**Liquid Metal Engineering Center
(LMEC)
Semiannual Technical Progress Report**

January-June 1969

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Liquid Metal Engineering Center

*Operated for
the U.S. Atomic Energy Commission by Atomics International*

A Division of North American Rockwell Corporation

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CONTENTS

	Page
Introduction	13
Summary	15
I. AEC Assistance and Consultation	21
A. Introduction	21
B. LMFBR Test and Facility Planning, Coordination, and Evaluation	21
1. Introduction	21
2. LMFBR Test Facility Planning	21
3. FFTF Test Planning, Coordination, and Evaluation	31
C. Technical Management of Contract AT(04-3)-781, LMFBR Piping Design Guide	31
1. Introduction	31
2. Discussion	32
3. Future Effort	40
D. Steam Generator and Intermediate Heat Exchanger Systems Performance and Contract Management	42
E. Sodium Pump Systems	44
1. Introduction	44
2. Project Management	45
3. Westinghouse Pump Study Contract	45
4. Byron Jackson Pump Study Contract	50
F. Sodium Valve Systems	50
1. LMFBR Valve Development	50
2. Sodium Pump Test Facility (SPTF) Development Valves	57
3. Fast Flux Test Facility (FFTF) Development Valves	57
G. Sodium-Water Reaction	62
II. Codes and Standards	69
A. Introduction	69
B. LMFBR Standards and Related Activities	69
1. Reactor Vessel	69
2. Circulating Cold Trap	70
3. Hot Trap for Removal of Sodium Impurities	71
4. Sodium Tanks	71
5. Centrifugal Free-Surface Sodium Pumps	72

CONTENTS

	Page
6. Electromagnetic Pumps	73
7. Instrumentation	73
8. Sodium-to-Air Heat Exchanger	74
9. Sodium Piping	75
10. Sodium Valves	77
11. Sodium Quality	78
12. Cover Gas for Reactor Grade Sodium	78
C. Coordination of LMEC Standards Effort with ORNL Standards Activities	79
1. Materials	79
2. Process Standards	82
III. Maintenance and Malfunction Analyses	85
A. Introduction	85
B. Information and Questionnaire Brochure	85
C. Incident, Malfunction, and Problem Report (IMPR)	85
1. LMEC Procedure II-5 Revision	85
2. IMPR Summary	88
3. Significant Events	89
D. Failure Data Handbook	90
E. Bayesian Statistical Model Theory for Mechanical Systems	91
IV. Quality Assurance	93
A. Introduction	93
B. LMEC QA Program	93
C. Ft. St. Vrain Steam Generators	95
D. QA Applied to Sodium Components Test Installation (SCTI)	95
E. QA Applied to Sodium Pump Test Facility (SPTF)	96
F. QA Applied to Large Component Test Loop (LCTL)	97
G. QA Applied to HNPF Pump Test Loop (HPTL)	97
H. LMEC Activities Relative to the LMFBR Program	98
V. Operation of Sodium Components Test Installation (SCTI)	99
A. Introduction	99
B. Main Steam Line Repair	99
C. Plant Checkout and Operation	99

CONTENTS

	Page
D. Condensate Polish System Modification.	106
E. Steam and Feedwater System Upgrading Modification	106
F. Data Acquisition System	107
G. FFTF Component Testing.	108
H. Future Effort.	108
VI. Liquid Metals Information Center	111
A. Introduction.	111
B. Responses to Requests.	112
C. Information Storage and Retrieval	112
D. Sodium and NaK Engineering Handbook.	114
VII. Sodium Pump Test Facility (SPTF)	115
A. Introduction.	115
B. Operational Performance Criteria.	115
C. Main Flow Loops and Related Sodium Systems	115
1. System Description.	115
2. Major Changes from the Previous Report	116
3. Problem Areas.	116
D. Main Flow Loop Analog Studies	120
E. Sodium Systems Stress Analysis	120
F. Instrumentation and Control	126
1. System Description.	126
2. Problem Areas.	128
G. Inert Gas, Vent, and Vacuum System.	128
1. System Description.	128
2. Major Changes from Conceptual System Design	128
3. Problem Areas.	128
H. Electrical System.	129
I. Site and Buildings.	129
J. Auxiliary Cooling System.	130
1. System Description.	130
2. Major Changes from Conceptual System Design	130
3. Problem Areas.	131

CONTENTS

Page

VIII.	Sodium Pump Seal Test Program.	133
	A. Introduction.	133
	B. Seal Test and Facility Checkout.	133
	C. Test Facility Modifications.	134
	1. Spindle Reinforcement.	134
	2. Support Structure Analysis.	134
	3. Piping Support Analysis.	134
	D. Sodium Test Vessel Fabrication and Inspection History.	134
	E. High-Pressure Secondary Pump Seal - FFTF	135
	F. LMFBF 60,000-gpm Pump Seal.	135
	G. Construction of Test Facilities	136
IX.	Sodium Pump Bearing Test Program	139
	A. Introduction.	139
	B. Discussion	140
	C. Future Effort.	141
X.	Precision Mechanisms in Sodium.	143
	A. Introduction.	143
	B. Experience Survey	143
	1. SRE	144
	2. HNPF.	144
	3. EBR-II	145
	4. EFAPP.	146
	C. Mechanical Element Tests	146
XI.	Materials Compatibility in Sodium.	149
	A. Introduction.	149
	B. Sliding Wear Tests	149
XII.	Steam Generator and Intermediate Heat Exchanger Performance Evaluation.	155
	A. Introduction.	155
	B. General.	155
	1. Comparison of Redundant Measurements.	156
	2. Accuracy of Thermocouples	159
	C. Steam Generator and IHX System Performance	159

CONTENTS

	Page
1. IHX Performance	161
2. Steam Generator Performance	163
D. IHX Primary Outlet Temperature Oscillation	165
E. Steam Generator Lower Tube Sheet Temperatures	168
F. Structural Analysis of IHX and Steam Generator	174
XIII. Instrumentation Testing, Evaluation, Calibration, and Standards	181
A. Introduction	181
B. High-Temperature Strain Gage Measurements	181
1. Evaluation and Analysis Procedures	181
2. Axial Calibration Fixture	182
3. Methods and Results for Calibration Bars	185
4. Modulus of Elasticity	187
XIV. Instrumentation and Standards Laboratory	203
A. Introduction	203
B. Laboratory Activities	203
XV. Chemical and Metallurgical Laboratory	207
A. Introduction	207
B. Chemical Laboratory	207
C. Metallurgical Laboratory	209
1. General	209
2. Examination of HNPF Pump Test Loop Pipe Samples	209
3. Analysis of a Failed Sodium Hot Trap	210
4. Examination of LCTL Pipe Sections	215
XVI. Operation and Maintenance of the LCTL, CETS, and HNPF Pump Test Loop; Modifications to the LCTL	217
A. Introduction	217
B. LCTL Operation and Maintenance	217
C. FFTF Flow/Duct Tube Sheet Sodium Erosion-Flow Test	221
1. Test T-1B	221
2. Test T-1D	222
D. FFTF Fin Tubing Test (T-2)	222
1. Test Plan	223
2. Facility Modification	223
E. Small Components Test Loop (SCTL)	224

CONTENTS

	Page
Bibliography of Reports Published During Reporting Period	225
Appendix: Sodium Pump Test Facility (SPTF) Drawings	227

TABLES

1. Water Test Facilities	23
2. Directory of Candidate Test Facilities	26
3. Proposed New Test Facilities	28
4. Alternate Plans for Proposed Facilities	30
5. Steam Generator Design Parameters	43
6. Range of IHX Design Parameters	44
7. Design Requirements for SPTF Isolation and Flow Control Valves . .	58
8. SPTF Design Thermal Transients	60
9. Design Requirements for FFTF Main Heat Transfer System Primary Sodium System Valves	63
10. Design Requirements for FFTF Main Heat Transfer System Secondary Sodium System Valves	65
11. SPTF Performance Criteria	116
12. SPTF Temperature Across Pipe Wall and Maximum Pipe Wall Stresses	124
13. SPTF Cumulative Usage Factors for Various Types of Transient Test Conditions	127
14. Sliding Wear Test Results	150
15. Comparison of Redundant Temperature Measurements	158
16. Alco/BLH Steam Generator and Alco IHX System Performance . . .	160
17. Strain Gage and Thermocouple Summary	175
18. Summary of Strain Calibration Data — Mean, Standard Deviation, and Confidence Limits at 95%	188
19. Strain Gage Calibration Data Summary at Delta Load = 9000 Pounds	189
20. Strain Gage Calibration Data — Comparison, Average	190
21. Impurities in LCTL Thermal Insulation	209

FIGURES

	Page
1. LMFBR Piping Design Guide Functional Work Plan.	33
2. Single Suction Sodium Pump Concept, Removable Concentric Casing (Westinghouse Drawing ED SK330610-J)	47
3. Valve Flow Characteristics (30-in. Flow Control Valves Sized for 60,000-gpm Pump)	60
4. Valve Flow Characteristics (20-in. Drain Control Valves Sized for Both 60,000-gpm and FFTF Test Pumps)	61
5. Valve Flow Characteristics (8-in. Flow Control Valves)	61
6. Valve Flow Characteristics (14-in. Flow Control Valves Sized for FFTF Pumps)	62
7. FFTF Primary Valves Installation Schematic Diagram	67
8. Maintenance and Malfunction Analysis Program Evaluation Sequence	86
9. Progression of Quality with Timeliness for Collective Disciplines	87
10. Sodium Components Test Installation Schedule of Events, January Through June 1969	101
11. SPTF Main Flow Loop Control Valve Cavitation Characteristics (LMFBR Prototype Pump)	118
12. SPTF Main Flow Loop Control Valve Cavitation Characteristics (FFTF Primary Pump)	119
13. SPTF Transient Test Temperature Profiles	123
14. SPTF Test Loop Schematic.	123
15. SPTF Temperature Profile Across Pipe Wall	125
16. Sodium Pump Seal Test Facility No. 2.	137
17. Sodium Pump Seal Test Facility No. 1.	138
18. N. S. Savannah Control Rod Drive Mechanism Operating Parts	148
19. Alco/BLH Instrumentation Schematic	157
20. IHX Primary Sodium (Shell Side) Temperature Profile - SCTI Data (May 14, 1969; ~1330 hr; 20% rated power)	162
21. Steam Generator Sodium Temperature Profile (May 14, 1969; ~1330 hr; 20% rated power)	164
22. Recording of IHX Outlet Temperature at Approximately 20% Flow (Sampled data, 1 Hz)	166
23. IHX Primary Exit Flow Geometry	167
24. Estimated Temperature Gradients Within Bottom Baffle Space of IHX at 20% Load	167

FIGURES

	Page
25. Temperature Boundaries Assumed for Steam Generator Tube Sheet Heat Transfer Analysis	169
26. Temperature in Steam Generator Lower Tube Sheet Area for "Rise-to-Power" Test	171
27. Steam Generator Lower Tube Sheet Thermocouple Data.	172
28. Steam Generator Lower Tube Sheet Temperature Data	173
29. Proposed Strain Gage Locations on IHX Lower Tube Sheet Region	176
30. Proposed Strain Gage Locations on IHX Upper Tube Sheet Region	177
31. Proposed Strain Gage Locations on Steam Generator Lower Tube Sheet Region.	178
32. Proposed Strain Gage Locations on Steam Generator Upper Tube Sheet Region	179
33. Axial Load Gage Calibration Facility	183
34. Axial Load Strain Gage Calibration Specimen.	184
35. Calibration Data - Strain Gage Bar No. 1.	191
36. Calibration Data - Strain Gage Bar No. 3.	192
37. Calibration Data Comparison - Strain Gage Bars No. 1 and 3 (Table 24, Columns 2 and 4).	193
38. Strain vs Temperature, Δ Applied Load = 9000 lb (9500-500)	194
39. Strain vs Temperature, Δ Applied Load = 4500 lb (5000-500)	195
40. Modulus of Elasticity at Temperature.	196
41. Envelope of Typical Modulus of Elasticity Values vs Temperature, Type 316 Stainless Steel.	199
42. Modulus of Elasticity Comparison, Strain Gage Bars No. 1 and 3. . .	200
43. Modulus of Elasticity Comparison, Strain Gage Bar No. 3	201
44. Pipe Section from LCTL Showing Intergranular Corrosion.	208
45. Portion of the Root of a Valve-to-Pipe Weld Removed from HNPF Pump Test Loop	210
46. Hot Trap, Tank-Head and Wall Around Sodium Inlet Pipe ($\sim 1/4$ size)	211
47. Main Crack (External) that Leaked Sodium at the Inlet Pipe- to-Tank-Head Weld.	212
48. Internal View of Main Crack and Welding Defect (tunnel or void) Due to Improper Fitup Between Inlet Pipe and Tank-Head (Mag: 1.5X)	212

FIGURES

	Page
49. Electron Tractograph of a Typical Fracture Surface in Sodium Inlet Pipe Adjacent to Inlet Pipe-to-Tank-Head Weld (Mag: 8,748X).	214
50. Photomicrograph of LCTL Pipe Section with Grain Boundary Precipitation in Evidence (Mag: 500X)	215
51. LCTL Modification for FFTF Flow Duct/Tube Sheet Sodium Erosion-Flow Test (T-1B)	218
52. FFTF Flow Duct/Tube Sheet Sodium Erosion-Flow Test (T-1B) Assembly	219
A-1. SPTF Piping Layout Plan Below Elevation 105 ft 0 in.	229
A-2. SPTF Piping Layout Plan Between Elevation 105 ft 0 in. and Elevation 130 ft 0 in.	231
A-3. SPTF Piping Layout, Elevation A-A	233
A-4. SPTF Modified Base Loop, FFTF Pump Plan	235
A-5. SPTF Topographic and Survey	237
A-6. SPTF Plot Plan	239
A-7. Artists Conception of SPTF	241
A-8. SPTF Grade and Pit Plan	243
A-9. SPTF Control Building Plans	245
A-10. SPTF East-West Section	247
A-11. SPTF North-South Section	249
A-12. SPTF Modified Base Loop, FFTF Pump Elevation	251
A-13. SPTF Auxiliary Cooling System P&I Flow Diagram.	253

INTRODUCTION

The overall objective of the LMEC is to provide optimum operation of the Center for implementing the following major functions:

- 1) Establishing LMFBR technology base for components, piping, and instrumentation systems
- 2) Advice and consultation —
 - a) Work statement preparation
 - b) Technical evaluation of proposals
 - c) Monitoring development contracts and test programs
- 3) Technical management of development contractors
- 4) Test facilities —
 - a) Construction
 - b) Operation
 - c) Test requirements, plans, performance, and evaluation
- 5) Quality assurance —
 - a) Coordinating LMFBR QA program
 - b) Reviewing, evaluating, and assisting contractor QA efforts
- 6) Codes and standards —
 - a) Preparing documents
 - b) Coordinating, reviewing, and evaluating contractors' codes and standards
- 7) Maintenance and malfunction analyses —
 - a) Developing collection plan
 - b) Collecting, evaluating, and disseminating information
- 8) Information collection and exchange (Liquid Metals Information Center, LMIC)
- 9) Training of industrial personnel.

The immediate purpose of the LMEC is to support the LMFBR program by supplying detailed technical effort to the LMFBR development program. To accomplish this, the LMEC program is divided into technical and administrative projects

according to special requirements of the LMEC and the LMFBR Program Plan. Each of the following sections in this progress report represents one of these projects. The relationship of each of these projects to the LMFBR Program Plan is indicated in the following table.

LMEC REFERENCE TO THE LMFBR PROGRAM PLAN

LMEC-69-30 Section No.	LMEC Project	LMFBR Program Plan Reference
I	AEC Assistance and Consultation	3-5.1, 3-5.2, 3-6, 3-8.2, 3-8.5, 3-11, 3-12, 5-1.1
II	Codes and Standards	2-2.3, 3-2.2
III	Maintenance and Malfunction Analyses	3-2.4
IV	Quality Assurance	3-2.3
V	Operation of Sodium Components Test Installation (SCTI)	3-5.1, 3-6.2, 3-6.5, 3-12.4
VI	Liquid Metals Information Center	All elements except Element 9
VII	Sodium Pump Test Facility (SPTF)	3-5.2
VIII	Sodium Pump Seal Test Program	3-5.2, 3-11.3.1
IX	Sodium Pump Bearing Test Program	3-5.2, 3-11.3.2
X	Precision Mechanisms in Sodium	3-3, 3-7.3, 3-10.3, 3-11, 5-1.6, 5-1.8
XI	Materials Compatibility in Sodium	5-1.6, 5-1.8
XII	Steam Generator and Intermediate Heat Exchanger Performance Evaluation	3-6, 3-12
XIII	Instrumentation Testing, Evaluation, Calibration, and Standards	4-1.4, 4-7.1 through 4-7.8, 4-7.10, 4-7.11
XIV	Instrumentation and Standards Laboratory	4-1.4
XV	Chemical and Metallurgical Laboratory	3-3.1, 5-5.1 through 5-5.7
XVI	Operation and Maintenance of the LCTL, CETS, and HNPF Pump Test Loop; Modifications to the LCTL	3-5.1, 3-5.2, 3-9, 4-1.4

SUMMARY

AEC ASSISTANCE AND CONSULTATION

LMFBR Test and Facility Planning, Coordination, and Evaluation

A survey of existing water test facilities suitable for use in the LMFBR program has been completed. Two government-owned facilities are recommended for most general water test and calibration of components and instruments.

The first draft of the LMEC Test and Facilities Document has been completed and will be issued during August.

Technical Management of Contract AT(04-3)-781, LMFBR Piping Design Guide

The AEC contract awarded to C F Braun & Co in October 1968 for the development and verification of a Piping Design Guide for the engineering of high-temperature liquid sodium piping systems is approximately 60% complete. The AEC has assigned LMEC technical management responsibility for this contract.

A total of 13 technical reports covering various studies made to form the basis for developing the guide have been issued by the contractor. Work has begun on the development of the design and analytical procedures for the guide. A first draft of the design guide is tentatively scheduled to be issued for review about the middle of August 1969.

Steam Generator and Intermediate Heat Exchanger Systems Performance and Contract Management

The Program Definition Phase studies were completed. LMEC is evaluating these studies to make recommendations for continuing work by the industrial contractors.

Sodium Pump Systems

Technical work on the Westinghouse Phase II studies was completed and final reports are being printed. The Medium Capacity Pump Study Report will be issued only to a limited distribution for review.

The specified thermal transient requirements were found to have a significant effect on design of both the medium and low capacity prototype pumps. The techniques and criteria used for stress analyses also had a major effect on the pump design.

Sodium Valve Systems

Operational and functional requirements for valves for the long-term needs of the LMFBR program have been revised. The design requirements were issued for the development valves for the SPTF and FFTF programs.

Sodium-Water Reaction

Analytical effort has been started to improve understanding of the behavior of steam generator leakage jets. It was found necessary to extend the range of existing steam tables to derive values of choking velocity and mass flow for flashing high-pressure water. The possibility of discontinuous choking at saturation has been recognized. Conditions for a minimum mach number in isentropic supersonic expansion have been derived.

Preliminary efforts have been started to correlate APDA wastage data by multiple regression analysis.

CODES AND STANDARDS

The LMEC Codes and Standards effort includes two major tasks: preparation of RDT standards for liquid metal system application and coordination with ORNL for the preparation of RDT standards that are applicable to both water and liquid metal systems.

Drafts have been prepared for sodium-cooled reactor vessels, circulating cold traps, centrifugal free-surface sodium pumps, instrumentation sensors, sodium-to-air heat exchangers, sodium valves, reactor grade sodium, and cover gas for reactor grade sodium. Work continues on draft standards for hot traps, sodium tanks, electromagnetic pumps, other instrumentation sensors, and sodium piping. Problems encountered to date continue to be the paucity of documented history for existing sodium-cooled plants and the need for improvement of design analysis techniques for elevated temperature application.

The ORNL coordination effort has been concentrated upon the preparation of RDT standards for structural materials and processes such as cleaning, welding, and nondestructive examination.

MAINTENANCE AND MALFUNCTION ANALYSES

A brochure, "Failure and Problem Reporting for Nuclear Reactors," was prepared as an information document and received wide distribution throughout the U. S. nuclear industry.

Incident, Malfunction, and Problem Reports (IMPR's) continued to be processed on events occurring at LMEC facilities. Several considered to be significant are reported herein.

Volume II of the Failure Data Handbook was printed, and initial RDT distribution was made. Volume I is scheduled for publication and distribution early in the next reporting period.

The preliminary study was completed on the potential of Bayesian statistical methods for application to test planning and mechanical failure model theory. A formal topical report was published, and initial distribution was made in advance of AEC patents release.

QUALITY ASSURANCE

The LMEC quality assurance program is now described by a manual containing 29 QA and LMEC procedures and three instructions. Additional procedures and instructions will be added as they become available.

A plan of action for the initial visit to the manufacturer's plant of the Ft. St. Vrain Steam Generators has been prepared and submitted to RDT.

The SPTF Procedures Manual containing the QA plan for this project has been issued to RDT and is undergoing review and comment by RDT and LMEC personnel. The QA documents to be prepared by the SPTF A-E during Title I have been listed, and material purchased by the A-E regarding QA activities during the design effort is being evaluated.

RDT F 2-2 T, "QA Program Requirements," has been received as a member of the RDT Ad Hoc QA Steering Committee. This standard is being used, as applicable, for LMEC purchases and to guide the internal LMEC QA program.

OPERATION OF SODIUM COMPONENTS TEST INSTALLATION (SCTI)

Reconstruction of the main steam line was completed and SCTI was returned to steaming operation. Plant performance testing was initiated and has proceeded

through the 40% power operating condition. Completion of these tests has been delayed by ball bearing failure in the bearing and seal housing of the primary sodium pump, by gasket failures at the steam outlet flange of the steam generator, and by a tube leak within the steam generator which occurred near the end of the report period and which remains under investigation.

SODIUM PUMP TEST FACILITY (SPTF)

The Title I design phase of the SPTF is complete. The Title I report and the Preliminary System Design Descriptions (PSDD's) are nearly complete. Title II, Final Design, will not start until the facility configuration is approved.

To accommodate the FFTF pump testing, a modified 30-in. -diameter test loop was selected.

SODIUM PUMP SEAL TEST PROGRAM

Construction of one seal test facility was completed and the second will be completed in the first quarter of FY 1970. A Fermi-type seal is being purchased to allow checkout of the two test facilities in FY 1970.

SODIUM PUMP BEARING TEST PROGRAM

Approval was received from the AEC for design and construction of the Pump Bearing Test Facility. The existing Hallam Pump Test Loop will be modified for this purpose. A surplus Hallam pump will be used as the test fixture for the test bearings.

PRECISION MECHANISMS IN SODIUM

The final draft of an experience survey has been compiled and will be published during the next report period. This survey summarizes operating experience with mechanical elements and mechanisms associated with four sodium reactor installations: SRE, HNPF, EBR-II, and EFAPP.

Test planning has been initiated for a roller nut control rod drive mechanism test. This device will be subjected to a sodium vapor environment to identify problem areas and to provide basic data for the design of the FTR reference prototype drive mechanism.

MATERIALS COMPATIBILITY IN SODIUM

Sliding wear tests are continuing with the better material combinations in 500 to 1200°F sodium liquid and sodium vapor.

Flame-sprayed wear resistant coatings are being evaluated under sliding wear conditions for various applications in the FFTF.

STEAM GENERATOR AND INTERMEDIATE HEAT EXCHANGER PERFORMANCE EVALUATION

Testing of the Alco/BLH steam generator and Alco IHX was resumed at the SCTI. Data from two representative test conditions were used to correlate operational results to predicted operation. Thermal and hydraulic predictions were matched very closely by operational data for both units except for the axial temperature profile in the steam generator. Comparison of data from redundant thermocouples for accuracy and for repeatability indicated reasonably good precision.

An investigation was performed for an apparent primary sodium temperature oscillation at the IHX outlet. This phenomenon appeared to be localized within the bottom baffle space in the IHX owing to lack of complete primary sodium mixing within the baffle space just prior to exiting the IHX.

Corrections were made to earlier predictions for steam generator lower tube sheet temperature profiles based on operational data.

An analysis was performed to specify the location of strain gage rosettes and thermocouples for the IHX and steam generator. A total of 164 strain gages and 53 thermocouples will be used.

INSTRUMENTATION TESTING, EVALUATION, CALIBRATION, AND STANDARDS

The most significant instrumentation accomplishment during the report period has been the calibration of bars 1 and 3 for the axial loading test fixture using the Gaertner micrometer microscope system. This demonstrates that an acceptable technique for calibrating the axial test fixture has been established. The Gaertner micrometer microscope has been calibrated to a traceable NBS standard. An average Young's Modulus of Elasticity (E) curve, calculated from the measured strain data, for bars 1 and 3 (Gaertner data) has been plotted. Its

deviation from the envelope is within that anticipated for variations owing to experimental errors. The maximum deviation of an average E, based on "typical" envelope values, from the calculated E, based on measured Gaertner values, is 5%.

It is shown that during these tests, the largest percentage difference in E (calculated from measured strain) between bars 1 and 3, using the Gaertner microscope, was 3.3%, which is reasonable considering the errors possible because of loading equipment, readout equipment, and the operator's reading of instruments.

Bar 3 was also calibrated with the DCDT after that unit had some modifications and with special setup procedures. It is shown that the maximum deviation from the Gaertner was 3.7%. This showed considerable improvement; therefore, further modification is under consideration to assure repeatability and eliminate difficult and time-consuming setup steps. A calibration of the bar need not be done each time a set of gages are calibrated. Calibration of the bar would be done on the average of once a year unless otherwise indicated.

OPERATION AND MAINTENANCE OF THE LCTL, CETS, AND HNPF PUMP TEST LOOP; MODIFICATIONS TO THE LCTL

Modification of the LCTL 3-in. sodium loop and preparation of the FFTF Test T-1B loop were essentially completed. During the 3-in. loop modification, however, a liquid penetrant test disclosed defects in the old pipe. Intergranular corrosion was identified as the major source of the indicated defects. A hot circulation test was initiated to establish near-term serviceability of the piping. The test was terminated early owing to shaft freeze-seal failures on the 3-in. loop circulating pump. Plans were made to reexamine and evaluate the piping following a performance test of the rotary EM pump in the T-1B test loop. The pump failed to meet required performance due to degradation of a braze alloy on the pump duct; coil rework and procurement of a new duct were initiated.

The FFTF Test T-1B assembly was received and, after determining that damage occurring in transit was only superficial, was prepared for installation. Planning was started for FFTF Test T-1D. Engineering and design for FFTF Test T-2 were also started. An SCTL A-E Selection Board Report was submitted for approval of the board's recommendation.

I. AEC ASSISTANCE AND CONSULTATION

(LMFBR Program Plan 3-5.1, 3-5.2, 3-6, 3-8.2, 3-8.5, 3-11, 3-12, 5-1.1)
O. J. Foust

A. INTRODUCTION

The primary purpose of this project is to provide technical assistance and consultation services as requested by the AEC in support of the Liquid Metal Fast Breeder Reactor (LMFBR) Program. This support encompasses the planning, coordination, and evaluation of LMFBR (and FFTF) test and facility requirements and includes reviews and evaluations as requested on pumps, valves, piping systems, purification, thermal transients and other thermal considerations, hydraulics, and electrical systems. This project is directly related to all other LMEC projects within the technical areas listed above.

B. LMFBR TEST AND FACILITY PLANNING, COORDINATION, AND EVALUATION (H. B. Dietz)

1. Introduction

The objectives of this task are to review and evaluate FFTF and LMFBR sodium component test requirements, evaluate existing test facility capabilities, and match test requirements with facilities and thereby establish new facility requirements for testing to be performed at the LMEC. Overall Conceptual System Design Descriptions are prepared for new test facilities needed for the LMFBR program. In addition, FFTF and LMFBR tests are reviewed with the contractor, coordinated between the contractor and the LMEC operating facility performing the testing, and the test results are briefly evaluated prior to being transmitted to the test requestor.

Work was started on this task during FY 1968 and will continue at the LMEC during FFTF and LMFBR testing.

2. LMFBR Test Facility Planning

a. Water Test Facilities for the LMFBR Program

The LMFBR Program Plan, Volume III, identifies a water test facility, titled "Large Hydraulic Test Facility," to be constructed at the LMEC. The water test facility is needed to support LMFBR Program Plan subtasks 3-8.2.2, 3-8.3.2, 3-8.5.2, and 3-12.4.2 for the sodium piping systems and intermediate heat exchangers. In particular, and program plan recommends construction of the

facility to demonstrate fabrication and field erection techniques of large piping systems. Operation of the facility would verify dynamic analysis techniques for these systems.

Water testing is needed particularly for pumps, intermediate heat exchangers, steam generators, core models, core components, fuel subassemblies, valves, and flowmeters. To fulfill this need for water testing, LMEC has reviewed the capabilities of numerous water test facilities in the United States as part of the updating of the LMEC test and facilities document. The existing water test facilities investigated are tabulated in Table 1. The NASA-owned water test facility located at Rocketdyne in Canoga Park is recommended for most of the general water test and calibration of components and instruments to 25,000 gpm expected to be performed by LMEC. If large-scale testing to 65,000 gpm plus is needed, the facility at the Edwards Air Force Base Rocket Test Site should be considered. For pump testing, most pump manufacturers have test facilities capable of flows greater than 60,000 gpm. Several existing facilities listed in Table 1 would be suitable for water-testing of pumps. Rocketdyne-Canoga and the Edwards AFB Rocket Test Site are recommended for water testing because of their capabilities and physical proximity to LMEC. Use of the Rocketdyne-Canoga facility should be given priority since it has sufficient head and flow capabilities for most tests, is government-owned (NASA), is only used 8 hr per day, and is located near the LMEC. The Edwards AFB Site is NASA-owned, and is recommended because of its high-flow and head capabilities and location within 100 miles of LMEC. The facilities recommended could have special test sections installed to perform testing as required.

LMEC recommends that fabrication and field erection techniques for large piping systems be demonstrated during construction of sodium test facilities and systems. These techniques may be demonstrated during fabrication of the Sodium Pump Test Facility or a special pipe insert to another sodium system. To verify dynamic analysis techniques, the necessary piping sections could be installed in one of the existing water test facilities at a significantly lower cost than for building a new water facility. LMEC recommends that the "Large Hydraulic Test Facility," which is similar to existing facilities, not be constructed for exclusive LMFBR use.

TABLE 1
WATER TEST FACILITIES

Candidate	Maximum Flow (gpm)	Pressure (psig)	Storage (gal)	Pressure Source	Pipe Size (in.)	Water Type	Instrumen- tation	Comments
Alden Hydraulics Lab., Worcester, Mass.	5,400 25,000	-	Outdoor pond	Gravity + pump	12 48	Filtered only	-	New loop under construction: 36-in. pipe, 18,000 gpm, 50-ft head.
Byron Jackson, Los Angeles, Calif.	100,000 hot loop 28,000 cold loop	3000 10	- 350,000	Test pump only Test pump only	2 to 23	Filtered, to 600°F Filtered, 70±10°F	Yes	Company-owned pump test facility. Schedule problem. Valve test facility limited to 28,000 gpm at 10 psig.
Colorado State Univ., Ft. Collins, Colo.	40,000 4,440	215 (ft) 430 (ft)	Reservoir Reservoir	Gravity Pump sup.	24 8 & 12	Irrigation district water	-	University-owned.
Edwards Air Force Base, Rocket Test Site, Edwards, Calif.	100,000 130,000	150 150	1,000,000 3,000,000	Gravity Gravity	36-42 54	Well water Well water	Yes Yes	NASA-owned. F-1 rocket engine test area. Requires tap into water line for test section.
Ingersoll-Rand, Phillipsburg, N. J.	5,000 30,000 100,000	- - -	- - -	- - -	12 24 open pit	- - -	- - -	Pump test facility.
Oak Ridge Nat'l Lab., Oak Ridge, Tenn	17,000	120	8000 (loop)	Pump	24 at pump 16 at test point	Potable	-	Reactor vessel loop.
Pacific Pumps, Huntington Park, Calif.	60,000	ΔP 22 at 60,000	Closed loop	Test pump only	24 & 30	Water temp to 300°F	-	Company-owned, closed loop.
Rocketdyne, Canoga Park, Calif.	26,000 600	150 2100	200,000	6000-gpm pumps (4)	12, 16, & 20-in. headers	Filtered, chlorinated, 7.2-7.8 pH	54 channels & 24 direct reading	NASA-owned.
Rockwell Mfg. Co., Porterville, Calif.	65,000	10-15	124,000	Gravity	48, 42, 36	-	Yes	Company-owned flowmeter calibration setup. Has 3, 3-line headers.
Santa Susana Field Lab., Chatsworth, Calif.	75,000	90	1,000,000	Gravity	42	50/50 muni- cipal and reclaimed water	Yes	NASA-owned facility. Requires tapping into 42-in. line for test section.
Westinghouse, Waltz Mill, Pa.	8,000	100	-	Pump	-	Water temp 70-300°F	-	Closed loop.
Worthington Corp., Harrison, New Jersey	10,000 100,000	-	Closed loop Open pit	Pump Gravity	18 24	Water temp to 450°F	-	Specimens to 48 in.
Combustion Engineering, Windsor, Conn.	18,000	95	-	Pump	14 (2)	Demineral- ized, 200°F	Yes	Max. test section 20 by 20 by 35 ft.

LMCC-69-30
23

b. Test and Facilities Document

The first draft of the LMEC Test and Facilities Document updating has been completed. This document will contain the following sections:

- 1) Introduction and Summary
- 2) Component, Instrument, and Sodium Technology Test Requirements
- 3) Test Facility Descriptions
- 4) Specific Testing Required
- 5) Proposed Facility Alternates.

The Test and Facilities Document was originally published as letter 68LMEC-2 with Enclosures (1) through (4) on January 12, 1968. The revision of this document has been prepared to incorporate additional information accumulated during the intervening period. The purpose of this document is to provide a ready reference of the testing required for components, instruments, and sodium technology, and of suitable existing test facilities and required new test facilities to arrive at a commercial reactor plant in the early 1980's.

Five main categories have been used to summarize test requirements for components, instruments, and sodium technology. The first four categories are the basic parameters: (1) temperature, (2) pressure, (3) flow, and (4) thermal transients. The fifth category, specific testing, identifies the activity required to properly test the components and instruments to prove their adequacy for the LMFBR program. The purpose in categorizing test requirements in this fashion is to facilitate the definition of test facility requirements and the ultimate matching of test requirements and test facilities.

To support the task of assembling information on the capabilities of existing LMFBR-oriented test facilities, a questionnaire was sent to potential candidates. Specific information obtained included the typical operating parameters (e. g., operating temperature, pressure, flow rate, loop size, etc.) in addition to type and extent of data acquisition system, and status and availability for the LMFBR program. Information solicited was limited to circulating sodium (both forced and thermal circulation) loops with greater than 1-in. pipe sizes (excluding static pots). A facility was considered a prime candidate if temperature limits exceed 1100°F or if pressure capability exceeds 100 psig. A facility was not considered

a likely prospect for LMFBFR testing when all of these parameters are low (i.e., temperature <1100°F, pressure <100 psig, flow rate <1000 gpm) or there was no thermal transient capability. Descriptions have been prepared for the existing or funded LMEC and non-LMEC (limited to the USA) facilities listed in Table 2. Since the facilities listed in Table 2 do not fulfill the total needs of the LMFBFR/FFTF test program, descriptions have been prepared for new facilities needed to supplement those listed. These new test facilities, with proposed use and programmatic need, are listed in Table 3.

Specific tests have been listed, scheduled, and matched with existing or proposed test facilities. The schedules reflect the concept of using test facilities for testing demonstration plant equipment in the 1970's and for development and proof-testing of equipment for the initial commercial plant in the early 1980's. Test loading diagrams have been prepared for all test facilities expected to be used for component, instrument, and sodium technology tests.

Fourteen new facilities (see Table 3) have been identified as required for component, instrument, and sodium technology testing. Since capital funds for all these facilities may not be immediately available and may never be available, it is important to establish a facility construction priority. The order of priority has been determined using a semi-analytical approach as follows:

Criticality Factor x Development Factor = Corrected Criticality Factor

Σ Corrected Criticality Factors (for a facility) = Utility Value.

Criticality factors for 60 categories of LMFBFR components, instruments, and sodium technology items were prepared by means of mathematical averages of inputs by 20 LMEC personnel. The first ten items are ranked as follows:

- 1) Steam generators
- 2) Core vessel and internals (hydraulics)
- 3) Fuel elements (hydraulics)
- 4) Safety rods
- 5) Intermediate heat exchanger
- 6) Sodium piping
- 7) Control rods
- 8) Sodium pumps (main loop)

TABLE 2
DIRECTORY OF CANDIDATE TEST FACILITIES
(Sheet 1 of 2)

Atomics International (AI)

High-Temperature Sodium Supply System
Reactor Sodium Environment Chamber
Low-Temperature Sodium Supply System
LMFBR 2-in. Flowing Sodium Loop

Aerojet-General Corporation (AGC)

System Loop No. 1 (SL-1)
Liquid NaK Loop No. 3 (LNL-3)

Argonne National Laboratory (ANL)

Core Component Test Loop (CCTL)
High-Temperature Sodium, Long-Term Environmental Test Loop
EBR-II
Nuclear Instrument Test Facility
Sodium Flowmeter Calibration Loop
Component and Materials Evaluation Loop (CAMEL)
Large TREAT Sodium Loop
LMFBR Burnout Limitations Study Loop
Fuel Failure Detection Loop
High-Temperature Furnace Facility
CP-5 Irradiation Facility
Radioactive Sodium Chemistry Loop

Atomic Power Development Associates, Inc. (APDA)

APDA Sodium Endurance Loop
APDA Sodium Technology Loop
APDA Rig 10
Enrico Fermi Atomic Power Plant

Babcock & Wilcox Co. (B&W)

Model Sodium-Heated Steam Generator

Battelle Northwest (BNW)

Fast Reactor Thermal Engineering Facility

Brookhaven National Laboratory (BNL)

Sodium Heat Transfer Facility

General Electric Co. (GE)

Loop No. 11, Thermal-Hydraulic Fuel and Flow Test Loop
Steam Generator Test Rig
Loop No. 12, Thermal Shock Loop
Refueling Cell Mockup

TABLE 2
DIRECTORY OF CANDIDATE TEST FACILITIES
(Sheet 2 of 2)

Liquid Metal Engineering Center (LMEC)

Sodium Components Test Installation (SCTI)
Small Components Test Loop (SCTL) (LCTL Modified)
Pump Seal Test Facility (PSTF)
Sodium Pump Test Facility (SPTF)
Sodium Mechanisms Test Installation (SMTI)
High-Temperature Strain Gage Laboratory
Pump Bearing Test Facility (PBTF)

Mine Safety Appliance

MSAR Loop 1, High Carbon System
MSAR Loop 2, High Oxygen System
MSAR Loop 3, High-Temperature Mechanical Properties Testing
MSAR 4-in. Pump Test Loop

Westinghouse

GPL-1 General Purpose Loop-1
GPL-2 General Purpose Loop-2

Water Test Facilities

Edwards Air Force Base, Rocket Test Site
Rocketdyne High-Flow (Water) Test Facility

- 9) Reactor vessel subcomponents
- 10) Sodium pumps (closed loop).

The development factor is an indication of previous success or lack of success in the development of that type of item. Facility utility values were used to arrive at the alternate plans shown in Table 4. Plan 1 represents what is needed, while Plans 2 and 3 sacrifice required testing capabilities but cost less.

The existing and proposed facilities listed in Tables 1, 2, and 3 represent the total envelope of major facilities (those requiring capital funding) needed to fulfill the nonradioactive development and proof-testing needs for Volume 3 (Components), 4 (Instruments), and 5 (Sodium Technology) of the LMFBR Program Plan.

The Test and Facility Document will be issued during September 1969.

TABLE 3
PROPOSED NEW TEST FACILITIES
(Sheet 1 of 2)

Facility	Use	LMFBR Program Plan Reference for Programmatic Need
Multi-purpose Sodium Test Facility (MSTF)	Tests of core component handling subassemblies and systems, piping system tests, reactor vessel hydraulics, reactor vessel components; erosion damage, flowmeter test and calibration, level sensors	3-7.3, 3-7.5, 3-8.5, 3-8.6 3-9.3, 4-1.4, 4-7.6, 4-7.10, 5-1.6, 6-3.1, 6-3.3, 6.5.3
Component Proof Test Loop (CPTL)	Thermal shock of small components, tests of core component handling elements and subassemblies, reactor vessel components, reactor control drive subassemblies, material tests	3-6.3, 3-7.3, 5-7.3, 6-2.3, 3-10.3, 5-1.8
Steam Generator Test Facility (SGTF)	Testing of new concept steam generators and intermediate heat exchangers	3-6.5, 3-12.4
Sodium-Water Integrated Facility Test (SWIFT)	Sodium-water reaction and vent relief system tests	3-6.4
Control Rod Test Loop (CRTL)	Reactivity control drive tests	3-10.5
Sodium Components Test Installation (SCTI) Auxiliary Heater	Replacement 35-Mwt sodium heater for intermediate heat exchanger and steam generator testing	3-6.5, 3-12.4, 4-3.6, 5-7
Sodium Instrument Test Tower (SITT)	Tests of temperature sensors, pressure sensors, level sensors, cable transmission, electrical connectors, neutron sensors (thermal) immersed to 40 ft in sodium	4-1.4, 4-5.1, 4-5.3, 4-5.4, 4-6.2, 4-7.1, 4-7.2, 4-7.3, 4-7.7, 4-7.8, 4-7.9, 4-7.10
In-Core Flow Test Insert (IFTI)	In-core instrument testing (nonradioactive), such as flowmeters, pressure and temperature sensors, and electrical leads	4-1.3, 4-1.4, 4-3.3, 4-5.1, 4-7.3, 4-7.5, 6-4

TABLE 3
PROPOSED NEW TEST FACILITIES
(Sheet 2 of 2)

Facility	Use	LMFBR Program Plan Reference for Programmatic Need
Temperature Pressure Test Chamber (TPTC)	Temperature and pressure sensor calibration in inert gas, cable transmission, connectors	4-1.4, 4-6.2, 4-7.1, 4-7.2, 4-7.3, 4-7.7, 4-7.8, 4-7.9, 4-5.4, 4-5.3
Fuel Handling Test Facility (FHTF)	Testing of complete fuel handling systems	3-7.5
Large Pump Bearing Test Facility (LPBTF)	Testing of sodium pump bearings for large pumps	3-11.3
Sodium Impurities Measurements Installation (SIMI)	Testing of carbon, oxygen, and hydrogen measuring devices in sodium	4-1.4, 4-3.2, 5-4
Sodium Purification Test Installation (SPTI)	Testing of cold traps, hot traps, and other sodium purification equipment	4-1.4, 5-2.3, 5.2.4, 5-4
Sodium Cleaning Facility (SCF)	Sodium cleaning of equipment removed from LMEC test facilities	Supports Volumes 3, 4, and 5

TABLE 4
ALTERNATE PLANS FOR PROPOSED FACILITIES

Proposed Facility	Construction Priority		
	Plan 1	Plan 2	Plan 3
Multi-purpose Sodium Test Facility	1	1	1
Component Proof Test Loop	2	2	3
Steam Generator Test Facility	3	3	-
Sodium-Water Integrated Facility Test	4	5	4
Control Rod Test Loop	5	6	5
Sodium Components Test Installation Auxiliary Heater	6	-	2
Sodium Instrument Test Tower	7	-	-
In-Core Flow Test Insert	8	4	6
Temperature Pressure Test Chamber	9	7	7
Fuel Handling Test Facility	10	-	-
Large Pump Bearing Test Facility	11	-	-
Sodium Impurities Measurements Installation	12	-	-
Sodium Purification Test Installation	13	-	-
Sodium Cleaning Facility	14	8	8

c. Component Proof Test Loop (CPTL)

During the review of LMFBF and FFTF test requirements (in conjunction with the preparation of the Test and Facility Document), a need for proof-testing of sodium components, especially in the fuel-handling and control element areas, has become evident. The existing Sodium Mechanism Test Installation (SMTI) and the Control Element Test Stand (CETS) had been considered previously for this work. The need exceeds the capabilities of the SMTI. Instrument and control element tests for the CETS precludes its use for fuel-handling tests. The concept of modifying the SMTI has been abandoned since a complete rework would be necessary, negating any cost savings. Work has been completed on definition of requirements for a new test loop called the Component Proof Test Loop (CPTL). No further work on an Overall Conceptual System Design Description for the SMTI modifications is contemplated.

The CPTL will be used to proof-test subsystems, components, and materials for LMFBR steam generators, pumps, reactor vessels, control elements, fuel elements, and handling systems. The loop will also be used to resolve special compatibility problems of sodium with LMFBR materials and to study sodium aerosol formation and "frosting" in cover gases.

The major features of the Component Proof Test Loop are outlined as follows:

- 1) Eight static sodium test vessels 4 ft in diameter, 4 ft deep, coded for 50 psi, individually heated from 300 to 1300°F, and equipped with purification devices, sample lines, and isolation valves
- 2) A thermal shock chamber filled with low-pressure argon and enclosing a transfer device and two uncovered sodium tanks at different temperatures
- 3) A 1000-ft² covered test area with 60-ft clear height
- 4) An insulated and heated sodium loop consisting of a fill and drain tank, a purification system, a 50-psi low-pressure leg supplying the static pots, and a 225-psi high-pressure, thermally conditioned leg for special tests.

Future work will include: (1) periodic review of FFTF and LMFBR component, instrument, and sodium technology test requirements; (2) periodic review of the status of existing sodium facilities throughout the U.S.; (3) revision of test loading schedules for LMEC facilities; and (4) preparation of Overall Conceptual System Design Descriptions for proposed LMEC test facilities.

3. FFTF Test Planning, Coordination, and Evaluation

Specific FFTF tests to be performed at the LMEC are discussed under the tasks describing the particular tests.

C. TECHNICAL MANAGEMENT OF CONTRACT AT(04-3)-781, LMFBR PIPING DESIGN GUIDE (J. J. Auleta)

1. Introduction

The C F Braun & Co was awarded a contract by the AEC for the preparation of an LMFBR Piping Design Guide. The contract is for the period October 1, 1968 through March 31, 1970. United Nuclear Corporation (UNC) was selected by Braun as the major subcontractor for this work. LMEC has been assigned technical management responsibility for this contract by the AEC.

A statement of the problem and background information for the contract and a discussion of the work accomplished during the initial phase of the contract for the period of October through December 1968 is presented in LMEC-69-1, "Liquid Metal Engineering Center (LMEC) Semiannual Technical Progress Report, July-December 1968."

The objective of the contract is to develop and put into usable form information that will serve to guide the design, fabrication, erection, and testing of large piping systems carrying liquid sodium at high temperature. The overall objective is to obtain practical design methods and test procedures that can be used with assurance.

2. Discussion

Technical work on this contract is approximately 60% complete. A first draft of the design guide is tentatively scheduled to be issued for review about the middle of August 1969. Publication of the design guide is scheduled for March 1970.

In January, the contractor issued Technical Report 100, "The Development and Verification of a Design Guide for LMFBFR Sodium Piping," which presents a convenient summarization of the design guide objectives and work plan. This report has been used to orient those unfamiliar with the overall scope of the work. Figure 1 has been reproduced from Report 100 and summarizes the detailed work plan for this contract. Each work task is shown in the figure along with the relative interdependence of each task.

a. Task 200-Series Study Reports

During this reporting period, the 200-series study tasks shown in Figure 1 were completed. The purpose of these studies was to investigate the present state-of-the-art and define considerations and analytical procedures to be developed.

As a result of these studies, Braun issued the following preliminary technical reports:

- 1) Report 210, "A Study of Failure Theories as Related to LMFBFR Piping Systems." The purpose of the study was to survey existing theories for predicting the imminence of failure and selecting those which provide an adequate basis for developing design procedures.

Figure 1
LMFBR Piping Design Guide
Functional Work Plan

- 2) Report 220, "A Review of Fabrication and Installation Requirements for LMFBR Piping." The purpose of the study was to identify the requirements with respect to workmanship, quality of materials, quality control, and test procedures that will ensure a satisfactory piping installation.
- 3) Report 223, "A Study of Heating and Insulation Methods for LMFBR Sodium Piping." The purpose of the study was to review the various methods applicable to heating and insulating sodium piping and provide an evaluation to compare their advantages and disadvantages.
- 4) Report 228, "A Review of LMFBR Piping Materials." The purpose of the study was to conduct a state-of-the-art survey on the selected materials for sodium piping to provide information on basic properties and data on the effects of environmental conditions of direct concern to the piping engineer. The selected materials for the sodium piping are Type 304 and Type 316 stainless steel, and 2-14% chromium - 1% molybdenum (2-1/4 Cr - 1 Mo) steel.
- 5) Report 234, "A Study of Scale Model Testing Methods Applicable to LMFBR Piping Design." The purpose of the study was to review model test methods for applicability to LMFBR piping design problems. Methods were evaluated for supplementing or complementing mathematical analysis and for establishing stress intensification factors for piping components.
- 6) Report 237, "A Study of Dynamic Analysis Methods as Related to LMFBR Piping Systems." The purpose of the study was to survey existing methods for analysis of the responses of LMFBR piping systems to internal and external forces of both transient and cyclical nature. The study will lead to later selection and development of dynamic analysis procedures for incorporation into the LMFBR piping design guide.
- 7) Report 240, "A Study of Instability Analysis Methods as Related to LMFBR Piping Systems." The purpose of the study was to review existing methods of instability analysis to select suitable procedures for incorporation into the design guide.

8) Report 243, "A Review of In-Service Surveillance Methods Applicable to Liquid Sodium Piping." The purpose of the review was to compile information on various types of surveillance methods in the areas of sodium leak detection, pipe movement, alignment and vibration, material inspection, strain measurement, crack detection, and logging of records. The results of the review will be utilized in preparing recommendations to be presented in the piping design guide.

LMEC has completed a technical review of these reports and has forwarded comments to the contracting officer for transmittal to Braun. Copies of the Braun reports have also been sent to a number of LMFBFR contractors who are presently conducting technical reviews.

b. Results of Study Reports

The study reports provide the necessary input for the work to be performed on the 300- and 400-series tasks. Following are discussions on some of the results presented in Technical Reports 214 and 217.

The first draft of Technical Report 214, "A Review of Piping Failure Experience," issued in November 1968, was revised and reissued in March 1969. This report presents a survey of piping failures reported in the literature, a discussion of the causes of failure, and a review of the measures that must be undertaken to prevent their occurrence in LMFBFR piping systems.

The following paragraphs are excerpted from Section 6, Conclusions and Recommendations, of Report 214:

"There are indications which appear to justify some cautious optimism with regard to the elimination of potential failures in LMFBFR sodium piping systems, although some reservations must be expressed. While the technology exists to ensure adequate initial design, and enough is known about fabrication and erection procedures and welding techniques to ensure a safe and reliable piping structure, reliance has to be placed very heavily upon the integrity with which these activities are carried out. It is here that the LMFBFR Piping Design Guide must play a vital role. Not only must it specify design, fabrication, installation and testing procedures reflecting the very best proven technology in all of these fields, but it must also spell out, in unequivocal language, what measures must be undertaken to guarantee their faithful implementation.

In reviewing the types of failure discussed in this report in the light of the characteristics of the LMFBFR, it is possible to conjecture upon the type of failure that potentially presents the greatest likelihood of occurrence in LMFBFR piping systems. Such a

failure would probably be located in the primary or secondary loop at a weld, or in the heat-affected zone adjacent to a weld, in the presence of a notch defect or gross geometric discontinuity. The primary cause of failure would probably be low-cycle thermal fatigue or creep strain ratcheting, with high-cycle thermal fatigue a possible factor. It is therefore recommended that the effect of these mechanisms upon the life of weld joints be the subject of a thorough research and testing program.

It is further recommended that additional study and development be carried out in the following areas:

- 1) Develop procedures for predicting cumulative creep strains and ratcheting in pipe and fittings.
- 2) Develop mixing tee geometries to minimize the effects of high-cycle thermal action on the pressure containing pipe-wall.
- 3) Develop piping component geometries and establish maximum geometric tolerances for manufacture, fabrication, and erection.
- 4) Study, develop and select in-service surveillance methods, including leak detection methods and strain-measuring.
- 5) Determine the candidate materials' minimum allowable physical and chemical properties.
- 6) Study the effects of low- and high-cycle thermal fatigue and creep strain ratcheting upon weld joint life."

The most difficult problem experienced by the contractor during this reporting period was the problem of formulating the high-temperature criteria from which reliable design and analytical procedures can be developed. The present state-of-the-art for designing high-temperature piping systems was determined to be inadequate when applied to LMFBR sodium piping systems.

In technical Report 210, "Study of Failure Theories," the contractor arrived at the following conclusions:

"The most pressing requirement is to perform evaluations of experimental data to establish the validity of presently available analytical methods which include the effects of creep, plastic cycling and ratcheting.

More experimental data on the basic creep properties of various materials are necessary, with particular emphasis on those suitable for use in the LMFBR program. Experimental testing of individual components under triaxial loading is also urgently needed to establish appropriate geometric factors."

Technical Report 217, "A Review of Piping and Pressure Vessel Code Design Criteria," issued in December 1968, was updated and reissued in April 1969. The purpose of the study was to review the bases used for establishment of design criteria and to evaluate the applicability of these bases and criteria to the more stringent design requirements envisioned for LMFBR piping systems.

The revised version of Report 217 contains the tentative design criteria for LMFBR piping. On the basis of the work completed for Task 217, the authors arrived at the conclusion that "the present nuclear codes (Section III, ASME Code for Nuclear Vessels including Code Case 1331, and USAS B31.7, Nuclear Power Piping Code) cannot be adopted for the design of LMFBR piping without modification."

It is also stated in Report 217, "It must be clearly understood that the conclusion stated above has been reached solely upon consideration of the problems associated with the unusually severe requirements for LMFBR systems, and in no way reflects upon the adequacy of present practices for the types of plants and for the service conditions for which they have been developed."

The tentative interim design assumptions formulated in April 1969 for proceeding with work on the 300- and 400-series tasks are quoted from Section 4 of Report 217:

"STRESS CATEGORIES The following are the stress categories for which appropriate design analysis procedures will be established.

- 1) Primary Stress
 - a) Sustained primary membrane stress
 - b) Transient primary membrane stress
 - c) Local primary membrane stress
 - d) Primary bending stress
- 2) Secondary Stress
 - a) Sustained secondary stress
 - b) Transient secondary stress
- 3) Peak Stress
 - a) Sustained peak stress
 - b) Transient peak stress

The definition of primary, secondary and peak stress will be as stated in Section 2.3 of this report.

STRENGTH THEORIES For the LMFBR Piping Design Guide either the maximum shear stress theory (Tresca) or the distortion energy theory (von Mises criterion) may be applied in the formulation of design analysis procedures for the transient or

short-term loadings, or for temperatures where creep is not a factor, as may prove the more convenient or expedient for any given application. For the sustained loadings either the maximum principal stress theory or the distortion energy theory may be used depending upon whether the calculated stresses are being limited by criteria based on stress rupture or creep strain, respectively.

CREEP AND RELAXATION Creep effects will be taken into account in relation to sustained primary stresses. Creep relaxation will be taken into account in regard to sustained secondary and sustained peak stresses.

RATCHETTING It will be a requirement of the LMFBR Piping Design Guide that plastic strain cycling will be permitted only to the extent that it can be satisfactorily demonstrated that shake-down will occur. Procedures to show how this may be verified will be developed for the Design Guide.

WALL THICKNESS The Boardman equation, or a modification to it, will be used for the calculation of wall thicknesses.

PRIMARY BENDING STRESSES As a design procedure, longitudinal bending stresses due to dead load or seismic effects will be limited independently to one-fourth of the allowable primary membrane stress intensity. This can be achieved by the provision of pipe supports and hydraulic dampeners sufficiently close together as to minimize these effects. The LMFBR Piping Design Guide will furnish appropriate guidelines. Alternative procedures limiting the combination of primary bending and primary membrane stresses will also be provided.

SECONDARY AND PEAK STRESSES Secondary and peak stresses will be computed as stress ranges on an elastic basis, in accordance with present practice, but a distinction will be made between those due to relatively sustained loads and those induced by transient conditions.

ALLOWABLE PRIMARY STRESS INTENSITY The allowable primary membrane equivalent stress will be based on the same fractions of yield and ultimate strengths and creep properties as used in the current ASME and USASI nuclear codes that are applicable in the creep range, based on 200,000-hour data. The method of extrapolation will be investigated in Task 312, with the object of obtaining a reliable correlation.

ALLOWABLE SECONDARY STRESSES The allowable values for short-term transient secondary stress ranges will be established as the sum of the yield strengths of the materials at the extremes of the ranges of temperature during the transient, modified to reflect the increase in strength due to the strain hardening effected by some permissible total strain. Allowable values of yield strengths for sustained secondary loads will be downgraded to reflect the effects of relaxation. Where this cannot be established with certainty, the allowable range will be taken as the yield strength at the lower (cold) extreme of temperature range.

ALLOWABLE PEAK STRESSES For transient peak stress ranges, the fatigue curve to be used will be determined as an average between the fatigue curves associated with the temperatures at the extremes of the temperature range at the point being analyzed. For sustained peak stresses, the procedure will be the same except that the fatigue curves will be downgraded to reflect the effects of relaxation.

(In general, this means that the low-temperature fatigue curves are those in current use. If no acceptable procedure can be readily established for downgrading the high-temperature curve, it can be arbitrarily set at zero. Thus the fatigue curve for sustained peak stresses would have ordinates equal to one-half the values of the low-temperature curve. This may yield results that are too conservative, but an improvement over the method suggested here will have to await the conductance of cyclic fatigue tests that properly reflect the effects of creep and temperature ranges.)

COMPUTATIONAL METHODS Except as modified by the criteria stated in the foregoing paragraphs, stresses will in general be computed in accordance with the procedures given in USAS B31.7, Appendix F."

It must be recognized that the above interim assumptions are tentative and may require some modification as a consequence of their further investigation during work on the 300- and 400-series tasks.

3. Future Effort

The contractor is presently working on the 300- and 400-series tasks shown in Figure 1. Properties of suitable materials will be summarized. Rules for fabrication and erection will be defined. Analytical procedures for system design analysis will be developed. These will include the following:

- 1) Pressure analysis
- 2) Flexibility analysis
- 3) Steady-state and transient thermal analysis
- 4) Mechanical loads analysis
- 5) Dynamic analysis
- 6) Fatigue analysis
- 7) Model testing
- 8) Instability analysis.

Completion of all of the preceeding tasks will provide the basis for the preparation of a draft for the Preliminary Piping Guide, which is scheduled for release about the middle of August 1969.

As presently conceived, the design guide will consist of three volumes as follows:

- 1) Volume I, Requirements
- 2) Volume II, Procedures
- 3) Volume III, Addendum.

The chapters of Volume I are tentatively titled as follows:

- 1) Chapter 1, Introduction, Scope, and Definitions
- 2) Chapter 2, Requirements for Class 1A Piping
- 3) Chapter 3, Requirements for Class 1B Piping
- 4) Chapter 4, Requirements for Fabrication, Installation, and Testing
- 5) Chapter 5, Requirements for Quality Assurance
- 6) Appendix I, Mandatory Design Data and Requirements.

The chapters of Volume II are tentatively titled as follows:

- 1) Chapter 1, Design Analysis Procedures for Class 1A Piping
- 2) Chapter 2, Design Analysis Procedures for Class 1B Piping
- 3) Chapter 3, Recommendations for Component Design and Verification
- 4) Chapter 4, Interface Liaison Procedures
- 5) Chapter 5, The Stress Report
- 6) Appendix II, Physical Properties, Non-Mandatory Material.

The sections of Volume III are tentatively titled as follows:

- 1) Addendum 1, Sample Stress Report
- 2) Addendum 2, Design Philosophy.

R&D requirements identified during studies of failure theory, materials, and analytical procedures will be summarized as a supplement to the design guide. Where possible, present R&D work within the LMFBR program will be referenced, and expansion of this work to include R&D for the piping guide may be recommended.

The draft of the Piping Design Guide will be used to analyze a typical LMFBR piping configuration to determine the degree of applicability. Those analytical procedures that have been fully defined and documented will be tried, and an attempt will be made to establish the limitations of the methods used, as well as the system configurations and/or components.

Appropriate revisions will be made to the methods incorporated in the guide. The revised draft is scheduled to be issued in March 1970.

D. STEAM GENERATOR AND INTERMEDIATE HEAT EXCHANGER SYSTEMS
PERFORMANCE AND CONTRACT MANAGEMENT (G. S. Budney and R. J. Gimera)

The overall objective of the AEC steam generator and IHX research and development program is to develop sodium-heated steam generators and IHX's that will perform reliably in LMFBR plants. The AEC has determined that most effective use of government and industrial resources in the R&D program can be achieved by means of a phased program, starting with the development of a plan for further study. Delineation of this plan is the scope of work for the Program Definition Phase (PDP), performed by industrial contractors under the technical direction of the LMEC.

The overall objective of the steam generator and IHX PDP is to develop and delineate a plan for the research, development, design, manufacture, test and evaluation, and mainenance, during operation, of reliable steam generators and IHX's for the national LMFBR program.

The major technical tasks of the PDP are as follows:

- 1) Definition of target-size steam generators and IHX's
- 2) Definition of design criteria and functional requirements for the target steam generators and IHX's to provide a design basis for the subsequent tasks
- 3) Identification and evaluation of concepts which meet the above criteria and functional requirements, and provide promise for eventual attainment of the program objectives
- 4) Identification of the technical and economic uncertainties associated with the candidate concepts which must be resolved to reduce the technical and economic risks for target-size components to a manageable level.
- 5) Development of plans, with schedules, cost estimates, and required facilities, for the R&D programs necessary to resolve uncertainties.

The long-term steam generator program plans are designed to meet the requirements of the 1000-Mwe LMFBR plant designs. The range of plant parameters applicable to steam generators is summarized in Table 5.

TABLE 5
STEAM GENERATOR DESIGN PARAMETERS
(Full-Load Conditions — Far-Term Plants)

Design Parameter	Maximum Value	Minimum Value
Feedwater Flow (lb/hr)	9.807×10^6	6.84×10^6
Feedwater Inlet Temperature (°F)	500	478
Steam Temperature at Turbine Throttle (°F)	1000	900
Steam Pressure at Turbine Throttle (psig)	2400	2400
Sodium Inlet Temperature (°F)	1071	966
Sodium Outlet Temperature (°F)	670	640
Sodium Flow (lb/hr)	92.0×10^6	64.25×10^6
Reheater:*		
Steam Flow (lb/hr)	6.9×10^6	6.39×10^6
Steam Inlet Temperature (°F)	630	610
Steam Outlet Pressure (psig)	540	515
Steam Outlet Temperature (°F)	1000	950
Sodium Inlet Temperature (°F)	1071	1000
Sodium Outlet Temperature (°F)	947	825
Sodium Flow (lb/hr)	27.12×10^6	25.41×10^6

*One LMFBR plant designer selected a nonreheat cycle.

The long-term IHX program plans are similarly designed to meet the requirements of the 1000-Mwe LMFBR plant designs. The ranges of design parameters from the 1000-Mwe plant design studies are listed in Table 6 together with LMFBR target values taken from the LMFBR Program Plan.

The major technical tasks performed under the PDP for the long-term plants were based on the parameters listed in Tables 5 and 6. The PDP studies were completed about the end of the fiscal year; LMEC is now evaluating these studies to make recommendations for continuing work by the industrial contractors.

TABLE 6
RANGE OF IHX DESIGN PARAMETERS
(Full-Load Conditions - Far-Term Plants)

Design Parameter	Maximum Value	Minimum Value	LMFBR Target Value
No. of IHX's/1000-Mwe Plant	6	2	2 to 6
Primary Sodium Inlet Temperature (°F)	1150	1000	900 to 1200
Primary Sodium Outlet Temperature (°F)	809	770	600 to 970
Primary Sodium ΔT (°F)	360	230	-
Primary Sodium Flow Rate/IHX (10^{-6} lb/hr)	63.7	15.4	-
Shell-Side Pressure Drop (psi)	4	2	10
Secondary Sodium Inlet Temperature (°F)	700	640	500 to 850
Secondary Sodium Outlet Temperature (°F)	1071	966	800 to 1160
Secondary Sodium ΔT (°F)	425	300	-
Secondary Sodium Flow Rate/IHX (10^{-6} lb/hr)	44.5	14.3	-
Tube-Side Pressure Drop (psi)	10	5	15 to 20
LMTD	121	82	83 to 100

E. SODIUM PUMP SYSTEMS (R. W. Atz and C. C. Conners)

1. Introduction

LMFBR Program Plan, Volume 3, "Components," identifies the need for establishing the technological base for design and fabrication of safe, reliable, and economic liquid metal pumps for commercial LMFBR power plants. Liquid metal pumps of 60,000- to 120,000-gpm (or more) flow capability at up to 1200°F and 450 ft Total Discharge Head (TDH) may be required for the larger FBR's. The largest pumps which have operated successfully to date (in this country) were built for Fermi (11,800 gpm), Hallam (7,200 gpm), and EBR-II (5,500 gpm).

To develop the technology needed for larger, high-temperature pumps, engineering studies were initiated by the AEC with Byron Jackson Co. and Westinghouse during FY 1967, with technical management assigned to LMEC. Technical efforts on these studies were essentially completed in FY 1969 and final reports are to be issued early in FY 1970.

PRC I

Figure 2. Single Suction Sodium
Pump Concept, Removable
Concentric Casing (Westinghouse
Drawing ED SK 330610-J)

LMEC-69-30

47

2. Project Management

During the second half of FY 1969, added emphasis was placed on development of a low-capacity prototype pump (~15,000 gpm). Project planning and technical efforts within LMEC were directed towards supporting this development area.

A task force was established to revise the draft of the RDT Pump Standard. This standard was rewritten so that it can be used with a specification to procure vertical, free-surface, centrifugal sodium pumps. The revised draft was completed in June 1969.

Drafts of the preliminary specification for procurement of a low-capacity prototype pump were reviewed. Comments were developed to assist in preparation of the final procurement specification.

3. Westinghouse Pump Study Contract

a. Phase I Study

The final report on the Large Sodium Pump Design Study — Phase I, WARD 3762-1, was issued during the second half of FY 1969. This study established basic parameters for free-surface, centrifugal sodium pumps in the size range of 10,000 to 200,000 gpm and 100 to 450 ft TDH. One concept, PRC 1 (see Figure 2), was recommended for further study.

b. Phase II Studies

(1) Medium Capacity Pump Design Study [Phase II-A, Contract AT(30-1)-3762]

Technical management of this Westinghouse design study was performed by LMEC for the AEC. This study was directed toward design of a 60,000-gpm, 350-ft-TDH, 1200°F, free-surface, centrifugal, sodium pump, having a piped suction with overflow line for sodium level control. This is the PRC 1 concept recommended by Westinghouse in the Phase I Study.

All technical effort on the study was completed in June 1969. (Technical sections of the report were written.) Drafts of the final report will be issued by Westinghouse for review early in FY 1970.

The final report defines the basic design of the pump and its major components. It also defines areas where additional development and testing is recommended. Some of the problem areas encountered during the study are discussed in the following paragraphs.

(a) Resolution of Component Design Uncertainties Involving Long-Term Materials Properties

Design requirements of a 30-yr operating life and ability to function in the environment of 35°F/sec thermal transients have imposed two conflicting constraints on the design of critically stressed components. For a part to retain its structural integrity under repeated thermal transients, it must be thin enough in cross-section to keep thermal stresses low. At the same time, the cross-section must be thick enough to resist creep under long-term steady-state stress. Thicknesses required to meet the ASME code on the Westinghouse design criteria result in severe thermal stresses when subjected to coolant transients. Thermal shock liners are necessary in some areas to reduce the magnitude of the thermal stresses to assure adequate fatigue life and guard against thermal stress ratcheting. The lack of available test data for very long-term creep rupture, thermal shock fatigue, and thermal stress ratchetting make it necessary to establish the above parameters on a conservative basis, thus compounding the design problems.

(b) Variations in Calculation Techniques

The design requirements for the pump tank exceed conditions for which current ASME codes are applicable. As a result, it has been necessary to establish a hybrid design technique from specific codes, code cases (such as 1331-4), and engineering judgment for evaluating stresses in the pump tank. While combined elastic-plastic-creep computer programs may be usable in the near future for complete analysis, the present state-of-the-art requires that empirical approaches be made to estimate stress levels and effects of cyclic stresses upon design life. By utilizing these empirical approaches, such as applying the ratio of cycles accumulated to cycles allowed and including factors for dwell time and creep-fatigue interaction, hopefully conservative estimates have evolved to produce safe designs. Degrees of conservatism have thus become judgment items which subsequently establish the resulting design philosophy. The validity of these empirical methods and their degree of conservatism can only be established by extensive test work and operating experience.

(c) Application of Hard Facing Materials

Availability of proven hard facing materials usable in 1200°F sodium is very limited. Present practice is to spray the materials onto a base metal using either a plasma, oxyacetylene, or tungsten - inert gas process. Because of the differences in thermal coefficients of expansion between the hard facing and base metal,

separation of the two materials can occur, particularly under the influence of thermal transients.

(d) Effects of High-Velocity Fluid Streams Upon Pump Materials

The high flow rates and head rises to be developed by LMFBR sodium pumps will require substantial increases in fluid velocities within the pumps. With the requirement for 1200°F operating capability, a potential for erosion exists.

(2) Low-Capacity Pump Design Study [Phase II-B, Contract AT(30-1)-3762]

Technical management of this Westinghouse design study was performed by BNW. LMEC provided technical assistance and consultation to RDT and reviewed preliminary documents prepared by Westinghouse. This study developed design information on a 13,000-gpm, 500-ft TDH sodium pump of the Fermi type (sump suction with no overflow line).

To meet the low NPSH requirement of 22 ft and maintain a minimum diameter impeller, a double-suction concept was adopted. Internal thermal shock liners are included in the pump barrel to meet the severe thermal transient requirements specified for the design study. Internal heat exchange tubes are shown on the supply lines to the bearings. They are included to reduce thermal transients which the bearing hard facing material would experience.

This study has also been completed and reports will be issued early in FY 1970.

4. Byron Jackson Pump Study Contract

The final report of the Phase I parametric study was revised to incorporate review comments. All revisions have been completed by Byron Jackson, and the report has been sent to the printers for typesetting.

F. SODIUM VALVE SYSTEMS (H. A. Ross-Clunis and R. B. Hinze)

1. LMFBR Valve Development

Operational and functional requirements for valves being developed to meet the long-term needs of the LMFBR program have been revised. Comments from the LMFBR Program Office have been incorporated; these comments are based, in part, on information from the 1000-Mwe LMFBR Follow-on Study

contractors. The original requirements for this large valve technology development program were published in LMEC-69-1.*

New operational requirements are listed as follows (original requirements are also listed for comparison):

<u>Requirement</u>	<u>Revised</u>	<u>Original</u>
1) Size range, nominal (in.):		12 to 48 (for all types)
a) Isolation valves	12 to 48	
b) Flow-control valves:		
(1) Full-range control	12 to 30	
(2) Low-range control	24 to 42	
c) Check valves	12 to 48	
2) Pressure (psig):		225 (maximum system)
a) Design (at design temp)	225	
b) Operating range	0 to 200	
3) Temperature (°F):		800 to 1200 (range of maximum operation)
a) Design	1210	
b) Operating range	250 to 1200	
4) Fluid velocity in pipe (ft/sec):		15 to 30
a) Design	30	
b) Operating range	10 to 40	
5) Sodium radiation level (r/hr, gamma)	1,000,000	10 ⁸
6) Service life (yr)	30	
7) External environment — either		Same
a) Air or inert gas; maximum temperature (°F) or	150	

*"Liquid Metal Engineering Center (LMEC) Semiannual Technical Progress Report, July-December 1968," LMEC-69-1 (March 31, 1968)

- b) Liquid sodium; temperature 250 to 900 Operating temperature range
(°F), except that full range
flow-control valves will be
used only in air environment
- 8) Plant operating cycles, normal: 1,000 to 10,000
- a) Startup and shutdown (number) 500
- (1) Cyclic pressure range (psi) 200
- (2) Rate of pressure change,
maximum (psi/sec) 20
- (3) Cyclic temperature
range (°F) 250 to 1200
- (4) Rate of temperature
change, maximum (°F/hr) 100
- b) Load following (number): 20,000
- (1) Cyclic pressure range (psi) 200
- (2) Rate of pressure change,
maximum (psi/sec) 20
- 9) Temperature transients, abnormal: Same transients, without
differentiation by group
- (Valves may be subjected to either of the following transient groups 1
or 2. Each valve must be capable of withstanding the most severe of
the two groups of transients.)

Group	No. of Cycles	Initial Temperature (°F)	Transient Description	Initial and Final Sodium Temperature Difference (°F)
1	300	1200	-20°F/sec for 15 sec	300
	25	1200	-30°F/sec for 10 sec	300
2	300	800	-10°F/sec for 30 sec	300
	25	800	+30°F/sec for 10 sec	300

Revised functional requirements are as follows:

- 1) Isolation and flow-control functions may be combined in a single unit within a comparable size range. (Such a unit is designated a dual-purpose valve.)
- 2) Isolation (shutoff) valves, flow-control valves, and dual-purpose valves shall be capable of being fully opened from the full-closure position and fully closed from the full-open position at 1200°F and maximum pressure differential of 200 psi for 1,000 cycles.
- 3) Isolation, flow-control, and dual-purpose valves shall be capable of full stroke in either direction within a 10-sec period.
- 4) Leakage past the seat, in either direction, of isolation and dual-purpose valves, with valve in full-closure position, shall not exceed 0.01% of design flow at maximum pressure differential of 200 psi. (Design flow is defined as flow rate at fluid velocity of 30 ft/sec.)
- 5) Full-range flow-control valves shall be capable of controlling flow from 20 to 120% of design flow at a ramp rate of 2% of design flow per minute. Low-range flow-control valves shall be capable of controlling flow between 1.5 and 25% of design flow. Both of these types of flow-control valves shall be designed for minimum hysteresis. Requirements for valves in this paragraph apply to the system consisting of a valve and its operator.
- 6) Pressure drop across full-range flow-control valves at 120% of design flow will be on the order of 5 to 10 psi; at 20% of design flow, * psi.
- 7) Low-range flow-control valves shall be designed for minimum pressure drop at design flow. Pressure drop across these valves at 20% of design flow will be on the order of * psi; at 1.5% of design flow, * psi. During normal reactor operation, low-range flow-control valves will be in full-open position. These valves will be used in main coolant lines to retard (brake) coolant flow immediately after emergency shutdown of reactor and pumps, and to control free-convection flow rate while decay heat is being removed from the reactor. Pressure drop through these valves will be low during the free-convection flow mode.

*Numerical value will be specified when available.

- 8) Check (anti-backflow) valves shall be capable of preventing reversal of normal flow. Valve design shall provide for valve to open sufficiently to allow approximately 1.5% of design flow at a differential pressure of approximately 1 psi to permit removal of reactor decay heat by natural convection or low-flow emergency means. Valve design shall include "non-slam" features (dash-pot or other means to permit setting valve closure time from full open to full closed position in the range of 5 to 10 sec) which reduce impact sufficiently to prevent generation of excessive inertial loads (fluid hammer) in the piping system and assure that no damage to the internal parts of the valve will result from repeated closures under operating conditions.
- 9) Isolation, flow-control, and dual-purpose valves shall be capable of operation either manually (by hand operator at valve, or extension therefrom) or by power operators. The operators shall be of proven design properly applied and supported from the valve structure where feasible
- 10) Valves submerged in liquid sodium using other than sodium as an operating fluid shall be provided with devices such that their operators can be located above or outside of the pool of liquid sodium.
- 11) Operators for isolation, flow-control, and dual-purpose valves shall be designed and located for ease of maintenance under all conditions.
- 12) The inert gas environment (one of the external environments listed in the above operational requirements section) shall be a gas that is chemically inert to sodium. If a pneumatic valve operator is used in this environment, any gas discharged from the operator shall also be chemically inert to sodium.
- 13) Valves shall be capable of having gas at a pressure of 10^{-6} mm Hg inside the valve when external gas pressure is atmospheric and valve body and bonnet are at a temperature less than 300°F.
- 14) Valve design shall be such that the flow within the valve at velocities in the specified range shall not cause vibration sufficient to result in damage to or malfunction of the valve or other components in the system.
- 15) Valves shall be self-draining.

- 16) Leakage of liquid sodium to an air or gas environment or from an air or gas environment into the valve shall be zero. For valves operating submerged in sodium, minor leakage is permissible.
- 17) Valves for use in an air or gas environment shall be provided with heaters that are capable of preheating the valve at a rate of 50°F/hr to a maximum temperature of 400°F. This rate requirement does not apply to the period during which sodium is thawing. Design of the preheating system shall be such that the valve will not be damaged during the heating operation. Instrumentation shall be provided to indicate when the valves have reached a safe operating temperature, i.e., all sodium is liquid (except sodium in a freeze seal).
- 18) Valves shall be capable of having sodium, which has been frozen in the valve, melted without damage to the valve. It may be assumed that a liquid path to a sodium-free surface exists at one end (nozzle) of the valve.
- 19) Valves shall have the capability of performing their shutoff and/or flow-control function at any temperature between 250 and 1200°F, and while temperature is changing at a rate not exceeding 100°F/hr in this temperature range. A valve shut at any temperature between 250 and 1200°F shall have the capability of being opened at any other temperature between 250 and 1200°F. Isolation and dual-purpose valves shall be capable of performing their isolation function with 1200°F sodium on only one side of the seat.
- 20) Valve supports shall be provided that will accommodate translational movements of the valve and growth due to thermal expansion of the valve body, bonnet, stem, and appurtenances.
- 21) Materials in the valves shall be suitable for service in 1200°F sodium systems containing 300-series austenitic stainless steels, higher nickel austenitic stainless steels, and ferritic (Cr-Mo) steels. The determination of suitability for service in sodium shall include consideration of changes in composition and properties of materials because of such factors as high temperature, mass transfer, carburization, and decarburization. Welding ends (nozzles) of the valves shall be compositionally and dimensionally compatible for welding purposes with the austenitic stainless-steel pipe elements to which they connect.

- 22) Welding ends (nozzles) of the valves and transitions thereto shall be proportioned to minimize differential dimensional response between pipe elements and valve body to thermal transients.

The most significant change in the requirements concerns flow-control valves. In the original requirements, all control valves were considered to have the same function, i. e., control of flow from 20 to 100% of full flow. The LMFBR Program Office has identified two applications for flow-control valves. The first application is to partition sodium flow between reheater and superheater in secondary systems. Valves for this use are designated "full-range" flow-control valves; these valves must be capable of controlling flow from 20 to 120% of design flow (essentially the same functional requirement as the control valves identified in the original requirements). The second application involves retardation (braking) of coolant flow in main piping immediately after emergency shutdown of reactor and pumps, and flow control during free-convection flow mode while decay heat is being removed from the reactor. Valves for this application are designated "low-range" flow control valves since they must be capable of controlling flow between 1.5 and 25% of design flow. During normal reactor operation, these valves will be in the full-open position; flow will be controlled by varying pump speed. It is possible that different valve concepts will be needed for these two applications.

In the operational requirements section, design values and operating ranges have been specified for pressure, temperature, and velocity. Design pressure and temperature are consistent with SPTF requirements. The upper limit of operating range for fluid velocity reflects Westinghouse's two-loop plant design.

Requirements for plant cycles have been amplified, giving rates and ranges of pressure and temperature changes, as appropriate, for startup-shutdown cycles and load-following changes. Only pressure cycles are listed for load-following changes since it is assumed that reactor inlet and outlet temperatures will be held constant by the plant control system.

Temperature transients have been clarified. Valves are to be designed for service in either high- or low-temperature coolant lines. Group 1 transients are thermal transient requirements for high-temperature lines; group 2, for low-temperature lines. Each valve is to be designed to meet the most severe of these two sets of transients. Valves so designed will be suitable for service in either high- or low-temperature piping.

In the functional requirements, duty requirements for the various types of valves have been amplified by incorporating all available information. Additional requirements, specifically on the pressure drop to be dissipated by flow-control valves at various flow rates, are needed to complete the preliminary design. These requirements will be completed when the information has been obtained.

Several items now included as functional requirements are amplifications of requirements in the scope of work of the valve development contracts, or are items that would normally be considered by sodium equipment designers. These items are:

<u>Item No.*</u>	<u>Topic</u>
12	Limitation on gas discharged by valve operator in an inert gas environment
13	Pressure design requirement to permit evacuation for mass-spectrometer leak check
17	Preheating
19	Valve function under various temperature conditions
20	Valve supports
21	Materials compatibility; designation of austenitic stainless steel as system piping material
22	Dimensions of valve ends

*Number in functional requirements listing

2. Sodium Pump Test Facility (SPTF) Development Valves

SPTF valve criteria were prepared for the development valve contractors. The valve sizes and requirements are to suit a base loop for 60,000-gpm pump testing, and also a modification of the loop for FFTF pump testing. The design requirements are tabulated in Tables 7 and 8.

3. Fast Flux Test Facility (FFTF) Development Valves

FFTF valve criteria were prepared for the development valve contractors. The valve sizes and requirements are to suit the FFTF main heat transport system which consists of a primary system and a secondary system. There are separate design requirements for each of these systems.

Notes (to Table 7):

1. Manually adjusted stops are to be provided on the flow control valves to permit return to a pre-determined position following closure.
2. Force-limiting devices are to be provided in the power operator to prevent damage to the valve from over-stroking. The over-riding manual operator is to provide positive closure capability.
3. Valve design shall be such that the flow within the valve at velocities in the specified range shall not cause vibration or cavitation sufficient to result in damage to or malfunction of the valve or other components in the system.
4. Valves shall be provided with heaters that are capable of preheating the valve at a rate of 50°F/hr to a maximum temperature of 400°F. This rate requirement does not apply to the period during which sodium is thawing. Temperature-indicating instrumentation shall be provided.
5. Valves shall be capable of having sodium which has been frozen in the valve melted without damage to the valve. It may be assumed that a liquid path to a sodium-free surface exists at one end (nozzle) of the valve.
6. If such devices as freeze stem seals are used in valves where the stem moves axially, the valve is to back-seat in the open position.
7. It is preferred that the valves be self-draining.
8. The flow control valves shall be capable of controlling flow to meet the requirements stated below. Requirements for valves in this paragraph apply to the system consisting of a valve and its operator.
 - a. Series 2 valves shall be used in a sodium control loop where control of flow shall have an accuracy of $\pm 2\%$ of actual flow from 72,000 to 15,000 gpm and 3% from 15,000 to 4,000 gpm.
 - b. Series 3 valves shall be used in a sodium control loop where control of flow shall be programmed to provide a variable change of flow rate from 0 to 44,000 gpm.
 - c. Series 9 valves shall be used in a sodium control loop where control of flow shall have an accuracy of $\pm 2\%$ from 15,000 to 3,000 gpm and $\pm 3\%$ from 3,000 to 1,000 gpm.
9. Valve internals shall be designed to minimize the possibility of a structural or mechanical failure that can result in inadvertent partial or full flow blockage in the valves. The design must assure that no foreign material can enter the flowing coolant stream.
10. Materials in the valves shall be suitable for service in 1200°F sodium systems containing 300-series austenitic stainless steels, higher nickel austenitic stainless steels, and ferritic (Cr-Mo) steels. The determination of suitability for service in sodium shall include consideration of changes in composition and properties of materials because of such factors as high temperature, mass transfer, carburization, and decarburization.
11. Valves shall be capable of having gas at a pressure of 10^{-6} mm Hg inside the valve when external gas pressure is atmospheric and valve body and bonnet are at a temperature less than 300°F. This requirement is for the purpose of preoperational testing. Special stem sealing methods may be employed for such testing. Any special sealing material or devices shall be easily removable.
12. Valves shall have the capability of performing their shutoff and/or flow-control function at any temperature between 250 and 1200°F, and while temperature is changing at a rate not exceeding 100°F/hr in this temperature range. A valve shut at any temperature between 250 and 1200°F shall have the capability of being opened at any other temperature between 250 and 1200°F. Isolation valves shall be capable of performing their isolation function with 1200°F sodium on only one side of the seat.
13. All joints, excepting a packed stem seal joint, which are employed in the containment of liquid sodium shall be sealed by welding.
14. Valves shall be provided with butt-weld-type end connections which shall be compositionally and dimensionally compatible for welding purposes with Type 304H stainless-steel pipe elements to which they connect. Welding ends (nozzles) of the valves and transitions to the body shall be proportioned to minimize differential dimensional changes between piping and valve body during thermal transient conditions.
15. A valve stem backup packing shall be provided.
16. Valve supports shall be provided that will accommodate translational movements of the valve and growth due to thermal expansion of the valve body, bonnet, stem, and appurtenances.
17. Valves shall be subject to hydrostatic pressure tests using a fluid approved by the valve contractor in conformance with the ASME Code Section III for Nuclear Vessels.
18. The ASME Code for Pumps and Valves for Nuclear Power (draft) and USAS B31.7, Nuclear Power Piping, shall be used as a design guide, where applicable.
19. For flow control valves, the effect of cavitation must be considered. The goal is to stage the pressure drop for the valve (or valves) to limit cavitation to the incipient point.

TABLE 8
SPTF DESIGN THERMAL TRANSIENTS

Group	Number of Cycles	Initial Temperature (°F)	Transient Description	Difference Between Initial and Final Sodium Temperature (°F)
1	100	800	+35°F/sec for 6 sec followed by +2°F/sec for 45 sec	300
1	35	1100	-35°F/sec for 6 sec followed by -2°F/sec for 45 sec	300
1	50	600	+4°F/sec for 120 sec	480
1	15	1100	-4°F/sec for 120 sec	480
2	40	800	+30°F/sec for 10 sec	300
2	40	1050	-30°F/sec for 10 sec	300

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Figure 3. Valve Flow Characteristics (30-in. flow control valves sized for 60,000-gpm pump)

Figure 4. Valve Flow Characteristics (20-in. drain control valves sized for both 60,000-gpm and FFTF test pumps)

Figure 5. Valve Flow Characteristics (8-in. flow control valves)

7693-2562

Figure 6. Valve Flow Characteristics (14-in. flow control valves sized for FFTF pump)

a. Primary System Valves

The design requirements for primary system valves are tabulated in Table 9.

b. Secondary System Valves

The design requirements for secondary system valves are tabulated in Table 10.

G. SODIUM-WATER REACTION (K. L. Adler)

LMEC has been assigned technical management of AEC sodium-water reaction work. To adequately support these management efforts, LMEC has investigated certain aspects of the reaction analytically.

The ability to predict the effects of a leak of water or steam into sodium through a given opening depends upon the ability to predict the rate of flow of water (steam) through that opening, regardless of what mechanism is finally shown to be responsible for observed structural damage. For the typical large pressure ratios between the water (steam) and sodium, the flow will always be "choked" at the exit of the leak passage and the resultant jet will be supersonic.

TABLE 9
DESIGN REQUIREMENTS FOR FFTF MAIN HEAT TRANSFER SYSTEM
PRIMARY SODIUM SYSTEM VALVES

Design Data	Hot Leg	Cold Leg	Cold Leg
Service	Isolation	Isolation	Check
Fluid	Sodium	Sodium	Sodium
Number per Loop	1	1	1
Size (in.)	30	18 to 22	18 to 22
Design Flowrate (gpm)	14,000	14,000	14,000
Design Temperature (°F)	1200	1200	1200
Operating Temperature Range (°F)	250 to 1200	250 to 1200	250 to 1200
Design Pressure (psig)	300	300	300
Normal Operating Pressure, Maximum (psig)	5	185	185
Pressure Drop at Design Flow, Maximum (psi)	0.1	0.4	0.4
Maximum Shutoff Differential Pressure (psi)	200	200	200
Across-Seat Leakage at Maximum Shutoff ΔP	Very small -- part of study		0.1% of design flow at 200 psi ΔP
Closing Period (sec)	10 to 150	10 to 150	3 sec total (nominal)*
Operator Type and Mounting	Part of study effort		Actuated by loss of flow
Failure Mode	As-is	As-is	-
Service Life (yr)	20	20	20
Lifetime Open-Close Operations (No.)	100	100	1000
Draining Capability	Not defined	Not defined	Not defined
Geometry Constraints	Not defined	Not defined	Not defined
Environment External to Valve	N ₂ with 5% maximum O ₂ at 150°F maximum		
Design Thermal Transients:			
Rate (°F/sec)	-20 for 6 sec	+15 for 11 sec then -9 for 15 sec	
Amplitude (°F)	-300 in 20 sec	+165 in 11 sec then -135 in 15 sec	
Lifetime cycles (No.)	10	10	
Rate (°F/sec)	-3 for 50 sec	-30 for 2 sec	
Amplitude (°F)	-260 in 180 sec	-120 in 15 sec	
Lifetime Cycles (No.)	500	500	
Stem Seal Type	Part of study effort		
Allowable Leakage to Environs	Zero	Zero	
Sodium Radiation	Not defined	Not defined	

*Total check valve closure time is 3 sec based on the Fermi modified check valves.
The rate of closure should be such that reverse flow of sodium is reduced to a minimum as rapidly as possible with the avoidance of sodium hammer.

Notes: See following page.

Notes (to Table 9) - General:

1. The valve(s) will be physically located in an inert atmosphere equipment cell in horizontal pipe runs.
2. Routine maintenance cannot be performed. Corrective maintenance becomes progressively more difficult with plant operation. These two considerations should be reflected in the design of the valves and operators.
3. Valve internals design is to preclude the possibility of a structural or mechanical failure that can result in inadvertent partial or full flow blockage in the valves. The design must assure that foreign materials such as broken valve pieces, part of gaskets, bolts, nuts, etc., cannot enter the flowing coolant stream.
4. Materials that are reactive or incompatible with sodium or austenitic stainless steels are not permitted in the valve.
5. Internal working parts of primary system valves must be remotely replaceable from the operating floor without the need for draining the primary loop. At the time of servicing, the sodium temperature range will be * and the total sodium head will be * (see Figure 7).
6. Valves shall be provided with heaters that are capable of preheating the valve at a rate of 50°F/hr to a maximum temperature of 400°F. This rate requirement does not apply to the period during which sodium is thawing. Design of the preheating system shall be such that the valve will not be damaged during the heating operation. Instrumentation shall be provided to indicate when the valves have reached a safe operating temperature, i. e., all sodium is liquid (except sodium in a freeze seal).
7. During operation, the primary system valves are exposed to radiation from large quantities of activated sodium. The design must include integral shielding to permit maintenance operations as follows:
 - a. All disconnects - electrical, instrument, and pneumatic - to be made accessible for human contact.
 - b. All removal preparations, including unbolting the flanges and shielding, to be made accessible for human contact.
8. Valves shall be capable of having sodium which has been frozen in the valve melted without damage to the valve. It may be assumed that a liquid path to a sodium-free surface exists at one end of the valve.
9. Valve design shall be such that the flow within the valve at velocities in the specified range shall not cause vibration sufficient to result in damage to or malfunction of the valve or other components in the system.

Notes - Isolation Valve:

10. In considering the valve and operator combination, a fundamental requirement is that no single unlikely failure is to permit sodium or sodium vapor to be released to the operating floor.
11. The capability to operate the valves must be assured. Possibilities for providing such assurance include conservative valve operator design and redundant operating provisions.
12. If such devices as freeze stem seals are used in valves where the stem moves axially, the valve is to back-seat in the open position such as to minimize sodium-oxide migration to and accumulation in the seal area.
13. Force-limiting devices are to be provided in the power operator to prevent damage to the valve from over-stroking. The over-riding manual operator is to provide positive closure capability.
14. Fluids that are reactive with sodium shall not be used in the valve or within the pipe galleries without double containment. Such double containment barriers shall have adequate warning instrumentation to signal any leakage through the first of the two containment barriers.

Notes - Check Valves:

15. Mechanisms, such as hinge points, should be self-flushing in the open position to preclude accumulation of oxides and subsequent binding.
16. Dash pots or other anti-slam devices are required to avoid mechanical damage to the valve or seat.
17. Reverse flow during valve closure is to be at the lowest value possible consistent with Note 16 above, to avoid thermal shock to other equipment. Leakage past the seat of the closed valve is to be minimized for the same reason.

*Numerical value will be specified when available.

TABLE 10
DESIGN REQUIREMENTS FOR FFTF MAIN HEAT TRANSFER SYSTEM
SECONDARY SODIUM SYSTEM VALVES

Design Data		Requirement
Service		1 isolation, 1 throttle – isolation (control range 30 to 100%)
Fluid		Sodium
Number per Loop		4 each
Size (in.)		10
Design Flow Rate (gpm)		3250
Design Temperature (°F)		1100
Operating Temperature Range (°F)		250 to 1100
Design Pressure (psig)		350
Normal Operating Pressure, Maximum (psig)		225
Pressure Drop at Rated Flow (psi)		1 (nominal)
Maximum Shutoff Differential Pressure (psi)		To be provided later
Across-Seat Leakage at Maximum Shutoff ΔP (% of Design Flow)		0.01
Closing Period (sec)		10
Operator Type		Electric with manual over-ride
Failure Mode		As-is
Design Service Life (yr)		20
Lifetime Full Open-Close Operations (No.)		1000
Draining Capability		Self-draining body
Geometry Constraints		Not critical
Environment External to Valve		Ambient air (0 to 120°F)
Operator Mounting		On or at valve
Design Thermal Transients:		
	Hot Leg	Cold Leg
Rate (°F/sec)	-20 for 4 sec	+4 for 65 sec then -2 for 80 sec
Amplitude (°F)	-200 in 20 sec	+260 in 65 sec then -160 in 80 sec
Lifetime cycles (No.)	10	10
Rate (°F/sec)	+9 for 6 sec	-1 for 75 sec
Amplitude (°F)	+100 in 40 sec	-120 in 180 sec
Lifetime cycles (No.)	500	500
Stem Seal Type	Part of study	
Leakage to Environs	Zero	
Radiation Level	None	

Notes: See following page.

Notes (to Table 10):

1. The valves will be located in ambient air in horizontal pipe runs.
2. The valves are accessible during plant operation; however, valve preventive maintenance must not interfere with plant operation. Preventive maintenance of the valve operator — which can either (a) be performed during reactor refueling periods or (b) be performed during, but without affecting, plant operation — is permissible.
3. A dual-purpose valve combines the isolation and flow-control functions into a single unit.
4. Manually adjusted stops are to be provided on the dual-purpose valves to permit return to a predetermined position following closure.
5. Force-limiting devices are to be provided in the power operator chain to prevent damage to the valve from over-stroking. The over-riding manual operator is to provide positive closure capability.
6. Valve design shall be such that the flow within the valve at velocities in the specified range shall not cause vibration sufficient to result in damage to, or malfunction of, the valve or other components in the system.
7. Valves shall be provided with heaters that are capable of preheating the valve at a rate of 50°F/hr to a maximum temperature of 400°F. This rate requirement does not apply to the period during which sodium is thawing. Design of the preheating system shall be such that the valve will not be damaged during the heating operation. Instrumentation shall be provided to indicate when the valves have reached a safe operating temperature, i. e., all sodium is liquid.
8. Valves shall be capable of having sodium which has been frozen in the valve melted without damage to the valve. It may be assumed that a liquid path to a sodium-free surface exists at one end (nozzle) of the valve.
9. If such devices as freeze stem seals are used in valves where the stem moves axially, the valve is to back-seat in the open position to minimize sodium-oxide migration to and accumulation in the seal area.
10. Valve internals design is to preclude the possibility of a structural or mechanical failure that can result in inadvertent partial or full-flow blockage in the valves. The design must assure that foreign materials such as broken valve pieces, part of gaskets, bolts, nuts, etc., cannot enter the flowing coolant stream.
11. Materials that are incompatible with sodium or austenitic stainless steels are not permitted in the valve.

7693-2563

Figure 7. FFTF Primary Valves Installation Schematic Diagram

In the recent literature, it has invariably been assumed that choking of a homogeneous, two-phase, single-component fluid in equilibrium occurs at local sonic conditions, as it must in steady flow of a single-phase fluid.

At LMEC, the possibility of choking at the saturation curves, where many derivatives are discontinuous, has been recognized. This alternative appears particularly important for the flashing of water. Preliminary computer exploration, using the 1967 IFC Formulation of the Thermodynamic Properties of Ordinary Water Substance, has defined a boundary between initial liquid states which lead to conventional "continuous" choking and those which lead to "discontinuous" choking during isentropic expansion. For such expansions, the maximum in mass flow per unit area (choking) has been shown to occur whenever the transition from subsonic to supersonic conditions occurs, whether that transition be continuous or discontinuous. Figures 12 and 14 of the 1967 ASME Steam Tables, for the choking velocity and the choking mass flow in equilibrium isentropic expansions, have been extended into the liquid region; and corrections to the published values for the states beyond the saturated vapor curve have been estimated. Limited analyses and calculations for other idealized adiabatic and diabatic expansions from initial liquid states have also been accomplished.

In the case of discontinuous isentropic choking, the supersonic mach number after the saturation curve has been found to decrease with further expansion, despite continued acceleration. Conditions for a minimum mach number have been derived and it has been shown that the characteristic waves of a Prandtl-Meyer expansion do not converge despite the anomalous behavior of the mach number. Programming for the calculation of the configurations of idealized two-dimensional (slit-type) jets has begun.

Analysis of the APDA wastage data, using the Efroymson multiple regression program, has failed yet to indicate convincing correlation with any of the tabulated variables or dimensionless combinations thereof. The initial water conditions, though, seem particularly interesting, since only two runs involved the continuous type of choking, and both showed unusually high wastage rates.

II. CODES AND STANDARDS

(LMFBR Program Plan 2-2.3, 3-2.2)
J. O. Nicholson

A. INTRODUCTION

The AEC Division of Reactor Development and Technology (RDT) has initiated a standards program which has the objectives of developing: (1) acceptable, specific, detailed engineering standards and quality assurance practices for application to the Commission's reactor development programs; and (2) systematic disciplined means of assuring application of the above, including the conduct of intensive and extensive engineering reviews, tests, surveillance, and inspection programs.

RDT has assigned responsibility for overall administration of the standards program to Oak Ridge National Laboratory (ORNL). LMEC has been given responsibility for drawing together proven technology and practices and developing basic engineering standards applicable to the Liquid Metal Fast Breeder Reactor (LMFBR) program. LMEC initiated work on LMFBR standards in FY 1967. The majority of standards are scheduled for completion by the end of FY 1970, with revision of standards to continue beyond that date to meet LMFBR program requirements. The LMEC standards effort is in support of LMFBR Program Plan Tasks 2-2.3 and 3-2.2.

B. LMFBR STANDARDS AND RELATED ACTIVITIES

1. Reactor Vessel

An RDT standard is being prepared for sodium-cooled reactor vessels to be used with loop-type systems. The format and general subject coverage will correspond to the RDT reactor vessel standard for water systems issued by ORNL. The standard will be based upon requirements applied for the SRE, HNPF, SEFOR, and Fermi reactor vessels, and will also include applicable requirements contained in the proposed regulation 10 CFR 51, "Pressure Vessel Criteria for Nuclear Power Facilities." This task was started in FY 1968, and a tentative standard is expected to be issued early in FY 1970.

The contract with Teledyne Materials Research was completed. A sample design specification that will satisfy the requirements of Section III of the ASME

Boiler and Pressure Vessel Code was prepared and issued as a Teledyne Technical Report, No. E-1122. General guidance, format, method of presentation, and depth of coverage are presented in this report, along with a Design Specification Check List. In addition, the allowable values of alternating stress intensity were revised such that for transients in which the metal temperature exceeds 1000°F for more than 10 min the cumulative usage factor will be reduced from 1.0 to 0.1. For transients in which the metal temperature does not exceed 1000°F for more than 10 min, the rules of Code Case 1331 will apply.

A late draft of the standard was provided for use as a guide in the preparation of a procurement package for the FFTF reactor vessel, head, and guard tank. User and vendor experience for this project will be incorporated into the standard before issuance of the tentative standard.

Major problems of this task continue to be: (1) existing reactor vessels for sodium-cooled plants were designed for operation at temperatures less than 1000°F, (2) operation of these vessels at design temperature has been limited, and (3) available water system technology is limited to 700 to 800°F. Consequently, engineering practices and technology available to establish requirements for the sodium-cooled reactor vessel standard have not been validated by long-term operation, and they may not apply to the more severe LMFBR service conditions. As near-term development programs (FFTF and Demonstration Plants) progress, solutions to these problems will be developed and incorporated into the standard.

2. Circulating Cold Trap

An RDT standard for a circulating cold trap for LMFBR and test system service is being prepared. The standard will follow a six-section format similar to that of military and other government specifications and will be based upon information contained in purchase specifications for SRE, HNPF, and Fermi cold traps, technical reports, and operating experience. Work on this standard was started in FY 1968 and has continued through this report period.

The draft cold trap standard has been revised to incorporate comments and suggestions received from the 1968 draft. Major revision effort has been focused upon a better definition of requirements and presenting more quantitative information.

Values used for past cold trap designs have been of an empirical nature and some traps of similar design have performed better than others. In all cases, trap capacity has been less than optimum, and premature plugging has occurred in many instances. Until more operating experience and development information are available, assurance cannot be given that cold traps procured to the requirements of this standard will provide optimum performance.

3. Hot Trap for Removal of Sodium Impurities

Work has started on the draft of a standard hot trap specification which will be suitable for procurement. A standard hot trap configuration is being considered which would be suitable for either oxygen removal or for carbon removal, depending upon the type of packing that is used.

Hot traps have been successful for removal of both oxygen and carbon. Oxygen hot traps, using a zirconium packing, have been used to protect zirconium moderator cans from oxidation. Carbon hot traps, using Type 304 stainless-steel packing, have been used to control carbon impurities in sodium.

Although some experience has been obtained in the performance of carbon hot traps, further work must be done to determine all of the factors affecting carbon transport in an LMFBR system.

4. Sodium Tanks

An RDT standard is planned to be prepared for sodium tanks used for storage, drain and fill, surge, and primary heat exchanger blowdown service. Preliminary work has begun.

Tank design, fabrication, and qualification will be governed by the ASME Boiler and Pressure Vessel Code, Section III, for the primary coolant system, and Section VIII for the secondary coolant system. However, consideration will be given in the standard to improving the adequacy of the hydrostatic test specified in the Code in representing probable thermal gradients experienced during normal and transient operation.

Progressive tank preheating, from the sodium-surface downward, will be investigated to reduce stress concentrations during expansion of the sodium.

5. Centrifugal Free-Surface Sodium Pumps

Large mechanical free-surface sodium pumps of the size required for LMFBF programs are not available. Although many of the techniques developed for the design of centrifugal pumps used in the chemical industry may be used in the design of large sodium pumps, the effect of the higher-temperature liquid sodium presents special problems which must be considered. Design problems with sodium pumps stem principally from the use of high-temperature sodium circulating through bearings and from metal fatigue and creep.

The standard for the centrifugal free-surface sodium pumps has undergone considerable internal revision in the last 6 months, both as to its technical content and method of presentation.

The standard is intended to supplement the ASME Code for Pumps and Valves for Nuclear Power. Therefore, details of technical design, such as minimum dimensions, web thicknesses, radii of fillets, and welding procedures, are excluded. Tables of allowable stress appearing in the Pump Code replace all quantitative stress statements in the previous draft of the standard. A study at LMEC of pump stresses is being conducted in parallel with the preparation of the pump standard, and will provide guidance in the design of sodium pumps. The ASME Code establishes three classes of pumps for nuclear service, designated as Classes I, II, and III in descending order of quality. The standard being prepared by LMEC covers pumps of Classes I and II only.

In the initial LMEC effort on pump standards, it was thought that there was merit in preparing at least two pump standards, one for a 100- to-15,000-gpm capacity, and another for 15,000- to-120,000-gpm capacity. However, it became evident that the technical content of both types would be essentially the same. As a result, only one pump standard, covering both ranges, is now in progress.

Certain design and performance requirements in the present draft of the standard have increased in number. The operational environment requirements have also increased to include transient, cyclical, and abnormal situations. In contrast, the detailed requirements for the design of the pump drive have been eliminated, which included the electric motor and the associated reduction gear drive. It is expected that standards for these two components will be written sometime in the future. To provide criteria in the selection of materials, a

rather detailed table of materials in several temperature ranges, covering specific shapes and forms of fabrication, such as plate, strip, and castings, has been added.

6. Electromagnetic Pumps

No effort has been spent on this standard during this report period.

7. Instrumentation

Five groups of instrumentation standards, covering liquid sodium level, flow, pressure, temperature, and impurities measurement, are to be prepared by the current LMFBR standards effort. These standards will cover only the sensor or transducer portion of the instrumentation system. The standards, based on the current state-of-the-art and past operating experience, are needed to assist instrumentation engineers in the procurement of instruments for use in LMFBR and related test facilities.

Instrumentation standards will be prepared in groups. Each group will contain one or more individual standards to accomplish a particular measurement. The individual standard will be for a specific type of sensor or measurement device. Since each standard is to be a part of the procurement package, the concept of a general standard for each grouping was abandoned in favor of individual standards for each type of measurement within its particular group. Consequently, each instrumentation sensor standard will contain both general and specific requirements.

During this report period, the draft of two standards, "Inductive Liquid Metal Level Measurement," and "In-Core Permanent Magnet Flowmeter," were completed and transmitted to ORNL, RDT, and LMFBR contractors for review and comment. Preliminary drafts of standards for "Resistive Liquid Level Measurement," and "High Temperature Fission Counter-Chamber," were completed and distributed within LMEC for review and comment.

The maximum operating temperature of the in-core permanent magnet flowmeter was specified in the standard as 1200°F instead of 1400°F. The decision to limit the temperature to the lower value was based on present availability of suitable magnetic material. Magnetic materials, such as Alnico VI and VIII, have a curie point which will allow long-term operation at 1000°F

and shorter times at 1200°F. Satisfactory performance at 1400°F, however, has not been attained by these materials.

Review of existing RDT and ASTM standards was initiated during this report period to determine the modifications or additions required to make these documents suitable for the special purpose applications required by the instrumentation task. As a result of the review, it became apparent that the existing RDT material and plant standards are aimed at structural applications and are not suitable for instrument applications, per se.

8. Sodium-To-Air Heat Exchanger

Removal of waste heat from a sodium-filled test system or an LMFBR system requires heat-exchanging components which will efficiently and safely reject unwanted heat energy. Requirements for such a heat exchanger are being investigated which will result in the publication of an RDT standard for a forced-air-cooled heat exchanger. Such a unit would be used as the principal component in the primary heat rejection system for a nuclear reactor system such as the FFTF or SEFOR, where a steam generator is not required, or where the unit would be used as an emergency standby unit in case of failure of the plant's steam generator.

Criteria for design of the sodium-to-air heat exchanger is based on Section III, Class A, of the ASME Code, even though the code stamp to be affixed to the unit may be for a less restrictive code class. Additional necessary requirements not covered in the code will be included, as for example, criteria for fin attachment to tubing if fin tubing is to be used in the tube bundle. All materials, fabrication techniques, and nondestructive testing methods for sodium containment parts will make use of the appropriate RDT standards. Special requirements such as preheating the tube bundle, incorporating an air exhaust stack, and providing insulation protection for the plenum walls, will be covered in detail. The structural support members, fan drive, and transmission components will be purchased or fabricated in accordance with standard commercial practices. All sodium containment seals will be specified as crevice-free welded joints including tube-to-tube sheet attachments which are normally rolled joints in commercial applications.

The first draft of the sodium-to-air heat exchanger standard was circulated for review in July 1968. Comments were received from ORNL, PNL, and BNW and are being incorporated in the latest revision to the standard which is in work at the present time. In order to support the immediate needs of FFTF, the revised draft is planned to be issued in July 1969, and will be included in the FFTF heat-dump bid package. As experience is gained in the application of the standard, and operation of equipment purchased, the standard will be updated accordingly to reflect state-of-the-art technology.

Technical requirements unique to sodium application included in the draft standard are as follows:

- 1) The tube bundle shall be designed to accommodate individual tube oxide plugging and freezing without damage to the sodium containment parts or structure.
- 2) Recommendation that forced-air cooling be used rather than induced air flow
- 3) Exhaust air stacks shall be employed.
- 4) The heat exchanger preheating capability shall be designed to achieve a 600°F minimum temperature to melt possible sodium oxide plugs in tubing.
- 5) Bellows joints shall be prohibited.
- 6) Brazed joints shall be avoided at sodium-wetted surfaces.

Further criteria for the sodium-to-air heat exchanger should consider design requirements for tube spacing and tube support since very little information is available on these subjects in existing codes and standards. Creep and high-temperature fatigue requirements will not be included in the LMEC-prepared standard at this time as sufficient information has not been evaluated to permit standardization of design at elevated temperatures. Similarly, the tube and tube bundle vibration phenomena is not sufficiently understood to specify with any degree of confidence design criteria in this area.

9. Sodium Piping

The effort on the sodium piping standards began in FY 1968 with the preparation of a detailed plan and schedule. This was followed by a preliminary

investigation of LMFBR piping requirements and by the review and evaluation of existing codes and standards for meeting these requirements. The results of these efforts indicated a need for coverage beyond that provided in existing documents. A detailed review of ASME draft USAS B31.7, "Nuclear Power Piping," dated February 1968, was completed. In many instances the requirements of B31.7 are inadequate for sodium systems. Particular deficiencies are those related to sodium technology and to elevated temperature service.

Preparation of the sodium piping design requirements standard was started in FY 1969 and continued through this report period. Chapter 1-II of USAS B31.7 is being used as a model for content and format. The standard will include:

- 1) Requirements for sodium piping, omitting those applicable to other piping
- 2) High-temperature requirements on the basis of the pending High-Temperature Code Case.

The standard will require more complete definition of design conditions with detailed and rigorous design analysis. It will permit the simplified approaches as given in USAS B31.7 only for the less severe services and conditions. While it is anticipated that these requirements will demand a substantial increase in computation over that required for present codes, the extra effort is considered essential for safe and reliable LMFBR systems.

During this report period, effort for the sodium piping design standard centered on the sections for Conditions and Criteria, Design Analysis, Pipe Supports, and an extended Systems section. It was decided to require Class I quality, as defined in B31.7, for LMFBR nonradioactive secondary systems as well as for the radioactive primary systems. This decision was based upon the stringent operating conditions of the secondary systems and the possible consequences should a failure result.

In support of FFTF procurement, a piping system procurement standard is being prepared. This standard will cover only the main heat transport piping systems. Separate standards for other system piping is planned.

10. Sodium Valves

Many types of valves have performed satisfactorily in high-temperature sodium systems. They have been used generally in the 500 to 1000°F temperature range and subjected only to moderate thermal shock. Most of the valves were configurations designed originally for use in conventional water, oil, or gas systems and converted or redesigned for use in sodium. The majority of the valves were between 2 and 6 in. in size, with a few ranging up to 16 in. There is no experience with sodium valves larger than 16 in.

To achieve the quality of valves needed for the development of LMFBR systems, valve suppliers and developers must be aware of existing sodium valve technology and have guidance in its application. The standard, "Sodium Isolation Valves," is being written for this purpose.

Work was begun in FY 1968 on the scope and plan of action for valve standards in general, and on the isolation standard (the first of five). The scope and plan of action was distributed to LMEC, PNL-FFTF, and RDT. A draft of the isolation valve standard was completed early in FY 1969 and has received extensive review, including a review performed by Nuclear Associates International (NAI) under contract with LMEC.

During this report period a revised draft of the standard for sodium isolation valves has been completed. Phase II, involving detailed technical analysis of sodium service valve criteria and application by NAI of Rockville, Maryland, has been completed. Peripheral problems concerned with the formulation of the sodium valve standard are in the areas of proprietary rights of the valve supplier, and his degree of discretion in the application of stringent standard requirements.

The design analysis requirements of the standard were revised to reflect Section III of the ASME Boiler and Pressure Vessel Code, and Code Case 1331, rather than Appendix F of the Code for Pumps and Valves. The present revision recognizes the basically different system design requirements imposed for valves operating at 1200°F for 24 yr with 300 cycles of heating and cooling, and 1000 opening and closing operations, as opposed to more conventional valve design and application. In this connection, the AEC "Failure Data Handbook," being

prepared by LMEC, should contribute immeasurably as a source of empirical data for upgrading the valve standard, and thus enabling designers to improve valve reliability through its use.

The quality assurance section of the standard was revised to comply with, and augment, the requirements of RDT standard F 2-2, "Quality Assurance Program Requirements." Two methods of qualification for service in sodium have been suggested and are being defined in the standard, either of which may be used depending upon the performance requirements of the valve in a specific application. Until valve technology is further developed for sodium application, a degree of flexibility must be maintained in the selection of the type of qualification required. One method of qualifying the design and manufacture of a valve is by prototype testing, the other method by service experience. The latter method is acceptable only as an interim method until prototype valves have been qualified for a specific application, recognizing the fact that prototype testing may require considerable time and, therefore, is not feasible in some instances.

11. Sodium Quality

The reactor grade sodium standard for use in LMFBR service has been extensively revised based on comments received from RDT, ORNL, and BNW. The impurities allowed in reactor grade sodium have been limited to those materials which may cause corrosion or act as neutron poisons in the fast breeder reactor. The revised standard is consistent with sodium that is available commercially.

Analytical procedures have been removed from the standard to permit the purchaser to utilize acceptable analytical techniques consistent with the equipment available. Where different analytical procedures are acceptable, the purchaser may select those procedures best suited to his capabilities.

Distribution of a tentative RDT Standard for "Reactor Grade Sodium" for general usage is expected early in FY 1970.

12. Cover Gas for Reactor Grade Sodium

The cover gas draft standard issued in 1967 has been revised consistent with suggestions from RDT, ORNL, and BNW. The cover gas purity requirements have been established at a high level to prevent continuing degradation of

sodium quality. The purity requirements specified are available commercially as a compressed gas or as a cryogenic liquid.

Analytical procedures have been purposely removed from the standard, permitting the seller and purchaser latitude in the determination of techniques which are most suitable for the individual application.

A tentative RDT Standard for "Cover Gas for Reactor Grade Sodium" is expected to be released for general usage early in FY 1970.

C. COORDINATION OF LMEC STANDARDS EFFORT WITH ORNL STANDARDS ACTIVITIES

1. Materials

Standards are being prepared for structural materials, special-purpose metallic materials, and miscellaneous nonmetallic materials.

The LMFBR Program Plan^{*} points out that the problems of design and construction for long-term service (up to 30 yr) at high temperatures in sodium and a fast-neutron flux are poorly known. In addition to this, experience has shown that many of the failures encountered in sodium-cooled reactors originated outside the core, which clearly indicates that more attention must be given to materials that make up the supporting systems.

The objective of this work at LMEC is the identification and development of material standards for the near-term LMFBR projects - SCTL, SCTI, SPTF, and FFTF. Application of the standards to these projects will provide a basis for formulating and validating standards to meet long-term service requirements.

To promote the application of RDT material standards by these test facilities and thereby provide early user input to the standards program, high priority is initially being given to the development of sodium system structural material standards. The structural materials of major interest are: (1) the austenitic stainless steels, (2) low-alloy steels, and (3) possibly high-nickel alloys such as Incoloy 800 and Inconel 625.

^{*}WASH-1107 (TID-4500, UC80), "LMFBR Fuels and Materials," prepared by Division of Reactor Development and Technology by LMFBR Program Office, Argonne National Laboratory, August 1968

RDT material standards that have been issued by ORNL are generally based on ASTM specifications, with revisions for water system applications. LMEC has reviewed these standards and found that in many cases the materials covered will serve the LMFBR program as well. However, certain additional requirements and modifications, with the inclusion of additional materials, are needed to meet the estimated sodium system structural material needs of an LMFBR program.

a. Structural Materials

A group of 34 RDT standards were identified for use in the RDT bid package for the FFTF reactor vessel. From this group, 19 standards were for various fabricated forms of structural materials. The technical requirements of these standards were reviewed in detail by RDT, ORNL, and LMEC representatives before issuance as tentatives.

Several changes were made to previously developed drafts of these standards. For weld repair of forgings and casting, the RDT Standard RDT F 6-1 T, "Welding," was referenced rather than applicable paragraphs of Section III of the ASME Boiler and Pressure Vessel Code. For liquid penetrant and magnetic particle examinations, RDT F 3-6 T, "Nondestructive Examination," was also referenced rather than Section III of the ASME Code. For defect levels in materials, the level requirement is given in the material standard and reference is given to the appropriate RDT standard on ultrasonic testing for acceptable processes. Impact properties of ASTM A-316 electrodes, E 8016-C3 and E 8018-C3, are to be measured in the stress-relieved condition. On hydrostatic testing of pipe, testing will be done for 2 min rather than 30 sec to allow the inspector more time for observation of the test piece. Cleaning and packaging requirements were added to the materials standards providing procedures to the purchaser. Other requirements relating to chemical composition, ladle and check analysis, heat treatment, mechanical tests, retests, cleanliness, inspection, quality assurance, corrosion tests, basis of purchase, and workmanship and finish were detailed on an individual basis within the material standards.

LMEC internal review was initiated on draft standards for the structural materials of nickel-iron-chromium and nickel-chromium-iron. The standards include plate, sheet, strip, forging, tubes, and pipe. These product forms of the materials have potential applications in LMFBR steam generators.

RDT material standards are being evaluated with respect to requirements of the ASME Pump and Valve Code and USASI B31.7, Nuclear Piping. This evaluation may result in a change in the format of presentation, with separation within the materials standards to meet any varying requirements of the major codes.

b. Special Purpose Metallic Materials

This category of standards includes such items as brazing alloys, facing materials, spring and bearing materials, and other specialized materials. In many instances, these standards either do not have an ASTM equivalent standard or lack sufficient basis within the ASTM standard to develop an RDT standard. The format of presentation in these instances is different from those standards that modify ASTM standards.

The following two standards were issued as tentatives for the FFTF reactor vessel bid package:

- 1) RDT M 6-2 T, "Mechanical Locking Devices"
- 2) RDT M 9-2, "Examination Requirements and Acceptance Standards for Seal Membranes."

A group of 17 materials were identified that require RDT standards for applications in equipment standards for pumps and valves, instrumentation devices, and precision mechanisms operating in sodium. Work on these standards will commence in the next report period.

c. Miscellaneous Nonmetallic Materials

This category includes materials such as thermal insulation, high-temperature radiation-resistant electrical insulation, elastomers, and concrete. A group of eight ceramic electrical insulating materials were identified for development into RDT standards as part of the instrumentation standards program. Effort on developing standards for these materials is expected to begin during the next report period.

Thermal insulation standards preparation has been initiated for material which is composed principally of calcium silicate and which has been used for thermal insulation at temperatures of 1200°F. Review of the literature on testing of this material under anticipated environmental conditions is continuing. Of

major concern is the possible leaching of halides and other substances on to the surfaces of 300 series stainless steel, and the subsequent corrosion of the stainless steel under operating environments. The leachable substances have at least two sources: (1) the insulation materials themselves contain chlorides on the order of 5 to 200 ppm and (2) moisture from external sources, e. g., rain, condensation from the equipment dripping on the insulation, and water used in the cement during insulation installation. Insulation standards for thermal non-conductive insulation will place emphasis on limiting the amount of halides present in the insulation material, and stipulate care in the packaging, storage, handling, and installation of the insulation prior to use, to preclude as much as possible the introduction of destructive trace compounds.

2. Process Standards

a. Welding

During this report period, a meeting attended by personnel from RDT-HQ, ORNL, and LMEC was held to determine the applicability of the welding standard, RDT-S-902, for the procurement of the FFTF reactor vessel. As a result, a new Appendix E was prepared to cover weld repair of materials. A revised edition of the welding standard was issued by ORNL under the number RDT F 6-1 T.

b. Weld Examination and Nondestructive Examination

Tentative standard RDT F 3-6 T, "Nondestructive Examination," was issued by ORNL during this report period. This standard combines the requirements contained in two previously issued standards — RDT-S-908, "Nondestructive Test Methods," and RDT-S-934, "Weld Examination." Revision of this standard was closely coordinated between ORNL and LMEC.

Four ultrasonic examination standards were reviewed by LMEC prior to ORNL issuance as tentative RDT standards. These standards include the changes required for application to the procurement of the FFTF reactor vessel. The standards are:

- 1) RDT F 3-1 T, "Ultrasonic Examination of Heavy Steel Forgings"
- 2) RDT F 3-4 T, "Ultrasonic Shear-Wave Examination of Plates"

3) RDT F 3-5 T, "Longitudinal Wave Ultrasonic Examination of Plain and Clad Plates"

4) RDT F 3-8 T, "Ultrasonic Examination of Metal Pipe and Tubing for Longitudinal Discontinuities."

c. Cleaning and Decontamination

These standards prescribe the cleanliness requirements for systems and components of the LMFBF program's reactors and test facilities and the general cleaning and decontamination procedures and processes for attaining these requirements. The standards cover systems and components which comprise the coolant system and those systems, equipment, and structures closely associated with the coolant system.

Inadequate or improper cleaning and decontamination methods in some instances in the past have been reported to have caused or contributed to serious problems in operating plants. A major objective of the standards effort is to prevent the future occurrence of such incidents.

LMEC participated with ORNL and RDT representatives in preparation of the standard on cleaning, RDT F 5-1 T, "Cleaning and Cleanliness Requirements for Nuclear Reactor Components." This document contains cleaning requirements given in earlier drafts of RDT S-913 and RDT S-973. RDT F 5-1 T supersedes both of these documents. This standard is intended for application to water and liquid metal reactor components. Technical requirements pertinent to cleaning components for liquid metal service were incorporated into the standard. The standard was issued as approved in March 1969 for use in the FFTF reactor vessel bid package. At the request of RDT, ORNL and LMEC are evaluating the requirement which prohibits halogenated cleaning agents and solvents from use with austenitic stainless steels. The evaluation includes the technical requirements related to avoidance of stress-corrosion effects and proven industry cleaning practices.

Facilities at Rocketdyne, a Division of North American Rockwell Corporation, were visited to evaluate clean rooms and clean areas used for cleanliness control. Sufficient information was obtained on cleanliness control to be used as a basis for preparation of a standard on this subject.

Comments were collected within LMEC on the first draft of an RDT standard for Cleaning Components Contaminated with Sodium. It is expected that a draft standard will be forwarded to RDT for approval during the next report period.

d. Other Plant Standards

Several other plant standards were reviewed and commented upon prior to their issuance under the new numbering system. These were:

- 1) RDT F 7-2 T, "Preparations for Sealing, Packaging, Packing and Marking of Components for Shipment and Storage"
- 2) RDT M 9-2 T, "Examination Requirements and Acceptance Standards for Seal Membranes"
- 3) RDT M 6-2 T, "Mechanical Locking Devices"
- 4) RDT F 8-1 T, "Preloading Threaded Fasteners and Closures."

The packaging standard, RDT F 7-2 T, was reviewed by RDT, LMEC, and ORNL personnel for use in the FFTF reactor bid package.

III. MAINTENANCE AND MALFUNCTION ANALYSES

(LMFBR Program Plan 3-2.4)

C. W. Griffin

A. INTRODUCTION

The purpose of the program is to develop a plan for collecting and applying operations, maintenance, and failure data from all LMFBR facilities; to maintain an up-to-date history of the sodium and other special components of each operating facility or rig; to evaluate, organize, and disseminate data with the objective of upgrading the reliability/availability of these facilities; and to utilize the data accumulated for the development of adequate standards and specifications.

B. INFORMATION AND QUESTIONNAIRE BROCHURE

A brochure* was prepared as an information document to the U.S. nuclear industry participants with respect to the potential for improved nuclear reactor reliability and safety through participation in a common failure reporting system. The fundamental theme of the brochure is, "What Can It Do For You?" The ultimate question to the industry is, "to what extent are you willing to participate?"

LMEC's existing system and its cumulative short- and long-range objectives are shown typically in the brochure as in Figures 8 and 9, respectively. Reporting methods, options, and applications are also discussed.

Response from industry to date is generally noncommittal but evidences interest.

C. INCIDENT, MALFUNCTION, AND PROBLEM REPORT (IMPR)

1. LMEC Procedure II-5 Revision

Changes to LMEC Procedure II-5, "Incident, Malfunction, and Problem Report," were made to afford clearer guidelines to separation of incidents from major malfunctions occurring at LMEC facilities. In addition to the RDT

*"Failure and Problem Reporting for Nuclear Reactors," LMEC-Memo-69-6 (May 1969)

7603-2564

Figure 8. Maintenance and Malfunction Analysis Program Evaluation Sequence

Figure 9. Progression of Quality with Timeliness for Collective Disciplines

examples, some specific ground rules were defined to afford the operator an easier method of differentiation between "incidents" and "malfunctions."

The format now incorporates a block next to the identification portion for differentiating between initial, interim, and final reports, which gives the preparer an opportunity to state the date of this report. In preparing reports, sequential additions to earlier efforts are identified as new information by making a straight mark or bar in the margin of the report over the range of the new information.

The vice chairman of the Facilities Review Committee schedules a regular meeting of this committee for the third Thursday of each month, and IMPR's for the month are reviewed at this time. Ad hoc subcommittees can be selected from the committee and other disciplines by the vice chairman at his discretion in the event that additional studies are required.

Incident reports and major malfunction reports must be prepared and released to AEC-SAN within 72 hr; minor malfunctions must be prepared within 10 days, and problems would have no stipulated time period. Initial documents are hand-written and released as such. The only approval signature required on the IMPR is that of the operations supervisor; but before release, the project engineer is required to initial the project cognizant block to indicate that he had been informed of the contents of the document. This initialing function may be delegated by the project engineer. Operations supervision is required to initiate the final report in the operations cognizant block similar to that of the project in the initial report.

Publication of the revised procedure will follow RDT review.

2. IMPR Summary

<u>Facility</u>		<u>Number Processed</u>	<u>Number Final Closeout</u>
SCTI	32	{ 8 incidents 8 major malfunctions 16 minor malfunctions	27
LCTL	9	{ 4 incidents 3 major malfunctions 2 minor malfunctions	3

3. Significant Events

a. LCTL Sodium Loop Piping Defect

In response to recommendations of the Facilities Review Committee concerning the corrosion cracks and pits discovered during routine inspection on the 3-in. sodium loop of the LCTL facility, an intensive thermal insulation analysis was made. The insulation was removed from the loop drain line and leached with water to determine the pH and analyze for impurity content of the resultant solutions. Results showed that the leach water was mildly alkaline, and the alkalinity and the amount of leachable impurities in solution decreases to the extent that the insulation was exposed to weathering.

A series of emission spectrographic analyses were performed on various sections of pipe to verify compositions. These confirmed that the pipe sections which exhibit intergranular corrosion are Type 304 stainless steel. A section of corroded heat reflector was also identified as Type 304. Continued metal-lurgical examinations identified intergranular attack as the source of the dye penetrations found on a third pipe section — 3-in.-diameter stub (west) off main loop. Evidence of slight carburization was detected on the inside surface of a 3-in.-diameter pipe section. Microhardness measurements confirmed that it was of limited extent; where the difference between core hardness ($86.5 R_p$) and surface hardness ($88.5 R_p$) is considered inconsequential.

This evaluation of the 3-in. loop pipe condition resulted in a plan for additional operation of the loop to determine whether an early failure would occur.

b. SCTI Electrical Circuit Breaker Failures

Several automatic plant shutdowns were triggered by the opening of the main circuit breaker on the 480-volt emergency bus. During the installation of a newly serviced and tested circuit breaker, it was found that one of the phase connections was hot to the touch. Further investigation revealed that a bolted connection on the bus bar was not tight. The arrangement of the bus bars was such that the circuit breaker had to be removed before the bolted connections could be checked and/or tightened. An additional check was made to verify that all bus connections were tight, and no recent difficulties with the circuit breaker have been encountered.

c. SCTI Sodium Pump Bearing Failures

Two primary sodium pump bearing failures were experienced and an extensive bearing failure analysis was conducted locally and by representatives from Byron Jackson Co. The principal cause was assigned by Byron Jackson to excessive preloading of the bearings and possible misalignment. Neither of these conditions should exist in the latest assembly of the pump because assembly prints were made available by the vendor and every critical dimension was met during installation.

d. SCTI Steam Generator Tube Failure

The chromatograph hydrogen detector indicated excessive hydrogen in the cover gas over the sodium in the steam generator, symbolizing a tube failure. Investigation of the apparent leak was initiated. Detailed observations indicated both tube sheets to be in excellent condition and free of any significant deposits, including those of any Na - H₂O reaction. Helium leak checks were performed which established that a leak exists within one tube. An axial traverse of the defective tube was conducted, and it appears that the leakage point exists approximately 19 ft below the top surface of the upper tube sheet.

D. FAILURE DATA HANDBOOK*

Volume II is presently being distributed. Volume I will follow as soon as editing and printing are complete. This is scheduled for the end of July 1969.

Volume I contains brief tabular summaries and recommendations on recorded events occurring at AEC-operated sodium facilities prior to 1967 with some reference to later events. This information is gleaned from records and published documents and, as a result, is not considered absolutely complete in either description or conclusion, but is informative. Reliability and maintainability concepts, methods, and applications are briefly discussed with indications of future developments with particular concern for mechanical components of nuclear energy conversion systems.

*"Failure Data Handbook for Nuclear Power Facilities; Volume I, Failure Data and Applications Technology; Volume II, Failure Category Identification and Glossary, " LMEC-Memo-69-7 (Vol I, to be published; Vol II, June 20, 1969)

Volume II is a detailed description of component, system, and failure categories identification systems for computer applications, and includes an extensive glossary of terms applicable to the information and data presented.

E. BAYESIAN STATISTICAL MODEL THEORY FOR MECHANICAL SYSTEMS

The preliminary study was completed which investigated the potential for, and methods of, applying Bayesian statistical theory to the development of a method for the optimal fitting of general test or stress/strain distribution curves based on experimental data. A formal topical report (LMEC-69-8) was published. This technique makes it possible to use a minimal number of measurements to develop reasonable confidence with respect to the true characteristics of the results and the predictability of subsequent results.

IV. QUALITY ASSURANCE

(LMFBR Program Plan 3-2.3)

G. A. Beer

A. INTRODUCTION

The LMEC Quality Assurance (QA) Unit has the following two fundamental responsibilities:

- 1) To assure quality of LMEC programs and test facilities consistent with RDT QA direction
- 2) To provide assistance to other organizations, associated with the LMFBR program, in development of their QA programs per RDT QA policy.

B. LMEC QA PROGRAM

In the development and implementation of the QA program for the LMEC, 18 QA procedures have been released, 11 of which were completed this report period. Eleven LMEC procedures, providing part of the QA program direction, have been incorporated in Section II of the QA Manual. Three quality control instructions have been incorporated in Section III of the manual to provide detailed instructions on specific applications. The procedures and instructions presently incorporated in the manual are listed in the following:

1) Section I - Quality Assurance Procedures:

QA-I-1, Rev A	Quality Program Plans
QA-I-2, Rev A	Quality Records and Documentation
QA-I-3	Quality Audit
QA-I-4, Rev A	Acceptance of LMEC Procured Material
QA-I-5	Material Control
QA-I-6	Process Control
QA-I-7	Process and Personnel Qualification
QA-I-8	Nondestructive Testing
QA-I-9	Inspection and Test

QA-I-10	Government Inspection
QA-I-12	Quality Control Instructions
QA-I-14	Specific Audit Procedures
QA-I-15	Inspection Planning
QA-I-16	Request for Support
QA-I-17, Rev A	Purchase Document Review
QA-I-18	Supplier Quality Evaluation
QA-I-19	Document and Configuration Control
QA-I-20	Quality Assurance Participation in Engineering Document Review

2) Section II - Quality Related LMEC Procedures:

LMEC-I-1	LMEC Functional Description
LMEC-II-1	Program for Assurance of Quality
LMEC-II-2	Calibration of Measuring Instruments and Test Equipment
LMEC-II-4	Use of RDT Standards and Other Codes and Standards by LMEC
LMEC-II-5	Incident, Malfunction and Problem Report
LMEC-II-6	Work Authorization and Performance Policy
LMEC-III-1	Preparation and Control of LMEC Procedures
LMEC-III-2	Preparation and Control of Procurement Specifications
LMEC-IV-1	Weld Filler Material Control
LMEC-IV-2	Nonconformance Control and Corrective Action
LMEC-V-6-1	Quality Provisions in Purchase Documents (Interim)

3) Section III - Quality Control Instructions:

QCI-101	Quality Control Instructions for Activities Prior to Proof Pressure Testing of Piping Systems
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QCI-103

Quality Control Instructions for Pressure
Vessels and Tanks

QAI-104

Quality Control Instructions for LMEC
Procured Valve Inspection

As part of the implementation of material receiving, inspection, and control, the LMEC warehouse was reviewed for component/material status. All items, previously received before establishment of LMEC QA procedures and standards, that were determined to be unacceptable for use were suitably tagged in accordance with LMEC Procedure IV-2, "Nonconformance Control and Corrective Action." Coordination with warehouse personnel provided segregation of unacceptable items, thereby preventing erroneous issue.

C. FT. ST. VRAIN STEAM GENERATORS

A plan of action was prepared for the inspection review of steam generators fabricated for the Ft. St. Vrain Gas-Cooled Reactor Plant [Contract AI(04-3)-633]. This plan of action was prepared after meetings with RDT site office personnel and GGA personnel at LaJolla, California. All necessary preparations for the initial visit (July 21 to August 22, 1969) to the manufacturer's plant have been completed.

D. QA APPLIED TO SODIUM COMPONENTS TEST INSTALLATION (SCTI)

Quality assurance was applied to two modifications to the SCTI. These were the steam and feedwater improvement and the demineralizer installation, Phase A. In both cases, the design was performed by Atomics International, with the construction being done by outside contractors. LMEC QA reviewed the design effort and construction specifications and established the QA requirements for construction. The construction contractors were required to have an effective inspection system. LMEC QA approved the contractors' quality plans and audited their activities to assure compliance to these plans. One of the contractors found it to his benefit to subcontract a professional inspection service to meet the quality requirements.

The quality files of both contracts were compiled at the completion of the jobs, verified to be complete and adequate by the Quality Verification section, and filed in the QA files.

The SCTI quality designee is presently establishing, with project management, an operation and maintenance system consistent with the requirements of the RDT Standard F 2-2 T, "QA Program Requirements."

QA is also supporting the project in revamping its material storage activities to be consistent with LMEC policy. The major change is in the area of material identification, inspection, and release for use.

The QA designee was an integral part of the primary sodium pump re-assembly procedure team that established the exact buildup and checkout operation following failure of the pump's bearing in early June.

A QA representative is presently serving on the steam generator failure evaluation committee following the steam generator tube failure. Quality verification personnel have also been inspecting the open ends of the steam generator to establish any difference in the tube sheets and heads from the last inspection of these areas.

A QA representative was a member of the board which selected the A-E who is to design a major upgrading of the SCTI feed and steam system. The QA program requirements of the newly issued RDT Standard F 2-2 T are being applied to this contract.

LMEC QA conducted two audits of the data acquisition system (DAS) vendor. Continual monitoring of the vendor's activities was accomplished by arrangements set up with the local DCAS representative.

E. QA APPLIED TO SODIUM PUMP TEST FACILITY (SPTF)

The QA designee has established, with LMEC project management and the A-E QA manager, the QA documentation required to be completed during Title I and to be used during Title II. This list is tailored to satisfy QA requirements during the design effort. These procedures will be monitored and audited by LMEC QA during the Title II effort. A similar evaluation and approval of expected Title II QA documents will be required prior to termination of Title II and start of construction.

The A-E gave a formal presentation of their quality assurance program to be applied during Titles I and II activities. This presentation was to answer

LMEC questions regarding the adequacy of A-E QA coverage during design. LMEC is presently resolving comments to this presentation.

The LMEC QA plan for SPTF was established and made part of the SPTF Procedures Manual which has been distributed for RDT, as well as internal LMEC, review and comment. This LMEC QA plan was based on the requirements of Section 2 (Management and Planning) of RDT Standard F 2-2 T and the LMEC QA program as defined in the LMEC QA Manual.

F. QA APPLIED TO LARGE COMPONENT TEST LOOP (LCTL)

The QA designee was a member of the board which selected the design contractor for LCTL modification to SCTL (Small Component Test Loop).

During examination of the loop prior to operation, some of the original piping showed areas of extensive pitting and some cracking. These areas were documented by photographs and liquid penetrant on sensitized tape. Metallographic examinations were also made indicating intergranular corrosion. A plan of action to run hot for 400 hr and then to re-examine the piping was established to determine the loop's capability for the upcoming test plan. After approximately 160 hr, problems with the sodium pumps caused the loop to be shut down. It was decided that sufficient time was accumulated to again re-examine the piping. Following removal of the insulation, what appeared to be a sodium leak immediately adjacent to one of the "test" areas was observed. This section has been removed from the loop for detailed inspection.

The pump failure to meet flow requirements resulted from a fabrication problem where the braze connecting the pump tube coils had cracked and in some cases pulled away from the coil. The coil was sent out for repair and a new braze procedure was established. The repair process is being monitored by QA at the vendor's facility.

G. QA APPLIED TO HNPF PUMP TEST LOOP (HPTL)

A program was established for examining the HPTL for possible use as a bearing test facility. A plan of action was established by the quality designee and agreed to by the project engineer. This involved nondestructive testing and metallographic examination of the existing loop piping. Preliminary results

indicated that a major expense would be involved in bringing the piping (the piping welds in particular) up to present minimum requirements for sodium loops. As a result, the project has recommended replacement of the loop piping if it is to be used as a bearing test facility.

H. LMEC ACTIVITIES RELATIVE TO THE LMFBR PROGRAM

LMEC maintains an active role in the RDT Ad Hoc QA Steering Committee which reviews and comments on QA standards being developed for RDT. As a member of this committee, the Standard RDT F 2-2, "QA Program Requirements," was reviewed and comments were submitted. Subsequent to the last QA Steering Committee meeting, RDT has approved the standard and preliminary copies are being used by LMEC as requirements for in-house and purchased QA systems.

The QA Unit Supervisor attended a meeting at RDT to review and discuss nuclear power plant quality assurance criteria prepared by Regulatory Division. This criteria was subsequently published in the Federal Register and will serve as QA requirements for nuclear projects requiring construction permits.

Draft No. 2 of BNW/FFTF QA Program Plan was reviewed and comments were prepared. The unit supervisor visited PNL to discuss comments on the plan. A copy of these comments was forwarded to RDT.

V. OPERATION OF SODIUM COMPONENTS TEST INSTALLATION (SCTI)

(LMFBR Program Plan 3-5.1, 3-6.1, 3-6.5, 3-12.4)
W. S. DeBear

A. INTRODUCTION

The primary objective of this project is to provide and operate a test facility for testing advanced prototype sodium-heated steam generators under simulated LMFBR operating conditions.

B. MAIN STEAM LINE REPAIR

Reconstruction of the main steam line was completed early in the report period. To complete construction, the following activities were successfully concluded:

- 1) All field welding was completed with a total of 62 major joints stress-relieved and 141 joints radiographed
- 2) All new steam piping was flushed to remove any residual contamination from construction work
- 3) A series of hydrostatic tests were performed to satisfy all applicable code requirements
- 4) New thermal insulation was applied to all new piping, and insulation patchwork was performed as required on other segments of the system.

C. PLANT CHECKOUT AND OPERATION

The primary sodium system was refilled on January 12, 1969, and circulation was reestablished. A special test procedure was performed with the primary system to complete recalibration of sodium pressure instrumentation. During this test, the upper gas seal on the primary pump shaft began to leak oil; subsequently, the loop was drained, the shaft seal was replaced, and a new set of bearings was installed as a routine maintenance activity. Inspection of the old seal indicated only normal wear after an 8,530-hr operation. The bearings appeared to be in satisfactory condition. The loop was then refilled, circulation was reestablished, and bulk sodium temperature was raised to 425°F.

During the startup interval, certified recalibration of all recording instruments and concurrent calibration of all plant control systems were completed. Additionally, performance of plant checkout procedures was concluded. These procedures were approximately equivalent to the preoperational test procedures which had been performed during 1964-1965 except for the elimination of some original steps which did not require repetition. The plant checkout procedures included: (1) visual verification that all equipment, lines, and valves were properly indentified; (2) a final recheck to ascertain that all instrumentation had been calibrated; and (3) a functional check of all equipment using standard operating procedures. Piping and instrumentation drawings also were corrected or were verified as being correct.

Operation of the SCTI on a steaming cycle was established on March 2, 1969. This action terminated the plant shutdown caused by failure of the main steam line on November 5, 1966. Initial steady-state operation was established with outlet steam conditions from the Alco/BLH steam generator of 620 psig and 600°F; this was the first step of the plant performance test series which is scheduled to include operation through the 100% power condition and a number of planned scrams from several power levels. To date, plant performance testing has proceeded to full steam pressure and temperature (2200 psig and 1050°F) and through the 40% power condition. Two major plant control subsystems were placed in the fully automatic mode for the first time; the automatic combustion control system and the secondary sodium/primary sodium flow control system both performed flawlessly after initial transfer. A total of 740 hr of steaming operation was accumulated since completion of the steam line repair. This operation is illustrated on Figure 10, along with shutdown intervals for maintenance activities discussed in succeeding paragraphs.

During initial operation, a number of plant outages resulted from various electrical problems with both the 480- and 4160-volt supply systems. These problems were found to be minor in nature and, after initial corrections, the performance of the electrical systems has been satisfactory. All 4160-volt switchgear and protective equipment has since been thoroughly overhauled and calibrated.

During March, a leak developed at the steam generator outlet flange after failure of the spiral-wound gasket. The original gasket utilized a carbon steel

5-15-69

Figure 10. Sodium Components Test Installation Schedule of Events, January through June 1969

stop (backing) ring outside the spiral-wound section to prevent distortion under temperature and pressure. Carbon steel proved to be inadequate for the required service and experienced significant creep and distortion. The vendor (Flexitallic) recommended new materials for both the gasket (Inconel) and the stop ring (Type 316 SS). These changes were agreed to by both Bechtel and LMEC and a new gasket was installed. Subsequently, maximum steam conditions of 240 psig and 1050°F were applied successfully in conjunction with resetting and operational checking of safety valves. However, in mid-May, after only 355 hr of service under steaming conditions, a second leak developed at the steam generator outlet flange.

After the removal from the flange, the defective gasket was found to have a non-uniform circumferential compression, with the steam leak occurring in the region of minimum thickness. In this region, gasket thickness measured 0.121 in. as compared with the stop ring thickness of 0.129 in. These measurements, and other observations, demonstrated that the gasket has not been concentric within the sealing faces of the flange and had not been clamped uniformly. This condition was facilitated by the design of the stop ring which, with perfect concentricity, provided less than 1/8-in. radial overlap between the flange face OD and the stop ring ID. Precise concentricity is almost impossible to achieve with a lap-joint flange which tends to shift during makeup.

Following renewed discussions with Bechtel and Flexitallic, a revised gasket design was selected for reinstallation. The new gasket was wound from Hastelloy-C to improve its spring characteristics, and was slightly smaller in both OD and width than the previous design. The reduced gasket OD brings more of the stop ring within the flange faces to provide improved restraint and more tolerance to slight misalignment. The reduced bearing area was chosen to permit a reduced bolt loading without reducing the unit loading on the gasket. An inner backing ring also was added to minimize distortion of the inner spiral windings of the gasket. The new gasket was placed in service at the end of May 1969, but as of the end of the report interval had not experienced sufficient operation to establish whether or not the redesign was fully successful.

Two separate bearing failures in the bearing and seal assembly of the primary sodium pump were experienced during the report interval. The first

occurred in April after 995 hr of operation following the routine replacement of the double row, angular contact bearings during the January outage for replacement of the leaking gas seal. This failure was attributed to improper loading of the bearings, with possible distortion under compression of the bronze oil pump impeller (which supports the inner race of the lower ball bearing) as a contributing factor. Damaged parts were either repaired or replaced by Byron-Jackson, and the pump was reassembled and returned to service in May. Prior to reassembly, a special thermocouple was installed to permit monitoring of the upper bearing temperature during operation.

Late in May, during plant restart following gasket replacement in the steam generator outlet flange, the special thermocouple monitoring pump bearing temperature indicated a rise above previously recorded values. On June 2, 1969, a manual shutdown was initiated because of excessive rate of rise of this temperature. At the time of shutdown, the bearing set had accumulated 649 hr of operation since the previous replacement. Upon disassembly of the bearing and seal housing, it was found that the lower bearing had undergone extensive damage to balls and races. There also was evidence that the inner race had rotated relative to the shaft sleeve. The upper bearing was in relatively good condition, with only a few balls showing any significant damage. The oil pump impellers were scored at the periphery and the lower impeller was also scored internally. The upper impeller was seized to the shaft sleeve, although it had been a slip fit at the time of installation.

During disassembly, it was observed that the double-row bearings had been installed in a face-to-face configuration as opposed to the back-to-back arrangement required by print. On investigation it was found that these matched bearings had been received, banded together, and with the manufacturer's recommendation that they be installed as banded. This recommendation had been followed, resulting in the inadvertent deviation from intended configuration. Prior to reassembly, it was also noted that the bearings which had failed, and the proposed replacements, were designated MRC 214R as opposed to Type MRC 7214 required by print. The bearing consultant who participated in the failure investigation pointed out that MRC 214R bearings were not optimum for the proposed service and that their thrust capability and life expectancy were less than for the MRC 7214. Calculations of life expectancy were performed, based on expected pump

loads, with the results indicating a minimum service life of 3400 hr for the MRC 214R versus 7800 hr for the MRC 7214. The actual service life of the failed set had been 649 hr. Following these observations, the better bearings were obtained and were used for reassembly in the desired back-to-back configuration.

All repair and reassembly operations on the bearing and seal housing, including reinstallation and drive motor connection, were conducted with the direct participation of a Byron Jackson field representative. Detailed drawings of the bearing and seal housing assembly were made available for this repair effort and all parts were returned to per-print conditions or were replaced by available spares. An exacting inspection and reassembly procedure was prepared and implemented to assure that all critical dimensions and fits were achieved during reassembly. This work was completed on June 14, 1969, and circulation in the primary system was resumed on June 16, 1969. During the repair activity Byron Jackson submitted several conclusions as to the probable cause of the bearing failure. The predominant causes were indicated as excessive preloading of the bearings and possible misalignment. The concern about bearing preload stems from the fact that it was necessary to press the outer races of the bearings into the bearing retainer during the previous installation. Also, on disassembly, the bearing retainer was found to be out of round. In several locations it was necessary to machine up to 0.007 in. of material from the retainer inner diameter to achieve print dimensions. These conditions may have been sufficient to cause an excessive nonuniform radial loading on the ball bearings. The reassembly procedure and the detailed attention to dimensional requirements and final alignment should preclude further difficulty from the two principal sources proposed by Byron Jackson.

Steaming operation was resumed at 2030 hours on June 18, 1969, and operation continued at the 40% power level through 1230 hours on June 21, 1969. At this time, an automatic shutdown was initiated as a consequence of a temporary low flow signal to the sodium heater (H-1). The initiating cause of this outage was a minor difficulty with the sodium level control instrumentation in the primary pump case. This problem was corrected and an attempt at plant re-start was made on the following day.

At 1320 hours on June 22, 1969, feedwater flow was re-established to the generator. At 1430 hours, the chromatograph was noted to be indicating in excess of 200 ppm hydrogen in the cover gas over the sodium in the steam generator. Subsequent range changes established that the actual hydrogen content in this region was in excess of 60,000 ppm. Water flow through the steam generator was secured at 1512 hours and the steam generator was vented to atmosphere. (During the course of these various determinations, the instrumentation was checked and found to be in satisfactory working condition.) At 1630 hours, sodium was drained from the secondary system to preclude possible leakage into the steam generator which was at lower pressure. Subsequent to the recognition of the high hydrogen content, a temperature spike, to a minimum temperature level of 550°F, was noted on the outlet steam temperature recorder. This temperature was in excess of the secondary sodium inlet temperature to the steam generator of 412°F and, initially, was believed to be indicative of a reaction on the water side of the steam generator. At approximately 1900 hours, a helium leak check was conducted by pressurizing the steam generator to 50 psi with helium and monitoring the cover gas in the secondary sodium system. This check indicated the presence of a small leak between these two systems.

Subsequent activities have been directed toward analyses of the steam generator leakage incident, visual examination of the condition of the accessible regions on the water side of the steam generator, and preparation of leak detection procedures. Principal findings as of the time of this report period include the following:

- 1) Steam generator water samples obtained during the course of the reaction did not indicate the presence of any significant quantity of Na-H₂O reaction products.
- 2) Visual examinations of the upper and lower tube sheets showed both to be in excellent condition, with no evidence of reaction products.
- 3) Helium leak checks established that a leakage path exists in only one tube, with initial indications that the leakage point is approximately 19 ft below the top surface of the upper tube sheet. This would place the leak approximately 13 ft below sodium level during normal operation.

- 4) No significant pressure or level disturbance occurred on the sodium side of the steam generator. The principal difference from normal operation was a requirement to vent gas from the space over the sodium following the reaction as opposed to the usual requirement for gas admission to make up for entrainment losses from this region.
- 5) Initial calculations based on water flow rate through the steam generator, and temperature rise above that of the incoming sodium, indicate that as much as 40 lb of sodium could have reacted as a result of the leakage. These calculations are subject to later refinement as additional data are derived.

Future activities will include additional analyses, continued leak detection studies to obtain more definitive information on leak location, dye penetrant examinations of all weld areas, and boroscopic examinations of the tube internals to the maximum depth possible. Investigations also are in progress relative to other inspection methods, i. e., ultrasonic and eddy current techniques, and to possible effects on adjacent tubes and throughout the system. Simultaneously, a welding procedure is under development for plugging the defective tube, and procedure and welder qualifications are being obtained.

D. CONDENSATE POLISH SYSTEM MODIFICATION

The initial construction contract for installation of the new condensate polish system was awarded and the first phase of the activity was completed. This initial effort resulted in the final placement of the demineralizer equipment and the completion of electrical connections. The second phase of the work, to install process piping and make pipe interconnections is tentatively scheduled for the shutdown interval starting October 1, 1969, for strain gage application on the Alco components.

E. STEAM AND FEEDWATER SYSTEM UPGRADING MODIFICATION

Proposals submitted by architect-engineer (A-E) firms for the design of the steam and feedwater system upgrading modification were received early in the report period for evaluation by an A-E selection board. The AEC approved the A-E selection board's report and recommendation and authorized the start of

negotiations to accomplish the design effort. During the report interval, a detailed scope of work was prepared and was submitted in informal form to the A-E; a final version was completed for formal submission at the end of the report period. Additional effort also has been devoted to improvements to the conceptual system design description. This document, LMEC-Memo-68-30, "SCTI Steam and Feedwater System Upgrading Modification Conceptual System Design Description," was submitted to the AEC for review and was returned with a number of comments and corrections. These have been incorporated into the revised CSDD along with additional, minor modifications to improve clarity. The revised CSDD was completed as of the end of the report interval and required only final internal reviews prior to release for publication.

F. DATA ACQUISITION SYSTEM

Fabrication of the SCTI Data Acquisition System (DAS) was completed in June 1969. The preliminary acceptance test was performed at Systems Engineering Laboratory (SEL), Ft. Lauderdale, Florida, and the DAS was shipped on June 24, 1969. The DAS hardware and software was successfully demonstrated during the preliminary acceptance test.

About 85% of the engineering design for the DAS installation was completed. The decision to install the DAS in an addition to the existing SCTI control room increased this engineering effort somewhat beyond that originally envisioned. The control room addition will provide a much better working environment for the DAS and associated personnel as compared to the original plans.

All of the special DAS analog input leadwire was received during the report period. The pneumatic-to-electric converters (required to allow recording of some of the existing process signals on the DAS) were received, but were returned to the vendor when they failed to pass inspection. The vendor expects to have the units repaired and returned to the LMEC soon enough to preclude any schedule delay due to this item. After considerable difficulty with one manufacturer regarding contract terms and conditions, purchase orders for electronic pressure transducers were placed with other suppliers. Again, delivery of these items is not expected to cause schedule delays.

Upon delivery of the DAS at the LMEC, the DAS will be temporarily installed in the control room of Building 019. The final acceptance tests, reliability demonstration run, and operator training on the DAS will be performed in

the temporary location. The DAS will be installed in the SCTI during the planned outage for strain gage installation.

G. FFTF COMPONENT TESTING

During the report interval, a firm requirement was established for testing an FFTF IHX model and several DHX units in SCTI. Although accurate dimensional information on these units was not available, a preliminary modification plan was developed to incorporate these components for test purposes. Lacking definitive data on equipment configuration and size, this plan was based on conservative upper-bound information received from BNW. The large dimensions assigned to the DHX units made it necessary to locate this equipment at a relatively remote position from the IHX, requiring extended runs of sodium piping and additional sodium storage capacity. Additional planning for this installation will be performed during the next report interval at which time it is expected that required data on the sizes and configurations of the FFTF components will be available. This work will take into consideration plans for testing advanced steam generators and, wherever possible, will attempt to maximize the applicability of FFTF modifications for forthcoming programs.

H. FUTURE EFFORT

The principal effort at the outset of the next report interval will be devoted to further analyses and investigations of the steam generator leak, to repair of the steam generator, and to a return to normal steaming operation. Upon completion of this work, plant performance testing will be resumed and will be concluded by testing through the 100% power condition. Following completion of the plant performance tests, the steady-state portion of the Alco test program will be started.

Upon completion of the tests described above, a plant shutdown of approximately 3 months duration is scheduled to permit installation of strain gages on the Alco IHX and Alco/BLH steam generator. During this same period, the control room extension to house the DAS will be completed, the DAS will be installed, and all necessary connections and checkouts will be concluded.

The SCTI steam and feedwater system upgrading modification Title I design effort will be undertaken by the A-E. Title I work will be completed, Title II design will be initiated, and initial procurement activities on long-lead items (e. g. , the high-pressure feedwater heater) will be undertaken.

Design of the FFTF component installation will be continued.

VI. LIQUID METALS INFORMATION CENTER

(LMFBR Program Plan 3-2.1)

J. J. Droher

A. INTRODUCTION

The Liquid Metals Information Center (LMIC) was established by the AEC to serve as a focal point for technically evaluated information and data on liquid metals technology and components, with initial emphasis on sodium and NaK as heat transfer and transport fluids. A quick-response computerized storage and retrieval system is utilized to provide comprehensive coverage of the subject matter of an inquiry. Over 6,000 documents, published since 1955 and relevant to sodium and NaK technology, have been processed for inclusion in the computerized data bank since the Center became operational in mid-1966. The Center is now processing new material at a rate of over 1000 documents per year.

While Center services are available to all qualified requesters in government, industry, and education, the primary users of the Center are those involved directly or indirectly with the national LMFBR program. To best perform this function, the Center's activities have encompassed the following specific areas of liquid metals technology: (1) properties; (2) chemistry; (3) materials compatibility; (4) fluid flow; (5) heat transfer; (6) components; (7) instrumentation, fabrication, operation, and maintenance; (8) purification; (9) handling and storage; (10) procurement; (11) liquid metal safety; and (12) systems. Thus, the Center is able to provide bibliographic citations, information abstracts, and evaluative responses to specific questions from those performing research and development in these subject areas. These subject areas encompass portions of all ten elements of the LMFBR Program Plan, with the exception of Element 9, Physics.

Those concerned with the LMFBR program are faced with the requirements for development of reliable components and systems containing engineering capabilities up to an order of magnitude greater than those developed to date. The Center has been preparing a Sodium-NaK Engineering Handbook for the use of present and future designers. The objective of this handbook is to include sufficient detail for basic understanding of sodium and NaK technology to the

extent that one could perform feasibility studies and conceptual design, size components and systems, develop preliminary component and system descriptions, and define basic constraints and parameters. A preliminary draft version of this handbook has been prepared, comments have been received from reviewers, and editing of the final version is now in progress.

Other LMIC functions include the maintenance of a basic reference library for the use of staff members and visitors to the LMEC, and maintaining cognizance of publication activities of the entire LMEC. The publications issued during this report period by the entire LMEC are listed separately in a Bibliography at the end of this report.

B. RESPONSES TO REQUESTS

During the past 6 months, LMIC has responded to 279 requests for information from various organizations, including all of the major participants in the LMFBR program. These requests have involved 360 separate subject categories, for which computerized searches were performed resulting in a total of 22,155 printouts containing bibliographic data and abstracts of documents with pertinent information.

C. INFORMATION STORAGE AND RETRIEVAL

An additional 478 documents were analyzed and indexed during the report period. The pertinent information has been keypunched and processed for storage in the computerized data bank, bringing to 6,721 the total number of documents from which information has been processed for storage on magnetic tape. LMIC received 352 new reports directly from the issuing organization during the past 6 months, while the remaining documents were identified through regular LMIC screening activities and then ordered through the regular channels.

The present computer system used by LMIC for storage and retrieval of information is the North American Rockwell Technical Information Processing System (TIPS). This system was written in assembly language for an IBM 7010 and is presently being converted for an IBM S/360. IBM has released a Document Processing System (DPS) written for S/360; routines within DPS are written in the Operating System/360 Assembly Language and require no further coding on the part of the system user. Narrative and bibliographic data are processed

into interrelated data sets, which can be searched for Boolean combination of keywords. The feasibility of using this new DPS program as an additional storage and retrieval tool for LMIC was explored, using a small number of accessions to test the effectiveness of the system for various retrieval modes which LMIC might wish to use. The trial runs of DPS were encouraging. When conversion of TIPS to the IBM S/360 is completed, additional cost/performance comparisons will be made.

The Key Word In Context (KWIC) program is a computer program which permutes on each descriptive word in a title (or other input) and lists each of these words in alpha-numeric order (along with the remainder of the title). KWIC is used internally at LMIC as a supplement to the main computer program for storage and retrieval of information to quickly locate prime references on a given topic. The KWIC program has been modified for use with the IBM 360/50 system and improvements were made which increased the maximum file size capacity and decreased the machine time required for processing a given number of records. The improved program was used to generate and print out a permuted alpha-numeric summary of the titles comprising: (1) the LMIC standard and reference files; (2) the subjects of evaluative responses (in the form of LMIC letters) containing the latest or most comprehensive summary of information on a particular topic; and (3) the titles of current programs or development efforts related to the technology of sodium and NaK as heat transfer and heat transport fluids. With the latest summary, it is now possible to quickly and conveniently locate prime information at the LMIC on a given topic.

A thorough review was made of all progress reports received during the reporting period that involved liquid metals technology. This information was used to update the status of tasks in a project file encompassing all current work in progress involving liquid metals.

A thesaurus of authorized descriptive terms is utilized internally when technical documents are processed for storage in the LMIC data bank so that computer questions can be structured concisely and accurately to retrieve pertinent references for a specific inquiry. A computerized procedure is utilized to maintain and print out the thesaurus. During the report period, a systematic review was made of all thesaurus entries, including main terms, scope notes,

subterms, and cross reference notations. As a result of the review, computer-input sheets reflecting the desirable additions, deletions, and changes were prepared; cards were keypunched; and a printout of the revised and improved version of the thesaurus was made.

D. SODIUM AND NaK ENGINEERING HANDBOOK

All 20 chapters of the Sodium-NaK Engineering Handbook have been submitted for DTIE editing, and all but two (Chapter 6, "Purification," and Chapter 12, "Pumps") have been so edited and returned to the respective authors for review; of these, seven chapters have been approved by the authors and returned to DTIE.

VII. SODIUM PUMP TEST FACILITY (SPTF)

(LMFBR Program Plan 3-5.2)

S. L. Pfahler

A. INTRODUCTION

The Sodium Pump Test Facility (SPTF) is being designed to conduct proof-testing and acceptance testing of large sodium pumps and other related sodium components for the LMFBR program. The present facility design criteria specify sodium testing capability over a flow range of 5,000 to 72,000 gpm at temperatures up to 1200°F in each of two loops.

The Title I design phase is complete. The Title I Report and the Preliminary System Design Descriptions (PSDD's) are nearly complete. Title II Final Design will not start until the facility configuration is approved.

B. OPERATIONAL PERFORMANCE CRITERIA

The design basis and performance criteria for the SPTF has not changed significantly since the previous report period.

The major facility test performance criteria are shown in Table 11. Additional capabilities being considered are pump nozzle load testing and extension of in-place calibration capability to 60,000 gpm.

C. MAIN FLOW LOOPS AND RELATED SODIUM SYSTEMS

1. System Description

The main flow loops and related sodium systems flow diagrams have not changed significantly since the previous report period. The feed and drain tanks have been increased in size to accommodate the larger sodium inventory. The feed tank and drain tank are 21 ft 6 in. and 25 ft 6 in. in diameter, respectively. Figures A-1 and A-2, in the Appendix of this report show plan layouts of the two 30-in. test loops. Figure A-3 is an elevation of one of the 60,000-gpm 30-in. test loops.

To accommodate FFTF pump testing, a modified 30-in.-diameter test loop was determined to be most economic. Figure A-4 shows a piping plan of this modified test loop.

TABLE 11
SPTF PERFORMANCE CRITERIA

Sodium Flow Range per Loop (gpm)	5000 to 72,000
Sodium Operating Temperature Range (°F)	400 to 1200
Design Head (ft of sodium)	350 at 1200°F and 60,000 gpm
Pump Suction Pressure	-4 to +25
Thermal Transient Capability:	
1) +35°F/sec for 6 sec followed by +2°F/sec for 45 sec from 800 to 1100°F	
2) -35°F/sec for 6 sec followed by -2°F/sec for 45 sec from 1100 to 800°F	
3) +4°F/sec for 120 sec from 600 to 1080°F	
4) -4°F/sec for 120 sec from 1100 to 620°F	
In-place Flowmeter Calibration - Maximum Flow (gpm)	28,000

2. Major Changes from the Previous Report

The present sodium air cooler design is unable to accommodate the high-rate thermal transient test requirements. Excessive stresses result in the tube-to-fin joint. A piping design change was necessary to reduce the temperature transient through the cooler. A delay and mixing chamber has been added on the cooler inlet piping. The incoming hot or cold sodium is mixed with the liquid in the vessel before it enters the cooler, which reduces the temperature transient at the cooler to an acceptable value.

3. Problem Areas

There are four major problem areas that have an impact on the SPTF final design and construction schedule. These are sodium valves, sodium pump information, uncertainty in the stress analysis and piping life cycles, and main loop sodium air cooler design.

The number of main flow control valves and the valve arrangement in each test loop cannot be finally determined until firm valve characteristics and design information are available. To determine butterfly valve cavitation characteristics for the control valves, a test program is presently being planned.

The design basis of each 30-in. main flow loop is that the sodium flow rate is controllable between 5000 and 72,000 gpm, with an accuracy of $\pm 2\%$ of actual flow rate from 72,000 to 15,000 gpm, and $\pm 3\%$ of actual flow rate from 15,000 to 5000 gpm. The valve design must not cause vibration or cavitation which would result in damage or malfunction of the valve or other components in the system. The valve must perform at any temperature between 400 and 1200°F. The valve must withstand high-rate thermal transients of $\pm 35^\circ\text{F}/\text{sec}$ for 6 sec followed by $\pm 2^\circ\text{F}/\text{sec}$ for 45 sec. The main flow loop control valves must be capable of removing 350 ft of head pressure at 60,000 gpm to fulfill test requirements.

The Conceptual System Design Description proposed two butterfly valves in series for controlling the main flow loop. Butterfly valves were selected as being less costly, with capability to provide the control accuracy and flow range required, and were considered likely to satisfy the thermal transient cyclic criteria. Other valves and flow control methods were determined to be more complex, heavier wall thickness, or more costly.

During Title I, further investigation of valve cavitation was made for both the 60,000-gpm pump and FFTF pump test conditions. Figure 11 indicates that four or possibly five butterfly valves must be required to meet the low pump suction requirements for the 60,000-gpm pump. Figure 12 shows the butterfly control valve requirements to satisfy the FFTF pump testing requirements. Because the present test information on valve cavitation is so limited and inconsistent, a test program is recommended to obtain usable design information prior to Title II design.

Title I design of the main flow loop has sufficient length to include three butterfly control valves in the return leg of the loop. If the results of the testing program indicate that additional valves are required, they can be installed in the other leg of the loop.

Alternate valve designs are also being investigated.

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Figure 11. SPTF Main Flow Loop Control Valve Cavitation Characteristics (LMFBR Prototype Pump)

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Figure 12. SPTF Main Flow Loop Control Valve Cavitation Characteristics (FFTF Primary Pump)

Pump design studies are currently under way. Detailed pump design parameters are still being developed. Pump design greatly affects SPTF design and costs. There is a need for the pump test requirements to be firmly established before final design is undertaken.

The design uncertainty associated with the piping loop and vessel stress analysis and thermal transient cycle life prediction is due to the lack of design data in this area, and continues as a problem. A materials test program has been proposed to develop data. The main loop sodium air cooler design is being re-evaluated.

D. MAIN FLOW LOOP ANALOG STUDIES

The analog simulation model was prepared to determine the SPTF system and control transient dynamics. Thermal transient control of the main flow loop will be by means of flow or valve programming. Title I work provided the required sodium feed and drain flow rates and the inert gas flow rates for thermal transient testing. The inert gas control dynamics for pump suction pressure control will be calculated during final design.

E. SODIUM SYSTEMS STRESS ANALYSIS

The sodium piping in the main loop, the feed and drain lines, and those portions of the auxiliary sodium piping systems that are exposed to the similar transient conditions as the main loop will be designed in accordance with USAS B31.7, Nuclear Power Piping and the high-temperature code case for this code agreed upon at the July 10, 1968 meeting of the design task force of B31.7. These are comparable to Article 4 of Section III of the ASME Code.

In general, the design will follow the detailed analysis set forth in Appendix F of USAS B31.7. The standard code analysis (i. e., the so-called simplified analysis) will be used to search for the higher stressed areas. If the standard analysis meets the allowable stress limitations of the code, the component designed will be satisfactory from a stress standpoint. However, the expected cyclic life of a piping component will be based on a peak stress derived from an analysis in accordance with Appendix F of USAS B31.7 rather than the standard code analysis.

The high-temperature code case modifies the allowable value (S_{all}) for primary membrane plus primary bending from $1.5 S_m$ to the following expression:

for $T_c \leq T \leq T_c + 200$,

$$S_{all} = 1.5 S_m - \left(\frac{T - T_c}{200} \right) (0.17 S_m + 0.33 S)$$

and

for $T > T_c + 200$,

$$S_{all} = 1.33 S_m - 0.33 S,$$

where

T = design temperature ($^{\circ}F$)

$T_c = 800^{\circ}F$ for austenitic stainless steels

S_m = allowable value of general primary membrane stress intensity

S = calculated value of primary membrane stress intensity.

The limit of secondary stress in the code is set at $3 S_m$ as modified by Note 1 of USAS B31.7 Table F-104. The high-temperature code case modifies this limit to be either $3 S_m$ or $3 S_a$ at 1 million cycles, whichever is the higher. B31.7 has an alternate concept called the simplified elastic-plastic discontinuity analysis. This analysis allows the $3 S_m$ limit to be exceeded providing calculations can be made to show that ratchet limitations are not exceeded. This analysis has the effect of reducing the number of cycles for fatigue life. This is a new concept that was presented to industry at the September 1968 meeting of the API in Dallas.

A separate investigation was made to study the effect that plastic straining might have on the elastic design basis in such areas in buckling and ratcheting. This study was made to build confidence in the design basis. The study concluded the following:

- 1) For a section of the straight piping subjected to the most severe temperature transient under primary loads of $1 S_m$ and $1.5 S_m$, no plastic strain occurred.

- 2) The results obtained at $1.5 S_m$ reveal plastic strain is impending. Any further increase in primary stress above $1.5 S_m$ will result in plastic strain and possible incremental distortion.
- 3) The absence of plastic strain for the stipulated load conditions negates the possibility for ratcheting and, therefore, the analysis for incremental distortion was not performed. If the design primary loads are increased, however, an extension of this analysis should be made to ascertain if incremental distortion, shakedown, or plastic cycling occurs. The employment of the multiaxial stress-state model in this study permits an increase to $1.5 S_m$ in primary stress before a possible ratcheting regime is approached. The limiting value of primary stress specified by the piping code case under the same set of conditions is $1.10 S_m$.

The primary, primary plus secondary, and peak stress intensities were determined for the higher stressed components of each type and size (such as elbows, bends, tapers, and branch connections (see Figure 13) and at the other higher stressed discontinuities (such as circumferential butt welds longitudinal butt welds, support points, clips, and heater element attachments).

The alternating component of the peak stress intensities of each component, determined for the various stress cycles, will be used to calculate the usage factor for each cycle (see Figure 14). Where the sum of these usage factors is less than one, the design will be considered acceptable.

The major variables affecting the transient thermal stress are flow rate, transient rate, and total temperature change. The stress cycles considered are as follows:

Type	Sodium Transient Rates, Duration, and Temperature
1) I	$35^{\circ}\text{F/sec} \times 6 \text{ sec}$ followed by $2^{\circ}\text{F/sec} \times 45 \text{ sec}$ from 800°F
2) II	$-35^{\circ}\text{F/sec} \times 6 \text{ sec}$ followed by $-2^{\circ}\text{F/sec} \times 45 \text{ sec}$ from 1100°F
3) III	$4^{\circ}\text{F/sec} \times 120 \text{ sec}$ from 600°F
4) IV	$-4^{\circ}\text{F/sec} \times 120 \text{ sec}$ from 1100°F
5) V	$30^{\circ}\text{F/sec} \times 10 \text{ sec}$ from 800°F

HOT SHOCK ONLY

HOT AND COLD SHOCK

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Figure 13. SPTF Transient Test Temperature Profiles

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Figure 14. SPTF Test Loop Schematic

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- 6) VI 30°F/sec x 10 sec from 700°F
- 7) VII Type I transient followed by Type II transient
- 8) VIII Type III transient followed by Type IV transient
- 9) IX Normal operation between 400°F and 1200°F.

Temperature gradients and stress levels for a typical thermal transient are shown on Figure 15 and Table 12.

TABLE 12

SPTF TEMPERATURE ACROSS PIPE WALL AND MAXIMUM
PIPE WALL STRESSES
(30-in. OD pipe; Type I transient)

Pipe Wall Element Number	Temperature (°F)			
	60,000 gpm	40,000 gpm	20,000 gpm	15,000 gpm
0	1006	1000	990	985
1	969	965	958	954
2	936	933	928	925
3	906	904	902	900
4	881	879	880	879
5	860	859	861	861
6	843	843	846	846
7	831	831	835	835
8	822	823	827	828
9	817	818	822	823
10	815	816	820	821
Maximum Pipe Wall Stresses	Stress (psi)			
	60,00 gpm	40,000 gpm	20,000 gpm	15,000 gpm
<u>Secondary:</u>				
Inside	-33,262	-32,189	-29,916	-28,758
Outside	35,802	34,589	32,000	30,700
<u>Peak:</u>				
Inside	-47,952	-45,908	-41,926	-40,097
Outside	21,857	21,393	20,337	19,646

Figure 15. SPTF Temperature Profile Across Pipe Wall

The calculations for the primary membrane plus primary bending stress intensities for the straight pipe, the elbow, and the mixing tee indicate the stresses at straight pipe, welds, and tapered transitions are well within the code-allowable stress limits. For the branch connections and curved members, the stress indexes are high and as a result, the primary stresses in these fittings are very close to their allowable limit.

The primary plus secondary stress intensities were developed for the same elbow and section of straight pipe. An initial conservative approach to the loop design has been to assume that the maximum range of loads and stresses from pressure, seismic load, deadload, expansion, and thermal transients act simultaneously.

In general, it appears that the available fatigue life will satisfy the system test requirements except for the back-to-back transient stress range. Usage factors shown in Table 13 give a good indication of the fatigue life utilized for the various types of transient test conditions.

The most severe stress cycle is VII. Ten of these cycles use the full life of the elbow, and 14 cycles the full life of the straight pipe. The next most severe stress cycle is VIII. Twenty cycles use the full life of the elbow and 60 the full life of the pipe.

F. INSTRUMENTATION AND CONTROL

1. System Description

The Title I control system for conducting thermal transient tests was selected based on results from the analog study.

A study was conducted to determine if in-place flowmeter calibration could be accomplished. In this study, the accuracy gained by calibrating the flowmeter with water at ambient temperature and by in-place calibration with sodium was evaluated. It was concluded that water calibration would improve the measuring accuracy over that to be expected if no calibration were conducted. In-place calibration of the flowmeter would not appreciably improve the overall metering accuracy of the initial installation. However, such a capability would be of value for periodic rechecking of the flow measuring equipment. It was

TABLE 13

SPTF CUMULATIVE USAGE FACTORS FOR VARIOUS
TYPES OF TRANSIENT TEST CONDITIONS

Stress Cycle	Number of Cycles	Allowable Number of Cycles	Usage Factor
30-in. Elbow - Proposed Number of Cycles ($\Sigma U = 0.893 < 1.0$)			
I	65	1,010	0.065
III	30	10,000	0.003
V	25	760	0.003
VI	25	600	0.042
VII	5	10	0.500
VIII	5	20	0.250
30-in. Straight Pipe, Same Loading Conditions as the Elbow - Proposed Number of Cycles ($\Sigma U = 0.485 < 1.0$)			
I	65	3,250	0.020
III	30	30,000	0.001
V	25	1,300	0.019
VI	25	5,000	0.005
VII	5	14	0.375
VIII	5	60	0.084
30-in. Straight Pipe - Normal Operation 400 to 1200°F and back to 400°F			
IX	500	500,000	0.001

recommended that the head sensing and readout instrumentation of the venturi flowmeter should be calibrated both initially and on a regular basis during the life of the plant.

The accuracies obtainable by various in-place calibration systems were determined. The maximum feasible flow rate for calibration was found to be approximately 28,000 gpm. The method of calibrating up to this flow rate is to determine the total sodium flow by measuring the change in weight of sodium in

the feed tank over the calibration period. The accuracy for this type of calibration, taking into account all the instrument system inaccuracies, was calculated to be $\pm 0.70\%$. This compared with an overall system accuracy, using volumetric measurement, of $\pm 1.23\%$. Means to extend the calibration range to 60,000 gpm by indirect methods are being considered as an additional study.

2. Problem Areas

Instrumentation uncertainties continue to relate to the availability of high-temperature strain gages and differential pressure transducers. Control uncertainties involve the availability of large sodium and inert gas flow control valves which are capable of the fast response times specified in the analog simulation studies.

G. INERT GAS, VENT, AND VACUUM SYSTEM

1. System Description

The argon supply unit has been changed from an engineered unit to a supplier-packaged unit. This change was made to reduce capital investment. The present system requires operating pressures of 500 and 100 psig.

2. Major Changes from Conceptual System Design

The most significant design change was the deletion of the large on-site storage tanks to provide capacity for transient testing. To provide argon gas in sufficient quantity, a dual pressure system has been selected. This design change was made because the high argon flow rates required during transient testing, 3.5×10^6 scfm, can be carried more economically in a 500-psig system than in a 150-psig system. The high-pressure system handles the transient flow. The low-pressure argon system at 100 psig provides for normal inerting, purging, and miscellaneous usage.

3. Problem Areas

There is a design problem in the sizing of the main vent line to relieve the feed tank pressure in the event of an abort of a high-rate transient test. The feed tank pressure must be reduced rapidly to avoid an overpressure condition on the test pump suction. Further analysis will be required when test pump design conditions are available.

H. ELECTRICAL SYSTEM

The major change in the electrical system since the previous report has been in the uninterruptible power system by the addition of an emergency gas engine generator. The Data Acquisition System (DAS) and the instrument controllers are supplied from the uninterruptible power system. The system consists of a battery charger, battery, and static inverter. In the event of a utility power failure the battery has sufficient capacity to continue to supply the DAS and the instruments for one hour. If the power interruption is for a long period, a gas engine generator is started to provide emergency power to the uninterruptible system and emergency lighting. This will allow the test loops to be shut down in an orderly manner.

I. SITE AND BUILDINGS

Figure A-5 in the Appendix of this report indicates the proposed new location of the facility within the LMEC complex at Santa Susana, California. Figure A-6 shows a plot plan and equipment location plan of the facility. A perspective of the facility, Figure A-7, shows an architectural cutaway of the proposed building.

The building consists of a highbay for the test pump installation and a two-story lowbay for the control room and equipment rooms to the north. A similar lowbay structure extends to the south to house the test loops and the purification and sampling equipment room. Figure A-8 shows the building plan. Figure A-9 shows the arrangement of the control room. Figures A-10 and A-11 show sections through the building indicating the layout and arrangement of equipment and the test loops within the facility.

The building is designed to accommodate two 60,000-gpm test loops. Figure A-2 shows the plan layout for these two loops. Figure A-3 is an elevation of one 60,000-gpm, 30-in. test loop. To provide for the FFTF pump test, a modified 30-in. test loop will be used. Figures A-4 and A-12 show the piping plan layout and elevation of the modified loop consisting of 18-in. inserts for testing the FFTF pump.

J. AUXILIARY COOLING SYSTEM

1. System Description

Figure A-13 in the Appendix of this report is a flow diagram of the SPTF auxiliary cooling system. The new cooling tower is located in the southwest corner of the site to reduce the possibility of water vapor coming in contact with the sodium area. Six-in. pipe mains will carry the water to and from a point outside the test building.

2. Major Changes from Conceptual System Design

There are five major design changes to the SPTF auxiliary cooling system. These are discussed in the following paragraphs.

The Sodium Components Test Installation (SCTI) cooling tower will not be used because of the relocation of the SPTF site. A separate SPTF cooling tower with a capacity of 10×10^6 Btu/hr has been added.

The maximum estimated SPTF cooling water heat load, when two 60,000-gpm pumps are tested simultaneously at minimum flowrate, has been reduced from 22.8×10^6 Btu/hr to 5.5×10^6 Btu/hr. The reasons for this large reduction in predicted cooling load are: (1) the specified drive motor horsepower was reduced from 6,500 to 5,500 and (2) later, a more realistic assumption was made that the maximum heat absorbed by the speed-control unit would be 20% of the rated motor input. The reduced heat load caused reductions in cooling water pipe size and in cooling water pump capacity.

The pump shaft seals and bearings were previously cooled by the intermediate cooling loops. During Title I, it was determined that the pump seals and bearings would be air-cooled and that the blowers will be furnished as part of the test pump package.

The maximum operating pressure for the system was increased from 50 to 85 psig because of the increased length of piping.

For sizing and cooling tower, the maximum operating temperature was decreased from 150 to 120°F. The cooling tower outlet temperature was decreased from 90°F to 80°F.

3. Problem Areas

The auxiliary cooling system design is well within the present state-of-the art, and there are no problem areas. Proven components and designs are used to ensure a reliable system.

VIII. SODIUM PUMP SEAL TEST PROGRAM
(LMFBR Program Plan 3-5.2, 3-11.3.1)
C. C. Conners

A. INTRODUCTION

The LMEC Sodium Pump Seal Test Program objectives are: (1) to determine the suitability of candidate shaft seals for use in large, free-surface mechanical sodium pumps for the LMFBR program; and (2) to verify supplier seal design data, standards, and criteria for manufacture and performance of seals.

Seals will be tested, data analyzed, and performance characteristics will be evaluated. Factors to be considered include reliability, life, efficiency, and maintenance requirements. Information will be obtained for judging the adequacy of future seal designs of like concepts.

The program consists of tasks for planned tests and evaluation of seals for: (1) an existing pump design, (2) the BNW/FFTF primary and secondary pumps, and (3) proposed LMFBR prototype pump designs.

B. SEAL TEST AND FACILITY CHECKOUT

LMEC initiated procurement of a test seal of the Enrico Fermi Atomic Power Plant primary pump seal design. This seal will be used to check out operationally both the oil and gas shaft seal test facilities. The facilities checkout will establish functional characteristics, verify the operation of system instrumentation and controls and provide a final test of system operating procedures. Similarity of the Fermi primary pump seal to future LMFBR pump seals may permit application of test results to the evaluation of future pump seal designs.

The Fermi primary pump seal will be identical in design and fabrication to the seal presently in use at Fermi. Minor modifications will include: (1) interfacing requirements with the LMEC test facilities; (2) instrumentation and controls as specified, or as required, to evaluate seal performance; (3) a viewing port below the seal to permit evaluation of the use of sweep gas techniques on seal performance (attempting to minimize sodium vapor entrainment at the oil drain cavity); (4) seal oil flow control; (5) oil drainage; (6) oil filter vent capability; and (7) handling slings with attachment points.

C. TEST FACILITY MODIFICATIONS

1. Spindle Reinforcement

Load deflection measurements were made on the bearing spindle support structure. Analysis of the data indicated that reinforcement was required to minimize the vibrational response. Spindle reinforcements were designed and fabricated. Installation of the reinforced spindles necessitated rewriting the seal drive system assembly and balancing procedures. Included in the revised procedures are more closely controlled assembly tolerances for better control of seal shaft runout and balance. Drawings were also revised showing the rework required to obtain a reference circle on the inside of the seal housing. This datum circle is needed to obtain coaxiality between the spindle and seal. A dummy arbor has been designed and fabricated, simulating the mass of a test seal shaft to be used during vibration tests.

2. Support Structure Analysis

Further vibrational analysis indicated that the natural frequency of the test vessel support structure is approximately 600 cpm and is caused primarily by the flexibility in the lower portion. Testing of the FFTF seals and the Fermi-type seal will not be required in this speed range. However, initial tests of the facility will be performed to evaluate potential vibrational problems. Stiffening will be added if required.

3. Piping Support Analysis

The fill and drain line systems of the seal test facilities were analyzed for thermal expansion stresses to determine the feasibility of adding an anchor to filter F-1. The proposed anchor is required to minimize vibration of the fill and drain line systems during test operation. Allowable stress was based on USAS B31.1.0, Power Piping Code. Results of the analysis indicate a maximum allowable temperature of 870°F with a rigid filter anchor. Since the lines will be operated at a maximum of between 500 and 600°F, the anchor was installed.

D. SODIUM TEST VESSEL FABRICATION AND INSPECTION HISTORY

To provide a deeper appreciation of the need for continual surveillance of fabricators through quality assurance plans, a chronological history was prepared

of the fabrication of the two sodium test vessels for the pump seal facilities. The compilation reveals an excessive number of fabrication discrepancies, each of which was eventually resolved. A total of 14 months elapsed from the original delivery date to the final acceptance date for the vessels. This introduced a potential delay in the program schedule. However, delays in procurement of a test seal were more severe than fabrication delays of the vessels.

E. HIGH-PRESSURE SECONDARY PUMP SEAL - FFTF

A study was initiated to define the capability of the seal test facilities for sodium testing of the high-pressure secondary pump seal for FFTF. A stress analysis of the sodium test vessels indicated a maximum allowable pressure of 100 psi at the maximum operating temperature of the flange hub of 100°F (ignoring thermal gradients). Curves were plotted for spindle bearing life versus vessel pressure and seal diameter. The allowable pressure at test temperature is inadequate to accommodate the FFTF secondary pump seal.

An alternate test program for this seal was proposed. Preliminary conclusions were that a test of the primary pump seal at temperature in sodium would be a test of the secondary pump seal from the standpoint of sodium environmental effects. A high-pressure room temperature test of the secondary pump seal at the supplier's facilities would complete testing. A detailed study of the test program for the secondary pump seal will be completed when a test request has been received.

F. LMFBR 60,000-GPM PUMP SEAL

Previous program plans initially scheduled procurement and testing of LMFBR 60,000-gpm pump seals, including two proposed designs and a third as yet unspecified design. Requests for proposal were reviewed by Byron Jackson and Westinghouse, and discussions were conducted on the procurement requirements. Priority assigned to the FFTF program has temporarily shifted the emphasis in the seal test program from procurement and test of the LMFBR 60,000-gpm pump seals to testing of FFTF pump seals. The seal proposal requests will be withdrawn until such time as priorities are reassigned.

G. CONSTRUCTION OF TEST FACILITIES

Test facility No. 2 has been completed with the exception of instrumentation and control, checkout, and calibration (see Figure 16).

Test facility No. 1 is partially insulated (see Figure 17).

Drive motor wiring is complete with the auxiliary blower system installed and operable. The motor blowers provide adequate cooling during low-rpm operation.

7694-40310

Figure 16. Sodium Pump Seal Test Facility No. 2

7694-40312

Figure 17. Sodium Pump Seal Test Facility No. 1

IX. SODIUM PUMP BEARING TEST PROGRAM
(LMFBR Program Plan 3-5.2, 3-11.3.2)
C. C. Conners

A. INTRODUCTION

The objective of the LMEC Sodium Pump Bearing Test Program is to verify the technology of sodium-lubricated fluid film bearings that will be used in future LMFBR sodium pumps.

Verification of the technology will be accomplished by conducting performance tests on bearings obtained from pump manufacturers. Analytical techniques being developed by Mechanical Technology Inc. under AEC Contract AT(30-1)-3930 and other applicable analyses will be used to predict bearing capabilities. Adequacy of bearing design, fabrication, quality assurance analysis, and materials will be evaluated.

Primary emphasis of the LMEC program is given to the hydrostatic radial bearing, since it is this concept which has been specified for pumps being considered for the LMFBR program on the Large Sodium Pump Study project.

To meet LMFBR goals, studies are being performed of new and basic techniques for analyzing turbulent bearing films and for development of film thickness measurement instrumentation. Concurrently, on the experimental side, LMEC is constructing a sodium Pump Bearing Test Facility (PBTF) to obtain the performance data required to verify analytical predictions and to assure the required degree of reliability in bearing performance predictions. As a part of the overall PBTF purpose, the present investigation is being undertaken to:

- 1) Provide facilities and methods to proof-test prototype bearings designed for use in FFTF primary sodium pumps and to obtain pump bearing performance data prior to scheduled testing of FFTF pumps
- 2) Obtain bearing test data that will assure improved accuracy in the prediction of bearing performance of proposed bearings for use in large pumps operating in 1200°F sodium.

B. DISCUSSION

As a result of the priority position assigned to the FFTF effort in the LMFBR program and the need to verify performance of a bearing for the FFTF main heat transfer pump, a test program for the FFTF pump bearing was developed by LMEC and approved by the AEC. This test program will subject an FFTF pump bearing to operating conditions simulating those anticipated in actual service. Measurements will be made of the bearing's load-carrying capability and sodium flow requirements. Other data to be obtained will include pressure distribution within the pockets, power consumption, and performance of hard-facing materials under repeated starts and stops.

Based on this test program, a concept for the bearing test facility was developed using the existing Hallam Sodium Pump Test Loop as a nucleus. The existing facility will be modified to meet the requirements for the Pump Bearing Test Facility (PBTF). An HNPF secondary sodium pump will be modified for use as the bearing test device. The test bearing will be mounted in this pump and supplied with sodium under pressure from a separate pump.

LMEC's recommended test program was based on exhaustive studies and investigations of various approaches which would expedite the testing of FFTF pump bearings. These investigations included comparisons and evaluations of other facilities as well as facilities available at LMEC. Following a tentative selection of the HNPF test loop, an extensive evaluation of this test loop was made to assess the degree to which the facility was capable of satisfying the test program requirements. It was found that several portions of the loop should be replaced for the intended application.

The condition of the 12-in. piping in the existing pump test loop was reviewed. Quality assurance inspections disclosed that the carbon content of the stainless steel was below the nominal value for Type 304, and some pipe welds did not meet requirements of current ASME codes or RDT standards. On these bases, it was decided that this pipe would not be used.

LMEC prepared a planning report which described the proposed test facility and included preliminary cost estimates on proposed method of accomplishment. The recommended PBTF was approved with comments and direction. LMEC will implement the program on this basis.

Work is now in progress on a conceptual system design description for the PBTF. Procurement of needed items of existing AEC-owned equipment has been initiated.

The services of a consultant have been obtained to provide a thorough analysis of the proposed method of hydraulically loading the test bearing.

C. FUTURE EFFORT

The conceptual system design description, which will include designs of alternate loading methods in addition to a static loading device, is planned for completion in October 1969. Procurement and assessment of the AEC-owned surplus equipment is planned for completion in December 1969. A test plan will be prepared on the basis of coordination with BNW test requirements, and a report will be submitted describing in detail the proposed hydraulic loading method.

X. PRECISION MECHANISMS IN SODIUM

(LMFBR Program Plan 3-3, 3-7.3, 3-10.3, 3-11)

J. H. Brindley

A. INTRODUCTION

Sodium coolant in the FFTF and in the LMFBR's will be used at or near 1200°F, resulting in removal of most oxide-bearing surface layers which provide corrosion resistance and, to some extent, lubrication and surface hardness. Thus, accelerated deterioration will be experienced on all engaged motion contact surfaces and may result in unexpected reactor shutdowns from component malfunctions or failures, thereby affecting power production costs quite severely. Thus, the importance of reliability in various mechanisms such as control rod bearings and gears or fuel holddown latches may be projected into a true economic perspective. Literature and experience surveys have shown that little data are available on material wear resistance in sliding, rolling, and fretting applications in sodium environments. Data peculiar to the design of mechanical devices for sodium service are insufficient to permit adequate design of elements for operation above 800 to 900°F. In view of the state-of-the-art and the potentially large financial benefits to be obtained by reducing reactor downtime, it is apparent that basic materials testing followed by prototype mechanisms tests must be performed.

The objective of the Precision Mechanisms in Sodium (PMIS) program is to obtain engineering information for the design of mechanical elements to ensure reliable operation in sodium liquid and vapor to 1200°F for the FFTF and for LMFBR's. The information obtained for bearings, gears, seals, latches, guides, spacers, connectors, and various mechanisms should permit a designer of fuel handling devices, control rod mechanisms, or core/fuel holddown devices to proceed with confidence as to such factors as allowable loadings and clearances, suitable material couples, friction, and wear factors.

B. EXPERIENCE SURVEY

An experience survey has been compiled covering operating experience with mechanical elements associated with the SRE, HNPF, EBR-II, and EFAPP reactor installations. This experience survey contains design descriptions,

operating conditions, and a brief history of maintenance requirements and mechanism malfunctions. Information sources consisted of manufacturing specifications, design drawing files, progress reports, maintenance reports, and contact with plant personnel. Final comments are being coordinated into the report with publication, as Volume II of LMEC-68-5, scheduled for the next report period.

A brief summary of the information presented on each reactor site is presented in the following paragraphs.

1. SRE

The Sodium Reactor Experiment (SRE) was designed with a minimum number of mechanisms required to function in a sodium environment. Consequently, this facility provided only limited information involving mechanical elements which operated in sodium.

Continuous difficulty was experienced with shaft freeze seals on the original freeze-seal-type sodium pumps. Little difficulty was experienced with the SRE-PEP free-surface pumps which were equipped with gas seals. These pumps did not, however, operate at full design temperature (to 1200°F).

Satisfactory operation was obtained with pump impeller wear rings, namely,

- 1) Type 316 SS on 304 SS for approximately 44,000 hr at sodium temperatures to 1030°F
- 2) Type 304 SS on 304 SS for 17,000 hr at speeds to 1500 rpm in 300 to 700°F liquid sodium.

Pump bearings (Colmonoy-5 on Colmonoy-6) also performed satisfactorily.

No difficulties were experienced with a Type 304 SS variable-orifice device operating in liquid and vapor sodium to 700°F.

Use of 300-series austenitic steel against similar material resulted in failure of the core clamps.

2. HNPF

The Hallam Nuclear Power Facility (HNPF) was also designed with a minimum number of mechanisms required to operate in a sodium environment.

Pump bearings (Colmonoy-5 on Colmonoy-6) and wear rings (Type 304 SS on 304 SS) operated well for approximately 20,000 hr in 300 to 945°F liquid sodium at speeds to 850 rpm. However, problems were encountered with foreign matter, inadvertently left in the system during maintenance and/or construction, migrating to the bearing area and causing binding.

Type 304 SS variable orifices for fuel channel flow regulation experienced excessive binding in the actuator mechanism located in the upper (colder) region of the reactor from sodium vapor deposition.

Valves with Stellite-6 wear pads performed satisfactorily in 300 to 900°F liquid sodium.

3. EBR-II

Both the Experimental Breeder Reactor-II (EBR-II) and the Enrico Fermi Atomic Power Plant (EFAPP) plants made extensive use of in-sodium handling and control mechanisms. Careful selection of interfacing materials, component clearances, and loads were required. In general, very satisfactory sodium mechanism operation has been experienced at these plants.

Aluminum-bronze alloys were extensively used at EBR-II for journal bearings and bushings. These components have operated successfully in sodium to 845°F with diametral clearances maintained uniformly quite large at 0.030 in.

Pump bearings (Colmonoy on Type 304 SS) and wear rings (Stellite on Type 304 SS) have operated successfully for over 10,000 hr in 300 to 700°F liquid sodium at speeds to 1075 rpm. However, rubbing and binding was experienced between the pump shaft and an aluminum-bronze labyrinth bushing; the clearance was opened up to 0.120 in. to alleviate the problem.

Valves containing aluminum-bronze bushings and Stellite-6 wear pads have operated without difficulty in 700°F liquid sodium.

A ball bearing failure was experienced in the oscillator rod drive after 5800 hr of exposure to sodium vapor and argon at 150°F.

Difficulty has also been experienced with sodium and sodium oxide buildup on sliding surfaces in the fuel unloading machine, causing sticking and seizing of the gripper mechanism.

4. EFAPP

For mechanisms in sodium, the design approach used was to keep all working clearances as large as possible, usually greater than 0.010 in., and to keep bearing loads light. With one or two exceptions, normal operating stresses in all load-bearing members are kept below 4000 psi.

In general, Stellite-6 and nitrided stainless steel both performed exceptionally well. Stellite-6 is best suited for repetitive wear applications, while the relatively thin nitride case on stainless steel is best suited for applications requiring resistance to self-welding and wear resulting from nonrepetitive or infrequent cyclic operation.

Sodium-sodium oxide deposits accumulated in mechanisms, bearings, a ball valve, and throughout argon blowers, dampers, and heat exchangers while handling sodium components at 300 to 350°F in the transport cask car, causing repeated malfunctions and operating difficulties.

Shallow scoring and cracking of pump bearing pads (Colmonoy) was experienced. These cracks were ground through the hard facing to reduce the hazard of spalling.

Valves throughout the system performed well, with the exception of several bellows leaks. Stellite hard facings were used on sliding surfaces such as guides, seats, and stems.

C. MECHANICAL ELEMENT TESTS

Further analysis of the sliding wear test data obtained in the Materials Compatibility In Sodium (MCIS) program has resulted in the selection of the following material combinations for bearing applications in 900 to 1200°F liquid sodium under high-loadings and low-speed conditions. This selection supersedes that given in the previous progress report.

- 1) Inconel-718 — Udimet-630
- 2) Udimet-630 — K-95
- 3) Udimet-630 — Stellite-6B
- 4) Hastelloy-C — Stellite-1016
- 5) Hastelloy-C — Inconel-718.

In addition, Udiment-630 vs Udimet-630 and Udiment-630 or Inconel-718 vs TZM are combinations which rate serious consideration for journal bearing and other mechanism applications.

A bid package, sent to six qualified vendors requesting quotations for fabrication of journal bearings from the above materials, proved to be disappointing in that only one vendor responded to the request. In compliance with RDT guidance, no further action is planned at this time, since followup of this activity should not be pursued until firm requirements from FFTF on journal bearing applications are received.

In response to a test request (T-20) from BNW/FFTF, planning has been initiated for a control rod drive mechanism (CRDM) test. The CRDM to be tested is shown in Figure 18. It is a hermetically sealed, linear motion device consisting of a lead screw driven by a collapsible rotating and rolling type nut. The roller nut consists of four annularly grooved rollers, two of which are mounted on each of two segments of a pivoted motor-rotor. Each of the two rotor segments has two salient poles to form a four-pole rotor for normal rotation. Pivoting of the segments allows disengagement of the nut from the screw by interruption of stator current for emergency control rod insertion.

The objective of the test is to identify problems that this type of rod drive mechanism will encounter in a sodium environment and to provide basic data for the design of the FTR reference prototype drive mechanism.

The drive mechanism will be operated in a vertical position over a pot of stagnant liquid sodium at temperatures to 1200°F. Argon cover gas laden with sodium vapors will be allowed to freely circulate within the drive mechanism internals.

7693-2570

Figure 18. N.S. Savannah Control Rod Drive Mechanism Operating Parts

XI. MATERIALS COMPATIBILITY IN SODIUM

(LMFBR Program Plan 5-1.6, 5-1.8)

J. H. Brindley

A. INTRODUCTION

Sodium Coolant in the FFTF and in LMFBR's will be used at or near 1200°F, resulting in removal of most oxide-bearing surface layers which provide corrosion resistance and, to some extent, lubrication and surface hardness. Thus, accelerated deterioration will be experienced on all engaged motion contact surfaces and may result in unexpected reactor shutdowns from component malfunctions or failures, thereby affecting power production costs quite severely. In view of the state-of-the-art (little information on material wear resistance in sliding, rolling, and fretting service) and the potentially large financial benefits to be obtained by reducing reactor downtime, it is apparent that basic materials testing must be performed.

The objective of the Materials Compatibility in Sodium (MCIS) program is to generate basic wear data which can be ultimately used in the design of mechanisms for operation in the sodium environment common to LMFBR's. The scope of the program will be defined by the requirements developed through Program Plan Task 3-3.1, "Materials Development Technical Liaison," and other technological requirements as they may occur. The information thus obtained will enable designers of bearings, gears, seals, latches, guides, spacers, connectors, and various mechanisms for fuel handling devices, control rod mechanisms, or core/fuel holddown devices to proceed with confidence as to such factors as allowable loadings, velocity, suitable material couples, friction, wear factors, and vapor deposition effects.

B. SLIDING WEAR TESTS

Testing has continued to determine sliding contact behavior of selected material combinations in high-temperature sodium liquid and sodium vapor environments.

Results obtained during this report period are presented in Table 14.

Test specimen and fixture geometry are identical to that shown and discussed in the previous progress report.

In response to a test request from BNW/FFTF (T-8, Addendum 1), flame-sprayed coatings are being evaluated under sliding wear conditions in sodium as shown in Table 14.

An addendum to NAA-SR-12446* will be published during the next report period summarizing the sliding wear test results and conclusions.

TABLE 14
SLIDING WEAR TEST RESULTS
(Sheet 1 of 4)

Material		Pin Sliding Velocity (cm/sec)	Load (lb)	Coefficient of Sliding Resistance at Test Temperature		Average Specific Wear on Pins (cm ³ /cm ² -kg x 10 ⁻¹¹)
Pin	Plate			Initial	Final	
In 500°F Liquid Cold-Trapped Sodium						
Rex-49	Inconel-718	9.3,11.7,14.1	6.04,4.83,4.03	0.15	0.42	0.57
Colmonoy-4	Colmonoy-5	↓	6.36,5.07,4.24	0.09	0.34	Mat'l buildup on pins
Colmonoy-75	Hastelloy-C		6.42,5.13,4.28	0.16	0.39	Mat'l buildup on pins
Hastelloy-C	Colmonoy-75		6.34,5.07,4.22	0.55	0.49	1.51
Stellite-1016	304 SS		6.27,5.02,4.18	0.28	0.28	No measurable pin wear
304 SS	Stellite-1016		6.49,5.19,4.32	0.52	0.35	0.70
In 900°F Liquid Cold-Trapped Sodium						
Inconel-718	Hastelloy-C	↓	6.03,4.82,4.02	0.42	0.46	1.38
Inconel-718	Udimet-630		6.28,5.02,4.18	0.45	0.30	14.2
Udimet-630	Stellite-6B		6.61,5.29,4.41	0.58	0.48	1.13
Inconel-718 [†]	Inconel-718 [†]		6.03,4.83,4.02	0.33	0.53	18.66
304 SS	Inconel-718 [†]		6.07,4.85,4.04	0.22	0.46	18.07
Inconel-718 [†]	Stellite-1016 [†]		5.94,4.75,3.96	0.27	0.40	43.44

*W. J. Freede, L. Newcomb, and R. S. Kennedy, "Static and Sliding Contact Behavior of Materials in Sodium Environments at Elevated Temperatures," NAA-SR-12446 (September 29, 1967)

[†]Flame-spray coating over a Metco-405 base coat over Type 304 SS base material.

TABLE 14
SLIDING WEAR TEST RESULTS
(Sheet 2 of 4)

Material		Pin Sliding Velocity (cm/sec)	Load (lb)	Coefficient of Sliding Resistance at Test Temperature		Average Specific Wear on Pins (cm ³ /cm-kg x 10 ⁻¹¹)
Pin	Plate			Initial	Final	

In 1200° F Liquid Cold-Trapped Sodium

Hastelloy-C	Hastelloy-C	9.3, 11.7, 14.1	6.9, 5.5, 4.6	0.10	0.12	6.30
Star-J	Stellite-6B		6.5, 5.2, 4.3	0.13	0.11	6.64
Hastelloy-C	TZM		6.5, 5.2, 4.4	0.21	0.21	4.71
Udimet-630	Udimet-630		8.6, 6.9, 5.8	0.35	0.31	Very slight mat'l buildup
Udimet-630	Inconel-718		8.4, 6.7, 5.6	0.35	0.68	3.04
Inconel-718	Udimet-630		8.6, 6.9, 5.8	0.20	0.28	21.7

In 1200° F Liquid Hot-Trapped Sodium

Udimet-630	Udimet-630		6.00, 4.80, 4.00	0.24	0.59	8.19
Inconel-718	Udimet-630		6.04, 4.83, 4.02	0.24	0.38	16.1
Udimet-630	Udimet-630		6.31, 5.04, 4.20	0.40	0.72	2.14
Udimet-630	Inconel-718		6.11, 4.89, 4.08	0.29	0.36	Very slight mat'l buildup
Inconel-718	Udimet-630		6.35, 5.08, 4.24	0.21	0.71	As above

In 500° F Sodium Vapor

Rex-49	Inconel-718		5.75, 4.60, 3.83	0.51	0.37	No measurable pin wear
Colmonoy-4	Colmonoy-5		5.88, 4.70, 3.92	0.38	0.52	No measurable pin wear
Colmonoy-75	Hastelloy-C		6.15, 4.92, 4.10	0.28	0.39	No measurable pin wear
Hastelloy-C	Colmonoy-75		6.04, 4.83, 4.02	0.34	0.45	1.17
Stellite-1016	304-SS		5.98, 4.78, 3.98	0.53	0.42	0.88
304-SS	Stellite-1016		6.16, 4.93, 4.11	0.43	0.41	0.56

TABLE 14
SLIDING WEAR TEST RESULTS
(Sheet 3 of 4)

Material		Pin Sliding Velocity (cm/sec)	Load (lb)	Coefficient of Sliding Resis- tance at Test Temperature		Average Specific Wear on Pins (cm ³ /cm ² -kg x 10 ⁻¹¹)
Pin	Plate			Initial	Final	
In 1200° F Sodium Vapor						
Stellite-1016	K-95	9.3,11.7, 14.1 <				

TABLE 14
SLIDING WEAR TEST RESULTS
(Sheet 4 of 4)

Material		Pin Sliding Velocity (cm/sec)	Load (lb)	Coefficient of Sliding Resistance at Test Temperature		Average Specific Wear on Pins (cm ³ /cm ² -kg x 10 ⁻¹¹)
Pin	Plate			Initial	Final	
In 1200°F Sodium Vapor (continued)						
Inconel-718	Stellite-1016	9.3,11.7,14.1 ↓	6.50,5.20,4.33	0.22	0.22	19.7
Hastelloy-C	Stellite-1016		5.87,4.70,3.92	0.20	0.18	24.2
Inconel-718	Hastelloy-C		6.16,4.92,4.10	0.30	0.43	3.5
Udimet-630	Hastelloy-C		6.11,4.89,4.07	0.13	0.22	2.9
K-95 (WC)	K-95 (WC)		6.67,5.34,4.45	0.16	0.12	0.6
Hastelloy-C	K-95 (WC)		6.65,5.32,4.43	0.20	0.24	3.9
K-95 (WC)	Hastelloy-C		6.06,4.85,4.04	0.07	0.11	0.8
Hastelloy-C	Udimet-630		6.05,4.84,4.03	0.24	0.18	11.1
K-801 (WC)	Stellite-6B		6.22,4.98,4.15	0.40	0.40	1.5
Stellite-1016	Udimet-630		6.02,4.82,4.01	0.42	0.31	3.5
Stellite-6B	Udimet-630	6.17,4.94,4.11	0.26	0.37	28.7	

XII. STEAM GENERATOR AND INTERMEDIATE HEAT EXCHANGER PERFORMANCE EVALUATION

(LMFBR Program Plan 3-6, 3-12)

R. J. Gimera

A. INTRODUCTION

Prototype models of intermediate heat exchangers and sodium-heated steam generators are to be tested in the Sodium Components Test Installation (SCTI) under the Sodium Component Development Program. The objective of the tests is to evaluate the performance of these heat exchangers so as to advance the development and design of reliable plant-sized units. At present, the units installed in the SCTI are an intermediate heat exchanger designed and built by Alco Products, Inc., and a steam generator designed by Alco and manufactured by Baldwin-Lima-Hamilton (BLH) Corp. The performance evaluation program had been previously conducted by the United Nuclear Corporation (UNC) and is now being continued by LMEC.

B. GENERAL

Testing of the Alco/BLH steam generator and the Alco intermediate heat exchanger (IHX) at the SCTI was resumed during this period after a 2-yr shut-down. Concurrently, LMEC assumed responsibility for evaluation of these units. This responsibility was formerly held by United Nuclear Corp. (UNC).

The design, construction, and testing of these units were planned as part of the Sodium Component Development Program. The program has the purpose of testing scaled-down prototypes of steam generators for sodium-reactor power plants.

Analyses performed by UNC, including their evaluation of results of SCTI test results during 1966, are being employed as reference data for the present evaluation effort.

The Alco IHX is a vertical, counterflow shell and tube design, 28 ft long by 3 ft in diameter. It contains 462 tubes of Type 304 stainless steel, 1/2-in. OD by 0.035-in. wall thickness. The shell side contains 27 disc and donut baffles.

The Alco/BLH steam generator is a vertical, once-through, counterflow unit 42 ft long by 32 in. in diameter. It contains 300 tubes of 1/2-in. OD and 0.104-in. wall thickness, with a sine-wave bend at their upper end. The shell side contains

57 disc and donut baffles. The top tube sheet is protected by a 28-in. cover gas space. The bottom tube sheet is protected by a thermal baffle of ten 1/4-in. steel plates spaced 1/8 in. apart. It is made of Type 316 stainless steel with an Inconel coating on all steam-side surfaces.

The steam generator and IHX are each instrumented with approximately 100 thermocouples for measuring temperatures of the shell-side sodium and of various points in the structures. Figure 19 shows the location and identification of most of these thermocouples as well as the principal terminal measurement transducers of the units.

The SCTI, a facility constructed specifically for this type of testing, includes a primary sodium loop linking the IHX to a gas-fired sodium heater, a secondary sodium loop linking the IHX to the steam generator, and a steam/water loop which includes pressure reducers, desuperheaters, a condenser, a feedwater pump, and feedwater heaters.

The SCTI operation during this period consisted of the greater portion of the plant performance tests. While primarily planned to check out the facility, these tests include intervals of steady-state operation at 20, 40, 60, 80, and 100% of rated load. It was decided to use test data obtained during these intervals to acquire experience in methods of analysis, investigate data and instrumentation problems, and obtain initial estimates of the performance of the units.

Up to this time, detailed analysis has been performed for two intervals of operation as follows:

- 1) A near steady-state interval during the temperature rise phase of the plant performance tests on March 26 with steam outlet temperature of 804°F
- 2) The 20% load steady-state level which was reached on May 15.

The 40% load level has also been run, but the data are not yet analyzed.

Procedures and results of analysis are described in the following paragraphs.

1. Comparison of Redundant Measurements

As a first step in establishing validity of the SCTI data, it was necessary to make a comparison of those temperatures which should be equal by virtue of their location in the system. This comparison is presented in Table 15. Agreement for

Figure 19. Alco/BLH Instrumentation Schematic

TABLE 15
COMPARISON OF REDUNDANT TEMPERATURE MEASUREMENTS

Secondary Sodium Hot-Leg Temperature (°F)	3/26/69	5/14/69
IHX Secondary Outlet TR 104-61	916	1070
Steam Generator Sodium Inlet TR 103-61	913	1065
Steam Generator Upper-End Internal TR 103-38 and -39	909	1068
Secondary Sodium Cold-Leg Temperature (°F)		
IHX Secondary Inlet TR 104-64	713	663
Steam Generator Sodium Outlet TR 103-62	714	659
Steam Generator Sodium Outlet TR 107	714	-
Primary Sodium Hot-Leg Temperature (°F)		
IHX Primary Inlet TR 104-62	917	1070
IHX Upper-End Internal TR 104-30	921	1070
Sodium Heater Outlet TR 101	910	1060
Primary Sodium Cold-Leg Temperature (°F)		
IHX Primary Outlet TR 104-63	754	750
IHX Primary Outlet TR 103	758	775
Feedwater Inlet Temperature (°F)		
TR 103-63	583	602
TRC 201	592	604
Steam Outlet Temperature (°F)		
TR 103-60	804	1049
TR 200	800	1054
Average of Two Upper Surface Thermocouples on Steam Generator Upper Tubesheet	808	N. G.
IHX Upper Terminal Fluid ΔT (°F)		
By TdR 101	~0.0	~0.5
By Difference of TR 104-61 and -62	~0.9	~0
IHX Lower Terminal Fluid ΔT (°F)		
By TdR 101	45	87
By Difference of TR 104-64 and -63	42	87
Steam Generator Upper Terminal Fluid ΔT (°F)		
By TdR 101	104	9
By Difference of TR 103-60 and -61	107	16
Steam Generator Lower Terminal Fluid ΔT (°F)		
By TdR 101	134	58
By Difference of TR 103-62 and -63	131	57

each set of data is generally within 7°F. However, there is a distinct 10°F bias between the sodium heater outlet temperature, TR 101, and the two IHX primary inlet temperatures. There is also an unexplained difference in the May 15 data between the two primary sodium cold-leg temperatures, TR 104-63 and TR 103. This difference was resolved in favor of the former on the basis of its consistency with the IHX lower terminal fluid ΔT . This discrepancy may also be related to the IHX primary outlet temperature oscillation which is discussed later.

Closer maintainance of steady-state conditions and more rigorous time correlation among the various recorders will hopefully improve these comparisons as testing proceeds.

2. Accuracy of Thermocouples

The internal thermocouples in the IHX and steam generator have been in place since the units were built and have never received individual calibration. There has been concern, therefore, as to their precision. A method of evaluating precision is provided by three locations in the IHX where sets of 12 thermocouples are located at the rim of the same disc baffle and should thus measure the same temperature. The spread of measurements for these was as follows (see Figure 19 for location of each group):

Thermocouple Identification	Baffle Location from Bottom	Temperature Spread (°F)	
		3/26/69	5/15/69
7 through 18	3	6	10
31 through 42	12	3	1
43 through 54	13	1	3

It is possible that the temperature spread includes local stream variations in sodium temperature as well as transducer scatter.

Thirty-two steam generator thermocouples and two IHX thermocouples are currently inoperative. Many of these are inaccessible for repair; however, good definition of shell-side sodium temperature profiles has been found possible for both units.

C. STEAM GENERATOR AND IHX SYSTEM PERFORMANCE

Table 16 lists performance parameters for the two sets of data. In computing these conditions, the only flow measurement utilized is the feedwater flow which is obtained from a recently calibrated venturi flowmeter. Secondary sodium flow was obtained by means of a steam generator heat balance. Primary

TABLE 16

ALCO/BLH STEAM GENERATOR AND ALCO IHX SYSTEM PERFORMANCE

Parameter	3/26/69 910 hr	5/15/69 1330 hr	Estimated by UNC
Feedwater Flow (lb/hr)*	28,400	22,490	23,100
Feedwater Inlet Temperature (°F)*	583	602	600
Steam Outlet Temperature (°F)*	804	1,049	1,050
Steam Outlet Pressure (psia)	1,943	2,200	2,200
Secondary Sodium Hot-Leg Temperature (°F)	914	1,065	1,065
Secondary Sodium Cold-Leg Temperature (°F)	714	660	665
Secondary Hot-to-Cold Temperature Drop (°F)*	200	405	400
Primary Sodium Hot-Leg Temperature (°F)	917	1,070	1,065
Primary Sodium Cold-Leg Temperature (°F)	756	750	765
Primary Hot-to-Cold Temperature Drop (°F)*	161	320	300
Secondary Sodium Flow (lb/hr)	348,000	161,130	170,000
Primary Sodium Flow (lb/hr)	434,000	203,930	227,000
Primary/Secondary Flow Ratio	1.24	1.27	1.33
Thermal Power (Mwt)	6.23	5.83	6.0
Percent Rated Power	20.7	19.4	20
Primary Sodium ΔT	161	320	300
Secondary Sodium ΔT	200	405	400
IHX Lower Tube Sheet ΔT	42	87	100
IHX Upper Tube Sheet ΔT	~0	~0	~0
Steam Generator Lower Tube Sheet ΔT	132	58	65

*Specified test condition

sodium flow was obtained by means of an IHX heat balance using the previously obtained secondary flow. This method places no reliance on the magnetic-type sodium flowmeters, which do not have a reliable calibration.

The 20% load conditions are also compared in Table 16 with the specified test conditions for this level as defined by UNC. Agreement is good enough to permit a comparison of the steam generator internal performance with UNC's predicted performance as discussed in the following paragraphs.

1. IHX Performance

The IHX primary (shell side) sodium temperatures are measured with internal thermocouples located at 16 different levels along the sodium flow path. A plot of these temperatures from data recorded on May 14 as a function of the percentage of heat transfer area (zero percent at bottom of IHX) is presented in Figure 20. The terminal temperatures are also included for reference purposes.

The overall heat transfer coefficient (U) for the cross-flow region of the IHX was determined from these data. The cross-flow region investigated extends from the upper end of the shroud at the bottom of the IHX to the last baffle at the upper end of the heat exchanger. This portion encompasses 64% of the total IHX heat transfer area. The secondary sodium temperatures are not measured at the beginning and end of the cross-flow area. These values are needed for terminal temperatures in the analysis and are calculated using the relationship

$$\frac{TPU - TPT}{TPU - TPL} = \frac{TSU - TST}{TSU - TSL} ,$$

where

TPU = IHX primary sodium upper terminal temperature

TPL = IHX primary sodium lower terminal temperature

TSU = IHX secondary sodium upper terminal temperature

TSL = IHX secondary sodium lower terminal temperature

TPT = primary sodium temperature at end of cross-flow area

TST = secondary sodium temperature at end of cross-flow area.

All of these temperatures are measured except TST, which can be calculated with the above relationship. The primary and secondary sodium temperatures at the upper end of the cross-flow area are equal; therefore, the LMTD cannot be evaluated based on these temperatures. Therefore, an intermediate point in the IHX must be selected where a difference exists between the primary and secondary temperatures. The heat transfer coefficient can then be evaluated between this point and the lower end of the cross-flow area. To minimize the effect of local variations in the heat transfer coefficient on the overall value, the heat transfer coefficient was calculated using each of the intermediate points in the cross-flow area up to 65% of the total IHX area (76% of the cross-flow area),

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Figure 20. IHX Primary Sodium (Shell Side) Temperature Profile – SCTI Data
(May 14, 1969; ~1330 hr; 20% rated power)

and the average of these values was used for the overall heat transfer coefficient. A value of $1533 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$ was obtained from this analysis. The individual values of U varied from 1400 to $1650 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$. The UNC calculations predicted an overall heat transfer coefficient of $1540 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$ for this region at rated operating condition. The value calculated from test data is in excellent agreement (though not directly comparable) with the predicted value. The primary sodium temperature profile for the cross-flow section was calculated with a constant value of $U = 1533 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$. The resulting function is plotted in Figure 20. As is evident in this plot, a very good fit of the primary sodium temperature as a function of heat transfer area can be obtained with a constant value for the heat transfer coefficient in the cross-flow region.

A separate analysis must be performed to evaluate the heat transfer coefficient near the primary sodium outlet (bottom) of the IHX. Evaluation of U in the axial flow region at the top of the IHX cannot be performed using these data because of the lack of a significant difference between the primary and secondary sodium temperatures in this region.

2. Steam Generator Performance

The steam generator sodium temperature profile is defined with a series of 27 thermocouples located at the center of each donut baffle in the sodium flow path. The sodium temperature profile in the steam generator for the 20% power operation (May 14, 1969) is presented in Figure 21.

The UNC-predicted steam generator sodium temperature profile for the 20% power operation is included in Figure 21 for comparison. Although the measured terminal temperatures agree well with the predicted values, the profile through the steam generator is considerably different than that predicted. UNC apparently calculated only the points at which saturated liquid and saturated vapor were achieved in the water-steam system and connected these points and the terminal temperatures with straight lines. The Alco heat transfer method for the superheat region which was adapted by UNC should yield an exponential curve in the superheat region similar to the measured profile.

The test data also indicated that 10% of the heat transfer area was required to preheat the water to the saturation point and then an additional 14% was required to vaporize the water. UNC predicted that only 7% of the area would be required

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Figure 21. Steam Generator Sodium Temperature Profile
(May 14, 1969; ~1330 hr; 20% rated power)

to preheat the water and an additional 7% required to vaporize the water into steam. This would indicate that the steam generator is less efficient than predicted in these two regions.

The temperature profile through the sodium and argon in the upper end of the steam generator was also investigated. Two thermocouple locations were available in the sodium and five locations were recorded in the argon. The temperature changes gradually from the sodium terminal temperature of 1065°F to the steam terminal temperature of 1050°F through this region. No discontinuity in temperature is evident at the sodium-argon interface.

D. IHX PRIMARY OUTLET TEMPERATURE OSCILLATION

A primary sodium flow rate of approximately 40% of rated flow has been employed for most of the operating duration of the plant performance tests. It was necessary, however, to reduce flow to the 20% level (220,000 lb/hr nominal) to obtain rated conditions for the 20% operating level. During the intervals when flow was at this level, an oscillation had been observed in IHX outlet temperature, TR 104-61. With the TR 104 Bristol recorder set in its visual indicating mode, this anomaly may be observed as an apparently random oscillation with a typical frequency of about 5 Hz. As the recorder has a single-channel sampling rate of 1 sample per second, it has not been possible to record an accurate time trace of this oscillation. Figure 22 shows a typical interval of recording at the one per second rate. The maximum total amplitude is over 50°F; however, the amplitude of a single oscillation cycle is more typically about 20°F. With flow at the 40% level, the oscillation is barely detectable with a total amplitude of only a few degrees.

A check to determine whether this mode of oscillation showed up on any related system measurements yielded generally negative results. None of the other three IHX terminal temperatures showed any oscillation. Primary and secondary sodium flows were stable. IHX internal thermocouples near the primary outlet end were stable. A thermocouple in the IHX primary outlet line, 20 ft downstream of the oscillating thermocouples (TR 102-1), was stable. The phenomenon thus appears to be localized at the IHX primary outlet. A possible explanation of the oscillation effect is proposed as follows.

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Figure 22. Recording of IHX Outlet Temperature at Approximately 20% Flow (sampled data, 1 Hz)

In addition to low sodium flow rate, the conditions associated with oscillation include a large change in sodium temperature within the bottom baffle space of the IHX. For example, Figure 20 shows a 58°F change in IHX primary sodium temperature within the bottom baffle space during the 20% load interval. While the overall arrangement of the IHX is counterflow, each interbaffle space is a local cross-flow heat exchanger, with a gradient in secondary/primary ΔT between top and bottom of the baffle space. As a result, it is possible to have appreciable temperature differences between cross-flow streams at the top and bottom of the baffle space. This difference is illustrated by Figures 23 and 24. Figure 23 shows the shell side flow geometry at the lower end of the IHX. Figure 24 shows the contrasting temperature change of two streams within the baffle space. Lines A and B of Figure 24 correspond to streams A and B, respectively, of Figure 23. For the 20% load conditions, stream A would encounter a secondary sodium temperature as high as 737°F, while stream B would encounter a secondary sodium temperature as low as 660°F. Thus, with both streams at the same initial temperature, stream B would be cooled considerably more than stream A. The various streams should combine to yield a mixed

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Figure 23. IHX Primary Exit Flow Geometry

7693-2574

Figure 24. Estimated Temperature Gradients within Bottom Baffle Space of IHX at 20% Load

mean IHX outlet temperature. However, the short flow path from this space to the primary exit nozzle may not permit thorough mixing of these streams. The observed oscillation may thus represent alternation of sodium slugs from various streams within the baffle space. The low flow rate associated with the oscillation would tend to magnify this effect by providing the maximum ΔT gradient within the baffle space and the poorest conditions for mixing. Circumferential temperature differences caused by the unsymmetrical exit geometry could also contribute to the effect.

E. STEAM GENERATOR LOWER TUBE SHEET TEMPERATURES

The most serious anomaly reported in the UNC analysis was the apparent failure of the steam generator lower tube sheet thermal shield to prevent significant heating of the tube sheet by sodium. UNC reported that the upper surface of the tube sheet was considerably hotter than was predicted by their finite-element heat transfer model using the measured terminal fluid temperatures as tube sheet boundary conditions. They also found an asymmetry in tube sheet external temperatures.

A sodium drainage path through the tube sheet existed during the test analyzed by UNC. The path has since been closed off in the belief that this action would correct the temperature problem.

The March 26 tube sheet temperature data were analyzed in a manner essentially parallel to that employed by UNC. Predicted temperatures at the various thermocouple locations were obtained by use of a 440-node TAP steady-state model of the tube sheet. However, the present analysis included two significant differences in temperature boundary conditions from the UNC conditions. These were as follows:

- 1) UNC used the sodium outlet temperature as the boundary temperature across the entire top face of the thermal shield. The current data show that the shield face temperature inboard of the tube bundle is 783°F, or 69°F higher than the sodium outlet temperature. This is a plausible measurement, as the inboard region of the shield face is upstream of the bottom cross-flow heat transfer pass. The measured temperature was therefore used as the TAP input for this area with an intermediate temperature used in the tube-bundle region as shown in Figure 25.

Figure 25. Temperature Boundaries Assumed for Steam Generator Tube Sheet Heat Transfer Analysis

- 2) The UNC data apparently included a feedwater temperature error of -20°F . This conclusion is based on a comparison of feedwater and external barrel temperatures for both the UNC and current data. Note in Figure 26 (reproduced UNC data) that the feedwater temperature is 20°F below barrel thermocouple measurements.

Figure 27 shows the comparison of measured and predicted tube sheet temperatures. Figure 26, a reproduction of the original UNC data, is shown for comparison of UNC and current results. The following observations are made:

- 1) In the current data, thermocouple measurements on the tube sheet surface outside the tube bundle (thermocouples No. 1, 3, 7, and 9) are close to or below predicted value.
- 2) If UNC had corrected their sodium and feedwater temperature boundary conditions as per the two differences discussed above, it appears that the temperature discrepancies outside the tube bundle would have largely been eliminated.
- 3) Both the UNC and current data show temperatures within the tube bundle (thermocouples No. 2 and 8) are well above predicted value and on a par with those outside the tube bundle.

It thus appears that the thermal shield functions as intended, but the steam tubes do not provide the predicted cooling to the tube-bundle region.

The current data were also compared to UNC data as regards symmetry of external temperatures. Figure 27 shows that the set close to the shell liner drain slot (thermocouples No. 66, 76, and 75) are generally higher than the two corresponding sets located 120 degrees away. The direction of asymmetry agrees with the UNC data and the magnitude of asymmetry is somewhat greater for the current data.

Figure 27 also shows that measured temperatures of external shell thermocouples are well below predicted values. The TAP model may need revision in this area.

Figure 28 shows results for a similar comparison of test and predicted temperature for the May 15 data. Results generally support the conclusions based on the March 26 data. However, the lower terminal fluid temperature difference for the May 15 data tends to result in less significant comparisons.

Figure 26. Temperatures in Steam Generator Lower Tube Sheet Area for "Rise-to-Power" Test

7693-2576

Figure 27. Steam Generator Lower Tube Sheet Thermocouple Data

Figure 28. Steam Generator Lower Tube Sheet Temperature Data

F. STRUCTURAL ANALYSIS OF IHX AND STEAM GENERATOR

A preliminary analysis of the thermal deflection of the plugged tubes, relative to the unplugged tubes, in the Alco/BLH steam generator revealed that the tubes could be making contact. A more detailed investigation is currently being conducted, utilizing numerical computer analysis techniques to more accurately define this problem. An attempt is being made to incorporate the steam generator thermal analysis data in the final results of the tube deflection. The original analysis was performed based on the thermal data extracted from United Nuclear Corporation Document UNC-5154, "Performance Evaluation of Heat Exchangers for Sodium-Cooled Reactors."

A letter was published giving the strain gage rosette reference point locations for gage installations on the Alco IHX and Alco/BLH steam generator for the plant performance test scheduled for the SCTI facility. This document specifies the location of 164 strain gages and 53 thermocouples, which are required to obtain the necessary data for the evaluation of these components. The distribution of the strain gages and thermocouples is listed in Table 17. The rosette reference point locations are indicated in Figures 29 through 32.

A meeting at Babcock and Wilcox Research and Development Division at Alliance, Ohio, was arranged on June 5 for the purpose of discussing installation procedures and test data results obtained by B&W on the Microdot 425 strain gage. The discussion of several topics and the exchange of ideas between B&W and LMEC has significantly benefited the strain gage calibration program.

A cursory review of the Alco IHX tube vibration problem has been completed. Two internal study reports were reviewed to obtain background and knowledge of past efforts to determine tube vibration characteristics. A study was then completed to investigate the advisability of further test efforts to investigate the IHX tube vibrations. This study results in a test plan to provide a means of determining the type of metal-to-metal impacting which occurs within the IHX (tube-to-tube, tube-to-shroud, and tube-to-tube baffle), as well as the location and dynamic characteristics of the unit. The proposed test method was to drain the secondary system, install accelerometers inside the tubes, and run a series of flow ramps to determine the tube dynamic characteristics as a function of primary sodium flow rate. In addition, it was suggested that a quick laboratory test be conducted on a few tubes simulating the IHX unit. The purpose of this experiment would be to verify the test procedure and obtain increased confidence in the test method prior to opening the IHX unit.

TABLE 17
STRAIN GAGE AND THERMOCOUPLE SUMMARY

Series	Microdot	Armour D - Platinum	Thermocouples
Intermediate Heat Exchanger			
100	33 (420)*	9 (6* on-line)	11 [†]
200	6 (425)*	2	2 [†]
300	22 (425)	6	8 (2 [†] on-line)
TOTAL	61	17	21
Steam Generator			
100	45 (420)*	11 (10* on-line)	15 [†]
200	9 (425)*	1*	3 [†]
300	16 (425)	4	6
400	-	-	8 [†]
TOTAL	70	16	32

Notes:

- 1) To further clarify and finalize rosette reference points and gage locations on the actual hardware, an installation drawing will be made.
- 2) A definition of the rosette configuration and its reference point will follow in a separate letter.

*Strain gages on-line = $(33 + 6 + 6) + (45 + 9 + 10 + 1) = 110$

†Thermocouples on-line = $(11 + 2 + 2) + (15 + 3 + 8) = 41$

Figure 29. Proposed Strain Gage Locations on IHX Lower Tube Sheet Region

Figure 30. Proposed Strain Gage Locations on IHX Upper Tube Sheet Region

Figure 31. Proposed Strain Gage Locations on Steam Generator
Lower Tube Sheet Region

Figure 32. Proposed Strain Gage Locations on Steam Generator Upper Tube Sheet Region

XIII. INSTRUMENTATION TESTING, EVALUATION, CALIBRATION, AND STANDARDS

(LMFBR Program Plan 4-1.4, 4-7.1 through 4-7.8, 4-7.10, 4-7.11)

J. W. McCarty

A. INTRODUCTION

The overall objectives of this project are: (1) to establish capabilities and facilities to develop and maintain standards of measurement; (2) to provide fixed, reproducible, known, sodium environmental conditions; and (3) to perform evaluation testing, calibration, and standardization functions for instrumentation used in the LMFBR program. Included in this project will be the determination of testing and test facilities requirements, modification of existing LMEC facilities, and design of new installations for testing and calibrating instrumentation developed under the LMFBR program. The project will also provide for testing and evaluation of commercial strain gages and for their adaptation to use in 1200°F sodium applications.

The basis for all planning and testing of instrumentation is Section 4 of the LMFBR Program Plan.

B. HIGH-TEMPERATURE STRAIN GAGE MEASUREMENTS

1. Evaluation and Analysis Procedures

Two techniques were tested for separating the gage from the calibration bar: (1) a hand-chiseling technique using a single-edge razor blade and (2) a machining technique using a mill-saw.

Analysis of the data resulting from tests on 12 gages removed using each technique (24 total gages) indicated less zero shift and gage factor variations using the mill-saw than with the chiseling technique. The variations in apparent strain due to temperature did not show any significant difference between techniques. The variation in apparent strain would appear to be the more severe problem, being on the order of 250 microstrain ($\mu\epsilon$) at 500°F and $\pm 200 \mu\epsilon$ at 900°F.

Tests were performed to evaluate the gage characteristics in tension and compression. Preliminary evaluation indicates zero shift each time the gage is cycled from tension to compression. The gage factor of the gage is essentially the same in compression as in tension.

The results of the shim separation tests and the tension/compression tests indicate a problem in either the concept of the intermediate shim or the weld techniques used to attach the gage. Conversations with NASA-FRC personnel and Microdot indicated that they were not satisfied with the Microdot Rollectrode, which is the same piece of equipment LMEC has been using for spot-welding the gages. The prime objection was inconsistent welds resulting from the inability of the operator to maintain uniform pressure.

Weld tests have been completed using a Unitek pressure trip hand probe. The data from this test showed a significant improvement in gage factor predictability from first to second application of the gage. Even though the chiseling technique was used to remove the gage after the first installation, the gage factor variations were less than the mill-saw test specimens. Only minor improvement in apparent strain was noted. A comparison test of the chiseling and mill-saw technique will be made using the pressure trip weld method for both.

2. Axial Calibration Fixture (G. J. Twa and M. G. Scheller)

The axial calibration system consists of an accurately machined bar, to which the strain gages to be calibrated will be attached, and a Baldwin-Wiedeman universal test machine (see Figure 33). Each calibration bar is calibrated by measuring strain, for varying loads applied to the bar in the test machine.

During actual gage calibration, all that would be monitored would be the load and individual gage output (see Figure 34).

To measure the strains induced during loading, an extensometer system, using a direct-current differential transformer (DCDT), was designed and installed on each of three calibration bars during their calibration. A repeatability verification was attempted with negative results. Several problems were found:

- 1) The DCDT was affected by spot-welding thermocouples on the bar.
- 2) A lubricant was necessary at high temperature.
- 3) The spring tension on the gage blocks affected the reading.

7694-10104A
Figure 33. Axial Load Strain Gage Calibration Facility

NOTES:

1. UNLESS SPECIFIED, TOLERANCE ON DECIMAL DIMENSIONS TO BE ± 0.001 in.
2. MATERIAL TO BE INCONEL X-750 HEAT TREAT PRIOR TO FINAL SIZING PER AMS 5668
3. ALL DIAMETERS TO BE CONCENTRIC TO A LINE CONNECTING THE CENTERS OF THE END DOWEL PINS WITHIN ± 0.001 in.
4. OPPOSITE FLATS OF THE SPECIMEN SHALL BE PARALLEL WITHIN 0.001 in./in.
5. ADJACENT FLATS SHALL BE PERPENDICULAR WITHIN ± 3 min OF ARC
6. THE DEVIATION OF THE GEOMETRIC CENTER OF SECTION A-A FROM A LINE CONNECTING THE CENTERS OF THE END DOWEL PINS SHALL NOT EXCEED 0.001 in.
7. $\sqrt{32}$ FINISH ALL OVER

7693-5575

Figure 34. Axial Load Strain Gage Calibration Specimen

- 4) There appeared to be some drag in the DCDT connecting elements, causing a difference between the readings going up in load and coming down.

- 5) The setup was critical and time consuming.

The Gaertner micrometer microscope was also used to measure strain. Not only were there repeatability problems with the DCDT but the Gaertner and DCDT data differed by as much as 25%.

The clamping assembly used with the bar in both the DCDT and Gaertner setups were modified to assure a tighter fit between the pins and the extensometer seats that are machined in the calibration bar. The improvement in the data resulting from this modification is summarized in the following sections. While both the Gaertner and DCDT data showed marked improvement, the Gaertner was selected as the primary method for the bars.

3. Methods and Results for Calibration Bars

The Gaertner micrometer microscope was calibrated using a stage micrometer consisting of a glass plate with lines etched at 0.001- and 0.010-in. spacing. A series of measurements was taken and then averaged to obtain the scale factor (microinches per turn of dial reading). The stage micrometer was calibrated using a Doall tool maker's microscope, which had been calibrated using a master set of gage blocks that are traceable to the National Bureau of Standards (NBS). Thus, the Gaertner micrometer microscope is calibrated to an NBS standard measurement and may be used as a calibration standard for measurement of small displacements.

The bar calibrations were performed at four temperatures (ambient, 350, 625, and 900°F). At each temperature, a load was applied from 500 to 9500 lb and a total of five output values were read in increasing and decreasing load increments. A minimum of 14 load cycles were applied at each temperature. The readings for the 14 cycles were then averaged to minimize operator reading error.

The data obtained from these tests were processed to obtain the measured strain in the bar vs applied load. The measured strains were then used in the

following statistical analysis equations based on the small sample theory (Student's t distribution) to calculate mean, standard deviation, and confidence limits.

1) Mean:

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i$$

2) Standard deviation:

$$S = \sqrt{\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n - 1}}$$

3) Confidence limits:

$$X_U = \bar{X} + t \frac{S}{\sqrt{n}}$$

$$X_L = \bar{X} - t \frac{S}{\sqrt{n}}$$

where n = number of measurements and t = Student's t (based on $n - 1$).*

The Modulus of Elasticity, E , was calculated in the following manner:

$$E = \frac{P}{\Delta \epsilon A} ,$$

where

P = Δ applied loads (lb)

$\Delta \epsilon$ = measured strain ($\mu\epsilon$)

A = effective area of bar (in.²).[†]

*Experimental Statistics, U.S. Dept of Commerce, NBS, Handbook 91, Table A-4.

[†]The area used was 0.5745 in.² and was an average area for the three bars.

The above data are shown in Table 18. In Table 19, the calibration data are summarized. The maximum deviation between bars 1 and 3 is 3.3%. This is a good comparison, considering geometric and materials differences in the two bars. A comparison of the DCDT data to the two-bars Gaertner data shows a maximum difference of 3.7%, but it should be noted that this required special setup procedures. Table 20 is an average of all data obtained — DCDT and Gaertner — and compares the individual calibrations to this average value.

The Gaertner calibration data for bars 1 and 3 in the form of applied load vs measured strain are shown in Figures 35 and 36, while a comparison plot is shown in Figure 37.

The averaged data in Table 20 are shown in Figures 38 and 39; they were calculated in the following manner:

$$\text{Average Value} = \frac{\epsilon_{1a} + \epsilon_{1b} + \epsilon_{1c}}{3}$$

$$\text{Difference (\%)} = \left(\frac{\epsilon_{1a} - \text{avg value}}{\text{avg value}} \right) \times 100\%$$

where

ϵ_{1a} = measured strain (DCDT, Bar 3)

ϵ_{1b} = measured strain (Gaertner, Bar 3)

ϵ_{1c} = measured strain (Gaertner, Bar 1).

The maximum difference was 2.4%.

4. Modulus of Elasticity

The "typical" modulus of elasticity (E) was obtained from nine reference sources; these values are plotted in Figure 40. Even among typical values of Young's Modulus, there is considerable differences based on the source of information; however, it is recognized that E values can have deviations from lot to lot of a particular metal and from heat treat to heat treat of specimens. Therefore, Figure 41 represents an envelope that encompasses all of the sources listed in Figure 40. The solid dot at room temperature conditions on the plot represents the data from two strain gages installed at the center of the bar and averaged over two load cycles. The accuracy of the gages and their readout equipment is nominally 2%.

TABLE 18
SUMMARY OF STRAIN CALIBRATION DATA - MEAN, STANDARD DEVIATION,
AND CONFIDENCE LIMITS AT 95%

Temperature (°F)	Instrument Type*	Strain Gage Bar 1				Strain Gage Bar 3				Standard Deviation		Standard Deviation	
		Strain	E x 10 ⁻⁶	Confidence 95% (μ in. /in.)		Strain	E x 10 ⁻⁶	Confidence 95% (μ in. /in.)		(μ in./in.)	E (psi)	(μ in./in.)	E (psi)
		(μ in./ in.)	(psi)	X _U	X _L	(μ in./ in.)	(psi)	X _U	X _L	Bar 1	Bar 3	Bar 1	Bar 3
75	G ↓	570.2	27.47	579.3	561.1	575.3	27.23	588.5	562.0	15.7	27.5	0.77	1.3
350		630.6	24.84	642.2	619.0	611.4	25.62	627.3	595.6	20.4	27.5	0.80	1.15
625		664.4	23.58	678.6	650.2	678.5	23.08	693.5	664.4	24.7	25.9	0.88	0.88
900		741.5	21.13	757.5	725.5	717.9	21.82	734.3	701.5	27.6	28.4	0.79	0.86
75	DCDT ↓	-	-	-	-	594	26.37	-	-	-	-	-	-
350		-	-	-	-	624	25.11	-	-	-	-	-	-
625		-	-	-	-	682	22.97	-	-	-	-	-	-
900		-	-	-	-	736	21.29	-	-	-	-	-	-

*G = Gaertner micrometer microscope

DCDT = Direct-current differential transformer

TABLE 19
STRAIN GAGE CALIBRATION DATA SUMMARY AT Δ LOAD = 9000 POUNDS

Temperature (°F)	Calibration Bar 1G		Calibration Bar 3G		Difference* Strain and E (%)	DCDT - Bar 3		Difference† Strain and E (%)
	Strain (μ in. /in.)	E x 10 ⁻⁶ (psi)	Strain (μ in. /in.)	E x 10 ⁻⁶ (psi)		Strain (μ in. /in.)	E x 10 ⁻⁶ (psi)	
75	570.2	27.47	575.3	27.23	0.9	594	26.37	3.7
350	630.6	24.84	611.4	25.62	3.1	624	25.11	0.5
625	664.4	23.58	678.5	23.08	2.1	682	22.97	1.6
900	741.5	21.13	717.9	21.82	3.3	736	21.29	1.0

$$*\% \text{ Difference} = \frac{\epsilon(\text{Bar 3}) - \epsilon(\text{Bar 1})}{\epsilon(\text{Bar 3})}$$

$$\dagger\% \text{ Difference} = \frac{\epsilon_{\text{Avg}(1\text{G}, 3\text{G})} - \epsilon_{\text{DCDT}}}{\epsilon_{\text{Avg}(1\text{G}, 3\text{G})}}$$

TABLE 20
STRAIN GAGE CALIBRATION DATA –
COMPARISON, AVERAGE

Temperature (°F)	E x 10 ⁻⁶ Average* (psi)	% Difference		
		Bar 1G†	Bar 3G§	DCDT**
75	27.02	1.7	0.8	2.4
350	25.19	1.4	1.7	0.3
625	23.21	1.6	0.5	1.0
900	21.41	1.3	1.9	0.6

*Average of DCDT and Gaertner data (DCDT – Bar 3,
Gaertner – Bars 1, 3)

† $\frac{\text{Avg} - \text{Bar 1}}{\text{Avg}}$ (100%)

§ $\frac{\text{Avg} - \text{Bar 3}}{\text{Avg}}$ (100%)

** $\frac{\text{Avg} - \text{DCDT}}{\text{Avg}}$ (100%)

Figure 42 is a comparison of the calculated E values from the measured strain when bars 1 and 3 were calibrated with the Gaertner. In Paragraph B.3, it was noted that an average effective area was used; this could result in an error of 1% and will be eliminated in the final calculations.

Figure 43 is a comparison of the calculated E values from measured strains on bar 3, once with the DCDT and once with the Gaertner.

LMEC-69-30
191

Figure 35. Calibration Data — Strain Gage Bar No. 1

7693-2582

LMEC-69-30
192

Figure 36. Calibration Data — Strain Gage Bar No. 3

LMEC-69-30
193

7693-2584

Figure 37. Calibration Data Comparison — Strain Gage Bars No. 1 and 3

LMEC-69-30
194

7693-2585

Figure 38. Strain vs Temperature, Δ Applied Load = 900 lb (9500-500)

7693-2586

Figure 39. Strain vs Temperature, Δ Applied Load = 4500 lb (5000-500)

7693-2587-1

Figure 40. Modulus of Elasticity at Temperature (Sheet 1 of 3)

7693-2587-2

Figure 40. Modulus of Elasticity at Temperature (Sheet 2 of 3)

7693-2587-3

Figure 40. Modulus of Elasticity at Temperature (Sheet 3 of 3)

7693-2588

Figure 41. Envelope of Typical Modulus of Elasticity Values vs Temperature, Type 316 Stainless Steel

LMEC-69-30
200

7693-2589

Figure 42. Modulus of Elasticity Comparison, Strain Gage Bars No. 1 and 3

LMEC-69-30
201

7693-2590

Figure 43. Modulus of Elasticity Comparison, Strain Gage Bar No. 3

XIV. INSTRUMENTATION AND STANDARDS LABORATORY

(LMFBR Program Plan 4-1.4)

J. W. McCarty

A. INTRODUCTION

The objectives of this project are: (1) to provide a capability and facilities for maintenance, calibration, and standardization of LMEC facilities instrumentation; (2) to develop and maintain LMFBR standards of measurement; (3) to provide a capability for the engineering and fabrication of LMFBR contractor instrumentation systems; (4) to provide the capability and facilities for the testing, evaluation, and calibration of high-temperature strain gages; (5) to provide for the writing of test, maintenance, and calibration procedures for LMEC instrumentation; and (6) to provide for the acquisition, receiving inspection, servicing, calibration, and storage of instrumentation in an Instrument Utilization Center. This activity is performed under guidance provided by Task 1.4, Volume 4, of the LMFBR Program Plan.

B. LABORATORY ACTIVITIES

Modifications to the LMEC Instrumentation and Standards (I&S) Laboratory have been proposed and approved for performance in FY 1970. These modifications are being made to provide adequate office, laboratory, and standards facilities for LMEC and LMFBR instrumentation support, including environment control and grounding.

The preparation of instrumentation maintenance and calibration procedures is continuing. Until these are completed, the laboratory will continue using manufacturers' and other North American Rockwell procedures. A schedule of procedures to be written is being prepared for forwarding to LMEC Quality Assurance.

The first LMEC QA audit was performed on the I&S Laboratory. All aspects were satisfactory with the exception of a need for prohibiting galvanometric measurements during nearby rocket engine tests which were shown to produce sufficient vibrations to upset calibration in progress, and the lack of instructions for maintenance and calibration procedures. The testing during rocket engine runs has been prohibited by laboratory directive and QA has approved interim use of alternate procedures.

Maintenance and calibration at LMEC is performed according to LMEC Procedure II-2, and all calibrations are traceable to National Bureau of Standards (NBS). Present capabilities and accuracies for calibrations performed in the LMEC I&S Laboratory are as follows:

- 1) DC volts source 0 to 1000 vdc $\pm 0.002\%$ reading
- 2) DC volts measure 0 to 1.6 vdc $\pm 0.007\%$ reading
 0 to 1100 vdc $\pm 0.0025\%$ input $+0.0001\%$ range
- 3) DC current source 0 to 50 amps $\pm 0.5\%$ reading
 and measure 0 to 15 amps $\pm 0.04\%$ reading
- 4) AC volts source 0 to 110 vac
 50 Hz to 20 kHz $\pm 0.02\%$ setting $+0.002$ range
 $+10 \mu$ volts
 20 Hz to 110 kHz $\pm 0.05\%$ setting $+0.005$ range
 $+50 \mu$ volts
 10 to 20 Hz $\pm 0.2\%$ setting $+0.005$ range $+50 \mu$ volts
 Frequency $\pm 3\%$ of setting
- 5) AC volts 0.0 to 1000 vac
 measuring 20 Hz to 20 kHz
 0 to 300 vac
 20 Hz to 50 kHz $\pm 0.03\%$ typ
- 6) AC current source 2.5 ma to 20 amp
 and measure 20 Hz to 100 kHz $\pm 0.03\%$ typ
 0 to 75 amp
 50 Hz to 2 kHz $\pm 0.03\%$ typ
- 7) Frequency source 10 Hz to 10 MHz $\pm 2\%/mo$
 0.1 Hz to 99.9 kHz $\pm 0.01\%/hr$
- 8) Frequency measure 0 to 50 MHz ± 1 count $\pm 3 \times 10^{-9}/day$
- 9) Flux measure 10 k lines/div $\pm 1\%$ FS
- 10) Resistance measure 0.1 to 10 meg $\pm 0.01\%$ $+0.0005$ ohms
 10 to 100 meg $\pm 0.02\%$
 100 meg to 1 k meg $\pm 0.2\%$
 1 to 11.1 k meg $\pm 2\%$

- 11) Resistance source 0 to 10 meg $\pm 0.01\%$ typ
 10 meg to 1 k meg $\pm 1\%$ typ
- 12) Capacitance source 100 Pf to 1 μ f $\pm 0.05\%$ typ
- 13) Capacitance measure 0.5 Pf to 1100 μ f $\pm 0.2\%$ typ
- 14) Inductance measure 0.05 μ h to 1100 h $\pm 0.2\%$ typ
- 15) Inductance source 1 h $\pm 0.01\%$ /yr
- 16) Pressure measure 0 to 50 psi $\pm 0.015\%$ read
 500 to 5000 psi $\pm 0.05\%$ read
- 17) Vacuum measure 10^{-9} torr $\pm 2\%$ approx
- 18) Flow-Gas measure 0 to 50 scim ± 1.8 scim
 0 to 500 scim ± 16.3 scim
 0.4 to 2.2 scfm ± 0.06 scfm
 4 to 24 scfm ± 0.8 scfm
- 19) Temperature source 32 to 2000°F $\pm 2^\circ$ F
 and measure

Equipment is on order that will improve in-house capabilities for NBS traceability.

XV. CHEMICAL AND METALLURGICAL LABORATORY
(LMFBR Program Plan 3-3.1, 5-5.1 through 5-5.7)
R. K. Wagner

A. INTRODUCTION

The objective of this program is to provide chemical and metallurgical laboratory support for LMEC activities and LMFBR activities as requested.

B. CHEMICAL LABORATORY

An effort to evaluate oxygen-in-sodium test results, sampling, and analytical methods on a statistical basis was initiated. Preliminary results indicate their dependence on sampling technique with higher standard deviations for the less reliable sampling methods. Experience has indicated that the sensitivity of oxygen-in-sodium determinations can be increased, particularly for low-oxygen concentrations with glassware modified to accommodate sodium samples of 5 gm. The total number of sodium samples obtained from LMEC systems are insufficient to permit a comprehensive statistical evaluation.

The design of a sodium sampler for LCTL use was reviewed. Recommendations based on current sampling, handling, and cleanliness practices were provided.

The emission spectrograph was adapted to provide verification analyses (qualitative) for structural materials. Standard plates were prepared for various types of stainless steel.

During this period, the chemical laboratory performed a variety of analyses. These included numerous analyses to verify material composition for valve bodies, pipe sections, thermal insulation from LCTL, oil samples from SCTI, and pipe and weld sections from the inactive HNPF pump test loop being assessed for use as a bearing test facility. For the latter system, these analyses established Type 304 stainless steel as the piping material and Type 308 as the weld filler metal. Low carbon values (<0.04 wt % for the piping is indicative of an L-grade stainless steel.

The analyses of thermal insulation from LCTL is related to the apparent corrosion (intergranular) observed on some external pipe surfaces of that system.

It was the purpose to determine the presence of impurities with sufficient potential to produce the localized intergranular corrosion observed (See Figure 44). Results of these analyses, tabulated in Table 21, show that:

- 1) The leach water is mildly alkaline.
- 2) The amount of leachable impurities decreased with increased weathering.
- 3) The amount of impurities leached from areas was, in general, less than that measured for either unexposed or protected areas.

Bearing failures in an SCTI sodium pump initiated the analyses of the oil samples. Residual elements detected in the samples were not considered unusual for the service environment. In addition to iron, trace quantities of cobalt, tungsten, chromium, and copper were detected.

7693-2591

Figure 44. Pipe Section from LCTL
Showing Intergranular Corrosion

TABLE 21

IMPURITIES IN LCTL THERMAL INSULATION
(wt %)

Material History	pH	Cl	SO ₄	Fe	Ca	Na	K	Mg	Total Dissolved Solids
Unexposed (new)	8.5	0.06	0.12	0.04	0.05	0.30	<0.005	<0.05	1.13
Exposed (protected)	8.3	0.04	0.16	<0.01	0.04	0.23	0.004	<0.05	1.80
Exposed (unprotected)	7.9	0.04	0.05	0.01	0.04	0.17	<0.002	<0.05	1.12

C. METALLURGICAL LABORATORY

1. General

A preliminary experiment was completed to evaluate the performance of a stress-corrosion-resistant stainless steel (Type 18-18-2) in 1200°F static sodium. Principal observations indicate: (1) a low depletion rate for silicon, and (2) the formation of a nonadherent surface layer which affected the apparent corrosion rate. Details of the experiment and test results are described in a recently published report.*

A review of materials for the LMFBR Pump Development Program was completed and submitted to the LMEC project engineer. One of the pertinent observations describes an absence of materials properties (mechanical) as affected by long-term exposure in high-temperature sodium.

Metallurgical assistance was provided in the review of numerous documents, which included reports from: (1) the LMFBR Piping Program, (2) the Steam Generator and IHX PDP,[†] and (3) various material and processing standards.

2. Examination of HNPF Pump Test Loop Pipe Samples

Metallurgical examination of pipe samples removed from the HNPF Pump Test Loop was completed. (This system is being assessed for use as a bearing test facility). There was no evidence of gross deterioration, only slight pitting and grain boundary attack. However, evidence of a substandard weld was found. Distinguishing features included:

*W. T. Lee, "Corrosion of Type 18-18-2 Stainless Steel in 1200°F Static Sodium," LMEC-69-11 (May 1969)

†Program Definition Phase

- 1) Improper joint preparation (thick to thin with no taper in the thicker section)
- 2) Excessive drop-through
- 3) Lack of penetration.

These features are readily identifiable in Figure 45, which shows a portion of the root of a valve-to-pipe weld.

3. Analysis of a Failed Sodium Hot Trap

A sodium leak was discovered in a Type 304 stainless-steel hot trap located in a sodium purification loop at Atomics International. The leak was detected indirectly during an examination of external heating elements. Because of LMEC interest in sodium component performance, RDT authorized transfer of the hot trap to LMEC for detailed failure analysis.

Available service records showed that the cylindrical hot trap (20 in. in diameter by 40 in. high) had operated for 17,000 hr at temperatures to 1240°F. During operation, approximately 30 thermal cycles — between 70 and 1240°F —

7693-2592

Figure 45. Portion of the Root of a Valve-to-Pipe Weld
Removed from HNPf Pump Test Loop

were imposed. Prior to installation in the sodium purification loop, the hot trap operated briefly in another sodium system. Operational history for this period of service is not available; however, it is believed that the thermal cycles imposed were few (less than 5) and that total operating time did not exceed 500 hr.

Prior to examination, residual sodium was removed from the hot trap by heating and draining followed by flushing with steam and water.

Extensive attack, as shown in Figure 46, was found on the external tank-head and wall surfaces. Maximum groove depth was 0.08 in., a 32% reduction of the 1/4-in.-thick wall. A small elliptical crack (see Figure 47) identified as the sodium exit was found at the inlet-pipe-to-tank-head weld. At this junction, the normal inlet temperature is 700°F with bulk sodium and tank temperature in the 1000 to 1100°F range. Sodium flow is estimated at 0.1 gpm.

A section through this weld joint (see Figure 48) revealed a crack transverse to the internal circumferential weld and a void (or tunnel) between the internal and external fillet welds. The crack joined with the elliptical crack and constituted the sodium leak path. The void, which extended through a 180-degree

Figure 46. Hot Trap, Tank-Head and Wall Around the Sodium Inlet Pipe (~ 1/4 size)

7693-2593

Figure 47. Main Crack (external) that Leaked Sodium at the Inlet Pipe-to-Tank-Head Weld

7693-2594

7693-2595

Figure 48. Internal View of Main Crack and Welding Defect (tunnel or void) Due to Improper Fitup between Inlet Pipe and Tank-Head (Mag: 1.5X)

arc, indicated welds of incomplete penetration due to improper fitup between the inlet pipe and tank-head.

Metallographic examinations revealed a series of secondary cracks in addition to the main leak. All appeared to originate in the weld and propagate longitudinally up to the inlet pipe and down across the weld. Extensive deformation twins and dislocation bands characteristic of creep or cyclic deformation were evident in the failed/cracked area. The multiplicity of transgranular cracks, at different locations along the internal weld, suggest fracture introduced by cyclic thermal stresses. The absence of branch cracking, pitting, or surface recession indicates that failure was not corrosion dependent.

Electron fractographic examination of a typical fracture surface revealed a series of fatigue striations (see Figure 49). Striations of this type are characteristic of thermal cycling. Such evidence offers strong support that thermal cycling contributed to crack initiation and growth in the failure area. The presence of dislocation bands and deformation twins suggest that creep also played a role in the fracture process.

The postulated failure mode involves cracking initiated by thermal stresses at the welding defect which acted as a stress raiser. Crack generation and growth was caused by fatigue owing to thermal cycling. Cycling occurred over the temperature range of 70 to 1200°F during heating and cooling and also as a result of mixing 700°F sodium with 1100°F sodium at the inlet-pipe-to-tank joint.

This experience, that at Dounreay (thermocouple block), plus those involving mixing tee's at LASL and HNPF, suggests that thermal fatigue (stress) may constitute one of the more prominent failure mechanisms confronting the LMFBR community.

Another example of a substandard weld was revealed when a sodium leak developed in a freeze trap during operation of SCTI. A metallurgical examination determined that the failure occurred in an extraordinarily large weld bead used to attach a thermocouple to a relatively thin-wall finned tube. In addition to the leak path, the weld contained numerous secondary cracks typical of weld bead fissuring. The substandard weld deposit, which penetrated the tube wall with approximately 100% drop-through, exhibited characteristics associated with metal-arc rather than the TIG process specified.

7693-2596

(Mag: 8,738X)

Figure 49. Electron Fractograph of a Typical Fracture Surface in the Sodium Inlet Pipe Adjacent to the Inlet Pipe-to-Tank-Head Weld (Mag: 8,748X).

Striations (or beach marks) extending from lower left to upper right are typical of fatigue fracture.

4. Examination of LCTL Pipe Sections

Potential failure areas were identified in certain pipe sections of the LCTL, which had been inactive and some parts of which were exposed to the weather for about 4 yr. During the nondestructive examination of a completed field weld, dye penetrant indications were detected on exposed pipe surfaces at some distance from the welds. Subsequent metallurgical examination identified intergranular corrosion (see Figure 44) in the Type 304 stainless-steel pipe sections as the source of the dye penetrant indications. For the two sections of pipe examined, penetration from 20 to 33% of the wall thickness was found. In all cases, corrosion originated on the external (thermal insulation/air) surfaces. Previous thermal history, where operation in the sensitization range occurred, was verified by metallographic examination with grain boundary precipitation in evidence (see Figure 50). This evidence, typical of "sensitized" stainless steel, was confirmed in a subsequent Strauss test.

A section of 0.010-in. -thick stainless-steel heat reflector, positioned between the sodium piping (and pipe heaters) and the rain-dampened thermal insulation, was damaged by corrosion, with penetration complete in some localized areas.

This experience again points out the vital necessity of protecting sensitized austenitic steels from potential corrosive media, such as rain or even condensed atmospheric moisture and pollutants, at all times.

Figure 50. Photomicrograph of LCTL Pipe Section with Grain Boundary Precipitation in Evidence (Mag: 500X)

XVI. OPERATION AND MAINTENANCE OF THE LCTL, CETS, AND HNPF PUMP TEST LOOP; MODIFICATION TO THE LCTL

(LMFBR Program Plan 3-51, 3-52, 3-9, 4-1.4)
L. B. Copeland

A. INTRODUCTION

It is the responsibility of this project to operate the Large Components Test Loop (LCTL) for LMFBR and FFTF component and instrument testing; to modify the LCTL to permit operation at LMFBR temperature and pressure conditions; and to maintain the Control Element Test Stand (CETS) and, until FY 1970, the HNPF Pump Test Loop. Planned tests to be performed in the LCTL during FY 1970 are the FFTF Flow Duct/Tube Sheet Sodium Erosion-Flow Leakage Test (T-1B), a second such FFTF Test designated T-1D, and the FFTF Fin Tubing Test (T-2). The large loop of the LCTL sodium system consists of a ferritic steel alloy (2-1/4 Cr - 1 Mo) which limits operation to 1000°F. To perform future LMFBR testing, the system will be modified to permit operation to 1200°F.

B. LCTL OPERATION AND MAINTENANCE

During modification of the 3-in. loop to accommodate FFTF Test T-1B (see Figures 51 and 52), liquid penetrant test of a weld joining new pipe to existing LCTL pipe showed defects in the old material. These defects were discovered during application of the welding standard, RDT-S-902. Subsequent metallurgical examination of specimens of the old pipe (AISI Type 304 stainless steel sensitized in previous service) identified intergranular corrosion as a major source of the indicated defects. As a consequence, other areas of the loop were liquid-penetrant tested, and indications of defects were found in some of these locations. Modification of the 3-in. loop was continued, and a hot circulation test was initiated to establish near-term serviceability of the piping. The parallel FFTF Test T-1B loop was isolated to avoid sensitizing or getting sodium into that loop. Pretest liquid-penetrant indications of defects were recorded (using pressure-sensitive tape and a high-resolution liquid penetrant) for comparison with post-test indications.

The plan for the hot circulation test was to thermally cycle within the range of 400 (to 500) and 1000(to 1100)°F for a period of about 400 hr. After 79 hr of

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Figure 51. LCTL Modification for FFTF Flow Duct/Tube Sheet Sodium Erosion-Flow Test (T-1B)

7693-4059A

Figure 52. FFTF Flow Duct/Tube Sheet Sodium Erosion-Flow Test (T-1B) Assembly

operation, the test was interrupted owing to failure of the shaft freeze seal on the 3-in.-loop circulating pump. During heatup, the freeze seal overheated allowing sodium to fill the pump case. The pump was dismantled, cleaned, reassembled, and the test was resumed. After 84 additional hr of operation, the pump was shut down to investigate abnormal temperatures of the reworked shaft freeze seal. Examination disclosed that the seal had failed again, flooding the case with sodium. A third attempt also failed when the reworked seal again could not be properly established.

It was decided to forego the balance of the hot circulation test and to examine and evaluate the piping on the basis of testing accumulated (163 hr and 4 thermal cycles). Prior to the examination, planned performance tests of the rotary EM pump in the T-1B loop were initiated. The pump failed to meet the required flow rate and pressure of 50 gpm and 150 psig, respectively. The poor performance was attributed to degradation of a braze alloy used on the pump duct. The pump duct consists of a 10-turn helical coil of tubing with a braze filler between coils to complete the electrical path for the eddy currents. Degradation of the braze results in high resistance to eddy current flow, hence, reduced pump performance. When repair of the duct was started, it was found that there were many voids and the braze material (an alloy of Ag, Cu, and In) had not wet the duct (AISI Type 316 stainless steel) on much of the interface surface. Procurement of a new duct was also initiated in case repair of the existing one proves unsuccessful. The mechanical pump in the 3-in. loop will also be reworked.

Routine maintenance, operator training, and instrument calibration were continued. Revision and updating of the preventive maintenance schedule, operating procedures, drawings, and equipment and instrument indexes were continued. New operating procedures were prepared as required for facility modifications. Routine standby operation of facility systems was performed when not in test. During standby, the supply, core, and drain tanks are controlled at 500°F; drain and vent lines at 350°F; and other sodium system piping is controlled at approximately 250°F.

Maintenance of the CETS was performed routinely to prevent deterioration of equipment. Routine maintenance of the HNPF Pump Test Loop was continued until April, when an examination of the facility was started under the Sodium Pump Bearing Test Program.

C. FFTF FLOW DUCT/TUBE SHEET SODIUM EROSION-FLOW TEST

1. Test T-1B

Modification of the LCTL 3-in. loop and construction of the T-1B loop was essentially completed; i. e., within the bounds set by the noted difficulties with the 3-in. loop and the pumps. It is estimated that, if rework of the pump duct is successful, Test T-1B will be initiated near the end of July 1969. If rework is unsuccessful and the new duct is required, the test will probably be delayed until mid-August.

Current plans for the test are to operate for 3 months with the present rotary EM pump. At this time, a new rotary EM pump is to be available to replace the present pump (which is on loan from another division of NR). At shutdown, the pump will be replaced, the T-1B assembly will be examined, and the T-1B loop will be modified to make it independent of the 3-in. loop. Testing will then be resumed for another 3-month period. During the first 3-month test period, operation will be at 800°F rather than 900°F as previously planned. When alternate plans for continuing the hot circulation test were being evaluated, it was determined that the present rotary EM pump should be restricted to 800°F operation because oxidation resistance of the braze alloy is considered too marginal at higher temperatures. (It should be noted that the pump was originally designed for 600°F operation.)

LMEC received the T-1B assembly and found it had been damaged in transit. Apparently, it had sustained a severe shock load, since banding straps were broken and piping was bent. BNW/FFTF representatives visited LMEC to inspect the assembly and to agree upon corrective action measures. As agreed, LMEC first tested all heaters for shorts and continuity; all were found acceptable. Visual examination of all (5) flowmeters disclosed no damage. The field strength was measured of one flowmeter magnet (from the unit most likely to have been damaged) and sensitivity of the flowmeter was calculated. Both values agreed closely with those of the supplier. The test assembly was therefore judged to be acceptable for use. The assembly was helium leak tested, thermocouples were installed, stainless-steel foil was installed over the heaters, and thermal insulation was applied; thus making it ready for installation in the test loop.

BNW/FFTF requested an LMEC-proposed modification be made to the spring-loaded module of the test assembly. Rather than determining spring load from a load/deflection calibration of the spring, the spring will be loaded with a device incorporating a direct-reading force gage. Detail design and procurement were completed and fabrication was nearly completed.

Design was nearly completed of the pump to replace the one now in the T-1B loop. This pump, an improved version of the rotary EM pump now installed, is designed for 1200°F service and to develop 175 psig at a flow rate of 100 gpm. Procurement of commercial components was initiated. They are expected to be available for installation by November 1, 1969.

2. Test T-1D

A draft test request was received from BNW/FFTF for a follow-on test to T-1B, designated T-1D. This test will investigate the effects of higher sodium velocities through the clearance between the flow duct and tube sheet. There will be two test specimen modules, one each with 0.035- and 0.045-in. diametral clearances. Total sodium flow is estimated to be 117 gpm at the required differential pressure across the test insert of 140 psi.

It is planned to obtain another pump like the one to be used on T-1B, thus permitting T-1D to be initiated while T-1B is in process. As conceived, it is believed test arrangements can be made to avoid interfering with the SCTL modification.

D. FFTF FIN TUBING TEST (T-2)

LMEC will perform a test for BNW to evaluate the adequacy of five different commercially available fin tube bond processes to withstand thermal transient cycles for conditions which are at least as severe as anticipated FFTF heat dump service.

Fin tube bond processes and possible degradation of the heat transfer coefficients owing to deterioration of fin-to-tube bonds will be evaluated and compared. This is to be accomplished by determining, and comparing, the overall heat transfer coefficients periodically throughout a series of thermal transient cycles.

1. Test Plan

A finned tube test structure, containing five fin tube specimens, will be provided by BNW and installed by LMEC in the 6-in. -by-8-in. loop of the LCTL for test. Steady-state test conditions will be established as follows:

1) Sodium flow rate (ft/sec)	1
2) Coolant air velocity (ft/min)	2000
3) Sodium inlet temperature (°F):	
a) For "Up-ramp" thermal cycle	700
b) For "Down-ramp" thermal cycle	1000
4) Air inlet temperature	Ambient
5) Air outlet temperature (°F)	100 to 300

After establishing these conditions, the specimens will be subjected to the specified thermal transient cycle by changing the sodium inlet temperatures as follows:

- 1) "Up-ramp": 700 to 1000°F in 20 sec, at approximately 15°F/sec
- 2) "Down-ramp": 1000 to 700°F in 20 sec, at approximately -15°F/sec.

The specimens will be subjected to 40 "up-ramp" and 40 "down-ramp" cycles. A visual inspection of the test specimens will be conducted at 20-cycle intervals. Evidence of oxidation, leakage, warpage, fin-to-tube bond failure, etc., will be noted and reported. At five cycle intervals, the steady-state overall heat transfer coefficient for each specimen will be determined.

Data recorded during the tests will include sodium flow rates, air velocities, sodium inlet and outlet temperatures, air inlet and outlet temperatures, barometric pressure, and ambient air wet bulb temperature. These parameters will enable calculation of the overall heat transfer coefficients, the log mean temperature differences, and total heat transfer values.

2. Facility Modification

Engineering studies and design layouts were initiated for the structural and piping design modifications for installing the assembly in the 6-in. -by-8-in. sodium loop. Instrumentation requirements were established and design was started.

E. SMALL COMPONENTS TEST LOOP (SCTL)

An Architect-Engineer Selection Board was formed for choosing a firm for the SCTL modification. Proposals were solicited, received, and evaluated. The Selection Board Report was prepared and submitted for approval of the board's selection.

The time-temperature operating history of the LCTL vessels was examined to determine if significant thermal cycle fatigue and creep rupture damage had occurred since construction nearly 10 yr ago. It was concluded that the operating conditions of pressure, temperature, and number and rate of cycles have been such that no significant stress-rupture, creep, or fatigue damage has occurred.

A trade-off study was made to determine whether the 6-in. -by-8-in. loop of the LCTL should be retained rather than removed during the SCTL modification. Design limitations of the loop (2-1/4 Cr - 1 Mo ferritic steel pipe) do not meet operating requirements for future LMFBR and FFTF tests, and added costs for extra equipment and buildings that would be required cannot be justified. As recommended by the study, the loop will be removed. A plan is under consideration to combine the dismantling effort with a metallurgical examination and evaluation of system piping and components.

An available CANEL pump drive was located that can be modified to adapt it to the CANEL pump that was obtained for use in the SCTL. Modification involves replacement of the alternator. With this modified, variable frequency drive unit, the SCTL pump can be operated at variable speed to control sodium flow rather than at constant speed with valve flow control.

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Note: LMEC Memos are informal documents that are intended primarily for AEC-RDT and LMEC use, and are initially issued to a limited distribution because of the nature of their contents.

**APPENDIX
SODIUM PUMP TEST FACILITY
(SPTF)
DRAWINGS**

Figure A-1. SPTF Piping Layout
Plan Below Elevation 105 ft 0 in.

NOTE:
HORIZONTAL STEEL MEMBERS ON COLUMN
LINES A, A', B, C, D, E ARE SIZED TO SUPPORT THE
PIPE HANGERS.

Figure A 2. SPTF Piping Layout Plan
Between Elevation 105 ft 0 in.
and Elevation 130 ft 0 in.

Figure A-3. SPTF Piping Layout,
Elevation A-A

LMEC-69-30
233

SCALE: $\frac{1}{16}'' = 1'-0''$

Figure A-4. SPTF Modified Base Loop, FFTF Pump Plan

Figure A-5. SPTF Topographic
and Survey

LMEC-69-30
237

Figure A-6. SPTF Plot Plan

Figure A-7.
Artists Conception of
SPTF

LMEC-69-30
241

OPTIC '69

Figure A-9. SPTF Control Building Plans

EAST-WEST SECTION

Figure A-10. SPTF East-West Section

Figure A-11. SPTF North-South Section

LMEC-69-30
249

Figure A-12. SPTF Modified
Base Loop, FFTF Pump
Elevation

Figure A-13. SPTF Auxiliary Cooling System P&I Flow Diagram

LMEC-69-30
253