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

SODIUM TECHNOLOGY PROGRAM
PROGRESS REPORT
FOR THE PERIOD ENDING MAY 31, 1971

THIS DOCUMENT CONFIRMED AS
UNCLASSIFIED
DIVISION OF CLASSIFICATION
BY GH/Kahn/amb
DATE 8/31/71

Approved by:

William E. Ray
W. E. Ray
Principal Investigator

Approved by:

P. Murray
P. Murray
Project Manager

Prepared for the U. S. Atomic Energy Commission
Division of Reactor Development and Technology
Under Contract No. AT(30-1)-4210, Task 1, Subtask B

Submitted to AEC/NY00 in August 1971

Westinghouse Electric Corporation
Advanced Reactors Division
P. O. Box 158
Madison, Pennsylvania 15663

R11-23

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

Printed in the United States of America
Available from
National Technical Information Service
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.95

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CONTENTS

Section		Page
1	INTRODUCTION.....	1-1
	1.0 General.....	1-1
	2.0 Summary of Objectives.....	1-1
	2.1 Wear, Bearing Test.....	1-1
	2.2 Interstitial Element Transfer.....	1-1
	2.3 On-Line Meter Characterization.....	1-2
	3.0 Summary of Prior Work.....	1-2
2	SODIUM WEAR TEST PROGRAM.....	2-1
	1.0 Wear, Bearing Tests.....	2-1
	1.1 Objectives.....	2-1
	1.2 Background.....	2-1
	1.3 Prior Work.....	2-1
	1.4 Current Progress.....	2-2
	1.4.1 Test Plan and Experimental Approach....	2-2
	1.4.2 System Design and Construction.....	2-8
	2.0 Self-Welding Evaluation In Sodium.....	2-17
	2.1 Objectives.....	2-17
	2.2 Prior Work.....	2-17
	2.2.1 Related Work.....	2-17
	2.2.2 Preparatory Work.....	2-17
	2.2.3 Facilities.....	2-17
	2.3 Current Progress.....	2-20
	2.3.1 Sodium Loop.....	2-20
	2.3.2 Test Chambers.....	2-20
3	INTERSTITIAL ELEMENT TRANSFER.....	3-1
	1.0 Objectives.....	3-1
	2.0 Prior Work.....	3-1

CONTENTS (CONTINUED)

Section	Page
2.1 Related Work Outside Westinghouse.....	3-1
2.2 Preparatory Work.....	3-1
2.3 Facilities.....	3-2
2.3.1 CEL-1.....	3-2
2.3.2 CEL-2.....	3-2
2.4 On-Line Metering.....	3-2
2.4.1 UNC Diffusion Carbon Meter.....	3-3
2.4.2 BNL Electromechanical Carbon Meter.....	3-3
2.4.3 Westinghouse Electromechanical Oxygen Meter.....	3-3
2.4.4 Cover Gas Hydrogen Monitoring by Gas Chromatagraph.....	3-3
2.4.5 Experimental Work.....	3-4
2.4.6 Thermodynamic Modeling.....	3-4
2.4.7 Diffusion Studies.....	3-4
3.0 Current Progress	
3.1 Facility Design and Installation.....	3-4
3.1.1 CEL-1.....	3-4
3.1.2 CEL-2.....	3-5
3.1.3 ITF.....	3-5
3.2 CEL-1 Experimental Data.....	3-13
3.3 On-Line Meters.....	3-20
3.3.1 UNC Diffusion Carbon Meter.....	3-20
3.3.2 BNL Carbon Meter.....	3-22
3.3.3 Westinghouse Oxygen Meter.....	3-24
3.4 Thermodynamic Modeling.....	3-26
APPENDIX A AS-RECEIVED ANALYTICAL DATA FOR THE SAMPLE MATERIALS.....	3-27
4 ON LINE METER CHARACTERIZATION.....	4-1
1.0 Objectives.....	4-1
2.0 Prior Work.....	4-1
3.0 Current Progress.....	4-1

CONTENTS (CONTINUED)

Section	Page
3.1 Oxygen Meter Characterization.....	4.1
3.2 TOM Subloop.....	4-2
3.3 Tests of Initial Batch Zircoa Tubes.....	4-3

LIST OF FIGURES

Figure	Page
2-1 Sweater Test Chamber.....	2-10
2-2 Typical Specimen Configurations.....	2-12
2-3 Sweater Drive Mechanism.....	2-13
2-4 Loop Assembly Isometric.....	2-14
2-5 Self-Welding System Schematic.....	2-21
2-6 Self-Welding Test Chamber.....	2-23
2-7 Hydraulic System for Self-Welding Tests in Sodium for 6, 12, and 24 Months.....	2-24
3-1 Carbon Source for CEL-1 and CEL-2.....	3-6
3-2 Standard Tab Exposure Chamber.....	3-7
3-3 CEL-2 Piping Layout.....	3-8
3-4 Interstitial Transfer Facility Schematic.....	3-9
3-5 Axial Temperature Distributions for Fuel Pins and Wire Wrap FFTF Fuel Assemblies.....	3-12
3-6 Loop Schematic of FFTF Primary System.....	3-13
3-7 Carbon Equilibrium Values C_e of Various Structural Materials.....	3-18
3-8 Response of BNL Carbon Meter to Cold Trapping.....	3-25
4-1 Zircoa Isopressed Tube Calibration.....	4-4

LIST OF TABLES

Table		Page
2-1	Estimated Operating Conditions for Specific FTR Core Components.....	2-3
2-2	Estimated Operating Conditions for Specific IVHM Components for FTR.....	2-4
2-3	Proposed Test Plan Conditions for FTR Core Components....	2-5
2-4	Proposed Test Plan Conditions for IVHM Components in FTR.....	2-6
2-5	Test Parameters for SWEATER.....	2-11
2-6	Estimated Operating Conditions for Specific FTR Core Components (Static Interfaces).....	2-18
2-7	Proposed Test Plan Conditions for Self-Welding Tests.....	2-19
2-8	Self-Welding Test Sample Design and Test Conditions.....	2-25
3-1	Analytical Data from Run 1 CEL-1.....	3-14
3-2	Analytical Data from Run 2 CEL-1.....	3-14
3-3	Analytical Data from Run 3 CEL-1.....	3-14
3-4	Analytical Data from Run 5 CEL-1 -- Effect of Position in Sample Tank on Equilibrium Carbon and Nitrogen.....	3-15
3-5	Analytical Data from Runs 6 and 7 CEL-1.....	3-16
3-6	Analytical Data from Run 8 CEL-1 -- Effect of Carbon Source and Cold Trap (ARMCO IRON).....	3-17
3-7	Test Conditions and Analytical Data for Runs 9, 10, 11, and 12.....	3-19
3-8	Flame Ionization Detector (F/D) Readings on the UNC Carbon Meter Under Varying Conditions.....	3-21
3-9	Analytical Data from Run 4 -- Cel-1 BNL Carbon Meter Readings at 1200°F vs Carbon Content ARMCO Iron Foil.....	3-23
3-10	Summary of Behavior of BNL Carbon Meters.....	3-23
A-1	As-Received Analytical Data for the Sample Material.....	3-27

SECTION 1 INTRODUCTION

1.0 General

This progress report on the Sodium Technology Program covers the work performed during the period from December 1, 1970 to May 31, 1971. The program is divided into the following subtasks:

Wear, Bearing Tests (See Section 2)

Sodium Wear Test Program

Self-Welding Evaluation in Sodium

Interstitial Element Transfer (See Section 3)

On-Line Meter Characterization (See Section 4)

The Interstitial Element Transfer subtask is a continuation of work reported as CEL continuation in WARD-4210T1-1, a progress report for the period ending November 30, 1970. The Wear, Bearing Tests and the On-Line Meter Characterization subtask were initiated during the third quarter of FY-1971.

2.0 SUMMARY OF OBJECTIVES

The primary objectives of each of the subtasks of this program are given below.

2.1 Wear, Bearing Tests

The objectives are to experimentally measure the wear rates and friction coefficients of several material combinations in interface configurations simulating FFTF core components under prototypic operating conditions; also to provide reactor designers with the quantitative data and experience factors necessary to successfully design components or component interfaces which will experience sliding or rubbing contact while immersed in high-temperature sodium.

2.2 Interstitial Element Transfer

The objectives are to provide experimental information and analytical relationships for design data so that the rate and direction of carbon and

nitrogen transfer and associated mechanical property changes of structural materials within liquid metal systems, representative of primary and secondary circuits of an LMFBR, may be predicted.

2.3 On-Line Meter Characterization

The objectives are to fully characterize the state-of-the-art liquid metal oxygen meters and provide the needed information on the performance characteristics of a standard electrochemical oxygen meter for FFTF and subsequent LMFBR applications.

3.0 SUMMARY OF PRIOR WORK

All work related to the present investigations and performed prior to the present period has been fully documented in:

AEC Contract AT(30-1)-4173

WARD-4173-1, "Sodium Technology Program Quarterly Progress Report for the Period Ending March 31, 1970."

WARD-4173-2, "Sodium Technology Program Quarterly Progress Report for the Period Ending June 30, 1970."

AEC Contract AT(30-1)-4210, Task 1

WARD-4210T1-1, "Sodium Technology Program Progress Report for the Period Ending November 30, 1970."

SECTION 2

SODIUM WEAR TEST PROGRAM

1.0 WEAR, BEARING TESTS

E. C. Bishop, L. Hoskins, J. L. McKinney
B. Minushkin, F. Peters, W. Wilson

1.1 Objectives

The objectives of the wear test program are:

1. To experimentally measure the friction coefficients and wear rates for several material combinations in interface configurations simulating FFTF core components under prototypic operating conditions.
2. To provide reactor designers with the quantitative data and experience factors necessary to successfully design components or component interfaces which will experience sliding or static contact under load while immersed in high-temperature sodium.

1.2 Background

The success of many design features and mechanisms for FFTF and LMFBR cores is dependent upon the ability of metallic surfaces, which are in contact under sodium, to slide over one another. The motion originates during operation of various mechanical components such as the core restraint device, control rod drives and refueling machines, or as the result of differential thermal expansion and/or flow or mechanically induced vibrations.

Design of these components and structures must include allowances for frictional loads and wear between contacting surfaces. Because of the complexity of friction and wear phenomenon in sodium, these allowances must be based on data obtained in tests which accurately simulate the surface contact and sodium conditions anticipated in the reactor.

1.3 Prior Work

During the last half of CY-1970 an extensive review of FFTF core, control rod drive mechanism, and in-vessel fuel handling machine designs was performed (AEC Contract AT(45-1)-2171) to identify components and interfaces which will be subject to frictional loads and wear while immersed in sodium. The need for data on friction coefficients and wear rates was established, and a Westinghouse Development Test Requirement Specification (WDTRS 1.27) was prepared which defined the important components and interfaces, their

operating conditions, and the test plan needed to obtain the friction and wear data.

The components interfaces on which design information is required are listed in Tables 2-1 and 2-2.[1] For each of the core and IVHM components identified, the table presents a schematic representation of the interface geometry, proposed materials, and operating parameters--including temperature, contact pressure, type of sliding motion, displacement, required life, dwell time, and tentative failure criteria.

The interface and operating parameters given in Tables 2-1 and 2-2 provided the basis for establishing contact simulation test conditions. The Proposed Test Plan Conditions[2] are given in Tables 2-3 and 2-4 for the core and IVHM components, respectively. In general, the test conditions were selected so that the temperatures, contact pressure, type of motion, ratio of pin diameter to displacement, and velocity are the same for the test specimens as for the actual component interface.

A program was initiated at ARD in December 1970 to experimentally measure friction coefficients and wear rates for several of the FFTF components under prototypic conditions. After about four weeks, work was suspended because of funding uncertainties, and the program remained inactive until AEC funding was provided in April 1971. Progress during the initial period is reported in the following section.

1.4 Current Progress

1.4.1 Test Plan and Experimental Approach

The test plan for the sodium wear test facility is embodied in Tables 2-3 and 2-4. This plan identifies a total of 65 tests that are needed to provide data on friction coefficients and wear rates for selected materials combinations under specified FFTF component operating conditions. The program is being coordinated with related work at LMEC. As a result of a meeting between ARD, LMEC, RDT, and WADCO personnel, ARD has initially been assigned responsibility for test numbers 7 through 11, 18, 19, 30, 39 through 40, A-2, A-4, and A-6 through A-14. In addition, ARD and LMEC are cooperating in the design, preparation, and, where practical, pre-exposure of test specimens.

The basic approach in the ARD program is to press two diametrically opposed horizontal pin specimens against plate specimens mounted on a vertically reciprocating rod immersed in flowing, well-characterized sodium. The contact bearing load (normal static load), the force necessary to move the

[1] WDTRS 1.27, "Wear Testing - FFTF Components (Revision 2 with Addendum)," Table I and Table 1 of Addendum, February 17, 1971, Contract AT (45-1)-2171, Task 1, Westinghouse Advanced Reactors Division, Madison, Pennsylvania.

[2] WDTRS 1.27, "Wear Testing - FFTF Components (Revision 2 with Addendum)," Table II and Table 2 of Addendum, February 17, 1971, Contract AT (45-1)-2171, Task 1, Westinghouse Advanced Reactors Division, Madison, Pennsylvania.

Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Fuel Assembly Duct Pads	Fuel Assembly Wire Wrap (Wire Against Fuel Pin and Wire Against Duct)	Control Assembly Duct Pads	Control Rod Drive Line Double Disconnect	Control Rod Drive Pots	Closed Loop Pins	Reflector Assembly Pads	Reflector Assembly Body	Sliding Surfaces Between Core Restraint Mechanism Yoke and Shielding	Pinned Joint between Linkage Bars in Core Restraint Mechanism	Instrument Tree Bottom Radial Bearing	Flexible Spine to Instrument Tree Guide Tube	Instrument Tree Anti-Rotation Lock	Control Rod Guide Tube to Lower Frame of Instrument Tree	Instrument Tree to Fuel Assembly Duct
Geometry			As Item 1		As Item 4		As Item 1	As Item 1	As Item 1				As Item 1	As Item 1	
Materials Combinations	Inconel 718/ Type 316 SS Inconel 718/ Inconel 718 WC Coating/ WC Coating Cr Flat/Cr Plate (a)	CN Type 316SS/ CN Type 316SS	As Item 1 (b)	Type 316 SS/ Type 316 SS	Inconel 718/ Type 316 SS	Inconel 718/ Type 316SS	Inconel 718/ Type 304 SS	Inconel 718/ Inconel 600	Inconel 718/ Type 304 SS/ Type 304 SS	Inconel 718/ Stellite Star J	Stellite Star J/ Stellite 6 Stellite Star J/ Inconel 718	Type 304 SS/ Nitrided 304	Stellite 6/ Stellite 6	Stellite 6/Type 304 SS Stellite 1016/ Type 304 SS	Type 304 SS/ Type 316 SS
Temperature (°F)	1160	1350	1160	(a) 400 (b) 1100	1100	1200	1160	400	(a) 400 (b) 900 to 1100	(a) 400	(a) 400 (b) 1100	1100	1100	1100	1160
Pressure (psi)	200 to 2000	0-40	(a) 100 (b) 2000	500	6000 to 10,000	To Be Determined	200 to 2000	200	2000	50,000	5000	200 to 500	Very Low or None	Very Low or None	1000
Motion	Reversed Sliding; Flat on Flat	Reversed Sliding	(a) Reversed Scram Slow Return Flat on Flat (b) Reciprocating Flat on Flat	Reversed Sliding; Cylindrical Pin on Flat	Reversed Sliding; Cylindrical Pin on Flat	(a) Longitudinal Reversed Sliding (b) Transverse Knocking Motion	Reversed Sliding Flat on Flat	Reversed Sliding Flat on Flat	Reversed Sliding Flat on Flat	Reciprocating Rotational	(a) Reciprocating Plus Axial (b) Axial	Static; Sliding During Removal	Reversed Sliding; Some Vibration; Flat on Flat	Reversed Sliding; Some Vibration;	Reversed Sliding; Some Vibration; Cylinder on Flat.
Distance of Motion (in.)	0.02 to 0.5	0.625	(a) 38 (b) Up to 0.5	38	38	To Be Determined	0.02 to 0.5	0.02 to 0.5	(a) 3 (b) 0.125	(a) 15°	(a) 180°, 8" (b) 1	20 to 25 feet	6	0.25	0.050
Velocity (ipm)	0.5 to 1.0	1	(a) Scram at 8640 (12 fps) Return at 4 (b) 0.5 to 1.0	Scram at 8640 (12 fps) Slow Return	Scram at 8640 (12 fps) Slow Return	To Be Determined	0.5 to 1.0	0.5 to 1.0	(a) 5 (b) 1	(a) 15° pm	(a) 0.5 to 1.0 rpm; 12 ipm (b) 1	12	12	1	120
Number of Cycles	1000	2000	(a) 1000 (b) 1000	855	855	To Be Determined	1000	1000	(b) 1000	(a) 1000	(a) 250 (b) 10,000	Spine 1 Tube 40	30	855	2 x 10 ⁸
Failure Criteria	Friction (a) Coefficients	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 to 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	Not Applicable	0.3 to 0.5	0.3 - 0.5	0.3 - 0.5
	Total allowable Wear (in.)	0.010	0.002 (On the Fuel Pin)	0.010	0.010	0.010	0.010	0.010	0.010	0.020	0.003	0.005 per Removal	0.010	0	0.050
	Breakaway Force	In Shear	Not Applicable	In Shear	500 lbs.	In Shear	Not Applicable	In Shear	In Shear	Not Applicable	Not Applicable	20,000 lbs. T/C Sheath 25 lbs.	In Shear	In Shear	In Shear
	Surface Interactions	No Self-welding	-----	No Self-welding	No Self-welding	No Self-welding	No Self-welding	No Self-welding	No Self-welding	Not Applicable	No Self-welding	No Self-welding	No Self-welding	No Self-welding	No Self-welding
Dwell Time in Reactor (months)	1	1	(a) 3 (b) 1	(a) 1 (b) 3	3	(a) 3 (b) 0	1	1	(a) 6 (b) 1	(a) 6 (b) 1	(a) 3 Total In- Reactor 120	30	3	3	3
<p>* Cold Worked Type 316 stainless steel/Cold Worked Type 316 stainless steel</p> <p>** Stellite 6/Cold Worked Type 316 stainless steel Cr Plate/Cold Worked Type 316 stainless steel</p> <p>Item 1: Pad is 0.685 inches in diameter.</p> <p>Item 2: Wire wrap is approximately 0.056 inches in diameter. Contact possible between wire and fuel pin and between wire and duct.</p> <p>Item 3: (a) Inside pad. (b) Outside pad.</p> <p>Item 4: (a) During refueling; (b) During operation.</p> <p>Item 6: Pin is 0.0625 inches in thickness; 4 inches in length. Radius at end of pin is 1/2 inches, as is that of the outer tube. Pressure: (a) 1, estimated from a 500 lb. load over an area 4 inches by 0.310; (b) From a 200 lb. load over same area.</p> <p>Item 9: (a) During refueling; (b) During operation. Pads are rectangular (1 inch length)</p> <p>Item 11: (a) During refueling; (b) During operation. Total joint length 9 inches; pin diameter 3 inches.</p> <p>Item 11: (a) During refueling; (b) During operation. Bearing width 6 inches; shaft diameter 18 inches.</p> <p>Item 12: Tube I.D. is 1.375 inches.</p> <p>Low friction coefficients are desirable, but not essential. Tests should not be concluded solely because coefficients exceed 0.5.</p> <p>All temperatures shown are maxima for the FTR improved core. The corresponding maxima for the first core are 200°F lower than those in Table 2-1.</p>															

Table 2-1. Estimated Operating Conditions for Specific FTR Core Components

Item		1 Grapple Finger Pin	2 Car Finger Operator	3 Grapple Bellcrank Bearing	4 Grapple Bellcrank Pin	5 Grapple bellcrank Pivot	6 Grapple Bellcrank Cam Follower and Car	7 Grapple Bellcrank Push Rod Pin	8 Upper and Lower Bellcrank Push Rod	9 Main Drive Shaft Bellcrank Pin	10 Main Drive Shaft Bellcrank Pivot	11 Toe Vertical Support Plate	12 Toe Inner Roller Guides	13 Toe Inner Roller Bearings	14 Lower Toe Shaft Bearing	15 Upper Toe Shaft Bearing	16 Toe Rack and Pinion Gear	17 Toe Outer Roller Guides	18 Toe Outer Roller Bearings
Geometry					As Item 2	As Item 1	As Item 2	As Item 1	As Item 1	As Item 2	As Item 1			As Item 1		As Item 12		As Item 2	As Item 1
Materials Combinations		Inconel 718/ Inconel 718 Stellite 1016/ Inconel 718	As Item 1	As Item 1	As Item 1	As Item 1	Inconel 718/ Type 304 SS	Inconel 718/ Inconel 718	As Item 7	As Item 7	As Item 7	As Item 1	Inconel 718/ Inconel 718 Inconel 718/ Stellite 3	As Item 12	As Item 6	As Item 6	As Item 7	As Item 12	As Item 12
Temperature (°F)		(a) 450 (b) 1100	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1
Pressure (psi)		(a) 45,000 (b) 1270	(a) very low (b) 0	(a) 376 (b) 0	(a) 160,200 (b) 139,200	(a) 3420 (b) 2480	(a) 95,800 (b) 82,800	14 lbs	4.7 lbs	14 lbs	14 lbs	0.9	355	355	736	112	874	Very low or zero	Very low or zero
Motion		Rotational reciprocation	Reverse sliding cylindrical pin on flat	Reverse sliding cylindrical pin on flat	Reverse sliding, cylindrical pin on flat	Rotational reciprocation	Reverse sliding, cylindrical pin on flat	Rotational reciprocation	Rotational reciprocation	Reverse sliding cylindrical pin on flat	Rotational reciprocation	Reverse sliding, flat on flat	Reversed sliding cylindrical pin on flat	Rotational reciprocation	Rotational reciprocation	Rotational reciprocation	Gear Action	Reverse sliding, cylindrical pin or flat	Rotational reciprocation
Distance of motion (in.)		0.125	1.5	1.5	1.5	0.15	1.125	0.19	0.77	1.5	0.13	12	12	6	10	10	--	12	6
Velocity (ipm)		1.37	9.84	9.84	9.84	1	7.38	1.25	5.03	9.84	2.82	141	141	70	117	117	--	141	70
No. of cycles		3500	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1
Failure Criteria	Friction Coefficients	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5	0.3 - 0.5
	Total Allowable Wear (in.)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	Breaking Force	Shear	Shear	Shear	Shear and tensile	Shear	Shear	Shear	Shear	Shear and tensile	Shear	Shear	Shear	Shear	Shear	Shear	Shear and tensile	Shear and tensile	Shear
	Surface Interactions	No self- welding	Not applicable	Not applicable	No self- welding	No self- welding	No self- welding	No self- welding	No self- welding	No self- welding	No self- welding	No self- welding	Not applicable	Not applicable	No self- welding	No self- welding	Not applicable	No self- welding	No self- welding
Dwell time in Reactor (months)		3.4	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1	As Item 1
Low friction coefficients are desirable, but not essential. Tests should not be concluded solely because coefficients exceed 0.5. For all items, conditions prefixed by (a) refer to refueling operations; prefixed by (b) refer to normal reactor operation. The temperature of 1100°F is based on FTR improved core operation.																			

Table 2-2. Estimated Operating Conditions for Specific IVHM Components for FTR

Test No.	Materials Combination	Temperature (°F)	Pressure (psi)	Travel Cycle (d-pin diam.)	Distance Traveled (in.)	Approx. Velocity (ipm)	Test No.	Materials Combination	Temperature (°F)	Pressure (psi)	Travel Cycle (d-pin diam.)	Distance Traveled (in.)	Approx. Velocity (ipm)
1	Inconel 718/Type 316SS	1160	2000	d/2	1000	1	26	CW Type 316SS/CW Type 316SS	1350	5	0.125"	2000	1
2	Inconel 718/Type 316SS	1160	2000	d/8	1000	1	27	CW Type 316SS/CW Type 316SS	1350	5	0.0625"	2000	1
3	Inconel 718/Type 316SS	1160	1000	d/2	1000	1	28	CW Type 316SS/CW Type 316SS	1350	1	0.125"	2000	1
4	Inconel 718/Type 316SS	1160	1000	d/8	1000	1	29	CW Type 316SS/CW Type 316SS	1350	1	0.0625"	2000	1
5	Inconel 718/Type 316SS	1160	200	d/2	1000	1	30	Type 316SS/Type 316SS	1100	500	20d	6.5 x 10 ⁴	Note 19
6	Inconel 718/Type 316SS	1160	200	d/8	1000	1	31	Type 304SS/Type 316SS	1160	1000	0.050"	2 x 10 ⁷	120
7	Inconel 718/Type 316SS	1200	4000	d/2	6.25 x 10 ⁶	37.5	32	Type 304SS/Type 316SS	1160	1000	0.100"	2 x 10 ⁷	120
8	Inconel 718/Type 316SS	1200	4000	d/4	6.25 x 10 ⁶	37.5	33	Inconel 718/Type 304SS	1100	2000	d/2	250	1
9	Stellite 6/CW Type 316SS	1160	100	d/2	7.6 x 10 ⁴	Note 19	34	Inconel 718/Type 304SS	1100	2000	d/8	250	1
10	Stellite 6/CW Type 316SS	1160	100	d/8	7.6 x 10 ⁴	Note 19	35	Inconel 718/Type 304SS	1160	2000	d/2	1000	1
11	Inconel 718/Type 316SS	1160	10,000	20d	6.5 x 10 ⁴	Note 19	36	Inconel 718/Type 304SS	1160	2000	d/8	1000	1
12	Inconel 718/Inconel 718	1160	2000	d/2	1000	1	37	Type 304SS/Type 304SS	1100	2000	d/2	250	1
13	Inconel 718/Inconel 718	1160	2000	d/8	1000	1	38	Type 304SS/Type 304SS	1100	2000	d/8	250	1
14	Inconel 718/Inconel 718	1160	1000	d/2	1000	1	39	Inconel 718/Stellite Star J	400	5000	d/2	330	0.008
15	Inconel 718/Inconel 718	1160	1000	d/8	1000	1	40	Inconel 718/Stellite Star J	400	5000	d/8	330	0.008
16	Inconel 718/Inconel 718	1160	200	d/2	1000	1	41	Inconel 718/Stellite Star J	1100	5000	d/2	2 x 10 ⁴	1
17	Inconel 718/Inconel 718	1160	200	d/8	1000	1	42	Inconel 718/Stellite Star J	1100	5000	d/8	2 x 10 ⁴	1
18	Cr Plate/CW Type 316SS	1160	100	d/2	7.6 x 10 ⁴	Note 19	43	Stellite Star J/Stellite 6	1100	5000	d/2	2 x 10 ⁴	1
19	Cr Plate/CW Type 316SS	1160	100	d/8	7.6 x 10 ⁴	Note 19	44	Stellite Star J/Stellite 6	1100	5000	d/8	2 x 10 ⁴	1
20	WC coating/WC coating	1160	300	d/2	1000	1	45	Type 304SS/Nitrided Type 304SS	1100	500	d/8	2 x 10 ⁴	12
21	WC coating/WC coating	1160	300	d/8	1000	1	46	Stellite 6/Stellite 6	1100	50	d	360	12
22	Cr plate/Cr plate	1160	300	d/2	1000	1	47	Stellite 6/Type 304SS	1100	50	d/8	430	1
23	Cr plate/Cr plate	1160	300	d/2	1000	1	48	Inconel 718/Inconel 600	400	200	d/2	1000	1
24	CW Type 316SS/CW Type 316SS	1350	20	0.125"	2000	1	49	Inconel 718/Inconel 600	400	200	d/8	1000	1
25	CW Type 316SS/CW Type 316SS	1350	20	0.0625"	2000	1							
<p>1. Test Nos. 1-6, 12-17 provide data for Items 1, 3(b), in Table 2-1.</p> <p>2. Test Nos. 7, 8 provide data for Item 6 in Table 2-1.</p> <p>3. Test Nos. 9, 10, 18, 19 provide data for Item 3(a) in Table 2-1.</p> <p>4. Test No. 11 provides data for Item 5 in Table 2-1.</p> <p>5. Test Nos. 20-23 provide data for Item 1 in Table 2-1.</p> <p>6. Test Nos. 24-29 provide data for Item 2 in Table 2-1.</p> <p>7. Test No. 30 provides data for Item 4 in Table 2-1.</p> <p>8. Test Nos. 31, 32 provide data for Item 15 in Table 2-1.</p> <p>9. Test Nos. 33, 34, 37, 38 provide data for Item 9 in Table 2-1.</p> <p>10. Test Nos. 35, 36 provide data for Item 7 in Table 2-1.</p> <p>11. Test No. 45 provides data for Item 12 in Table 2-1.</p> <p>12. Test Nos. 39, 40, provide data for Item 10 in Table 2-1.</p> <p>13. Test Nos. 41-44 provide data for Item 11 in Table 2-1.</p> <p>14. Test No. 46 provides data for Item 13 in Table 2-1.</p> <p>15. Test No. 47 provides data for Item 14 in Table 2-1.</p>							<p>16. Test Nos. 48, 49 provide data for Item 8 in Table 2-1.</p> <p>17. With the exception of test nos. 24-29, 31, and 32, the testing configuration should be a flat pin on plate. Nos. 24-29 should be carried out by using a cylindrical-end pin on cladding tubing on plate, or by simulation of operation conditions, using wire on cladding tubing. Nos. 33 and 34 should be carried out using a cylindrical-end pin on plate. For all tests a pin diameter of 1/8 inch is acceptable. However, in view of the need to establish relatively high pressures in some tests, a pin diameter of 3/32 inch will be acceptable if the required pressures cannot be obtained with a 1/8 inch diameter pin.</p> <p>18. Test nos. 1-6, 12-17, and 20-23 should be carried out with a dwell period of one week in mid-test. During this time specimens should be maintained at the test temperatures and pressure, but will be motionless.</p> <p>Decisions on the incorporation of dwell period into other tests will be contained in later revisions of this specification.</p> <p>19. Table 2-1 indicates two velocities, one fast (12 fps) during scram situations and then a slow return from the scram position (4 ipm). The tests should replicate this situation as close as is feasible.</p> <p>20. Tests on Cold Worked Type 316 stainless steel/Cold Worked Type 316 stainless steel for Item 1 in Table 2-1 have already been completed and are not included in Table 2-2.</p>						

Table 2-3. Proposed Test Plan Conditions for FTR Core Components

Test No.	Materials Combination	Temperature (°F)	Dwell Time (hrs)	Pressure (psi)	Travel Cycle (d = pin dia.)	Total Distance Travelled (in.)	Approx. Velocity (ipm)	Test No.	Materials Combination	Temperature (°F)	Dwell Time (hrs)	Pressure (psi)	Travel Cycle (d = pin dia.)	Total Distance Travelled (in.)	Approx. Velocity (ipm)
A-1	Inconel 718/ Inconel 718	450	---	1000	6d	300	10	A-12	Stellite 1016/ Inconel 718	450	---	2000	6d	3000	100
		1100	168	500	--	---	--			1100	168	0	--	---	--
		450	---	1000	6d	300	10			450	---	2000	6d	3000	100
A-2	Inconel 718/ Inconel 718	450	---	5000	6d	300	10	A-13	Inconel 718/ Stellite 3	450	---	500	6d	3000	100
		1100	168	2000	--	---	--			1100	168	0	--	---	--
		450	---	5000	6d	300	10			450	---	500	6d	3000	100
A-3	Inconel 718/ Inconel 718	450	---	1000	d/2	300	1	A-14	Inconel 718/ Stellite 3	450	---	2000	6d	3000	100
		1100	168	500	--	---	--			1100	168	0	--	---	--
		450	---	1000	d/2	300	1			450	---	2000	6d	3000	100
A-4	Inconel 718/ Inconel 718	450	---	5000	d/2	300	1	A-15	Inconel 718/ Type 304 SS	450	---	500	6d	3000	100
		1100	168	2000	--	---	--			1100	168	0	--	---	--
		450	---	5000	d/2	300	1			450	---	500	6d	3000	100
A-5	Inconel 718/ Inconel 718	450	---	500	6d	3000	100	A-16	Inconel 718/ Type 304 SS	450	---	2000	6d	3000	100
		1100	168	0	--	---	--			1100	168	0	--	---	--
		450	---	500	6d	3000	100			450	---	2000	6d	3000	100
A-6	Inconel 718/ Inconel 718	450	---	2000	6d	3000	100	NOTES 1. Test Nos. A-1, A-2 provide data for Items 2, 3, 4, 8, 9 in Table 2-1. 2. Test Nos. A-3, A-4 provide data for Items 1, 5, 7, 8, 10 in Table 2-1. 3. Test Nos. A-5, A-6 provide data for Items 11, 12, 13, 16, 17, 18 in Table 2-1. 4. Test Nos. A-7, A-8 provide data for Items 2, 3, 4 in Table 2-1. 5. Test Nos. A-9, A-10 provide data for Items 1, 5 in Table 2-1. 6. Test Nos. A-11, A-12 provide data for Items 11 in Table 2-1. 7. Test Nos. A-13, A-14 provide data for Items 12, 13, 17, 18 in Table 2-1. 8. Test Nos. A-15, A-16 provide data for Items 6, 14, 15 in Table 2-1. 9. All tests should be performed using a flat pin on plate configuration, for which a pin diameter of 1/8 inch is acceptable. If the required pressures cannot be obtained with a 1/8 inch diameter pin, a pin diameter of 3/32 inch is acceptable.							
		1100	168	0	--	---	--								
		450	--	2000	6d	3000	100								
A-7	Stellite 1016/ Inconel 718	450	---	1000	6d	300	10								
		1100	168	500	--	---	--								
		450	---	1000	6d	300	10								
A-8	Stellite 1016/ Inconel 718	450	---	5000	6d	300	10								
		1100	168	2000	--	---	--								
		450	---	5000	6d	300	10								
A-9	Stellite 1016/ Inconel 718	450	---	1000	d/2	300	1								
		1100	168	500	--	---	--								
		450	---	1000	d/2	300	1								
A-10	Stellite 1016/ Inconel 718	450	---	5000	d/2	300	1								
		1100	168	2000	--	---	--								
		450	---	5000	d/2	300	1								
A-11	Stellite 1016/ Inconel 718	450	---	500	6d	000	100								
		1100	168	0	--	---	--								
		450	---	500	6d	3000	100								

Table 2-4. Proposed Test Plan Conditions for IVHM Components in FTR

plate (frictional load), and the displacement are continuously measured. Friction coefficients are calculated as the ratio of the frictional and the measured normal static loads on the pin-plate specimen.

$$\mu = \frac{F}{W}$$

where: μ = friction coefficient

W = normal static or bearing load

F = frictional load-force necessary to move reciprocating plate specimen.

Wear data will be obtained from measured length and weight changes of the pin and from quantitative analysis of wear scars on the plate specimens using a surface profiling instrument. The wear data will be expressed as specific wear:

$$\frac{V}{WL} \quad , \quad \frac{\text{in}^3}{\text{lb} - \text{in.}}$$

or

$$\frac{d}{PL} \quad , \quad \frac{\text{in.}}{\text{psi} - \text{in.}}$$

where: V - volume wear, in^3

d = depth of wear, in.

W = bearing load, lb

P = bearing pressure, lb/in^2

L = sliding distance, in.

Experience has indicated that in conventional wear situations, the specific wear is influenced by factors such as:

1. Environment
2. Hot hardness
3. Transitions in wear characteristic which are often brought about by the wear process
4. Contact geometry and sliding mode

5. Bearing pressure
6. Surface finish
7. Friction characteristics

Items 1, 4, 5, and 6 are controlled by utilizing test conditions and specimens which are prototypically related to the FTR components. Item 2 is characteristic of the material, and Item 7 is determined by the material and operating conditions.

Additional information will be obtained on surface morphology, chemical composition, and metallurgical changes. Current plans include the testing of specimen surfaces in the "as-received" condition and after pre-exposure to sodium under conditions selected to produce the same surface composition and metallurgical conditions as anticipated for the actual FFTF component.

1.4.2 System Design and Construction

Design of the sodium wear test facility was essentially completed, materials were ordered, and fabrication of major components was initiated during the fourth quarter of FY-1971. In order to accelerate the wear test program in support of FFTF design, two such facilities are being constructed. The primary design restraint is that the tests be prototypic of actual wear situations in the FFTF core. This requires use of the specimen configurations, loading, motions, and sodium conditions identified for the several FTR wear interfaces in WDTR 1.27. A summary of the test parameters and operating conditions necessary to prototypically reproduce most of these wear interfaces is given in Table 2-5 and these form the basis for design of the Sodium Wear Test Rig (SWEATER).

Each SWEATER Facility will consist of two functional sub-systems: the wear test machines and a sodium supply loop. The wear test machines will facilitate prototypic testing under sodium or in the cover gas space and will include the wear specimens, specimen mounts, reciprocating drive, loading mechanisms, and seals and load and displacement measuring instrumentation. The Sodium Supply Loop will provide a source of purified and characterized sodium at appropriate temperature, impurity content, and flow rate to the wear test vessel. The loop will be a conventional isothermal EM pumped loop with a cold trap for achieving the desired sodium chemistry and by-pass sampling and oxygen meter stations for characterizing the sodium.

A schematic drawing of the wear test machine is shown in Figure 2-1. The wear tests are performed inside a 6-inch x SCH 40 x 2-foot long stainless steel chamber by pressing two horizontally loaded, diametrically opposed pin (or flat) specimens against two wear plates mounted on a vertically reciprocating rod. Typical specimen details are shown in Figure 2-2. The reciprocating rod is guided by ball bushings and sealed by a welded, nested bellows assembly mounted on the top flange. The normal static loads are applied to the test specimens by horizontal push rods loaded by externally mounted pneumatic cylinders and transmitted into the test chamber through a

4340-1

Figure 2-1. Sweater Test Chamber

Table 2-5. Test Parameters for SWEATER

Wear Test Machine

Operating Temperature	400 to 1350°F
Specimen Configuration	a. Flat-on-flat b. Cylinder on-flat
Contact Pressure	200 to 10,000 psi
Motion	a. Reciprocating, 0.02 to 3-inch displacement b. Rotational $\sim \pm 7\text{-}1/2^\circ$ c. Reciprocating plus rotation d. a or b or c plus vibration
Total Travel	Up to 10,000 inches
Velocity	1 to 37.5 ipm
Dwell Time	0 to ~ 6 month
Specimen Surface Condition	a. As-fabricated and installed b. Pre-exposed to reproduce expected surface compositional changes

Sodium Supply Loop

Purity	<5 ppm oxygen, <2 ppm hydrogen, maintained by cold trap, 25 micron particulate filter
Flow	0.1 to 2 feet per second past wear surfaces
Characterization	On-line oxygen meters. Bypass sampling for metals, O, H, N, C, and particulates as required.

Figure 2-2. Typical Specimen Configurations

Figure 2-3. Sweater Drive Mechanism

4340-4

Figure 2-4. Loop Assembly Isometric

linear ball bushing and bellows sealed assemblies located on the side flanges. All bellows, seals, and bushings are located in the gas space.

The vertical reciprocating motion (Figure 2-3) will be generated by a Scotch Yoke and adjustable cam mechanism, driven by a variable speed electric motor and standard gear reduction unit.

The reciprocating drive and horizontal push rods will be instrumented to provide continuous measurement of load and displacement. The load cells will be located outside the test chamber and calibrated to correct for parasitic loads. Under normal operating conditions, drag loads due to the ball bushings and the spring constant of the bellows should be less than ~ 5 percent of the normal or frictional loads. High precision dial indicators will measure deflection in the horizontal rods to provide a possible measure of wear rate.

Sodium flow is maintained past the wear surfaces by a flow shroud. The shroud provides an annular flow passage around the specimen assembly. Side leakage is minimized by an auxiliary bellows attached to the shroud and to the horizontal push rods.

The sodium supply loop (Figure 2-4) will be essentially an isothermal system capable of supplying up to two gpm of sodium at temperatures as high as 1350°F to each of four parallel wear test chambers. The initial facilities will contain only two chambers per system. Approximately ten percent of the flow (~ 0.5 gpm) will be bypassed through an economizer and forced circulation cold trap operating at temperatures down to $\sim 250^{\circ}\text{F}$ to control impurity levels. An on-line oxygen meter and bypass sampling station will be provided to characterize the sodium. One of the bypass sampling stations will contain a 25-micron porous stainless steel filter element.

The salient design features of the SWEATER facilities are summarized below.

1.4.2.1 Wear Test Machine

Important features of the Wear Test Machine are:

1. The wear tests are to be conducted in a flowing sodium stream.
2. The drive mechanism is capable of reproducing the basic reciprocating motions and under selected conditions combining this with one or more of the other motions (rotational or vibrational).
3. Instrumentation is provided to permit continuous direct measurement of the normal static and static or dynamic frictional loads, displacement, velocity. Load cells will be calibrated or located to eliminate parasitic loads (due to bearings, seals, drives, etc.).
4. The specimen mounts provide prototypic support and are capable of accepting the various interface configurations.
5. Assembly techniques and reference points are provided to ensure proper alignment of the specimens.

6. Specimen installation and replacement will be possible without shutting down parallel test sections and should be accomplished with minimum downtime (one week maximum) to expedite completion of the test work.
7. The load, motion, displacement, and velocity are easily adjustable or changeable by simple replacement of drive components over the range indicated in Table 2-5.
8. The wear test chamber is designed and constructed to permit cleanup by vacuum distillation of sodium.
9. The test chamber or specimen mounts have provisions for exposing material control samples during the wear test.

1.4.2.2 Sodium Supply Loop

Important features of the Sodium Supply Loop are:

1. The sodium supply loop is an isothermal forced circulation loop capable of supplying a controlled flow of up to two gpm to each of two parallel wear test chambers (with provisions for future installation of additional wear test chambers).
2. A portion of the flow is bypassed through a cold trap of proven design and performance (available at ARD to provide control of impurity content of the sodium). The cold trap is sized to reduce the oxygen level from relatively high values (~ 100 ppm) to less than five ppm within approximately 24 hours.
3. A bypass sampling station is provided which samples sodium supplied to the wear test chamber at the test temperature.
4. An oxygen meter station is provided for on-line monitoring of the oxygen activity of sodium supplied to the wear test chambers.
5. The system is completely drainable.
6. The system is capable of continuous unattended operation.
7. Provisions are included to permit independent draining and flushing (or rinsing) of each wear test chamber before loop flow is initiated to minimize contamination of the other operating test chambers.

2.0 SELF-WELDING EVALUATION IN SODIUM

J. Y. Chang, P. N. Flaggella, F. Peters, W. E. Ray, S. L. Schrock

2.1 Objectives

The objectives of these tests is to provide information on self-welding characteristics of FFTF reactor materials with relevance to the component configurations anticipated in the reactor.

2.2 Prior Work

2.2.1 Related Work

Authorization to initiate this work program was received from the AEC during this reporting period. Therefore no prior work has been performed on this task. Work performed by others applicable to this program have reported adhesion or self-welding occurred for the materials tested.

A German study^[3] using austenitic materials, stabilized ferritic steel, and a nickel base alloy as well as several hard facing and hard metal alloys showed "a more or less pronounced tendency for all the materials to weld together" after 168 hours exposure in sodium at 580 and 700°C.

2.2.2 Preparatory Work

The basic need and specifications for this program were identified by FFTF designers in the Westinghouse Development Test Requirements Specification, WDTRS 1.27^[4]. Table 2-6 presents the components and materials involved and the expected environmental operating conditions. Under those conditions the possibility of self-welding exists. Table 2-7 gives the material combinations for the self-welding tests planned. The prior work indicated above has been used to provide preliminary information on suitable material combinations for FTR use. However, the data were obtained under conditions not prototypic of those anticipated for the many components of the FTR. Thus, it is not possible to evaluate directly the performance of the selected materials under FTR operating conditions without further data.

2.2.3 Facilities

In order to perform satisfactory tests in sodium to evaluate the possibility for self-welding of selected material combinations under a known compressive

[3] K. Bendorf, "Experimental Investigations of Self-Selding of Structural Materials Under Sodium," Nucl. Eng. Des. 14, pp. 83-98 (1970).

[4] WDTRS 1.27, "Wear Testing - FFTF Components (Revision 2 with Addendum)," February 17, 1971, Contract AT (45-1)-2721, Task 1, Westinghouse Advanced Reactors Division, Madison, Pennsylvania.

Table 2-6. Estimated Operating Conditions for Specific FTR Core Components (Static Interfaces)

Item	Fuel Assembly Inlet Nozzle/ Receptacle	Reflector Nozzle/ Receptacle	Core Support Structure tapered Shear Locks	Core Support Structure Removable Section (Basket)	Core Support Structure Seal at Basket	Nut and Bolt	Fuel Assembly End Cap to Grid
Geometry						Screw Thread
Materials Combinations	Type 316 SS/ Inconel 718 Cr-plate/ Inconel 718 WC-coating/ Inconel 718 Nitrided 316/ Inconel 718	Type 316 SS Inconel 718 Cr-plate/ Inconel 718 WC-coating/ Inconel 718 Nitrided 316/ Inconel 718	Type 304 SS/ Type 304 SS	Type 304 SS/ Type 304 SS	Type 304 SS/ Type 304 SS	Type 304 SS/ Type 304 SS A286/Type 304 SS	Type 316 SS/ Type 316 SS
Temperature °F	400 to 800	400 to 800	400 to 800	400 to 800	400 to 800	400 to 800	400 to 1200
Pressure (psi)	10,000	2000	2000 to 6000	2000	30,000 de- creasing to 1000	15,000	1000
Dwell time in reactor (months)	6 (Nozzle) 90 (Receptacle)	6 (Nozzle) 90 (Receptacle)	240	120	120	240	1 at 400°F 3 at 1200°F

Table 2-7. Proposed Test Plan Conditions for Self-Welding Tests				
Test No.	Material Combination	Temperature (°F)	Pressure (psi)	Exposure Time (months)
1	Type 304SS/ Type 304SS	800	30,000	6
2		800	10,000	6
3		800	10,000	12
4		800	2,000	6
5		800	2,000	12
6		800	2,000	24
7	A286/ Type 304SS	800	30,000	6
8		800	15,000	6
9		800	15,000	24
10	Type 316SS	800	10,000	6
11	Inconel 718	800	2,000	6
12	Cr-plate	800	10,000	6
13	Inconel 718	800	2,000	6
14	WC-coating/	800	10,000	6
15	Inconel 718	800	2,000	6
16	Nitrided Type	800	10,000	6
17	316SS/Inconel 718	800	2,000	6
18	Type 316SS/ Type 316SS	1200	1,000	6

stress, it was felt that a dynamic sodium loop with cold trapping capabilities was required so that the oxygen content could be maintained below ten ppm during testing. A Thermal Fluids Loop (TFL) was previously built by Westinghouse and was made available for the self-welding program. Basic system requirements are available including instrumentation and controls. By making the necessary modifications and additions, satisfactory tests can be performed.

2.3 Current Progress

2.3.1 Sodium Loop

Design effort was initiated on modifications to the Thermal Fluids Loop necessary to make the loop applicable to the self-welding test program. The program calls for a non-isothermal forced circulation sodium system capable of operating unattended with continuous chemistry control and monitoring.

System operational parameters include primary sodium flow of two gpm at a maximum temperature of 1200°F. Sodium chemistry will be monitored with a Westinghouse oxygen meter and a by-pass sample line.

Self-welding test chambers operate in series off a system by passes in the hot (two chambers, 1200°F) and cold (ten chambers, 800°F) regions of the circuit (Figure 2-5). Each test region is equipped with a surge tank and flow meter. Due to a multi-interface problem, flow through the test chambers will be maintained low (0.25-0.50 gpm) with the majority of the flow by passing the test sections. Level control devices will be placed in the surge tanks and the last test chambers. An automatic gas system has been designed to keep system pressures in the proper ranges and thus aid in level control.

Regenerative heat exchangers were designed for the primary and cold trapping system. Surge tank, dump tank, and cold trap revisions were initiated. Fabrication drawings have been essentially completed and are awaiting final review.

Control system philosophy has been developed and modifications are underway. Additional instrumentation needs have been identified. Heater and thermocouple layouts have been initiated. Panel layouts and functions are being designated.

Some material purchased under the defunct radioactive corrosion product program has been identified for use on the Self-Welding System (SWS). Orders have been placed for piping, valves, and heating cables. The existing containment structure will be modified to accommodate the addition of the self-welding chambers.

2.3.2 Test Chambers

As a result of the Wear Program Meeting held at LMEC on April 15 and 16, 1971, the conceptual design of the self-welding test apparatus has been re-examined

The equipment has been redesigned to meet the above requirement as well as to measure the break-away force required to separate the two specimen surfaces while remaining in the sodium at approximately 400°F after the self-welding experiment. Figure 2-6 shows the test chamber which consists primarily of seven functional sections: sodium chamber, a sodium vapor cooling column, a cover gas chamber with seal, a linear bushing, and a bearing and coupling to provide for wiping between the test samples, and a hydraulic cylinder to provide the compression force. The sodium chamber will hold approximately 15 in³ of sodium. This chamber is designed not to be dumped until the end of the test to minimize temperature fluctuations on the samples. A sodium vapor cooling column was added to minimize vapor deposition near the seal area. The temperature of the cooling column will be controlled at the desired level by auxiliary heaters.

The Hydraulic System is shown schematically in Figure 2-7. The cylinders marked E-1 and E-2 are located in the hot-leg (1200°F) regions of the system. The remaining cylinders are located in the cold-leg (800°F) of the sodium loop. The hydraulic systems are divided into two sections with oil pressures of 1528 and 407 psia. Such an arrangement eliminates the need for pressure regulators which are a possible source of oil leakage.

To provide continuous reliable pressure on the test samples for up to two years, an accumulator with a ten gallon capacity was chosen to compensate for internal or external oil or gas leakage. This accumulator saves electrical power and reduces the heat that would otherwise be generated in the system by constant operation of a pump against the relief valve. Assuming a typical leak-rate in hydraulic system of four mm³/hr after two years of operation, the pressure change in the oil lines would be five psia. The change in load associated with this leakage would be 100 psi which is approximately 0.3% for the test samples which are under 30,000 psi compressive stress (see Table 2-7).

A strain gage type transducer and Bourdon tube pressure gauges with an accuracy of 0.1% of full scale will be used to continuously monitor the oil and gas pressure of the system.

Self-welding test sample design and proposed wiping test conditions are listed in Table 2-8. Currently, the degree of wiping motion performed at the start of the test has not been finalized between ARD, LMEC, WADCO, and the AEC.

Figure 2-6. Self-Welding Test Chamber

Table 2-8. Self-Welding Test Sample Design and Test Conditions

Test Surface (a)						Wiping Treatment		Self-Weld Test		
Test No.	Material Combination	Area of Contact (in ²)	Exposure Temp. (°F)	Geometry (d)		Load During Wiping (Pound Force)	Angle, Speed, Sequence of Rotational Direction and Accumulated No (Deg., Deg/sec A, B, etc, C1 ^(b) Cu ^(c))	Temp. (°F)	Pressure x10 ⁻³ (psi)	Exposure Time (month)
				I.D. (in)	O.D. (in)					
1	304/304	0.25	800	1.0	1.672 ^(e)	1.232	A[10,10/sec,C1(4)]	800	30	6
2	304/304	0.75	800	1.0	1.398	1.388	A[10,10/sec,C1(4)]	800	10	6
3	304/304	0.75	800	1.0	1.398	1.388	A[10,10/sec,C1(4)]	800	10	12
4	304/304	1.00	800	1.0	1.508	0.264	A[10,10/sec,C1(4)]	800	2	6
5	304/304	1.00	800	1.0	1.508	0.264	A[10,10/sec,C1(4)]	800	2	12
6	304/304	1.00	800	1.0	1.508	0.264	A[10,10/sec,C1(4)]	800	2	24
7	A286/304	0.25	800	1.0	1.672 ^(e)	1.232	A[10,10/sec,C1(4)]	800	30	6
8	A286/304	0.50	800	1.0	1.279	0.147	A[10,10/sec,C1(4)]	800	15	6
9	A286/304	0.50	800	1.0	1.279	0.147	A[10,10/sec,C1(4)]	800	15	24
10	316/In718	0.75	800	1.0	1.398	1.388	A[10,10/sec,C1(4)]	800	10	6
11	316/In718	1.00	800	1.0	1.508	0.264	A[10,10/sec,C1(4)]	800	2	6
12	Cr-P/In718	0.75	800	1.0	1.398	1.388	A[10,10/sec,C1(4)]	800	10	6
13	Cr-P/In718	1.00	800	1.0	1.508	0.264	A[10,10/sec,C1(4)]	800	2	6
14	WC-Coat/ In718	0.75	800	1.0	1.398	1.388	A[10,10/sec,C1(4)]	800	10	6
15	WC-Coat/ In718	1.00	800	1.0	1.508	0.264	A[10,10/sec,C1(4)]	800	2	6
16	Nit304/In 718	0.75	800	1.0	1.398	1.388	A[10,10/sec,C1(4)]	800	10	6
17	Nit304/In 718	1.00	800	1.0	1.508	0.264	A[10,10/sec,C1(4)]	800	2	6
18	316/316	2.00	1200	1.0	1.884	1.129	A[10,10/sec,C1(4)]	1200	1	6

(a) Surface conditioning under flowing Na

(b) C1: Clock direction (Look from ceiling to floor)

(c) Cu: Counter clock direction

(d) Sample geometry is shown Sketch 1

(e) Exceptional shape is shown in Sketch 1

(f) Based on 70 ft-lb torque on cylinder push rod, assume friction coefficient 1

(g) Test surfaces finished to 63 microns.

Sketch 1

Sketch 2

SECTION 3

INTERSTITIAL ELEMENT TRANSFER

C. Bagnall, T. A. Galioto, B. R. Grundy, S. Orbon,
W. E. Ray, S. L. Schrock, S. A. Shiels

1.0 OBJECTIVES

The objectives of this program are to provide experimental information and analytical relationships for FFTF and LMFBR design use, so that the rate and direction of carbon and nitrogen transfer and the associated mechanical property changes of structural materials within liquid metal circuits representative of primary and secondary reactor plant systems may be predicted.

2.0 PRIOR WORK

2.1 Related Work Outside Westinghouse

The current AEC sponsored interstitial transfer program is part of an overall national program on sodium technology. The work at Westinghouse interfaces with, and in some areas complements, work being performed at ANL. Programs at AI, BNL, GE, MSAR, and UNC, which have now been terminated, are also relevant to the Westinghouse effort.

In the important area of carbon meter calibration and operation, the Westinghouse program will benefit from past work at UNC and BNL where the meters were developed and at MSAR where the UNC meter was used successfully in high carbon environments. The ANL program is perhaps the most extensive one outside Westinghouse. ANL personnel are concentrating primarily on relating carbon transport to chemical species, fundamental studies of interstitial activities in structural materials, and on adapting experimental meters for on-line use in EBR-II. The meter program particularly is of interest to Westinghouse.

AI's program (now terminated) interfaced in the area of material properties. They were to investigate the effect of carbon and nitrogen content of stainless steel on mechanical properties.

2.2 Preparatory Work

During the first half of FY-1970, extensive preparatory work on the interstitial transport program was performed in anticipation of the current AEC contract. This work involved a preliminary survey of the literature and identification of the key problems in defining interstitial transfer in sodium systems. An experimental approach was decided, and a facilities design concept was originated. The program and design philosophies were embodied in the work program that was submitted in November 1969.

2.3 Facilities

2.3.1 CEL-1

CEL-1 was filled with sodium and began operation in August 1970. Various operating problems were subsequently encountered. The alterations required to rectify these problems were:

1. Redesign of the BNL Carbon Meter by-pass loop.
2. Re-orientation of the UNC Carbon Meter side arm to allow easier access to other loop components.
3. Replacement of a faulty valve.
4. Redesign of the dump tank cover gas system to allow dumping under positive pressure instead of gravity.
5. Relocation of the Westinghouse Oxygen Meter in a separate by-pass line.
6. Relocation of the cold trap regulating valve.

The alterations indicated above have solved the CEL-1 operational difficulties.

Procedures were developed for changing both the carbon meter and oxygen meter probes, loading and unloading specimens, and the operation of the on-line vacuum distillation unit.

As expected, the principal operating problem involves the presence of hydrogen in the system introduced from the UNC carbon meter. Accumulation of hydrogen in essentially stagnant bypass lines and the subsequent surge of hydrogen when flow was initiated in these lines caused the cold trap to plug. It was decided to use the UNC meter on an intermittent basis only and to cold trap during these periods.

2.3.2 CEL-2

The piping layout of CEL-2 was changed to improve access to loop components, and the design improvements on CEL-1 were incorporated in the new loop layout. All component parts were machined and welding of the components was 95% completed.

2.4 On-Line Metering

During the last reporting period, all proposed metering devices were obtained and installed on CEL-1.

2.4.1 UNC Diffusion Carbon Meter

The operating parameters for the gas console were functionally evaluated. The procedures set out by the previous operators, MSAR, [5] were followed and found to be valid.

Problems in controlling and measuring the gas flow rates were encountered. These were overcome by installing a Matheson Linear Mass Flowmeter with electrical readout immediately before the FID (Flame Ionization Detector).

A calibration of the FID was obtained using the methane fraction of the calibration gases. 100% efficiency was confirmed for conversion of the CO fraction of the calibration gases to CH_4 by the catalytic converter.

2.4.2 BNL Electrochemical Carbon Meter

Of the three meters initially ordered, the first was damaged in transit, and the second was damaged during installation. The third meter was installed without incident, and an EMF in the expected range was obtained. The meter shorted after 280 hours and subsequently after 333, 458, and 516 hours of operation. The short was easily corrected by rotating the center electrode. Hydrogen present in the loop greatly affected the BNL meter reading. When hydrogen was present in the cover gas, a depression of EMF was observed; when the hydrogen was removed the meter recovered. This effect appears to be directly on the meter and not the result of an interaction between hydrogen and carbon in the sodium.

Operation of the BNL carbon meter and the UNC carbon meter simultaneously on a small loop appears very difficult because of the hydrogen injected into the loop by the UNC meter.

2.4.3 Westinghouse Electrochemical Oxygen Meter

Meter operation was limited by the stage reached in development of the ceramic electrolyte by WADCO in cooperation with Zirconium Corp. of America. The three electrolyte tubes tested produced EMF's which deviated considerably from theoretical values. This and the short lifetime of the tubes were probably the consequence of impurity concentrations at grain boundaries within the ceramic material.

2.4.4 Cover Gas Hydrogen Monitoring by Gas Chromatograph

The Fisher Gas Partitioner (Model 29) was installed on CEL-1 to monitor cover gas hydrogen content. Operation of the system was satisfactory. Unequivocal indication of hydrogen has been very useful in showing potential dangers including the tendency for hydrogen to accumulate in static side loops and the

[5] S.J. Rodgers and R.J. Shreve, "The Effect of High-Temperature Sodium on the Mechanical Properties of Candidate Alloys for the LMFBR Program. Techniques for Monitoring High Carbon Activity Sodium: An Evaluation of the UNC Carbon Meter. Topical Report No. 16," MSAR-70-54, May 1970.

detrimental influences of hydrogen on the electrochemical carbon meter.

2.4.5 Experimental Work

One run in the experimental program was completed during the previous reporting period. The tank was loaded with Type 304L stainless steel foils which were exposed for 265 hours at 1200°F. Analysis of the foils after exposure showed a change in carbon level from 340 to 550 ppm while nitrogen levels remained constant. It was inferred that these initial data reflected the initial surface condition of structural materials in the CEL-1 system.

2.4.6 Thermodynamic Modeling

Effort was directed towards establishing a theoretical model for interstitial transfer in sodium systems. The approach taken was to develop computational techniques using classical thermodynamics for the determination of equilibrium carbon profiles in a closed stainless steel system under an arbitrary temperature profile and to later modify this by introducing kinetic effects. The model derivation was published as Appendix A in WARD-4210T1-1.

2.4.7 Diffusion Studies

A review of the diffusion data for carbon in stainless steel and techniques for using data to calculate carbon gradients in stainless steel were published as Appendix B in WARD-4210T1-1.

3.0 CURRENT PROGRESS

3.1 Facility Design and Installation

3.1.1 CEL-1

CEL-1 has operated almost without incident since the last reporting period. System limitations have now been fully evaluated and potential operating problems can, in the main, be avoided.

Certain operating procedures have been tried because of specific program requirements. For example, samples were removed from the sample tank at various temperatures to investigate the effect of lowering the loop temperature before sampling (the normal procedure) on the measured C_e value in the foil. Removal at 1300°F was generally successful; however, in one instance, problems were encountered when the hot specimens contacted the teflon seats in the ball valves. These seats are normally maintained at <200°F by external cooling. Analysis of the foils indicated that there was no effect of sampling temperature thus making a high temperature sampling technique unnecessary. The CEL-2 loading columns have been fitted with gate valves, rather than ball valves; thus eliminating the teflon seats.

Operation of the initial carbon source (2-1/4 Cr - 1 Mo foil) was not satisfactory, and a new carbon source was designed. Preliminary experiments using

a sodium carbide/sodium mixture encapsulated in iron foil and immersed in the sample tank were successful and are reported in the Experimental Program Section. Rather than use sodium carbide for the new carbon source, it was decided to use a graphite powder/sodium mixture. Capsules to contain this mixture were fabricated from mild steel tubing 9 inch long, 1/2 OD x 10 inch wall, crimped and welded at both ends. Each capsule was filled to a height of about six inches and contains approximately 5g of graphite powder. The powder was vacuum degassed prior to loading to remove absorbed water vapor and gaseous hydrocarbons. Nineteen of the capsules were enclosed in a 3 inch Sch 40 flow-thru chamber shown in Figure 3-1. This chamber will replace the existing carbon source in CEL-1. A second chamber is under construction for installation in CEL-2.

Because of the problems associated with running the UNC and the BNL carbon meters on the same system, it was decided to remove the BNL meter from CEL-1 and run two BNL meters on CEL-2. Also, because of a general lack of success with the meters, an alternative measuring system is being installed on each loop. This will consist of a constant temperature (1300°F) exposure in which tabs will be exposed to the flowing sodium environment. The chamber will utilize an "air lock" loading system as used on the sample tanks (Figure 3-2). The loading columns are currently under construction and will be ready for installation during July.

Hydrogen accumulation in CEL-1 reached a level at which it presented a potential operating problem. It was decided to clean up the entire system by using an external cold trapping device. The procedure has proven to be completely successful, and the cover gas hydrogen level was reduced below its limit of detection.

A CEL-1 operating manual is about 80 percent complete and will be issued during June.

3.1.2 CEL-2

CEL-2 has been fabricated and installed and is ready for startup. The piping layout is shown in Figure 3-3. Remaining work items prior to shakedown and commissioning consist of minor additions to the cover gas system and installation of smoke detectors and the carbon source.

The principal differences between CEL-1 and CEL-2 are in piping layout details, use of two BNL meters, the absence of an UNC meter, and selection of gate valves instead of ball valves on the loading chambers. Additional control equipment for the BNL meters and the oxygen meter has been ordered on Westinghouse funds and is due for June delivery. Advantage will be taken of the intervening time period to perform shakedown tests on the loop.

3.1.3 ITF

A conceptual design for the Interstitial Transfer Facility has been completed. It is intended that the facility will be a simulation of the FFTF primary system. The ITF is a forced circulation ΔT loop consisting basically of two hot leg regions, a cold leg region, an electromagnetic pump, three flow meters

Figure 3-1. Carbon Source for CEL-1 and CEL-2

Figure 3-2. Standard Tab Exposure Chamber

Figure 3-3. CEL-2 Piping Layout

LEGEND

- 1 SODIUM PUMP
- 2 HEAT EXCHANGER
- 3 LOW FLUX HEATER REGION
- 4 HIGH FLUX HEATER REGION
- 5 AIR BLAST COOLER
- 6 SURGE TANK
- 7 FLOW METER
- 8 COLD TRAP
- 9 SHELL AND TUBE HEAT EXCHANGER
- 10 AIR BLAST COOLER
- 11 ELECTROCHEMICAL OXYGEN METER
- 12 HEATER/COOLER SYSTEM
- 13 CARBON METER
- 14 TAB EXPOSURE STATION
- 15 DUMP TANK
- 16 SAMPLE SECTIONS

Figure 3-4. Interstitial Transfer Facility Schematic

and a heat exchanger. The hot legs, cold leg, heat exchanger, and certain lengths of connecting piping are all used as specimen test sections. Test section locations are chosen to represent critical regions of the FFTF system. The oxygen concentration is controlled by varying the temperature in a by-pass cold trap line and measured using an electrolytic oxygen meter. The carbon activity is measured using a suitably calibrated carbon meter and/or standard tabs. The nitrogen activity is measured using standard tabs. The meter and tab exposure station will be located in separate bypass lines with suitable temperature control.

Access to specimens located through the test sections will be accomplished by removing welded end caps located at each end of the test sections.

The proposed design is shown schematically in Figure 3-4. Cold sodium (800°F) leaves the sodium pump (1) and splits into two lines. The major portion of the flow passes through the tube side of the tube-in shell heat exchanger (2) and is heated to 1050°F. The sodium then passes through the low flux heater region (3) and is heated to approximately 1150°F. The second flow path by-passes the heat exchanger and enters a high flux heater region (4). The sodium is heated to 1360°F before rejoining the main flow. It then passes through the shell side of the heat exchanger (2) and is cooled to 900°F. The remaining heat is dumped by an air blast cooler (5) after which the sodium returns to the pump (1) via a surge tank (6) and a flow meter (7). The main circuit is heated initially by trace heaters around the system. The main heat input is by clamshell radiant heaters along the low heat flux hot leg and by immersion heaters in the high heat flux hot leg.

The oxygen level is maintained by using a cold trap (8). The cold trapping temperature is achieved by passing the sodium through the shell side of a shell and tube heat exchanger (9) and an air blast cooler (10) prior to entering the cold trap. The sodium is returned through the tube side of the heat exchanger and is reheated to the mainstream temperature before rejoining the main flow. An electrochemical oxygen meter (11) monitors the oxygen activity continuously. A heater/cooler system (12) controls the oxygen meter temperature.

Interstitial activities are monitored by a carbon meter (13) and a standard tab exposure station (14) maintained at constant temperature.

The sodium charge is filled from the dump tank (15) and drained back to the tank during shutdown.

Specimens in the form of long lengths of three mil foil are loaded through extensions to the several sample sections (16). These extensions are welded closed during operation.

A Conceptual System Design Description (CSDD) has been written for the ITF and is currently awaiting managerial approval before submittal to USAEC. In order that the ITF can be built to simulate the FFTF primary system, it was necessary to analyze the available FFTF design data and determine the surface area, temperature profiles, and surface area to volume ratios. The necessary surface area data and temperature profiles have been calculated. The FFTF system was separated into 17 major components or groups of components, and

each was considered individually. These components are:

1. Fuel Pin and Wire Wrap
2. Fuel Assembly Shield Plug, Duct, and Upper Nozzle
3. Control Rod Pin Bundle - Row 3 Assemblies
4. Control Rod Pin Bundle - Row 5 Assemblies
5. Control Rod Pin Bundle - Row 7 Assemblies
6. Control Rod Assembly Perforated Can, Guide Plates and Absorber Assembly
7. Control Rod Assembly Shield Plug, Duct, and Upper Nozzle
8. Inner Reflector Assembly
9. Outer Reflector Assembly
10. Radial Shielding
11. Core Barrel
12. Reactor Vessel Thermal Shield
13. Reactor Vessel
14. Core Support Structure
15. Instrument Tree
16. In-Vessel Handling Machine (IVHM)
17. Ex-Reactor Coolant Piping, Pump and Intermediate Heat Exchanger (IHX)

Results of the analysis are presented in the form of axial temperature distribution trend curves, with the accumulated surface area represented by each curve indicated along that curve at various points. Trend curves are drawn for each 50°F increment in temperature seen by each of the seventeen mentioned categories above. Figure 3-5 shows this breakdown for the fuel pins/wire wrap (Category 1). The axial temperature distribution trend curve for the Ex-Reactor Coolant Loop (Category 17 above) is plotted as temperature (°F) versus axial distance (Y) in feet from the reactor outlet (Y = 0) to the reactor inlet (Y = 352). All other components are plotted as temperature (°F) versus axial distance (X) in inches from the reactor inlet (X = 0) to the reactor outlet (X = 478). For the purpose of this study, it is assumed that the reactor inlet is at the bottom of the inlet plenum and the reactor outlet is at the top of the sodium pool. The schematic diagram shown in Figure 3-6 indicates the FFTF system as analyzed in this study.

Figure 3-5- Axial Temperature Distributions for Fuel Pins and Wire Wrap FFTF Fuel Assemblies

The analysis was conducted on the basis of the FFTF improved core design, which stipulates an $\sim 800^{\circ}\text{F}$ inlet sodium temperature and a 1050°F outlet sodium temperature. All surface area data were calculated from the most current design data. In several instances, however, the temperature distribution data available did not reflect the latest design modifications. Even so, these data were taken as representative of the present FFTF design. Work is in progress on calculating surface area to sodium volume ratios.

Figure 3-6. Loop Schematic of FFTF Primary System

1340 13

3.2 CEL-1 Experimental Data

Twelve loop test runs have now been completed. The purpose of these experiments, together with a discussion of each set of results is given below.

Run 1 was utilized to condition the internal loop surfaces and establish the average loop surface carbon level for future reference. A number of Type 304L stainless steel foils was inserted and run in low oxygen sodium at 1200°F until equilibrium was approached. No hot trapping took place during this run. It was found that the foils equilibrated at 532 ppm carbon, having started at 340 pp. The as-received conditions are given for all materials in Appendix A of this section. This is in agreement with the the observation (from earlier work under Westinghouse sponsorship) that loop piping is ordinarily of high carbon and nitrogen content on internal surfaces.

Complete data for Run 1 are shown in Table 3-1.

Table 3-1. Analytical Data from Run 1 CEL-1						
Alloy	Carbon (ppm)		Nitrogen (ppm)		Duration (hr)	Loop Temp. °F
	Initial	Final	Initial	Final		
Type 304 L SS	340 $\pm$ 30 ^(a)	532 $\pm$ 65	929 $\pm$ 64	928 $\pm$ 63	265	1200
(a) All data are given with 1 σ limits						

Run 2 involved exposure of both pure (ARMCO) iron and Type 304 stainless steel foils. The loop was initially hot trapped at 1100°F for one week. The foils were then inserted and held in 1200°F sodium for 316 hours. The results are shown below in Table 3-2.

Table 3-2. Analytical Data from Run 2 CEL-1						
Alloy	Carbon (ppm)		Nitrogen (ppm)		Duration (hr)	Loop Temp. °F
	Initial	Final	Initial	Final		
ARMCO Iron	110 $\pm$ 2	35 $\pm$ 6	<10	25 $\pm$ 3	316	1200
Type 304 L SS	340 $\pm$ 30	228 $\pm$ 27	929 $\pm$ 64	793 $\pm$ 57	316	1200

Run 3 was also conducted at 1200°F; but this time continuous hot trapping at 1100°F was used. Table 3-3 gives the results after 251 hours.

Table 3-3. Analytical Data from Run 3 CEL-1						
Alloy	Carbon (ppm)		Nitrogen (ppm)		Duration (hr)	Loop Temp. °F
	Initial	Final	Initial	Final		
Type 304 L SS	340 $\pm$ 30	189 $\pm$ 14	929 $\pm$ 64	906 $\pm$ 78	251	1200
Type 316 L SS	204 $\pm$ 14	146 $\pm$ 5	533 $\pm$ 33	474 $\pm$ 48	251	1200
Incoloy 800	485 $\pm$ 9	784 $\pm$ 41	1316 $\pm$ 96	1710 $\pm$ 43	251	1200
2 1/4 Cr-1 Mo	1080 $\pm$ 53	125 $\pm$ 26	32 $\pm$ 3	159 $\pm$ 48	251	1200

Comparison of Type 304 L stainless steel carbon data in Runs 1, 2, and 3 show how the carbon content of the foil sample was first increased due to

high surface carbon levels on the containment tubing, then successively lowered by the two hot-trapping treatments. It will be noted that, despite continuous hot trapping in Run 3, Incoloy 800 gained considerable carbon and 2-1/4 Cr-1 Mo did not lose as much as might have been expected.

Run 4 was intended to be the first calibration run for the BNL carbon meter. The sample tank was charged with iron foil samples and the loop temperature was set at 1200°F. The system was initially hot trapped to lower the carbon activity of the sodium. It was anticipated that once the hot trap was shut off the activity would "drift" to higher levels as carbon diffused from the containment walls into the sodium and that this change would manifest itself as changes in meter reading and foil analysis values. Towards the end of the run the carbon source was used but apparently with no effect. Samples were withdrawn periodically and the meter output recorded continuously.

Data for this run are given in the section dealing with on-line meters, together with some discussion of the results.

Run 5 was used to determine the presence or absence of an activity variation within the sample tank. Twenty-seven samples of ARMCO iron were exposed for 48.5 hours at 1200°F. All were removed at the same time. The data shown in Table 3-4 indicate that the slight variation in the analysis figures is quite random when taken as a function of specimen location. It can therefore be assumed that efficient mixing takes place in the tank.

Table 3-4. Analytical Data from Run 5 CEL-1--Effect of Position in Sample Tank on Equilibrium Carbon and Nitrogen						
Position in tube	Carbon ^(a) and Nitrogen Values (ppm)					
	Tube ^(b) 11		Tube 12		Tube 13	
	C	N	C	N	C	N
Top	23	10	19	10	22	10
Middle	23	10	21	10	20	10
Bottom	20	13	19	11	24	11
(a) Two foils analyzed together to increase accuracy						
(b) The three specimen tubes, 11, 12, and 13 are located symmetrically within the circular section of the sample tank.						

Runs 6 and 7 represent a turning point in the overall program direction. Serious concern over the operation of the two carbon meters (see later section) led to initiation of an alternate method for carbon activity

monitoring of the sodium and containment materials. From Run 4, it appeared that measurement of concentration changes in the pure iron foils (in this case equivalent to activity measurements) was difficult, since a relatively large activity alteration in the sodium produced a change of only a few ppm carbon in the foil, within the 10-30 ppm range. Consequently, it was decided to examine Type 304 L stainless steel as a possible standard material against which to measure changes in the other structural alloys.

In order to minimize equilibrating times, the change from a ferritic to an austenitic alloy necessitated an increase in operating temperature from 1200°F to 1300°F. At a later stage as a precaution against unsatisfactory operation of the carbon meters at low activity levels, an additional Type 304 L stainless steel sample leg will be inserted in the loop system and will be controlled at 1300°F. The main sample tank may then be operated at other temperatures in the 800-1400°F range.

The test conditions and data for Runs 6 and 7 are given in Table 3-5. It was expected that the interstitial activities would "drift" to higher levels during operation at 1300°F as carbon and nitrogen diffused from the containment materials.

Table 3-5. Analytical Data from Runs 6 and 7 CEL-1						
	Carbon (ppm)			Nitrogen (ppm)		
	Before Exposure	After Run 6	After Run 7	Before Exposure	After Run 6	After Run 7
304 L SS	340 $\pm$ 30	70 $\pm$ 7	87 $\pm$ 6	929 $\pm$ 64	656 $\pm$ 15	677 $\pm$ 32
316 L SS	204 $\pm$ 14	95 $\pm$ 5	109 $\pm$ 4	533 $\pm$ 33	350 $\pm$ 3	380 $\pm$ 5
ARMCO Iron	110 $\pm$ 2	15 $\pm$ 3	18 $\pm$ 3	10	10	10
Material	304 L stainless steel, 316 L stainless steel, ARMCO Iron					
Temperature	1300°F					
Duration	Run 6: 97 hr, Run 7: 119 hr					
Hot Trapping	None					

The values obtained for carbon concentrations after Run 6 are the lowest yet obtained: 70 $\pm$ 7 ppm for Type 304 L stainless steel and 95 $\pm$ 5 ppm for Type 316 stainless steel. These data compare with values at 1200°F from Run 3 of 189 $\pm$ 14 ppm for Type 304 L stainless steel and 146 $\pm$ 5 ppm for Type 316 L stainless steel. The ARMCO Iron was low at 15 $\pm$ 3 ppm. Run 7 indicated an increase in activity in all cases as expected.

The nitrogen data show a similar trend although the values are much higher than for the carbon.

The objective of Run 8 was to evaluate a new carbon source. The source consisted of two capsules fabricated from 3-mil thick iron foil and filled with a Na/Na₂C₃ mixture. The capsules were inserted in the sample tank together with ARMCO Iron specimens. Data for the run are given in Table 3-6.

Table 3-6. Analytical Data from Run 8 CEL-1 - Effect of Carbon Source and Cold Trap (ARMCO Iron)						
Specimen Removal Sequence	Loop Temp. (°F)	Time at Temp. (hr)	Cold Trap (°F)	Carbon (ppm)	Nitrogen (ppm)	Carbon Source
1	1200	20	295	14	6	
2	1200	44	295	14	6	
3	1200	68	300	14	11	no cold trapping between these specs.
4	1200	188	-	39	10	
5	1300	20	-	42	7	Carbon Source OUT
6	1000	42	290	15	8	Carbon Source IN
7	1000	115	-	36	8	No cold trap

The results show that:

1. The carbon activity of the sodium was increased by the new carbon source. Cold trapping during the first three sampling periods suppressed the level at 14 ppm; but the fourth sample exposed for 120 hours with the cold trap off increased in carbon concentration to 39 ppm (compare this value with data obtained from Run 5, Table 3-4, where the concentration of carbon after exposure at 1200°F ranged from 19 to 24 ppm).
2. As inferred above, the cold trap operating at 300°F (and at 5-10% of loop flow) is effective in removing carbon from the sodium. Specimen 6 exposed at 100°F for 42 hours with the cold trap set at 290°F and the carbon source removed confirmed this finding. This foil showed a drop from 42 ppm (the equilibrium figure established at 1300°F with the carbon source in) to 15 ppm. At the same temperature with the cold trap off and the carbon source replaced, the concentration returned to 36 ppm (Specimen 7).

Runs 9, 10, 11, and 12 were the first set of experiments conducted at 1300°F using Type 304 L stainless steel foil as the standard against which to measure the behavior of other materials. Complete operational and carbon analysis data are given in Table 3-7; the latter are plotted in graphical form in Figure 3-7.

Figure 3-7. Carbon Equilibrium Values C_e of Various Structural Materials

Table 3-7. Test Conditions and Analytical Data for Runs 9, 10, 11, and 12					
Foil Material		Temperature (°F)	Duration (hr)	Carbon Source	Cold Trap
Run 9 304 L SS, 316 L SS, ARMCO Iron		1300	140	Na/Na ₂ C ₂ in Fe Capsule in Sample Tank	OFF
Run 10 304 L SS, 316 L SS, ARMCO Iron, 321 SS		1300	116	None	24 hr/290°F between Runs 9 & 10
Run 11 304 L SS, 316 L SS, ARMCO Iron, 321 SS, I 800, 2-1/4 Cr-1 Mo Croloy		1300	120	Na/Na ₂ C ₂ in Fe Capsule in Sample Tank	OFF
Run 12 304 L SS, 316 L SS, ARMCO Iron, 321 SS, I 800, 2-1/4 Cr-1 Mo Croloy		1300	97	None	Continuous Trapping Through Run at 310°F
Foil Material	As-Received (ppm)	After Run #9 (ppm)	After Run #10 (ppm)	After Run #11 (ppm)	After Run #12 (ppm)
304L SS	340 ± 30	3025 ± 671	139 ± 28	654 ± 151	117 ± 0 ^(a)
316 L SS	204 ± 14	4070 ± 497	129 ± 31	870 ± 90	156 ± 1
ARMCO Iron	110 ± 2	25 ± 2	31 ± 9	26 ± 1	26 ^(b)
321 SS	696 ± 19	--	1145 ± 64	2212 ± 11	823 ± 20
Incoloy 800	485 ± 9	--	--	1200 ± 35	240 ± 7
2 1/4 Cr-1 Mo Croloy	1080 ± 53	--	--	150 ± 24	--
^(a) Two identical analyses for 304 L SS specimens					
^(b) One analysis only					

Figure 3-7 provides an indication of the form experimental data from the CEL loops will take.

The figure shows concentration of carbon in Type 304L stainless steel plotted against equilibrium concentration determined in the other reactor materials. The data for Type 304L stainless steel vs Type 316L stainless steel fall on a straight line which lies in a position parallel to, but just below a curve for Type 304L stainless steel plotted against itself; indicating as might be expected that equilibrium concentrations in the two alloys are similar, but always slightly higher in Type 316L stainless steel.

Some of the experimental points for Type 304L stainless steel vs ARMCO Iron also fall on a line, approximately parallel to the one above. However, when carbon concentration in Type 304L stainless steel exceeds about 140 ppm, the linearity abruptly ceases and concentration in the iron remains nearly constant within the 25-30 ppm range. The one data point for 2-1/4 Cr-1 Mo alloy lies on a projection of this line through the low carbon ARMCO Iron data.

The curves shown for Incoloy 800 and Type 321 stainless steel are also drawn in linear form although as yet there is no real justification for this. The most striking feature of these data is perhaps the high carbon concentrations found in Type 321 stainless steel when in equilibrium with Type 304L stainless steel containing only 100 ppm. This suggests that Type 321 stainless steel will carburize if used in the core of a system constructed of an unstabilized stainless steel.

Further, there is sufficient titanium present in the Type 321 stainless steel to combine with up to 1300 ppm carbon. Because of the great affinity of titanium for carbon it is likely that, even at the low carbon activities expected in the reactor system, TiC will always be able to form. This indicates that Type 321 stainless steel will always carburize to a level of 1300 ppm. Once the titanium has been fixed, the Type 321 stainless steel curve in Figure 3-7 might be expected to parallel the Type 304L and Type 316L stainless steel curves. However, until more data are obtained the above hypothesis must be considered as tentative at best. One critical point which has not been discussed is the interacting role of nitrogen.

3.3 On-Line Meters

3.3.1 UNC Diffusion Carbon Meter

When operating at temperature (1200-1400°F), the hydrogen component of the decarburizing gas used for this meter diffuses into the sodium loop via the iron membrane of the meter probe. This hydrogen has presented operational problems, both in its effect on BNL carbon meter performance and in the conflict between the need for certain carbon levels in the loop and the need to trap the hydrogen. A further change was made to the meter gas supply and analysis console in an attempt to reduce the magnitude of hydrogen insertion. A solenoid valve was placed in the probe supply line and this enables a change to pure argon from decarburizing gas to be made. In addition, the meter has not been operated continuously at high temperature; whenever possible,

the probe has been reduced to a low temperature.

Meter readings have been made with the probe operating at 1200°F and 1400°F. In general there has been no correlation between meter readings during a given run and the analyses of exposed tab materials at the low carbon activities that have been used thus far. Indications were that the meter was operating at its limit of sensitivity. This limit appeared to be set by the background carbon level, which was significantly above the zero level normally set to compensate for the residual hydrocarbon content of the de-carburizing gas. In practice the variability of this background is considerable and hides small changes caused by carbon activity in the sodium.

An investigation of the source of this background was made. Typical results are given below. Table 3-8 shows some readings made on the system flame ionization detector (FID) under the different conditions listed.

Table 3-8. Flame Ionization Detector (FID) Readings on the UNC Carbon Meter under Varying Conditions	
Conditions	Reading (FID units) During Test Period
1. UNC probe operating at 1400°F, Run 2	365-385
2. UNC probe operating at 1400°F, Run 3	440-530
3. UNC probe operating at 1200°F, Run 2	220-225
4. UNC probe operating at 1200°F, Run 3	340-410
5. UNC probe operating at 220°F	135-185
6. Remove probe from circuit and directly connect together the copper supply lines	90-171
7. Remove external run of copper line; directly connect together the console bulkhead fittings	180-240
8. Conditions 6 and 7 plus lower catalytic converter temp. from 600°F to 495°F	Falls from 240 down to 80 then recovers to 185
9. Raise catalytic converter from 495°F back to 600°F	Peaks at 9900, recovers to 250 after 12 hours

Checks on the sensitivity of the FID were made during this period to verify that there was no significant change. It was determined that the converter was only 90% efficient at 495°F. The table illustrates: the large zero variable which makes precise reading difficult; all the readings with the probe at 1200°F and about 50% of the readings with the probe at 1400°F can be accounted for by carbon generated within the console or in the decarburizing gas. Some carbon (but it cannot be determined if all carbon) is generated by the catalytic converter. The catalytic converter is not in-line when the system zero is being set. Therefore the zero setting makes no compensation for non-hydrocarbon carbon-bearing gases, such as carbon monoxide, should traces be present in the decarburizing supply gas. An attempt to distinguish any such carbon content of the supply gas, by reducing flow in steps and extrapolating readings to zero flow was not successful because FID response was non-linear with respect to flow. The gas console pipework has been modified to include the catalytic converter in the "zero FID" mode of operation, but this in itself is no cure since it will merely introduce the same variability about the zero setting.

In addition to the above tests, it was demonstrated that almost any part of the gas system could produce temporary bursts of carbon if heated. Taken together these tests suggest the console itself to be a significant source of carbon. Consultation with ANL confirms that ARD's UNC carbon meter background level is about 10 times higher than that of ANL's UNC carbon meter. It is possible this arises from the previous use that the system has seen. The console piping is being rebuilt and a new catalytic converter installed; at the same time necessary components for a second UNC probe will be added. Since the possibility of non-hydrocarbon, carbon-bearing gases in the supply gas cannot be ruled out, a second gas supply is to be ordered to a specification covering such impurities.

3.3.2 BNL Carbon Meter

Only in Run 4 has a sufficiently long period of continuous meter operation been obtained for correlation with sodium exposed foil samples. Analytical data for the ARMC0 iron material exposed during this run, together with the BNL meter readings, are given in Table 3-9.

The changes in carbon levels during the run were slight as were the changes in meter readings. Over the very narrow range covered, no definite relationship was revealed.

Tests were performed on one meter in which the meter temperature was varied at constant loop temperature and vice versa. The results obtained by varying the meter temperature agree closely with those of BNL for a 304 stainless steel containment. With the meter operating at 1200°F, the loop was varied between 900 and 1200°F. As expected for short term temperature changes, there was no significant effect on meter EMF. Two further individual observations suggest that the meter is close to being a useful tool if reliability

Table 3-9. Analytical Data from Run 4--CEL-1 BNL Carbon Meter Readings at 1200°F vs Carbon Content ARMC0 Iron Foil				
Exposure Time (hr)	Avg. Loop Temp. (°F)	BNL Meter Reading at 1200°F (mv)	Foil Carbon (ppm)	Analysis Nitrogen (ppm)
24	1210	46.9	25+2	22
40	1220	46.0	28+2	19
88	1200	45.0	26+2	25
1315	1200	45.0	28+2	--
38	1200	43.5	20+2	13
80	1200	43.0	44+2	5

Table 3-10. Summary of Behavior of BNL Carbon Meters	
Meter Number	Summary of Performance
CMR 15	Open circuit internally
CMR 14	Over pressurized at startup; reversed EMF, high internal resistance
CMR 17	Worked correctly from startup. First internal short at 280 hours; operation terminated after six further internal shorts. Total operational time - 540 hrs.
CMR 35 (mild steel body)	EMF 1/4 expected value at startup and for 250 hours; expected EMF 250-1074 hours; reversed EMF at 1074 hours.
CMR 36 (mild steel body)	Previously used at BNL but new electrode used; worked corrently from startup; first internal short after 240 hours; developed very high EMF (1.6V) after 1100 hours.

can be improved. The first is based on the typical meter reading of 45 mv at 1200°F. Assuming the Nernst equation is applicable to the meter, this EMF converts to a carbon activity of 0.10. Upon cooling the loop and allowing the meter to equilibrate for several days at 1030°F, the carbon activity was measured at 0.41. Using Longson and Thorley's carbon solubility data^[6] and assuming Henry's Law holds, the carbon concentration in sodium at 1200°F is 1.9 ppm, and at 1030°F, 1.6 ppm. The meter readings are quite reasonable on the basis that the carbon concentration in the sodium remained approximately constant. The second such observation was made after the new carbon source was installed. Clear indication of the removal of carbon by the cold trap was given by the meter. This is shown in Figure 3-8. The gas chromatograph was used to confirm the absence of significant hydrogen during this test. Five BNL meters have now been operated. Inherent problems of the meter and the detrimental effects of hydrogen have resulted in an overall lack of reliability. A summary of behavior of the five meters is given in Table 3-10.

When shorting of the meter internally by iron whisker growth occurs, the fault can be easily corrected by rotating the reference electrode in the molten salt. However, recovery to the original EMF does not usually occur making subsequent EMF comparison dubious. The more shorts that occur, the less likely does full recovery become. BNL claims that construction of the meter body from mild steel reduces the whisker growth problem. This was certainly confirmed in the single new meter of this type. The previously used meter of mild steel construction with a replacement electrode quickly shorted; however, some of the phenomena observed in our tests, such as reversed EMF and very large EMF of same polarity are outside BNL's experience.

Quantitative data on the level of hydrogen at which significant depression of EMF occurs was obtained. Hydrogen level can be controlled by the cold trap, and for saturation temperatures >350°F there is sufficient partial pressure in the cover gas for direct confirmation with the gas chromatograph. The effect of hydrogen on the meter is significant at 400°F saturation temperature (one ppm H in Na) producing a 5mv depression. At 360°F saturation temperature (1/2 ppm H in Na) the effect has become negligible (<0-2 mv depression).

3.3.3 Westinghouse Oxygen Meter

During this period WADCO high-purity isopressed electrolytes became available and were incorporated into Westinghouse oxygen meters. In tests of these meters two significant calibrations were made. The first of these was performed by setting oxygen content using the cold trap. Four data points were obtained within a trap temperature range 290-400°F. These resulted in the following least squares correlation of meter EMF and oxygen concentration:

$$E \text{ (volts)} = 1.793 - 0.057 \log C_{Ox} \text{ (ppm)} \text{ (Oxygen meter at } 700^{\circ}\text{F)}$$

[6] B. Longson and A.W. Thorley, "Solubility of Carbon in Sodium," TRG-Report-1906, May 1970.

Figure 3-8. Response of BNL Carbon Meter to Cold Trapping

this the correlation agrees closely with those previously obtained on FPL-2 ($E = 1.794 - 0.057 \log C_{Ox}$ and $1.793 - 0.056 \log C_{Ox}$) indicating a negligible hydrogen effect. This agrees with predictions and data from BNL^[7]. In-line distillation analyses were also made at the 15 and 3 ppm levels. Eight analyses resulted in the correlation:

$$E = 1.806 - 0.068 \log C_{Ox} \text{ (Oxygen meter at } 700^{\circ}\text{F)}$$

which is in reasonable agreement with the trap calibration. In an attempt to determine the analytical blank, the hot trap was operated at 1200°F . This quickly reduced the oxygen level to three parts per billion as indicated by the oxygen meter using the first correlation above. There were some difficulties with the distillation apparatus, however, and the lowest analysis obtained was three ppm oxygen.

3.4 Thermodynamic Modeling

The data obtained from the analysis of the FFTF design data will be used in a theoretical determination of carbon transport in FFTF. Two techniques will be used: first, the mass balance technique as described in WARD-4210T1-1; second, it will assume that the lowest temperature in the system controls the carbon activity of the sodium and hence the carbon level of the structural steels at any temperature. The latter technique only requires knowledge of the temperature profile of the system.

Plots relating the equilibrium carbon content of the steel, the equilibrium carbon content of the sodium (C_e^{Na}), BNL meter reading, and the saturation temperatures for carbon in sodium (T_{sat}^{Na}), have been computed using the available theoretical data. These plots will be used in the above study.

[7] G. Kissel and B. Minushkin, "Hydrogen-Oxygen Interactions in Liquid Sodium, " to be published in Proceedings of AIME Symposium on Chemical Aspects of Corrosion and Mass Transfer in Liquid Sodium, October 1971.

APPENDIX A AS-RECEIVED ANALYTICAL DATA FOR THE SAMPLE MATERIALS

Table A-1. As-Received Materials Analysis																				
Material	Wt. %																ppm			
	Co	Cr	Cu	Mn	Mo	Nb	Ni	Pb	Sn	Ti	V	Zr	Si	Al	B	Fe	C	N	S	P
Type 304 L SS		19.51	+	1.80			9.45		+	+	+		0.53	+		R	340 +30	929 +64	96 +17	168 +6
Type 316 L SS	+	16.70	0.12	1.55	2.54	-	13.06	-	+	+	-		0.40	+	-	R	240 +14	533 +33	148 +30	43 +3
ARMCO Iron	-	+		+	-	-	+	-	-	+	-	-				R	110 +2	<10		
2 1/4 Cr- 1 Mo Croloy		2.30		0.42	1.00	0.01	0.02			+			0.39			R	1080 +53	32 +3	<30	68 +4
Incoloy 800		21.42	0.54	0.88	-		31.12			0.42			0.35			43.90	485 +9	1316 +96	<30	<25
Type 321 SS	0.06	17.37		1.42	0.20		9.65			0.53			0.86			R	696 +19	20 +2	107 +3	<20
R Remainder																				
+ Trace Detected																				
- Not Detected																				
One sigma limits are given for C, N, S, P																				

SECTION 4

ON-LINE METER CHARACTERIZATION

R. P. Colburn, B. R. Grundy, G. R. Taylor

1.0 OBJECTIVES

The program will provide needed information on the performance characteristics of a standard electrochemical oxygen meter for the FFTF and subsequent LMFBR applications. A standard meter is currently manufactured by Westinghouse Nuclear Instrumentation and Control Department.

A key component of the meter is the solid electrolyte. The process for producing a high-quality electrolyte has been developed at WADCO, and Zircoa, the commercial supplier, has adopted this process. Therefore, verification of adequacy of quality of the commercially available electrolyte is an essential part of the program.

Performance of the standard meter is to be tested by operating ten meters on a newly built subloop added to an existing ARD facility. The primary calibration method will be the standard vanadium wire equilibration method developed at ANL. A similar ten meter test is to be run at ANL. The number of meters tested will enable a statistically valid assessment to be made.

2.0 PRIOR WORK

Pre-contract work at Westinghouse was in the area of oxygen meter development and field testing. The developed meter employs a gaseous (air) reference electrode in conjunction with a small yttria-doped thoria electrode tube and yields the following advantages: well defined and stable reference conditions, low sodium temperature coefficient, little or no ambient temperature coefficient, instantaneous response to oxygen activity changes, and good resistance to mechanical shock and thermally induced mechanical stress.

High-purity ThO_2 - 7-1/2 wt. % Y_2O_3 electrolytes were developed at WADCO under AEC sponsorship. Examples of these electrolytes were incorporated into meters for field testing at ARD and showed excellent consistency of performance.

3.0 CURRENT PROGRESS

3.1 Oxygen Meter Characterization

AEC funding was received to start a ten oxygen meter characterization program. This arises from Westinghouse's successful development of an in-line

oxygen meter and its subsequent choice as the standard meter for the National Meter Program for LMFBR (organized by ANL). A similar test is to be made at ANL closely coordinated with that of the Advanced Reactors Division.

3.2 TOM Subloop

A conceptual design for a subloop on FPL-2 was completed. The following is a summary.

The ten oxygen meter (TOM) subloop to be attached to FPL-2 will be independently pumped with inlet and outlet placed as close together as possible on the primary loop in a zero differential pressure arrangement. In conceptual design, the subloop contains an EM pump, finned tube cooler, ten oxygen meters distributed in three parallel arms with clamshell heaters on the inlet side of the individual arms, vanadium wire equilibration module, and flowmeter. The zero differential pressure tapping with independent pump renders the subloop flow insensitive to primary loop flow perturbations. The combination of cooler and clamshell heaters with proportional controllers enables the temperature of the meters to be held closely to 700°F for subloop inlet temperatures ranging from 750-1000°F.

As a result of design reviews, two significant changes were made. The meters are now in two groups of five with bypass lines and normally operate in series. This allows direct flow measurement in all meters. The system, including oxygen meters, is drainable. This is significant to the meters themselves, providing for two possible electrode insertion techniques: with or without sodium in the loop and meter housings. There is considerable experience with both techniques.

Design of the cooler/heater system before the meter group has been based on easily available components rather than attempting to convert an input sodium temperature range of 750-1000°F to 700°F at the meters (initial design criterion). In particular, two light, easily mounted blowers are used on a finned tube cooler. Heat transfer calculations show that the input temperature range which can be accommodated is about 650-900°F. Heater and thermocouple layout have been finalized. Displacement of sodium from the vanadium wire module for wire removal must be made with the TOM subloop pump operational. Care must be taken in design and later, in operation, to insure that sodium is not pumped into the gas control system. Design details of the gas system were completed. If correct gas pressures are used, there is no danger of the sodium level rising. Calculation of pressure heads were made on the basis of maloperation in which the whole FPL-2/TOM gas system is initially at uniform pressure. In the worst cast a rise in level of approximately one foot 4 inches can occur. Provision of a vertical pipe above the vanadium wire module of at least this height will be made.

Drafting for TOM is 70% complete. ANL drawings for the vanadium wire equilibration module were accepted by Quality Assurance as working drawings provided required changes were properly drafted.

Construction of the vanadium wire equilibration module, FPL-2 cabinet changes, gas system, and electrical control panels is under way. Initiation of purchasing requests for materials and components is 95 percent complete.

Tests of a Honeywell Data Logger (with a Digital Voltmeter and paper point-out) were made on the two oxygen meters currently operating in FPL-2. This unit has proved quite satisfactory, but when reading it out, it causes a small deflection on a differential voltmeter and recorder system also displaying oxygen meter output. In view of this, and the added capacitance which a stepping switch will introduce in the final system, tests were initiated on an inexpensive operational amplifier for meter isolation. This has proved quite satisfactory with maximum contribution and change to oxygen meter output of 0.15 mv. The next highest grade of amplifier has been ordered. The Data Logger will also be used to readout two thermocouples per oxygen meter and is capable of $1/2^{\circ}\text{F}$ resolution at 700°F .

3.3 Tests of Initial Batch Zircoa Tubes

Zircoa have produced the initial batch of isopressed thoria/yttria electrolyte to a WADCO specification. Three electrolyte tubes have been made available for a rapid assessment of quality. Westinghouse Research Laboratories have subjected small surplus pieces of tube to a phosphoric acid etch (90 minutes at 90°C) with before and after Scanning Electron Microscopy examination. Small quantities of a second phase, high in yttria content, were detected at $\sim 15\%$ of the grain boundary triple points. The phosphoric acid etch attacked and removed this second phase. The three tubes were incorporated into Westinghouse oxygen meters and tests started on FPL-2 and CEL-1 at 700°F . Operational times of 920 hours (Tube #4-08-6), 614 hours (Tube #4-19-2), and 614 hours (Tube #4-20-2) have been reached.

Tube #4-08-6 showed some drift down in EMF over the first 40 hours; stable operation has been obtained since with reproducible calibration possible against cold trap temperature. Tubes #4-19-2 and #4-20-2 differed by only 1 mv for the first 50 hours of joint operation. Between 50-120 hours, Tube #4-20-2 drifted up by 10 mv with respect to Tube #4-19-2; stable operation has been obtained since with reproducible calibration possible against cold trap temperature. However, after about 450 hours, a slow drift down of Tube #4-20-2 with respect to Tube #4-19-2 has been noted.

Figure 4-1 summarizes the calibration correlations obtained and compares them with calibration of three meters incorporating WADCO laboratory produced isopressed electrolytes. The numbered points are associated with electrolyte Tube #4-08-6; points 1 and 2 are displaced from the final correlations as they were taken during the initial period of drift.

All temperature coefficient measurements have fallen in the range $+0.02$ to $+0.07$ mv/ $^{\circ}\text{F}$.

On the basis of this information and material tests at Westinghouse Research Laboratories and WADCO, WADCO may reject this batch of tubes for the ten meter tests at ARD and ANL.

Figure 4-1. Zircoa Isopressed Tube Calibration

Two meters using Zircoa tubes from further batches (with WADCO recommended process changes) are to be inserted in FPL-2 for a rush test. This will only last 100 hours so that the schedule for FPL-2 modifications will not be delayed. If further tests are required prior to the full ten meter tests, they will be made on the modified system.