0	1.0	1.0	1.0	NA
$\dot{Q}$, w/cm^2	NA	~90	~30	~30	~30	~30	NA
B, Tesla	NA	NA	NA	NA	NA	NA	NA
Axial Field, Kv/m	NA	No	No	No	No	No	NA
Ash Type	NA	NA	NA	NA	NA	NA	Rosebud
Seed	K_2CO_3	K_2CO_3	K_2CO_3	K_2CO_3	K_2CO_3	K_2CO_3	K_2CO_3
SO_2 Level, m/o	--	--	--	--	--	--	--
Duration-Hrs.	NA	22	20	20	20	20	NA

OPERATING MODE	SLAG COLD	SLAG COLD	NON-SLAG SH	NON-SLAG SH	CLEAN SH	NON-SLAG SH	
Test ID	W-40	W-41	D-9	D-10	D-11	45	
Test Section	WESTF	WESTF	MTS(6)	Transition	Transition	MTS	
Approx. Date	10/78-1/79	1/79-8/79	9/79	10/79	11/79	12/79	
Electrode Material(1)	Cu	Cu-Pt (+) Cu-W/Cu (-)	$LaCrO_3$	NA	NA	Zirconia	
Insulator Material	$MgAl_2O_4$	BN	MgO	MgO	MgO	NA	
T_E, °C	150/275	150	To 1900	NA	NA	1800	
J, amp/cm^2	To 1.25	0.9	NA	NA	NA	0.9	
$\dot{Q}$, w/cm^2	~125	~125	--	NA	NA	30	
B, Tesla	NA	NA	NA	NA	NA	NA	
Axial Field, Kv/m	Yes	Yes	No	No	No	No	
Ash Type	Eastern	Eastern	Rosebud	Rosebud	--	Rosebud	
Seed	K_2CO_3	K_2CO_3	K_2CO_3	K_2CO_3	K_2CO_3	K_2CO_3	
SO_2 Level, m/o	0.01	0.01	0.01	0.01	0.01	0.06	
Duration-Hrs.	14(4)	63(5)	5(7)	13(5)	11	9	

(1) Anode and Cathode Unless Otherwise noted
(2) U-02 Phase III Proof Test
(3) With ZrO_2
(4) Four Runs
(5) Two Runs
(6) Materials Test section
(7) Two Runs

3.0 WBS 1.3 - WESTF MODIFICATION

Activity within this task is directed towards extending the capabilities of WESTF and incorporating facility and operational improvements. The major activity is that associated with the addition of a conventional 3 tesla magnet. In this regard, the design of the magnet modification has been completed and fabrication activities are in progress. Completion of the magnet modification has been impacted by a slip in delivery of the coil final assembly fixture. Completion of the magnet modification is anticipated by the end of February.

In order to integrate the magnet into the WESTF test area, extensive facility modifications and rearrangements are required. Engineering associated with this activity is on schedule and nearing completion. Major hardware items are being procured. A slip in the vendor delivery date for the magnet power supply, to mid-March 1980, has necessitated postponement of the facility shutdown date to March.

Equipment required for the mini-computer expansion has been received and is being installed and checked out.

4.0 WBS 1.4 - PROJECT MANAGEMENT AND DOCUMENTATION

Significant project documentation issued during this quarter included the following:

- Quarterly Report, July-September 1979.
- Project Management Summary Baseline Report, FY 80 Revision, Final Issue.

A project review meeting was held with recently assigned DOE personnel on November 5, 1979 to review program history, methods and accomplishments.

IV. DETAILED DESCRIPTION OF TECHNICAL PROGRESS

1.0 WBS 1.1 ELECTRODE AND INSULATOR MATERIALS

1.1 WBS 1.1.1 - Experimental Materials Fabrication

1.1.1 Material Development

Electrode Materials

WESTF Test 43 will be a test of Pt capped anodes and Fe cathodes under hot slagging conditions. In designing these electrodes two areas of concern were: 1) the method of attaching the Pt caps to the Al_2O_3 substrates on the anode electrodes, and 2) devising a way of protecting the Fe cathode surface from oxidation prior to slag injection during the initial period of a WESTF test. These problems were remedied by successfully diffusion bonding the Pt caps to the Al_2O_3 substrates of the anodes and by applying a plasma sprayed coating of $NiAl/Al_2O_3$ to the top of the Fe cathodes to impede oxidation. Details of each specific technique are discussed below.

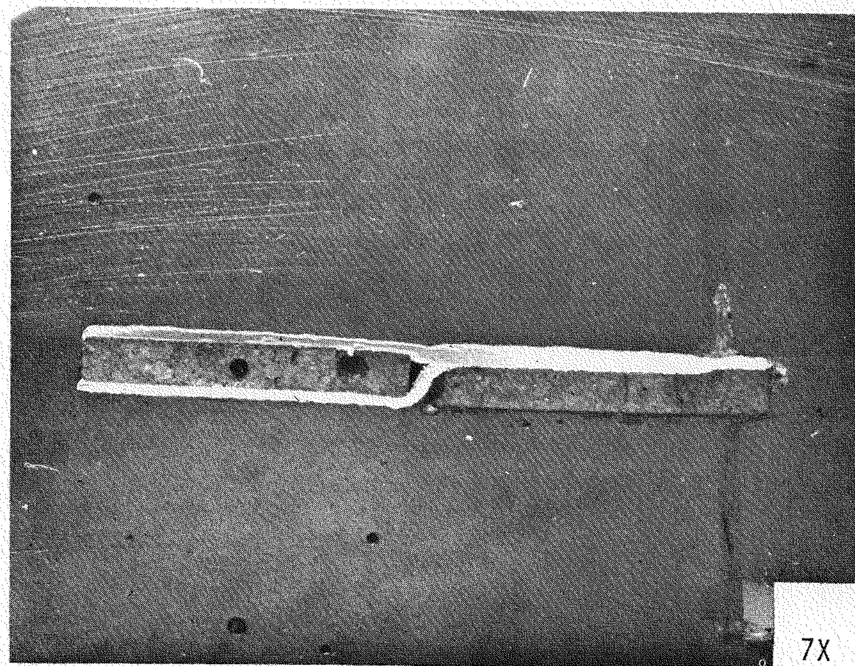
The initial attachment method considered for bonding Pt foil to high density Al_2O_3 was by diffusion bonding. It characteristically shows higher bond strengths than conventional attachment techniques, such as brazing. In particular, previous work (Reference 4) had shown that an excellent diffusion bond between platinum and alumina could be achieved if the surfaces of the materials were properly cleaned. All of the Pt and Al_2O_3 components were therefore cleaned and treated in the following manner.

The platinum pieces were cleaned and agitated in acetone for 30 minutes. They were then annealed at 1475^{o}C for 20 minutes in a vacuum (10^{-6} torr). The alumina pieces were boiled in a 40% nitric acid solution for 5 minutes. After rinsing with water they were annealed in air at 1000^{o}C for 30 minutes. The foils and blocks were subsequently aligned and positioned in a graphite lined hot press. The bonding conditions, which proved to be satisfactory, were a temperatue of 1500^{o}C at a pressure of 300 psi for 30 minutes. Visual examination of the Pt/Al_2O_3 assemblies revealed excellent adherence between the two components. A spare assembly was sectioned and mounted for micro-optical inspection of the bond. Figures 2 and 3 display both macro-and microphotographs of the ceramic-metal interface. The photographs clearly show there is a true bond between both the Pt/Pt and the Pt/Al_2O_3. The Pt/Pt joint exhibits only a very few micropores at the higher magnifications. The Pt/Al_2O_3 interface reveals tiny fingers of the Al_2O_3 extending into the platinum metal, but no pores are detected at the joint. A 'reaction' zone is also visible and as yet, is unidentified. A line trace and spot analysis using the SEM will be run to resolve its identity.

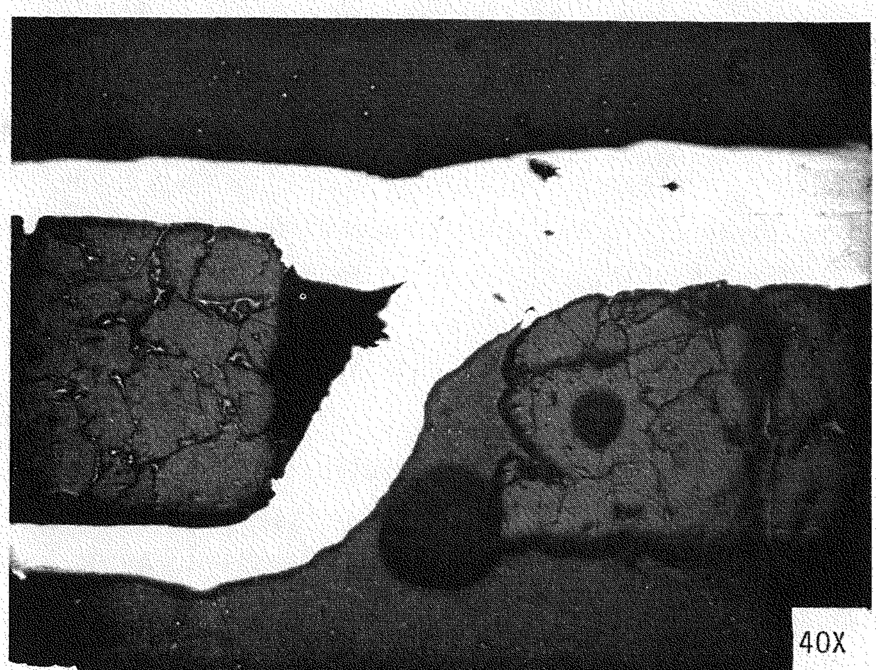
The methods considered for protecting the WESTF Test 43 Fe cathodes from oxidation prior to slag injection were: 1) Electroplating chromium metal on the surface and 2) Plasma spraying a coating of NiAl/Al_2O_3. A number of sample electrodes were electroplated with from 0.5 to 5 mil thick chromium and then subjected to an air atmosphere at 1000^{o}C for 3 hours. All of the electrodes visualy displayed a great deal of oxidation/corrosion. It was apparent that the electroplated layer of chromium was porous enough to allow oxidation of the iron and corrode the carbon steel surface during the three hour duration test. Its performance was felt to be inadequate for protecting the Fe cathodes during an actual test run. Another set of sample electrodes were then coated with a plasma sprayed layer of 60 w/o NiAl/40 w/o Al_2O_3. Two different thicknesses of the ceramic, 2 and 5 mils, were applied to the steel surface. These samples were heated in air at 1000^{o}C for 3 hours as in the previous case. Visual inspection of the 2 mil thick coating revealed almost total absence of any ceramic layer and a great deal of corrosion of the metal. The 5 mil thick coating, on the other hand, was still visible and able to protect the steel from major oxidation. Figure 4 depicts the cross section of both unprotected and coated (5 mil thick) 1018 carbon steel. The 60 NiAl/40 Al_2O_3 coating sufficiently delays oxidation during the 3 hour time period and is suitable for use as a protective coating on the carbon steel cathode electrodes.

General Insulating Materials

Slag compatibility testing of additional candidate insulators was deferred.

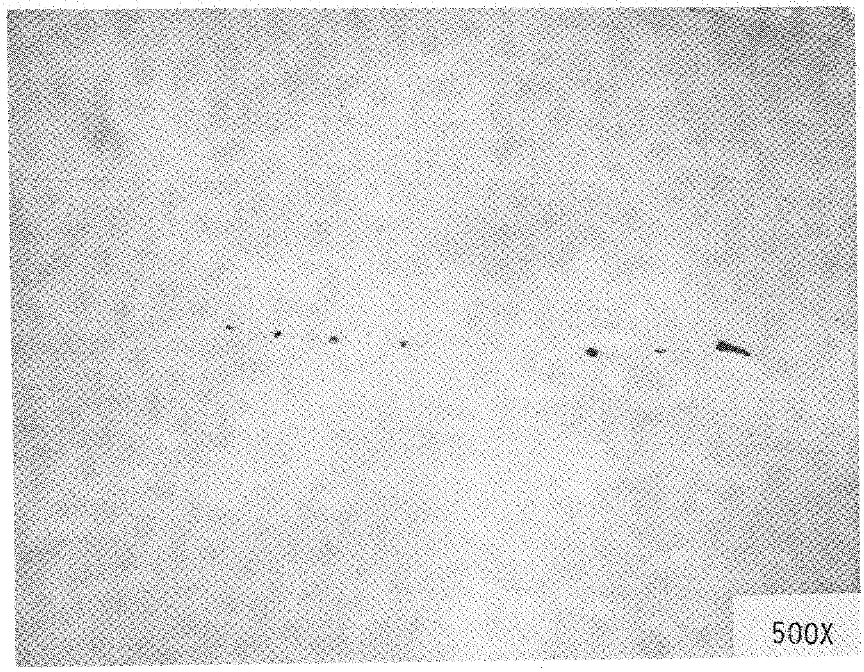


(A) Macrophotograph of Pt/Al_2O_3 Bond

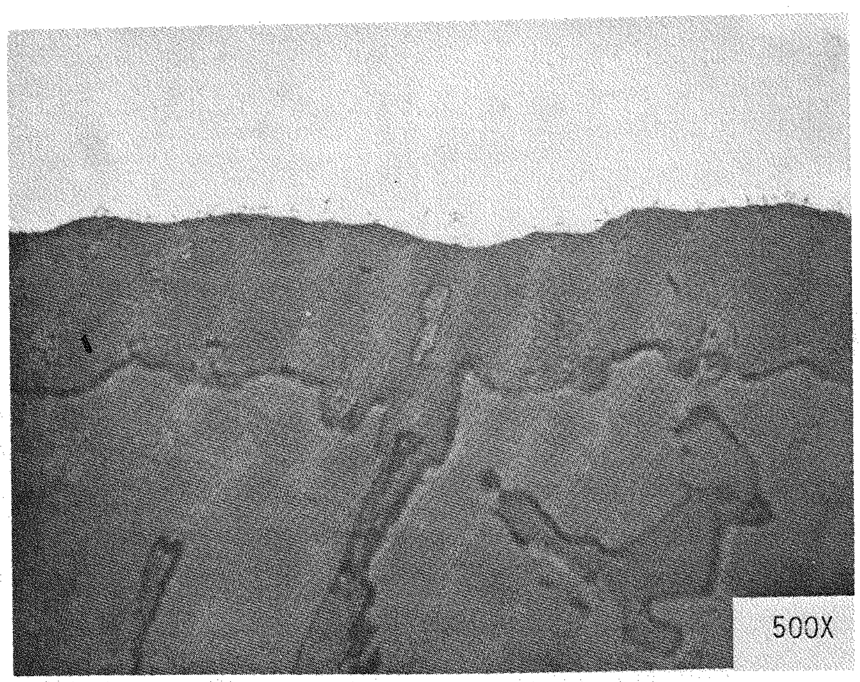


(b) Close View of Both Pt/Al_2O_3 and Pt/Pt Bond

Figure 2. Diffusion Bonding of Platinum

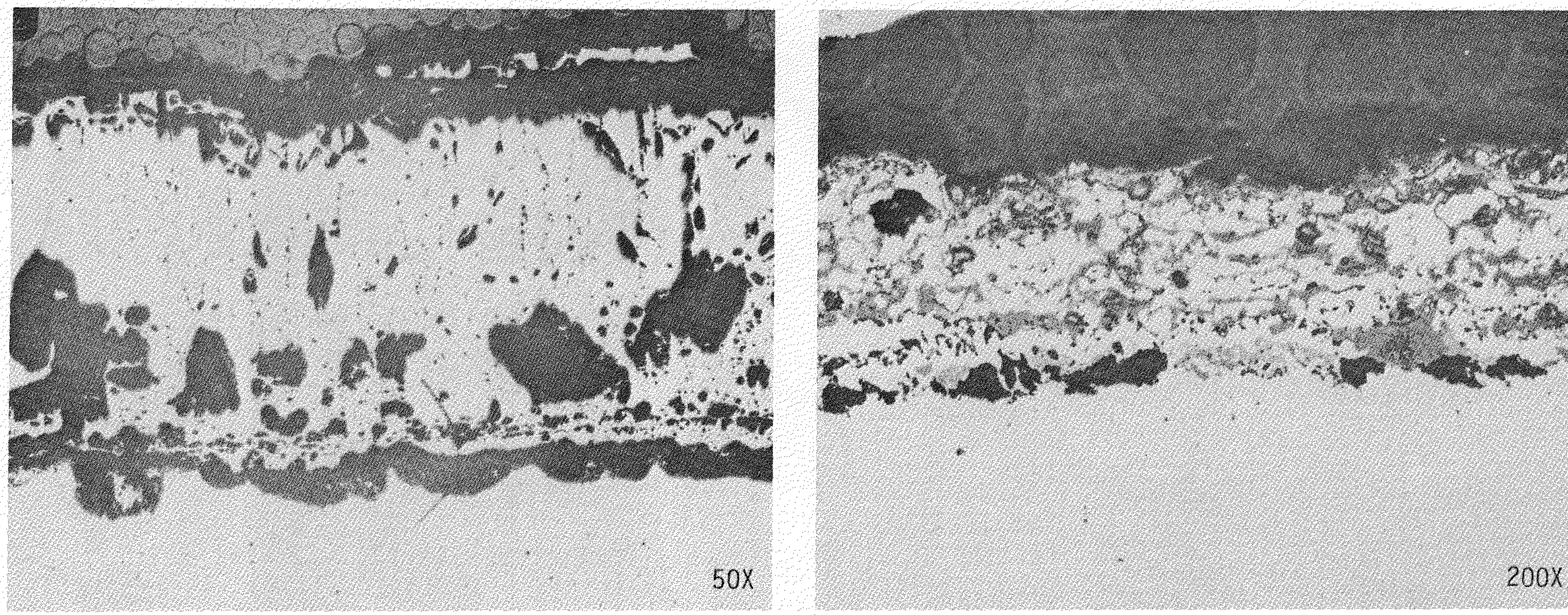


(A) Pt to Pt



(B) Pt to Dense Al_2O_3

Figure 3. Diffusion Bonding of Platinum



(A) Without any Protective Coating

(B) With a 5 Mil Thick Coating of 60 NiAl/40 Al_2O_3

Figure 4. Micrographs of the Surface of Low Carbon Steel (1018) after Heating in Air for 3 Hours at 1100^{o}C

A spinel ($MgAl_2O_4$) castable was obtained from Norton Company, which has shown promise in MHD air preheater applications (Reference 5). It is felt that this material may prove to have better servicability than MgO castables in a slagging environment. X-Ray analysis of the spinel showed it to have minor phases of α Al_2O_3 and MgO with a trace of $CaAl_2O_4$. To experimentally evaluate its slag/ K_2CO_3 compatibility the downstream transition section of WESTF Test 45 was lined with both MgO and the spinel castable. Following the test run, sections of the slag coated castables were cut and mounted for micro-optical evaluation. Results will be reported upon completion of this evaluation.

Attachment Techniques

Work continued on the development of an attachment technique for bonding nickel mesh to the indium doped hafnia current leadout material which is proposed for use in the electrode structure for WESTF Test 44. In_2O_3 doped compounds are difficult to braze directly, principally due to the vaporization of In_2O at low temperatures.

Initial studies focused on trying to apply a gold layer to the ceramic, by diffusion bonding, to eliminate reduction at the bond interface when the material is subsequently brazed to the nickel mesh. This work was carried out in a vertical tube furnace where a 50 psi pressure was applied to the ceramic from the top by use of a lever arm. Table 4 presents the conditions and results obtained in the bonding study. Two compositions were supplied by Battelle Northwest Laboratories as follows:

- 55 m/o In_2O_3 - 15.8 m/o Pr_2O_3 - 26 m/o Yb_2O_3 - 36.7 m/o HfO_2
- 43.3 m/o In_2O_3 - 3.5 m/o Tb_4O_7 - 3.5 m/o Y_2O_3 - 49.6 m/o HfO_2

All of the attempts to obtain a secure smooth layer of gold to the In_2O_3 doped HfO_2 proved unsatisfactory. The problem stemmed primarily from the

TABLE 4

ATTACHMENT CONDITIONS AND RESULTS FOR DIFFUSION BONDING
GOLD TO HfO_2 DOPED WITH IN_2O_3

TRIAL	BONDING TEMP, °C	TIME @ TEMP, hrs.	SUBSTRATE	GOLD FORM	REMARKS
1	1050	16	ZrO_2	1/2 mil thick foil	Au adheres to ZrO_2 substrate in balls, suspect melting of Au, no adherence to IN_2O_3
2	1000	2	ZrO_2	1/2 mil thick foil	Au adheres to ZrO_2 substrate, doesn't wet the IN_2O_3
3	1000	2	SiC	1/2 mil thick foil and paste	Au adhered to IN_2O_3 some remnants of Au on SiC; trial braze to Ni mesh proved unsuccessful; very weak bond obtained
4	1000	1	SiC	2 mil thick foil and paste	Au has not softened completely
5	1040	1	SiC	2 mil thick foil and paste	Au still not softened sufficiently
6	1050	4	SiC	2 mil thick foil and paste	Au has melted, some vaporization apparent
7	1050	1	SiC	2 mil thick foil and paste	Au has bonded to IN_2O_3 but also sticks to SiC - when separating the two, gold peels off the IN_2O_3 taking off some of the ceramic with it
8	1060	1	BN	2 mil thick foil and paste	Au has melted - no adherence to either ceramic bodies
9	860	1	BN	gold paste	Au paste coated IN_2O_3 surface well, attempt made to bond it to Ni mesh achieved very weak bond

extreme temperature sensitivity of gold. The gold foil and/or paste that was used either did not soften enough to chemically bond to the ceramic or it melted into gobules which dropped off from the sides of the ceramic. In addition, a completely inert substrate was not found for supporting the gold/ceramic bonding operation. The gold tended to adhere to both the In_2O_3 doped Hf O_2 and the substrate when a weak attachment was achieved. Separation from the substrate usually broke the bond between the gold and the indium doped hafnia.

Due to the difficulties experienced with the gold application, other alternatives were investigated. Table 5 presents other more conventional bonding efforts. Attempts to braze nickel mesh directly to HfO_2 doped with In_2O_3 were unsuccessful. Attempts were then made to coat the ceramic first with a conductive layer by plasma spraying. Both copper and nickel were plasma sprayed to the HfO_2 and then brazed to the Ni mesh. The bond achieved in both cases proved to be very strong and there appeared to be total wetting of the surfaces. The attachment with the plasma sprayed copper was subsequently heated at $500^{\circ}C$ for 100 hours to observe if any deterioration of the bond might take place due to the oxidation of the copper layer. No loss of bond strength was evident after 100 hours. A final test of the attachment will entail applying a current through the mesh for a period of time to see if it affects the bond. Success in this test will solidify the use of either plasma sprayed copper or nickel for attaching the current leadouts in WESTF Test 44.

WESTF Test 49 is tentatively scheduled to be a test of 0.5 $(SrZrO_3) \cdot 0.5$ $(Sr_{0.25}La_{0.75}FeO_3)$ electrodes processed by MIT. These ceramic electrodes are to be attached either to a copper mesh or directly to a copper cooling block. Preliminary attachment trials have been started with small samples sent from MIT. Initial results reveal that a bond between the ceramic and mesh can be achieved by a conventional brazing technique. Work will continue to obtain an optimum bond.

TABLE 5

ATTACHMENT CONDITIONS AND RESULTS FOR BONDING HfO_2 DOPED WITH IN_2O_3* TO NICKEL MESH

TRIAL	CERAMIC PREPARATION	BRAZE	BONDING PARAMETERS Temp	Time	Atm	REMARKS
1	None	TICUSIL	850°C	3.5 min	10^{-5}	The braze did not wet the HfO_2
2	None	BT	779°C	3.5 min	10^{-5}	No wetting of the HfO_2 observed
3	2-5 mil thick plasma sprayed copper applied to surface	BT	779°C	3.5 min	10^{-5}	Excellent bond was achieved, manual pulling did not destroy the attachment
4	2-3 mil thick plasma sprayed nickel applied to surface	BT	779°C	3.5 min	10^{-5}	Excellent bond was achieved; bond could not be broken by manual pulling

* Material supplied by Battelle Northwest for the attachment study.

1.1.2 Material Characterization

Thermal Conductivity

WESTF Test 49 will screen electrodes of the 0.5 ($SrZrO_3$) · 0.5 ($Sr_{0.25}La_{0.75}FeO_3$) composition which was developed by MIT. The thermal conductivity was determined using preliminary material samples to support detail design of the test section. The thermal diffusivities were measured by BPNL using a laser pulse technique from near room temperature to temperatures up to 1750^oC. The conductivity (λ), given in Figure 5, was calculated from the thermal diffusivity (α), room temperature density (ρ), thermal expansion (Δ/ℓ) and the specific heat (C_p) by the equation.

$$\lambda = \alpha\rho\ C_p$$

Additional thermal diffusivity measurements will be made by BPNL using samples from the specific batch of MIT material which will be used for WESTF Test 49.

1.2 WBS 1.1.2 - Laboratory Screening Tests

1.2.1 Electrochemical Corrosion Tests

The extent and severity of electrochemical corrosion has been previously modeled (Reference 6) and it is directly related to the electrochemical stress, ECS. The equation describing the ECS is:

$$ECS = \frac{P_{O_2}^A}{P_{O_2}^C} = \exp \left| \frac{4F\ J_x\ \ell\ (1-r^*)}{RT\ \sigma_T\ (\bar{t}_i\ r^* + \bar{t}_e)} \right|$$

where:

$P_{O_2}^A/P_{O_2}^C$ is the partial pressure of oxygen at the slag/anode and slag/cathode interfaces, respectively,

F is the Faraday constant,

J_x is the current density,

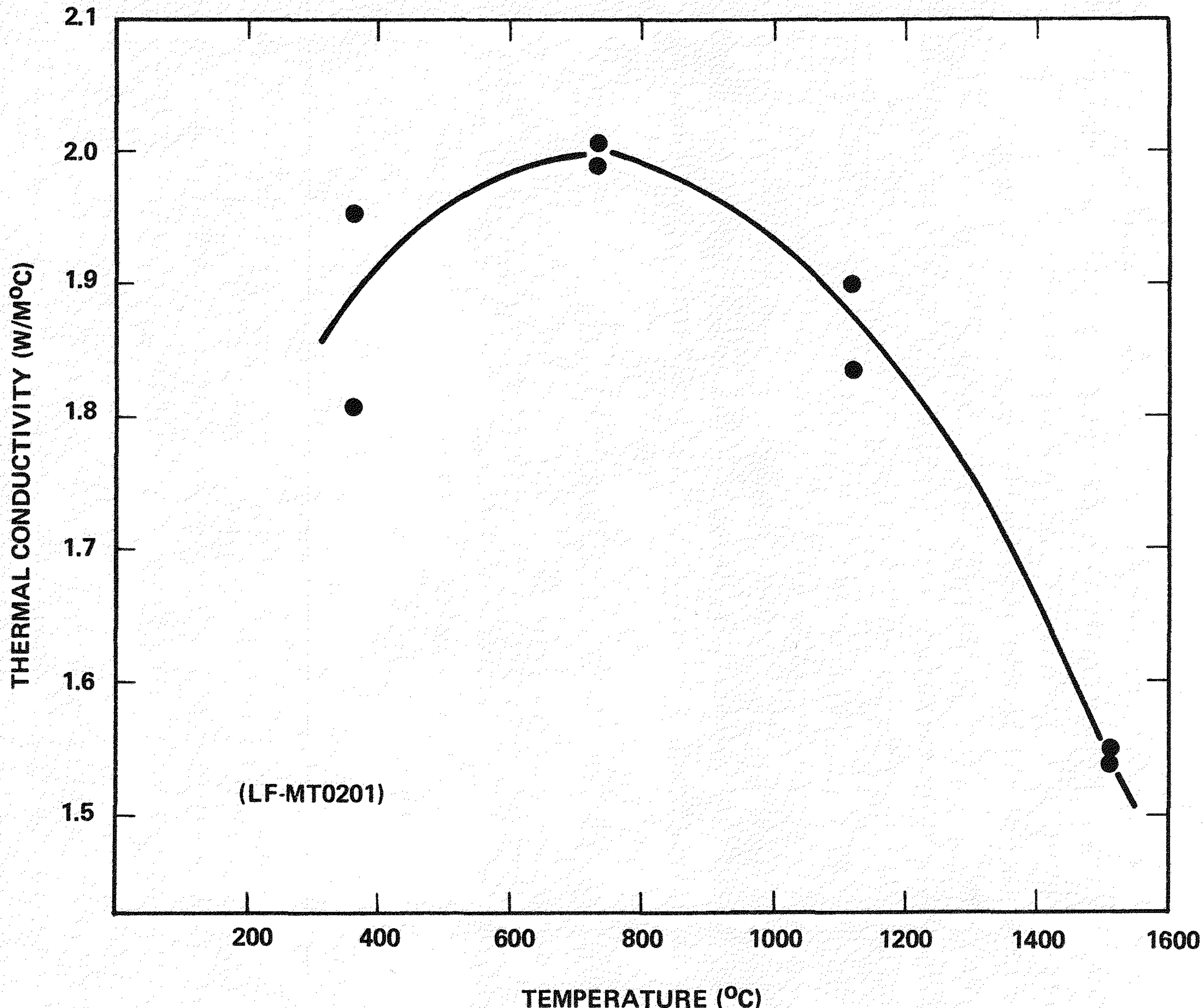


Figure 5. Thermal Conductivity of 0.5 $(SrZrO_3) \cdot 0.5\ (Sr_{.25}La_{.75}FeO_3)$

ℓ	is the slag layer thickness,
J_T	is the total electrical conductivity of slag,
r*	is the relative polarization factor,
t_i, t_e	is the ionic and electronic transference numbers of slag
R	is the gas constant and
T	is the temperature

Inspection of the above equation reveals that most of the terms are slag dependent properties. Thus the approach of modifying slag properties to minimize t_i and ℓ and to minimize J_T by suitable doping is a very important and viable method of minimizing the ECS. It is known that the easiest method of increasing both t_e and J_T is through additions of transition metal ions to the slags. Electrical and electronic conductivity is increased by an electron trapping mechanism between ions of different valence. This can be represented for a transition metal oxide by;

$$Me^{+2}\ O\ Me^{+3} \rightarrow Me^{+3}\ O\ Me^{+2}$$

Two areas, reflecting the role of slag composition on electrochemical reactions have been examined. The first deals with the effect of iron content in the slag on corrosion of platinum, while the second investigates the effect of cobalt additions on slag polarization.

Corrosion and Iron Content of Slags

Earlier studies have shown that additions of iron oxides to slags greatly reduces the rate of electrochemical corrosion of $3MgAl_2O_4 \cdot 1Fe_3O_4$ ceramic electrodes (References 7 and 8). See for example, the nearly exponential type curves in Figure 6. These results clearly implicate the iron content in slags as the principal factor effecting corrosion, i.e., the CaO, MgO content which differ significantly between eastern and western USA slags appear to have no major role in electrochemical corrosion.

Essentially identical corrosion results have been obtained with metallic 80 Pt - 20 Rh anodes as shown in Figure 6. Corrosion of the platinum alloy, at ≈1 amp/cm^2, decreased by a factor of over 20 as -Fe_2O_3 content in slag varied between zero and about 10 m/o. The slags used in these experiments (Reference 9) were W-55 (0 m/o Fe_2O_3), W-50 Rosebud (3.5 m/o Fe_2O_3) and E-03 Illinois (9.5 m/o Fe_2O_3). Since available data shows that the electrical conductivity of slags is at least linearly dependent on iron content (Reference 10) and that t_e, the electronic transference number, also increases slightly with Fe_2O_3 (Reference 10), the exponential like decrease in corrosion rates shown in Figure 6 is qualitatively consistent with that predicted by the ECS equation. The applicability of this equation to metallic as well as ceramic electrodes suggests that the role of iron content in slags on corrosion is a general phenomenon which holds true wherever ion blocking electronically conducting electrodes are used. In conclusion, these results indicate that Western coal slags are much more corrosive than Eastern coal slags. It is expected this trend will hold true under all proposed MHD channel operating conditions since electrochemical corrosion has been shown to be important not only under hot mode but, cold, and superhot operating conditions as well. Slag compositional modification should be pursued as an effective method of minimizing corrosion.

Polarization Measurements

Polarization measurements of cobalt modified Western coal slags with stainless steel electrodes were made using a technique described by Perkins (Reference 11). In this method, two rods (0.25" diameter 304 stainless steel) were immersed for a depth of 1 in. in a bath of molten slag while maintained at a distance of 3/4 in. apart. At a point 3/4 in. equidistant between the steel electrodes, a (Pt)-(Pt-10Rh) thermocouple and reference electrode (.040" wire) was immersed which served to measure both temperature as well as voltages between anode and cathode. In operation, a constant external voltage was impressed across the cell while current and the voltage drops (polarization voltages) between the central probe and the two electrodes were continuously read. In general, about a 10 minute hold at a given applied voltage was required to obtain stable voltammetry readings.

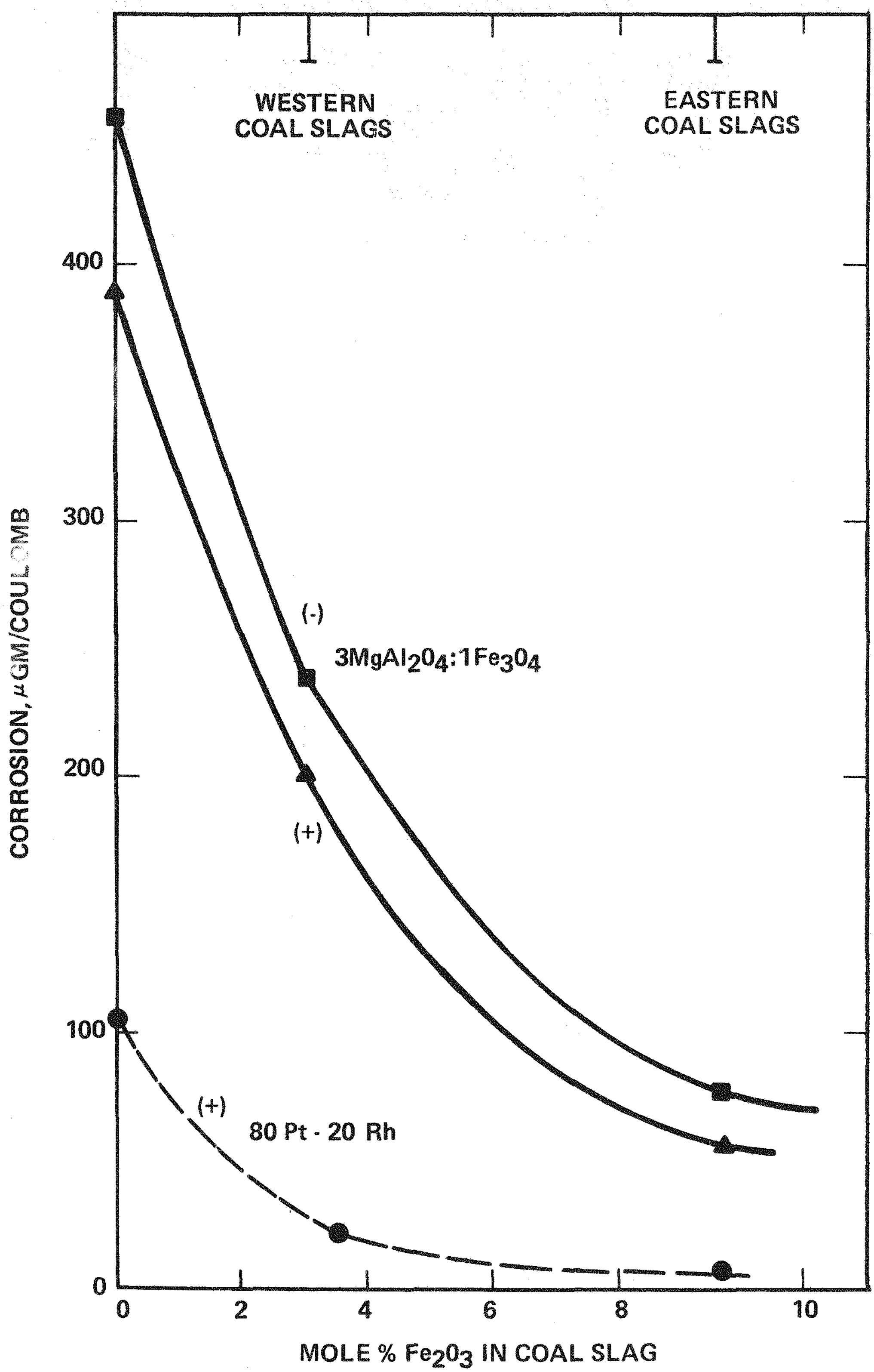


Figure 6. The Effect of Fe_2O_3 Content in Coal Slag on Corrosion

There is a distinct advantage in using metal electrodes vis a vis ceramic electrodes (Reference 12) for polarization measurements in slags. Since the electrical resistance of metals is low relative to that of slags the electrical leads can be attached at a reasonable distance above the liquid slag bath into which the tips of the electrodes are immersed.

With most ceramic electrodes, electrical leads must be immersed in the slag bath, thereby complicating construction of polarization cells and increasing the probability of material failures during the test.

Polarization tests have been run at 1400°C in W-50 slag Rosebud slag (Reference 9) containing 10 w/o K_2O to which various amounts of Co_3O_4 were added. The concentrations of cobalt in the slags are given in Table 6. The stainless steel electrodes were not changed during these series of tests, except for run VC where fresh electrodes were used to check for reproducibility.

The results are shown as anode and cathode polarization voltages versus current in Figures 7 through 9. In Figure 7, the logarithm of current is plotted as the abscissa whereas in Figures 8 and 9, current is plotted on a linear scale. The good agreement between tests VB and VC in 3.1 m/o Co_3O_4 doped slag indicate that the use of the same stainless steel electrodes throughout these experiments is justified.

Generally, speaking, a linear relationship between polarization voltages and current implies electronic (ohmic) conductivity in the slag. When the polarization voltage is linearly dependent on the logarithm of current, it is probable that ionic transport is the predominant mode of current transfer. It can be seen in Figures 7 to 9 that both modes of electrical conductivity occur in these tests. Current transfer at the cathode is predominately electronic at low current density but changes to ionic at high current density. The opposite effect is found at the anode. Since it was found at the conclusion of these tests that the anode had undergone much more material loss than the cathode (35% versus 10% loss) it is probable that the anode slag was contaminated by reaction products. Thus we will only consider cathode polarization data in the following discussion.

TABLE 6

POLARIZATION SS 304 ELECTRODES IN W-50,* ROSEBUD SLAG WITH COBALT ADDITIONS

RUN ID	COBALT ADDITIONS w/o	COBALT ADDITIONS m/o	MEAN RESISTANCE, CATHODE, Ω	CRITICAL RESISTANCE, CATHODE, Ω
VA	0	0	10.1	15.4
VB	10	3.1	5.4	8.2
VC**	10	3.1	5.1	8.0
VD	18	6.1	1.9	4.0
VE	23	8.0	1.5	2.6

* 10 w/o U_2O

** New electrodes

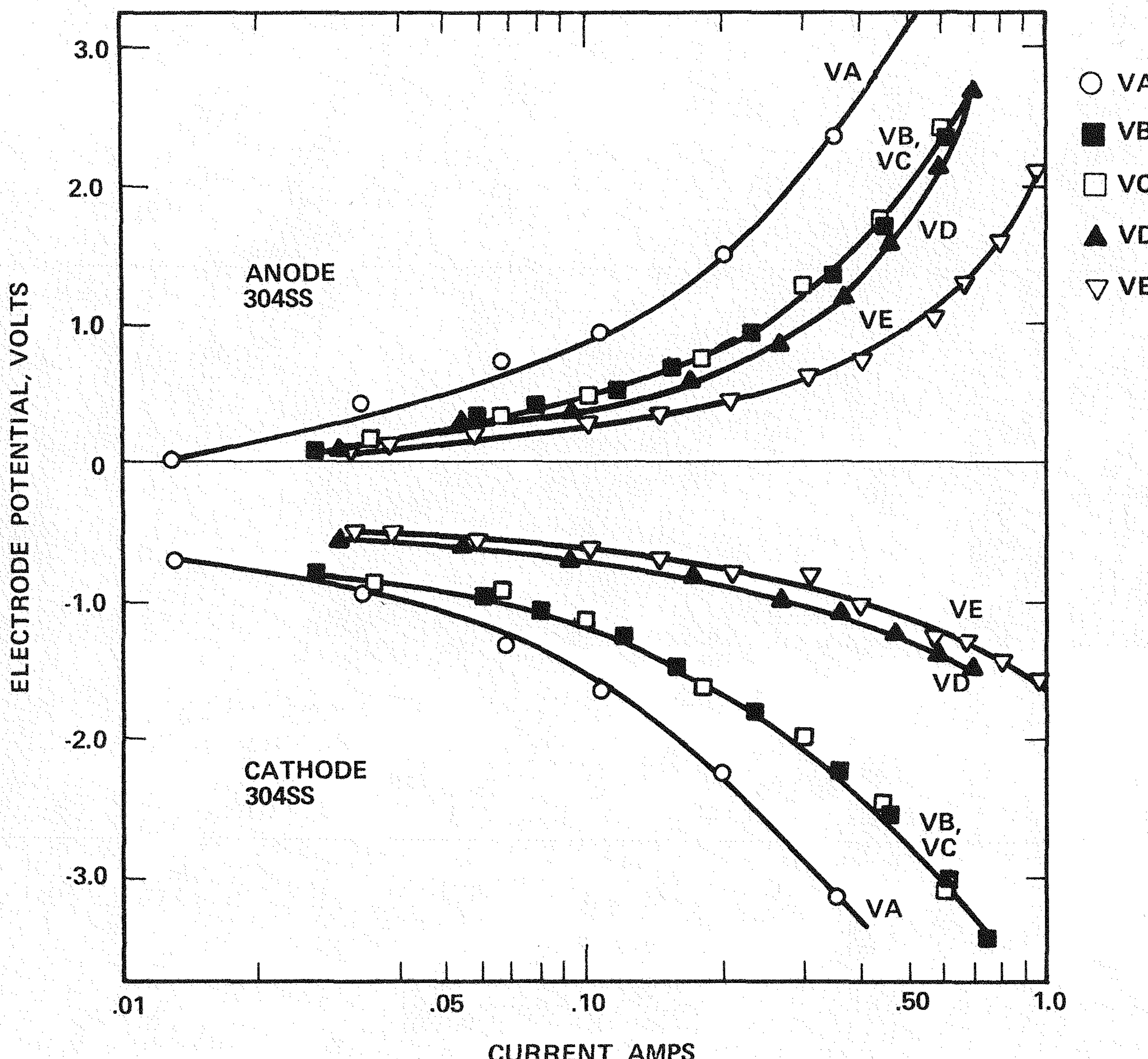


Figure 7. Electrode Polarization of 304 Stainless Steel in Cobalt Modified Slags

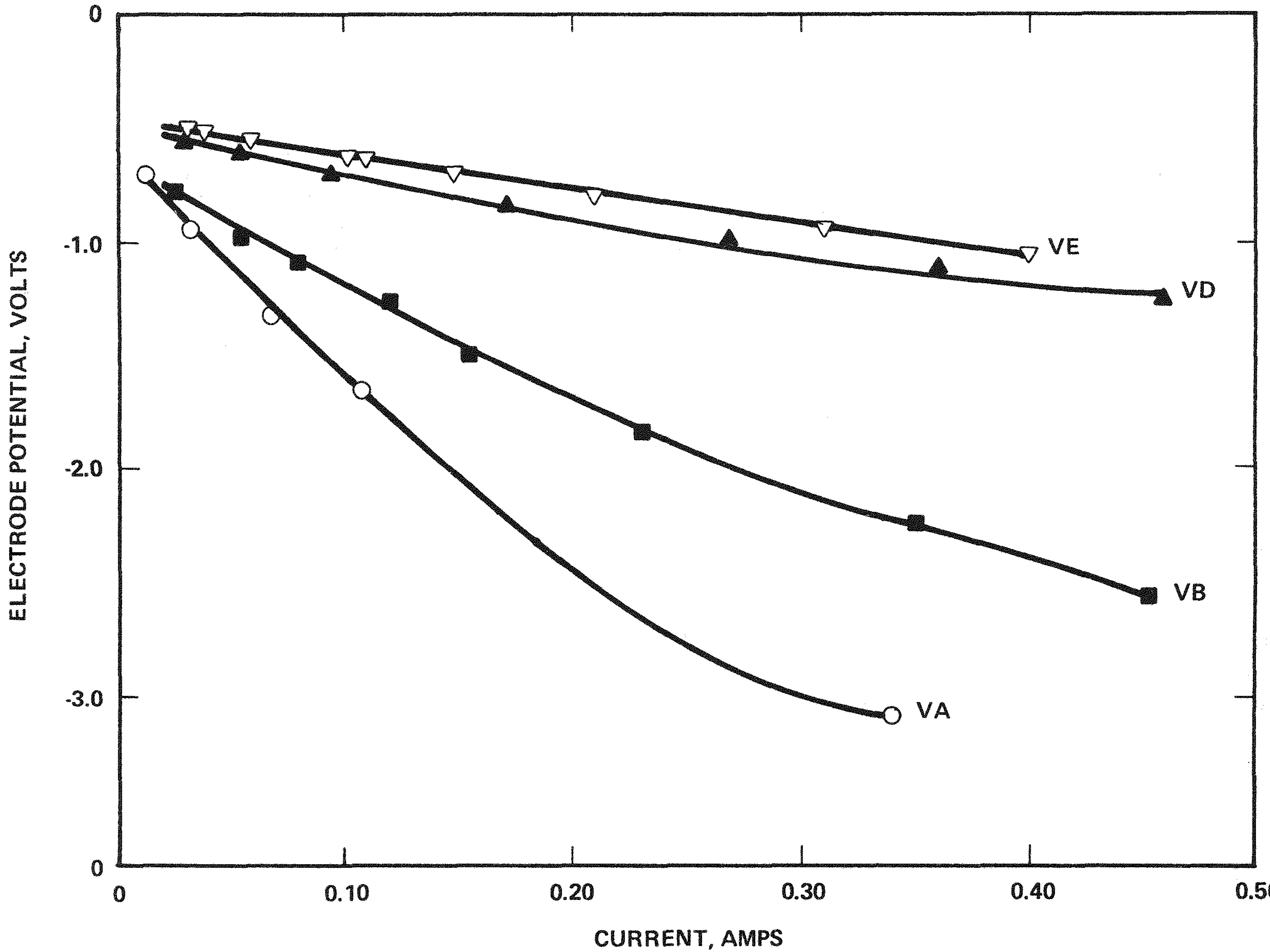


Figure 8. Cathode Polarization Curves for W-50 Slag with Cobalt, Stainless Steel 304 Electrodes

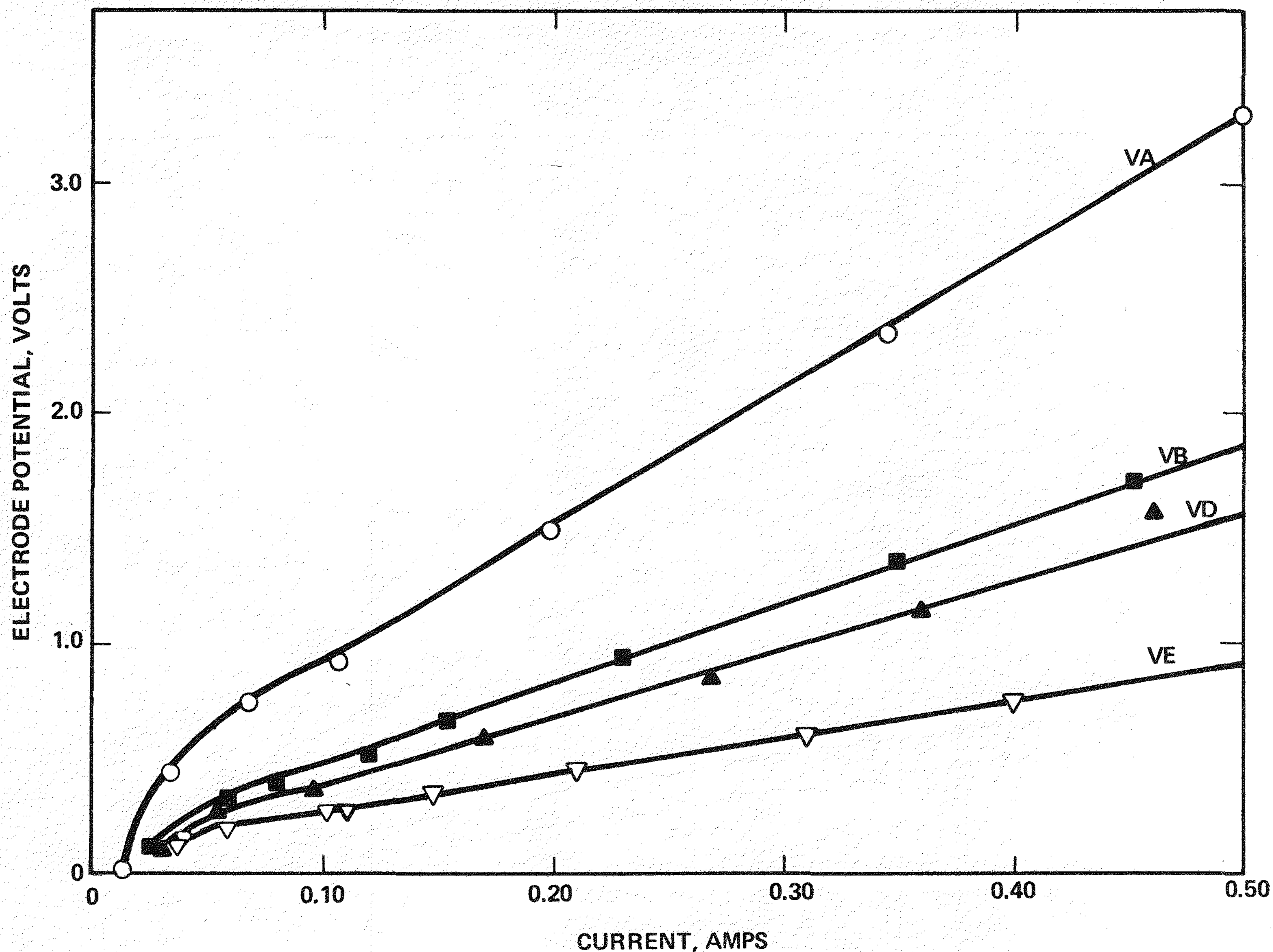


Figure 9. Anode Polarization Curves for W-50 Slag with Cobalt, Stainless Steel 304 Electrodes

The effect of cobalt on slag polarization at the cathode is manifested in two ways. With increasing Co content, there is a marked decrease in "mean resistance", $\bar{R}$ ($\Delta E/\Delta I$) in the ohmic or electronically conducting portion of the polarization curve (Figures 8 and 9) and there is a decrease in R_c (E/I), the "critical resistance" at which the conduction mechanism changes from electronic (linear) to ionic (semilogarithm). This data is summarized for the cathode in Table 6. $\bar{R}$ is a measure of the change in total electrical resistivity of the slag while Rc reflects changes in both the total resistance as well as the electronic contribution to the resistivity of the slag. Therefore, these results conservatively imply that the total conductivity and perhaps as well the electronic transference number of the slag, increase about six fold when 8 m/o Co_3O_4 is added to a Western Rosebud slag. Figure 10, a plot of mean conductance ($1/\bar{R}$) versus mole fraction Co_3O_4, shows an "S" type relationship and suggests that cobalt additives are most effective in the 3-8 m/o Co_3O_4 level.

To summarize, these results indicate that major reductions in polarization, electrical resistivity and ionic transference number of the slag can be achieved in Rosebud slags with moderate additions of cobalt. Thus, for example, reduction of the electrochemical stress, ECS by a factor of $\approx 10^{30}$ at elevated temperatures is possible simply by doping the slag with 3 m/o Co_3O_4.

Future studies will focus on evaluating the effect of other transition metal ions (i.e., Fe, Mn etc.) on slag polarization to find the best efficacious additive for minimizing electrochemical stress.

1.2.2 Anode Arc Erosion Studies

It is planned to continue investigations of anode arc erosion using the type II Material Test Section (MTS II) rather than the laboratory test rig previously used. Prior tests using the laboratory test rig were reviewed (Reference 3) with particular emphasis directed towards the TiB_2 clad copper and Inconel samples.

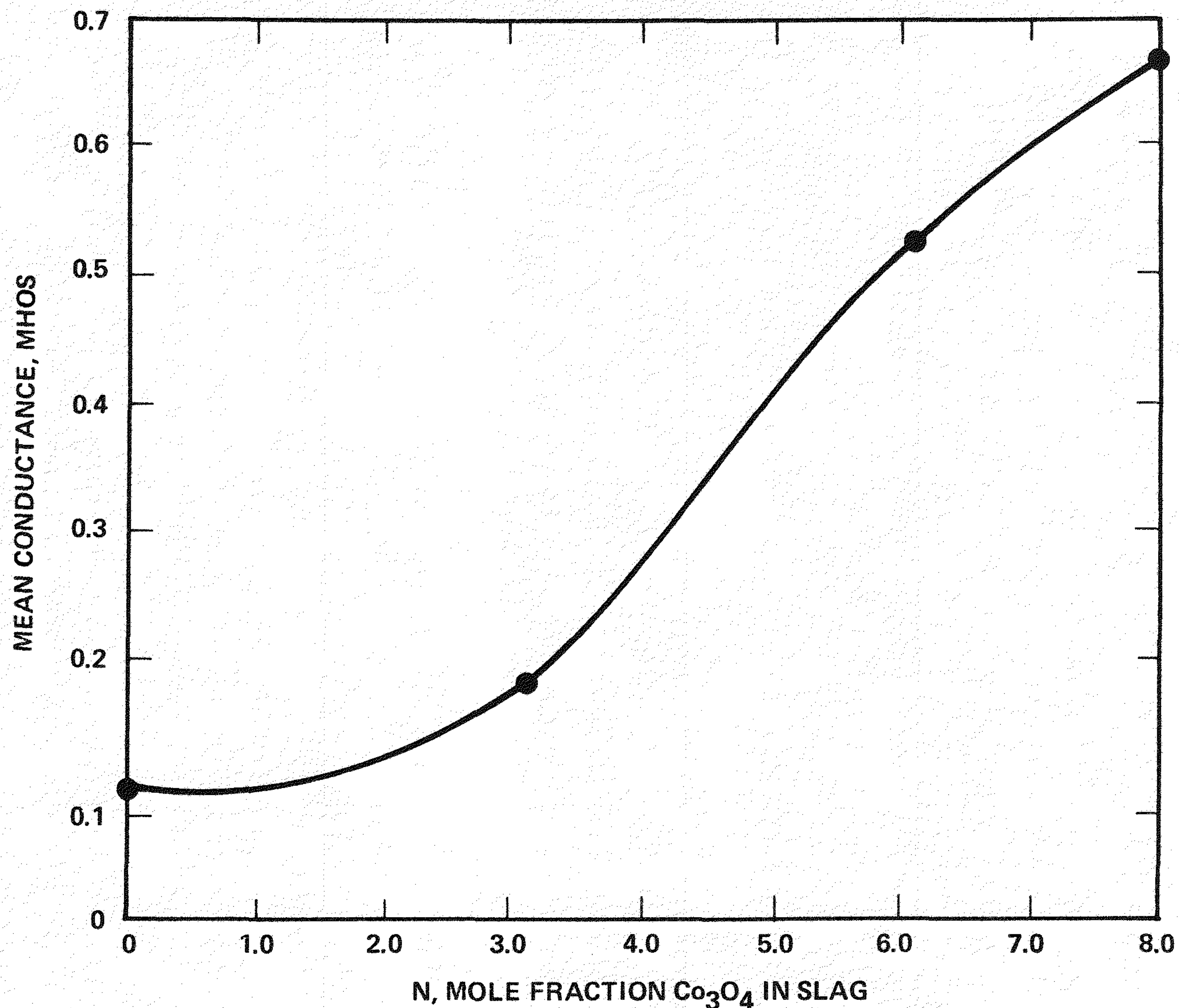


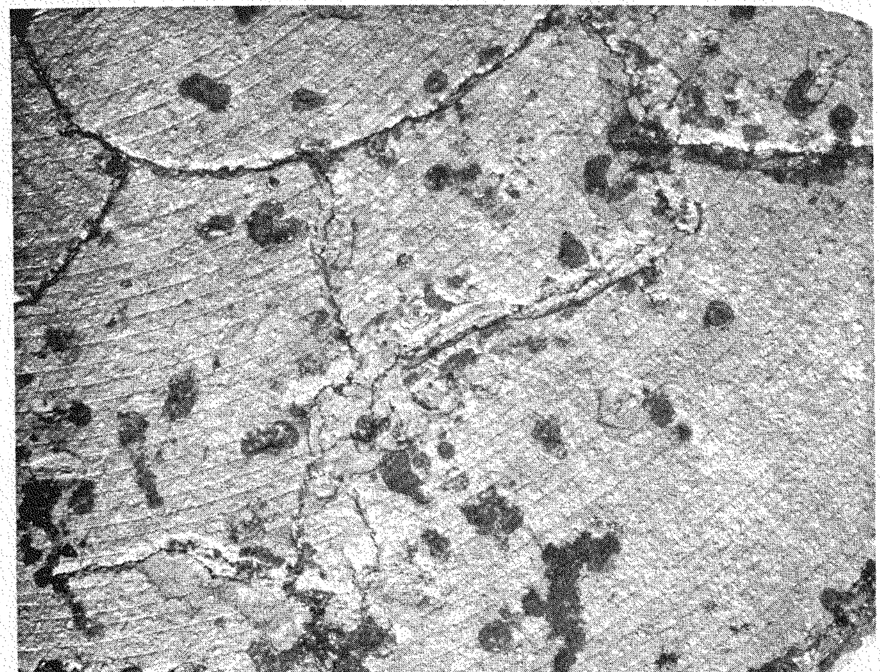
Figure 10. Effect of Cobalt Additions on Mean Conductance $(1/\bar{R})$ at Cathode

The TiB_2 clad copper showed an arc erosion rate that was comparable to platinum clad copper in the laboratory arc erosion test and both samples were reported to be significantly better than pure copper anodes (Reference 1). The TiB_2 clad copper showed a larger number of tiny, shallow arc tracks that seemed to concentrate along pre-existing coating cracks. The TiB_2 clad Inconel was crack-free, but showed more concentrated arc erosion and a much greater degree of damage. Metallographic and SEM/EDA evaluations were performed on these samples.

Figure 11 shows macrophotographs of the arc damaged surfaces of the TiB_2 clad copper and TiB_2 clad Inconel sample. The surface of the TiB_2 clad Inconel is much more disturbed than that of the TiB_2 clad copper. Figure 12 shows SEM photographs of arc spots from the same surfaces, but at 1000X. The arc appears to have shattered the TiB_2 coating on copper and bored a hole through the TiB_2 coating on Inconel. Spot EDA analyses identified elements that are either associated with the coatings, i.e., Ti, B, Cl (the TiB_2 coating is chemically vapor deposited from a chloride system), the substrate, i.e., Cu, Fe, Ni, Cr, or the flyash applied during the laboratory arc test, i.e., Al, Ca, S, Fe.

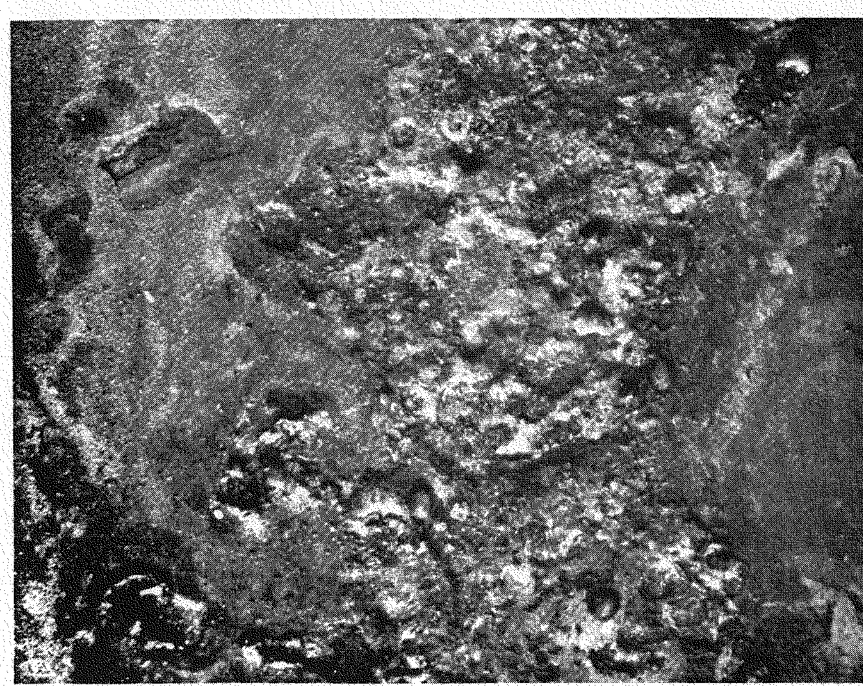
Cross-sections of the as deposited coatings and tested areas are shown in Figures 13 and 14. Measured TiB_2 coating thicknesses are 0.9 to 1.0 mils on copper and 1.0 to 1.4 mils on Inconel. There is evidence of chemical attack of the substrate during coating deposition and is manifested as grain boundary attack of the copper and surface attack of the Inconel. Grain boundary etching would improve the adherence of TiB_2 to copper even though there is a significant mismatch in the thermal expansion of the two materials. As tested, the TiB_2 is shattered but retained on the copper; the copper is discolored in a very limited area at the root of the arc spot. On the other hand, the Inconel shows possible interaction between the coating and the substrate and/or a heat affected zone.

SEM photographs of arc damaged areas of the coatings are shown in Figure 15. On the copper sample, the TiB_2 is fractured and possibly driven into the soft copper matrix. On the Inconel sample the coating disappears into the matrix and, with presence of titanium in the matrix confirmed by EDA analysis, apparently has reacted with the high nickel content of the Inconel.



15X

(A) TiB_2 Copper



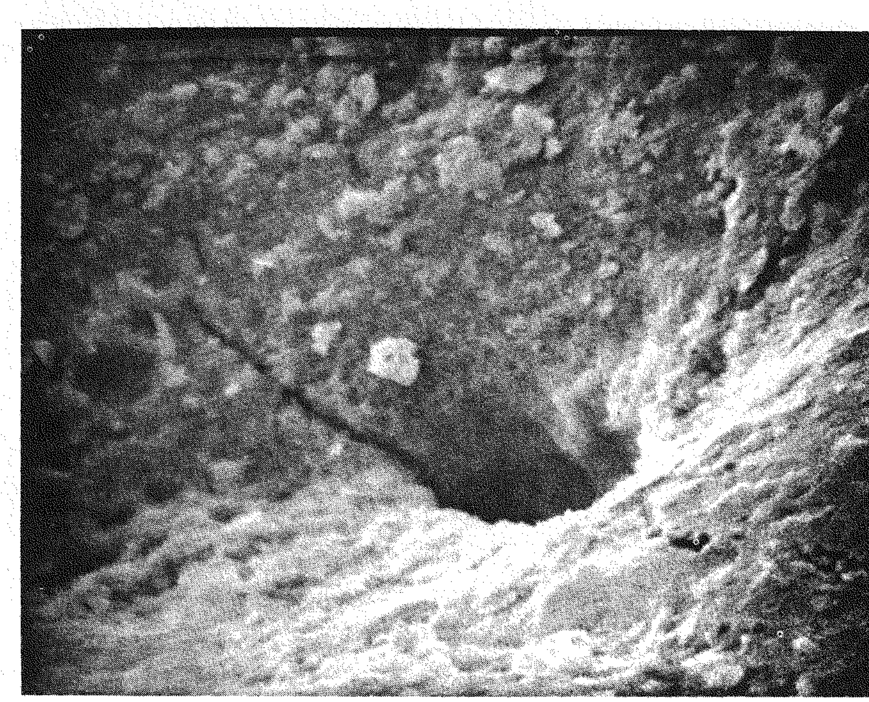
15X

(B) TiB_2 on Inconel

Figure 11. Macrophotographs of Arc-Damaged TiB_2 Surfaces

1000X

(A) On Copper, Post-Test



1000X

(B) On Inconel, Post-Test

Figure 12. SEM Photographs of Damaged TiB_2 Surfaces

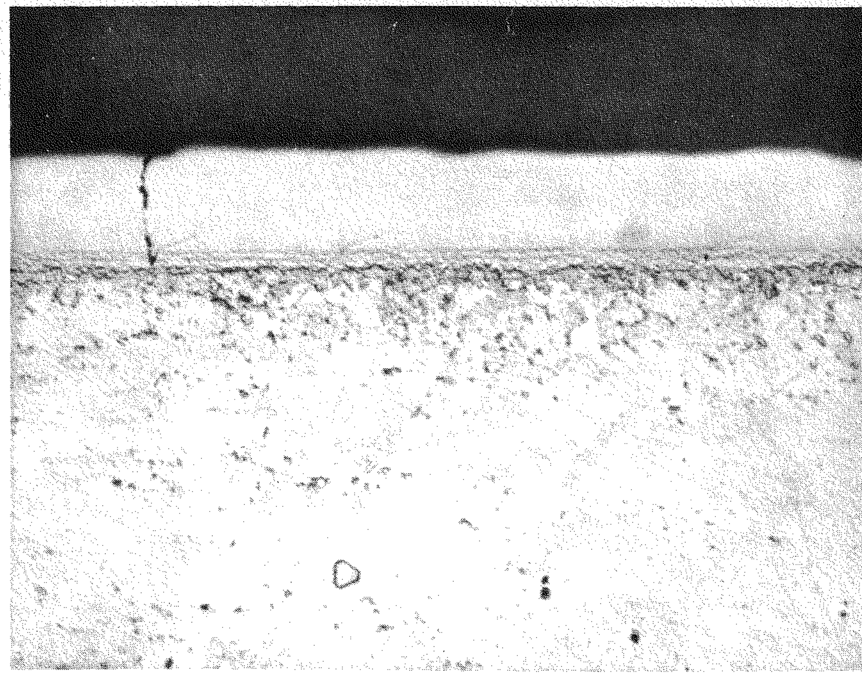
4000X

(A) As Deposited

4000X

(B) Arc Tested

Figure 13. As-Deposited and Arc Tested TiB_2 Coatings on Copper



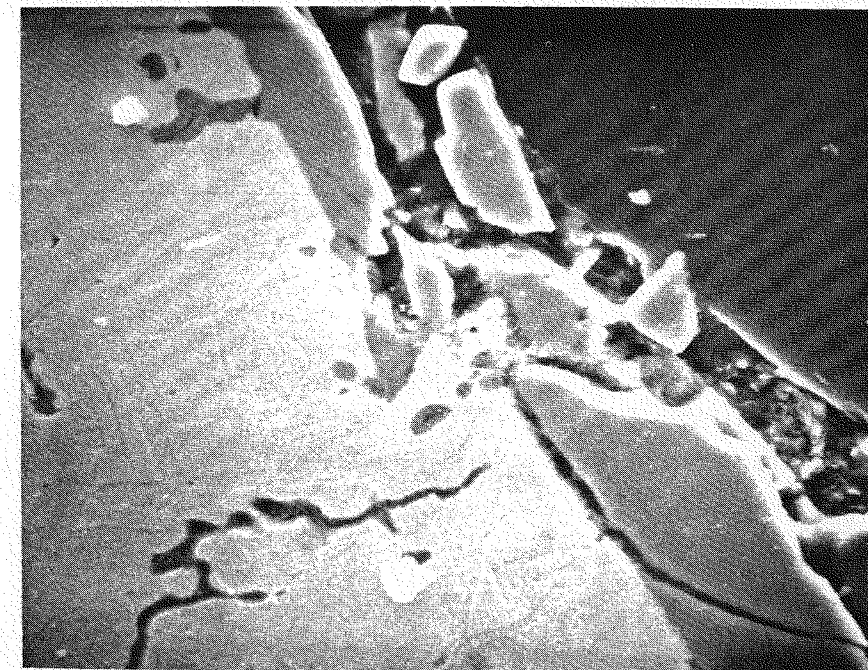
4000X

(A) As Deposited

250X

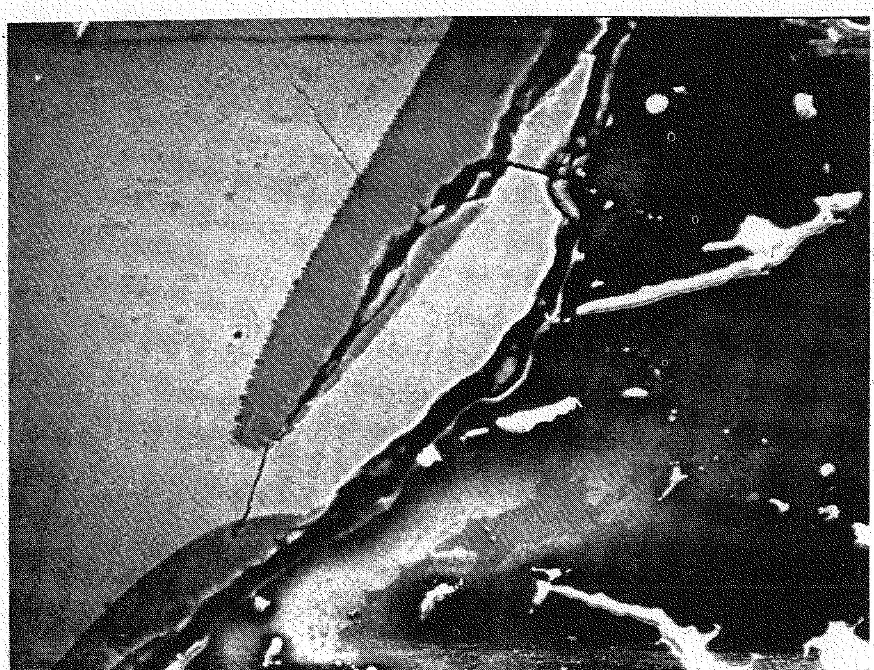
(B) Arc Tested

Figure 14. As-Deposited and Arc Tested TiB_2 Coatings on Inconel



850X

(A) TiB_2 Copper



625X

(B) TiB_2 on Inconel

Figure 15. Photographs of TiB_2 Clad Samples

The encouraging results on TiB_2 clad copper and the results of the analysis indicate that further work should be done on this system to evaluate different cladding techniques especially those that provide a graded interface or otherwise improve the thermal shock resistance of the coating.

2.0 WBS 1.2 - ENGINEERING TESTS

This task covers the engineering and development tests which are conducted in the Westinghouse Electrode Systems Test Facility (WESTF). These tests permit the evaluation of electrode/insulator materials and systems under dynamic and representative MHD channel environmental conditions and at modest scale. In comparison, the laboratory screening tests provide data where only one or two aspects of the channel environment are simulated. These tests are of value in providing both an initial screening of materials and an effective method of investigating selected phenomena in depth, such as electrochemical corrosion.

In order to provide the most effective use of this facility in the engineering development and evaluation of improved electrodes, three types of WESTF tests have been identified. These WESTF tests are;

- Screening Tests
- Development Tests
- Life Tests

Entry of materials into the general development sequence of WESTF testing is contingent upon the material being identified as a 'candidate' material based on laboratory tests completed as part of the WBS 1.1 activity or an equivalent activity completed elsewhere. As materials progress through the engineering development and evaluation process they will be rejected or identified as 'promising' based on performance in WESTF under the total MHD channel environment. WESTF tests span the range from screening tests, which are relatively simple tests requiring a limited amount of test materials and detail design activity, to life tests which are the final test prior to generator testing.

These three levels of testing can be characterized further, as follows:

- Screening Tests
  - these tests will identify materials that are resistant to the full MHD environment. These 'promising' materials will be subjected to the next level of testing.
  - these tests will verify the performance of fundamental electrode/insulator structures, i.e., attachments, current leadouts, etc.
  - these tests will be used to study basic degradation mechanisms

- Development Tests
  - these tests focus upon the engineering development of electrodes/ insulators based upon 'promising' materials.
  - these tests investigate the performance and durability of electrode/insulator systems over a range of operating conditions, with material processing variations and with appropriate design or configuration variations. Those electrode/ insulator systems that surpass performance and durability criteria will be designated as 'promising' and tested at the next level.
  - these tests also allow the study of degradation phenomena in a full MHD channel configuration and environment.

- Life Tests
  - these tests will demonstrate long term performance and durability of electrode/insulator systems and qualify them for subsequent generator testing.

To place current and planned WESTF test activity in perspective, the current developmental status of MHD electrode and insulator systems must be appreciated. Using the above definitions, platinum clad copper is the current anode baseline material for the slagging cold operating mode and, in view of its projected use, is a 'promising' material, by definition. However, detailed developmental testing and evaluation is required to truly characterize this material. Other 'Candidate' materials for the slagging cold mode have been identified via laboratory screening tests. With regard to the slagging hot and non-slagging super-hot operating modes, a number of 'candidate' materials have similarly been identified.

Therefore, the near term WESTF test activity is being directed towards development tests on platinum clad anodes and copper-tungsten cathodes in the slagging cold operating mode plus screening tests of candidate materials for the slagging cold, slagging hot and non-slagging super-hot operating modes.

Table 7 provides a revised summary of WESTF tests which are planned at this time. With the successful introduction of the type II Materials Test Section (MTS II), this revision reflects the transition from the total use of WESTF test sections to the use of MTS II test sections for screening tests and WESTF test sections for development tests.

2.1 WBS 1.2.1 - TEST ENGINEERING

2.1.1 Development Requirements

Preliminary test specifications are issued to initiate design activity on the channel for each test. Materials development/procurement and electrode systems development activities are initiated based on the Preliminary Test Specification. Final Test Specifications are issued after completion of all development activities and provide the basis for detail design of the channel and WESTF testing.

During this quarter, Preliminary Test Specifications were issued for WESTF Tests 46 (including Rev. 1), 47, and 48 (including Rev. 1) and Final Test Specifications were issued for WESTF Tests 43, 45, and D-10, Run 2. Each of these tests are discussed in following sections.

WESTF Test D-10, Run 2

WESTF Test D-10, Run 2 continues the evaluation of alternate thermal designs for the WESTF Test 42 inlet transition section. The designs, based on thermal analysis, consist of three different thicknesses of 85% dense high purity MgO and four different attachments in a test article composed of inlet and outlet transition sections joined together.

TABLE 7

PLANNED WESTF TESTS

OPERATING MODE	SLAG COLD	NON-SLAG SH	SLAG HOT	NON-SLAG SH	SLAG HOT	NON-SLAG SH	NON-SLAG SH
Test ID	W-47	W-42	W-43	W-46	49	48	W-44
Test Section	MTS II(4)	WESTF	WESTF	Transition	MTS II	Transition	WESTF II
Approx. Date	1/80	1/80	2/80	2/80	TBD	2/80	TBD
Electrode Material(1)	Cu-Pt (+) Cu-W/Cu (-)	ZrO_2 Based HfO_2 Based Perovskite	Pt (+) Fe (-)	NA	$LaFeO_3$(3)- $SrZrO_3$- $SrFeO_3$	NA	HfO_2 Based (2)
Insulator Material	BN	Various	$MgAl_2O_4$ Al_2O_3	Various	TBD	Various	Various
T_E, °C	~150	1700-1900	1000-1300	NA	1700-1900	NA	1700-1900
J, amp/cm^2	0.9	NA	To 1.25	NA	to 1.25	NA	TBD
Q. w/cm^2	~125	60	~80	NA	TBD	NA	~80
B, Tesla	TBD	NA	NA	NA	NA	NA	NA
Axial Field, Kv/m	Yes	NA	Yes	NA	TBD	No	TBD
Ash Type	Rosebud	Rosebud	Rosebud	Rosebud	Rosebud	Rosebud	Rosebud
Seed	K_2CO_3	K_2CO_3	K_2CO_3	K_2CO_3	K_2CO_3	K_2CO_3	K_2CO_3
SO_2 Level, m/o	0.06	0.06	0.06	0.06	0.3	0.06	0.3
Duration-Hrs.	~10	8/Increm.	~20	~10	~20	~10	~20

OPERATING MODE	SLAG HOT	NON-SLAG SH	SLAG HOT
Test ID	TBD	TBD	TBD
Test Section	TBD	TBD	TBD
Approx. Date	TBD	TBD	TBD
Electrode Material(1)	SiC	ZrO_2 Based HfO_2 Based Perovskite	$MgCr_2O_4$
Insulator Material	Si_3N_4	TBD	$MgAl_2O_4$ Al_2O_3
T_E, °C	1000-1300	1700-1900	1000-1400
J, amp/cm^2	To 1.25	To 1.25	To 1.25
Q, w/cm^2	~80	<60	~80
B, Tesla	NA	TBD	TBD
Axial Field, Kv/m	Yes	TBD	Yes
Ash Type	Rosebud	Rosebud	Rosebud
Seed	K_2CO_3	K_2CO_3	K_2CO_3
SO_2 Level, m/o	0.3	0.3	0.3
Duration-Hrs.	~20	~8/Increm.	~20

(1) Anode and Cathode Unless Otherwise noted
(2) With Indium Current Leadout
(3) MIT Material
(4) Materials Test section II

The Run 2 objective is to investigate the presence of a slag layer under Run 1 conditions and then assess the effect of the slag layer on the durability of the MgO liner at higher surface temperatures than were achieved in Run 1.

WESTF Test 43

Test 43 is the first screening test of materials under hot slagging conditions in WESTF. Its objective is to assess the durability of platinum anodes and iron cathodes under these conditions and to relate their performance to that predicted by laboratory screening tests in liquid slag.

The test section contains 12 electrode pair on a pitch of 1.36 cm. The cathodes are 1018 carbon steel with a surface area of 1 cm x 6 cm exposed to the plasma. A sketch of the cathode is shown in Figure 16. Electrode surface temperatures should range from 1300 K (inlet) to 1525 K (outlet). The distance from the electrode surface to the centerline of the water coolant passage varies from 2.59 to 3.04 cm, and the hydraulic diameter of the water passage is 0.32 cm. Plasma sprayed alumina and alumina adhesive cement provide high temperature electrical insulation; polyimide tape provides additional electrode insulation on the cooler electrode surfaces. The faces of the cathodes are coated with a thin layer of plasma sprayed mixture of nickel aluminide/alumina. The purpose of this coating is to provide oxidation protection for the iron before a slag layer develops and an electrical potential is applied.

The anodes consist of a 0.025 cm platinum foil diffusion-bonded to an alumina block. There are four segments per electrode assembly as shown in Figure 17. Each segment has a platinum foil leadout passing through a central slot. The electrode assembly is brazed to a nickel mesh/copper heat sink assembly with TiCuSil. The basic overall electrode dimensions and pitch are the same as the cathode wall. Anode surface temperatures range from 1400 K (inlet) to 1625 K (outlet). The thickness of the platinum/alumina assembly ranges from .119 cm to .577 cm. The distance from the electrode surface to the centerline of the water coolant passage varies from 2.59 to 3.04 cm and the hydraulic diameter is 0.32 cm. Alumina adhesive cement provides the high temperature electrical insulation; polyimide tape insulates the cooler surfaces. Design details are given in Section IV - 2.1.2.

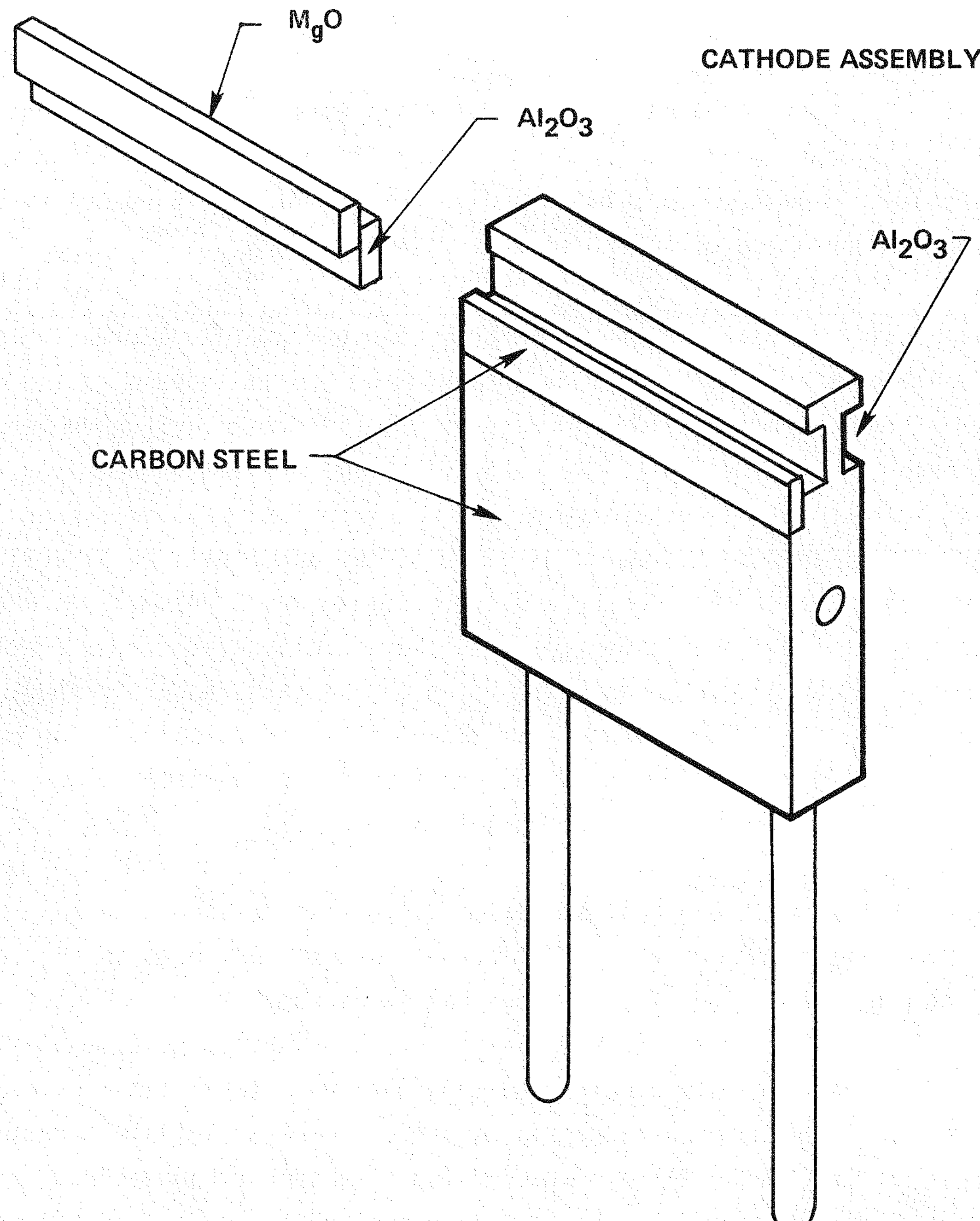


Figure 16. WESTF Test 43 Cathode

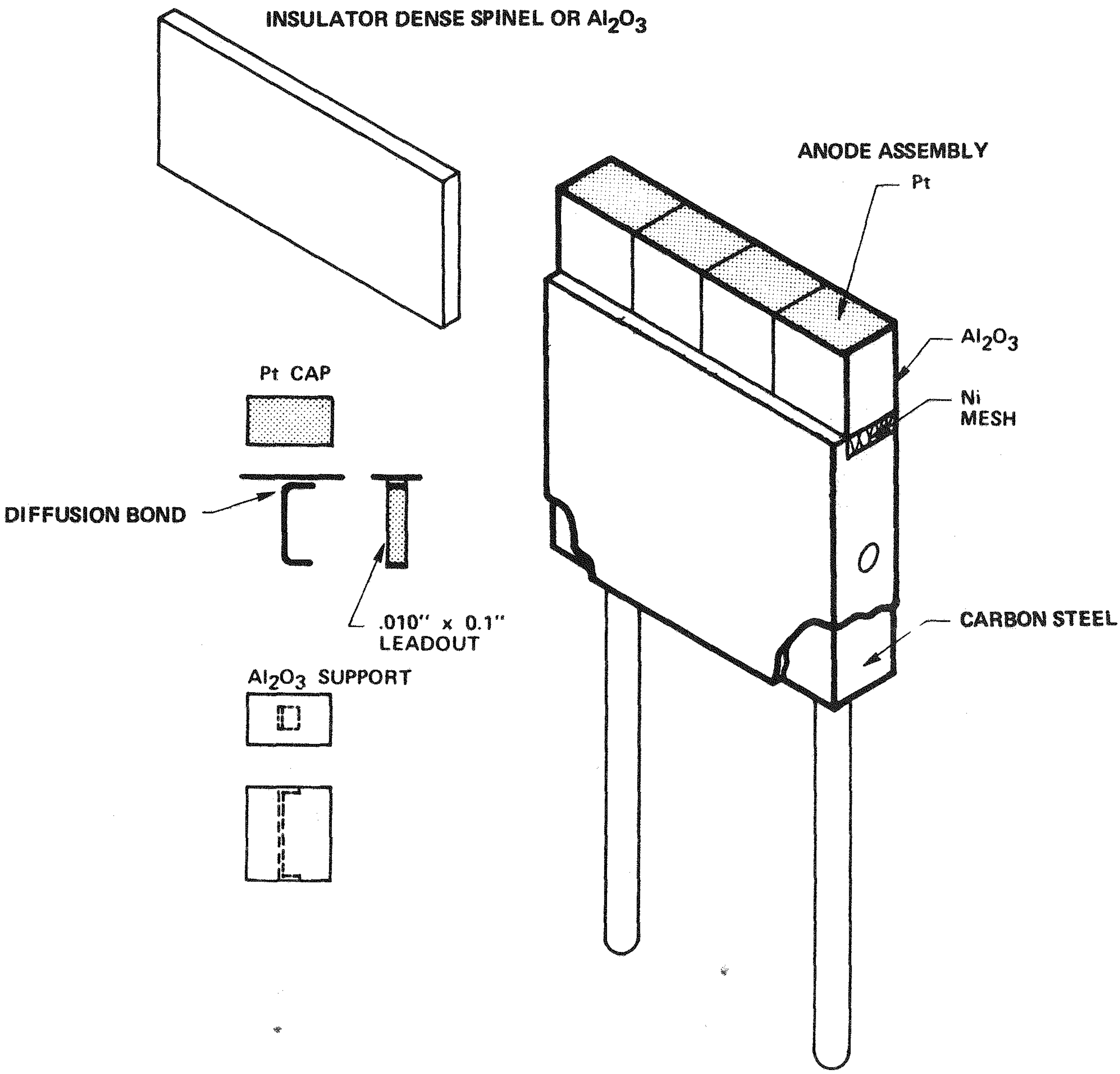


Figure 17. WESTF Test 43 Anode

The interelectrode insulation on the cathode wall is dense magnesia operating at an average surface temperature of 1510 K (inlet) to 1675 K (outlet) and ranging in thickness from 1.12 cm to 2.04 cm. Dense spinel operating at an average surface temperature of 1625 K (inlet) to 1785 K (outlet) is used on the anode wall at thicknesses ranging from .12 cm to .58 cm. Fused cast alumina is used to line the insulating walls and the transition sections. A thickness of 0.6 cm provides a maximum surface temperature of 1650°C in the transition sections and of 900°C for the insulating walls.

WESTF Test 44

A preliminary test specification issued for WESTF Test 44 is guiding the design of a modular channel section that is a prototype of the test section design to be developed for use with the magnet that is to be installed in WESTF. The test includes a hafnia-based electrode ($0.063 \cdot Tb_4O_7 \cdot 0.063\ Y_2O_3 \cdot 0.874\ HfO_2$) with an integral indium doped hafnia leadout ($0.16\ Y_2O_3 \cdot 0.55\ In_2O_3 \cdot 0.29\ HfO_2$) to be supplied by BPNL for testing under super-hot non-slagging conditions. The objective of this test is to evaluate this material when operated at an electrode surface temperature of 1750°C.

WESTF Test 45

The objective of WESTF Test 45 is to evaluate dense single-phase yttria stabilized zirconia as an electrode in a non-slagging super-hot environment. Two electrode pairs of 0.188 in thick yttria stablilized zirconia are imbedded in a high purity periclase refractory with MgO castable and placed in the Material Test Section. The electrodes are designed to run at a surface temperature of ~1800°C with a current density of 0.9 A/cm^2.

WESTF Test 46

The objective of WESTF Test 46 is to provide comparative performance data on 85% and 97% dense high purity MgO, a 98% pure MgO, and an MgO castable in a super-hot, western slag environment. The 85% dense MgO is a reference material; the 98% pure MgO and the castable are candidates for insulating walls and WESTF mixer combustor linings, respectively.

The test article is composed of inlet and outlet transition sections joined together. The design surface temperature of all materials in this test is 1700°C. On the upstream section, two adjacent walls are lined with a high purity MgO (NORTON, MG-NT-0201) and the other two are lined with another high purity MgO (TRANS-TECH, MG-TT-0401). The latter material will have a finer degree of segmentation than the former. The downstream section has two adjacent walls lined with 98% MgO (HARKLASE, MG-HW0501) and the opposite walls lined with MgO castable (PERMANENTE 165, MG-KA0201).

WESTF Test 47

The objective of WESTF Test 47 is to evaluate the performance of platinum clad copper in a slagging cold western slag environment. The platinum clad copper is considered the reference material for this operating mode. This test will also provide for initial operation and checkout of Type II Materials Test Section (MTS-II).

The electrode surface exposed to the slag/plasma is 0.75 in. diameter (0.442 in^2) and is contained within a cylindrical boron nitride (lava on the cathode side) insulator with a 0.25 in. wall thickness. The anode wall will consist of 0.010 in. platinum clad copper electrodes. The cathode electrodes will be run without any cladding or coating.

WESTF Test 48

WESTF Test 48 is a continuation of insulator material testing begun with WESTF Test 46. The objective of WESTF Test 48 is to provide comparative performance data on an 85% dense high purity MgO, a fused cast spinel, a spinel castable, and a fused cast alumina in a super-hot western slag environment. The high purity MgO is a reference material; the other materials are candidates for insulating walls and WESTF mixer and combustor linings, respectively.

The test article is composed of inlet and outlet transition sections joined together. On the upstream section, two adjacent walls are lined with a high purity MgO (NORTON, MG-NT-0201) and the other two are lined with fused cast spinel (MA-CR-0101). The downstream section has two adjacent walls lined with

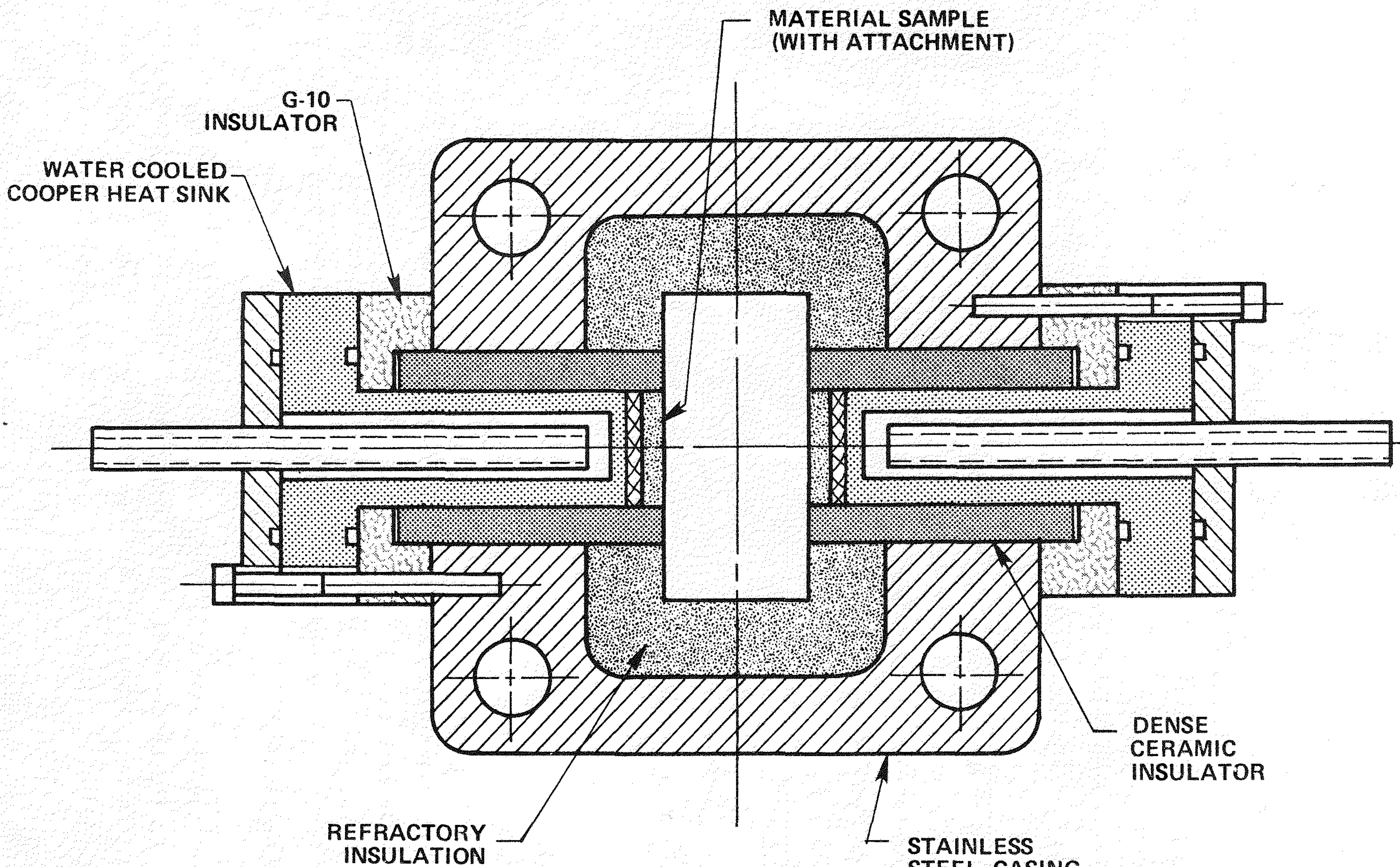


Figure 18. Type II Materials Test Section Schematic

fused cast alumina (MONOFRAX A-AL-CC0201), and the opposite walls lined with spinel castable (MA-NT-0301).

2.1.2 Experiment Design

Type II Materials Test Section (MTS II)

A second generation Materials Test Section (MTS II) has been designed to replace the original MTS described in the prior quarterly report (Reference 12). This test section, schematically shown in Figure 18 and termed MTS II, consists of a square stainless steel casing, which is internally water cooled, that can be lined with either refractory castable or refractory brick insulation. The test section incorporates three removable water cooled assemblies on both the anode and cathode walls. These assemblies can accommodate either slagging cold wall, slagging hot wall or non-slagging super-hot wall materials. Dependent upon the requirements of the particular test, the MTS II test section can include the following diagnostic instrumentation:

- Sample calorimetry
- Sample thermocouple(s)
- Insulation thermocouple(s)
- Optical sight port (viewing center 'anode')
- Retractable gas stream thermocouple

The removable assemblies incorporate an electrode material (or insulator material) 0.75 in. diameter which is attached to the water cooled copper heat sink. This is surrounded by a 0.25 in. thick tubular insulator to aid in assuring easy removal from the body of the test section and, in the case of electrode material tests with impressed current, to minimize potential electrical leakage. MTS II, as currently configured, is not intended to be used in conjunction with the WESTF magnet which will be installed shortly.

As presented in subsequent sections, the MTS II Test Section has been fabricated and its checkout and initial use will be in conjunction with WESTF Test 47 which will be run in early January 1980.

WESTF II Test Section

Layout work has been completed on the modified test section structure intended for use with the 3 tesla conventional magnet which is to be installed in WESTF. The primary constraint on the design of this test section is the available space within the magnet bore. The general features of the WESTF II test section design are presented in Reference 12.

During this quarter, details of the design, which reflect its intended initial use in the WESTF Test 44 test of BPNL hafnia electrodes with integral oxide current leadout material, were revised to include the following:

- change in electrode pitch resulting from the change in electrode thermal diffusivity/conductivity.
- change in the design of the insulating wall elements.

Specific details relating to the change in electrode sizing are presented in a succeeding section covering the thermal design and sizing of the WESTF Test 44 electrodes.

The detailed design of the insulating wall elements has been revised to effect increased lateral segmentation to minimize electrical leakage. While this alternate design simulates the peg-wall concept, because of the small duct size the individual insulated sections are a larger percentage of the overall lateral length than would be true in a larger duct. The insulating wall elements are shown in Figure 19.

A thick-walled rectangular tube of fiber reinforced G-11 material has been obtained and is being evaluated for use as the external structural member of the test section. Use of this tubular material offers the potential advantage of minimizing the number of axial joints for a given test section as compared to machining window frames from plate stock. In addition, the fiber reinforcement orientation is more favorable from the standpoint of both strength and leak tightness. This sample is shown in Figure 20.

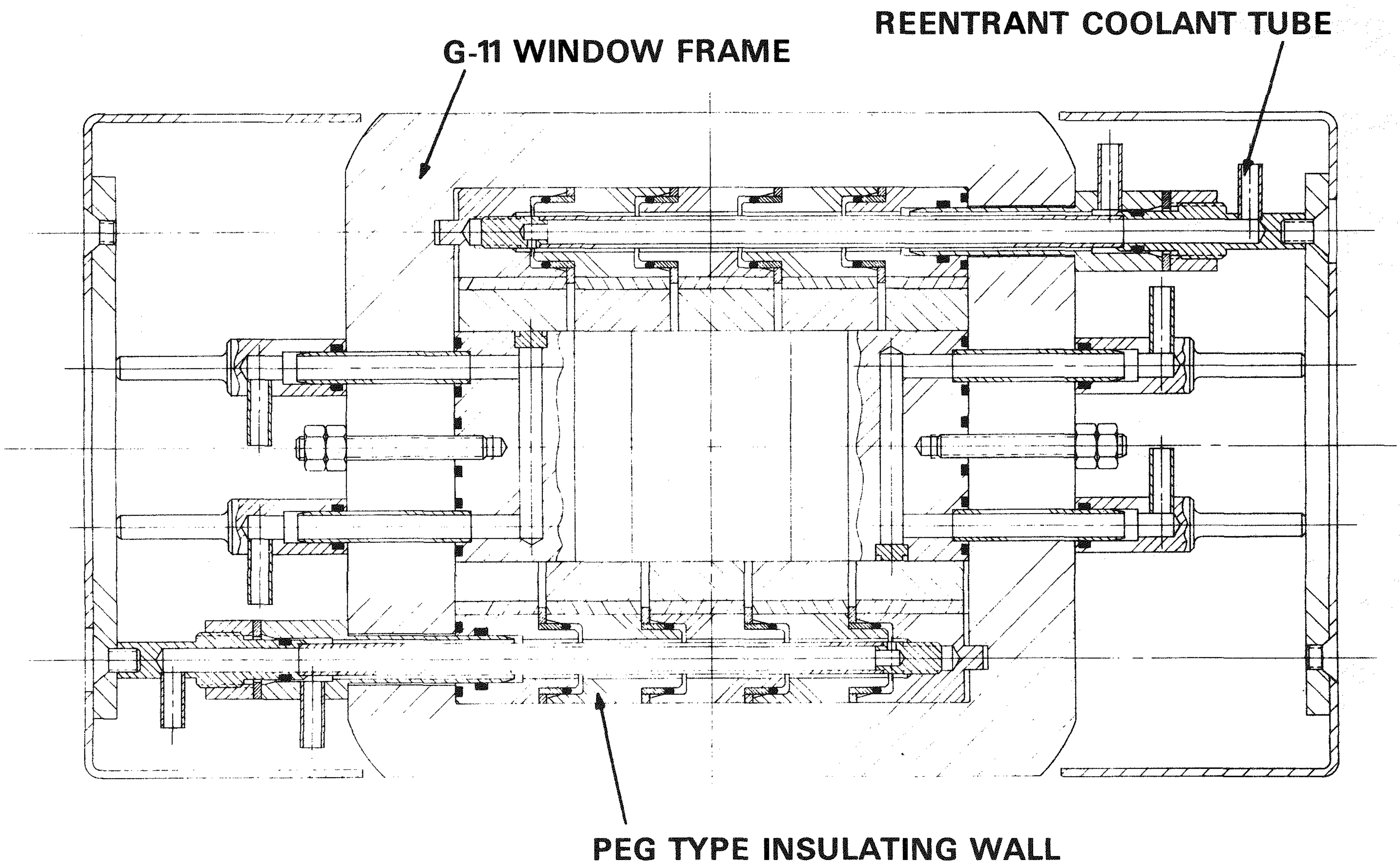


Figure 19. WESTF II Test Section Insulating Wall

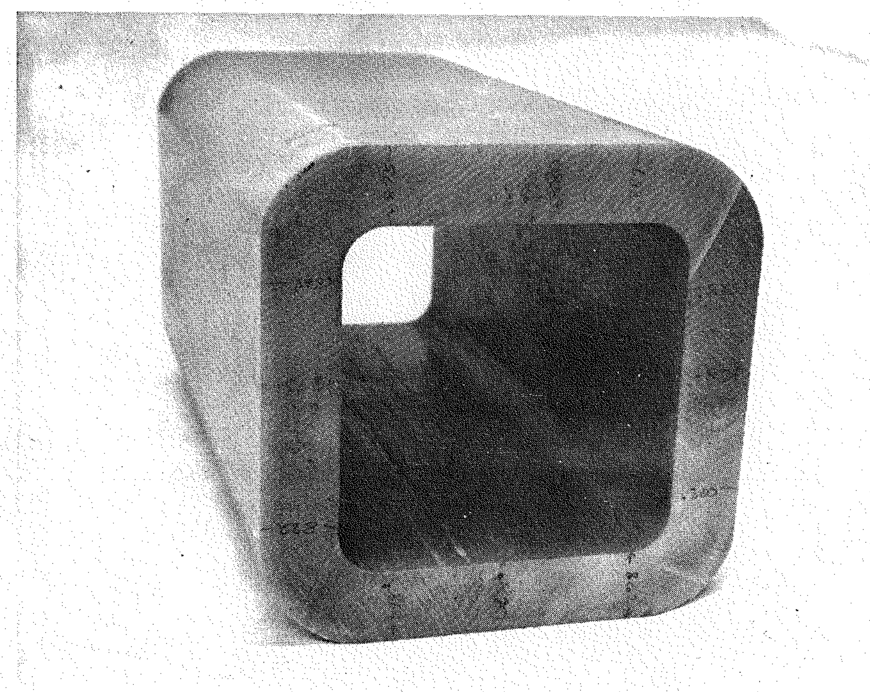


Figure 20. Square Tube of NEMA Grade G-11 High Pressure Laminate

Prototype Gas Stream Thermocouple

The use of fixed Ir/Rh thermocouples to measure plasma temperatures directly in prior MHD tests has met with only limited success. In general, these thermocouples have provided useful temperature readings only as the system is coming up to operating temperature. Failure of the thermocouples usually occurs shortly after seed and ash are introduced. In order to extend the performance beyond that achievable with a fixed thermocouple, an alternative thermocouple measurement system has been designed and subsequently checked out in WESTF Test D-11 under clean firing conditions.

Since failure of the thermocouples appears to be largely a question of time at temperature, an injection system was designed in which the thermocouple could be inserted into the gas stream for the time required to read plasma temperatures. The thermocouple is then withdrawn. Figure 21 is an assembly drawing of an injection system design which was used successfully in WESTF Test D-11. A permanent magnet, not shown in the figure, was used to insert the thermocouple and to remove it when desired. A mechanical valve in the injection assembly system permits removal and replacement of the thermocouple should it fail during a lengthy test. The use of a protective gas flush minimizes deposition of seed and ash on the valve. Use of the injection thermocouple system during a run involves setting up the data acquisition system so that it would exclusively read the temperatures of the Ir/Rh thermocouple at a three times per second rate as it is injected into the channel. A typical curve giving the transient thermocouple response is shown in Figure 22.

A special test was run to determine just how much the introduction of protective gas influences the thermocouple readings. The protective gas was turned off during this test after the injected thermocouple had come to an equilibrium temperature of 1844^{o}C. When the protective gas was turned off, the temperature rose some 60^{o}C to 1906^{o}C. The use of a protective gas to reduce the exposure of the thermocouple to high temperatures once the magnitude of the required corrections are demonstrated appears to be feasible.

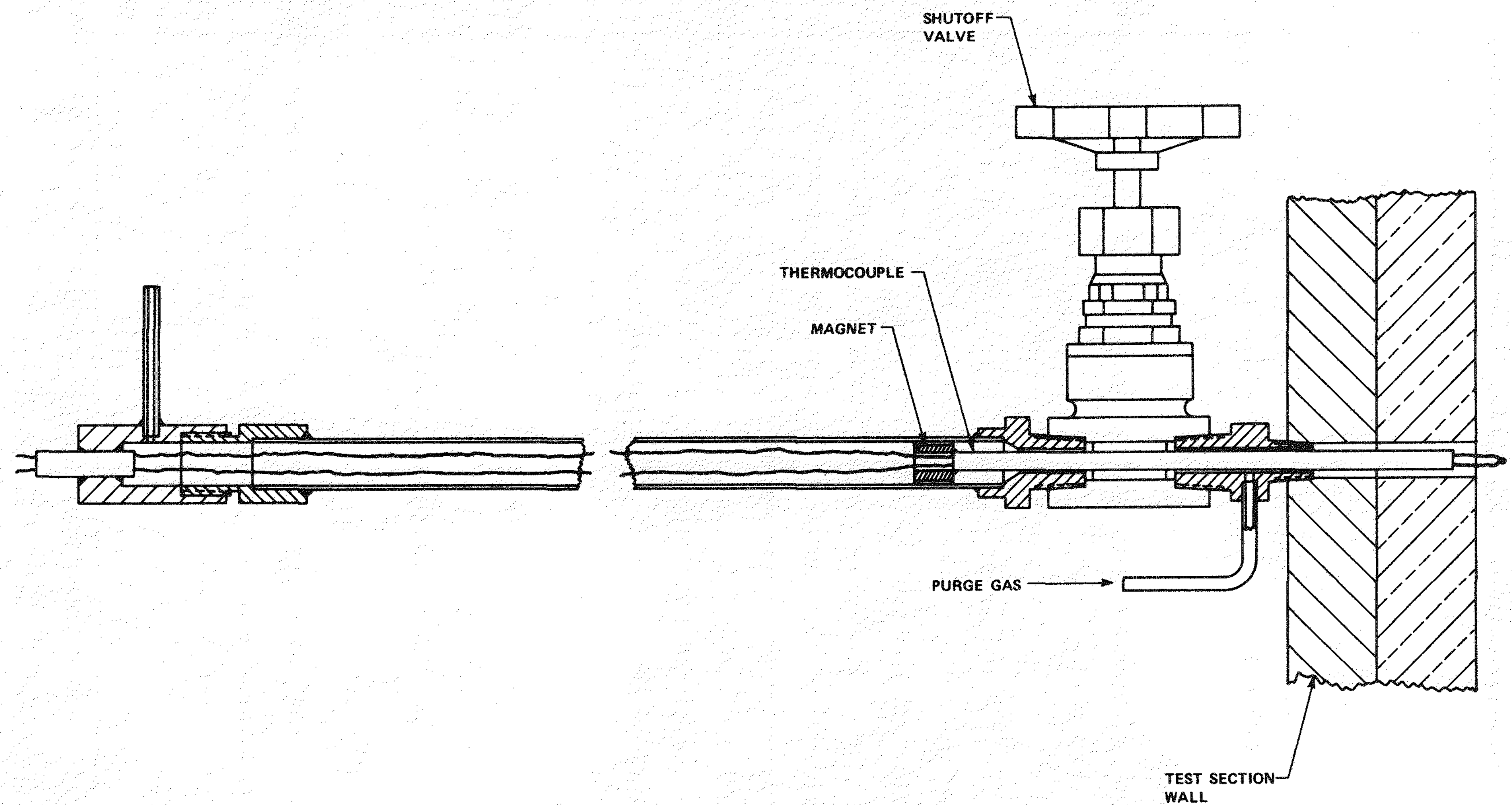


Figure 21. Insertable Gas Stream Thermocouple

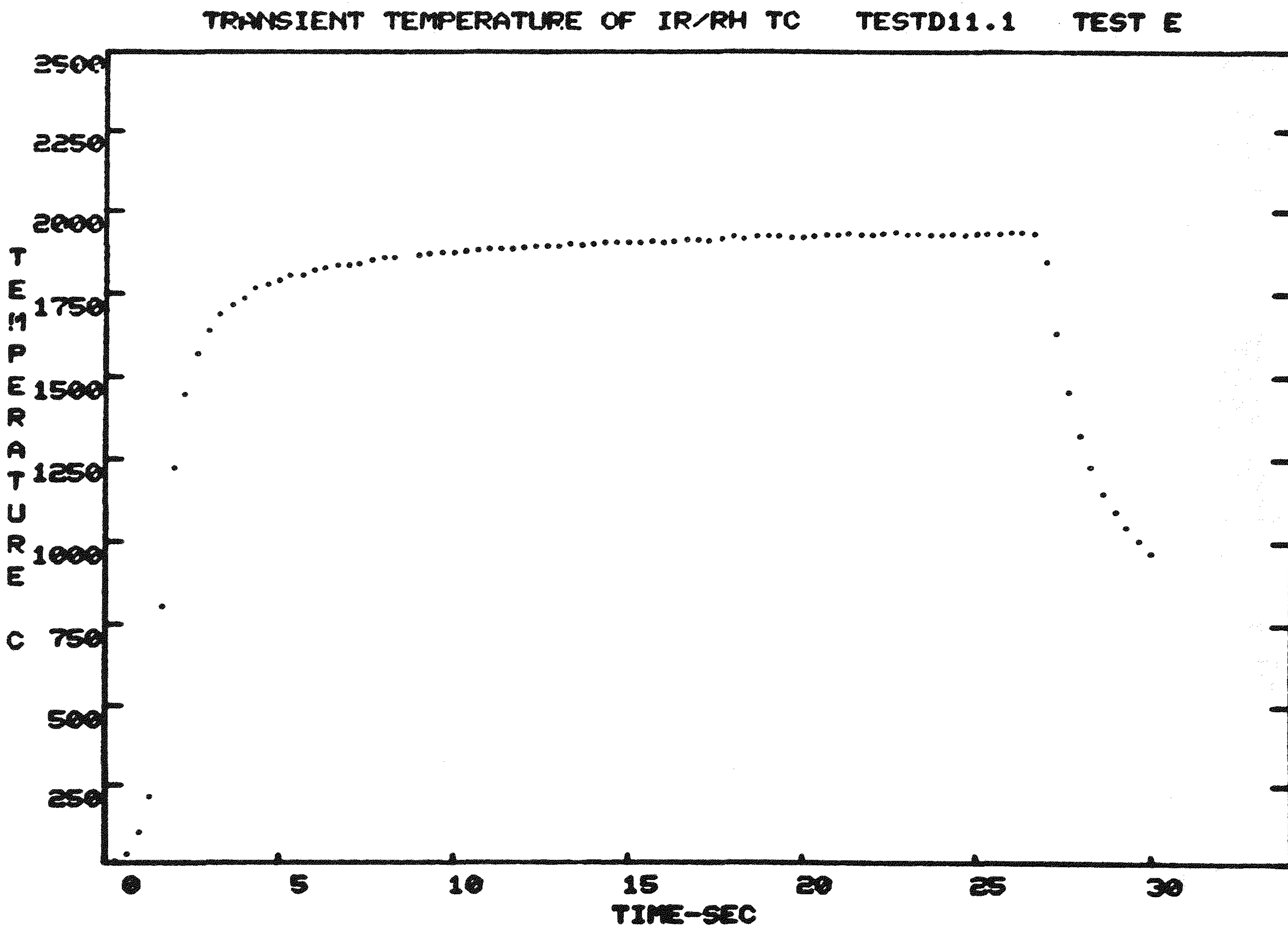


Figure 22. Computer Plot of Indicated Temperature

Some effort was made to determine whether the rate of rise of the thermocouple versus time, when the thermocouple was first injected, could be used to predict the final equilibrium temperature. While steeper slope curves were observed to correspond to higher final temperatures, it was concluded that this approach to minimizing the thermocouple exposure to the ambient was not accurate enough to be usefuel at this time. In addition, the injection system as used in Figure 21 appears to be capable of the standing up for the required number of measurements. A single thermocouple was used for 2 separate runs. In addition, the thermocouple can be changed under operating conditions should it fail.

Correction of Thermocouple Temperature Data

A thermocouple mounted in a hot gas stream reads its own temperature. In order to determine gas temperature the energy balance between the heating of the thermocouple by the hot gas stream and loss of heat by conduction and radiation must be worked out. Correction curves are shown in Figures 23 through 25. These curves are based on use of a 5 in. long Ir/Rh thermocouple having .032 in. diameter wires, a .055 in. diameter bead and an emissivity of 0.2.

Figure 23 gives the temperatures corrections which must be added to the thermocouple temperature readings as a function of wall temperature for plasma velocities of 300, 400, 500 and 600 meters/sec. The sytem pressure was 2 atmospheres. Figures 24(a) gives temperature corrections as a function of plasma velocity for different wall temperatures with the system at 2 atmosphere pressures and with the thermocouple reading 2250°C.

Figure 24(b) gives the temperature correction for the system at 2 and at 1 atmospheres pressure. Figure 24(c) gives temperature as a function of plasma velocity for a thermocouple reading of 2200°C and 1 atmosphere.

Since most of the thermocouple data of interest relates to operating temperatures in excess of 1900°C, the data of Figure 25 is provided to give temperature correction data as a function of plasma velocity for thermocouple

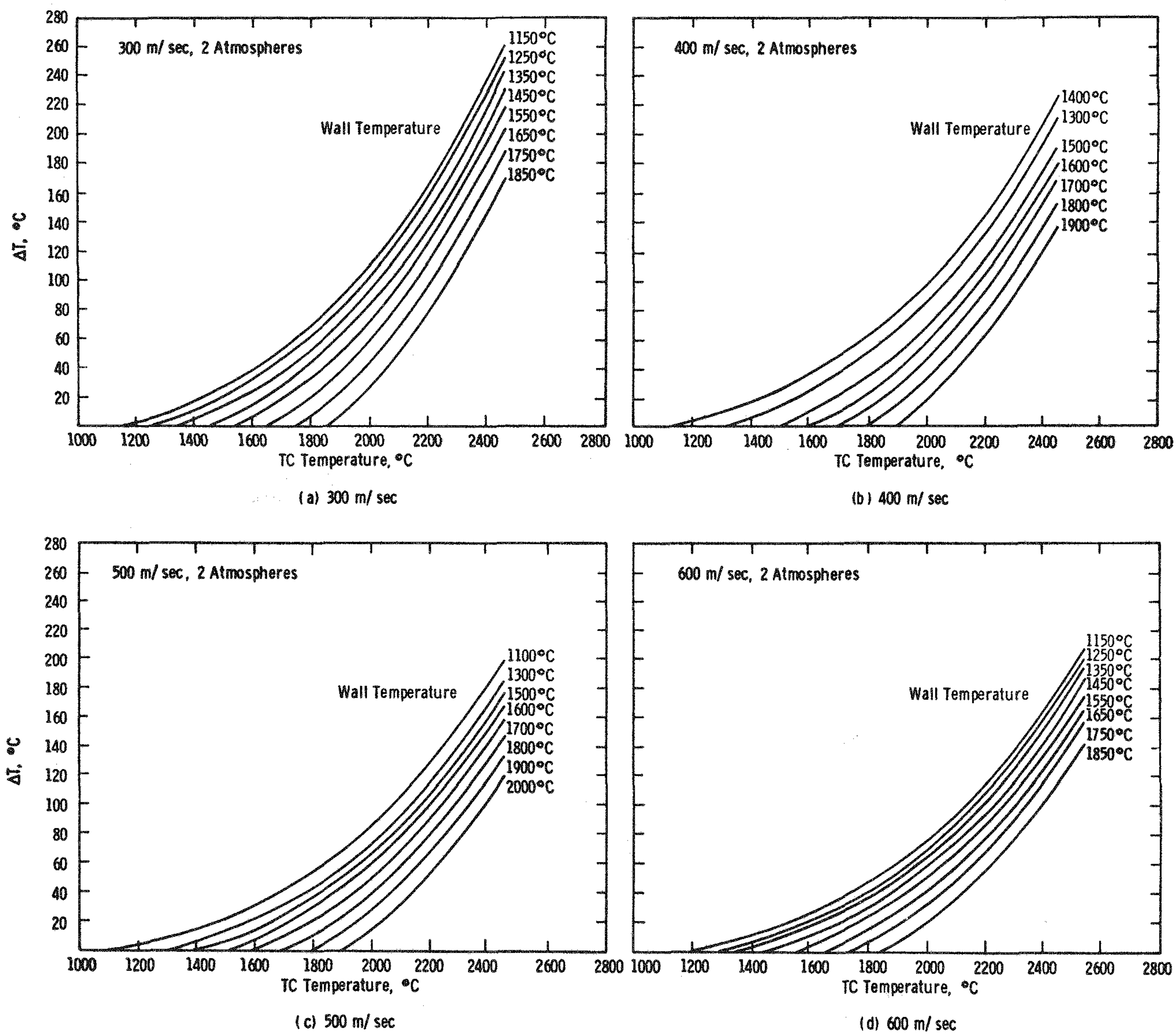
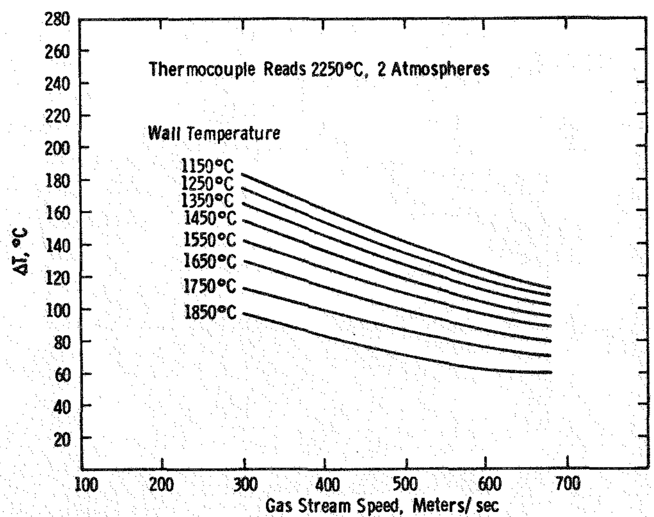
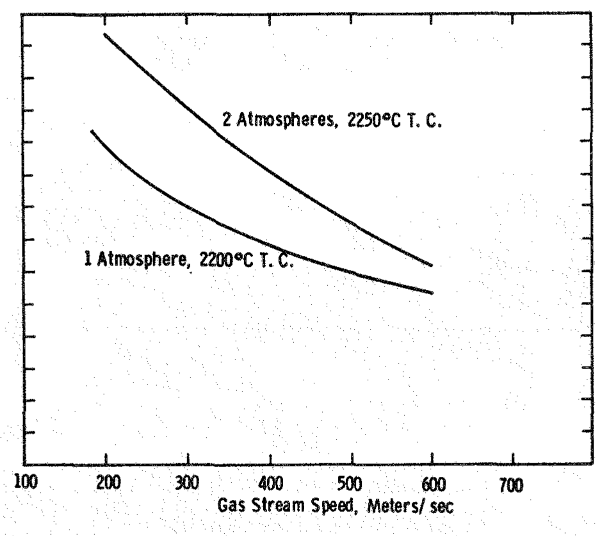


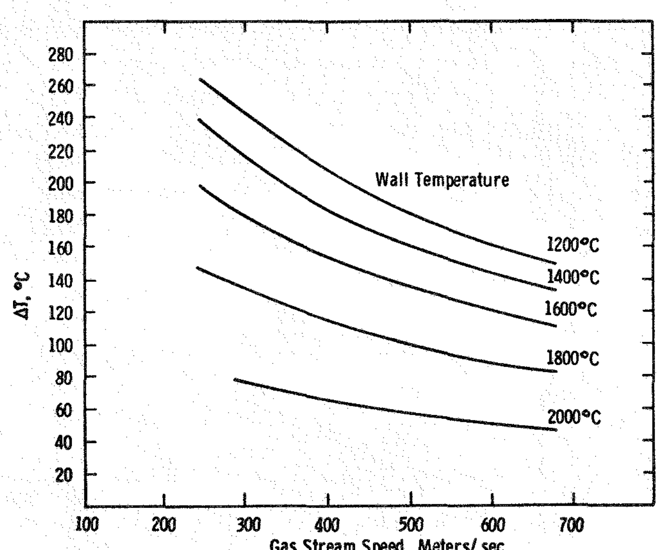
Figure 23. Thermocouple Correction Temperatures for Different Wall Temperatures at 2 Atm.



(a) 2 Atmospheres, Thermocouple Reading 2250°C



(b) 2 Atmospheres, 1 Atmosphere 1400°C wall, Thermocouple Readings as Indicated



(c) 1 Atmosphere, Thermocouple Reading 2200°C

Figure 24. Thermocouple Corrections as Function of System Variables

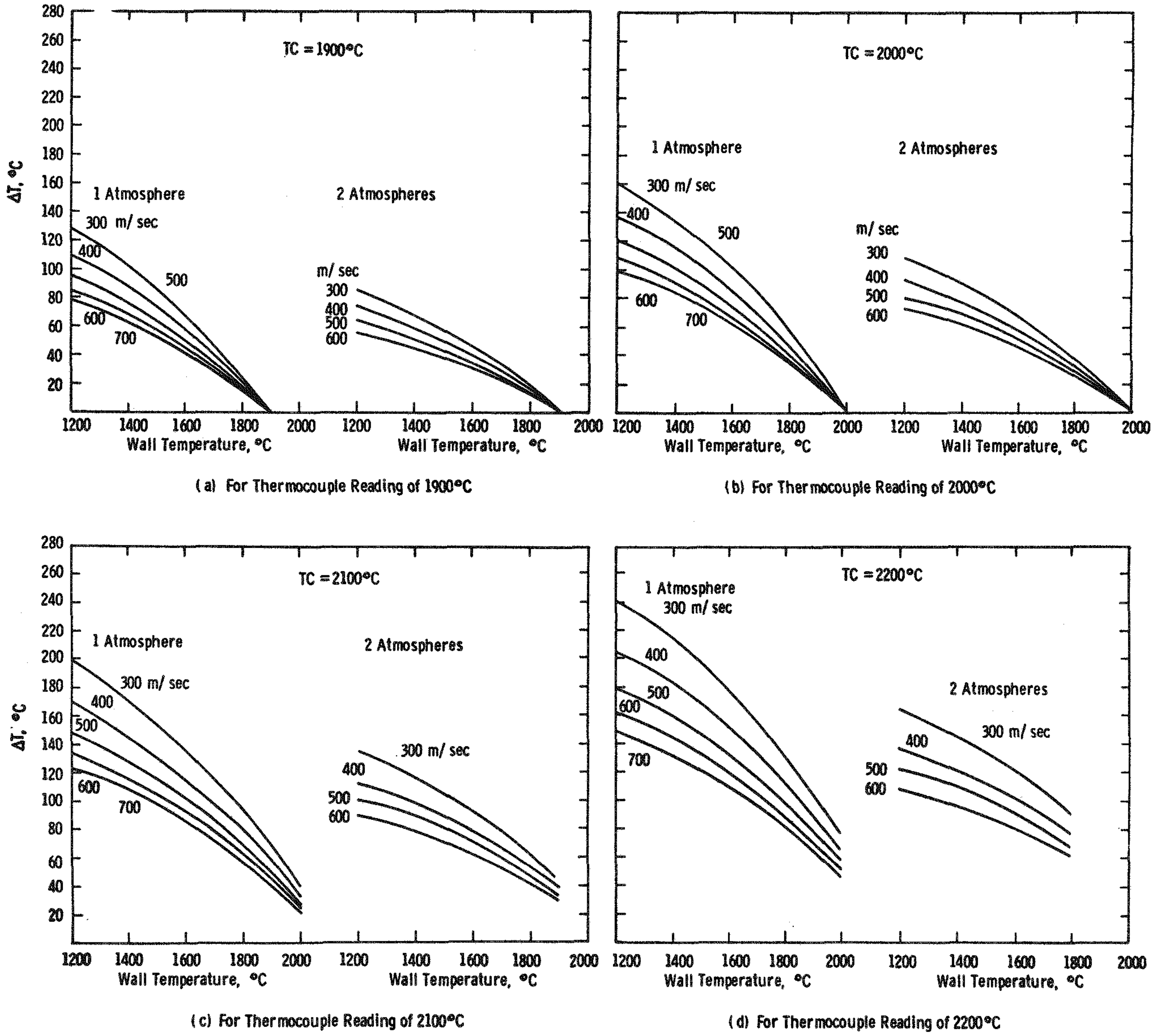


Figure 25. Thermocouple Correction Temperatures for Different Velocity and System Pressure

readings of 1900°C, 2000°C, 2100°C and 2200°C and system pressures of 1 and 2 atmospheres. Corrections for intermediate pressure can be approximated by interpolation.

WESTF Test 43

WESTF Test 43 is the first screening test of materials under slagging hot conditions. Platinum anodes and iron cathodes were identified as candidate materials as a result of prior laboratory screening tests. The primary objective of this test is to assess the durability of these materials over a range of surface temperatures, 1000 to 1350°C, under slagging hot conditions and to relate their performance to that predicted by laboratory screening tests.

Details of the thermal analysis required for electrode sizing was previously reported (Reference 2). During this quarter the preferred hydraulic arrangement and instrumentation requirements were defined.

Efforts were also directed toward the development of on-line mini-computer algorithms to aid in monitoring of material temperatures during the test through the projection of ceramic assembly surface temperatures as a function of bulk ceramic temperature measurements and heat fluxes developed from the water calorimeter measurements.

WESTF Test 44

WESTF Test 44 will provide for the initial operation of the WESTF II test section, i.e., the test section which is being designed to be compatible with the dimension constraints of the magnet bore. In structuring this test, it was also decided that the hafnia electrodes (0.063 $Tb_4O_7 \cdot 0.063\ Y_2O_3 \cdot 0.874\ HfO_2$), with integral indium oxide current lead out (0.16 $Y_2O_3 \cdot 0.55 In_2O_3 \cdot 0.29$ Hf) developed by BPNL, would be included.

Detailed thermal design of the electrodes was completed based on the thermal diffusivity measurements, and calculated thermal conductivity values, provided by BPNL. Subsequent to completion of this design activity, BPNL obtained new heat capacity data which altered the calculated values of thermal conductivity.

The changes to the rare earth hafnium oxide were small, approximately 2 to 4%, which were not significant. However, the change in thermal conductivity of the oxide current leadout using In_2O_3 was significant. The revised values are approximately 50% of the previously reported values. As a result the thermal design of the electrodes was revised to reflect the change in thermal conductivity values and at the same time to include Joule heating effects based on recently supplied resistivity data.

The thermal design constraints applicable to the electrode walls, in descending order of importance, were established as follows:

1) Electrode and insulator coverage surface temperature - 1750^oC (electrode), 1550 $\pm$ 100^oC (insulator).
2) Hafnia/current leadout interface temperature -1250 $\pm$ 100^oC.
3) Compliant layer/leadout interface temperature - $<$550^oC.
4) Surface heat flux - $>$40 w/cm^2.

A further constraint on the electrode design was to maintain compatibility with the design of the WESTF II test section which was being completed in parallel.

Based upon the conceptual design shown in Figure 26 and on geometric and thermal symmetry only one half of the electrode assembly was modeled to complete the thermal sizing. The finite difference model for the electrode configuration is shown in Figure 27. Thermal conductivity data for the WESTF Test 44 materials are presented in Figure 28. Electrical conductivity data for the current leadout is given in Figure 29.

As shown on Table 8 the predicted thermal parameters for WESTF Test 44 satisfy the test requirements.

WESTF Test D-11

WESTF Test D-11 was designed to investigate facility and test section thermal response to clean-firing operation over a range of fuel equivalence ratios and mass flow rates. The test section was composed of back to back transition sections. The upstream section transition was lined with 0.325 inch thick

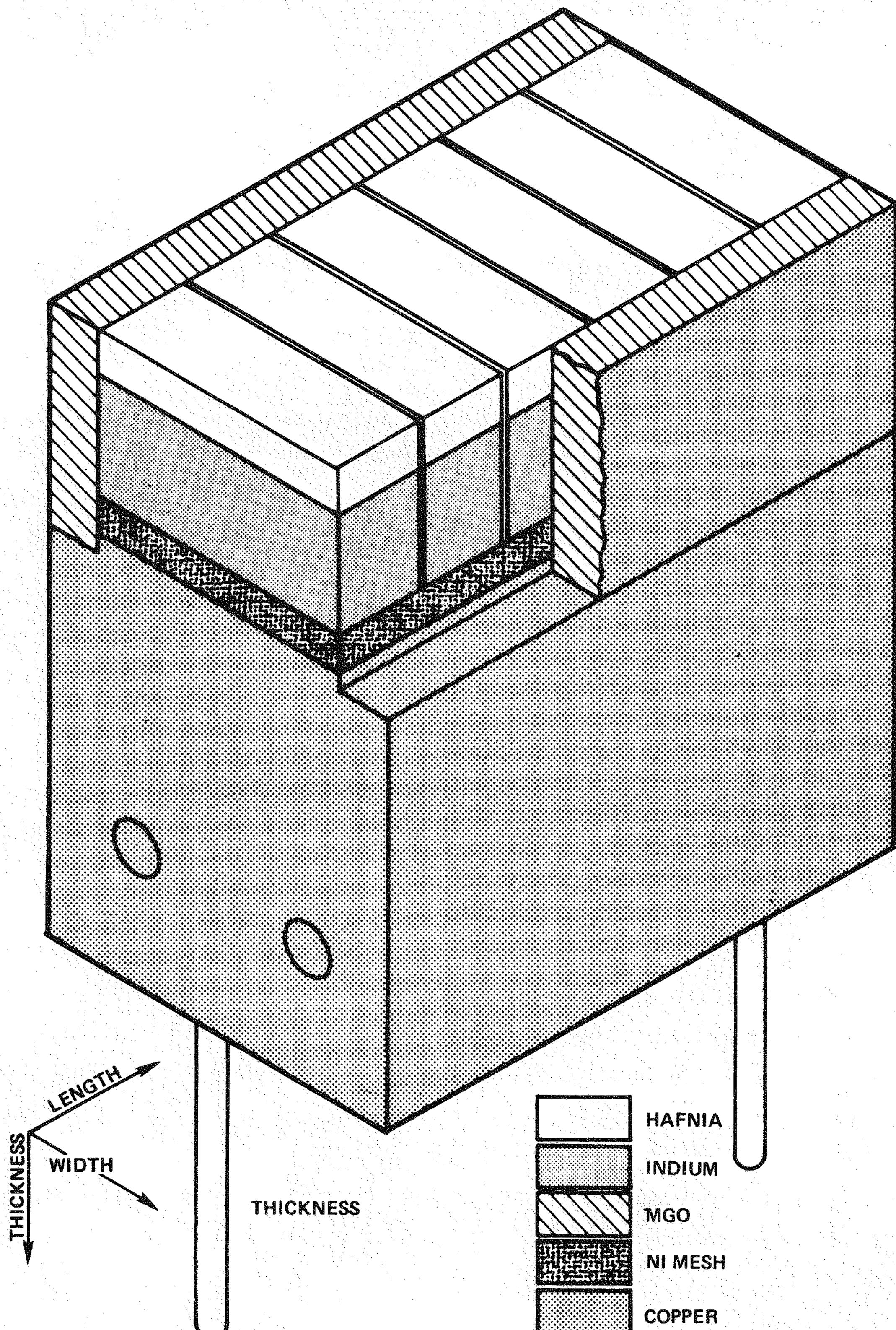


Figure 26. WESTF Test 44, Electrode Conceptual Design

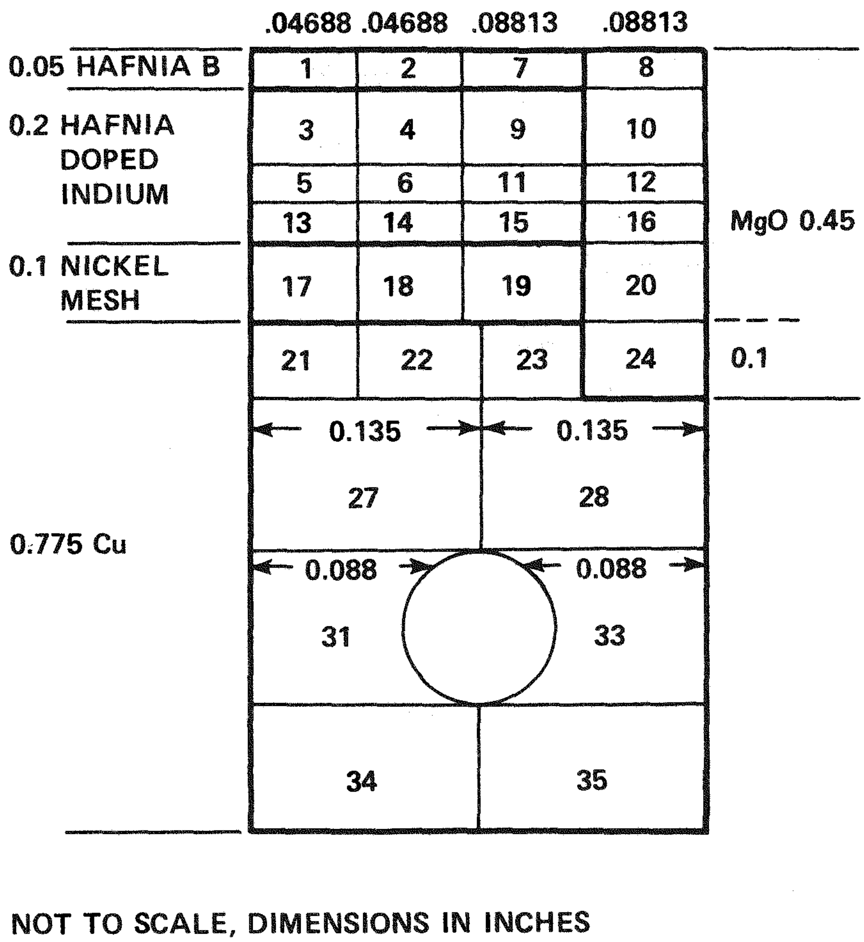


Figure 27. Finite Difference Electrode Model for WESTF Test 44

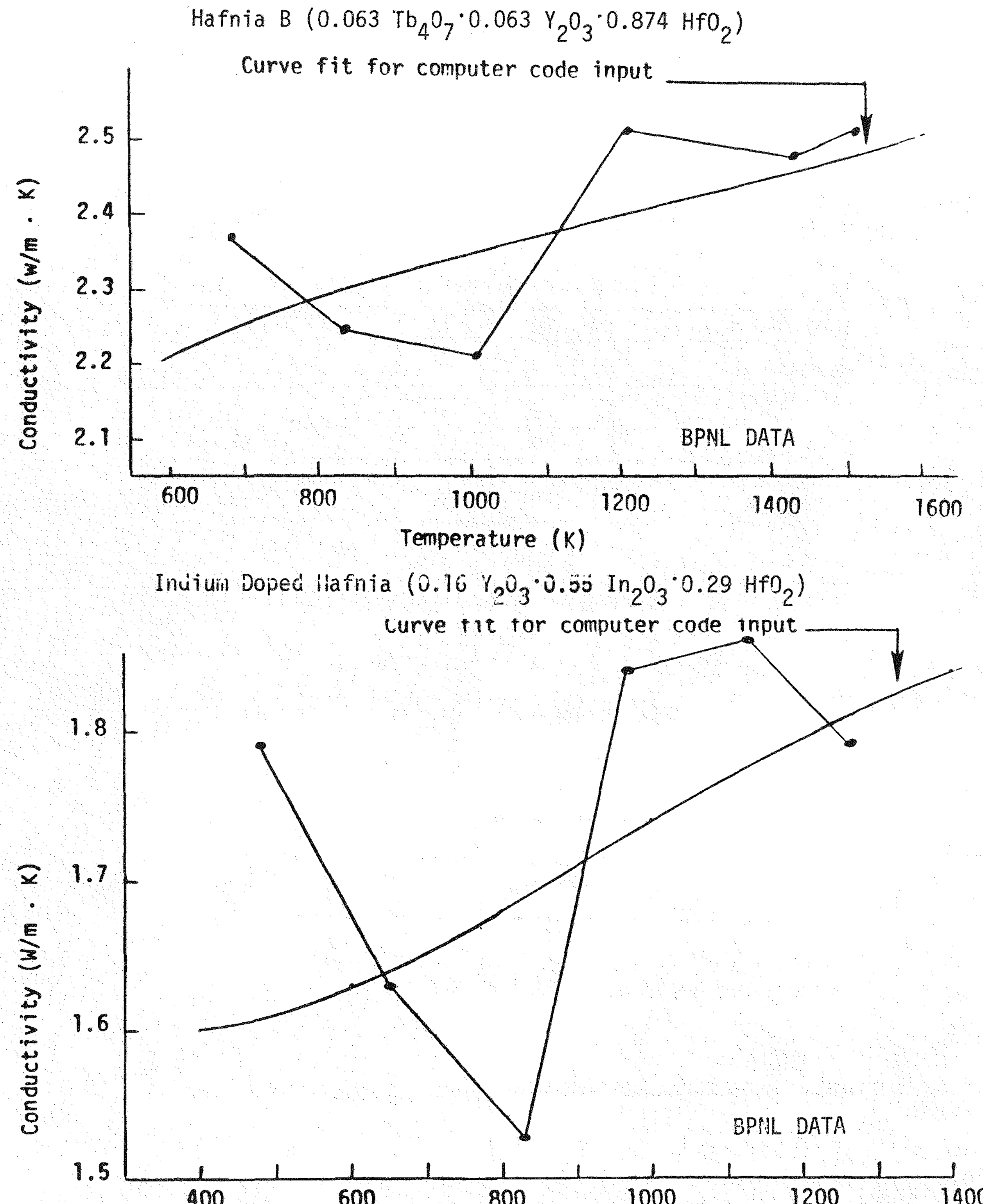


Figure 28. Thermal Conductivity of WESTF Test 44 Electrode Materials

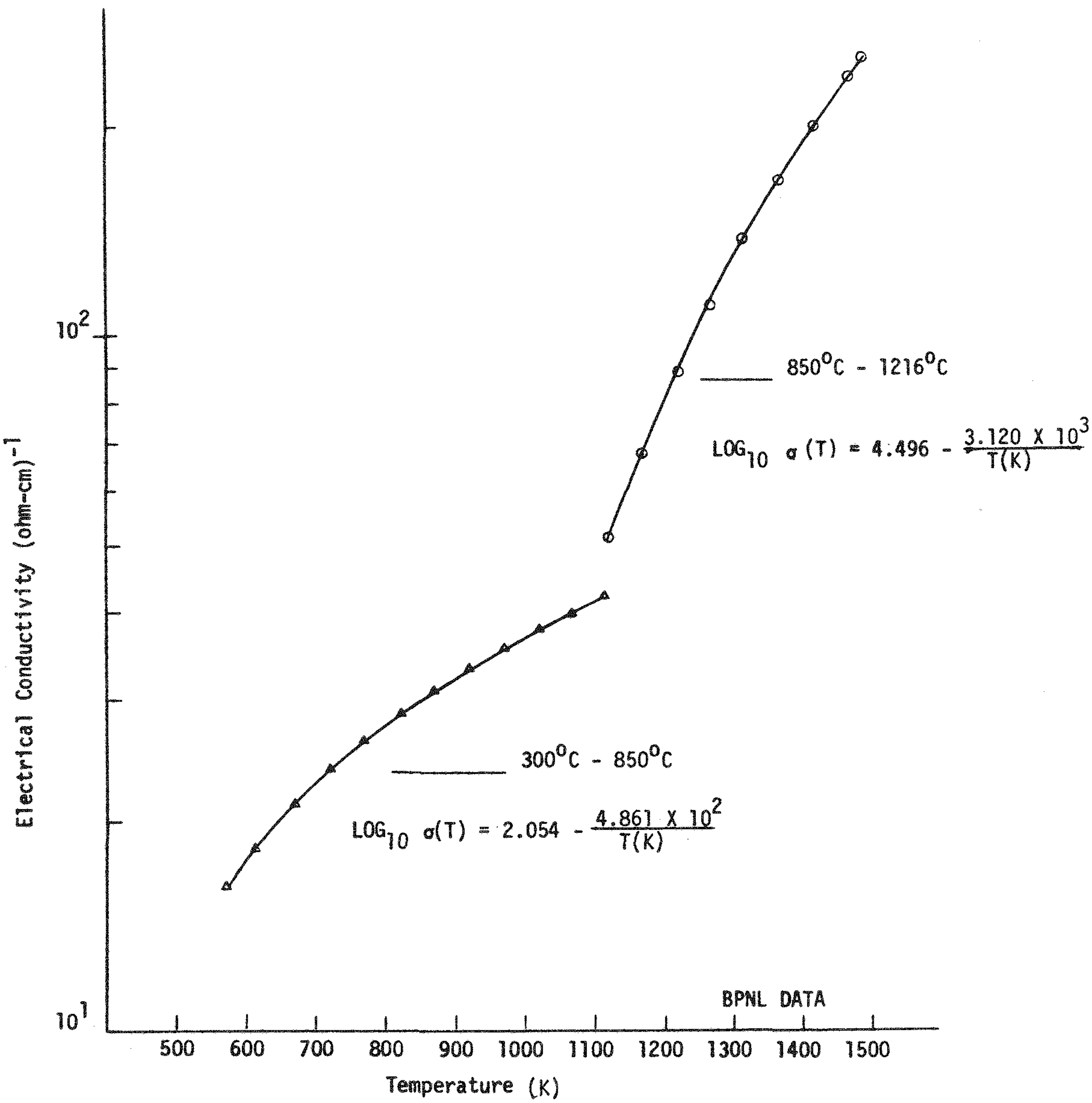


Figure 29. Electrical Conductivity of Indium Doped Hafnia ($0.16\ Y_2O_3 \cdot 0.55\ In_2O_3 \cdot 0.29$ Hf)

TABLE 8

PREDICTED PARAMETERS FOR WESTF TEST 44

Parameter of Interest	Plasma Temperature (K)		
	2480	2550	2670
Avg. Electrode Surface Temp. ($^oC/K$)	1739/2012	1798/2071	1902/2175
Avg. Insulator Surface Temp. ($^oC/K$)	1319/1592	1378/1651	1489/1762
Avg. Interface "Attachment" Temp.- Hafnia B, Indium Doped Hafnia ($^oC/K$)	1304/1577	1328/1591	1395/1668
Avg. Interface "Attachment" Temp. - Indium Doped Hafnia, Nickel Mesh ($^oC/K$)	185/458	231/504	250/523
Avg. Interface "Attachment" Temp. - Nickel Mesh, Copper Heat Sink ($^oC/K$)	81/354	92/365	100/373
Avg. Electrode Surface Heat Flux (W/cm^2)	48.0	49.1	50.7
Avg. Insulator Surface Heat Flux (W/cm^2)	88.2	89.2	90.1
Total Face Avg. Heat Flux (W/cm^2)	61.1	62.2	63.5
Total Facility Mass Flow Rate (kg/sec)	0.327	0.285	0.213
Total Coolant Flow Rate (gph)	85-95	85-95	85-95

Norton MgO (85% dense) TiCuSil brazed to 0.1 inch nickel mesh which was in turn brazed to copper. The downstream transition functioned as a spacer and incorporated the insertable gas stream thermocouple previously described. The insulation thickness of 0.325 inch was selected to limit the insulation surface temperature of $1650^{o}C$.

The primary design activity was that associated with definition of the facility operating map, consistent with the temperature limits of the insulating walls, to provide significant thermal performance data. The planned operating map, shown in Figure 30, is intended to investigate facility performance and the interrelationship of the adiabatic flame temperature; the fuel equivalence ratio or stoichiometry; the various degrees of oxygen enrichment; the total mass flow rate, and the insulating wall surface temperature and heat flux. Table 9 summarizes the facility operating conditions for the particular path/point of the WESTF Test D-11 Operating Map.

WESTF Test 45

WESTF Test 45 is the first screening test of an electrode material in WESTF in the non-slagging super-hot operating mode. This test, using the Materials Test Section (MTS), incorporates dense single-phase yttria stabilized zirconia. Each of the electrodes has a thickness of 0.188 inches with an exposed area to the plasma of 0.177 $inches^2$. The two electrode pairs are imbedded in the brick with MgO castable. Type 'S' thermocouples are positioned 2 mm from its surface in the downstream electrode pair. Electrical leadouts (.040 in. Pt wire) are attached to the back surface of each electrode with Pt paste and mesh. A sight port is included to view the surface of one of the downstream electrodes. A one dimensional thermal analysis was used to predict the surface heat fluxes and electrode surface temperatures at the selected mass flow rates. Table 10 summarizes the thermal design conditions for WESTF Test 45.

WESTF Test 46

WESTF Test 46 is the first of an anticipated series of insulator material screening tests. The primary objective of this test, and test series, is to

TABLE 9

PLANNED OPERATING CONDITIONS, WESTF TEST D-11

Condition Path	Condition Point	Fuel Kg/Sec	Fuel %	Air Kg/sec	Air %	Oxygen Kg/sec	Oxygen %	Fuel Equivalence Ratio ϕ_f	Oxygen Enrichment N_o	Total Mass Flow kg/sec	Estimate Plasma Temperature ^oK
1	1	0.00626	39.3	0.0469	10.6	0.0218	35.5	0.64	2.0	0.075	2550
	2	0.00697	43.8	0.0465	10.5	0.0216	35.2	0.72	2.0	0.075	2650
	3	0.00801	50.3	0.0458	10.3	0.0212	34.6	0.84	2.0	0.075	2760
	4	0.00893	56.1	0.0451	10.2	0.0209	34.1	0.95	2.0	0.075	2815
2	1	0.0157	98.7	0.0794	18.0	0.0369	60.1	0.95	2.0	0.132	2815
	2	0.0141	88.5	0.0805	18.2	0.0374	60.9	0.84	2.0	0.132	2760
	3	0.0123	77.0	0.0818	18.5	0.0379	61.9	0.72	2.0	0.132	2650
	4	0.0110	69.2	0.0826	18.7	0.0383	62.5	0.64	2.0	0.132	2550
3	1	0.0123	77.0	0.0920	20.8	0.0427	69.6	0.64	2.0	0.147	2550
	2	0.0115	71.9	0.110	24.9	0.0255	41.6	0.75	1.0	0.147	2480
4	1	0.0115	71.9	0.110	24.9	0.0255	41.6	0.75	1.0	0.147	2480
	2	0.0124	77.8	0.105	23.8	0.0293	47.8	0.77	1.2	0.147	2550
	3	0.0142	88.9	0.0969	21.9	0.0360	58.6	0.81	1.6	0.147	2650
	4	0.0157	98.5	0.0897	20.3	0.0416	67.9	0.84	2.0	0.147	2760
5	1	0.0157	98.5	0.0897	20.3	0.0416	67.9	0.84	2.0	0.147	2760
	2	0.0159	100	0.117	26.4	0.0325	53.1	0.89	1.2	0.165	2650
	3	0.0159	100	0.146	32.9	0.0236	38.5	0.925	0.7	0.185	2550
	4	0.0159	100	0.167	37.7	0.0172	30	0.95	0.44	0.200	2480
6	1	0.0156	97.9	0.150	33.8	0.0347	56.6	0.75	1.0	0.200	2480
	2	0.0156	97.9	0.150	33.8	0.0347	56.6	0.75	1.0	0.200	2480

TABLE 10

WESTF TEST 45 THERMAL DESIGN CONDITIONS

PLASMA TEMP, K	MASS FLOW RATES (Kg/s) FUEL	AIR	OXYGEN	TOTAL	PREDICTED HEAT TRANS. COEF. (Btu/hr ft^2-°F)	PREDICTED SURFACE HEAT FLUX(w/cm^2)	PREDICTED SURFACE TEMP °C	PREDICTED TYPE S THERMOCOUPLE READING °C	ELECTRODE THICKNESS (inches)
2550	.0062	.0446	.0162	.067	92	22.8	1834	1555	0.188
2550	.0068	.0493	.0182	.074	100	23.3	1860	1581	0.188

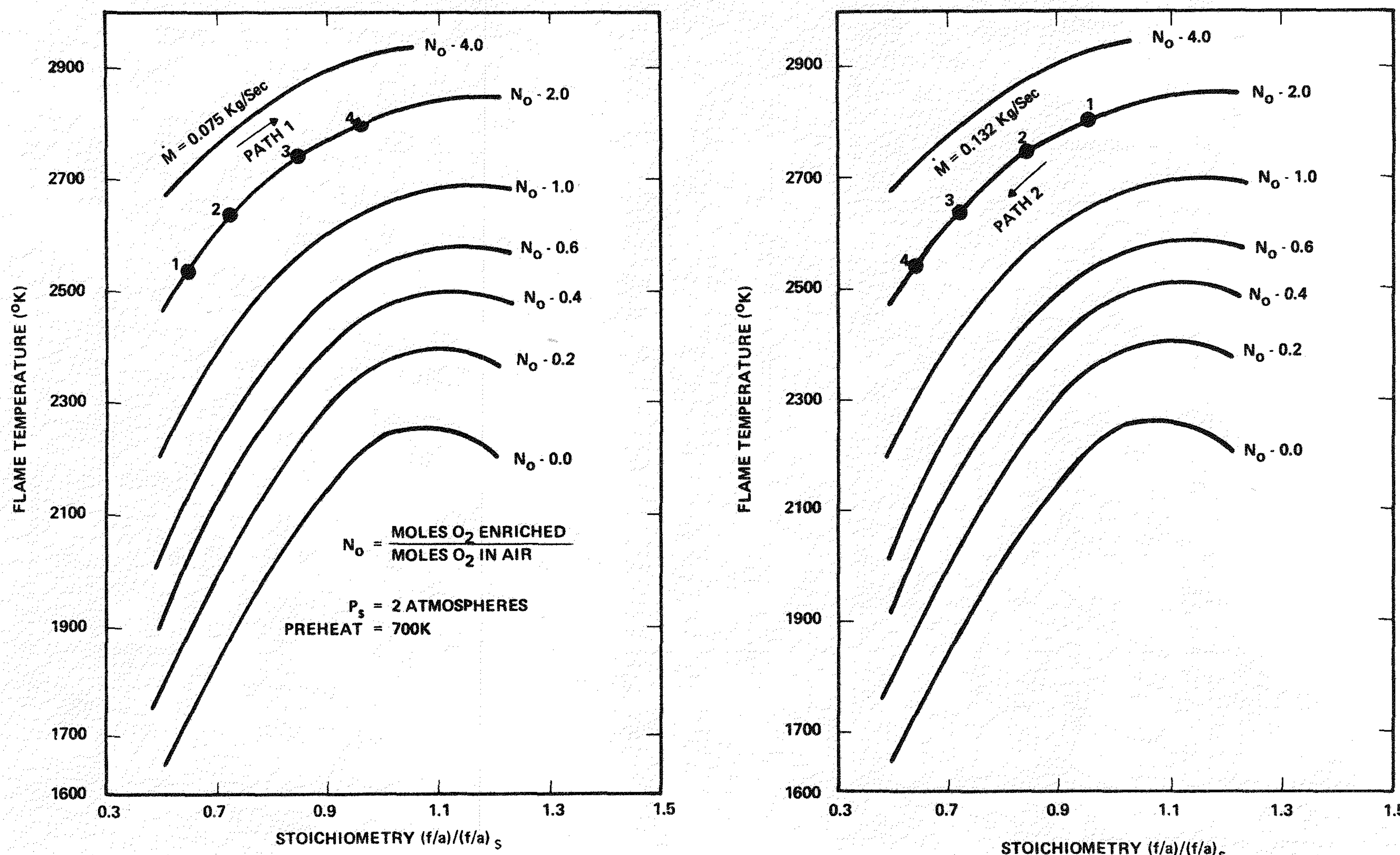


Figure 30. WESTF Test D-11 Planned Operating Map

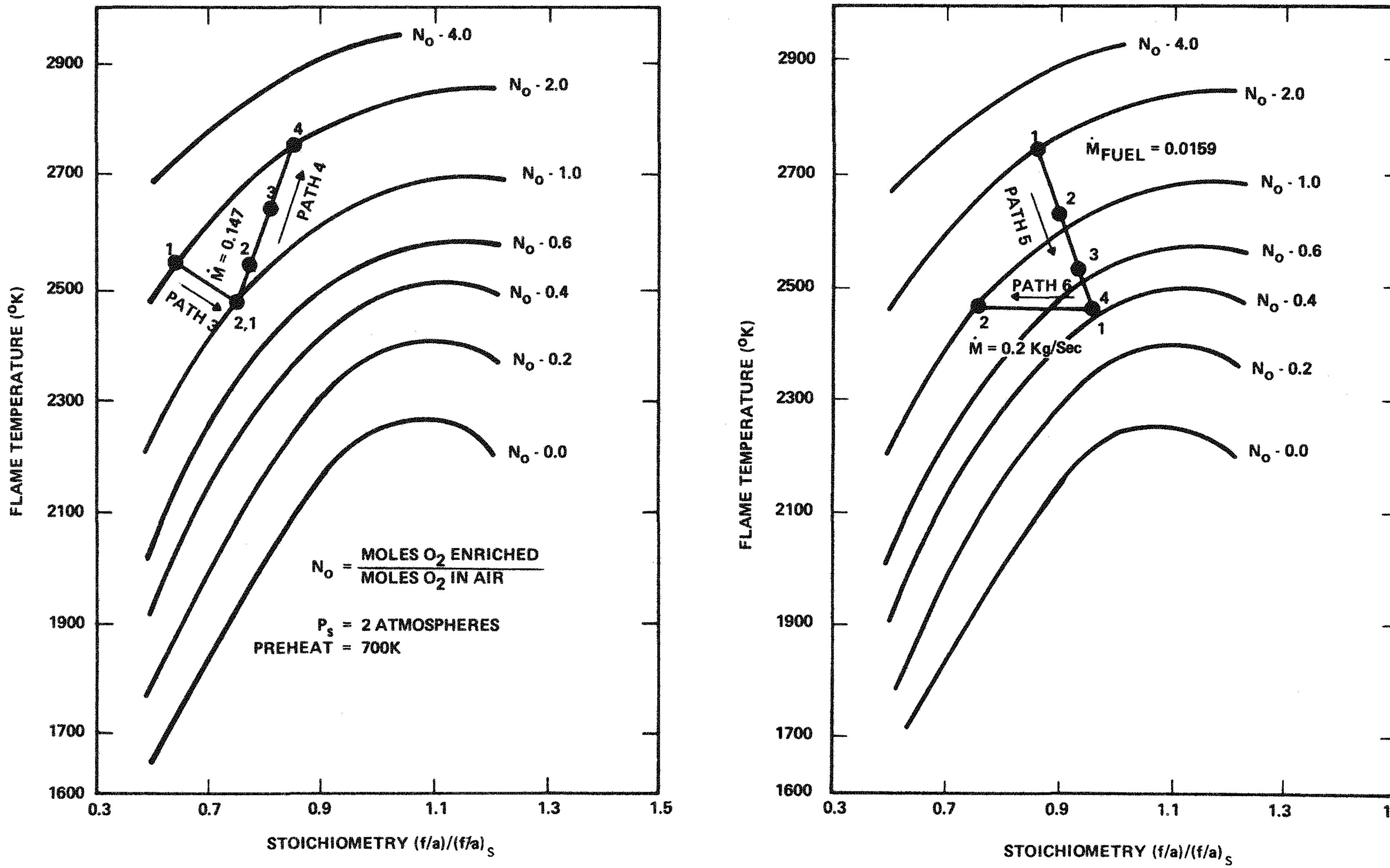


Figure 30. WESTF Test D-11 Planned Operating Map (Continued)

evaluate the relative performance of candidate insulator materials under non-slagging super-hot operating conditions. This test is intended to yield insulator material performance at a surface temperature of 1700°C. Two WESTF transition sections, lined with appropriate thicknesses of the insulating material, form the test section.

Since the construction of each wall is relatively uniform and homogeneous and the ratio of surface area to thickness is quite large, the thermal sizing was completed on the basis of a one-dimensional analysis. The plasma temperature drop along the axial length of the duct is relatively small based on a predicted heat balance. The resulting insulator sizing information is presented in Table 11 based upon the one-dimensional analysis. A comparison of thermal conductivity data, which formed the basis for the thermal sizing, is shown in Figure 31. The general facility operating parameters for WESTF Test 46, based in part on the results of the post-test analysis of WESTF Test D-11, are presented in Table 12.

WESTF Test 47

The initial operation and checkout of the MTS II test section will be WESTF Test 47. This test will evaluate the performance of platinum clad copper in a slagging environment, western slag. The platinum clad copper is considered the reference material for this operating mode. Each electrode surface exposed to the slag/plasma will be (0.442 in^2) 0.75 in. in diameter and will be contained within a cylindrical boron nitride (lava on the cathode side) insulator with a 0.25 inch wall thickness. The anode wall will consist of 0.010 inch platinum clad copper electrodes. The cathode electrodes will be run without any cladding or coating. A one-dimensional thermal analysis has been used to predict the surface heat fluxes and electrode surface temperatures at the selected mass flow rate.

2.1.3 Post-Test Analysis

WESTF Test D-10

WESTF Test D-10 consisted of two runs which were completed on October 12 and October 22, 1979. The primary objective of this test was to provide comparative performance data on four different types of inlet transition

TABLE 11

MATERIAL SIZING AND CONFIGURATION
FOR WESTF TEST 46

Transition Section[1] Numerical Designation (Location)	Material Component (Manufacturer's Nomenclature)	Surface Area Dimensions (in)	No.	Thickness (in)
1 - Inlet	Norton 85% MgO	4 11/16 x 1	1	0.42
	Norton 85% MgO	4 11/16 x 2	1	0.42
1 - Inlet	Trans-tech 97% dense MgO	4 11/16 x 1	1[2]	0.51
	Trans-tech 97% dense MgO	4 11/16 x 2	1[2]	0.51
2 - Outlet	Harklase MgO (magnesite)	4 11/16 x 1	1	0.43
	Harklase MgO (magnesite)	4 11/16 x 2	1	0.43
2 - Outlet	Castable Permanente 165 MgO	4 11/16 x 1	1	0.33
	Castable Permanente 165 Mgo	4 11/16 x 2	1	0.33

[1]General configuration is L shaped for 1 x 2" in flow cross section over 4 11/16" axial length.

[2]These pieces are segmented.

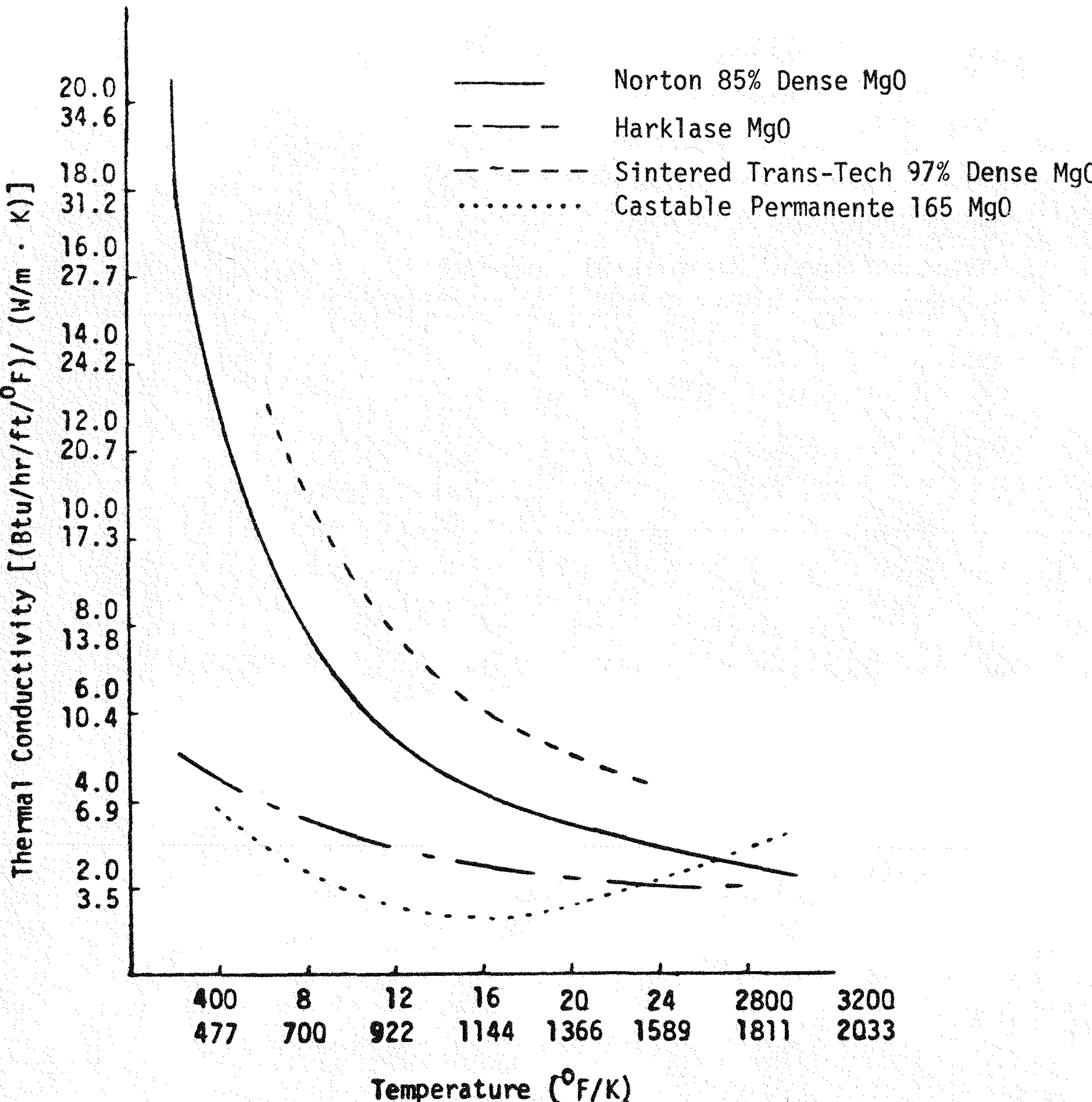


Figure 31. Thermal Conductivity of WESTF Test 46 Materials

TABLE 12

FACILITY PARAMETERS FOR WESTF TEST 46

Plasma Temperature	2675 K
Fuel Equivalence Ratio	0.72-0.76
Oxygen Enrichment Ratio (N/O)	2.0
Mass Flow	~0.134 kg/s
Fuel Flow	0.0130 kg/s
Air Flow	0.0836 kg/s
Oxygen Flow	0.037 kg/s
Static Pressure	1.4-1.5 atm absolute
Preheat Temperature	~500K
Cooling Water Flow	Eight independent circuits with 60-80 gph flow circuit

section constructions and to select the preferred one to be incorporated into the inlet transition section for WESTF Test 42. As discussed in Reference 12, severe erosion of the inlet transition section was encountered in WESTF Test 41 - Run 2.

The four different constructions incorporated in this test was as follows:

- Design 1 - MgO brazed to Ni mesh
- Design 2 - MgO attached to copper with RTV
- Design 3 - MgO attached to copper with Aremco-Coat 543 (Cu)
- Design 4 - MgO attached to copper with Aremco Pryo-Bond 566 (SS)

Thermal Analysis

In general, the MgO surface temperatures attained in WESTF Test D-10 were somewhat lower than the test objective of 1450 to 1650°C. Preliminary analysis of the Run 1 thermal data indicate that the surface temperatures ranged from 1100°C in the inlet transition section to 1025°C in the outlet transition section. The reduced temperatures were the result of a lower adiabatic flame temperature, as determined by experimental measurements, than that predicted by the theoretical code for the predefined facility operating conditions, including the effects of a lower channel pressure. For Run 2, operation of WESTF was at a fuel equivalence ratio which was intended to increase the flame temperature and hence the operating temperature of the MgO insulation. Preliminary thermal analyses indicate that an increase in insulator surface temperature of approximately 300°C was achieved in Run 2 for designs 3 and 4. No significant increase was noted for designs 1 and 2. From a review of thermal data, insulator thermocouples and calorimetry, the trend data shows that the attachments were functional throughout Run 1. Therefore, the loss of attachment for designs 3 and 4, discussed below, appears to have occurred during shutdown from Run 1. From the thermal data it is also implied that the loss of attachment for design 2 occurred during Run 2 shutdown.

From the combined thermal and material performance, design 1 was selected for use in WESTF Test 42.

Materials Evaluation

In situ inspection of the channel interior after Run 1 showed all walls to be intact with little apparent erosion. It was agreed to make a second run of the channel to accumulate more time on it for a better evaluation of the alternate thermal designs and attachments. In addition it was decided to increase the predicted surface temperatures to better test the durability of the MgO. This was accomplished by increasing the fuel equivalence ratio from 0.75 to 0.95 to yield a theoretical increase in plasma temperature. WESTF Test D-10, Run II was run without incident for a duration of six hours. The facility was shut down rapidly to preserve whatever slag layer might have accumulated on the magnesia surface.

The overall condition of both the electrode and insulating walls were judged to be good from an erosion/corrosion standpoint. Figures 32 and 33 show the post-test condition of the channel walls. The distinguishing features on all four walls are the cracks and fissures in the MgO insulation. As is obvious in the figures, the cracks extend laterally across the width of the walls and are present along the whole length of the channel. They are most likely a result of the fast cooldown used in shutting down the facility in Run 2. The top insulating wall and the SS adhesive/RTV electrode wall display a light brownish coloration on its surface. There is very little noticeable slag build up on the walls. The other two walls exhibit a very 'sooty' black coloration which is as yet unexplainable. Examination of the four different attachment techniques revealed only one was still intact, the brazed joint to nickel mesh. The two metal adhesives and the RTV bond were all loose from the copper cooling block. The thermal stresses attained at the bond interface during the rapid shutdown were probably great enough to break the bonds in these three cases. The more compliant nature of the nickel mesh was most likely the reason there was no failure for this design.

Figure 32. WESTF Test D-10 Electrode Walls, Post-Test

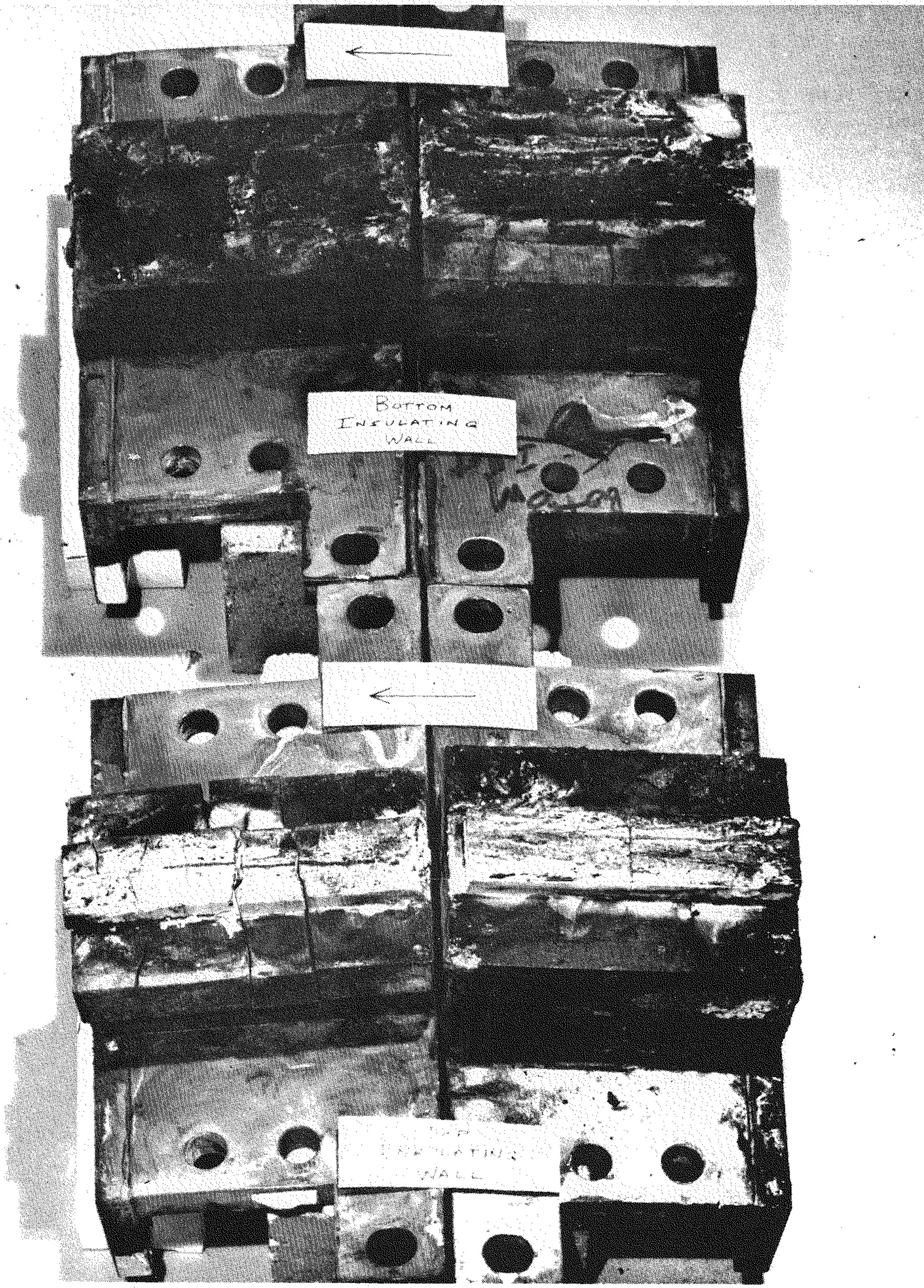


Figure 33. WESTF Test D-10 Insulating Walls, Post-Test

WESTF Test D-11

Following installation in WESTF a gasket leak was noted in the WESTF Test D-11 test section. As a result, an alternative operating map from that defined in Table 9 was used in the conduct of the test. This alternative operating map was the result of the reduction in test section pressure due to the leak. Test section pressures were limited to 1.4 atm. as compared to the desired pressure level of 2.0 atm.

Thermal Analysis

The maximum adiabatic flame temperature obtained during WESTF D-11 was determined to be approximately 2675 K. This condition corresponded to a mass flow rate of 0.134 kg/sec, a channel static pressure of 1.4 atmA, a fuel equivalence ratio of 0.72 to 0.76, and a degree of oxygen enrichment equal to approximately 2.0. The general facility response and this operating point determined from the experimental measurements will be used to establish the facility conditions for WESTF testing in the immediate future. Modification and revision of the facility response maps and operating points will continue in an iterative fashion to provide the required precision for future design and analysis efforts. Table 13 provides a summary of the most significant operating points achieved during WESTF Test D-11.

A number of specific conclusions can be drawn from the post-test analysis of WESTF Test D-11. The on-line theoretical calculations of adiabatic flame temperature do provide highly useful trend data to aid in the logic of testing decisions during the conduct of WESTF experiments. Some modifications to the computer code input may however have to be made in order to more properly reflect actual experimental facility response over a wide range of fuel equivalence ratios, degrees of oxygen enrichment and mass flows.

The calorimetric algorithms which make use of the on-line data reduction of coolant flow rate and coolant bulk temperature rise provide extremely useful real time indices of surface heat flux. These are of value in the decision process during the conduct of a WESTF experiment.

TABLE 13

WESTF TEST D-11 DATA SUMMARY

Test Point	1 Objective	1 Actual	2 Objective	2 Actual
Total Mass Flow, kg/s	0.132	0.134	0.132	0.134
Fuel Equivalence Ratio	0.95	0.96	0.72	0.76
Degree of Oxygen Enrichment	2.0	2.0	2.0	2.0
Channel Static Pressures, atm	1.7	1.41	1.7	1.41
Adiabatic Flame Temperature near Combustor Exit, K	2815	2525	2650	2675
Ceramic Surface Temperatures, ^{o}C	1700 Max.	1150-1690	1700 Max.	1350-1900
Average Surface Heat Flux, w/cm^2	65-80	18.7-51.4	45-60	18.7-58.1

The insertable gas stream themocouple mechanism provides a usefuel tool in extrapolating the plasma temperature throughout the duration of the test. This test has demonstrated the use and successful operation of this retractable thermocouple concept for WESTF MHD testing in clean environments. Its survivability for slagging environment tests has however yet to be determined.

The degradation of the thermocouple within the ceramic appears to be somewhat dependent upon the presence of seed and or slag. This test has demonstrated a 100% survival rate for thermocouples for clean environments when the thermal specification for depth, type and configuration are followd. These thermocouples in turn provided accurate and consistent measurements of local ceramic temperature and temperature trends. As a result, extrapolation of ceramic surface temperatures is much easier.

Materials Evaluation

The general condition of the test section was judged to be good from an erosion standpoint. Figures 34 and 35 present the post-test condition of the channel walls. The most noticeable feature is the green coloration of all four walls. Several scrapings of the green coating was selected from the channel walls and sent for chemical analysis. Several cracks through the magnesia insulation were also observed in some of the walls.

2.2 WBS 1.2.2 - Test Assembly Fabrication

2.2.1 Materials Test Section II

Following completion of the design of MTS II, see Section IV - 2.1.2, an initial set of test section hardware was fabricated. No difficulties were encountered in completing the fabrication and assembly activity. The initial use of this test section will be in conjunction with WESTF Test 44, see below.

2.2.2 WESTF Test Sections

During this quarter, test sections for WESTF Tests D-10, D-11, 42, 45, and 47 were assembled and delivered for installation in WESTF. The test section for WESTF Test 43 is nearing completion.

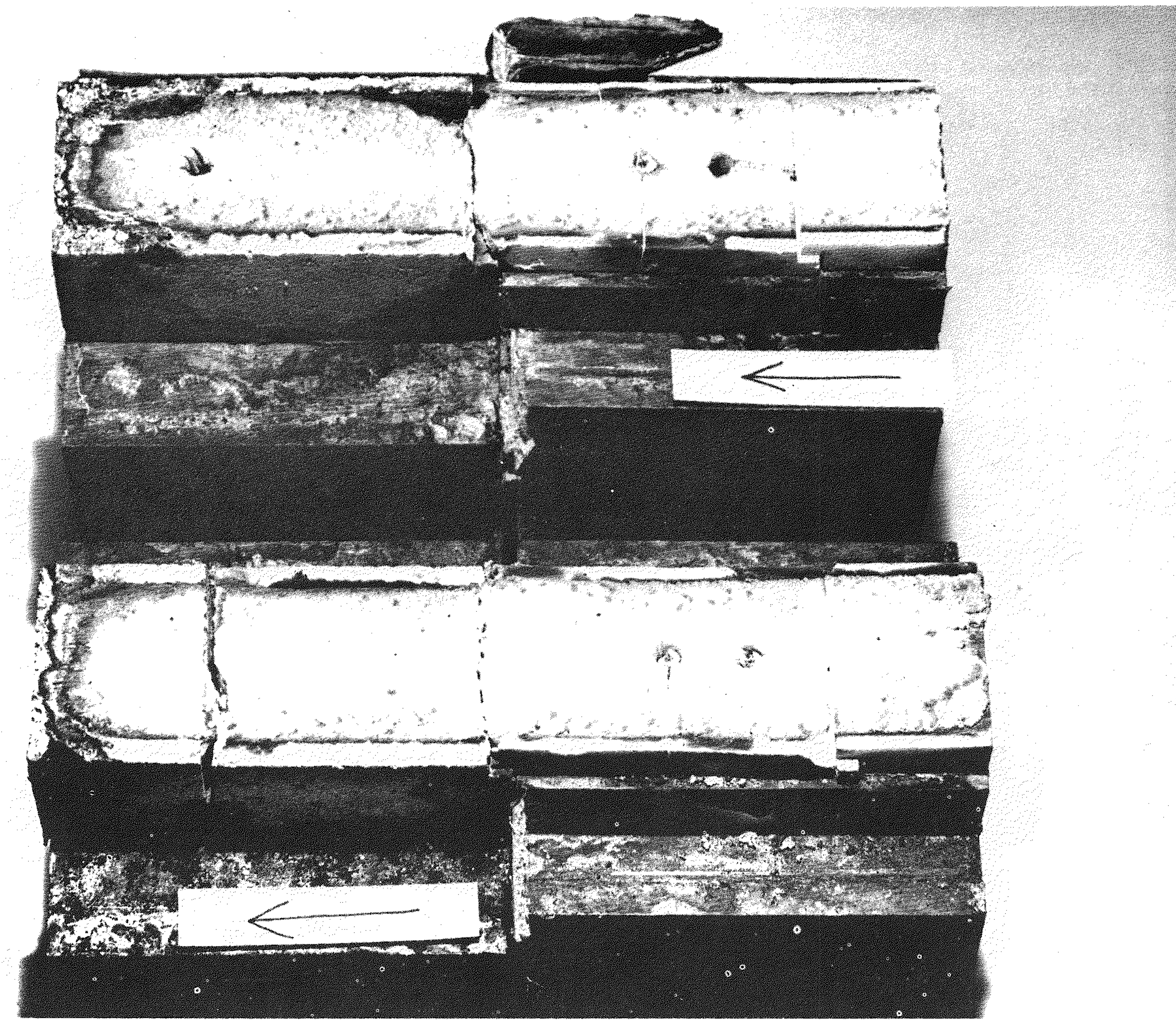


Figure 34. WESTF Test D-11 Electrode Walls, Post-Test

Figure 35. WESTF Test D-11 Insulating Walls, Post Test

WESTF Test D-10

The construction of the D-10 (Run 1) test section was described in the previous quarterly report (Reference 12). The test section was modified for WESTF Test D-10, Run 2, by replacing one of the failed gas thermocouples with an optical sight port to view the surface of the design 3 (.418 in. thick MgO) wall.

WESTF Test D-11

The objective of WESTF Test D-11 was to investigate facility and test section thermal response to operation over a range of fuel equivalence ratios. To achieve this objective, it was necessary to modify existing transition section walls to accommodate the additional instrumentation required to obtain meaningful data.

The test section was made up of inlet and outlet transition sections joined together as shown in Figure 36. The upstream transition section is the primary test article; the downstream transition section served as a space, but also provided the opportunity to test an "injectable" gas steam thermocouple intended to overcome problems associated with gas stream thermocouple life.

The upstream transition section was lined with 0.325 inch thick Norton MgO (85% dense) TiCuSil brazed to 0.1 inch thick nickel mesh which is CuSil brazed to copper, Each wall contained an iridium-rhodium gas stream thermocouple and in Type R thermocouple located 0.16 inch below the hot surface of the MgO. An optical sight port was also present in this section. The downstream section was lined with 1.173 inch thick Harklase MgO. It contained, in addition to the experimental gas stream thermocouple, one iridium-rhodium gas stream thermocouple in one side wall and a Type R thermocouple in the other side wall.

Fabrication, assembly and checkout of this test section was completed with the assembly delivered for test.

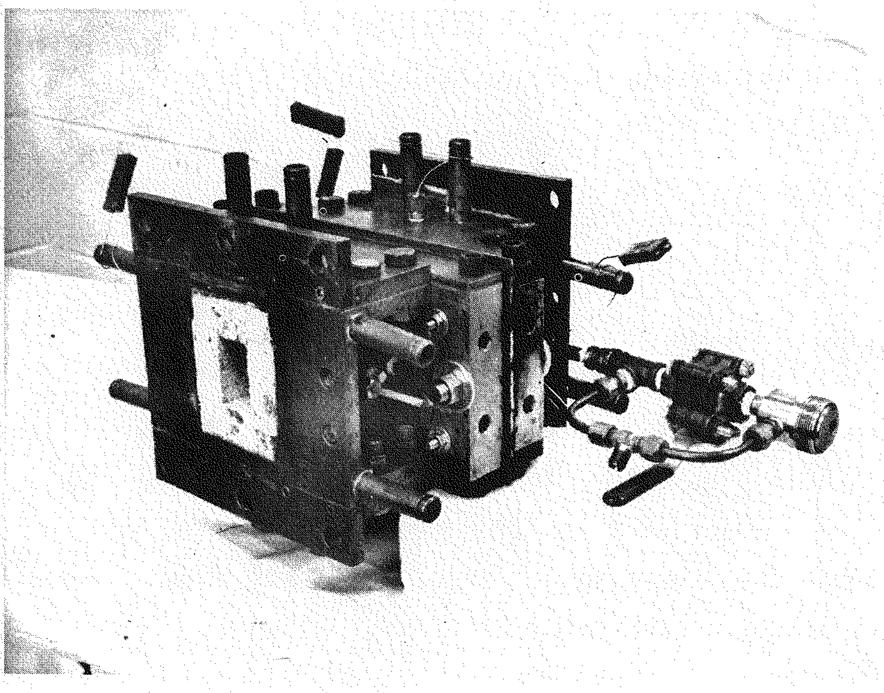


Figure 36. WESTF D-11 Test Section (viewed from the exit end)

WESTF Test 42

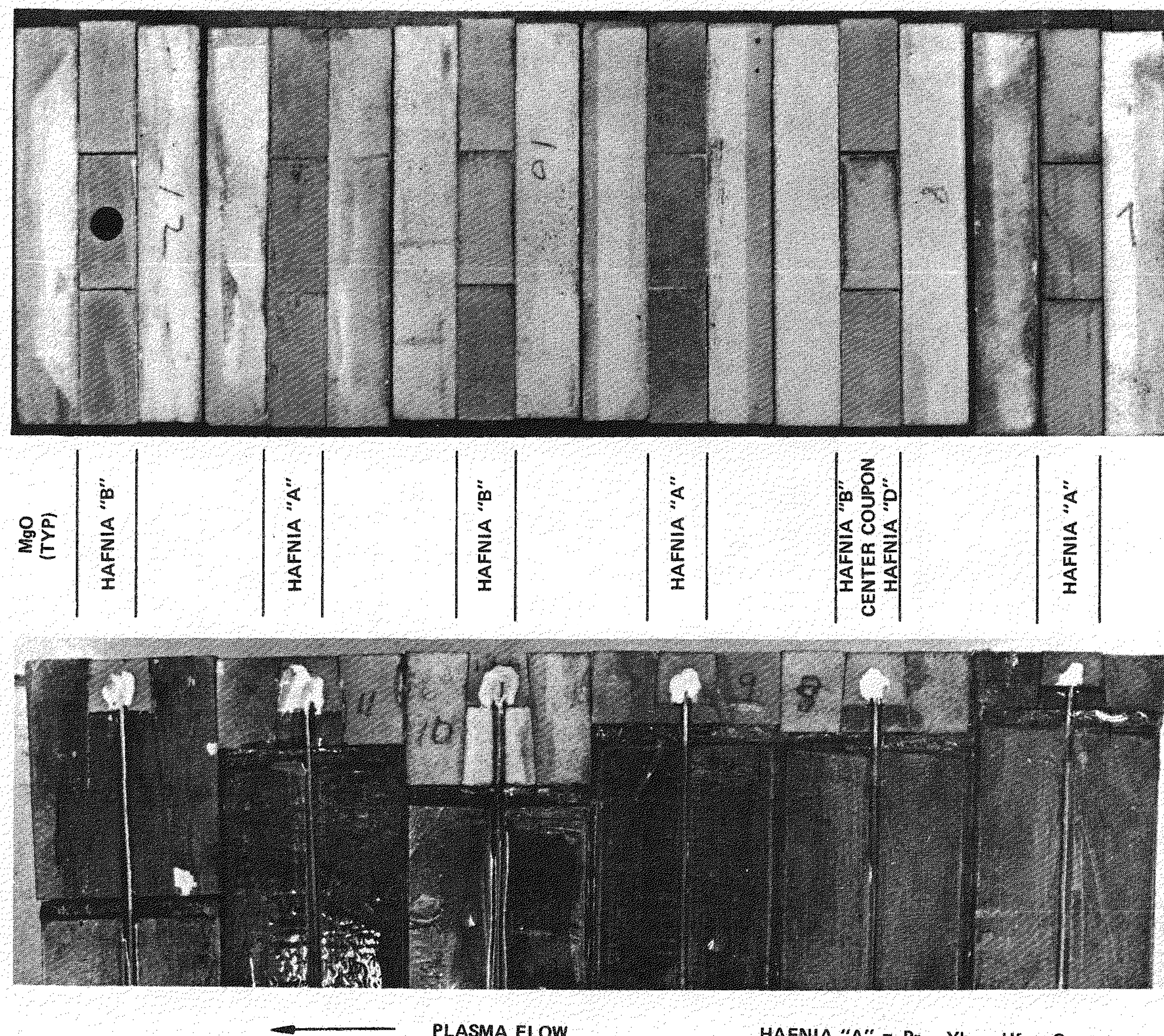
The objective of WESTF Test 42 is to compare the relative performance of zirconia and hafnia based electrode compositions over a range of temperatures in a non-slagging super-hot MHD environment in the absence of electrical or magnetic fields.

The assembly of this test section was completed and shipped to the facility for testing. Recommendations made on the basis of the results of WESTF Test D-10 led to the selection of .325 in. thick Norton 85% dense MgO brazed to 0.1 in. thick nickel mesh as the inlet transition section lining for this test. A low silica zirconia adhesive was used to bond the coupons to the magnesia bases and to hold the tapered magnesia back and side insulators together for TiCuSil brazing to each nickel mesh/copper cooling block sub-assembly. In addition to thermocouples within the coupons, the assembly includes an optical sight port viewing through a hafnia "B" coupon on the cathode wall to sight on a hafnia "D" coupons on the anode wall. The C wall is shown in Figure 37.

WESTF Test 43

WESTF Test 43 is a test of platinum anodes and iron cathodes under slagging hot conditions. A photograph of a partially assembled typical anode and cathode is given in Figure 38. The anode subassembly was prepared by diffusion bonding the platinum to the alumina tile. A platinum electrical lead, passing through a slot in the center of each tile is also diffusion bonded to the base of the alumina. The anode cooling blocks were prepared by brazing the nickel mesh to the cooling block with Nicrobraz 30, cutting stress relief slots through the mesh, and then brazing the anode sub-assembly to the mesh with TiCuSil. The cathode was machined from carbon steel. The side plate was brazed in place and the surface coated with plasma sprayed nickel aluminide. Electrode coolant tubes and plugs were then silver soldered in place and flow and pressure checks made on each electrode.

Electrical insulation is applied to metal electrode surfaces by painting on an alumina adhesive coating. The adherence of this coating was tested on a piece



HAFNIA "A" = $Pr_{.27}\ Yb_{.09}\ Hf_{.64}\ O_2$

HAFNIA "B" = $Tb_{.20}\ Y_{.10}\ Hf_{.70}\ O_2$

HAFNIA "D" = $Er_{.82}\ Hf_{.18}\ O_2$

Figure 37. WESTF Test 42 C Wall

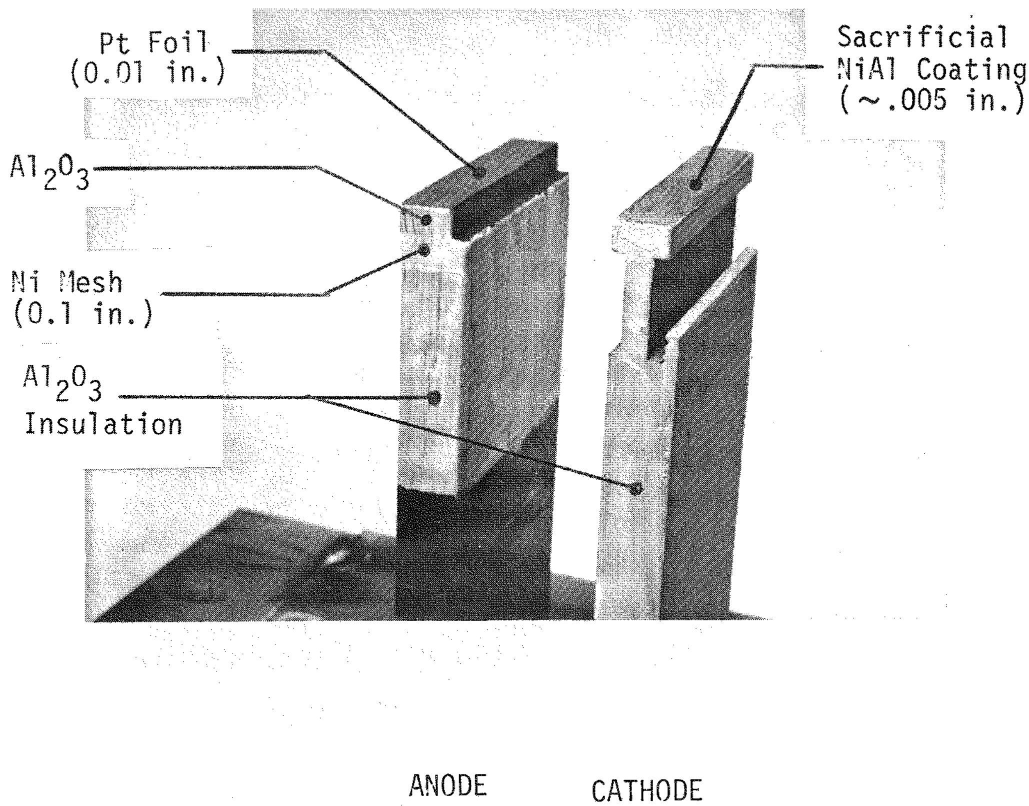


Figure 38. Typical Platinum Anode and Iron Cathode (less insulating tiles) for WESTF TEST 43

of carbon steel by directly impinging the flame of a propane torch on the coating as shown in Figure 39. Resistance measurements before and after the test showed this material to be a good temperature resistant insulator. Polyimide tape will be used for insulation on cooler surfaces of the electrode walls.

All components for WESTF Test 43 have been machined and the assembly and instrumentation of the electrode walls is in progress. Cooling blocks have been assembled on the insulating walls and electrical tests have been made. The insulating walls and tunsition section are ready to accpet the alumina tiles. Because the attachment is RTV, the tiles will be placed into position during the final assembly of the channel.

WESTF Test 45

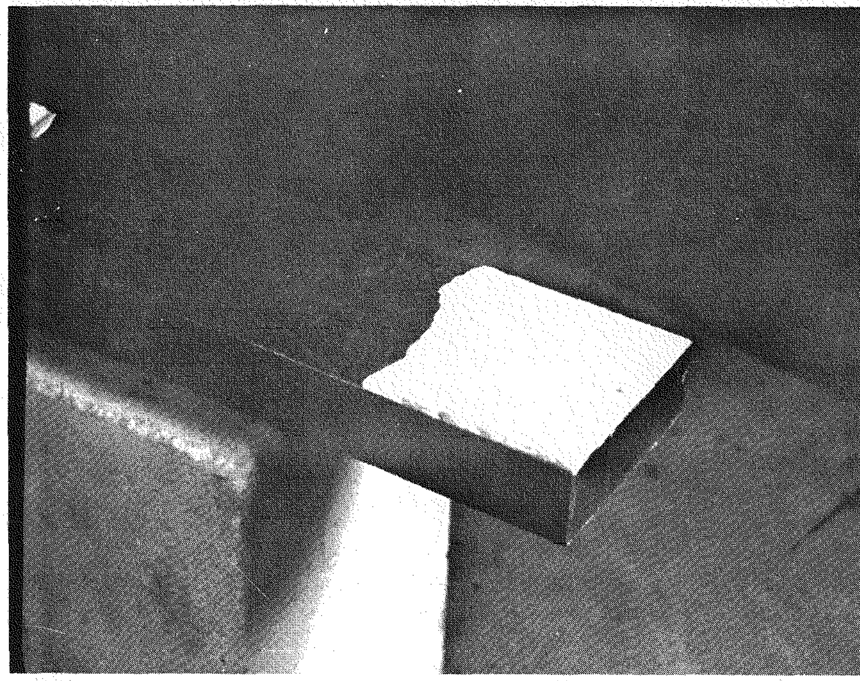
WESTF Test 45 incorporated samples of dense single-phase yttria stabilized zirconia and represented the first electrode material screening test in WESTF in the non-slagging super-hot mode. The fabrication and assembly of the WESTF Test 45 MTS was completed without difficulty.

WESTF Test 47

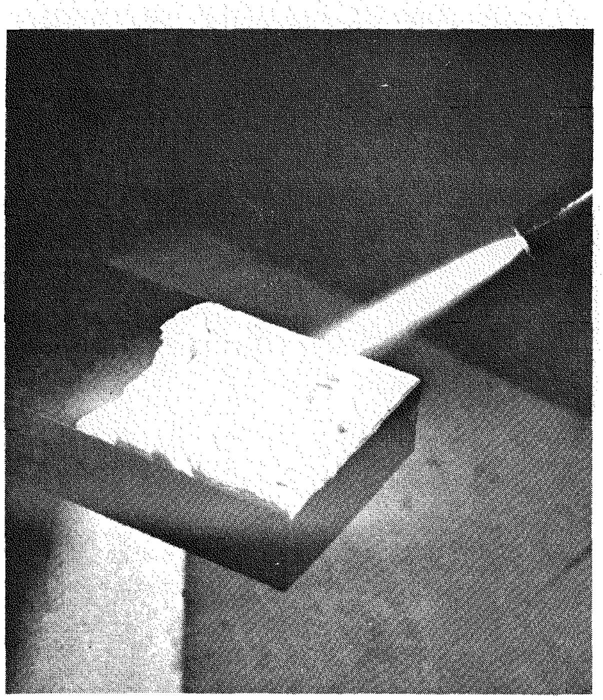
WESTF Test 47 represents the first use of the MTS II test section described in Section IV-2.1.2, and incorporated platinum clad copper anode material samples and bare copper cathode samples; boron nitride was used for the cylindrical insulators on the anode wall. For the anode, platinum foil 0.010 inch thick was brazed directly to the water cooled copper bases. Figure 40 shows a number of views of the WESTF Test 47 MTS II hardware prior to final assembly. Assembly of this unit was completed without difficulty and the test seciton is awaiting test in early January 1980.

2.3 WBS 1.2.3 - WESTF Operations

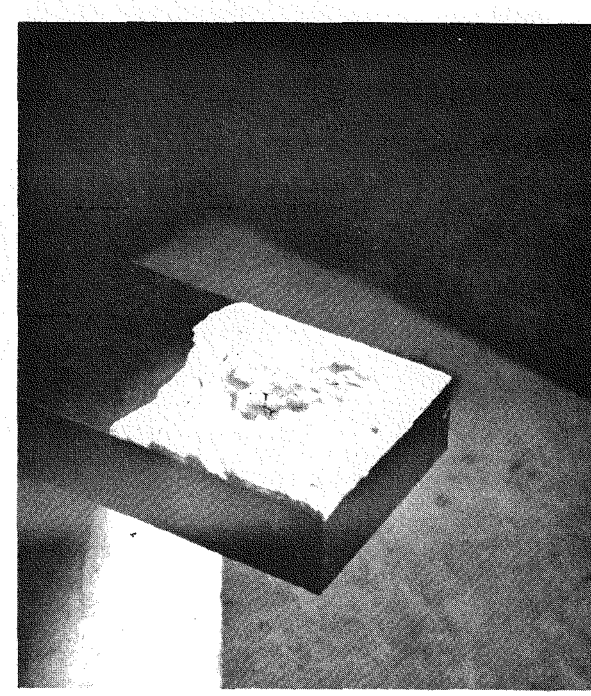
During this quarter WESTF Tests D-10 (2 runs), D-11 and 45 were completed. Three tests which were anticipated to be completed during this period were not completed due to our unanticipated high frequency of vacations, coupled with normal holidays and operating personnel reassignment due to



a) As Coated

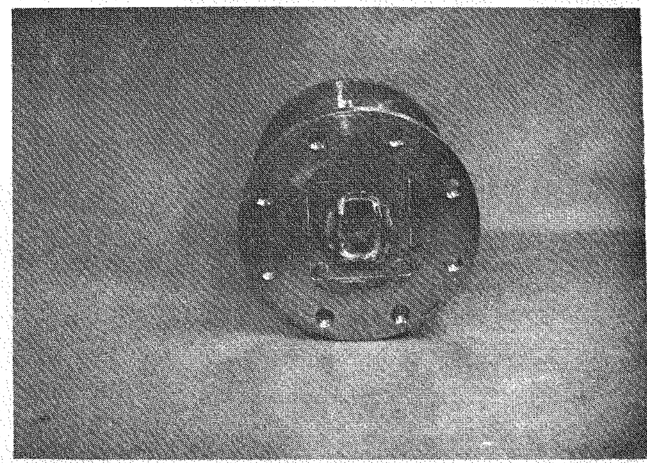


b) Direct Flame Impingement

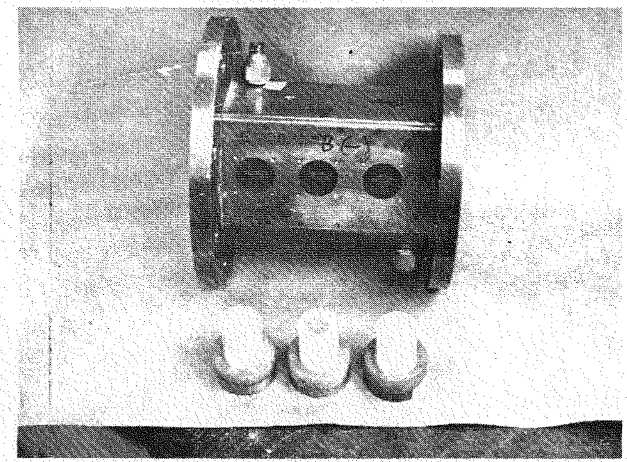


c) After torch test (discoloration and microcracking, no loss of adherence)

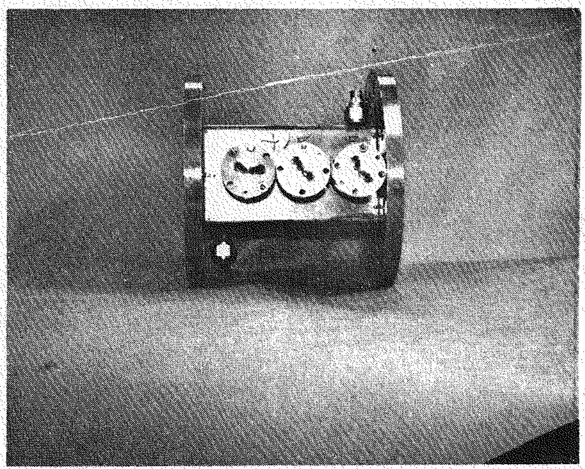
Figure 39. Alumina Adhesive (Aremco 503) - High Temperature Insulation for WESTF 43



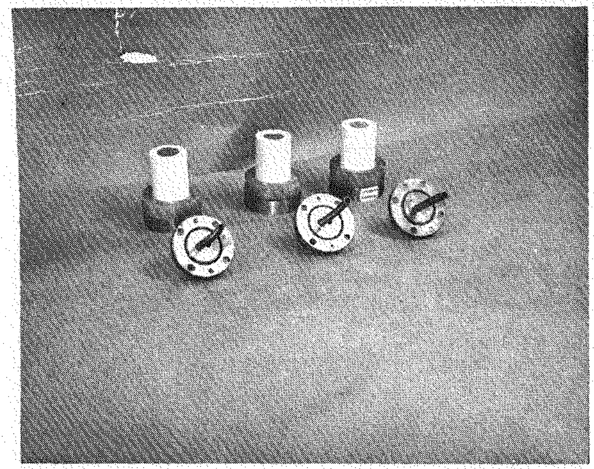
(A) Inlet View



(B) Side View with Electrode Assemblies Displayed



(C) Side View with Electrode Assemblies Inserted



(D) Electrode Assemblies, Water Cooled

Figure 40. Materials Test Section II, with Electrodes for WESTF Test 47

medical reasons. At the close of the quarter a revised sequence of WESTF tests was established, i.e., WESTF Tests 45, 47, 42 and 43, to accommodate personnel availability and to minimize changeover activities from one type of test section to the other.

2.3.1 Pre-Test Activity

Work has continued on characterizing the plasma temperature and composition at various operating conditions. It was determined that the water addition with the seed/ash mixture only lowers the flame temperature by $\lesssim$50°C and increases the water content in the plasma approximately 10% above the amount normally formed during combustion. The effect of these two factors is not thought to be significant enough to warrant design and implementation a dry feed system at the present time.

In order to achieve a 0.3 mole percent SO_2 level in the plasma, the sulfur in the fuel would have to be increased from the present 0.28 weight percent to $\sim$5.25 weight percent. This would result in an unacceptable release of SO_2 to the atmosphere with the present scrubber. An analysis will be performed to determine the best approach for removing the SO_2 and seed from the exhaust gases in order to reach the desired level of SO_2 in the plasma.

As a first step to increasing the SO_2 level in the plasma, 108 lbs. of TNPS (di-tertiary nonyl polysulfide) was added to 683 gal. of #2 fuel oil before Test 45 was run. This increased the sulfur content in the fuel to 1.1 weight percent, and gives a $\sim$0.06 mole percent SO_2 level in the plasma.

Data from each test is continuously stored on disk and continuing improvements in the computer displays are being made to better handle the data and resultant calculations. The estimated plasma temperature is being calculated from the fuel, air, and oxygen ratios and the preheat temperature. Efforts are continuing to increase the accuracy of this value by increasing the family of pre-computed curves obtained from Westinghouse Proprietary Combustion Computer Programs. Other display options have been added to record and display the data obtained from attempts to measure the plasma temperature using the insertable thermocouple, see Section IV-2.1.2, which is in the gas stream for only a short time.

During this quarter, test section installation, checkout and post-test removal operations were completed for the following:

- WESTF Test D-10 (removal)
- WESTF Test D-11
- WESTF Test 45
- WESTF Test 47 (installation and checkout)

2.3.2 Test Operations

WESTF Test D-10

WESTF Test D-10, Run 1, was completed on October 12, 1979. This test was run to evaluate alternate inlet transition section thermal designs and attachments for WESTF Test 42. Table 14 presents the average conditions achieved during the test as well as the test chronology. During this short duration test the facility was operated at two different plasma temperatures to investigate test section thermal response.

WESTF Test D-10, Run 2, was completed on October 22, 1979. This test was run to confirm if a slag layer developed under the Run 1 conditions and to assess the presence of a slag layer and durability of the MgO at higher predicted surface temperatures. Table 15 presents the average conditions achieved during the test as well as the test chronology. This test was run much like Run 1, but the shutdown was rapid in order to "freeze" the slag layer at near the operating thickness.

WESTF Test D-11

WESTF Test D-11 was completed on November 20, 1979. This clean-firing test was run to investigate facility and test section thermal response to operation over a range of fuel equivalence ratios and mass flow rates. Table 16 presents the average conditions achieved during the test and Table 17 presents the test chronology. During the first series of conditions analysis of the exhaust gases was attempted, but the values obtained were inconsistent within themselves. No reason is known for the discrepancies. The test section developed

TABLE 14

WESTF TEST D-10 OPERATING CONDITIONS AND CHRONOLOGY

	Condition 1	Condition 2
Gas Temperature, °K	2600	2800
Static Pressure, atm	1.1	1.1
Plasma Mass Flow, Kg/sec	0.075	0.075
K_2CO_3 Seed Concentration, %K	1.0	1.0
Flyash Concentration (Rosebud)	0.001	0.001
Heating Rate, °C/min	5-10	---
Cooling Rate, °C/min	---	20 to 1200°C, 5-10
Cooling Water Flow, gph	69	69

Condition	Date	Time	Elapsed Time, hours
Air Preheat On	10/12/79	0825	0
Combustor On	10/12/79	1055	2.50
Condition 1 estb.	10/12/79	1210	3.75
Seed On	10/12/79	1255	4.50
Condition 2 estb.	10/12/79	1540	7.25
Seed Off	10/12/79	1655	8.50
Air Preheat Off	10/12/79	1740	9.25
Combustor Off	10/12/79	1805	9.67

TABLE 15

WESTF TEST D-10, RUN 2 OPERATING CONDITIONS AND CHRONOLOGY

	Condition 1	Condition 2
Gas Temperature, °K	2600	2750
Static Pressure, atm	1.1	1.1
Plasma Mass Flow, Kg/sec	0.075	0.075
K_2CO_3 Seed Concentration, %K	1.0	1.0
Flyash Concentration (Rosebud)	0.001	0.001
Heating Rate, °C/min	20-30	---
Cooling Rate, °C/min	---	Fast
Cooling Water Flow, gph	69	69

Condition	Date	Time	Elapsed Time, hours
Air Preheat On	10/22/79	0735	0
Combustor On	10/22/79	0935	2.00
Condition 1 estb.	10/22/79	1020	2.75
Seed On	10/22/79	1125	3.83
Condition 2 estb.	10/22/79	1415	6.67
Seed Off	10/22/79	1725	9.83
Air Preheat Off	10/22/79	1725	9.83
Combustor Off	10/22/79	1725	9.83

TABLE 16

WESTF TEST D-11 OPERATING CONDITIONS

	Series 1	Series 2
Gas Temperature, °K	see below	see below
Static Pressure, atm	1.1	1.4
Plasma Mass Flow, Kg/sec	0.075	0.132
K_2CO_3 Seed Concentration, %K	0	0
Flyash Concentration	0	0
Heating and Cooling Rate, °C/min	20	20
Cooling Water Flow, gph	69-93	69-93

Condition, Series 1	Gas Temperature, °K
1-1	2621
1-2	2694
1-3	2770
1-4	2815

Condition, Series 2	Gas Temperature, °K
2-1	2836
2-2	2790
2-3	2710
2-4	2636

TABLE 17

WESTF TEST D-11 CHRONOLOGY

Condition	Date	Time	Elapsed Time, hours
Air Preheat On	11/20/79	0730	0
Combustor On	11/20/79	0935	2.00
Condition 1-1 established	11/20/79	1015	2.75
Change to condition 1-2	11/20/79	1430	7.00
Change to condition 1-3	11/20/79	1530	8.00
Change to condition 1-4	11/20/79	1645	9.25
Change to condition 2-1	11/20/79	1715	9.75
Condition 2-1 established	11/20/79	1730	10.00
Change to condition 2-2	11/20/79	1750	10.33
Change to condition 2-3	11/20/79	1820	10.83
Change to condition 2-4	11/20/79	1850	11.33
Change to condition 2-3	11/20/79	1942	12.20
Change to condition 1-1	11/20/79	2005	12.58
Condition 1-1 established	11/20/79	2015	12.75
Combustor Off	11/20/79	2050	13.33
Air Preheat Off	11/20/79	2050	13.33

a gasket leak during final preparations prior to startup. The leak was judged to be relatively minor in nature and the test was continued, however at a reduced pressure level from that originally planned. As a result the actual operating map for this test was significantly different from that originally planned (see Section IV-2.1.3 for further details).

WESTF Test 45

WESTF Test 45 was completed on December 7, 1979. This test was run to evaluate dense single-phase yttria stabilized zirconia as an electrode in a non-slagging super-hot environment. Table 18 presents the average conditions achieved during the test as well as the chronology. This was the first test with the higher sulfur content in the fuel (1.1 w/o) and appears to be the highest that can be used without additional exhaust gas cleanup. No difficulties were encountered during this test.

3.0 WBS 1.3 - WESTF MODIFICATIONS

3.1 MINI-COMPUTER/DAS

The equipment required for the expansion of the mini-computer was received in early December. The magnetic tape subsystem has been incorporated into the operating system and is being used to store files and data. The additional core memory system includes a mapped system which permits simultaneous use of two operating programs without interference. This mapped system requires a modification of the operating system which has also been received. This equipment will be installed and checkout out early in the next quarter. With completion of this latter activity, the planned expansion of the mini-computer system will be complete.

3.2 MAGNET INSTALLATION

Satisfactory progress has been achieved in most areas associated with the magnet modification and supporting facility modification activities. However, the following items have impacted the planned schedule, resulting in the postponement of the planned facility shutdown to March:

- A one month delay in the availability of the magnet core final sizing fixture.

TABLE 18

WESTF TEST 45 OPERATING CONDITIONS AND CHRONOLOGY

Gas Temperature, °K	2600
Static Pressure, atm	1.1
Plasma Mass Flow, Kg/sec	0.075 to 0.068
K_2CO_3 Seed Concentration, %K	1.1
Flyash Concentration (Rosebud)	0.0011
Heating and Cooling Rate, °C/min	30
SO_2, Mole Percent	0.062

Condition	Date	Time	Elapsed Time, hours
Air Preheat On	12/7/79	0730	0
Combustor On	12/7/79	1015	2.75
Conditions established	12/7/79	1035	3.08
Reduced mass flow	12/7/79	1215	4.75
Seed On	12/7/79	1220	4.83
Seed Off	12/7/79	1820	10.83
Combustor Off	12/7/79	1905	11.58
Air Preheat Off	12/7/79	1905	11.58

- A vendor change in delivery for the magnet power supply, now mid-March 1980.

The current magnet power supply delivery date of mid-March was negotiated with the vendor and represents a two month improvement over that identified by the vendor prior to negotiation.

The engineering drawings applicable to the magnet modification have been reviewed and minor comments incorporated. The magnet coils have been cut to size and insulation burn-off operations successfully completed. Assembly and insulation of individual coils are in process with a number of coils completed. Availability of the coil final sizing fixutre is expected in early February while magnet modification should be complete by the end of February.

Occupancy drawings covering the WESTF test area as well as other non-MHD facilities which are impacted by the WESTF magnet addition, have been completed and are being reviewed prior to final release. The building addition, required to house displaced non-MHD equipment, has been completed. Transfer of equipment is expected to begin in January. Design drawings have been completed for modifications to the WESTF test passage and procurement initiated.

The status of primary long lead procurements which support the addition of the magnet to WESTF are as follows:

- Load Interrupter Switches - delivery in February 1980
- Magnet Power Supply - delivery slipped to mid-March 1980
- 5 kV Feeder Cable - received
- PS to Magnet Cable - received

Installation of the new power line from the main substation to Building 301 has been deferred to the next quarter. This action does not impact the magnet installation schedule.

4.0 WBS 1.4 - PROJECT MANAGEMENT AND DOCUMENTATION

The following required project documentation was issued during the reporting period:

- Monthly Report for September 1979
- Monthly Report for October 1979
- Monthly Report for November 1979
- Quarterly Report for the period July-September 1979

Based on DOE comments, the Project Management Summary Baseline Report, FY80 Revision, was issued in final form.

A project review meeting was held in November with recently assigned DOE personnel to review the background, technical approach and accomplishments of the program. A further meeting is planned for January 1980.

V. SUMMARY PLANS NEXT REPORTING PERIOD

Summary plans covering significant activities during the next reporting period, January-March 1980, are presented below according to the Work Breakdown Structure primary tasks.

WBS 1.1 - ELECTRODE AND INSULATOR MATERIALS

- Complete evaluation of attachment techniques for WESTF Tests 44 and 49.
- Initiate evaluation of sputtered TiB_2 as a slagging cold wall anode material.
- Conduct polarization studies on slags with varying iron oxide content.
- Begin comprehensive assessment of platinum clad copper as slagging cold wall anodes.

WBS 1.2 - ENGINEERING TESTS

- Issue Test Specifications for the following WESTF Tests:
  - 0.5 $SrZrO_3 \cdot 0.5\ (Sr_{.25}La_{.75}FeO_3)$, MIT material - WESTF Test 49, MTS II test section.
  - BPNL hafnia material - WESTF Test 50, MTS II test section.
- Complete design of WESTF II test section.
- Complete fabrication of prototype sections of WESTF II test section.
- Complete primary post-test analysis of WESTF Tests 47, 42, 43 and 46.
- Complete fabrication and assembly of test sections for WESTF Tests 43, 46, 48, 49 and 50.
- Complete WESTF Tests 47, 42, 43 and 46.

WBS 1.3 - WESTF MODIFICATION

- Complete installation and activation of mini-computer subsystems.
- Complete magnet modification.
- Initiate facility shutdown and rework for magnet installation.

WBS 1.4 - PROJECT MANAGEMENT AND DOCUMENTATION

- Issue October-December 1979 Quarterly Report.
- Issue monthly progress reports.
- Participate in project review/planning meetings with DOE personnel.

VI. REFERENCES

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VII. CONCLUSIONS

Shutdown of the WESTF facility, to permit installation of the conventional 3 tesla magnet and other related facility modifications, has been postponed to mid-March. As a result of this change in schedule WESTF testing will be continued. It is expected that WESTF Tests 42 (hafnia and zirconia coupons), 43 (platinum anodes and iron cathodes), 47 (platinum anode and copper cathode), and 46 (MgO insulator materials) should be completed during the first quarter of CY 80.

Analysis of continuing laboratory electrochemical corrosion tests indicate that Western coal slags are much more corrosive than Eastern coal slags due to the effect of iron content in slags on corrosion. Further, this is a general phenomenon applicable to metallic as well as ceramic electrodes and is expected to hold true under all proposed MHD channel operating conditions, i.e., from slagging cold wall to non-slagging super-hot wall. In addition, major reductions in polarization, electrical resistivity and ionic transference number of the slag (Rosebud) can be achieved with moderate additions of cobalt to the slag. Future studies will evaluate the effect of other transition metal ions on slag polarization.

The addition of the type II Materials Test Section (MTS II) provides a cost effective test section for screening electrode and insulator materials when compared to the WESTF test sections previously used. Increased use of this test section is anticipated in screening candidate materials and investigating degradation phenomena for the slagging cold, as well as slagging hot and non-slagging super-hot operating modes. For tests which require inclusion of magnetic effects, such as developmental testing associated with slagging cold electrodes, the WESTF II test section will be used.

Environmental restrictions have precluded attaining the desired sulfur level in WESTF testing, 0.3 m/o SO_2. Current operations are limited to 0.06 m/o SO_2. This does, however, represent a factor of four increase in sulfur level over that which characterized prior tests. The extent of required scrubber modifications is being investigated.

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