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FFTF SODIUM EROSION
TESTS T-I-B AND T-I-D

HANFORD ENGINEERING DEVELOPMENT LABORATORY

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HANFORD ENGINEERING DEVELOPMENT LABORATORY

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FFTF SODIUM EROSION
TESTS T-1-B AND T-1-D

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CONTENTS

List of Illustrations	iv
List of Tables.	vii
I Introduction.	1
II Summary and Conclusions.	2
III Discussion.	4
A. T-1-B and T-1-D Test Apparatus Description.	4
B. Modules T-1-2, T-1-3, T-1-4, T-1-5 and T-1-6.	7
C. Modules T-1-7 and T-1-8	10
D. T-1-B Test Description.	11
E. LCTL Performance.	15
F. T-1-D Test Description.	17
G. Module Disassembly.	26
H. Permanent Zero Reference and Temporary Grid System.	45
I. Stereo Microscope Inspection.	46
J. Surface Area Photographs.	47
K. Precision Diametrical Measurements.	75
L. Profilometer Measurements	84
M. Particulate Recovery and Examination.	85
IV References	87
Appendix A	A-1
Appendix B	B-1
Appendix C	C-1
Appendix D	D-1

ILLUSTRATIONS

Figure 1	T-1-B Assembly	5
Figure 2	T-1-D Assembly	6
Figure 3	T-1-5 Module Prior to Assembly	8
Figure 4	T-1-4 Outer Cylinder	8
Figure 5	T-1-6 Module Prior to Assembly	9
Figure 6	T-1-7 Module Prior to Assembly	9
Figure 7	Modules T-1-2, 3, 4 and 5 Cross Section.	12
Figure 8	Module T-1-6 Cross Section	12
Figure 9	T-1-B Total Flow vs ΔP	13
Figure 10	T-1-B Module Flow at 750°F and 950°F	13
Figure 11	T-1-B Flow at 750°F on 10/24/69 and on 10/26/69.	14
Figure 12	T-1-B Module Flow for 130 Days at 750°F.	16
Figure 13	Module T-1-7 and 8 Cross Section	18
Figure 14	T-1-7 Upper Annulus Flow vs ΔP	19
Figure 15	T-1-7 Leakage Flow vs Seat Load.	20
Figure 16	T-1-8 Leakage Flow vs Seat Load.	21
Figure 17	T-1-D and T-1-7 Flow vs Time at 750°F.	23
Figure 18	T-1-7 Seat Leakage vs Time and Spring Load	24
Figure 19	T-1-8 Seat Leakage vs Time	25
Figure 20	Machine Work on Modules T-1-2, 3, 4, and 5 Prior to Disassembly.	28
Figure 21	Machine Work on Module T-1-6 Prior to Disassembly.	28

Figure 22	Module T-1-2 Ready for Disassembly	29
Figure 23	Module T-1-2 After Disassembly	29
Figure 24	Module T-1-2 Inner Cylinder ~ 0 deg. Reference. . . .	30
Figure 25	Module T-1-2 Inner Cylinder ~ 190 deg. Reference. . .	30
Figure 26	Module T-1-2 Outer Cylinder.	31
Figure 27	Module T-1-3 Inner Cylinder ~ 90 deg. Reference . . .	31
Figure 28	Module T-1-3 Inner Cylinder ~ 190 deg. Reference. . .	32
Figure 29	Module T-1-3 Outer Cylinder.	32
Figure 30	Module T-1-4 Inner Cylinder ~ 180 deg. Reference. . .	34
Figure 31	Module T-1-4 Inner Cylinder ~ 280 deg. Reference. . .	34
Figure 32	Module T-1-4 Outer Cylinder.	35
Figure 33	Module T-1-6 Outer Cylinder.	35
Figure 34	Module T-1-6 Outer Cylinder.	36
Figure 35	Module T-1-6 Inner Cylinder.	36
Figure 36	Module T-1-6 Inner Cylinder ~ 0 deg. Reference. . . .	37
Figure 37	Module T-1-5 Outer Cylinder ~ 0 deg. Reference. . . .	37
Figure 38	Module T-1-5 Inner Cylinder ~ 110 deg. Reference. . .	38
Figure 39	Module T-1-7 After Disassembly	41
Figure 40	Module T-1-7 Inner Cylinder After Disassembly. . . .	41
Figure 41	Module T-1-7 Outer Cylinder Seat Area.	42
Figure 42	Module T-1-8 After Disassembly	42
Figure 43	Module T-1-8 Inner Cylinder After Disassembly. . . .	43
Figure 44	Module T-1-8 Inner Cylinder Seat Area.	43
Figure 45	Module T-1-8 Outer Cylinder Seat Area.	44
Figure 46	Module T-1-2 Inner Cylinder Erosion Surface Area . .	48

Figure 47	Module T-1-3 Inner Cylinder Erosion Surface Area. . .	50
Figure 48	Module T-1-4 Inner Cylinder Erosion Surface Area. . .	51
Figure 49	Module T-1-5 Inner Cylinder Erosion Surface Area. . .	52
Figure 50	Module T-1-6 Inner Cylinder Erosion Surface Area. . .	53
Figure 51	Reference Cylinder Grid A2.	55
Figure 52	Module T-1-2 Grid A3.	56
Figure 53	Module T-1-3 Grid A9.	57
Figure 54	Module T-1-4 Grid A31	58
Figure 55	Module T-1-4 Grid A18	60
Figure 56	Module T-1-5 Grid A34	61
Figure 57	Module T-1-6 Grid A23	62
Figure 58	Module T-1-6 Grid A36	63
Figure 59	Module T-1-6 Grid T1.	65
Figure 60	Module T-1-7 Flow Annulus 0 deg. Reference.	66
Figure 61	Module T-1-7 Seat Annulus 0 deg. Reference.	67
Figure 62	Module T-1-7 Spherical Seat	68
Figure 63	Module T-1-7 Spherical Seat	69
Figure 64	Module T-1-8 Inner Cylinder Seat Annulus 0 deg. Ref..	70
Figure 65	Module T-1-8 Inner Cylinder Flow Annulus 0 deg. Ref..	71
Figure 66	Module T-1-8 Inner Cylinder Conical Seat.	73
Figure 67	Module T-1-8 Outer Cylinder Conical Seat.	74
Figure 68	Inner Cylinder Diameter vs Distance	81
Figure 69	Outer Cylinder Diameter vs Distance	82
Figure 70	Post-Operation Gap Change vs Distance from Leading Edge	83

TABLES

Table 1	T-1-B Module Diametrical Measurement Elevations. . .	76
Table 2	T-1-B Module Inner Cylinder Leading Edge Location. .	76
Table 3	T-1-B Module Diameter Measurements	77
Table 4	T-1-B Module Original and Final Measurement Comparison.	78
Table 5	T-1-B and T-1-D Particulate Analysis	86

HEDL-TME-71-99

E R R A T A

This report is a preliminary design. The referenced design is different from the original.

I. INTRODUCTION

This report presents results of sodium erosion tests T-1B and T-1D. The objective of these tests was to evaluate erosion effects of high velocity sodium through annuli with diametrical clearances ranging from 0.005 to 0.045 inch, and to measure seat leakage and evaluate erosion effects through two seat configurations, a cone-on-cone and a sphere-on-cone.

The T-1B erosion test apparatus has five test modules, T-1-2, T-1-3, T-1-4, T-1-5 and T-1-6, with diametrical clearances of 0.005, 0.010, 0.010, 0.025 and 0.010 inch, respectively. All modules were fabricated from 304 SST; however, the T-1-4 module outer cylinder erosion surface was a split sleeve made from Stellite 6B and Inconel 718. The T-1-6 module was equipped with a conical plug and seat. This apparatus was operated approximately 3000 hours at 750°F in the Large Components Test Loop (LCTL) at the Liquid Metal Engineering Center (LMEC) from October 1969 through February 1970.

The T-1D erosion test apparatus fabricated from 304 SST, has two test modules, T-1-7 and T-1-8, with diametrical clearances of 0.035 and 0.045 inch, respectively. T-1-7 was designed with a sphere-on-cone seat and T-1-8 had a cone-on-cone seat. Seat Leakage was measured on both modules throughout the test; however, due to limited flow capacity of the test loop, T-1-7 was the only module to have high volumetric flow. This apparatus was operated for approximately 3800 hours at 750°F in the LCTL at LMEC from June 1970 through December 18, 1970.

II. SUMMARY AND CONCLUSIONS

The T-1B and T-1D test apparatuses accumulated 3000 and 3800 hours operation, respectively, at 750°F. A nondestructive inspection of the five T-1B test modules T-1-2, T-1-3, T-1-4, T-1-5 and T-1-6 and two T-1-D test modules T-1-7 and T-1-8 was performed to determine the erosion effects of sodium flowing through annuli with diametrical clearances varying from 0.005 through 0.035 inch. The sodium velocity ranged from 23 ft/sec to 56.6 ft/sec through the test surface annuli. A maximum velocity of 81.8 ft/sec was calculated through the slotted seat of the T-1-6 module. Module T-1-7 was equipped with a sphere-on-cone seat and module T-1-8 was equipped with a cone-on-cone seat. T-1-8 also had a machined scratch estimated at 0.008 inch wide by 0.004 inch deep, at an angle of 30 deg. across the outer conical seat to simulate reactor conditions. Seat leakage rates were measured for both T-1-7 and T-1-8 modules. During the 3800 hours, module T-1-7 sphere-on-cone seat leakage decreased from 0.291 to 0.151 gpm with a seat load of 120 pounds and a ΔP of 140 psi, while module T-1-8 cone-on-cone seat leakage increased from 0.034 to 0.062 gpm with a seat load of 400 pounds and a ΔP of 140 psi. The velocity of sodium leakage across the T-1-7 sphere-on-cone seat cannot be accurately calculated, because the leakage area across the seat is unknown. Assuming all seat leakage flow was through the machined scratch, velocity estimates range from 150 to 340 ft/sec across the T-1-8 conical seat. The sodium, flowing through the machined scratch, cut a matching groove ~0.009 inch wide by ~0.0015 inch deep in the opposite conical seat.

Precise measurements of surface erosion on the T-1-B and T-1-D modules were not possible due to the lack of precision base profilometer and diametrical measurements on the specimens at specific locations prior to original assembly. However, maximum values were obtained by using the information obtained from the piping completion records, as-built dimensions on the fabrication prints, one inner cylinder control specimen and measurements obtained after completion of testing. The maximum erosion rates measured on the T-1-B apparatus were on modules T-1-3 and T-1-5, which had a rate of

1.022×10^{-3} inch/yr and 0.66×10^{-3} inch/yr, respectively, at a distance of 0.200 inch from the leading edge. The erosion rate across T-1-8 module conical seat is 3.5×10^{-3} inch/yr in the area adjacent to the machined scratch.

Erosion rates of the T-1B and T-1D test apparatus modules do not appear to be a serious problem with sodium velocities up to approximately 60 ft/sec. Localized leakage across damaged seat areas can produce high velocities and increased erosion rates which may cause problems over long periods of time.

Erosion rates in the order of 0.1 to 1 mil/yr are difficult to measure accurately. Two items become extremely important in determining these rates. The first requires precise before and after measurement of specimen surfaces at specific locations and second, the length of time the test is conducted under constant test conditions. Destructive examination of some specimens could yield better information on surface conditions and may be required to determine if a surface has a particulate build up or erosion.

If we have future sodium erosion tests, the apparatus should employ a device for top and bottom specimen alignment, zero reference and assembly marks and precise measurements at specific locations using profilometer and diametrical measuring machines that can be standardized before and after each measurement. Full flow filters should also be used in the inlet piping and the oxygen content of the test sodium controlled to meet reactor grade requirements. The test should be set up for several years duration at steady state operating conditions with interim examinations at one year intervals. The T-1-D apparatus was equipped with a full flow filter and the oxygen content was controlled at ~ 4 ppm throughout the test. The T-1-B apparatus did not have a filter and plugging with particulates from circulating sodium in the loop caused flow problems during the first few hours of operation, which ultimately resulted in the removal of the test apparatus from the loop for disassembly and inspection. The oxygen concentration varied from 3 ppm to 19 ppm throughout the test.

III DISCUSSION

A. T-1-B AND T-1-D TEST APPARATUS DESCRIPTION

The T-1-B test apparatus contains five test modules, T-1-2, T-1-3, T-1-4, T-1-5 and T-1-6, connected to common inlet and outlet headers. Each module is equipped with an electromagnetic flow meter, thermocouples and trace heaters. Trace heating elements are also connected to the inlet and outlet piping. Figure 1 shows the T-1-B assembly prior to crating for shipment to LMEC for testing.

The T-1-B test apparatus was fabricated using 304 SST with a minimum 0.04% carbon content. The apparatus was designed in accordance with ASME, USAS B31.7, Code for Pressure Piping, Nuclear Power Piping¹, Class II Draft USA Standard, February 1968.

One module, T-1-4, contained a split sleeve as the outer erosion surface. One half of the sleeve was fabricated from Stellite 6B and the other half from Inconel 718. The sleeve was precision machined, pressed into the outer cylinder and welded in place.

The T-1-D test apparatus contains two test modules, T-1-7 and T-1-8, connected to common inlet and outlet headers. Each module is equipped with thermocouples and trace heaters. The T-1-7 module was equipped with an electromagnetic flow meter to measure annular flow. Each module was equipped with a seat and a seat leakage collection tank. The T-1-7 seat was a sphere on cone design and the T-1-8 was a cone on cone design. Figure 2 shows the T-1-D apparatus prior to shipment to LMEC for testing.

The T-1-D test apparatus was fabricated using 304 SST with a minimum 0.04% carbon content. The apparatus was designed in accordance with USAS B31.7, Code for Pressure Piping, Nuclear Power Piping, requirements for Class II, Draft 1968.

Precise leakage measurements were obtained by knowing the tank volume between two level indicators and by measuring the time for the sodium to fill the tank between the level indicators.

Figure 1. T-1-B Test Apparatus

Figure 2. T-1-D Test Apparatus Before Testing

B. MODULES T-1-2, T-1-3, T-1-4, T-1-5 AND T-1-6

Each module consists of two basic components, the inner and outer cylinders. The inner cylinder represents the fuel element nozzle nesting inside an outer cylinder which represents the core basket receptacle. A narrow annular space ranging from 0.005 inch to 0.025 inch* simulates FFTF clearance between the fuel element nozzle and core basket receptacle and allows leakage flow.

Modules T-1-2, T-1-3, and T-1-5 were machined from certified 304 stainless steel with a minimum carbon content of 0.04%. Surface finish of the primary test surfaces ranged from 12 to 16 rms. The FFTF fuel element nozzles proposed for testing will have a 32 finish. Modules T-1-2, T-1-3 and T-1-5 are identical except for the diametrical clearances between inner and outer cylinders, which are 0.005, 0.010 and 0.025 inch, respectively. The clearance was obtained by varying the OD of the inner cylinder and maintaining constant ID of the outer cylinder. Figure 3 shows finished parts of module T-1-5.

Module T-1-4 is identical to T-1-3 except that a sleeve was inserted into the outer cylinder. One half of the test surface was machined from Inconel 718 and one half from Stellite 6B. The diametrical clearance between inner and outer cylinders is 0.010 inch. Figure 4 shows the outer cylinder of T-1-4 module.

Module T-1-6 is made from 304 stainless steel of the same type used in the other T-1-B modules. The diametrical clearance between cylinders is 0.010 inch, the same as modules T-1-3 and T-1-4. Module T-1-6 is equipped with a slotted conical plug and seat arrangement which simulates a proposed fuel element nozzle for the core basket. Figure 5 shows module T-1-6 prior to assembly. The bellows attached to the top of T-1-6 inner cylinder allows the attachment of a loading mechanism, external to the module, to simulate the buoyant weight of the fuel duct.

*Diametrical clearance

Figure 3. T-1-5 Module Prior to Assembly.

Figure 4. T-1-4 Outer Cylinder

Figure 5. T-1-6 Module Prior to Assembly

Figure 6. T-1-7 Module Prior to Assembly

C. MODULES T-1-7 AND T-1-8

Each module consists of an inner cylinder and an outer cylinder. The inner cylinder represents the fuel element nozzle and the outer cylinder represents the core basket receptacle. Modules T-1-7 and T-1-8 were designed with diametrical clearances of 0.035 and 0.045 inch, respectively, between the nozzle and core basket. The T-1-8 outlet pipe was blocked to prevent upward annular flow due to the limited pumping capacity of the LCTL. Both Modules were equipped with spring-loaded seats typical of the FTR conceptual design (i.e. the seat between the fuel element nozzle and core basket). The T-1-7 inner cylinder had a spherical seat of 1.000 inch radius. The outer cylinder had a conical seat with an included angle of 120 deg. producing a line contact. T-1-8 was equipped with a cone-on-cone seat. Both inner and outer cylinder cones had 120-deg. included angles. The seat on the T-1-8 outer cylinder was purposely scratched to produce a leak. The scratch made at a 30 deg angle across the seat was measured at 0.009 to 0.013 inch wide x 0.005 inch deep after 3800 hours operation.

Figure 6 shows the T-1-7 module prior to assembly.

D. T-1-B TEST DESCRIPTION

Testing of the T-1-B apparatus was initiated in the Liquid Metal Engineering Center in Canoga Park, California on October 25, 1969. The apparatus was installed in the LCTL and operated (steady state) at 750°F, with a differential pressure of 140 psi across the test modules. This set of conditions simulates the FFTF inlet temperature and pressure across the fuel element nozzle and core basket. The load on module T-1-6 seat was set to 1410 pounds to simulate a fuel duct seat load of 900 pounds. The test was to operate on a continuous basis for 3000 hours. (See Reference 2 for the T-1-B test plan.) Figures 7 and 8 show a cross section view of modules T-1-2, 3, 4, 5 and 6. The sodium flow path is indicated by the arrows.

During the first two days of T-1-B operation, data were taken for a plot of flow vs ΔP at 750°F, 900°F and 750°F, in that order. The ΔP ranged from 20 to 140 psi. Figure 9 shows the flow vs ΔP for the total system at 750°F, 900°F and 750°F. Note that the system flow decreased for each successive curve, and indicates that plugging of the modules began with the start of testing. Figure 10 shows the flow through each module at the first 750°F curve and following 900°F curve. Note that T-1-4 and T-1-5 shows a decrease in flow, while T-1-2, T-1-3 and T-1-6 show a slight increase. Plugging of T-1-5 and T-1-4 is indicated; however, Figure 11 shows the flow through each module for both 750° curves, and only T-1-5 shows a significant change.

Module T-1-4 flow was much lower than T-1-3, although the original diametrical clearance was designed to be equal. Original measurements show the T-1-3 and T-1-4 diametrical gaps to be 0.010 and 0.0096, respectively. However, calculations made using the coefficient of expansion for Stellite 6B, Inconel 718 and 304 SST show that the diametrical clearance of T-1-4 changed from 0.0096 to ~0.0068 at 750°F and to ~0.0061 at 900°F, while the clearance within T-1-3 remained essentially the same at 0.010.

**T-1-2, -3, -4, -5 MODULES
.005, .010, .010, .025 DIAMETRAL CLEARANCE**

Figure 7. Modules T-1-2, 3, 4 and 5 Cross Section

**T-1-6 MODULE
0.010" DIAMETRAL
CLEARANCE-SPRING LOADED SEAT**

Figure 8. Module T-1-6 Cross Section

Figure 9. T-1-B Total Flow vs ΔP

Figure 10. T-1-B Module Flow at 750°F and 950°F

Figure 11. T-1-B Flow at 750°F at 10/29/69 and 10/26/69

E. LCTL PERFORMANCE

The T-1-B test was operated for approximately 3000 hours. During this time, the test apparatus was out of normal steady state test conditions 26 times for a total of 129.1 hours.³ The ΔP dropped to zero 16 times for a total of 23.5 hours. Gas ingestion into the circulating sodium and loss of pump power caused most of the interruptions. Temperature dropped below 700°F twice when flow was restored to the loop. Oxygen concentration in the test sodium ranged from 3 ppm to 19 ppm. Average oxygen concentration was ~11 ppm.

Figure 12 shows the flow through each T-1-B module for 130 days. Numbers shown on this figure refer to a list of interruptions which resulted in a flow change in one or more modules as indicated in Figure 12. The list of "T-1-B interruptions and effects" is located in Appendix A.

Figure 12. T-1-B Module Flow for 130 Days at 750°F.

F. T-1-D TEST DESCRIPTION

The T-1-D test plan was designed to determine: (1) the flow rate through a 0.035-inch diametrical clearance fuel element nozzle/core basket receptacle assembly at 750°F sodium temperature with differential pressures ranging from 60 to 140 psi; (2) long term erosion effects with differential pressure at 140 psi and sodium temperatures of 750°F; (3) leakage rates across two typical fuel element nozzle-to-core basket receptacle seats at 750°F sodium temperature with differential pressures ranging from 60 to 140 psi and with various spring preloads.⁷ Figure 13 shows a cross section view of Modules T-1-7 and 8. The sodium flow path is indicated by arrows.

Testing of the T-1-B apparatus was initiated in the Liquid Metal Engineering Center in Canoga Park, California on June 2, 1970 and terminated on December 2, 1970. The apparatus was installed in the LCTL and operated (steady state) at 750°F with a differential pressure of 140 psi across the T-1-7 module flow annulus and the T-1-7 and T-1-8 nozzle/receptacle. The steady state seat load was set at 100 pounds on the T-1-7 sphere-on-cone seat and at 400 pounds on the T-1-8 cone-on-cone seat. The test was to operate on a continuous basis for 3800 hours.

During the first few days of T-1-D testing, data were taken for flow vs ΔP and spring load (pounds). Figure 14 shows the T-1-7 upper annulus flow rate vs Δ pressure (psi) as the pressure is increased from 60 psi to 140 psi with a sodium temperature of 750°F. Figure 15 shows the initial and final seat leakage of the T-1-7 sphere-on-cone seat for pressures of 60 and 140 psi and seat loads from 70 to 520 pounds. Single points were obtained at 80, 100 and 120 psi with a seat load of 320 pounds. Data points preceded by "N" were obtained at the start of testing and were taken in sequence as indicated by the numbers "N-1" through "N-15". Data points preceded by a "C" were obtained at the end of testing and were taken in sequence as indicated by the numbers "C-1" through "C-13". The data show that seat leakage decreased from 0.291 gpm to 0.151 gpm after 3800 hours operation at a pressure of 140 psi and a seat load of 120 pounds. All data points

Figure 13. Module T-1-7 and 8 Cross Section

Figure 14. T-1-7 Upper Annulus Flow vs ΔP

show a decrease in seat leakage for corresponding pressures and seat loads after 3800 hours operation at 750°F.

Figure 16 shows the initial and final seat leakage of the T-1-8 cone-on-cone seat for pressures of 60 and 140 psi and seat loads from 70 to 520 pounds. Single points were obtained at 80, 100 and 120 psi with a seat load of 320 pounds. Data points preceded by "N" were obtained at the start of testing and were taken in sequence as indicated by numbers "C-1" through "C-13". The data shows that seat leakage increased from 0.034 gpm to 0.062 gpm after 3800 hours operation at a pressure of 140 psi and seat load of 400 pounds. All data points show increased seat leakage for corresponding pressures and seat loads after 3800 hours operation at 750°F.

A self-welding test was performed at 0 psi on both T-1-7 and T-1-8 modules to determine if self welding had occurred during testing. The test results were negative but the leakage flows shown by points "A" before, and "B" after self-welding test in Figures 15 and 16 show that T-1-7 seat leakage increased by 0.026 gpm and that T-1-8 seat leakage increased by 0.038 gpm.

Figure 15. T-1-7 Leakage Flow vs Seat Load

Figure 16. T-1-8 Leakage Flow vs Seat Load

The T-1-D apparatus was operated for approximately 3800 hours. During this time the apparatus was out of test conditions 39 times. Figures 17, 18 and 19 show the T-1-D and T-1-7 flow and temperature vs time, T-1-7 seat leakage vs time and T-1-8 seat leakage vs time.

Figure 17 shows that the T-1-7 upper flow annulus flow and T-1-D total flow remained almost constant until the loop was drained at 103 days. The flow increased by ~1 gpm when the loop was reactivated and gradually increased to 30 gpm by the end of testing. The cause of this increase is unknown, but it is suspected that the ΔP across the loop increased slightly. Temperature control was good throughout the test as indicated.

Figure 18 shows the T-1-7 sphere-on-cone seat leakage vs time and seat load vs time. Seat leakage shows many fluctuations throughout the test. Many are directly related to seat load changes and to the times when the apparatus was out of test conditions. Circled numbers at the top refer to times when the apparatus was out of test conditions. A list of T-1-D interruptions, effects, dates and length of time for each interruption is contained in Appendix "B". Leakage generally decreased throughout the test as indicated. Seat loading initially started at 120 pounds, but was maintained at 100 pounds during much of the 3800-hour test period. Seat load was reduced to zero and the loop drained on several occasions.

Figure 19 shows the T-1-8 cone-on-cone seat leakage vs time. Seat leakage dropped from 0.021 gpm to 0.006 gpm during the first 100 days of operation. The leakage increased from 0.006 to 0.071 gpm after the outage at 100 days and then fluctuated to a high of 0.079 and a minimum of 0.064 gpm throughout the remainder of the test period. Many of the changes in seat leakage are directly related to "out of test conditions" of the loop. The list of T-1-D test interruptions is located in Appendix "B". The steady state seat load was 400 pounds throughout the test except for some "out of test condition" periods when the load was reduced to zero psi when the loop Δ pressure was also zero.

Figure 17. T-1-D and T-1-7 Flow vs Time at 750°F

SEAT LEAKAGE T-1-7 MODULE (~140 PSI ΔP)

Figure 18. T-1-7 Seat Leakage vs Time and Spring Load

Figure 19. T-1-8 Seat Leakage vs Time

G. DISASSEMBLY

The T-1-B apparatus was received by BNW in June 1970. A procedure⁴ was written to remove and disassemble modules T-1-2, T-1-3, T-1-4 and T-1-6 from the test apparatus. Module T-1-5 was removed at LMEC before the test apparatus was shipped to BNW.⁵

Each test module was cut from the test apparatus using a rolling wheel-type pipe cutter and photographed. The ends of all exposed pipes were sealed with polyethylene and plastic tape. Each module was placed in a clean polyethylene bag and then placed in a clean metal container equipped with a tight metal cover. Each container was marked with the module number and padded to prevent damage to the module.

One by one, each module was removed from the containers into a clean zone set up in the WADCO Tech Shops. A reference mark was scribed across the top and ~1 inch down the side opposite the inlet pipe. A lathe was used to make two cuts on each module, as shown in Figures 20 and 21. These cuts did not penetrate into the area containing sodium. The final cut to remove the outlet plenum was made using a rolling wheel-type pipe cutter.

As the outlet plenum was cut off from each module, ~1/4 inch of sodium was removed from both parts and the parts were then placed in a clean container of filtered Dowanol EB. The container, marked with the number of the module it contained, was in a clean ventilated hood. The Dowanol-sodium reaction was monitored and the solution mixed at frequent intervals. As the reaction subsided, grade "A"* demineralized water was added in small quantities until the resultant solution was ~50% distilled water. The solutions were drained and saved in individual containers marked with the module number. Each module was allowed to set in 100% grade A distilled water for 24 hours, drained, rinsed with pure ethyl alcohol reagent quality and then dried at 300°F. All solutions used to clean the modules were saved in clean polyethylene containers marked with the module number.

*Grade "A" demineralized water defined by RDT Standard F-5-1.

After cleaning and drying, each module was visually examined, photographed, pressed apart and photographed again. Figures 22 through 38 are pictures taken as each module was disassembled.

The following is a list of Figures 22 through 38 with a short explanation of each.

- Figure 22. Module T-1-2 ready for disassembly with the hydraulic press.
- Figure 23. Module T-1-2 after disassembly using hydraulic press.
- Figure 24. T-1-2 inner cylinder. Small amount of particulate at top right side of leading edge. Sodium was present along this side which is centered at ~ 0 deg. from reference zero, or ~ 180 deg. from the module inlet pipe. Module had soaked in 100% grade A water for 24 hours prior to disassembly.
- Figure 25. T-1-2 inner cylinder. Center of picture is at ~ 190 deg. from reference zero.
- Figure 26. T-1-2 outer cylinder. View from top showing small amount of particulate along annulus entry. Inlet pipe is on right side.
- Figure 27. T-1-3 inner cylinder. Center of picture is at ~ 90 deg. from reference 0 deg., although flow patterns are visible around small spot along the leading edge only; small specks of particulate were found in area.
- Figure 28. T-1-3 inner cylinder. Center of picture is at ~ 190 deg. from reference zero. One small piece of particulate was found at the top right side along the leading edge.
- Figure 29. T-1-3 outer cylinder. Top view shows small specks of particulate along annulus entry. Inlet pipe is on the left side of the picture.

Notes:

1. Machine off 1/8 inch.
2. Machine a 70° angle 1/8 inch deep for welding.
3. Use a parting tool to cut 5/16 deep. Wall thickness if 3/8 inch.
DO NOT cut through wall.

Figure 20. Machine work on Modules T-1-2, 3, 4, and 5 prior to disassembly.

Figure 21. Machine work on Module T-1-6 prior to disassembly.

Figure 22. Module T-1-2 Ready for Disassembly

Figure 23. Module T-1-2 After Disassembly

Figure 24. Module T-1-2 Inner Cylinder
-0 deg.

Figure 25. Module T-1-2 Inner Cylinder
~190 deg. Reference.

Figure 26. Module T-1-2 Outer Cylinder

Figure 27. Module T-1-3 Inner Cylinder
~90 deg. Reference.

Figure 28. Module T-1-3 Inner Cylinder
~190 deg. Reference.

Figure 29. Module T-1-3 Outer Cylinder

- Figure 30. T-1-4 inner cylinder. Center of picture is ~ 180 deg. from zero reference or facing the inlet pipe. A small amount of sodium was present in the module, as shown in the center of the picture. Only small specks of particulate can be seen. A vertical line to the left of center identifies the area where the Inconel and Stellite outer cylinder liners were located.
- Figure 31. T-1-4 inner cylinder. Center of picture is ~ 280 deg. from reference zero. Flow patterns are shown around two areas along the leading edge; however, these two particles were not found when the module was disassembled.
- Figure 32. T-1-4 outer cylinder. Small particles show along annulus leading edge. Matching spot of sodium can be seen below inlet pipe. Inconel liner is on right side of the picture and the Stellite on the left.
- Figure 33. T-1-6 outer cylinder. Top view showing annulus leading edge and small specks of particulate present at disassembly.
- Figure 34. T-1-6 outer cylinder. Bottom view showing seat area. Stepped spot on seat can be identified in matching area in Figure 35. Seat outlets can be identified along the seat area. There is no apparent erosion in this area.
- Figure 35. T-1-6 inner cylinder. View of seat area showing stepped mark visible in Figure 34. Cylinder surface area above the seat is pitted slightly in the area where lateral flow was present. Area in seat outlet shows flow patterns and appears to be eroded; however, the seat outlets were made with an EDM machine which produces a finish similar to that in the picture.

Figure 30. Module T-1-4 Inner Cylinder
~180 deg. Reference.

Figure 31. Module T-1-4 Inner Cylinder
~190 deg. Reference.

Figure 32. Module T-1-4 Outer Cylinder

Figure 33. Module T-1-6 Outer Cylinder.

Figure 34. Module T-1-6 Outer Cylinder

Figure 35. Module T-1-6 Inner Cylinder

Figure 36. Module T-1-6 Inner
Cylinder ~ 0 deg. Reference

Figure 37. Module T-1-5 Outer Cylinder ~ 0 deg.
Reference

Figure 38. Module T-1-5 Inner Cylinder ~ 110 deg. Reference

Figure 36. T-1-6 inner cylinder. Center of picture is ~ 0 deg. reference. Heavy scratch shown along leading edge was made during original assembly and has a matching mark on the outer cylinder.

Figure 37. T-1-5 outer cylinder. This picture was taken at LMEC when T-1-5 was disassembled prior to shipment of the T-1-B apparatus to BNW. Many particles are present, and were analyzed later and discussed in another section of this report.

Figure 38. T-1-5 inner cylinder. Center of this picture is ~ 110 deg. reference. A large particle is shown on the right side along the leading edge.

After disassembly, the particulate from each module was collected and placed in a clean container marked with the proper module number. All particulate was examined and the analysis is reported under Section M, Particulate Recovery and Analysis.

The T-1-D apparatus was received by WADCO in December 1970. Written procedures⁸, similar to those for T-1-B, had been written to remove, disassemble and inspect the T-1-7 and T-1-8 modules from the test apparatus.

Each module was handled in a similar fashion to the T-1-B modules with some improved techniques incorporated. Each module had a specially built stainless steel container with protective cover for use in clean-up of the sodium using filtered Dowanol EB and grade "A" distilled water. Each module also had a specially built storage container to contain and support the inner and outer components after disassembly.

All solutions used to clean the T-1-8 module were collected and filtered through a 0.6 micron and then a 0.2 micron filter. The filter residue was later analyzed; this analysis is discussed under Section M, Particulate Recovery. The T-1-7 solution was contaminated with Metal-X from a fire extinguisher when a small glob of sodium, from the inlet chamber

of T-1-7, floated to the surface of the cleanup solution and caught fire. Although the fire was small, a considerable amount of Metal-X was used and contaminated the cleanup solutions. The Metal-X was rinsed away and the module replaced into a clean tank of filtered Dowanol EB.

Figures 39 through 45 show the T-1-7 and T-1-8 modules as they looked immediately after disassembly. The following is a list of figures and a short discussion of each:

- Figure 39. Module T-1-7 inner and outer cylinder after disassembly. Figure 6 shows a similar photograph prior to assembly and testing.
- Figure 40. T-1-7 inner cylinder after disassembly.
- Figure 41. T-1-7 outer cylinder seat area. Arrows show where the inner cylinder spherical seat made contact with the outer cylinder conical seat.
- Figure 42. T-1-8 inner and outer cylinder after disassembly.
- Figure 43. T-1-8 inner cylinder after disassembly.
- Figure 44. T-1-8 inner cylinder seat area. This picture shows the groove, cut by flowing sodium, across the conical seat. This groove matches the scratch machined across the outer cylinder seat made to simulate expected reactor conditions.
- Figure 45. T-1-8 outer cylinder seat area. Machined scratch is located on the left side of the conical seat.

Figure 39. Module T-1-7 After Disassembly

Figure 40. Module T-1-7 Inner Cylinder after Disassembly

Figure 41. Module T-1-7 Outer Cylinder Seat Area

Figure 42. Module T-1-8 After Disassembly

Figure 43. Module T-1-8 Inner
Cylinder after Disassembly

Figure 44. Module T-1-8 Inner Cylinder Seat Area

Figure 45 Module 7-18 Outer Cylinder Seat Area

H. PERMANENT ZERO REFERENCE AND TEMPORARY GRID SYSTEM

Each module was rinsed in grade "A" water and dried after disassembly was completed.

Zero reference marks were added to the inner and outer cylinders. These marks matched the marks made on each module before disassembly. The zero reference is ~ 180 deg. from the inlet pipe.

A temporary grid system was applied to the inner and outer cylinder erosion surfaces. Vertical marks were made at 10 deg. intervals around each inner and outer cylinder, starting with the zero reference mark. These lines were numbered 1 through 36. Horizontal marks were made at 0.25-inch intervals starting 0.25-inch down from the leading edge of each cylinder, the horizontal lines were labeled A, B, C, D, E, F, G, H, K, M, N, R, S, T, V, W, X, and Y. The grid was applied with a nylon tipped pen containing a low chloride ink. The ink can be removed with reagent grade acetone.

Zero reference marks were added to the T-1-7 and T-1-8 modules, but the grid system was omitted because the erosion surface areas appeared to be in perfect condition.

I. STEREO MICROSCOPE INSPECTION

Each T-1-B and T-1-D inner cylinder was inspected using a stereo microscope. The range of power varied from 7 to 30. Data sheets were filled out on each cylinder, and from these data, selected areas were later photographed at 30X and surface area profiles made using a Tally Surf machine. Lateral lighting was used in this inspection to highlight surface areas.

A Questar telescope/microscope, aided by inspection mirrors and external lighting, was used to inspect each T-1-B and T-1-D outer cylinder. This inspection was much more difficult and time consuming than the previous inspection of the inner cylinders. Data sheets were filled out on each cylinder, and from these data, selected area profiles were made using a Tally Surf machine. Areas selected for further examination usually matched those of the inner cylinder. In most cases, one surface is usually a mirror image of the other. Photography equipment was not available, however, to take high magnification pictures of the inner cylinder surfaces without first splitting the outer cylinder in half.

Stereo microscope inspection of the inner cylinder surfaces indicates that erosion is not a serious problem. Machine marks, from the edge to ~0.030-inch down, are slightly rounded, and leading edges of the cylinders have some areas where material is missing. These areas are shown in detail on the 30X pictures and in precision measurements discussed in following sections of this report.

J. SURFACE AREA PHOTOGRAPHS

A slit camera was used to photograph the erosion surface area of modules T-1-2 through T-1-6. These photographs show the temporary grid system on each module erosion surface and the permanent zero reference marks added to the top and bottom of each cylinder. Note that the permanent reference marks are not on the erosion surface, but in a low velocity area. The following list of figures are pictures taken with the slit camera. They have been reduced to 80% of full size. Most showed the entire surface area of each module, but the prints have been slightly cropped.

Figure 46 T-1-2 inner cylinder erosion surface area. Area in Photograph is from 340 deg. through 0 deg. and back to ~315 deg. Flow patterns are not evident on this module. The darker areas are discoloration caused by the slow sodium and dewanol reaction in a narrow annulus and by the formation of small amounts of NaOH. The leading edge of this inner cylinder was measured as being 0.006-inch below the leading edge of the outer cylinder. A line along the bottom of the "V" grid line shows the trailing edge of the outer cylinder.

Figure 47 T-1-3 inner cylinder erosion surface. Surface area covered is from 160 deg. through zero and back to 160 deg. Flow patterns are visible from ~100 deg. through 280 deg. Measurements taken after disassembly indicate that this inner cylinder was off center by ~.003 inch, with only .002-inch clearance at 0 deg. reference. The discoloration in the area between 300 deg. and 340 deg. indicates that the gap between the inner and outer cylinders was very small and was the last part of the sodium to be reacted.

Figure 48 T-1-4 inner cylinder erosion surface. Surface area covered is from 140 deg. through 0 deg. and back to 140 deg.

Figure 46. Module T-1-2 Inner Cylinder Erosion Surface Area.

Flow patterns are visible across most of the surface area. Vertical lines at ~ 8 deg. and 176 deg. show the area where the Inconel and Stellite liners meet. A flow pattern has developed along each interface. The Stellite liner extends from ~ 8 deg. to 178 deg. and the Inconel liner from 178 deg. to 8 deg. Several areas along the leading edge indicate the presence of particulates during operation. Some small amounts of particulate were recovered from this module, as shown in Figure 32. Measurements taken before disassembly indicate that the inner cylinder of this module was centered inside the outer cylinder. Measurements taken after disassembly indicate that the leading edge of T-1-4 inner cylinder was ~ 0.025 inch above the leading edge of the outer cylinder. A thin line can be seen below the leading edge of the T-1-4 inner cylinder shown in this figure.

Figure 49 T-1-5 inner cylinder erosion surface area. Surface area covered in this figure is from 360 deg. through 0 deg. and back to 360 deg. Flow patterns are visible all along the leading edge. Measurements taken after disassembly indicate that the leading edge of the inner and outer cylinders match.

Figure 50 T-1-6 inner cylinder erosion surface area. Surface area covered in this figure is from 180 deg. through 360 deg. and back to 195 deg. A large scratch seen in grid A and B-2 was made during original assembly. A matching groove was made on the outer cylinder. Measurements taken after disassembly indicate that the leading edge of the inner cylinder was ~ 0.026 inch above the leading edge of the outer cylinder. No measurements could be taken from the bottom before disassembly to determine if the inner cylinder was centered in the outer cylinder; however, the absence of any discoloration indicates it was centered.

Figure 47. Module T-1-3 Inner Cylinder Erosion Surface Area

Figure 48. Module T-1-4 Inner Cylinder Erosion Surface Area

Figure 49. Module T-1-5 Inner Cylinder Erosion Surface Area

Figure 50. Module T-1-6 Inner Cylinder Erosion Surface Area

Selected areas of each inner cylinder erosion surface were photographed at 10X (10 diameters) and enlarged to 30X. During the fabrication of T-1-B modules, an extra inner cylinder was fabricated of the same materials and this cylinder has been used as reference. The following list of figures was taken of the T-1-B modules at 30X.

- Figure 51. Reference cylinder surface area (T-1). Arrow at top of picture shows the leading edge of the reference cylinder. The grid lines enclosing the area are visible on the sides and bottom of grid number A2. The machined surface is typical of the other T-1-B inner cylinder surfaces as originally machined.
- Figure 52. Module T-1-2 inner cylinder grid A3. Reference Figure 46. Grid A3 was discolored in Figure 46, but this figure shows the machine marks very clearly and compares with the original surface. Arrow indicates leading edge of grid.
- Figure 53. Module T-1-3 inner cylinder grid A9. Reference Figure 47. Grid A9 is typical of several along the leading edge of T-1-3. Machine marks are not as clear in this photograph as in reference photograph (Figure 51). Arrow indicates leading edge of grid.
- Figure 54. Module T-1-4 inner cylinder grid A31. Reference Figure 48. Flow pattern around trapped particulate. Machine marks are not as pronounced as in the reference Figure 51. This area is typical of many along the leading edge. Arrow indicates leading edge of grid.
- Figure 55. Module T-1-4 inner cylinder grid A18. Reference Figure 48. Figure 48 shows flow patterns across grid A18.

Figure 51. Reference Cylinder Grid A2

Figure 52. Module T-1-2 Grid A3

Figure 53. Module T-1-3 Grid A9

Figure 54. Module T-1-4 Grid A31

Figure 55 (30X) indicates that the machine marks are not as pronounced as in the Reference Figure 51 and that there is no gross erosion. Arrow indicates leading edge on grid.

- Figure 56. Module T-1-5 inner cylinder grid A34. Reference Figure 49. Figure 49 shows a flow pattern from the leading edge in grid A34. Figure 56 (30X) indicates a possible buildup of crud near the center along the leading edge. Machine marks are not as pronounced as the Reference Figure 51. The series of scratches from left to right were a result of assembly or disassembly. Arrow indicates leading edge of grid.
- Figure 57. Module T-1-6 inner cylinder grid A23. Reference Figure 50. Figure 50 shows grid A23 along the leading edge of the inner cylinder. Figure 57 shows several small craters along the leading edge of grid A23. The largest is ~.023 inch in diameter. These craters are believed to be mechanical damage occurring during assembly of the module. Arrow indicates leading edge of grid.
- Figure 58. Module T-1-6 inner cylinder grid A-36. Reference Figure 50. Figure 50 shows grid A36 along the leading edge of the T-1-6 inner cylinder. Craters approximately .021 to .028 inch in diameter are shown along the leading edge of grid A36. The craters have a depth that is below the normal surface plane and have metallic ridges along the outer edges on the sides and downstream that extend above the normal surface plane. Sodium flow across these craters has changed the normal appearance of these areas. A large vertical mark on the left side of the grid is also believed to be mechanical and caused during original module assembly. The arrow indicates the leading edge of grid.

Figure 55. Module T-1-4 Grid 18

Figure 56. Module T-1-5 Grid A34

Figure 57. Module T-1-6 Grid A23

Figure 58. Module T-1-6 Grid A36

Figure 59 Module T-1-6 inner cylinder grid T-1. Reference Figure 50. Figure 50 shows grid T-1 along the trailing edge of module T-1-6 just above the lower seat area and outlet orifices. The surface area is rough, as shown in the photograph. The surface area is similar in all T grids 1 through 36. Destructive examination will be necessary in order to determine if this is crud buildup, erosion or chemical attack of the surface.

The following is a list of figures which were taken of the T-1-D modules. These pictures were taken at 10X and enlarged to 30X.

Figure 60. T-1-7 inner cylinder flow annulus leading edge at 0 deg. reference. Arrow indicates leading edge.

Figure 61. T-1-7 inner cylinder seat annulus leading edge at 0 deg. reference. Arrow indicates leading edge.

Figure 62. T-1-7 spherical on cone seat. This is one of the worst areas along the seat. Four distinct rings can be seen where the module was unseated when spring pressure was released and then resealed. The small rings are ~0.002 to 0.003 inch wide and appear to be the result of surface galling caused by line contact.

Figure 63. T-1-7 spherical seat. Similar to the above picture, but also shows three small areas where self-welding may have started. These areas, indicated by arrows, are ~0.020 inch in diameter.

Figure 64. T-1-8 inner cylinder seat annulus leading edge at 0 deg. reference. Surface marks were present prior to original assembly.

Figure 65. T-1-8 inner cylinder flow annulus leading at 0 deg. reference.

Figure 59. Module T-1-6 Grid TI

Figure 60. Module T-1-7 Flow Annulus 0 deg. Reference

Figure 61. Module T-1-7 Seat Annulus 0 deg. Reference

Figure 62. Module T-1-7 Spherical Seat

Figure 63. Module T-1-7 Spherical Seat

Figure 64. Module T-1-8 Inner Cylinder Seat Annulus 0 deg. Reference

Figure 65. Module T-1-8 Inner Cylinder Flow Annulus 0 deg. Reference

Figure 66. T-1-8 inner cylinder conical seat. Groove cut by sodium flowing in a machined scratch on the outer cylinder. Two grooves are shown. This was caused by the inner cylinder rotating slightly when it was unseated by releasing spring tension during testing. Lower marks on the seat were caused while machining a seal weld in preparation for disassembly.

Figure 67. T-1-8 outer cylinder conical seat machined scratch. This picture is slightly over 30X magnification. The groove is ~.009 wide x .005 deep.

Figure 66. Module T-1-8 Inner Cylinder Conical Seat

Figure 67. Module T-1-8 Outer Cylinder Conical Seat

K. PRECISION DIAMETRICAL MEASUREMENTS

Precision measurements were made of the inner and outer cylinders using a Moore Coordinate Machine. Circular charts were made at each elevation measured, thus giving a profile of the diametrical changes at each elevation. Each chart contains the module number, elevation number, outer or inner chart division (usually 0.001 in./div), date and initials of the technician operating the machine. The machine was standardized before and after each measurement, and this information is written on the chart with a line pointing to the division representing that diameter. The measurements are then added or subtracted to this dimension to obtain the true diameter at any point.

Table 1 shows the module numbers and the elevation numbers. Below each elevation number is the distance down from the cylinder leading edge to that measurement. Later measurements of inner and outer cylinders show that not all inner and outer cylinder leading edges were in alignment after module assembly.

Table 2 shows the elevation of the inner cylinder leading edge above (+) or below (-) outer cylinder leading edge for each module, average velocity through annulus, average flow through annulus and Reynolds number.

Table 3 shows the average, minimum and maximum diameters at each elevation for each module. The average was taken from six diameter measurements made at 30 deg. angles around the module starting at 0 deg. reference.

Table 4 shows the original diameter of the T-1-B and T-1-D inner and outer cylinders, the average diameter at each elevation measured with the Moore Coordinate machine, the original and final surface finish, original and final diametrical gap and the outer cylinder change in diameter with elevation.

The Moore Coordinate Machine uses a ball 0.031 inch in diameter as the stylus with 9 grams pressure and a rotational speed of 2 rpm to make the precision diametrical measurements.

TABLE 1
T-1-B AND T-1-D MODULE DIAMETRICAL MEASUREMENT ELEVATIONS

Inner Cylinder	Elevation Numbers and Distance from Leading Edge					
	1	2	3	4	5	6
T-1-0	0.015	0.030	0.200	3.735	4.200	---
T-1-2	0.015	0.030	0.200	---	---	---
T-1-3	0.015	0.030	0.200	---	---	---
T-1-4	0.015	0.030	0.200	---	---	---
T-1-5	0.015	0.030	0.200	3.735	4.200	---
T-1-6	0.015	0.030	0.200	3.450	---	---
T-1-7 Flow Annulus	0.015	0.030	0.200	---	---	---
T-1-7 Seat Annulus	---	---	---	0.015	0.030	0.200
Outer Cylinders						
T-1-2	0.015	0.030	3.735	---	---	
T-1-3	0.015	0.030	3.735	3.700	---	
T-1-4	0.015	0.030	0.200	---	---	
T-1-5	0.015	0.030	0.200	1.625	3.735	
T-1-6	0.015	0.030	0.200	3.735	---	
T-1-7*	4.750	0.200	0.030	0.015	---	
T-1-7**	---	---	---	---	2.500	

*This dimension measured with respect to inner cylinder flow annulus.

**This dimension measured with respect to inner cylinder seat annulus.

TABLE 2
ELEVATION OF INNER CYLINDER LEADING EDGE
WITH RESPECT TO OUTER CYLINDER LEADING EDGE

Module Number	T-1-2	T-1-3	T-1-4	T-1-5	T-1-6	T-1-7
Elevation Above and Below Outer Cylinder Leading Edge	-0.006	+0.011	+0.025	+0.004	+0.026	Not Applicable
Average Velocity of Sodium Through Annulus Ft/Sec	26.47	40.49	23.03	50.50	26.95*	56.60**
Average Flow of Sodium Through Annulus gpm	1.87	5.75	3.25	17.88	3.82	27.75**
Reynolds Number	1,860	9,960	3,970	30,990	6,630	48,760

*Velocity through slotted seat area was 81.8 ft/sec.

**T-1-7 flow annulus values.

TABLE 3
T-1-B
MODULE DIAMETER MEASUREMENTS

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
<u>Inner Cylinders</u>						
T-1-0 Avg. Dia.	2.86924	2.86932	2.86947	2.86950	2.86954	
Min. Dia.	2.86921	2.86928	2.86943	2.86945	2.86948	
Max. Dia.	2.86928	2.86936	2.86953	2.86955	2.86958	
T-1-2 Avg. Dia.	2.87357	2.87483	2.8745			
Min. Dia.	2.87333	2.87468	2.86989			
Max. Dia.	2.87374	2.87493	2.87006			
T-1-3 Avg. Dia.	2.88336	2.88392	2.88436			
Min. Dia.	2.88322	2.88377	2.88423			
Max. Dia.	2.88349	2.88404	2.88446			
T-1-4 Avg. Dia.	2.86974	2.87026	2.87004			
Min. Dia.	2.86965	2.87016	2.86997			
Max. Dia.	2.86982	2.87036	2.87014			
T-1-5 Avg. Dia.	2.85429	2.85478	2.85502	2.85497	2.85491	
Min. Dia.	2.85422	2.85472	2.85494	2.85498	2.85490	
Max. Dia.	2.85435	2.85486	2.85507	2.85496	2.85493	
T-1-6 Avg. Dia.	2.87715	2.87727	2.87716	2.87719		
Min. Dia.	2.87704	2.87717	2.87704	2.87712		
Max. Dia.	2.87736	2.87742	2.87730	2.87725		
Flow Annulus						
T-1-7 Avg. Dia.	2.84505	2.84531	2.84530	---	---	---
Seat Annulus						
T-1-7 Avg. Dia.	---	---	---	2.84566	2.84567	2.84579
<u>Outer Cylinders</u>						
T-1-2 Avg. Dia.	2.88305	2.88330	2.87973			
Min. Dia.	2.88282	2.88318	2.87820			
Max. Dia.	2.88326	2.88340	2.88102			
T-1-3 Avg. Dia.	2.89591	2.89560	2.89631	2.89576		
Min. Dia.	2.89542	2.89482	2.89606	2.89526		
Max. Dia.	2.89648	2.89640	2.89658	2.89616		
T-1-4 Avg. Dia.	2.87857	2.87951	2.87885			
Min. Dia.	2.87776	2.87866	2.87806			
Max. Dia.	2.87920	2.88016	2.87952			
T-1-5 Avg. Dia.	2.88139	2.88129	2.88089	2.87988	2.87961	
Min. Dia.	2.88112	2.88103	2.88070	2.87964	2.87952	
Max. Dia.	2.88159	2.88150	2.88108	2.88017	2.87969	
T-1-6 Avg. Dia.	2.88673	2.88660	2.88642	2.88613		
Min. Dia.	2.88600	2.88594	2.88602	2.88556		
Max. Dia.	2.88745	2.88728	2.88688	2.88670		
Flow Annulus						
T-1-7 Avg. Dia.	2.88031	2.88039	2.88001	2.88001	---	
Seat Annulus						
T-1-7 Avg. Dia.	---	---	---	---	2.88195	

Note: All measurements in inches.

TABLE 4
T-1-B AND T-1-D PARAMETERS

TABLE 4

Module Number Inner Cyl	Original Diameter (in)	Final Diameter (in. from Leading Edge)					Orig. Finish (RMS)	Final Finish (RMS)	Orig. Diametrical Gap (in.)	Final Diametrical Gap at (at ___ In. from Leading Edge)				
		.015	.030	.200	3.735	4.2				.015	.030	.200	3.735	4.20
T-1	2.8695	2.8692	2.8693	2.8695	2.8695	2.8695	12	---	---	---	---	---	---	---
T-1-2	2.8750	2.8738	2.8748	2.8745	---	---	12	12→15	0.0051	0.0092	0.0085	0.0052	---	---
T-1-3	2.8845	2.8834	2.8839	2.8844	---	---	12	6→8	0.0100	0.0125	0.0117	0.0114	---	---
T-1-4	2.8702	2.8697	2.8703	2.8700	---	---	4	6→7	0.0096	0.0089	0.0092	0.0088	---	---
T-1-5	2.8550	2.8543	2.8548	2.8550	2.8550	2.8549	12	4→10	0.0250	0.0271	0.0265	0.0259	0.0249	0.0247
T-1-6	2.8775	2.8772	2.8773	2.8772	2.8772	---	12	6→8	0.0100	0.0095	0.0093	0.0092	0.0089	---
T-1-7FA	2.8453	2.8450	2.8453	2.8453	---	---	--	17→22	0.03467	0.03496	0.03470	0.03501	---	---
T-1-7SA	2.8458	2.8456	2.8457	2.8458	---	---	--	17→22		0.03639	0.03638	0.03616	---	---
Outer Cyl		.015	.030	.200	3.735				Change in Outer Cylinder Dia. from Orig					
									.015	.030	.200	3.735		
T-1-2	2.8801	2.8830	2.8833	---	2.8797	---	16	23→28	+0.0029	+0.0032		-.0004	---	
T-1-3	2.8945	2.8959	2.8956	---	2.8958	2.8963*	16	10→26	+0.0014	+0.0011	---	+0.0018	+0.0013**	
T-1-4	2.8798	2.8786	2.8795	2.8788	---	---	12	10→100	-.00123	-.00029	-.00095	---	---	
T-1-5	2.8800	2.8814	2.8813	2.8809	2.8796	2.8799**	16	8→20	+0.0014	+0.0013	+0.0009	-.0004	-.0001****	
T-1-6	2.8875	2.8867	2.8866	2.8864	2.8861	---	16	11→60	-.00077	-.00090	-.0011	-.0014	---	
T-1-7FA	2.8800	2.8800	2.8800	2.8804	2.8803	---	--	17→24	0	0	+0.0004	---	---	
T-1-7SA	---	---	---	---	---	2.88195	--	17→24	---	---	---	---	---	

*3.700 In. from Leading Edge
**1.5 In. from Leading Edge

**T-1-3 at Elevation 3.700 in.
****T-1-5 at Elevation 1.500 in.

Some of the charts from the Moore Coordinate Machine are in Appendix C. A short discussion of each chart is included.

Figure 68 shows the change in inner cylinder diameter versus distance from the inner cylinder leading edge. The reference diameter was the diameter given in the piping completion record.⁽¹⁾ It will be noted that the spare inner cylinder labeled T-1-0 was plotted as a reference, and that this curve shows some taper from 0.015 to 0.200 inch from the leading edge. All T-1-B modules show a smaller diameter than the reference at 0.015 inch except T-1-6 and T-1-7, which are the same.

Figure 69 shows the change in outer cylinder diameter versus distance from the outer cylinder leading edge. The reference diameter was the diameter given in the piping completion record.⁽¹⁾ Two cylinders, T-1-4 and T-1-6, show a smaller diameter than originally measured and four cylinders, T-1-2, T-1-3, T-1-5 and T-1-7, show a larger diameter. This wide variation in diameter changes is primarily due to lack of initial diametrical information along the leading edge.

Figure 70 shows the post-operation diametrical gap change versus distance from the leading edge. Modules T-1-4 and T-1-6 show a consistently smaller gap than originally measured, indicating a possible material deposition on these surfaces. Modules T-1-2, T-1-3 and T-1-5 show a larger gap along the leading edge, which approaches zero change as the distance from the leading edge increases.

Maximum values of diametrical gap change at 0.200 inches from the leading edge are 9×10^{-4} inches and 14×10^{-4} inches for T-1-5 and T-1-3, respectively.

Erosion rates calculated from Figure 70 assume that the erosion rate is uniform and equal on all surfaces. The change in diametrical gap plotted in this figure includes the change involved on four surfaces and is for 3000-hour operation, except for T-1-7, which has 3800 hours of operation.

Example 1

T-1-5 gap change at 0.200 inches from the leading edge is 0.9×10^{-3} inches.

$$\text{Erosion rate/yr} = \left(\frac{0.9 \times 10^{-3}}{4} \right) \left(\frac{8766}{3000} \right) \approx 0.66 \times 10^{-3} \text{ inches/year.}$$

Example 2

T-1-3 gap change at 0.200 inches from the leading edge is 1.4×10^{-3} inches.

$$\text{Erosion rate/yr} = \left(\frac{1.4 \times 10^{-3}}{4} \right) \left(\frac{8766}{3000} \right) \approx 1.02 \times 10^{-3} \text{ inches/year.}$$

All diameter and diametrical changes plotted on Figures 68, 69 and 70 are an average of 6 diameter measurements taken from charts made with the Moore Coordinate Machine, at 30 deg. angles starting from zero reference.

Figure 68. Inner Cylinder Diameter vs. Distance

Figure 69. Outer Cylinder Diameter vs. Distance

Figure 70. Post-Operation Gap Change vs. Distance from Leading Edge

L. PROFILOMETER MEASUREMENTS

Profilometer measurements were made of the inner and outer cylinders using a Tally Surf machine. The stylus radius was 0.0001 inch and traveled at a speed of 1.4 inches per minute with a stylus pressure of 0.1 gram. Most of the profile measurements were made in the vertical direction in grid "A" across the leading edge. Length of the profile trace varied, but was normally between 0.200 inch and 0.250 inch. The unused inner cylinder, T-1, was used as a reference. The Tally Surf machine amplification was varied to show more of the leading edge and to show the surface finish. The RMS surface finish, horizontal and vertical amplification, module number, grid number, angular rotation and inner or outer cylinder were recorded for each different measurement. Although the vertical amplification varied from 200 microinches to 20 microinches per minor division, the horizontal amplification was 0.002 inches per minor division for all measurements. An average of six measurements was made for each module except T-1-8. No measurements were made on T-1-8, since it did not have annular flow. Several profilometer tapes and a general discussion are included in Appendix D.

Profilometer tapes provide a permanent, recorded profile and the RMS surface finish of the surface measured. These measurements can be utilized as a reference for comparison with future measurements to determine if the surface profile is changing. Very accurate alignment and indexing are required to reproduce a profilometer tape for comparison. Surface imperfections of 20 microinches can be magnified to 0.100 inches on the profilometer tape. The radius of an outside edge can also be recorded by using a lower vertical magnification. Profilometer measurements used in conjunction with precision diametrical measurements can provide a basic reference for determining surface erosion.

M. PARTICULATE RECOVERY AND EXAMINATION

A clean separate glass container with a lid was used to collect the particulate from each module during disassembly. Each container was labeled with the module number and date to identify the particulate from each module. A clean paper was placed under each module during disassembly to catch any particulate from the operation. The analysis of particulates was made by the WADCO Analytical Chemistry Laboratory by spark source mass spectrography and are qualitative only. The weight of particulate collected during disassembly was approximately 1 milligram. Most of this came from module T-1-4. Table 5 shows the results of this analysis and gives 304 SST as a comparison.

Each module was placed in a clean container of filtered Dowanol EB during the original cleanup. After all sodium had been reacted, the solutions were placed in clean polyethylene containers and labeled with each module's number to identify the solution. These solutions were filtered through a 0.6 micron filter and then through a 0.2 micron filter. These filters and particulate were then analyzed by the Analytical Chemistry Laboratory using emission spectrography. Table 5 shows the results of this analysis and gives 304 SST as a comparison.

TABLE 5
T-1-B AND T-1-D PARTICULATE ANALYSIS

WADCO SPARK SOURCE MASS SPECTROGRAPHY					EMISSION SPECTROGRAPHY								304 SST
MODULE					MODULE								
Element	T-1-2	T-1-3	T-1-4	T-1-5*	T-1-6	T-1-2	T-1-3	T-1-4	T-1-6	T-1-7	T-1-B Inlet Header	T-1-B Outlet Header	
Ag						<0.001	<0.001	M	<0.001	T	<T	M	<0.001
Al	<0.6	2	3.2	0.03	1.7	2	2	S	2	S	M-S	S	>5
Au												<T	
B	<0.2	0.1	<0.1		<0.1			T			T	T	
C	7.5	8	12		6.2								
Ca	<0.8	10	1.4	0.01	0.3	5	2	T-M	0.5	M	T-M	M	0.5
Co	<1.3	<0.5	7.2	0.2	<0.4								
Cr	<1	17	6	0.3	3	>5	2	M-S	>5		M	M-S	5
Cu						2	0.2	M	2	M-S	M	M	0.2
Fe	<1.3	23	34	25	70	>5	>5	M-S	>5	M-S	M-S	M-S	>5
Ga										T-M			
Hf						<0.005	<0.005		<0.005				<0.005
In						<0.005	<0.005		<0.005				<0.005
K	<0.8	10	4.8		7.5	0.1	0.2		0.2				1
Li						0.2	0.2	<M	0.2		M	<M	0.2
Mg	<0.4	0.5	0.7		<0.1	1	0.5	T-M	2	M	T-M	M-S	>5
Mn	<1	1.2	0.6	0.2	0.3	0.2	0.2	T-M	0.5	M	T-M	T-M	0.2
Mo				0.2				T-M			<T	T-M	
Na	48	19	8.3	3	4.3	5	2	S	2		T-M	M-S	5
Ni	<1.3	2.5	1.4	7	1.9	0.5	0.2	M	2	M	M	M	0.5
O	34	4	19.3		3								
P	<0.0	0.3	0.4		0.2								
Pb						1	1	T-M	1	M	M	M	0.05
S	<0.6	0.3	<0.4		0.2								0.03
Si	<0.6	1.4	<0.4	0.5	0.4	>5	>5	M	>5	S	M	T-M	>5
Sn						>5	2	M	0.2	M	M	M	0.1
Ti						1	0.5	T	1	T-M	T	T-M	1
Zn						0.5	2		0.5	M			0.5
Zr			0.4						0.02				0.01

*LMEC Emission Spectrometer Analysis

Symbol	Meaning	App'x Conc.
S	Strong	Greater than 1%
M	Moderate	1% to 0.01%
T	Trace	Less than 0.01%

IV REFERENCES

1. BNW Pressure Piping Completion Record for Drawing H-3-28368 (T-1-B).
2. Test Plan TPL-01-SA-001, "FFTF Flow Duct/Tube Sheet Sodium Erosion Flow Test (T-1-B)," LMEC, November 6, 1969.
3. Final FFTF Test T-1-B Test Report 7/LMEC-111, LMEC, January 15, 1971.
4. T-1-B Disassembly Procedure, F. R. Standley, June 1970, BNW
5. Trip Report, A. B. Webb, March 19, 1970, BNW
6. T-1-D Fabrication Documentation, A. B. Webb, April 1970, BNW
7. T-1-D Test Plan TPL-01-SA-002, "FFTF Flow Duct/Receptacle Erosion Flow Test Plan" LMEC, May 25, 1970.
8. T-1-D Disassembly Procedure, F. R. Standley, December 1970, WADCO
9. Final FFTF Test T-1-D Test Report
10. FFTF Tests T-1-B and T-1-D Measurement Error Analysis.

APPENDIX A

T-1-B SODIUM EROSION TEST DEVIATIONS FROM NORMAL OPERATION

Summary of events, including instances in which the test section $\Delta P > 150$ psi or < 130 psi, which constitute interruptions to FFTF Test T-1-B.

<u>Number</u>	<u>Date</u>	<u>Hours</u>	<u>Interruptions and Effects</u>
①	11/3/69	7.3	ΔP was purposely lowered to 20 psi while switching to flow through core tank. A slight decrease in indicated flow rates occurred for all modules except -2. Sodium temperature decreased to 560°F due to colder sodium from core tank and increased back to 750°F after 11 hours.
①A	11/4/69	16.3	ΔP was lowered to zero for backflushing operation and to values less than 130 psi for subsequent removal of gas. An evaluation of flow rate changes is presented in the transmittal document. Sodium temperature dropped temporarily to 680°F.
①B	11/5/69 11/6/69 11/7/69	62.0	ΔP decreased unexpectedly to 125 psi due to gas in the pumps. ΔP was then lowered purposely to values less than 130 psi to remove the gas. There was no significant change in module flow rates except for -5 module flow rate which increased 0.7 gpm. Sodium temperature dropped temporarily to 695°F.
①C	11/12/69	0.3	ΔP dropped to zero when core tank upper valve was closed by a signal from a temperature controller when its set point was lowered purposely. There was no change in flow rates at 140 psi ΔP and in sodium temperature when flow was re-established.

<u>Number</u>	<u>Date</u>	<u>Hours</u>	<u>Interruptions and Effects</u>
②	11/13/69	0.1	ΔP dropped below 130 psi when one pump was de-energized unexpectedly. Each module flow rate increased slightly at 140 psi ΔP . Sodium temperature remained within test limits.
③	11/14/69		T-1-5 module vibration test.
④	12/8/69	0.5	ΔP was purposely lowered to zero as both pumps were de-energized for connecting electrical circuitry to protect pump ducts from high temperature. Effects of this interruption are discussed in the transmittal document.
⑤	12/12/69 to 12/24/69		Flows showed decrease but were the result of instrument error during this period.
⑤A	12/22/69	0.0	ΔP dropped to zero when pump power was inadvertently cut off. Normal conditions were resumed within two minutes. There were no significant changes in flow rates and temperature.
⑥	12/24/69		Flow instrument re-zeroed.
⑦	12/30/69	3.4	ΔP was lowered purposely to zero while performing plugging runs on sodium from the circulating system. Effects of this interruption are discussed in the transmittal document.
⑧	12/31/69	0.5	ΔP dropped to zero when faulty circuit breaker cut off pump power. Indicated flow rate through -5 module at 140 psi ΔP increased slightly. The other module flow rates and sodium temperature showed no significant change. Flow stopped purposely by cutting off pump power for electrical check.
⑨	12/31/70	1.1	ΔP dropped to zero when faulty circuit breaker cut off pump power. There were no significant changes in flow rates and temperature.

<u>Number</u>	<u>Date</u>	<u>Hours</u>	<u>Interruptions and Effects</u>
⑩	1/2/70	0.1	ΔP was lowered purposely to zero for an electrical check of the pumps. There were no significant changes in temperature and flow rates at 140 psi ΔP . ΔP was lowered purposely to zero while performing plugging runs on sodium from the circulating system. There are no comparable data on flow rates and temperature.
		0.6	ΔP dropped to zero when faulty circuit breaker cut off pump power. There are no comparable data on flow rates and temperature.
		0.5	ΔP was lowered purposely to zero to replace the faulty circuit breaker (replacement was not completed due to dimensional discrepancy of replacement breaker). There are no comparable data on flow rates and temperature.
⑪	1/3/70	0.1	ΔP dropped to zero when pump power was cut off by faulty circuit breaker. There are no comparable data on flow rates and temperature.
		8.4	ΔP dropped to zero when pump power was cut off by faulty circuit breaker. A suitable breaker was obtained and installed. There are no comparable data on flow rates and temperature.
		0.3	ΔP was lowered purposely to zero when one pump over-heated due to inoperative air blower. There are no comparable data on flow rates and temperature.
		0.1	ΔP was lowered purposely to zero while switching to closed loop flow. There were no significant changes in temperature and flow rates at 140 psi ΔP .
⑫	1/13/70		T-1-5 module vibration test.
⑬	1/14/70		T-1-5 module vibration test.

<u>Number</u>	<u>Date</u>	<u>Hours</u>	<u>Interruptions and Effects</u>
(13A)	1/15/70	0.5	ΔP decreased gradually to 103.8 psi due to gas in the pumps. ΔP was then lowered purposely to values less than 130 psi to remove the gas. There are no comparable data on flow rates and temperature.
		0.3	ΔP was lowered purposely to 20 psi while switching to flow through core tanks. There were no significant changes in flow rates. Sodium temperature decreased temporarily to 694°F.
(14)	1/22/70		Series of plugging runs on sodium from the core tank.
(15)	1/27/70		Series of plugging runs made.
(16)	1/28/70	0.4	Pumps were shut down - flow changed to closed loop configuration - flushing operation - T-1-5 had a slight increase in flow to 19.0 gpm noted prior to the flushing operation. ΔP was lowered purposely to zero while switching to closed loop flow. There were no significant changes in temperature. Flow data is discussed in the transmittal document.
(17)	2/4/70	0.5	Temperature fell below test conditions.
(18)	2/5/70		Series of plugging runs made.
(19)	2/6/70	1.3	ΔP dropped to zero when core tank outlet valve was closed inadvertently. Sodium temperature decreased to 670°F during the interruption. Flow data is discussed in the transmittal document, 70LMEC-241.
(20)	2/8/70		Series of plugging runs made.
(21)	2/11/70		Series of plugging runs made.
(22)	2/12/70		Series of plugging runs made.

<u>Number</u>	<u>Date</u>	<u>Hours</u>	<u>Interruptions and Effects</u>
(23)	2/19/70		Series of plugging runs made.
(24)	2/20/70	0.2	ΔP was lowered purposely to values less than 140 psi while switching to closed loop flow for flushing operation. There was no significant change in sodium temperature. Flow data is discussed in the transmittal document, 70LMEC-244.
(25)	2/27/70		Three plugging runs made from core tank.
(26)	2/28/70	3.9	ΔP dropped to zero when the pumps were cut off by an incoming power failure. Flow and temperature data are discussed in the transmittal document.
(27)	3/5/70		End of test at 12:30 p.m.

APPENDIX B

T-1-D SODIUM EROSION TEST DEVIATIONS FROM NORMAL OPERATION

<u>Number</u>	<u>Date</u>	<u>Interruption and Effects</u>
①	16 June '70	ΔP was purposely lowered to 60 psi to more safely accommodate seat load changes per WADCO direction. The effects of this seat load adjustment are masked by the variations observed in general, during the initial phases of the test, as discussed in data packages 2, 2a, 3, 4, 5, and 6.
②	24 June '70	ΔP was purposely reduced to 60 psi several times to accomplish the -7 module unseating force operation per Deviation No. 5.
③	24 June '70	ΔP was purposely reduced to zero psi to accomplish the -7 module seat flushing operation per Deviation No. 6. No change was observed in the -7 module seal leakage rate as a result of the flushing operation.
④	1 July '70	ΔP was dropped to zero psi when a spurious trip shut down the pumps. This event was reported to LMEC Incident & Problem Report (IPR) No. LCTL-037. A step change of the -7 module leakage rate from 0.4 gpm to 0.2 gpm occurred across this shutdown, i.e., measurements taken prior to and compared with measurements taken after the interruption. The instrumentation systems were examined and found to be satisfactory, indicating a change had occurred in the internals of the -7 module. The -8 module was apparently unaffected.
⑤	5 July '70	ΔP was purposely lowered to 20 psi to accommodate seat load change of the -8 module from 1260 lbs. to 1250 lbs. No significant change in the -8 module leakage flow rate.
⑥	21 July '70	ΔP dropped to zero when facility was shutdown due to a failure of a temperature controller in an inactive part of the facility. For details, see LCTL - IPR No. 039. Small changes in module leakage rates were observed as

<u>Number</u>	<u>Date</u>	<u>Interruption and Effects</u>
⑥ (continued)		follows: the -7 changed from 0.25 gpm to 0.24 gpm, the -8 module from 0.01 gpm to 0.007 gpm. Again, some internal changes within the modules are suspected to be the cause.
⑦	21 July '70	ΔP dropped to zero when facility was shut down when pumps were tripped off by an incoming power dip. Details available in LCTL-IPR No. 040. The effects described in the previous interruption include this event with regard to the fact that only one -7 module leakage measurement was taken between these two events.
⑧	29 July '70	Although the ΔP requirement was not violated, a temperature decrease below the required minimum of 700°F was experienced as a result of heaters being de-energized for circuit breaker maintenance (see LCTL-IPR No. 044). The minimum temperature reached was 690°F, test inlet temperature. A -7 module seat leakage rate change was experienced during the temperature transient, but returned to previous levels upon return to normal test conditions.
⑨	30 July '70	ΔP was reduced to zero when the pumps tripped off due to pump overtemperature caused by a human error when a pump cooler blower was shut off (see LCTL-IPR No. 043). No significant changes were observed across this shutdown in test parameters.
⑩	1 Aug. '70	Although the minimum temperature limit of 700°F was not exceeded, a temperature decay to 720°F was encountered when heater breakers experienced some problems which were quickly resolved. No effects upon test parameters.
⑪	5 Aug. '70	ΔP dropped to 127 psi during a valve test procedure unrelated to test T-1-D. The details are discussed in LMEC LCTL-IPR No. 045. There was no change in test parameters across this incident.
⑫	5 Aug. '70	A short, high temperature excursion was experienced wherein the test inlet temperature exceeded 770°F for six minutes, reaching a maximum of 780°F. No effect upon data. Details discussed in LCTL-IPR No. 046.

<u>Number</u>	<u>Date</u>	<u>Interruption and Effects</u>
(13)	13 Aug. '70	ΔP dropped to 114 psi and recovered during a facility incoming power dip. No effect upon data.
(14)	14 Aug. '70	ΔP dropped to 20 psi when pump P2B tripped off. Details in LCTL-IPR No. 047. No effect upon data.
(15)	16 Aug. '70	ΔP dropped to zero when both pumps tripped off. Details in LCTL-IPR No. 048. No significant change in test data was observed.
(16)	16 Aug. '70	ΔP dropped to 62 psi when P2B pump tripped off on over-temperature due to failed blower air hose. No effect upon data. Details in LCTL-IPR No. 049.
(17)	20 Aug. '70	ΔP purposely reduced to 80 psi to accommodate installation of new air hoses on both blowers. No effect upon data.
(18)	3 Sept. '70	ΔP dropped to zero when both pumps tripped off. Details in LCTL-IPR No. 053. No changes observed in test data parameters.
(19)	4 Sept. '70	ΔP was reduced to zero several times while trouble shooting previous pump trip problem. The -7 module seat leakage rate increased somewhat from 0.23 gpm to 0.25 gpm across this event. See LCTL-IPR No. 055
(20)	7 Sept. '70	ΔP was lowered to 12 psi to accommodate replacement of cooling blower air filters. No change in test data observed.
(21)	8 Sept. '70	ΔP was lowered to accommodate a -7 module seat load adjustment. A step change was observed in the -7 module seal leakage rate accompanying this adjustment, from 0.25 to 0.28 gpm.
(22)	12 Sept. '70	ΔP was lowered to accommodate a -7 module seat load adjustment. A slight drop in the -7 module seat leakage rate of approximately 0.007 gpm was observed at this time.

<u>Number</u>	<u>Date</u>	<u>Interruption and Effects</u>
(23)	25 Sept. '70	ΔP dropped to zero when facility was shut down due to power loss attributed to local brush fires in area. Details, refer to LCTL-IPR No. 057. Both the -7 and -8 modules spring loads were reduced to zero per Deviation No. 9 in conjunction with the test loop draining.
(24)	28 Sept. '70	ΔP lowered to zero during reinitiation of test conditions when a facility vent valve failed and the loops were again drained and modules unloaded. Details of the vent are available in LCTL-IPR No. 058. The reinitiation and re-draining were accomplished per Deviation Nos. 10 and 11, although nominal steady-state conditions were not re-established.
(25)	4 Oct. '70	ΔP returned to 140 and steady-state conditions re-established. Reinitiation of test accomplished per Deviation No. 12. Drastic changes were observed in seat leakage rates as follows: the -7 module rate decreased from 0.26 gpm to 0.13 gpm while the -8 module rate increased from 0.007 gpm to 0.08 gpm. The -7 module annular flow rate changed from 28.0 gpm to 29.0 gpm across this event. It is believed that both modules changed during the two unloading and reloadings.
(26)	5 Oct. '70	ΔP dropped to 130 while conducting a special procedure exercising facility valves causing pumps to ingest gas. No changes observed in test data.
(27)	14 Oct. '70	ΔP dropped to 86 psi during above mentioned special procedure exercising facility valves, and pumps again became gas bound. The -7 module leakage rate dropped approximately 0.010 gpm across this event.
(28)	28 Oct. '70	ΔP dropped to zero when facility control panel power was lost. See LCTL-IPR No. 059. No significant change was observed in test parameters.
(29)	29 Oct. '70	

<u>Number</u>	<u>Date</u>	<u>Interruption and Effects</u>
(30)	12 Nov. '70	ΔP dropped and oscillated below normal during special procedure exercising facility valves, again causing pumps to become gas bound. No effect on data. See update to LCTL-IPR No. 047.
(31)	13 Nov. '70	ΔP lowered to zero to accommodate evaluation of gas entrapment in system. The -7 module leakage rate increased by 0.005 gpm to 0.13 gpm. No effect upon the -8 module leakage rate.
(32)	18 Nov. '70	ΔP reduced to zero to aid in gas elimination in system, source unknown. In order to prevent excessive down time in future procedures, the test was shut down purposely while special procedure for exercising facility valves was in operation. No significant changes observed in test data.
(33) (34) (35)	19 Nov. '70	ΔP reduced to zero to accommodate special procedure without potential of excessive test time loss. No effect observed upon test data.
(36) (37)	25 Nov. '70	ΔP reduced to zero to accommodate special procedures for facility valve checkout. No effect upon test data.
(38)	29 Nov. '70	ΔP dropped to zero when pumps tripped off during a facility power outage. See update to LCTL-IPR No. 040. The -7 module leakage rate was observed to increase from 0.135 to 0.150 gpm across these events. No effect observed upon the -8 module leakage rate.
(39)	30 Nov. '70	ΔP reduced to zero to accommodate special proecures for facility valve checkout. No effect upon test data.

APPENDIX C

Figures D-1 through D-9 show some of the charts from the Moore Coordinate machine. The following is a discussion of these charts.

Figure D-1. Figure D-1 shows the charts from elevations 2 and 5 on the reference inner cylinder T-1. Note that the upper chart indicates a smooth surface and shows a maximum diametrical variation of 0.0001 inch from a true circle. The lower chart shows a slightly rougher surface, an increase in diameter of ~ 0.0004 inch and a maximum variation of less than 0.0001 from a true circle.

Figure D-2. This figure shows three charts from module T-1-2. The two upper charts are from elevations 1 and 2 of the inner cylinder and elevation 3 of the outer cylinder. The upper chart is 0.015 inch down from the leading edge and has a rougher surface than the reference cylinder. Elevation 2 is 0.030 inch down from the leading edge. The two charts show an increase in diameter as the distance from the leading edge increases. The third chart from elevation 3 of the T-1-2 outer cylinder shows that the cylinder is egg shaped. The difference between minimum and maximum diameters is 0.0028 inch. Several of the outer cylinders are egg shaped from the information shown on the charts.

Figure D-3. This figure shows two charts from the T-1-3 outer cylinder at elevations 1 and 3. The top chart indicates a rough leading edge larger in diameter than the original 2.8945 inch. The

lower chart indicates a smoother surface located at the approximate elevation of the inner cylinder trailing edge.

Figure D-4. This figure shows two charts from the T-1-4 inner cylinder at elevations 1 and 2. Both charts show a smooth surface with a maximum diametrical variation of 0.0001 inch from a perfect circle. Both charts indicate an increase in diameter as the distance from the leading edge increases. These figures are typical of many of the charts of inner cylinders.

Figure D-5. This figure shows two charts from the T-1-5 outer cylinder at elevations 2 and 4. Both indicate that the outer cylinder is somewhat egg shaped. The cylinder diameter decreased at each elevation measured from the leading edge until after the length of the inner cylinder was obtained. See Table 4.

Figure D-6. This figure shows two charts from the T-1-5 inner cylinder at elevations 1 and 4. T-1-5 inner cylinder diameter increases with distance from the leading edge. Note that the top chart at elevation 4 is almost a perfect circle.

Figure D-7. This figure shows two charts from the T-1-6 module. The top one is from T-1-6 outer cylinder at elevation 2. The surface in the area between 330 deg. and 0 deg. is the same area where damage occurred during original assembly. The lower chart of the T-1-6 inner cylinder at elevation 2 shows a sharp projection at ~350 det. This projection is part of a deep scratch which has metal pushed out on both sides.

Figure D-8. This figure shows three charts from the T-1-7 module; two from the inner cylinder at elevations 1 and 3 and one from the outer cylinder at elevation 1. The top chart is from the outer cylinder flow annulus at the trailing edge of the inner cylinder. The second and third charts, elevations 1 and 3, are from the leading edge of the inner cylinder flow annulus at elevations of 0.015 and 0.200 inch respectively. The depression indicated at 30 deg., elevation 1, on the T-1-7 inner cylinder is a small flat spot caused by handling after disassembly. The T-1-7 inner cylinder shows an increase in diameter as the distance from the leading edge increases.

Figure D-9. This figure shows three charts from the T-1-7 module. The first and third charts are from the T-1-7 inner cylinder seat annulus at 0.015 and 0.200 inch from the leading edge. These charts also show an increase in diameter with an increase in distance from the leading edge. Chart two from the T-1-7 outer cylinder elevation 4 matches the elevation 1 on the inner cylinder flow annulus leading edge. The size and shape of this chart is almost identical to the one shown on Figure D-8 for elevation 1.

T-1 Inner Cylinder
Elevation No. 5
Scale: 0.0001 in./div

T-1 Inner Cylinder
Elevation No. 2
Scale: 0.0001 in./div

Figure D-1
C-4

Figure D-2

T-1-3 Outer Cylinder
Elevation No. 1
Scale: 0.0002 in./div

T-1-3 Outer Cylinder
Elevation No. 3
Scale: 0.0002 in./div

Figure D-3

T-1-4 Inner Cylinder
Elevation No. 1
Scale: 0.0001 in./div

T-1-4 Cylinder
Elevation No. 2
Scale: 0.0001 in./div

Figure D-4

T-1-5 Outer Cylinder
Elevation No. 4
Scale: 0.0001 in./div

T-1-5 Outer Cylinder
Elevation No. 2
Scale: 0.0001 in./div

Figure D-5

T-1-5 Inner Cylinder
Elevation No. 4
Scale: 0.0001 in./div

T-1-5 Inner Cylinder
Elevation No. 1
Scale: 0.0001 in./div

Figure D-6

T-1-6 Outer Cylinder
Elevation No. 2
Scale 0.0002 in./div

T-1-6 Inner Cylinder
Elevation No. 2
Scale: 0.0001 in./div

Figure D-7

Figure D-8

Figure D-9

APPENDIX D

Figure P-1. This trace is typical of three traces made on the reference inner cylinder leading edge and surface. Two magnifications are shown, the first is $50\mu\text{"/div.}$ and continues through match lines "A-A" for 0.17 inches. This surface finish is 12 RMS. The trace shown was made across grid "A" at 15 deg.

A trace from the T-1-2 inner cylinder across grid A at 179 deg. shows the leading edge and surface back ~ 0.11 inch. The finish is 13 RMS. Two additional traces were made at A-28 deg. and A-299 deg. These two traces show a surface finish of 15 RMS each, although the profiles were very similar in appearance to A-179 deg. shown in Figure P-1.

Figure P-2 The top trace is the leading edge of T-1-4 outer cylinder at A-85 deg. The trace shows a lip greater than .001 inch on the leading edge. Two additional traces at 35 deg.A and 277 deg.A show the same profile and the same magnitude. The vertical amplification is $100\mu\text{"/div.}$, or 1/5 that of the reference cylinder. The surface finish is >100 RMS in all "A" grids measured, but dropped to 10 RMS in the "B" grids immediately below. The high surface finish reading is primarily due to the lip on the leading edge.

The second trace is shown in three parts starting with the leading edge and progressing back to ~ 0.25 inches. This trace is from T-1-2 outer cylinder grid "A"-325 deg. The trace shows a dip of 10.5 minor divisions or ~ 0.000525 inch.

Two other traces of T-1-2 outer cylinder at "A" 28 deg. and 179 deg. show very similar traces. This indicates that the outer cylinder diameter increased by 0.001 inch. This is believed to be caused during original machining, but base data is not available for confirmation. The surface finish was 23 to 28 RMS for all traces.

Figure P-3. The top trace in Figure P-3 is the leading edge of the T-1-3 inner cylinder across grid "A" at 5 deg. The leading edge is tapered ~ 0.020 inch. The high peaks appearing on this trace at ~ 0.020 inch to 0.040 inch are caused by particulate deposition on the surface in grid A-1. The surface finish is 6 RMS. The second trace is a continuation of the first trace with match lines "A" - "A". Note the finish is very smooth after 0.010 inches. The third trace is the leading edge of the T-1-3 outer cylinder across grid "A" at 125 deg. Note the continuous taper through 0.200 inches.

Figure P-4 The top trace shows the leading edge of the T-1-5 inner cylinder across grid A at 111 deg. Note the second part of this trace shows a gradual increase in diameter through 0.190 inches. Diametrical measurements also reflect this increase in diameter. The surface finish is 6 RMS. The third trace is the leading edge of the T-1-5 outer cylinder across grid "A" at 336.5 deg. This trace shows a slight lip on the leading edge of this cylinder.

Figure P-5. The top trace shows the leading edge of the T-1-6 inner cylinder across grid "A" at 225. The trace indicates a pit 0.004 wide by $\sim 100\mu$ deep in the leading edge. Surface finish is 6 RMS. The second trace is the T-1-6 outer cylinder leading edge. Crud buildup is indicated in these traces. Diametrical measurements show that the I.D. of the outer cylinder decreased ~ 0.001 inch from the original diameter.

Figure P-6. The first trace shows the leading edge of the T-1-7 inner cylinder flow annulus. The leading edge appears to be smoother than the traces below and is typical of three traces made at 0, 10, and 350 deg. The second trace is the leading edge of the seat annulus of T-1-7 at 0 deg. This is also typical of three traces made at 0, 10, and 350 deg. The seat annulus shows a taper for the first 0.060 inch. The third trace is the T-1-7 outer cylinder flow annulus leading edge. The fourth trace shows the T-1-7 outer cylinder seat annulus leading edge. None of the last three traces were in an area of high velocity sodium. It should be noted that the vertical magnification is 2/5 that of the reference cylinder and each division is 50μ ". The surface finish varies from 17 to 20 RMS on the inner cylinder and 18 to 23 RMS on the outer cylinder.

Figure P-7. Three traces of a specimen with a 0.003 inch radius. Note that the vertical trace changes to a horizontal trace in $\sim 1/2$ divisions or 0.003 inch in the top trace. This changes slightly as the vertical amplification is increased from 200 microinches per division as shown in the two lower traces.

Figure P-1

T-1-4 OUTER CYL. 85°A
 100 M"/DIV. VERTICAL
 .002"/DIV. HORIZONTAL

FINISH 85°A > 100 RMS
 85°B - 10 RMS

Figure P-2

D-6

Figure P-3

D-7

Figure P-4

D-8

Figure P-5

Figure P-6

D-10

Figure P-7

DISTRUBUTION

W. G. Albert	WADCO	N. J. Georges	ARD
L. R. Besel	WADCO	G. Jones	ARD
L. J. Defferding	WADCO	E. Paxson	ARD
W. M. Gajewski	WADCO	R. J. Slember	ARD
J. G. Gallagher	WADCO		
R. E. Heineman	WADCO	G. Finch	RDT
R. N. Johnson	WADCO	F. Goldner	RDT
H. T. Knight	WADCO	P. R. Riley	RDT
D. J. Lagrou	WADCO	F. R. Standerfer	RDT-PNP
C. A. Munro	WADCO	A. Taboda	RDT
J. Muraoka	WADCO	A. Waterhouse	RDT-PNP
D. J. Oakley	WADCO		
G. J. Rogers	WADCO	L. B. Copeland	LMEC
F. R. Standley (10)	WADCO	D. K. Darley	LMEC
E. G. Stevens	WADCO	R. W. Dickinson (2)	LMEC
J. C. Tobin	WADCO	J. Mantle	LMEC
B. G. Twining (2)	WADCO		
G. R. Waymire	WADCO		
A. B. Webb	WADCO		
J. E. Werle	WADCO		
J. G. Wett	WADCO		