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Astronuclear
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SNPO-C

WANL-TME-2735
SEPTEMBER 1970

DATA ITEM T-119

**CORE PERIPHERY
MODEL TEST 64DT-212 (U)**

FINAL REPORT

MASTER

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Subcontract NP-1
CODE IDENT NO. 14683

WANL-TME-2735
SEPTEMBER 1970

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by H. J. C. TIC, date SEP 11 1973

DATA ITEM T-119

CORE PERIPHERY

MODEL TEST 64DT-212 (U)

FINAL REPORT

SECRET	REVISION	NOV 1973	Class.	Date
DETERMINATION	TR	U	4-15-82	
Class: U

Approved by: J. G. Gallagher
J. G. Gallagher, Manager
NERVA Design Engineering

INFORMATION CATEGORY
<u>Confidential R D</u>
<u>J. G. Bonner</u> 7/14/70
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ABSTRACT

(CRD) The cyclic corrosion resistance capability of an R-1 type periphery featuring a multiple layer Z-liner pyrofoil wrapper was experimentally measured. The results obtained from this investigation indicate that a full length wrapper of this type has a low probability of achieving the ten hour lifetime R-1 reactor requirement. Good agreement was realized between the measured test data and the predicted thermal hydraulic conditions. The corrosion damage to the pyrofoil wrapper was more than predicted. Analysis indicates that both the amount of hydrogen leakage through the gaps at the Z-liner butt joints and the pyrofoil corrosion rates were greater than expected. Examination of the wrapper O. D. disclosed that no measurable corrosion damage occurred at temperatures below approximately 2400°R.

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1.0 INTRODUCTION

1.1 TEST IDENTIFICATION

1.1.1 Type of Report

This report is a final report.

1.1.2 Applicable Documents

Specification

Number - EC677564

Paragraph No. - 3.1.1.1.3, 3.1.1.1.3.1, 3.1.1.1.3.2, and
3.1.1.1.4

Title - Performance/Design and Qualification Requirements Core
Periphery for Nuclear Subsystem

Date Drafted - January 23, 1969.

Test Scope

Number - 64DT-212

Revision - Rev. 3

Title - TFFL-2a.0005 Corrosion Test

Date of Release - Rev. 3, November 28, 1969

Test Plan

Number - TIS - 2

Revision - Rev. A

Title - Core Periphery

Date of Release - Rev. A, December 29, 1969.

Operating Test Plan

Number - DRM 51343

Revision - Rev. C

Title - Operating Test Plan for 64DT-212 Core Periphery Model

Date of Release - March 4, 1970

1.1.3 Functional Category of Test

Development type test to give corrosion resistance capability and a qualitative picture of the corrosion behavior of the pyrofoil wrapper.

1.1.4 Contractor

Contractor's Name - WANL

Contract Number - 14683, Subcontract NP - 1

Date of Submission: September, 1970

1.1.5 Test Facility

Location - WANL Hydrogen Test Facility, Cell No. 1 at Large, Pa.

Date of Test - March 5, 1970.

Test Period

Phase I Ambient Test:
(non-thermalized)

June 5, 1969
June 16, 1969
June 26, 1969

Phase II Ambient Test:
(thermalized)

October 17, 1969
October 24, 1969
October 28, 1969

Phase III Intermediate Power Test:

January 13, 1970
February 5, 1970

Phase IV Full Power Test:

February 18, 1970
February 26, 1970
March 5, 1970

1.2 PURPOSE

The objective of this test is to give a qualitative picture of corrosion behavior of the outside layer of a thermalized pyrofoil wrapper design at estimated NERVA R-1 wrapper temperature conditions.

2.0 REFERENCES

(U) Section 2.0 identifies related documents which influenced the procurement, design assembly, disassembly or operation of the 64DT-212 (TFL-2a. 0005) test model.

(U) The list will include drawings, procedures, TISs, and interoffice memoranda.

2.1 DRAWING LIST

(U) The following drawings describe the model and details of components.

<u>DRAWING NO.</u>	<u>SHEET NO.</u>	<u>TITLE</u>
7 11J720	1 of 19	General Assembly
WT701736	2 of 19	Spacers
WT701736	3 of 19	Simulated Elements
WT701736	4 of 19	Simulated Inner Core
WT701736	5 of 19	Filler Tile
WT701736	7 of 19	Spacer Assembly
WT701736	8 of 19	Lower Support
WT701736	9 of 19	Insulator
WT701736	10 of 19	Upper Support
WT701736	11 of 19	Buffer Plate
WT701736	12 of 19	Manifold Assembly
WT701736	13 of 19	Bolt
WT701736	14 of 19	Element and Spacer Assembly
WT701736	15 of 19	Core Sub Assembly

2.1 DRAWING LIST (cont'd.)

<u>DRAWING NO.</u>	<u>SHEET NO.</u>	<u>TITLE</u>
WT701736	16 of 19	Impedance Liner Sub Assembly
WT701736	17 of 19	Chuck, Adapter and Inlet Gas Sub Assembly
WT701736	18 of 19	Seal Segment
WT701736	19 of 19	Instrumentation Assembly (Used in Phase I)
711J815	1 of 1	Instrumentation Assembly (Used in Phase II through IV)
NT701509	1 of 1	Heater Rod Modified
NT701542	3	Reflector Shroud
WT701630	2	Cylinder (Reflector)
100E078	1 of 1	Impedance Liner (Z - Liner)

The following drawings depict the wiring diagrams between the sensing and recording devices:

576F925	8	Thermocouple Locations
576F925	6	FS - 1 Thermocouple System for TFL
388D545	1	Possible connection Options - Data Acquisition Trailer System for Thermocouples, Transducers, Strain and LVDT.

The following drawings describe the flow system:

576F925	1	Overall FS - 1 Flow Diagram
576F925	2	Basic Flow Loop
576F925	4	Basic Pneumatic Loop
576F925	5	Overall Pneumatic Loop
576F925	7	FS-1 Pneumatic Control System

2.2 DOCUMENTATION

	<u>Document No.</u>	<u>Date</u>	<u>By Dept.*</u>	<u>Subject</u>
2.2.1	<u>Procedures</u>			
	TFLP-104	1/18/69	TFFL	WANL Operating Procedure
2.2.2	<u>Test Information Sheets</u>			
	TIS-2	5/19/69	TFFL	64DT - 212 Corrosion Test Core Periphery
	TIS-2, Rev. A	12/9/69	TFFL	64DT - 212 Corrosion Test Core Periphery
2.2.3	<u>Test Scope</u>			
	64DT-212-0	1/2/69	RD	Scope of Test for TFL-2a -0005 Corrosion Test
	64DT-212-1	2/13/69	RD	Scope of Test for 64DT-212 Corrosion Test
	64DT-212-2	8/12/69	RD	Scope of Test for 64DT-212 Corrosion Test
	64DT-212-3	10/28/69	RD	Scope of Test for 64DT-212 Corrosion Test
2.2.4	<u>Inter Office Memorandums</u>			
	TRD-67-368	11/13/67	RD	Core Wrapper Study, NR-1 Configuration; Comparison of ID & OD Corrosion
	RD-1136	6/26/68	RD	Fabrication and Assembly Techniques for The R-1 Core Periphery Wrapper
	RD-1139	7/12/68	RD	TFL - 2a. Core Periphery Tests for R-1
	RD-1162	9/16/68	RD	Thermal Conductivity Data Generated for R-1 Pyrofoil Wrapper Design
	TRD-68-416	11/11/68	RD	Verification of Corrosion Constants
	TRD-68-422	11/18/68	RD	Periphery Design; Pyrofoil Wrapper R-1 Reflector

* TFFL - Thermal and Fluid Flow Laboratory

TD - Thermal and Fluid Flow Design

TND - Thermal and Fluid Flow Design

RD - Reactor Design

NDE - Nerva Design Engineer .g

2.2 DOCUMENTATION (cont'd.)

<u>Document No.</u>	<u>Date</u>	<u>By Dept.</u>	<u>Subject</u>
RD-1467	1/28/69	RD	TFL 2a. Periphery Corrosion Test Schedules
RD-1767	6/4/69	RD	DRM 51313 - Test Plan for 64DT-212 Core Periphery Model, Phase I
TD-70-030	2/12/70	TD	Corrosion Estimate for the Core Periphery Test 64DT-212

2.24 Inter Office Memorandums

CE-2056	12/6/67	TFFL	TFL-2a. Filler Strip Tests
CE-2115	4/3/68	TFFL	TFL-2a. CORE Periphery Tests
HPP-1054	6/10/68	TFFL	Development Test Status Report
CE-2136	7/1/68	TFFL	Core Periphery Status Report
CE-2142	9/4/68	TFFL	Strain Evaluation for TFL-2a. Model Wrapper Test
CE-1054	1/16/69	TFFL	Request for Preliminary Sizing Analysis for TFL 2a. COO5 Alternate
CE-1053	1/17/69	TFFL	Request for Design Analysis for TFL 2a. COO5 Core Periphery Model
CE-1069	1/28/69	TFFL	Project 725 Change Notification
CE-1196	6/26/69	TFFL	Thermalization of the 64DT-212 Core Wrapper Assembly
CE-1251	8/27/69	TFFL	64DT-212 Thermalization Review Meeting
CE-1277	9/15/69	TFFL	64DT-212 Phase II Model
CE-1280	9/17/69	TFFL	Request for Radial Expansion Test Profile for 64DT-212-2 Core Periphery Test
CE-1281	9/17/69	TFFL	Availability of Code 2-PDS-30141 Pyrofoil for 64DT-212 Rebuild
CE-1288	9/25/69	TFFL	Status of Pyrofoil Order No. 05683 Status of ERCO No. 16849
CE-1301	10/9/69	TFFL	Minutes of Core Periphery Meeting
CE-1313	11/5/69	TFFL	Minutes of Core Periphery Meeting
CE-1320	11/18/69	TFFL	Core Periphery Model Test
CE-1351	1/30/70	TFFL	64DT-212 & 211 Core Periphery Model Meeting

2.2 DOCUMENTATION (cont'd.)

	<u>Document No.</u>	<u>Date</u>	<u>By Dept.*</u>	<u>Subject</u>
2.2.4	<u>Inter Office Memorandums</u>			
	TE-1353	2/2/70	TFFL	64DT-212-III-1 Test Evaluation & Recommendation
	TE-1360	2/12/70	TFFL	64DT-212 & 211 Core Periphery Model Meeting
	TE-1366	3/9/70	TFFL	Transmittal of DRM No. 51343, Rev. A, B, & C
	TE-1435	5/26/70	TFFL	DRM No. 51355 Rev. E
	TE-1434	5/26/70	TFFL	DRM No. 51361 Rev. A.
	DRM 51313	5/29/69	TFFL	Operating Test Plan for 64DT-212 Core Periphery Model, Phase I
	DRM 51328	8/12/69	TFFL	Thermalization Plan for the 64DT-212 Core Assembly
	DRM 51333	8/29/69	TFFL	64DT-212 Core Diameter Measurement History
	DRM 51338	9/24/69	TFFL	Operating Test Directive for 64DT-212 Core Periphery Model, Phase II
	DRM 51339	10/23/69	TFFL	Preliminary Test Information from Core Periphery Test-64DT-212 Phase III
	DRM 51338 Rev. A	10/28/69	TFFL	Operating Test Directive for 64DT-212 Core Periphery, Phase II
	DRM 51340	11/14/69	TFFL	Post Cycle I Inspection of the 64DT-212 Thermalized Core Subassembly
	DRM 51342	12/1/69	TFFL	Lateral Support Loading Requirements for the Assembly of the 64DT-212 Phase III Core Periphery Test Model
	DRM 51343	12/5/69	TFFL	Operating Test Directive for 64DT-212 Core Periphery Model: Phases III, IV, & V
	DRM 51343 Rev. A	1/28/70	TFFL	Operating Test Directive for 64DT-212 Core Periphery Model Phases III, IV, & V

2.2 DOCUMENTATION (cont'd.)

	<u>Document No.</u>	<u>Date</u>	<u>By Dept.</u>	<u>Subject</u>
2.2.4	<u>Inter Office Memorandums</u>			
	DRM 51343 Rev. B	2/25/70	TFFL	Operating Test Directive for 64DT-212 Core Periphery Model Phases III, IV, & V
	DRM 51343 Rev. C	3/4/70	TFFL	Operating Test Directive for 64DT-212 Core Periphery Model Phases III, IV, & V
	DRM 51355	3/20/70	TFFL	64DT-212 Core Periphery Test Post Test Inspection
	DRM 51355 Rev. A	3/24/70	TFFL	64DT-212 Core Periphery Test Post Test Inspection
	DRM 51355 Rev. B	3/24/70	TFFL	64DT-212 Core Periphery Test Post Test Inspection
	DRM 51355 Rev. C	4/1/70	TFFL	64DT-212 Core Periphery Test Post Test Inspection
	DRM 51355 Rev. D	4/1/70	TFFL	64DT-212 Core Periphery Test Post Test Inspection
	DRM 51361	4/7/70	TFFL	64DT-212 Core Periphery Test Phase IV Post Test Inspection
	DRM 51355	5/1/70	TFFL	64DT-212 Core Periphery Test Post Test Inspection
	DRM 51361 Rev. A	5/6/70	TFFL	64DT-212 Core Periphery Test Phase IV Post Test Inspection
	DRM 51564	4/3/69	RD	Informal Design Review of Core Periphery ECC-677564
	DRM 1068 Rev. E	9/15/69	RD	NERVA Reactor Component Alternates
	DRM 51898	10/9/69	RD	Core Periphery Design Review

2.2 DOCUMENTATION (cont'd.)

<u>Document No.</u>	<u>Date</u>	<u>By Dept.</u>	<u>Subject</u>
<u>2.2.4 Inter Office Memorandums</u>			
DRM 1004 Rev. B	1/28/69	TND	Steady State Thermal Analysis of the Lateral Support System & Core Periphery Specification
DRM 1007	5/16/69	TND	Performance Analysis of the Core Periphery Pyrofoil Wrapper
DRM 51671	5/26/69	TD	Thermal Analysis of the 64DT-212 Core Periphery Model
DRM 51963	9/5/69	TD	Post Test Fluid Flow Analysis of the 64DT-212 Ambient Test
DRM 52122	11/25/69	TD	Thermal Analysis of the 64DT-212 Core Periphery Model Phase II
DRM 52455	4/4/70	TD	Post Test Thermal Analysis of the 64DT-212 Core Periphery Test Phase IV
DRM 1068	12/27/68	HDE	NERVA Reactor Component Alternates
DRM 1068 Rev. A	1/27/69	HDE	NERVA Reactor Component Alternates
DRM 52075	10/9/69	NDE	Thermal Distortion of Foil Test Model (64DT-212-2)
DRM 51377	7/30/70	TFFL	Core Periphery Model Test Report (Final)
DRM 51369	8/14/70	TFFL	64 DT Core Periphery Test Core Porosity Experiments

3.0 DESCRIPTION OF TEST MODEL

(U) The 64DT-212 Core Periphery Test model was the second assembly of an R-1 Cold Buffer type periphery to be experimentally evaluated by the Thermal and Fluid Flow Laboratory.

(CRD) The model features a multiple layer Z-liner wrapper made from pyrofoil tape. The model is 6 inches in diameter, 47 inches long, and contains (a) a 3.5 inch diameter core assembly, (b) a simulated graphite unimpregnated reflector, and (c) a modified NRX-A2 type lateral support and seal system. Assembly details of the model are contained in Drawing 711J720. Fig. 3-1 shows a cross section of the model and Fig. 3-2 shows a cutaway view of the test article which includes the model installed in the FS-1 furnace.

(CRD) The model core assembly consists of an NbC coated inner core, uncoated simulated elements, and uncoated cold periphery type spacer assemblies which included 0.125 inch thick insulating tile. The wrapper which is sandwiched between the elements and insulating tile is the primary hardware being tested. The wrapper is nominally 180 mils thick and consists of 27 layers of Z-liners. Each layer contains 12 Z-liners which are preformed from full length pyrofoil strips 1-1/8 inch wide and a nominal thickness of .0055 inch. Each Z-liner is approximately two simulated fuel element flats wide by 47 inches long. The initial liners are butt-joined to the mating element periphery surfaces with a temporary bonding agent (Petrolatum PDS 30189-1) which is used for assembly purposes only. Subsequent Z-liners are similarly joined to previously positioned consecutive layers to achieve total nominal wrapper thickness including petrolatum of 180 mils. The numerous small width Z-liners are sized from layer-to-layer to provide a uniform distribution of butt joints, and to maintain a controlled butt edge-to-edge clearance within 0 to 30 mils. Within the 0 to 30 mil full length axial gap, a local gap of 10 mils or less must exist.

(CRD) The wrapper, used in the Phase I ambient temperature hydrogen flow tests, was made from non-thermalized material which was obtained from Union Carbide Corporation on purchase order 59-NXD-04423. Specifications for the material were:

(CRD) Rolls of Grafoil Graphite Tape 0.0055^{+0.002}/_{-.001} thick x 1-1/8" wide x 100 ft. long.

Figure 3 - 1: Cross Section of 64DT-212 Test Assembly

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Figure 3-2. 64DT-212 Test Assembly Installed in Furnace

(U) The Westinghouse materials process Spec. No. PDS 30182-2, Rev. B was a requirement, along with a "Certification of Conformity" required with shipment of parts.

(U) In June of 1969, the 64DT-212 Phase I core periphery test was conducted. The preliminary results of the test showed that at ambient temperature hydrogen flow conditions, the impedance characteristics of the model changed because of an across layer growth experienced by the wrapper.

(CRD) Following the Phase I test, some dimensional instability in the wrapper was detected and to fulfill the requirements defined in Scope of Test 64DT-212-2, the wrapper material was changed from a non-thermalized condition to a thermalized condition. The core assembly for the Phase II test model contained all of the components used in the Phase I test model with the exception of replacing the outer four (4) layers with Z-liners made from thermalized rerolled pyrofoil per PDS 30141-1, procured on ERCO 16849. The wrapper, assembled with Z-liners made from non-thermalized pyrofoil per PDS 30182-2, was thermalized as an assembly in a fixture then the outer four layers replaced. In general, the process for the thermalization cycle was to heat the fixture to $5000^{\circ}\text{R} \pm 200^{\circ}$ in a helium atmosphere at 2 ± 1 psig pressure at a heat-up ramp rate of 7 ± 1 degrees per minute. The fixture was maintained at 5000°R for 60 ± 2 minutes prior to initiating cool down. A detailed description of the thermalization procedure is described in DRM 51377.

(U) In October of 1969, Phase II of the Core Periphery Test 64DT-212 was conducted. During the Phase II test, it was found that the axial pressure distribution measured in the seal cavities did not fulfill the expected design profile. In order to provide a graduated seal impedance schedule, the seal segments were modified for the subsequent test phase (Phase III, IV, and V) in order to produce a more favorable axial pressure distribution. With the exception of the modified seal segments all other components were the same as used in the Phase II model.

(U) A summary of the Mechanical Design Features of each Phase of the 64DT-212 test model is shown in Tables A-1, A-2, and A-3 (Appendix A).

4.0 SUMMARY OF TESTS

4.1 NARRATIVE

The TFL-2a.0005 (64DT-212) Core Periphery test configuration was designed, assembled and tested to qualitatively evaluate the corrosion behavior of the outside layer of a thermalized pyrofoil wrapper design at representative R-1 wrapper temperature conditions.

The purpose of the test was to subject the wrapper to a hydrogen pressure flow environment for 8 cycles for a total steady state test time of 80 minutes at outer layer temperatures of 2500°R.

The objective of the test was to obtain qualitative data of the pyrofoil wrapper corrosion resistance capability in order to confirm design assumptions not obtainable through analysis.

4.2 TEST CONDITION

4.2.1 Test Identification

Each series of test points are identified by one of the following notations:

Ambient Tests (Example)

Test Identification (cont'd.)

Heated Test (Example)

(U) Four (4) series of tests were conducted, Phase I through Phase IV. A fifth phase planned to measure the model ambient flow impedance following a complete shutdown after Phase IV was eliminated and a similar test incorporated as part of the Phase IV test to avoid complete shutdown of the test facility.

4.2.2 Test Summary

(U) Table 4-1 provides a summary of the purpose and conclusions from each of the four test phases. A more complete discussion of the test chronology is discussed in Sections 4.3.2.2. A summary comparing the specified and measured conditions for the tests are shown in Tables B-1, B-2, B-3, and B-4 of Appendix B. Detailed chronological test events are described in TFFL Test Record Books K23056 and K27463.

TABLE 4-1
SUMMARY OF TEST PHASES AND CONCLUSIONS

Test Phase	Purpose	Test Conclusions
Phase I	Define impedance characteristics of model at various flow conditions and ambient temperature.	<ol style="list-style-type: none">1. Test fixture material not dimensionally stable.2. Wrapper needed to be thermalized in situ.
Phase II	Repeat phase I measurements following wrapper thermalization. Demonstrate repeatability of ambient flow impedance measurements.	<ol style="list-style-type: none">1. Repeatability of pressure profile and flow characteristics established.2. Good correlation between predicted pressure profile and measured values.
Phase III	Provide model thermal and fluid flow characteristics at intermediate power levels to predict operating conditions at full power conditions.	<ol style="list-style-type: none">1. Achieved favorable seal system pressure profile.2. Pressure profile agreed well with predicted profile.3. Leakage flow not accounted for in analytical model could explain extraneous model heat losses. Wrapper probably major leakage flow path.
Phase IV	Temperature cycle the wrapper eight times at 10 minutes each, with a wrapper o.d. temperature of 2500°R.	<ol style="list-style-type: none">1. Test phase successfully completed. Met original test objective of 8 - 10 minute cycles without through penetration of wrapper.2. Post and pretest flow impedance measurements reproducible.3. Bridging of filler strips appears to explain increase of model pressure drop with time.4. Good correlation between predicted and measured temperature and pressure profiles.

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4.3 TEST RESULTS

4.3.1 Recorded Data

A detailed tabulation of the major recorded test data is provided in DRM 51377 Appendixes A-D. Appendix C of DRM 51377 provides a record of photographic surveillance which was compiled on post-test condition of test hardware.

4.3.2 Test Scope Compliance

All data required items as specified in Section 4 of the Test Scope Document 64DT-212-0 were satisfactorily fulfilled with the exception of Items C3 and D which were subsequently deemed as not essential to the objectives of the investigation. Item C3 required post-test weight measurements of selected Z-strips. Item D required that an estimate of overall effective thermal conductivity of the wrapper be determined from the experimental temperature measured and the results compared with SRI results.

The discussion of data reported herein will be primarily directed to (1) presenting experimental results on each phase of test conducted, and (2) providing information from the post-test examination and dimension inspection measurements which may be helpful in interpreting the experimental results.

4.3.3 Test Observations and Commentary

4.3.3.1 Phase I Ambient Temperature Hydrogen Flow Impedance Test (Non-Thermalized Wrapper Model) 64DT-212-1-AH₂ (U)

The purpose of the Phase I ambient temperature hydrogen flow test was to provide sufficient pressure information to define the impedance characteristics of the model during various modes of test operation.

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~~Atomic Energy, August 1964~~

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The objective of the Phase I test was to provide ambient temperature flow-pressure data which would explain in part or in its entirety the pressure drop anomaly experienced between the two consecutive ambient flow tests conducted with the 64DT-031 test model. The results of the Phase I tests showed the wrapper assembly to be dimensionally unstable at the subjected test operating flow pressure conditions.

Three (3) series of flow tests were conducted, 1-AH₂-1, -2, and -3 as planned. Upon completion of Test 64DT-212-1AH₂-1, a normal shutdown was performed and a post test as - is system calibration of the absolute pressure measuring systems performed. A repeat of the 1-AH₂-1 test followed, 64DT-212-1AH₂-2. Following a review of the data and inspection reports, a third test, 64DT-212-1-AH₂-3A through 3E, was conducted. The Phase 1-AH₂-3 experiments were conducted utilizing the same operating procedures as prescribed for the Phase 1-AH₂-1 and AH₂-2 tests; with the exception that the flow rates were varied over a wider range. A summary of the specified and measured test conditions are listed in Table IV (Appendix B)

At the nominal flow rate of 0.011 lb/sec the reference model pressure drop from the -1AH₂-1 series of test was measured at 64 psi. The overall pressure drop was closely repeated in the second test, -1AH₂-2. In the third test of Phase I (-1AH₂-3), variations in pressure drop at constant flow conditions were observed. The pressure drop showed a decrease of about 42% from the start to end of test from 64 psi to 37 psi at .011 lb/sec flow. An operating map of the Phase I test results given in Figure 4-1 defines when this change in pressure drop occurred. This curve shows the test fixture material was not dimensionally stable. (Figure 4-2 shows the difference in absolute pressure levels measured along the axial length.) The

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Figure 4-2. Phase 1 Seal Cavity Measured Axial Pressure Distribution (Helium Flow Test)

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pressure distribution curves show that a significant high loss of impedance occurred across the last seal. Examination of the test assembly revealed a growth in the pyrofoil wrapper material and an increase in the filler strip gap dimensions as a result of the diametral change. An average diametral increase of 10 mils at the forward end to about 30 mils at the aft end was measured. The pressure change is attributed to this wrapper growth and its effect on the filler strip gap and the seating of the seal segments. Figure 4-3 compares the normalized axial pressure distribution at the various flow conditions. No significant overall change in model pressure drop was experienced as a result of changes in flow in the parallel and by-pass flow systems.

4.3.3.2 Phase II Ambient Hydrogen Flow Tests (Thermalized Wrapper Model) 64DT-212-11-AH₂

The purpose of Phase II test was to provide pressure information at various flow conditions to define the impedance characteristics of a thermalized wrapper model under normal modes of test operation.

Phase II test was conducted following the thermalization of the wrapper as an assembly by EML. The objective of the thermalization process was to cure the pyrofoil wrapper contained in the 64DT-212 core assembly so its thermal growth characteristics were partially and/or completely stabilized. Two thermalization cycles were performed at process temperature of $5000^{\circ}\text{R} \pm 200^{\circ}\text{R}$, one under a representative reactor temperature profile and the other under a best effort full length isothermal profile. The thermalization process left the wrapper assembly without petrolatum with the exception of the outer four (4) layers which were replaced with thermalized rerolled Z-liners on final assembly. A detailed description of the thermalization process is provided in DRM 51377.

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Figure 4-3: Phase I - Normalized Seal Cavity Average Axial Pressure Distribution (Helium Flow Test).

Three (3) series of flow tests were conducted, II-AH₂-1, -2, and -3 as planned. Upon completion of Test 64DT-212-II AH₂-1, a normal shutdown was performed and a post-test system calibration of the absolute pressure measuring systems performed. A repeat of the II AH₂-1 test followed 64DT-212-II AH₂-2. Following a review of the data and inspection reports, a third test, 64DT-212-II AH₂-3A through 3K, was conducted. The Phase III-AH₂-3 experiments were conducted utilizing the same operating procedures as prescribed for the AH₂-1 and AH₂-2 tests; with the exception that the flow rates were varied over a wider range.

Table B-4 (Appendix B) summarizes specified and measured conditions for the test.

4.3.3.2.1 Experimental Results

At the nominal design flow rate of .011 lb/sec, the reference model pressure drop was measured at 33 psi. Comparing the reference pressure drop with the Phase I test results at about the same flow rate showed the Phase I start of test pressure drop to be 64 psi and the end of test to be 37 psi. The overall pressure drop was closely repeated in the second and third tests. An operating map of the Phase II test results is given in Figure 4-4.

A typical seal cavity pressure distribution along the length of the model is shown in Figure 4-5. The seal cavity pressure distribution within the measured accuracy showed no significant change from start of test to end of test. Diameter measurements before and after test show no significant changes.

4.3.3.3 Phase III Experimental Plan: 64DT-212-III-HH₂

The results following the Phase II test showed that an unfavorable seal cavity pressure distribution existed and the seal schedule was changed to the requirements defined in Table A-3 (Appendix A) in order to provide a favorable seal cavity pressure distribution.

The purpose of the Phase III experimental plan was (a) to provide pressure drop

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Figure 4 - 4: Phase 2 Measured Pressure Drop - Flow Relationship

Figure 4 - 5: Phase 2 - Seal Cavity Axial Pressure Distribution Data

information at ambient temperature test conditions to establish a reference pressure profile for the model, and (b) to provide thermal and hydraulic information at an intermediate power level for predicting the operating conditions for the subsequent full power hydrogen corrosion test.

Two tests were conducted "-IIIHH₂-1" and "-IIIHH₂-2." The results of the first test (-IIIHH₂-1) showed a discrepancy between measured and predicted conditions of matching power, temperature, and pressure drop. A repeat of the intermediate power test (-IIIHH₂-2) was conducted in an attempt to resolve this discrepancy. The "-IIIHH₂-2" test was conducted with coolant water only in the hot end electrode, eliminating all other water flows in the furnace components.

The Phase III heated hydrogen flow tests were controlled utilizing the W/W 26% Rhe thermocouple at Station 38 inches located in the simulated elements. While maintaining a constant back pressure of 436 psig at a constant model flow rate, the power level was adjusted to maintain the prescribed temperature at Station 38.0 inches within test limitations.

After three (3) minutes of steady-state flow stabilization at design test conditions, the power was supplied to the heater and adjusted to the intermediate operating level prescribed.

Power up and down ramp rates were limited to 10 KW per step change at 5 second intervals until specified power levels were reached. Pressure drop and inlet pressure were monitored throughout but at no time were they made controlling parameters. Upon completion of 64DT-212 Phase III -HH₂-1 test, a normal shutdown was performed and a post test as-is system calibration of the absolute pressure measuring systems performed. Following the test, data reduction was performed followed by a preliminary evaluation of test information. Experimental results from the test were evaluated and when compared with the analytical predicted conditions, the retest -III-HH₂-2 followed.

4.3.3.3.1 Experimental Results, (-IIIHH₂-1 Test)

A summary of the specified and measured test conditions are listed in Table B-4 (Appendix B). At the nominal test flow rate of .0335 lb/sec., the new reference model pressure drop was measured at 80 psi. The seal cavity pressure distribution data showed satisfactory results which allowed the subsequent heated flow tests to be initiated. The operating seal cavity pressure distributions are given in Figure 4-6. Normalized values are shown in Figure 4-7.

In order to match the specified element control temperature at Station 38.0, 58% more than the predicted power (40KW) was required. Measured model pressure drop was 103 psi which was 39% lower than predicted. Post test heat balance calculations were performed and heat losses other than required to heat the gas flowing through the seal system was estimated at about 32% for the 63 KW power level.

4.3.3.3.2 Experimental Results, (-IIIHH₂-2 Test)

Power levels, temperatures, and pressure drop closely matched the results of the -IIIHH₂-1 test. Heat balance of the system after the test showed a heat loss of about 30% at the 43 KW operating power level. Over cooling of the water jacketed furnace components was not the heat sink for all of the unaccountable heat losses. A by-pass fluid flow path internally in the model would account for the remaining unaccounted for heat losses.

4.3.3.4 Phase IV Full Power Heated Hydrogen Flow Test

The purpose of the Phase IV test was to temperature cycle the wrapper eight (8) times at ten (10) minutes each, for a total test duration of 80 minutes at full outer layer wrapper steady state temperature conditions (2500°R). Three (3) tests, -IVHH₂-A, B, and C, were conducted in order to fulfill the objectives prescribed for the test, each test

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Figure 4 - 6: Phase 3 - Seal Cavity Axial Pressure Distribution Data

Figure 4-7: Phase 3 - Seal Cavity Normalized Axial Pressure Distribution

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requiring a new heater element. The first, "-IVHH₂-A," was terminated following a heater corrosion failure. This failure was attributed to hydrogen leakage through the porous walls of the inner core. To correct this problem, the heater cavity pressure flow control mode of operation was changed. The control was changed from a (heater cavity-model exit) differential over pressure control to a (heater cavity-model inlet) differential over pressure control. After the change over, the second test (-IVHH₂-B) was unsuccessfully attempted. The "-IVHH₂-B" test was terminated as a result of a heater sublimation failure. This failure was a result of the abnormally high power level (140kw) at which the heater was required to operate in order to reach the element control temperature. The abnormally high operating power level required was attributed to a higher than normal helium flow through the heater cavity system. To correct this problem the flow metering system at the aft end of the heater was modified by incorporating a stack-up of grafoil gaskets. These gaskets were compressed around the heater to provide a higher flow impedance. After replacing the heater and incorporating the modification, the third test (-IVHH₂-B) was attempted and successfully conducted. During the early test cycles, high model pressure drops were experienced which resulted in a change in test plan. Following cycle C4 the mode of control was changed from adjusting power at constant model flow to adjusting power and flow to maintain a reasonable pressure drop during the test.

The Phase IV heated hydrogen flow tests were controlled utilizing the W/W 26% Rhe thermocouple at station 38 and/or station 26, located in the simulated elements and chromel/alumel thermocouples located at station 36.0 in the filler strips. While maintaining a constant back pressure of 436 psig, at constant flow conditions, the power level was adjusted accordingly to maintain, within practical test limitations, the prescribed temperature of the simulated element. Simulated element thermocouples at station 38 were used as the primary control sensor with the thermocouples located at station 26 used as the backup alternate. Power levels were adjusted to provide the best match between

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element temperature level at station 38.0 and the temperature difference between element and filler strip at the corresponding station. Time cycles were adjusted accordingly to meet the minimum test duration requirement of 80 minutes. Pressure drop and inlet pressure were monitored throughout the test but at no time were they made controlling parameters.

4.3.3.4.1 Experimental Results

(U) Table B-4 (Appendix B) summarizes the specified and measured test conditions.

(U) Eight (8) temperature cycles were completed as planned. Cycle 1 was completed in the "IVHH₂-B" test and cycles 2 through 8 in the "IVHH₂-C" test. A total steady state test duration of 98 minutes was accumulated at the temperature control range of $3390^{\circ} \pm 180^{\circ}\text{F}$. Each test cycle had a duration of about 30 minutes. The averaged power generated by the heater was 92 kw or 39% over the predicated model requirements.

(U) Figure 4-8 summarizes for the Phase IV test the measured simulated fuel element temperature versus time. Figure 4-9 gives the measured model ΔP versus time for the Phase IV test.

4.3.3.4.2 Post Test Examination

(U) A summary of dimensional measurements are presented in Appendix A (DRM 51377).

4.3.3.4.3 Filler Strips

From the results of the core diameter measurements bridging of filler strips was suspected. Bridging of the filler strip was suspected to exist from about 27 to 43 inches. Figure 4-10 shows a comparison of the measured core diameters before and after the test. Slight corrosion damage was observed on the inboard faces of the filler strip pieces. Figures 4-11 and 4-12 show the typical observed corrosion pattern.

4.3.3.4.4 Fuel Elements

(CRD) Post test condition of the peripheral element surface showed corrosion, deposition, and plating. Table 4-2 is a summary of general notes observed on post test inspection. In

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Figure 4-8: Phase IV Model Temperature - Time History (Average Fuel Element Temperature)

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Figure 4-9: Phase IV Model Pressure Drop - Time History

Figure 4 - 10: Phase IV Post and Pre-Test Comparison of Average Core Diameter Measurements (3 psi Bundling)

Figure 4-11: Phase IV Post Test Examination Photograph of Filler Strip Condition
Showing Tile Corrosion (Filler Strips S-7, S-8, S-9) (U)

Figure 4-12: Phase IV Post Test Examination Photograph of Filler Strip
Condition Showing Tile Corrosion (Filler Strips S-10, S-11, S-12)

TABLE 4-2

FUEL ELEMENT POST-TEST EXAMINATION

	<u>E-1, ELEMENT,</u>		<u>E-2, ELEMENT,</u>		<u>E-3, ELEMENT,</u>	
Corrosion Starts:	21 Station.		20, 5 Station		Station 22	
Corrosion Regions:	Butt joints. Across "A" face.		27 station face to t/c CR-surface		Butt Joints	
Corrosion Patterns:	Starts at Station 21 and follows the butt joint down to Station 43. Across surface corrosion at Station 27. Plating and deposition from Station 26 to 46.		At Station 27 corroded through to the t/c hole causing a channel type corrosion path along the CR surface. 3 layers of Z-liners remained on the element at Station 37 to Station 46.		Corroded the element at the butt joint to the depth of the thermal - capsule from Station 29.5 to 44.5. The corrosion was probably attributed to the hydrogen source from the instrumentation hole and corrosion identified in E-2. Cross face corrosion at Stations 28, 5 and 45, 75.	
		<u>Station, Inches</u>		<u>Station, Inches</u>		<u>Station, Inches</u>
*Minimum Operating Gap:	5 mils	4	> 5 mils	2	> 5 mils	2
*Maximum Operating Gap:	35 mils	22	≈ 35 mils	32	≈ 35 mils	23
Maximum Corrosion Depth:	75 mils	46	through to t/c	27	To the thermal capsules - 237 mils	29.5 - 44.75
Maximum Corrosion Width:	250 mils	38, 5	Across A face, element broke into 2 pieces	27	310 mils	41
	<u>E-4, ELEMENT,</u>		<u>E-5, ELEMENT,</u>		<u>E-6, ELEMENT,</u>	
Corrosion Starts:	20 Station.		20, 5 Station.		21 Station.	
Corrosion Regions:	Butt areas and across "A" face.		Butt areas. Across face.		Butt joints and across the face.	
Corrosion Patterns:	Starts at Station 20 to Station 47 along the butt joints. Across "A" face at Stations 30, 38, 5, and 46. "Z"-liner attached at Station 37. Plating occurs at Station 45.		Butt area from Station 20, 5 to 47. Across face at Stations 35, 41, 5, and 46. Deposition and plating from Station 32 to 47.		Along the butt joints from Station 21 to 47. Across the "A" face at Stations 30, 5 and 40. Plating and deposition in Station 43 area. Transition through to element at Station 46.	
		<u>Station, Inches</u>		<u>Station, Inches</u>		<u>Station, Inches</u>
*Minimum Operating Gap:	< 5 mils	3	< 5 mils	3	< 5 mils	2
*Maximum Operating Gap:	≈ 35 mils	19	≈ 35 mils	18	≈ 35 mils	20
Maximum Corrosion Depth:	200 mils	46	75 mils	26	125 mils	30, 5
Maximum Corrosion Width:	200 mils	38, 5	260 mils	26, 5	250 mils	26, 5

*Butt joint gaps determined from surface light refraction, and flow patterns.

TABLE 4-2 (CONTINUED)

FUEL ELEMENT POST-TEST EXAMINATION

	<u>E-7, ELEMENT,</u>		<u>E-8, ELEMENT,</u>		<u>E-9, ELEMENT,</u>	
Corrosion Starts	20 1 Station		20 3 Station		20 1 2 Station.	
Corrosion Regions	Gap and across surface		Butt joints Across surface		Butt joints and across face	
Corrosion Patterns	Station 21 to 47 butt joints. Z -liner attached from Station 28 to Station 33. Cross surface corrosion at Stations 35 and 41 3. Plating and deposition exists from Station 33 to Station 47.		Along butt joints from Station 21 to 47. Across face at Stations 25 75 and 31.5 Light deposition and plating at Station 45		Butt joint corrosion starts at Station 20 1/2 to Station 47. Corrosion across face at Station 26 and 41 75. Z -liner attached from Station 28 to 32 and from Station 31 to 36. Deposition and plating Station 36 to 47.	
	<u>Station, Inches</u>		<u>Station, Inches</u>		<u>Station, Inches</u>	
*Minimum Operating Gap	< 3 mils	7	< 5 mils	4	< 5 mils	4
*Maximum Operating Gap	≈ 20 mils	46	≈ 25 mils	21	≈ 35 mils	
Maximum Corrosion Depth	65 mils	37	65 mils	37	70 mils	32
Maximum Corrosion Depth	220 mils	39	240 mils	41.5	160 mils	32
	<u>E-10, ELEMENT,</u>		<u>E-11, ELEMENT,</u>		<u>E-12, ELEMENT,</u>	
Corrosion Starts	Station 21 1 2		Station 20		Station 19, 5	
Corrosion Regions	Exits in butt joints and gaps.		Initiates in butt joint gaps.		Exists in butt joints and gaps	
Corrosion Patterns	Across face element corrosion at Station 42 Severe channel corrosion from Station 24 to 32 on surface. Station 27 to 30 severe channel corrosion on surface Z -liner attached from Station 32 to 38 1 2 Corrosion, deposition and plating from Station 37 to 47.		Cross element corrosion at Station 25 3 4 Severe channel corrosion from 24 to 35 on surface AL. Pattern corrosion, deposition (Station 36), plating 36 and 44.		From Station 19 to 25 light corrosion with deposition existed. From Station 25 to Station 47 channel corrosion existed with various degrees of corrosion.	
	<u>Station, Inches</u>		<u>Station, Inches</u>		<u>Station, Inches</u>	
*Minimum Operating Gap	< 5 mils	13	< 3 mils	4	< 3 mils	4
*Maximum Operating Gap	≈ 25 mils	35	≈ 35 mils	42.3	≈ 35 mils	41
Maximum Corrosion Depth	90 mils	28	155 mils	28	80 mils	30
Maximum Corrosion Width	200 mils	42	240 mils	33	190 mils	33

*Butt joint gaps determined from surface light refraction, and flow patterns.

sector $\Theta = (30^\circ - 90^\circ)$ corrosion penetrated through to the thermocouple instrumentation hole. The remainder of the inspection report defining the element condition is reported in DRM 51355. Figure 4-13 shows a typical observed corrosion pattern. No corrosion was found on the adjacent faces of the fuel elements giving some evidence of the presence of helium in the fuel element interelement gaps.

4.3.3.4.5 Wrapper

(CRD) Corrosion penetration existed in each of the outer five (5) layers and in each of the twenty-one (21) inner layers. Layer 22 had no through penetration; however, signs of incipient corrosion were noted in areas of the butt joint gaps.

(CRD) Generally, the wrapper corrosion was traceable to areas where butt joints existed. Typical hand sketches of patterns for sector $\Theta = (240^\circ - 300^\circ)$ are reproduced schematically in Figures 4-14 through 4-18. DRM 51361, Rev. A presents typical corrosion patterns for sectors $\Theta = (30^\circ - 60^\circ)$, and $\Theta = (150 - 180)$. Buckling occurred circumferentially around the wrapper at about the 43 inch core station. Figure 4-19 shows this buckling phenomena. In addition, for reference, a view is added showing the axial movement of the wrapper. DRM 51377 gives a complete catalog of post-test photographs of the wrapper.

4.3.3.4.6 Inner Core

(CRD) Coating cracks were noted from about Stations 14 through 44. Severe cracking and flaking noted between stations 38 and 43. Corrosion first appeared at about station 19.5. Deposition was found to first exist from about Station 26 1/2 to 31. Post-test condition of core was found to be satisfactory, except where cracks were found in the coating and where local areas showed flaking. Figure 4-20 illustrates the general condition of the core.

Figure 4-14: Phase IV Post Test Examination of Pyrofoil Wrapper Layer 18 (Hand Sketch)

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Figure 4-15: Phase IV Post Test Examination of Pyrofoil Wrapper Layer 19 (Hand Sketch)

Figure 4-16: Phase IV Post Test Examination of Pyrofoil Wrapper Layer 20 (Hand Sketch)

Figure 4-17: Phase IV Post Test Examination of Pyrofoil Wrapper Layer 21 (Hand Sketch)

Figure 4-18: Phase IV Post Test Examination of Pyrofoil Wrapper Layer 22 (Hand Sketch)

Figure 4-19: Various Views Illustrating the Buckling Type Crease and Axial Movement of the Wrapper (Phase IV Post Test Examination) (U)

Figure 4 - 20: Phase IV Post-Test Examination of Inner Core

5.0 ANALYSIS

5.1 STRUCTURAL ANALYSIS

5.1.1 Structural Analytical Model of Test Fixture

(U) The test fixture was modeled for structural analysis by dividing the heater rod, inner core, simulated fuel elements, wrapper, pyrotiles, filler strips and seal system into a series of concentric layers of a 30° sector as shown in Figure 5 - 1. This analytical model was used in the calculation of intercomponent operating gaps, radial expansion data and wrapper strains. The model was conservatively assumed to be free of all loads and only free thermally induced displacements at the calculated maximum operating temperature profile were considered. The inner core was treated as a cylinder upon which free expansions of all other components were stacked with the restriction that the wrapper had to stretch without slipping to fill the entire 30° arc.

5.1.2 Analytical Results and Comparison with Post - Test Examination

5.1.2.1 Intercomponent Axial Flow Gaps

(U) Filler strip and tile gaps were calculated for the maximum operating temperature profile. The results are shown in Figure 5 - 2. and represent the growth of the initial assembly gaps. The additional gap between fuel elements at operating conditions was assumed to be negligible compared to the assembly gaps. It should be noted that because the operating gaps are a function of the temperature profiles and the temperature profiles are a function of operating gaps distribution, the calculation of gaps and temperatures is an iterative process which requires several iterations for convergence. No measured operating gaps are available for comparison with calculated values; however, the calculated gaps are reflected in comparisons of calculated and measured temperature profiles and power levels.

Figure 5-1: Structural Analytical Model (U)

Figure 5 - 2: Filler Strip/Tile Gap Distribution

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5.1.2.2 Radial Expansion at Seal Segment Interface

(CRD) The maximum radial free thermal growth of the assembly at the seal segment interface was also calculated using the Structural Analytical Model. Because the test fixture was thermalized as an assembly, no additional growth components such as petrolatum outgassing were considered. The results are shown in Figure 5 - 3 with the maximum growth at the hot end being approximately 13 mils. This maximum expansion was judged to be sufficiently less than the 30 mil nominal plunger cap clearance to assure compatibility between the expanded core assembly and the lateral support system. No problems with lateral support springs bottoming out were observed during the testing.

5.1.2.3 Wrapper Ratcheting

(CRD) Post-test of the model revealed that the wrapper had been displaced aft into local clearance slots in the aft end support plate, and that local buckled deformations of the wrapper were present at the hot end. The following axial compression mechanism was postulated to explain this cumulative cyclic motion and buckling. The features of this postulated mechanism are shown schematically in Figure 5 - 4.

(CRD) 1. As core and simulated fuel heat up, they expand axially in the forward direction due to constraint by the aft end graphite support plate.

(CRD) 2. As the fuel is moving forward, slipping occurs between the first and second layers of wrapper adjacent to the fuel where the friction coefficient is lower than at the wrapper/fuel interface. The axial pressure drop and the cooler temperature of the hard pyro and fillers also tend to hold the wrapper aft while fuel moves forward.

(CRD) 3. During cool-down the fuel contracts and drags the wrapper aft. The hard pyro and fillers cool faster than the wrapper, and along with the pressure drop also tend to drag the wrapper aft. Because the wrapper slips over the fuel while the fuel is heating and moving forward, and moves with it during cool-down when the fuel is moving aft, there is a net aft displacement of the wrapper for the complete cycle.

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Figure 5 - 3: Calculated Radial Expansion at Seal Segments Versus Axial Station

NOTE: FUEL IS ABOUT .045" LONGER THAN WRAPPER AT TEMPERATURE.

Figure 5-4: Schematic of Pyrofoil Wrapper Test Assembly Illustrating Wrapper Buckling

(CRD) 4. The process repeats with each cycle, forcing wrapper into local clearance slots in graphite support plate and eventually causing the observed buckled deformations.

5.1.2.4 Wrapper Strain Analysis

(CRD) Wrapper strains were calculated at maximum operating temperatures based on the Structural Analytical Model and are shown in Figure 5 - 5 . These calculated wrapper strains are higher than the thermalized pyrofoil strain capability based on data available at the time of the testing and caused concern that the wrapper might tear. However, it was pointed out that a continuous wrapper was assumed in the calculation of these strains and that strain relief due to slipping would probably reduce them to an acceptable level. No local wrapper tears were observed during post-test inspection.

5.2 THERMAL AND FLUID FLOW ANALYSIS

5.2.1 Introduction

(U) This section of the Data End Item report presents the thermal and fluid flow analysis used to evaluate the testing performed on the 64DT-212 core periphery model. This test was conducted over a long period of time necessitating frequent analyses to support component hardware changes, provide new operating test guidelines, and perform post test analysis. This section of the report includes a description of the heat conduction and fluid flow models, the input data, and the methods relevant to the pretest and post test analyses performed for each Phase of testing. A comparison of measured and calculated results are shown where applicable.

5.2.2 Thermal and Fluid Flow Models

(CRD) A heat conduction model of the core periphery test configuration was made by dividing the heater rod, the inner core, the simulated fuel elements, the pyrofoil wrapper, the pyrotile, the filler strips, the inner reflector and the shroud into appropriate nodes. A

Figure 5 - 5: Pyrofoil Wrapper Strain Versus Axial Station

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30° sector was selected as being representative of the configuration. Figure 5 - 6 illustrates the component parts of the model described by the heat conduction nodal array. A total of 11 core stations were represented for both on and off seal locations at core stations 1.8, 4.6, 10.2, 15.8, 18.6, 26.3, 29.9, 32.7, 38.3, 43.9 and 46.8. The location of instruments was the basis for selecting several of these axial locations.

A fluid model was developed for the gaps between the tile and filler strips, the seal coolant channel holes and the seal plena. The location of these flow passages is given in Figure 5 - 6. The filler strip gaps given in Figure 5 - 2 were used to model the filler strip - tile flow passage. These gaps were calculated for the assembled condition, measured after assembly, and then modified to reflect the hot operating conditions. The seal coolant hole diameters shown on Figure 5 - 6 were sized to limit temperatures both in the filler strips and the reflector spring cavity. Both the heat conduction model and the fluid flow models were coupled in the analysis to provide the thermal and hydraulic environments in the test configuration.

5.2.3 Method of Analysis

The TRACK computer program described in WANL-TME-2697 was used for all thermal and hydraulic calculations. Input data to TRACK consisted of the conduction nodal model, the fluid model of the flow passages, the test boundary conditions, and the material property data. Material data were reviewed to obtain the most recent property information. Thermal conductivity, specific heat, and density were obtained from the reference specification for each component material given in Table 5 - 1.

In order to provide guidelines for operation of the hot test, the power input to the analyses was adjusted to attain a maximum O.D. pyrofoil wrapper temperature of 2500°R. The power distribution was based on the inner core temperature distributions observed in the previously run 64DT-031 core periphery test. This resulted in the heater power distribution given in Figure 5 - 7.

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Figure 5-6: Components of Thermal and Fluid Flow Analytical Model

TABLE 5 - I
REFERENCE TABLE FOR MATERIAL PROPERTIES

<u>Component</u>	<u>Material</u>	<u>Spec. No.</u>	<u>Source</u>
Heater Rod	Graphitite-G	PDS 30020-3	DRM 51472, Rev. E
Inner Core	Graphitite-G	PDS 30020-3	DRM 51472, Rev. E
Simulated F. E.	Graphitite-G	PDS 30020-3	DRM 51472, Rev. E
Wrapper*	Plain Unbonded Grafoil	PDS 30182-2	DRM 51472, Rev. E
Insulating Tile	Pyrolytic Tile	PDS 30016	DRM 51472, Rev. E
Filler Strip	Graphitite-G	PDS 30020-3	DRM 51472, Rev. E
Seal Segments	Graphitite-G	PDS 30020-3	DRM 51472, Rev. E
Reflector	P-03 Graphite	PDS 30086-1	DRM 51472, Rev. E
Shroud	Stainless Steel 304	PDS 30066	DRM 51472, Rev. E
Test Fluid	Hydrogen		WANL NSS-FA-022

*Wrapper is thermalized as an assembly requirement, with exception of outer three (3) layers.
Outer three (3) layers are thermalized and re-rolled pyrofoil per specification PDS-30141-1.
Thermal properties of green (PDS 30182) grafoil were used in this analysis

Figure 5 - 7: Normalized Axial Power Distribution for Phase III and IV

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For all phases of analysis it was assumed, (1) that there were no flow paths other than those communicating with the seal chamber plena, (2) that the specified power includes only that power associated with the fluid heat pickup and does not include system losses, and (3) nominal property values obtained from the Thermal Design Standard Materials Library were representative of the physical property behavior. A typical set of input parameters included nodal pressure drop 170 psid, inlet temperature 540°R, inlet pressure 620 psia, and total power input as required to achieve a 2500°R wrapper O.D. temperature.

5.2.4 Comparison of Predictions and Results

Due to the many Phases of testing a brief synopsis and post-test comparison with calculations was made for Phases I, II, and III, with the major emphasis placed on the Phase IV final power test.

5.2.4.1 Phase I Ambient H₂

(CRD) The ambient Phase I test was run as a checkout test to establish the flow characteristics of the test model. A major difference between the 64DT-212 test model and the previous test model 64DT-031 was the replacement of the PO3 graphite reflector barrel with H4LM graphite. An anomaly was observed in the seal chamber pressure distribution for a measured pressure drop of 65.5 psid and a flow rate of 0.011 lb/sec. To simulate the measured pressure distributions two adjustments to the analyses were made. A series of filler strip-tile gaps were introduced into the analytical fluid model and resulted in the comparisons given in Figure 5 - 8 . In addition, porous flow calculations were made to establish the porous flow across the H4LM graphite reflector barrel at the individual seal chamber stations using both the measured seal chamber pressures and the initial plena pressure. This porous flow calculation was then used as a bleed flow option in the TRACK computer program. Introducing both the improved filler strip-tile gap distribution and the porous flow calculation into the fluid model gave results shown in Figure 5 - 9 in the best

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Figure 5 - 8: Seal Cavity Axial Pressure Distribution Using Various Filler Strip/Tile Gap Distribution

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Figure 5 - 9: Seal Cavity Axial Pressure Distribution Including Porous Flow Effects

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corroboration of measurement and calculation for this Phase of test. It was concluded that a combination of extraneous leakage and porous flow resulted in the anomalous pressure distributions observed in the ambient test. Due to the possible implications at heated flow conditions, it was recommended that the Phase II ambient test, the H4LM graphite reflector barrel be replaced with a PO3 graphite barrel, and to thermalize the pyrofoil wrapper. Thermalization of the pyrofoil wrapper would insure that the wrapper was outgassed, thus minimizing the growth expectancy. In addition, due to the observed pressure distribution, it was recommended that a seal segment cooling hole scheme be implemented in the design.

5.2.4.2 Phase II Ambient H₂

(CRD) The Phase II ambient predictions were made using an as-measured filler strip-tile gap distribution and specifying a model pressure drop of 53 psid. The Phase II ambient test was conducted at the specified flow rate of 0.0163 lb/sec and resulted in a Δp of 22 psid. Post test analyses indicated that a large leakage flow area would have to be used to simulate the test conditions. Attempts were made to simulate the test conditions by increasing the available flow area in the filler strips. These attempts were unsuccessful.

5.2.4.3 Phase III Intermediate Power Tests

(U) The next series of tests, Phase III, were performed at intermediate power levels of 44KW, 58KW, and 63KW. The initial comparisons of the measured and the calculated material temperatures in the fuel elements and filler strips indicated that the measurements were much lower than the calculations. To confirm the power levels, a heat balance was performed. Based on the measured inlet and outlet temperatures, the calculated heat input to the test model for the 44KW run was 19KW and for the 63KW run was 27KW. The calculated power input was lower than the measured power input as the calculations do not include system losses attributed to electrode cooling and chuck end effects.

(U) Figure 5 - 10 and 5-11 present a comparison of the calculated and measured

Figure 5 - 10: Comparison of Measured and Calculated Component Temperatures for Test Run ID (Phase III)

Figure 5 - 11: Comparison of Measured and Calculated Component Temperatures for Test Run IC (Phase III)

fuel element and filler strip temperatures for the Phase III intermediate power tests. Considering the instrumentation accuracy good agreement was exhibited between the measurements and the calculations. Note that as a power input of 30KW and 20.5KW to the analytical model was required to achieve the corroboration of data for the 64KW and the 44KW cases, respectively. The predicted and measured pressure drops for the 44KW part power run were 168 psid versus 105 psid and the flow rates 0.0335 lb/sec versus 0.028 lb/sec. For the measured pressure drop 105 psid, Figure 5-12 illustrates that the calculated seal chamber pressure distributions showed good agreement with the measurements. Figure 5-13 gives the normalized pressure distribution for the test configuration with and without the seal segment coolant holes. One may conclude from these data, that the prescribed seal segment cooling hole arrangement resulted in the desired seal chamber pressure distributions.

5.2.4.4 Phase IV Full Power

Utilizing the analytical model for the Phase III part power runs, a series of full power calculations were made specifying pressure drop and power. These calculations provided a pre-test thermal evaluation and recommendations for conducting Phase IV of the test. The resulting predictions are given in Figures 5-14, 5-15, and 5-16. Figure 5-14 provides a power-flow map of wrapper O.D. temperature of 2500°R. Figure 5-15 presents the comparable fuel element and filler strip temperatures at model stations 26 and 38. Figure 5 - 16 presents the temperature difference between the fuel and the filler strip. Figures 5-14 through 5-16 were used to prescribe the operating guidelines for Phase IV of this test.

For the post-test Phase IV analysis the steady state conditions at the end of cycle two were selected as being representative of steady state operation. These included: model inlet temperature 515°R, model flow rate 0.0315 lb/sec, and an estimated power into the model 75KW. The calculations resulted in the temperatures, pressures, and flow rates

Figure 5-12: Axial Seal Pressure Distribution During Part Power Run (Phase III)

Figure 5 - 13: Comparison of Calculated and Measured Seal Cavity Pressure Distribution with Seal Coolant Holes (Phase I)

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Figure 5-14: Prediction of Sta. 38 Wrapper O.D. Temperature and Model Flow Rate (Phase IV)

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Figure 5-15: Prediction of Sta. 38 and Sta. 26 Fuel Element and Filler Strip Temperature vs Heat Pickup in the Model Fluid

Figure 5-16: Predicted Temperature Difference Between the Fuel Element and Filler Strips vs Heat Pickup in the Model Fluid

given in Figures 5 -17 through 5 -22 . Of prime concern was the thermal performances of the pyrofoil wrapper shown on Figure 5 - 18 . Based on the observed station 38 fuel material temperatures and the constant power-flow input to the model, it appears that the test objective (O. D. wrapper temperature of 2500°R), was achieved as steady state for all cycles. The temperature drop across the wrapper was 1120°R which should be representative during all cycles.

(CRD) Figure 5 - 18 shows the calculated material temperature distributions through all the components of the test model. Besides the thermal performance of the wrapper, several maximum material temperatures are of note: the maximum material centerline temperature for the heater rod was 5375°R (constraint is 6260°R), the maximum spring cavity temperature was 1178°R (constraint is 1360°R) and the maximum reflector temperature was 1160°R (constraint is 1360°R).

(U) Simulated fuel element and filler strip material temperatures were recorded at stations 2.0, 10.0, 18.0, 26.0, 36.0, and 44.0 inches. Figure 5 - 19 presents a comparison between the measured values and the calculated values both in the simulated fuel and the filler strips. The calculated performance of the wrapper O. D. is also indicated relative to the fuel element performance which was the controlling temperature mode during the test. The favorable agreement between the measured and calculated temperatures confirms that the wrapper O. D. achieved the test objective for the assumed nominal material thermal conductivities. It should be noted that the uncertainty on the measurements, i. e., thermocouple error, data acquisition error, was estimated by the Thermal and Fluid Flow Laboratory to be approximately $\pm 180^{\circ}\text{R}$. The uncertainty on material thermal conductivity is discussed in a latter section. Figure 5-20 presents the range of steady state temperature measurements for cycles 2 through 8. In general, the calculations pass through the median of these measurements.

(U) Neglecting the fact that the measured and calculated pressure drops were not

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Figure 5-17: Test Phase IV Calculated Wrapper Temperature Distribution for Cycle 2

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Figure 5-18: Test Phase IV Calculated Component Temperature Distribution for Cycle 2

Figure 5-19: Test Phase IV Calculated and Measured Fuel Element and Filler Strip Temperatures for Cycle 2

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Figure 5-20: Test Phase IV Calculated and Measured Fuel Element and Filler Strip Temperatures for Cycles 2

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in agreement and normalizing the calculated and measured seal plena pressures, good agreement resulted in the pressure distributions as illustrated on Figure 5-21. This insured that sufficient hydraulic bundling was available during the test. Figure 5-22 illustrates the flow split between the seal hole flow and the filler strip-tile gap which are the prime contributors to the test model pressure drop. The seal holes were sized to perform in this manner.

(CRD) Figure 5-23 shows the effect of leakage flow through the pyrofoil wrapper on ambient pressure drop measurements. The isothermal test data cited on this Figure are described in the Periphery Trade Study (Trade Study No. 752, Appendix A-4). The data shown in this Figure represent the extremes in the measured data and suggest that some of the data originally assumed to be least reliable explains the mismatch between calculated and measured model pressure drop.

5.2.4.5. Effect of Uncertainty of Thermal Conductivity

(U) The effect on temperature at the wrapper-tile interface resulting from the uncertainty of thermal conductivity property data was taken into consideration. An effective thermal conductivity was calculated for heat transfer from the wrapper I. D. to the tile O. D. for a constant heat flux using equation (1).

$$q'' = \left[\frac{l}{\frac{\Delta X_1}{k_{n1}} + \frac{\Delta X_2}{k_{n2}}} \right] (T_1 - T_2) \quad (1)$$

where

- q'' = heat flux
- ΔX_1 = wrapper thickness
- ΔX_2 = tile thickness
- k_{n1} = nominal wrapper thermal conductivity (at average wrapper temperature)
- k_{n2} = nominal tile thermal conductivity (at average tile temperature) taken from T. D. Standard Material Library
- T_1 = wrapper I. D. temperature as calculated
- T_2 = tile O. D. temperature as calculated

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Figure 5-21: Test Phase IV Calculated and Measured Fluid Temperature and Pressure Axial Profiles for Cycle 2

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Figure 5-22: Test Phase IV Calculated Fluid Flow Split Using Indicated Seal Hole Configuration for Cycle 2

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Figure 5-23: Comparison of Calculated and Measured Pressure Drop Data for Phase IV
Showing Range of Measured Wrapper Leakage
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The effective thermal conductivity was calculated for the system using equation (2).

$$K_{\text{eff}} = \frac{\Delta X_1 + \Delta X_2}{\frac{\Delta X_1}{k_{n1}} + \frac{\Delta X_2}{k_{n2}}} \quad (2)$$

Using the calculated effective thermal conductivity pairs of k_1 , k_2 , the limiting case for the maximum interface temperature at a one sigma uncertainty level can be calculated, where wrapper conductivity = $K_1 + 1$ and tile conductivity = $K_2 + 1$.

$$T_w = T_i - \left(\frac{\Delta X_i}{k_{si}} \right) q'' \quad (3)$$

where

T_w = calculated interface temperature, and
 k_{si} = adjusted thermal conductivity

Upon performing the calculations at a 1 σ level it was determined that the variance on the nominal wrapper O. D. temperature could be + 82° to - 98°.

5.2.4.6 Conclusions

(U) In summary, the following conclusions can be made for Phase IV of this test series:

(U) 1. The test objective specified in Scope of Test 64DT-212 was obtained, i.e., an O.D. wrapper temperature of 2500°R. Based on measured conditions the calculations for cycle 2 resulted in an O.D. wrapper temperature of 2633°R. The one sigma uncertainty on this nominal temperature was calculated to be + 82°, - 98°.

(U) 2. To achieve the conditions given in 1. the specified power level was 75KW, the model flow rate was 0.0315 lb/sec and the model inlet temperature 515°R.

(CRD) 3. The calculated model pressure drop was 198 psi, considerably higher than the measured 147 psi. This large difference may be attributed to the sensitivity of the model to leakage flow paths. In particular, the parallel leakage flow paths through the pyrofoil wrapper are significant and largely explain the apparent difference between measured and calculated pressure drop at ambient conditions. Past history of the testing performed on

(CRD) this model has demonstrated large differences in measured and calculated pressure drops.

However, for purposes of analysis, of prime consideration was the total flow rate and the power to achieve the test objective. By specifying the power and flow rates in the analysis, the internal temperatures were calculated and were in good agreement with the measurements.

(U) 4. The measured and calculated normalized seal chamber pressure distributions were in good agreement.

5.2.5 Permeable Flow

5.2.5.1 Model Permeability Effects

(CRD) The original Phase IV test plan called for maintaining the heater cavity Helium pressure at a value of 5 ± 5 psi higher than the GH_2 outlet pressure. The heater corrosion failure which resulted in the termination of both the Phase IV-HH₂-A and B tests came about as a result of permeable flow of GH_2 from the interelement gaps through the core and into the heater cavity. To remedy this the balance of the Phase IV test was run with the heater cavity Helium pressure set at 5 ± 5 psi above the model inlet pressure in order to prevent flow of GH_2 into the heater cavity. As a result of this change in test procedure some of the helium in the heater cavity could diffuse through the core into the interelement gaps and possibly into the pyrofoil wrapper as well. This section examines permeable flow effects through the core and its relationship both to the measured helium flow and to core bundling.

5.2.5.2 Core Permeability Measurements

(CRD) Fig. 5-24 gives the measured permeability data for the "212" core along with measured data for the "031" core as a point of reference. The "212" core data were measured for the core mounted in the furnace with the fuel elements, wrapper and filler strips in place. The core leakage data as reported have been corrected for extraneous leakage associated with the chuck. These are the data used in the permeable flow calculations reported in this section. The "031" core data were measured on a bench assembly on a bare graphite "G" core similar to the "212" core. Experimental data presented in DRM 51369 show that the addition of the simulated fuel elements to the "031" core results in a reduction in core flow of a factor of 2-4. This discrepancy between the bench tests ("031" "core") and the in-situ measurements on the "212" core is felt to be due to three factors: (1) Bundling effects were not modelled in the "212" assembly; bundling tends to decrease the measured permeable flow; (2) The effectiveness of the sealing of the aft end

Figure 5-24: Measured Test Fixture Core Permeability

of the "212" core could not be monitored, consequently this could have been a source of extraneous leakage; (3) Chuck leakage was measured in a bench test and may not have reproduced the precise furnace fixture geometry and sealing. The test fixture installed in the furnace does not lend itself to accurate porosity measurements. A recent evaluation and comparison of leakage measurements on two graphite "G" cores which have been tested were published in DRM 51369. These results indicate that the "031" leak rates in the figure are probably more representative of the "212" core. However, the evaluation which follows was based on the higher leakage rate shown.

5.2.5.3 Permeable Flow Analytical Model

(CRD) The major assumptions made in the accompanying analysis are: (1) plane Poiseuille flow; (2) one-dimensional porous flow. Two analytical models were examined: Case 1 - An interelement gap between adjacent simulated fuel elements of 0.8 mil was assumed; the interelement pressure distribution was calculated. It was assumed that there was no flow except in the radial gaps between simulated fuel elements. Case 2 - The interelement pressure distribution was set at the LSS pressure profile and the resultant permeable helium flow calculated for Case 1; the helium flow and pressure distribution was derived in the following manner.

(CRD) Divide the interelement gaps axially into k segments. For the n^{th} segment the following flow balance equation is solved for the incremental length (ΔX) for a specified pressure differential:

$$\sum_{i=1}^{n-1} W_{pi} + \frac{1}{2} A \left[\frac{P_{HC}^2 - \bar{P}_n^2}{\mu RT} \right]^B \Delta X_n = \frac{mwt^3 [P_{ni}^2 - P_{no}^2]}{24 \mu R T \Delta X} \quad (4)$$

$$\bar{P}_n = \frac{1}{2} [P_{ni} + P_{no}] \quad (5)$$

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The total porous flow is then:

$$W_p = \sum_{i=1}^k W_{pi} \quad (6)$$

W_p = total porous flow rate

W_{pi} = porous flow entering i^{th} axial increment from heater cavity =

$$A \left[\frac{P_{HC}^2 - P_n^2}{\mu R T} \right]^B$$

A, B = constants

P_{HC} = heater cavity pressure assumed equal to model inlet pressure

P_{ni}, P_{no} = inlet and outlet pressure to n^{th} axial segment

m = number of interelement gaps = 12

μ = viscosity

R = gas constant

T = absolute temperature

W = interelement gap width

ΔX = length of axial segment

t = interelement gap thickness

For Case 2, knowing the pressure profile the total permeable flow can be calculated from equation (6).

5.2.5.4 Comparison of Analytical Predictions with Measured Test Fixture Data

All of the following calculations and measurements were made at ambient conditions.

Fig. 5-25 shows the calculated core helium flow for Case 1 and 2 for ambient test conditions. The calculated flow rates differ by a factor of 5-6 for the two analytical models. Fig. 5-26 shows the assumed interelement pressure profile for Case 2. This curve is compatible with the measured lateral support system pressure profile. The heater cavity pressure was assumed to be uniform. The flow metering plug located at the aft end of the model will tend to make the heater cavity pressure fall off as indicated. Fig. 5-27 shows the comparison

Figure 5-25: Comparison of Calculated Helium Porous Flow Through Inner Core for Two Assumed Models (Ambient Temperature)

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Figure 5-26: Assumed Normalized Axial Pressure Distribution
for Porous Flow Analysis (Case 2)

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Figure 5-27: Calculated Interelement Gap Pressure Distribution (Case 1)

for a model pressure drop of 100 psi, between the Case 1 calculated axial pressure profile the measured LSS pressure distribution. The Case 1 calculated pressure profile would predict a very small inward directed bundling force.

(U) Fig. 5-28 shows a comparison between the Case 2 calculated helium flow rate and the total measured model helium flow rate. In addition an estimate of core helium flow derived from the total measured flow data is shown.

(U) The total measured helium flow consists of: (a) core flow; (b) chuck flow; (c) metering plug flow. Two measurements of chuck leakage flow were made for two different degrees of compression of the grafoil washers. In addition, separate measurements were made of the chuck leakage. The estimated core flow was obtained by subtracting the measured chuck leakage and metering plug leakage from the total measured helium flow. The curve marked minimum flow is associated with the minimum washer compression. This curve shows reasonably good agreement between the measured and calculated (Case 2) data.

(U) The Case 2 assumption of the interelement pressure distribution is in reasonable agreement with the measured leakage data. Several explanations can be offered for the difference between the Case 1 and Case 2 computations:

(CRD) 1. Porous flow through the grafoil wrapper provides a potentially significant flow path. No data on the permeability of a grafoil blanket exist. The presence of helium in the "212" wrapper was not evident in terms of reduced corrosion damage to the wrapper.

(CRD) 2. Two dimensional porous flow within the core itself contributes another parallel leakage path. Fig. 5-29 was developed to examine this possibility. A one inch axial section of the core was taken and both the porous flow rate through the core itself and through the interelement gaps were calculated as a function of the driving pressure differential. The effect of uncertainties in the interelement gap distribution is also shown. What this graph illustrates are three facts. (a) The porous flow axially through the "212" core is not a significant percentage of the flow through the interelement gap; (b) Axial flow through the

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Figure 5-28: Comparison of Calculated (Case 2) and Measured Helium Porous Flow Through Test Fixture (U)

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Figure 5-29: Comparison of Calculated Axial Porous Flow in the "212" Core with the Calculated Axial Flow in the Interelement Gaps (1" Axial Section)

interelement gaps is quite sensitive to variations in the radial gaps between adjacent simulated fuel elements.

(CRD) 3. Gaps between the simulated fuel elements and the core have been neglected but may add significantly to the available leakage path. As a point of reference for the tightly bundled NRX-A6 core, the effective hydraulic gap thickness between the simulated fuel elements was evaluated to be 1.2 mils.

(CRD) 4. Measurement of the interelement gap distribution is not precisely known. Ambient measurements indicate gaps between 0.6 - 1 mil for the "212" periphery assembly.

5.2.5.5 Conclusions

(CRD) The major conclusion drawn from the analysis of permeable flow in the test fixture is:

(CRD) (1) The interelement gap pressure distribution can not be accurately predicted on account of uncertainties in the core permeability; however Case 1 and Case 2 bracket the expected range of interelement pressures.

5.3 CORROSION ANALYSIS

5.3.1 Analytical Models

(CRD) Calculated and estimated corrosion results given in this section were determined by three methods. First, since the NRX-A6 periphery test ⁽¹⁾ was a similar test and the periphery also contained graphite parts and a pyrolytic foil wrapper, the results of that test were extended to the "212" development test.

(CRD) Second, corrosion calculations were performed using the ICAP computer program. This computer program calculates the corrosion in specified flow channels having graphite walls with hydrogen flowing between them. It is applicable in the laminar flow region at thermal conditions which lead to reactions involving C, H₂, CH₄, and C₂H₂. Reactions considered are $C + 2H_2 \rightleftharpoons CH_4$ and $2C + H_2 \rightleftharpoons C_2H_2$. The forward reaction rate expression has a temperature dependence of the form $\alpha \exp(\beta/T)$, where α and β are specified for each reaction and each material. Fundamental corrosion test data and the resulting corrosion constants for graphite and pyrofoil materials are given in Reference 2. Because of the lack of data on the "212" test pyrofoil and the scatter in results for the pyrofoil tested, calculations were performed using the nominal reaction rate constants as well as ten times these values. Accurate definitions of the flow channel size (in most applications a small axial leakage path) as well as the corrosion constants are required for the ICAP results to be meaningful. In many cases, the corrosion depends strongly on the amount of hydrogen available which is a function of the leakage flow channel size. This channel size usually has a large degree of uncertainty.

(CRD) The third corrosion calculational method was based on the assumption that there was sufficient hydrogen available to allow a forward corrosion reaction only. That is, the corrosion is limited by the reaction rate constants rather than the amount of hydrogen available. Because of the large amount of observed corrosion in the periphery components,

¹WANL-TME-1717, Core Periphery Development Test on an NRX-A6 Wrapper Design Concept, March 1968.

²WANL-TME-2677, NERVA Core Periphery Design Concepts, Section A-4.0.2.1, March 1970.

a comparison to this maximum corrosion rate was meaningful. As for the ICAP evaluations, these comparisons were made with the nominal corrosion rate constants and ten times these values.

5.3.2 Corrosion Pretest Analysis (U)

(CRD) Pretest corrosion calculations included a comparison of the similarities between the models and test conditions of the 60 minute NRX-A6 Periphery Development Test and the proposed 80 minute 64DT-212 Periphery Test. The two test models had many similarities. Figure 5-30 shows a cross-section of the NRX-A6 Periphery Test which may be compared to the "212" test piece in Figure 3-1. The "A6" model had a 50 mil cylindrical foil wrapper made of 4 inch wide, 5 mil thick axial strips, while the "212" model had a zig-zag foil wrapper made of .64 to .75 inch wide 5.5 mil thick axial strips. A comparison of the axial models is given Table 5-2. This table also includes a comparison of the NRX-A6 model test conditions and the pretest estimate of test conditions for the "212" model. This estimate was based on the Phase 3 thermal and fluid conditions. The pyrofoil wrapper in the NRX-A6 model operated at a higher temperature than the "212" wrapper.

(U) A summary of the NRX-A6 periphery test results is given in Column III of Table 5-2. Based on the difference in test models and the difference in expected test conditions for the "212" model, the second column was formulated.

(CRD) Assuming the wrapper would not conform well to the simulated fuel elements, the pyrofoil ID regression depth for a forward reaction (pure hydrogen atmosphere) is given as a function of temperature in Figure 5-31. This is for nominal corrosion constants. At 3700°R, the regression would be 4 to 40 mils considering a 10 X uncertainty in corrosion.

(CRD) This evaluation led to an estimate that little ID wrapper corrosion would occur if the wrapper conformed well to the simulated fuel elements and that corrosion in the interior portion of the wrapper would not be excessive.

(CRD) The "212" test results did not confirm this prediction. Gross corrosion occurred throughout the wrapper downstream of station 28. The post test evaluation led to the conclusion that:

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Figure 5-30: Trimetric Cutaway Illustration of TFL-2a Model (NRX-A6)

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TABLE 5-2
PRETEST COMPARISON OF R-1 (212) AND NRX-A6 PERIPHERY TESTS

	<u>NRX-A6 Periphery Test</u>	<u>64DT-212 Dev. Test</u>
I. Geometry		
1. Internal to insulation	Simulated filler strips Assy gaps 0.6-1.0	Simulated fuel elements Assy gaps slightly better
2. Pyrofoil wrapper	0.05" cylindrical	0.18 zig-zag
3. Pyro Tile	0.125" strips	0.125" half chevron
4. External to insulation	Seal system with flow holes	Sim. filler strips and seal system with flow holes
II. Test Conditions		
1. Flow	0.014 lb/s	0.028 lb/s
2. Pressure drop	19 to 14 psid	Est. 65 psid
3. Time	60 min SS one cycle	80 min 8 cycle
4. Total electrical power	92 to 106 KW	Est. 130 KW
5. Temperatures:		
a. Hot side (pyrofoil I.D.)	3600-4000°R	3700°R
b. Cold side	1850°R	900°R
c. Grafoil O.D.	3300-3700°R	2500°R

TABLE 5-2 (CONTINUED)
PRETEST COMPARISON OF R-1 (212) AND NRX - A6 PERIPHERY TESTS

	<u>NRX-A6 Periphery Test</u>	<u>64DT-212 Dev. Test</u>
III. Test Results and Estimates		
1. O.D. surface of wrapper	Corrosion grooves at pyro tile interfaces 30 mils in the 50 mil pyro-foil wrapper.	Much less or none because of lower temperature
2. Interior volume of wrapper	Little corrosion evident which was not associated with corrosion groove on wrapper O.D.	Estimate more could occur because of 4x on ΔP , 1.33 X on time, and different geometry; however, temperature is lower
3. I.D. of pyrofoil	Soot marks, a few pinhole size corrosion holes	Est. similar if foil conforms well to sim. F.E. If foil conforms very poorly to fuel element contour, wrapper corrosion should not be larger than 1.33 times the observed 30 mil O.D. corrosion in the A6 test. Note that the A6 test O.D. temperature and 64DT-212 test runs 33% longer
4. Sim. filler strips or FE	2 mils avg regression 8 mils maximum from 7-20" plating from 20-50"	Est. maximum of 5 times more corrosion (4 x on ΔP , 1.33 x on time)

CORROSION DAMAGE TO PYROFOIL VS. TEMPERATURE

Figure 5 - 31: Calculated Pyrofoil Regression Depth (Perpendicular to Basal Plane) Versus Temperature - Forward Reaction Only

(CRD) 1) Considering startup and shutdown periods, the equivalent corrosion test time at 3900°R station - wrapper I.D. temperature was 115 minutes compared to the steady state test time of 80 minutes at 3700°R considered in the pretest evaluation.

(CRD) 2) Large amounts of hydrogen were available to the interior portion of the wrapper, primarily because of axial leakage through the butt joints between the edges of the wrapper layers. There was no evidence of significant corrosion at similar (but further separated) butt joints in the A6 periphery test wrapper and NRX-A6 reactor wrapper.

(CRD) 3) Corrosion rates for the pyrofoil material were at least ten times the nominal values obtained from correlations of available test data.

5.3.3 Post Test Corrosion Evaluation Equivalent Test Time

(CRD) The 276 minute Phase IV test consisted of 8 cycles operated at peak power, pressure and temperature ($\approx 3900^\circ\text{R}$ wrapper I.D. temperature) for approximately 12 minutes per cycle. For balance of the test run, the test fixture was operated at lower temperatures and pressures. Figs. 4-18, 4-19 show the model pressure drop and temperature during the test. To obtain an estimate of the equivalent test time at a fixed temperature and pressure profile, an equivalent test time has been defined as the time which would produce the same corrosion damage as a test run at a constant pressure of 40 atmospheres and a wrapper I.D. temperature of 3900°R. The equivalent test time is determined as follows:

$$t_{\text{eq.}} = \frac{1}{R_{3900^\circ\text{R}}} \int_0^{276 \text{ min.}} R \, dt$$

where

R = Wrapper corrosion rate in pure GH_2 at the measured wrapper I.D. temperature

R_{3900} = Wrapper corrosion rate in pure GH_2 at a wrapper I.D. temperature = 3900°R

The calculated equivalent test time is 115 minutes.

5.3.4 Corrosion Analysis and Comparisons to Test Observations

- (CRD) Post test corrosion analysis was aimed at understanding the reason for the unexpectedly severe corrosion in the pyrofoil wrapper. The type of severe wrapper corrosion which occurred during the test is illustrated in Fig. 5-32 and shown in detail in Section 4.3.3.4.5. Gross corrosion occurred in the wrapper downstream of station 28. The figure shows a section of the wrapper and portions of the simulated fuel elements at station 41 which were completely corroded away.
- (CRD) A higher than expected axial leakage as well as higher pyrofoil corrosion rate were investigated. The numerous small gaps at the butt joints (shown in the figure) were considered as a source of leakage and analyzed using the ICAP computer code. Similar but less numerous joints in the NRX-A6 Periphery Test and NRX-A6 Reactor Test had not shown evidence of significant corrosion. Secondly the 5" isothermal test section data which were felt to be the most accurate data did not indicate leakage flows which could be attributed to large butt joint gaps.
- (CRD) The corrosion patterns indicated that hydrogen leakage through these gaps was the source of corrosion. The calculations which are described are based on a 5.5 mil thick flow path (the thickness of a single pyrofoil layer) at least 10 mils wide, extending axial through the entire 47" length of the wrapper.
- (CRD) Fig. 5-33 shows the results of this calculation for a leakage path with the axial temperature profile of the wrapper I.D. Pressure drop during the test increased from 100 psid to 200 psid during the course of the high power test; therefore, the 200 psid used for the analysis is high and gives higher calculated corrosion values. As described in the previous section, the equivalent test time was 115 minutes. Under these conditions (using nominal corrosion rate constants) the hottest pyrofoil layer (ID layer) would be penetrated to a depth of 4.5 mils adjacent to the butt joint gaps of the neighboring layers. Results of the same calculation for corrosion in the direction parallel to the basal planes of the pyrofoil are given in Figure 5-34.

Figure 5-32: Pyrofoil Wrapper Corrosion Pattern Showing Region Totally Destroyed by Corrosion Damage

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Figure 5-33: Calculated Wrapper Corrosion Perpendicular to Basal Plane for Nominal Rate Constants

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Figure 5-34: Calculated Corrosion Parallel to Basal Planes for Nominal Rate Constants

(CRD) The calculation described above was repeated with the corrosion rate constants increased by a factor of ten. The corrosion regression at the postulated through axial gap in the ID layer is shown in Fig. 5-35. The corrosion depth is about four times greater than the corrosion with nominal corrosion constants.

(U) The effect of axial pressure drop is illustrated in Fig. 5-36. This figure indicates that the corrosion results calculated with 200 psid are only about 20% less than those calculated with 100 psid. Since the pressure drop varied from 100 to 200 psid during the test, there is only ~ 10% error associated with using the higher value for the entire calculation.

(CRD) Based on measured temperatures and thermal analysis, axial temperature profiles were defined for the different wrapper layers. ICAP calculations similar to those described above were made for these different layers. The maximum regression depth was selected from each calculation and plotted in Fig. 5-37. Maximum regression depths are also given on the figure for forward reaction rates at the 212 periphery test temperatures and the R-1 wrapper temperatures. These calculated regressions are compared to test results for some of the cooler wrapper layers. A detailed examination in one local region of the wrapper revealed places where corrosion originating at the butt joints had penetrated the adjacent 5.5 mil thick wrapper layer. These are indicated on the figure (layer 18, 21, 25 and 27). Where no symbol is included, the source of corrosion could not be determined. This comparison indicates that observed corrosion of the outermost wrapper layers cannot be explained by any of the postulated corrosion models even with increased corrosion constants. This suggests that more detailed experimental data are needed to establish an accurate analytical model of the corrosion mechanism in pyrofoil. The simplified models which consider only external surface corrosion effects are not adequate.

(CRD) Fig. 5-38 shows the measured data showing the extreme aft and forward stations at which corrosion damage completely penetrated a given layer. These data were taken from an examination of the pyrofoil segments adjacent to fuel element pieces E-9 and E-10 (Reference Figure 3-1). Observable corrosion damage occurred on all layers with the

Figure 5-35: Calculated Corrosion Depth Profile

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Figure 5-36: Calculated Maximum Regression Depth Perpendicular to Basal Plane vs Pressure Drop

Figure 5 - 37: Comparison of Measured Wrapper Corrosion Depth Perpendicular to Basal Plane with Various Analytical Calculations

Figure 5 - 38: Axial Limits of Total Wrapper Corrosion

exception of layer 22. Layers 1-15 were bonded together so that no measured data are shown for those layers. The ICAP model, using nominal rate constants, predicts complete corrosion damage from station 32-42. With 10 times the nominal rate constants complete corrosion damage would extend from stations 26-44 (Ref. Fig. 5-35). The measured data are from station 28-45 which agrees with the 10 X nominal rate constants.

(CRD) An analysis of the corrosion in pyrofoil was made separate from the ICAP analysis on the basis of a forward reaction rate only. Two models were hypothesized: (1) Constant linear radial temperature profile through the wrapper (2630°R maximum OD temperature); (2) Time varying linear profile through wrapper (2630°R maximum OD temperature). These models will be discussed in order. Figure 5-39 shows the results of the first model both for the test fixture and also for the R-1 wrapper boundary conditions. The data point for 120 minutes test time is reproduced on Figure 5-38. Figure 5-32 shows a particular region of the wrapper where a very large area of the wrapper was completely destroyed. This particular example gives credence to the assumption that corrosion through only one-half of the wrapper from gaps on each side of a given layer can result in destruction of a given layer.

(CRD) Figure 5-40 shows schematically what is hypothesized for the second model. As each layer corrodes through the balance of the wrapper is compressed into the space thus created. When this occurs, the temperature profile was changed in a step-wise manner, maintaining an ID temperature of 3900°R and an OD temperature of 2630°R . The resultant predicted corrosion damage is shown on Figure 5-41. This model also does not, with nominal rate constants, predict the extensive corrosion damage observed on the outermost layers, although it explains a possible mechanism for the corrosion damage shown in Figure 5-32.

Figure 5-39: Wrapper Corrosion Damage for a Forward Reaction Rate and a Fixed Linear Temperature Profile

TIME = 0
 INITIAL BUILD.
 (TYP. SECTION)

TIME $\approx$ 47 MIN.
 AFTER LAYER 2 HAS
 BEEN CORRODED THROUGH

TIME $\approx$ 58 MIN.
 AFTER LAYER 4 HAS
 BEEN CORRODED THROUGH

ASSUMPTIONS:

1. FORWARD REACTION RATE ONLY
2. NOMINAL RATE CONSTANTS
3. TIME VARYING LINEAR TEMPERATURE PROFILE
4. CORROSION ORIGINATES IN BUTT JOINTS

Figure 5-40: Profile of Model Wrapper Corrosion Mechanism

Figure 5 - 41: Wrapper Corrosion Damage for a Forward Reaction Rate and a Time Varying Linear Temperature Profile

5.4 CODE VERIFICATION

The utility of the TRACK computer program for modelling the fluid and thermal characteristics of the 64DT-212 test fixture has been demonstrated to be reasonably good. The use of the ICAP program for corrosion computations has not been adequate in predicting the expected corrosion damage. The major difficulty is probably in two areas: (1) uncertainties in rate constants. DRM 1067 discusses the fact that certain types of graphite exhibit variations in rate constants of as much as 100; (2) secondly, some LASL experimental data, (Reference Appendix A - 4, Nerva Core Periphery Design Concepts-WANL TME-2677) suggest that corrosion may not be exclusively a surface phenomena.

6.0 CONCLUSIONS

6.1 SPECIFICATION AND TIS REQUIREMENTS

(U) Table 6 - 1 relates the test results to the applicable specification and TIS requirements.

TABLE 6 - 1

(CRD) SUMMARY OF SPECIFICATION AND TIS REQUIREMENTS

Specification/TIS	Paragraph	Requirement	Test Conclusion
ECC 677564	3.1.1.1.2.3.1	Impede Radial Leakage	Test demonstrated no radial leakage occurred through wrapper.
ECC 677564	3.1.1.1.2.3.2	Impede Axial Flow	Test fixture demonstrated inadequate axial flow impedance on the basis of measured corrosion damage.
ECC 677564	3.1.1.1.2.4	Provide Thermal Impedance	Test provided good correlation with predicted radial temperature gradient.
ECC 677564	3.1.2.3	Useful Operating Life- 600 Minutes, 60 Cycles Max.	Not demonstrated in Test.
TIS-2	1.1	Indicate Wrapper O.D. Cyclic Corrosion Resistance Capability	Wrapper O.D. corrosion resistance appears compatible with R-1 temperature conditions.

6.2 TEST CONCLUSIONS

(U) On the basis of the preceding discussion, the following conclusions have been reached:

(CRD) 1. The wrapper design concept (full length pyrofoil wrapper) tested does not have the requisite 10 hour lifetime. It did, however, demonstrate the original planned 80 minute capability. Differences in assembly and fabrication procedures between the "212" model and the R-1 reactor make extrapolation of the test corrosion behavior to the R-1 configuration difficult.

(CRD) 2. Larger leakage flow through the wrapper occurred than was expected as evidenced by wrapper corrosion damage.

(CRD) 3. The wrapper O.D. incurred some minimal corrosion, possibly associated with the fact that the calculated wrapper O.D. temperature was 2630°R. From an inspection of the wrapper O.D., it was observed that no measureable corrosion damage occurred in regions exposed to temperatures less than approximately 2400°R.

(CRD) 4. The observed corrosion damage was not analytically predicted with the present modelling of the corrosion phenomenon. Pyrofoil corrosion reaction rates at least ten times greater than those based on previous test data are required to calculate comparable damage.

(CRD) 5. No significant corrosion occurred on the radial faces of the simulated fuel elements giving possible evidence of the presence of helium in the interelement gaps.

(CRD) 6. The interelement gap pressure distribution was not accurately calculated because of uncertainty in the gap size and core permeability. However, interelement pressure must be close to the measured LSS pressure profile in order to explain the measured helium flow.

(U) 7. Differences between the calculated model pressure drop and the measured value can be partially explained by leakage flow through the wrapper. The normalized

measured pressure distribution in the LSS agreed well with the predicted shape.

(U) 8. Excluding uncertainties associated with extraneous model heat losses, good agreement was realized between the predicted and measured temperature profiles.

(CRD) 9. Wrapper strain capability was demonstrated to be adequate. Slippage occurred between pyrofoil layers, relieving wrapper strain. No wrapper tears were observed during post-test inspection.

(CRD) 10. Ratcheting of the wrapper could be a potential problem for the R-1 configuration. It is, however, difficult to quantitatively relate test results to the R-1 configuration in view of differences in support features between the test fixture and the R-1 assembly.

(CRD) 11. Radial expansion of the "212" core appeared to be compatible with the "212" lateral support system.

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APPENDIX A

SUMMARY OF TEST FIXTURE MECHANICAL DESIGN FEATURES (U)

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TABLE A-1
SUMMARY OF MECHANICAL DESIGN FEATURES OF PHASE I TEST MODEL
DEFINED BY SCOPE OF TEST 64DT-212 (U)
(GENERAL ASSEMBLY DRAWING No. 711J720)

COMPONENT	MATERIAL	DESCRIPTION
Heater 'A'	Graphite - Commercial Grade Graphitite "G"	NT701509-101, Tapered solid rod, uncoated.
Inner Core	Graphite - PDS-30020-2	WT701736-402, NbC coated.
Simulated Element	Graphite - PDS-30020-2	WT701736 - Sheets 3 and 14, full length uncoated, with and without instrumentation holes.
Wrapper (27 Layers)	Pyrofoil - PDS-30182-2	100E078, full length Z-liners .0045 to .0075 thick fabricated by TFL/RA personnel.
Insulating Tile	Graphite - Pyrolytic - PDS-30016-1	WT701736-501, full length .125 inch thick, cool periphery type.
Spacer (Filler Strip)	Graphite - PDS-30020-2	WT701736 - Sheets 2 and 14, full length cool periphery type, with and without instrumentation holes.
Seal System	Graphite - Commercial Grade Graphitite "G"	Seal System, WT701736 - Sheet 18. 17 rows of seal segments. Each row having 12 flow holes. Rows 1 through 3, 0.104 dia. Rows 4 through 17 no flow holes.
Inner Reflector	Graphite - Commercial Grade H4LM	Non-Impregnated full length one piece construction with access holes for external plunger spring loading.
Lateral Support System	Inconel "X" Springs - No. 1 Temper. ASM 5698/	Spring/Plunger/Spacer/Plug Loading Hardware Spring Rate: 224 lb/in. Maximum Spring Deflection: 0.100 inches.

TABLE A-2
SUMMARY OF MECHANICAL DESIGN FEATURES OF PHASE II TEST MODEL
DEFINED BY SCOPE OF TEST 64DT-212 (U)
(GENERAL ASSEMBLY DRAWING No. 711J720)

COMPONENT	MATERIAL	DESCRIPTION
Heater 'A'	}	Components reused from Phase I Model
Inner Core*		
Simulated* Element		
Wrapper*, ** (27 Layers)	Pyrofoil - Specification unknown. Outer four (4) layers made from rerolled pyrofoil per specification PDS-30131-1	With exception of outer four (4) layers, wrapper thermalized as an assembly per requirements defined in DRMs 51328 and 51332.
Insulating Tile	}	Components reused from Phase I Model
Spacer *** (Filler Strip)		
Seal System		
Inner Reflector	Graphite - Commercial Grade, PO-3	Non-Impregnated full length one piece construction with access holes for external plunger spring loading.
Lateral Support System	Components reused from Phase I Model	
* Subjected to two (2) thermalization cycles following Phase I tests.		
** Outer four 4 layers not thermalized with the assembly. Z-liners installed utilizing full surface bonding with petrolatum-benzene solution.		
*** Not used in the thermalization process.		

TABLE A-3
SUMMARY OF MECHANICAL DESIGN FEATURES OF PHASE III, and IV
TEST MODEL DEFINED BY SCOPE OF TEST 64DT-212 (U)
(GENERAL ASSEMBLY DRAWING NO.711J720)

COMPONENT	MATERIAL	DESCRIPTION
Heater 'A', 'B' and 'C'	Graphite - Commercial Grade Graphitite "G"	NT701509-101, Tapered solid rod, un- coated.
Inner Core *		
Simulated *		
Element		
Wrapper*, ** (27 Layers)	} Components reused from Phase II Model	
Insulating Tile		
Spacer *** (Filler Strip)		
Seal System	Graphite - Commercial Grade Graphitite "G"	Seal System, WT701736 - Sheet 18. 17 rows of seal segments. Each row having 12 flow holes. Rows 1 through 6, 0.104 dia. Rows 7 through 11, .063 dia. Rows 12 through 16, .055 dia. Row 17, .046 dia.
Inner Reflector	} Components reused from Phase II Model	
Lateral Support System		

* Subjected to two (2) thermalization cycles following Phase I tests.

** Outer four (4) layers not thermalized with the assembly. Z-liners installed utilizing full surface bonding with petrolatum-benzene solution.

*** Not used in the thermalization process.

APPENDIX B

COMPARISON OF MEASURED AND SPECIFIED OPERATING TEST CONDITIONS

TABLE B-1

MEASURED OPERATING PARAMETERS FOR THE 64DT-212 PHASE I AMBIENT TEMPERATURE HYDROGEN FLOW TESTS (U)

<u>Operating Control Parameters</u>	<u>1B</u>	<u>2A</u>	<u>2B</u>	<u>2C</u>	<u>2D</u>	<u>2E</u>	<u>2F</u>	<u>2G</u>
Model exit, pressure, psig	439	438	438	438	438	438	430	438
Model hydrogen flow, lb/sec	.0107	.0041	.0108	.0092	.0110	.0110	.0110	.0110
Model inlet to atmosphere pressure differential, psi	+1	+0.5	+6.9	+5.9	+5.2	+5.0	+5.0	+4.9
Heater cavity to model exit pressure differential, psi	X	+1.5	+8.2	+9.1	+10.0	+10.0	+10.8	+10.5
Exit nozzle hydrogen coolant flow, lb/sec	O	.0043	.0049	.0188	.0385	.0385	.0385	.0605
<u>Monitoring Test Parameters</u>								
Model pressure drop, psi	64	23	62	63	69	68	68	68
Furnace helium atmosphere flow (max), lb/sec	.0122	.0097	.0155	.0157	.0159	.0159	.0159	.0159
Heater cavity helium inlet flow, lb/sec	*	*	*	.0002	*	.0001	.0002	.0002

* BELOW DP INSTRUMENT MEASURING RANGE.

TABLE B-1 (Cont'd.)

MEASURED OPERATING PARAMETERS FOR THE 64DT-212 PHASE I AMBIENT TEMPERATURE HYDROGEN FLOW TESTS (U)

<u>Operating Control Parameters</u>	<u>3A</u>	<u>3B</u>	<u>3C</u>	<u>3D</u>	<u>3E</u>	<u>3F</u>	<u>3G</u>	<u>3H</u>
Model exit, pressure, psig	438	435	435	439	438	435	435	435
Model hydrogen flow, lb/sec	.0114	.0132	.0165	.0150	.0087	.0075	.0180	.0166
Model inlet to atmosphere pressure differential, psi	+4.6	+4.2	+5.0	+4.8	+5.0	+4.8	+5.0	+4.8
Heater cavity to model exit pressure differential, psi	+9.1	+9.1	+9.1	-4.4	+9.1	+9.1	+9.1	+9.1
Exit nozzle hydrogen coolant flow, lb/sec	.0519	.0517	.0453	.0453	.0453	.0455	.0455	.0456
<u>Monitoring Test Parameters</u>								
Model pressure drop, psi	47	55	65	36.5	29.5	25.5	44	65
Furnace helium atmosphere flow (max), lb/sec	.0147	.0173	.0188	.0132	.0114	.0102	.0151	.0199
Heater cavity helium inlet flow, lb/sec	.0013	.0007	.0002	.0019	.0023	.0025	.0015	.0001

TABLE B-1 (Cont'd.)

MEASURED OPERATING PARAMETERS FOR THE 64DT-212 PHASE I AMBIENT TEMPERATURE HYDROGEN FLOW TESTS

<u>Operating Control Parameters</u>	<u>3I</u>	<u>3J</u>
Model exit, pressure, psig	438	438
Model hydrogen flow, lb/sec	.0108	.0109
Model inlet to atmosphere pressure differential, psi	+4.9	+4.9
Heater cavity to model exit pressure differential, psi	+9.1	+9.1
Exit nozzle hydrogen coolant flow, lb/sec	.0456	.0601
<u>Monitoring Test Parameters</u>		
Model pressure drop, psi	37.5	36.5
Furnace helium atmosphere flow (max), lb/sec	.0133	.0133
Heater cavity helium inlet flow, lb/sec	.0018	.0018

TABLE B-2
COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING CONDITIONS
FOR THE 64DT-212 PHASE II AMBIENT TEMPERATURE HYDROGEN FLOW TESTS (U)

<u>Operating Control Parameters</u>	<u>Specified*</u>	<u>Measured 1A</u>	<u>Specified*</u>	<u>Measured 1B</u>	<u>Specified*</u>	<u>Measured 1C</u>	<u>Specified*</u>	<u>Measured 1D</u>
Model exit, pressure, psig	436 $\pm$ 5	435	436 $\pm$ 5	435	436 $\pm$ 5	434	—	435
Model hydrogen flow, lb/sec	.0070	.0075	.0110	.0116	.0110	.0116	—	.0151
Model inlet to atmosphere pressure differential, psi	5 $\pm$ 5	+1.4	5 $\pm$ 5	○	5 $\pm$ 5	○	—	+2
Heater cavity to model exist pressure differential, psi	5 $\pm$ 5	+0.6	5 $\pm$ 5	+0.7	5 $\pm$ 5	+0.7	—	+0.9
Exit nozzle hydrogen coolant flow, lb/sec	○	○	○	○	.050	.0516	—	.0521
<u>Monitoring Test Parameters</u>								
Model pressure drop, psi	34	13.6	61	32.8	61	33.6	—	47.2
Furnace helium atmosphere flow, lb/sec	.009	.0061	.013	.0125	.013	.0125	—	.0521
Heater cavity helium inlet flow, lb/sec	.002	.0004	.002	.0004	.002	.0004	—	.0004

* DRM 51338

TABLE B-2 (Cont'd)

COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING CONDITIONS
FOR THE 64DT-212 PHASE II AMBIENT TEMPERATURE HYDROGEN FLOW TESTS

<u>Operating Control Parameters</u>	<u>Specified *</u>	<u>Measured 1E</u>
Model exit, pressure, psig	—	435
Model hydrogen flow, lb/sec	—	.0153
Model inlet to atmosphere pressure differential, psi	—	+0.2
Heater cavity to model exit pressure differential, psi	—	+0.9
Exit nozzle hydrogen coolant flow, lb/sec	—	.0525
<u>Monitoring Test Parameters</u>		
Model pressure drop, psi	—	53.6
Furnace helium atmosphere flow, lb/sec	—	.0155
Heater cavity helium inlet flow, lb/sec	—	.0004

* DRM 51338

TABLE B-2 (Cont'd.)

COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING CONDITIONS
FOR THE 64DT-212 PHASE II AMBIENT TEMPERATURE HYDROGEN FLOW TESTS

<u>Operating Control Parameters</u>	Specified*	Measured 2A	Specified*	Measured 2B	Specified*	Measured 2C	Specified*	Measured 2D
Model exit, pressure, psig	436 $\pm$ 5	436	436 $\pm$ 5	437	—	440	—	440
Model hydrogen flow, lb/sec	.0070	.0078	.0110	.0112	—	.0150	—	.0076
Model inlet to atmosphere pressure differential, psi	5 $\pm$ 5	0	5 $\pm$ 5	0	—	0	—	-.1
Heater cavity to model pressure differential, psi	5 $\pm$ 5	+6	5 $\pm$ 5	+7	—	+9	—	+6
Exit nozzle hydrogen coolant flow, lb/sec	.050	.0498	.050	.0502	—	.0503	—	.0530
<u>Monitoring Test Parameters</u>								
Model pressure drop, psi	34	20	61	32	—	53	—	21
Furnace helium atmosphere flow, lb/sec	.009	.0129	.013	.0159	—	.0195	—	.0112
Heater cavity helium inlet flow, lb/sec	.002	.0005	.002	.0004	—	.0004	—	.0004

TABLE B-2 (Cont'd)

COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING CONDITIONS
FOR THE 64DT-212 PHASE II AMBIENT TEMPERATURE HYDROGEN FLOW TESTS

<u>Operating Control Parameters</u>	<u>Specified*</u>	<u>Measured 3A</u>	<u>Specified*</u>	<u>Measured 3B</u>	<u>Specified*</u>	<u>Measured 3C</u>	<u>Specified*</u>	<u>Measured 3D</u>
Model exit, pressure, psig	436 $\pm$ 5	437	436 $\pm$ 5	436	436 $\pm$ 5	436	436 $\pm$ 5	436
Model hydrogen flow, lb/sec	.0070	.0073	.0090	.0092	.0110	.0110	.0130	.0131
Model inlet to atmosphere pressure differential, psi	5 $\pm$ 5	-.4	5 $\pm$ 5	-.4	5 $\pm$ 5	-.7	5 $\pm$ 5	-.4
Heater cavity to model pressure differential, psi	5 $\pm$ 5	-.7	5 $\pm$ 5	-.8	5 $\pm$ 5	-.9	5 $\pm$ 5	-1.0
Exit nozzle hydrogen coolant flow, lb/sec	.050	.0496	.050	.0499	.050	-.0498	.050	.0498
<u>Monitoring Test Parameters</u>								
Model pressure drop, psi	34	19	47	26	61	34	75	44
Furnace helium atmosphere flow, lb/sec	.009	.0122	.012	.0142	.013	.0156	.015	.0173
Heater cavity helium inlet flow, lb/sec	.002	.0004	.002	.0004	.002	.0004	.002	.004

* DRM 51338

TABLE B-2 (Cont'd.)

COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING CONDITIONS
FOR THE 64DT-212 PHASE II AMBIENT TEMPERATURE HYDROGEN FLOW TESTS

<u>Operating Control Parameters</u>	<u>Specified*</u>	<u>Measured 3E</u>	<u>Specified*</u>	<u>Measured 3F</u>	<u>Specified*</u>	<u>Measured 3G</u>	<u>Specified*</u>	<u>Measured 3H</u>
Model exit, pressure, psig	436 $\pm$ 5	436	—	436	436 $\pm$ 5	436	436 $\pm$ 5	436
Model hydrogen flow, lb/sec	.0150	.0150	—	.0170	.009	.0092	.011	.0112
Model inlet to atmosphere pressure differential, psi	5 $\pm$ 5	-.5	—	-.3	5 $\pm$ 5	-.5	5 $\pm$ 5	-.4
Heater cavity to model pressure differential, psi	5 $\pm$ 5	-1.1	—	-1.3	5 $\pm$ 5	-.9	5 $\pm$ 5	-1.0
Exit nozzle hydrogen coolant flow, lb/sec	.050	.0498	—	.0496	.050	.0499	.050	.0498
<u>Monitoring Test Parameters</u>								
Model pressure drop, psi	90	55	—	72	47	30	61	38
Furnace helium atmosphere flow, lb/sec	.017	.0189	—	.0205	.012	.0128	.013	.0150
Heater cavity helium inlet flow, lb/sec	.002	.0004	—	.0004	.002	.0004	.002	.0004

*DRM 51338

TABLE B-2 (Cont'd.)

COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING CONDITIONS
FOR THE 64DT-212 PHASE II AMBIENT TEMPERATURE HYDROGEN FLOW TESTS

<u>Operating Control Parameters</u>	<u>Specified*</u>	<u>Measured 3I</u>	<u>Specified*</u>	<u>Measured 3J</u>	<u>Specified*</u>	<u>Measured 3K</u>
Model exit, pressure, psig	436 $\pm$ 5	437	—	437	436 $\pm$ 5	436
Model hydrogen flow, lb/sec	.015	.0152	—	.0171	.011	.0109
Model inlet to atmosphere pressure differential, psi	5 $\pm$ 5	-.3	—	-.5	5 $\pm$ 5	-.5
Heater cavity to model pressure differential, psi	5 $\pm$ 5	-1.2	—	-1.4	5 $\pm$ 5	-.9
Exit nozzle hydrogen coolant flow, lb/sec	.050	.0500	—	.0503	.050	.0506
<u>Monitoring Test Parameters</u>						
Model pressure drop, psi	90	60	—	72	61	40
Furnace helium atmosphere flow, lb/sec	.017	.0189	—	.0202	.013	.0145
Heater cavity helium inlet flow, lb/sec	.002	.0004	—	.0004	.002	.0004

*DRM 51388

TABLE B-3

COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING
CONDITIONS FOR THE 64DT-212 INTERMEDIATE POWER TEST (PHASE III)

TEST NO. 64DT-212-III-HH₂

Operating Control Parameters	Specified*	Measured O ¹	Specified*	Measured	
				1A ¹	1B ¹
Model exit, pressure, psig	436 ± 5	432	436 ± 5	437	436
Model hydrogen flow, lb/sec	.0163	.0160	.0335	.0330	.0329
Model inlet to helium atmosphere pressure differential, psi	1 ± 1	+1	1 ± 1	+1	+1
Heater cavity to model exit pressure differential, psi	5 ± 5	+ .9	5 ± 5	+1.6	+1.6
Exit nozzle hydrogen coolant flow, lb/sec	.050	.050	.050	.0488	.0638
Element temp. sta. 38.0, °F	Ambient		-----	Ambient	-----
Element temp. sta. 26.0, °F	Ambient		-----	Ambient	-----
Filler Strip temp. sta. 36.0, °F	Ambient		-----	Ambient	-----
<u>Monitoring Test Parameters (Reference Only)</u>					
Model pressure drop, psi	53	20	223	80	85
ΔT (Element - F.S.) sta. 38.0, °F	Ambient		-----	Ambient	-----
ΔT (Element - F.S.) sta. 26.0, °F	Ambient		-----	Ambient	-----
Power Requirements; (KW):					
Net Model :	Ambient		-----	Ambient	-----
Total Heater :	Ambient		-----	Ambient	-----
Reflector temp. (max.), °F	Ambient		-----	Ambient	-----
Exhaust gas temp. (max.), °F	Ambient		-----	Ambient	-----
Furnace helium atmosphere flow, lb/sec	.015	.0078	.015	.0175	.0176
Heater cavity helium inlet flow, lb/sec	.001	.0004	.001	.0004	.0005
Current flow, amperes	Ambient		-----	Ambient	-----
Potential drop, volts	Ambient		-----	Ambient	-----

¹ Ambient temperature hydrogen flow points.

TABLE B-3 (Cont'd.)

COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING
CONDITIONS FOR THE 64DT-212 INTERMEDIATE POWER TEST (PHASE III)

TEST NO. 64DT-212-III-HH₂

<u>Operating Control Parameters</u>	<u>Specified*</u>	<u>Measured 1C</u>	<u>Measured 1D</u>	<u>Measured 2D</u>
Model exit, pressure psig	436 $\pm$ 5	429	432	432
Model hydrogen flow, lb/sec	.0335	.0332	.0333	.0333
Model inlet to helium atmosphere pressure differential, psi	1 $\pm$ 1	+1	+1	+1
Heater cavity to model exit pressure differential, psi	5 $\pm$ 5	+6.3	+7.9	+9.1
Exit nozzle hydrogen coolant flow, lb/sec	.070	.0636	.0634	.0649
Element temp. sta. 38.0, °F	1265	765	1235	790
Element temp. sta. 26.0, °F	940	{ 540 510	872	560
Filler Strip temp. sta. 36.0, °F	_____		852	570
		200	276	223
<u>Monitoring Test Parameters (Reference Only)</u>				
Model pressure drop, psi	168	98	103	95
ΔT (Element - F.S.) sta. 38.0, °F	_____	565	959	567
ΔT (Element - F.S.) sta. 26.0, °F	_____	389	665	401
Power Requirements; (KW):				
Net Model:	40	_____	_____	_____
Total Heater:	_____	43	63	43
Reflector temp. (max), °F	900	198	268	213
Mixed exhaust gas temp. (max), °F	200	161	217	
Furnace helium atmosphere flow, lb/sec	.015	.0176	.0183	.0175
Heater cavity helium inlet flow, lb/sec	.001	.0004	.0005	.0004
Current flow, amperes	1050	1148	1298	1082
Potential drop, volts	38	37.5	48.2	39.5

TABLE B-4

**COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING
CONDITIONS FOR THE 64DT-212 FULL POWER TEST (PHASE IV)**

TEST NO. 64DT-212-IV-HH ₂ AMBIENT FLOW POINTS				
<u>Operating Control Parameters</u>	<u>Specified</u>	<u>Measured</u> <u>O²</u>	<u>Specified</u>	<u>Measured</u> <u>AO²</u>
Model exit, pressure, psig	436 ± 5	435	436 ± 5	435
Model hydrogen flow, lb/sec	.0163	X ¹	.0282	X ¹
Model inlet to helium atmosphere pressure differential, psi	1 ± 1	+ .7	1 ± 1	+1.5
Heater cavity to model exit pressure differential, psi	5 ± 5	3	5 ± 5	+1.3
Exit nozzle hydrogen coolant flow, lb/sec	.050	X ¹	.050	X ¹
Element temp. sta. 38.0, °F	Ambient	—	Ambient	—
Element temp. sta. 26.0, °F	Ambient	—	Ambient	—
Filler Strip temp. sta. 36.0, °F	Ambient	—	Ambient	—
<u>Monitoring Test Parameters (Reference Only)</u>				
Model pressure drop, psi	53	20	92	70
ΔT (Element - F.S.) sta. 38.0, °F	—	—	—	—
ΔT (Element - F.S.) sta. 26.0, °F	—	—	—	—
Power Requirements; (KW):				
Net Model:	—	—	—	—
Total Heater:	—	—	—	—
Reflector temp. (max), °F	—	—	—	—
Exhaust gas temp. (max), °F	—	—	—	—
Furnace helium atmosphere flow, lb/sec	.015	X ¹	.015	X ¹
Heater cavity helium inlet flow, lb/sec	.001	X ¹	.001	X ¹
Current flow, ampheres	—	—	—	—
Potential drop, volts	—	—	—	—
Time to temp., minutes	—	—	—	—
Cumulative steady state test duration	—	—	—	—
Cumulative total test time, minutes	—	—	—	—
Cycle time, minutes	—	—	—	—

* Test was controlled at the best matched element temperatures to maintain corresponding filler strip temperatures in order to meet the test objective of wrapper O.D. temperature of 2500°R for a total nominal duration of 80 minutes.

X¹ Data reduction not completed.

Note: "A" designates 1st model heater.

² Ambient temperature hydrogen flow points.

TABLE B-4 (Cont'd)

COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING
CONDITIONS FOR THE 64DT-212 FULL POWER TEST

TEST NO. 64DT-212-IV-HH₂²

<u>Operating Control Parameters</u>	<u>Specified</u>	<u>Measured</u> <u>A1³</u>
Model exit, pressure, psig	436 ± 5	435
Model hydrogen flow, lb/sec	.0282	X ¹
Model inlet to helium atmosphere pressure differential, psi	1 ± 1	+1.5
Heater cavity to model exit pressure pressure differential, psi	5 ± 5	+1.3
Exit nozzle hydrogen coolant flow, lb/sec	.70	X ¹
Element temp. sta. 38.0, °F	3265	1604 ²
Element temp. sta. 26.0, °F	2640	1062 ²
Filler Strip temp. sta. 36.0, °F	—	330 ²
<u>Monitoring Test Parameters (Reference Only)</u>		
Model pressure drop, psi	53	70
ΔT (Element - F.S.) sta. 38.0, °F	—	—
ΔT (Element - F.S.) sta. 26.0, °F	—	—
Power Requirements; (KW):		
Net Model:	82	—
Total Heater:	—	70
Reflector temp. (max), °F	900	320
Exhaust gas temp. (max), °F	350	X ¹
Furnace helium atmosphere flow, lb/sec	.015	X ¹
Heater cavity helium inlet flow, lb/sec	.001	X ¹
Current flow, amperes	1440	1267
Potential drop, volts	57	55
Time to temp., minutes	1.0	—
Cumulative steady state test duration	80	0
Cumulative total test time, minutes	TBD	35.5
Cycle time, minutes	TBD	35.5

* Test was controlled at the best matched element temperatures to maintain corresponding filler strip temperatures in order to meet the test objective of wrapper O.D. temperature of 2500°R for a total nominal duration of 80 minutes.

X¹ Data reduction not completed.

² Maximum level reached.

³ Test terminated because of heater corrosion failure.

TABLE B -4 (Cont'd)

COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING
CONDITIONS FOR THE 64DT-212 FULL POWER TEST

TEST NO. 64DT-212-IV-HH₂²

<u>Operating Control Parameters</u>	<u>Specified</u>	<u>Measured BO¹</u>	<u>Specified</u>	<u>Measured BO¹</u>
Model exit, pressure, psig	436 $\pm$ 5	432	436 $\pm$ 5	431
Model hydrogen flow, lb/sec	.0163	.0157	.0315	.0316
Model inlet to helium atmosphere pressure differential, psi	1 $\pm$ 1	+1.5	1 $\pm$ 1	+1.6
Heater cavity to model inlet pressure differential, psi	5 $\pm$ 5	+3	5 $\pm$ 5	+3
Exit nozzle hydrogen coolant flow, lb/sec	.050	.0778	.050	.0763
Element temp. sta. 38.0, °F	Ambient	—	Ambient	—
Element temp. sta. 26.0, °F	Ambient	—	Ambient	—
Filler strip temp. sta. 36.0, °F	Ambient	—	Ambient	—
<u>Monitoring Test Parameters (Reference Only)</u>				
Model pressure drop, psi	20	21.3	75	77.5
ΔT (Element - F.S.) sta. 38.0, °F	—	—	—	—
ΔT (Element - F.S.) sta. 26.0, °F	—	—	—	—
Power Requirements; (KW):				
Net Model:	—	—	—	—
Total Heater:	—	—	—	—
Reflector temp. (max), °F	—	—	—	—
Exhaust gas temp. (max), °F	—	—	—	—
Furnace helium atmosphere flow, lb/sec	.020	.0147	.020	.0155
Heater cavity helium inlet flow, lb/sec	.0120 .0005	.0026	.0120 .0005	.0049
Current flow, amperes	—	—	—	—
Potential drop, volts	—	—	—	—
Time to temp., minutes	—	—	—	—
Cumulative steady state test duration, minutes	—	—	—	—
Cumulative total test time, minutes	—	—	—	—
Cycle time, minutes	—	—	—	—

* Test was controlled at the best matched element temperatures to maintain corresponding filler strip temperatures in order to meet the test objective of wrapper O.D. temperature of 2500°R for a total nominal duration of 80 minutes.

¹ Ambient temperature hydrogen test points.

² Test points BO2 and BO4 waived during test because of limited helium supply available.

TABLE B 4 4 (Cont'd)

COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING
CONDITIONS FOR THE 64DT-212 FULL POWER TESTTEST NO. 64DT-212-IV-HH²

Operating Control Parameters	Specified	Measured BO3 ¹	Specified	Measured BO5 ¹
Model exit, pressure, psig	436 ± 5	431	436 ± 5	431
Model hydrogen flow, lb/sec	.0315	.0319	.0315	.0319
Model inlet to helium atmosphere pressure differential, psi	1 ± 1	+1.6	1 ± 1	+1.6
Heater cavity to model inlet pressure differential, psi	-10 ± 2	-10.5	-15 ± 2	-14.5
Exit nozzle hydrogen coolant flow, lb/sec	.050	.0777	.050	.0778
Element temp. sta. 38.0, °F	Ambient	—	Ambient	—
Element temp. sta. 26.0, °F	Ambient	—	Ambient	—
Filler Strip temp. sta. 36.0, °F	Ambient	55	Ambient	55
<u>Monitoring Test Parameters (Reference Only)</u>				
Model pressure drop, psi	75	77.5	75	77.5
ΔT (Element - F.S.) sta. 38.0, °F	—	—	—	—
ΔT (Element - F.S.) sta. 26.0, °F	—	—	—	—
Power Requirements; (KW):				
Net Model:	—	—	—	—
Total Heater:	—	—	—	—
Reflector temp. (max), °F	—	—	—	—
Exhaust gas temp. (max), °F	—	—	—	—
Furnace helium atmosphere flow, lb/sec	.020	.0157	.020	.0158
Heater cavity helium inlet flow, lb/sec	$\frac{.0120}{.0005}$	.0045	$\frac{.0120}{.0005}$	.0040
Current flow, amperes	—	—	—	—
Potential drop, volts	—	—	—	—
Time to temp., minutes	—	—	—	—
Cumulative steady state test duration, minutes	—	—	—	—
Cumulative total test time, minutes	—	—	—	—
Cycle time, minutes	—	—	—	—

* Test was controlled at the best matched element temperatures to maintain corresponding filler strip temperatures in order to meet the test objective of wrapper O.D. temperature of 2500°R for nominal duration of 80 minutes.

¹ Ambient temperature hydrogen flow points.

² Test points BO2 and BO4 waived during test because of limited helium supply available.

TABLE B -4 (Cont'd)

**COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING
CONDITIONS FOR THE 64DT-212 FULL POWER TEST**

TEST NO. 64DT-212-IV-HH₂³

<u>Operating Control Parameters</u>	<u>Specified*</u>	<u>Measured BO6¹</u>	<u>Specified*</u>	<u>Measured B1</u>
Model exit, pressure, psig	436 ± 5	432	436 ± 5	435
Model hydrogen flow, lb/sec	.0315	.0310	.0315	.0308
Model inlet to helium atmosphere pressure differential, psi	1 ± 1	+1.5	1 ± 1	+1.1
Heater cavity to model inlet pressure differential, psi	5 ± 5	+2.0	5 ± 5	+2
Exit nozzle hydrogen coolant flow, lb/sec	0.100	.0830	.0100	.0723
Element temp. sta. 38.0, °F	Ambient	—	3390 ± 180	3240
Element temp. sta. 26.0, °F	Ambient	—	2200	2165
Filler Strip temp. sta. 36.0, °F	Ambient	—	670	471
<u>Monitoring Test Parameters (Reference Only)</u>				
Model pressure drop, psi	75	76	170	78.8
ΔT (Element - F.S.) sta. 38.0, °F	—	—	2720	2769
ΔT (Element - F.S.) sta. 26.0, °F	—	—	1770	1833
Power Requirements; (KW):				
Net Model:	—	—	60	—
Total Heater:	—	—	100	140
Reflector temp. (max), °F	—	—	900	465
Exhaust gas temp. (max), °F	—	—	300	420
Furnace helium atmosphere flow, lb/sec	.020	.0157	.020	.0157
Heater cavity helium inlet flow, lb/sec	<u>.0120</u> <u>.0005</u>	.0049	<u>.0120</u> <u>.0005</u>	.0023
Current flow, amperes	—	—	1600	1890
Potential drop, volts	—	—	63	74
Time to temp., minutes	—	—	8 - 12	48
Cumulative steady state test duration	—	—	80	2
Cumulative total test time, minutes	—	—	TBD	88
Cycle time, minutes	—	—	TBD	52.5

* Test was controlled at the best matched element temperatures to maintain corresponding filler strip temperatures in order to meet the test objective of wrapper O. D. temperature of 2500°R for a total nominal duration of 80 minutes.

¹ Ambient temperature hydrogen flow point.

² Test terminated because of heater sublimation failure.

TABLE B -4 (Cont'd)

COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING
CONDITIONS FOR THE 64DT-212 FULL POWER TEST
TEST NO. 64DT-212-IVHH₂ (PRETEST)

<u>Operating Control Parameters</u>	<u>Specified*</u>	<u>Measured CO₁</u>	<u>Specified*</u>	<u>Measured CO₁</u>
Model exit, pressure, psig	436 ₊	428	436 ₊	438
Model hydrogen flow, lb/sec.	.0163	.0162	.0315	.0325
Model inlet to helium atmosphere pressure differential, psi	1 ₊ 1	+ .4	1 ₊ 1	+ 1.2
Heater cavity to model inlet pressure differential, psi	5 ₊ 5	+ 2	5 ₊ 5	+ 2
Exit nozzle hydrogen coolant flow, lb/sec.	.050	.0581	.100	.0750
Element temp. sta. 38.0, °F	Ambient	_____	Ambient	_____
Element temp. sta. 26.0, °F	Ambient	_____	Ambient	_____
Filler Strip temp. sta. 36.0, °F	Ambient	65	Ambient	70
<u>Monitoring Test Parameters (Reference Only)</u>				
Model pressure drop, psi	20	27	75	108
T (Element - F. S.) sta. 38.0, °F	_____	_____	_____	_____
T (Element - F. S.) sta. 26.0, °F	_____	_____	_____	_____
Power Requirements; (KW):				
Net Model:	_____	_____	_____	_____
Total Heater:	_____	_____	_____	_____
Reflector temp. (max.), °F	_____	_____	_____	_____
Exhaust gas temp. (max.) °F	_____	_____	_____	_____
Furnace helium atmosphere flow, lb/sec	.020	.0082	.020	.0169
Heater cavity helium inlet flow, lb/sec	.0012 .0005	.0014	.0012 .0005	.0025
Current flow, amperes	_____	_____	_____	_____
Potential drop, volts	_____	_____	_____	_____
Time to temp., minutes	_____	_____	_____	_____
Cumulative steady state test duration, minutes	_____	_____	_____	_____
Cumulative total test time, min.	_____	_____	_____	_____
Cycle time, minutes	_____	_____	_____	_____

* Test was controlled at the best matched element temperatures to maintain corresponding filler strip temperatures in order to meet the test objective of wrapper O. D. temperature of 2500°R for a total nominal duration of 80 minutes.

1 Ambient temperature hydrogen flow points. Note: "C" designates 3rd model heater

TABLE B -4 (Cont'd)
COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING
CONDITIONS FOR THE 64DT-212 FULL POWER TEST
TEST NO. 64DT-212-IV-HH₂

<u>Operating Control Parameters</u>	<u>Specified*</u>	<u>Measured C2</u>	<u>Specified*</u> C3	<u>Measured C4</u>
Model exit, pressure, psig	436 $\pm$ 5	446	438	427
Model hydrogen flow, lb/sec	.0315	.0314	.0321	.0313
Model inlet to helium atmosphere pressure differential, psi	1 $\pm$ 1	+ 1.2	+ 1.5	- .3
Heater cavity to model inlet pressure differential, psi	5 $\pm$ 5	+ 2.5	+ 2.0	+ 7.5
Exit nozzle hydrogen coolant flow, lb/sec.	0.10	.0755	.0742	.0709
Element temp. sta. 38.0, °F	3390 $\pm$ 180	3440	3460	3360
Element temp. sta. 26.0, °F	2200 $\pm$	2832	2710	2460
		2665	2500	2220
Filler Strip temp. sta. 36.0, °F	670	671	660	620
Filler Strip temp. sta. 26.0, °F	430	545	477	453
<u>Monitoring Test Parameters (Reference Only)</u>				
Model pressure drop, psi	170	147	166	210
ΔT (Element - F. S.) sta. 38.0, °F	2720	2769	2806	2740
ΔT (Element - F. S.) sta. 26.0, °F	1770	2287	2233	2007
Power Requirements; (KW) :				
Net Model:	66			
Total Heater:	120	91	88	92
Reflector temp. (max.), °F	900	615	610	565
Exhaust gas temp. (max.), °F	300	274	260	274
Furnace helium atmosphere flow, lb/sec	.020	.0166	.0180	.0222
Heater cavity helium inlet flow, lb/sec	.0012 .0005	.0010	.0010	.0011
Current flow, amperes	1860	.575	.593	.593
Potential drop, volts	65	57.5	55.5	57.5
Time to temp., minutes	8 - 12	39	8	8
Cumulative steady state test				
duration at 3390 $\pm$ 180 °F, min.	80	16	28	41
Cumulative total test time, min.	TBD	141	164	186
Cycle time, minutes	TBD	53	23	22

* Test was controlled at the best matched element temperatures to maintain corresponding filler strip temperatures in order to meet the test objective of wrapper O.D. temperature of 2500 °R for a total nominal duration of 80 minutes.

TABLE B -4 (Cont'd)

COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING
CONDITIONS FOR THE 64DT-212 FULL POWER TEST
TEST NO: 64DT-212-IV-HH₂

Operating Control Parameters	Measured C5	Measured C6	Measured C7	Measured C8
Model exit, pressure, psig	438	427	438	438
Model hydrogen flow, lb/sec.	.0311	.0311	.0315	.0313
Model inlet to helium atmosphere pressure differential, psi	+ 1.2	+ 0.2	+0.3	+0.3
Heater cavity to model inlet pressure differential, psi	+ 6	+ 7.5	+ 7	+7
Exit nozzle hydrogen coolant flow, lb/sec.	.0716	.0672	.0677	.0676
Element temp. sta. 38.0, °F	3540	3520	3410	3320
Element temp. sta. 26.0, °F	2510 2260	2670 2320	2550 2240	2460 2180
Filler Strip Temp. sta. 36.0, °F	589	571	541	545
Filler Strip Temp. sta. 26.0, °F	462	462	439	431
<u>Monitoring Test Parameters (Reference Only)</u>				
Model pressure drop, psi	200	190	192	176
T(Element-F.S.) sta. 38.0, °F	2951	2949	2869	2775
T(Element-F.S.) sta. 26.0, °F	2048	2208	2111	2029
Power Requirements; (KW) :				
Net Model				
Total Heater	90	96	95	91
Reflector temp. (max.), °F	555	520	500	500
Exhaust gas temp. (max.) °F	274	283	283	278
Furnace helium atmosphere flow, lb/sec	.0204	.0202	.0198	.0192
Heater cavity helium inlet flow,	.0011	.0011	.0012	.0011
Current flow, amperes	1575	1617	1610	1575
Potential drop, volts	57	59	59	58
Time to temp., minutes	8	8	7	9
Cumulative steady state test duration at 3390± 180°F, minutes	54	69	83	98
Cumulative total test time, min.	208	231	254	276
Cycle time, minutes	22	23	23	22

*Test was controlled at the best matched element temperatures to maintain corresponding filler strip temperatures in order to meet the test objective of wrapper O.D. temperature of 2500°R for a total nominal duration of 80 minutes.

TABLE B -4 (Cont'd)

COMPARISON BETWEEN SPECIFIED AND MEASURED OPERATING
CONDITIONS FOR THE 64DT-212 FULL POWER TEST

TEST NO. 64DT-212-IV-HH₂ (POST TEST)

<u>Operating Control Parameters</u>	<u>Specified</u>	<u>Measured CO₂¹</u>	<u>Specified</u>	<u>Measured CO₃¹</u>
Model exit, pressure, psig	436 ± 5	435	436 ± 5	432
Model hydrogen flow, lb/sec	.0315		.0163	
Model inlet to helium atmosphere pressure differential, psi	1 ± 1	-0.3	1 ± 1	+1.7
Heater cavity to model inlet pressure differential, psi	5 ± 5	+2	5 ± 5	+6.3
Exit nozzle hydrogen coolant flow, lb/sec	.010	.0676	.050	.0670
Element temp. sta. 38.0, °F	Ambient	—	Ambient	—
Element temp. sta. 26.0, °F	Ambient	—	Ambient	—
Filler Strip temp. sta. 36.0, °F	Ambient	56	Ambient	56
<u>Monitoring Test Parameters (Reference Only)</u>				
Model pressure drop, psi	75	100	20	35
ΔT (Element - F.S.) sta. 38.0, °F	—	—	—	—
ΔT (Element - F.S.) sta. 26.0, °F	—	—	—	—
Power Requirements; (KW):				
Net Model:	—	—	—	—
Total Heater:	—	—	—	—
Reflector temp. (max), °F	—	—	—	—
Exhaust gas temp. (max), °F	—	—	—	—
Furnace helium atmosphere flow, lb/sec	.020	.0169	.020	.0074
Heater cavity helium inlet flow, lb/sec	.0012 .0005	.0054	.0012 .0005	.0035
Current flow, amperes	—	—	—	—
Potential drop, volts	—	—	—	—
Time to temp., minutes	—	—	—	—
Cumulative steady state test duration, minutes	—	—	—	—
Cumulative total test time, minutes	—	—	—	—
Cycle time, minutes	—	—	—	—

* Test was controlled at the best matched element temperatures to maintain corresponding filler strip temperatures in order to meet the test objective of wrapper O.D. temperature of 2500°R for a total nominal duration of 80 minutes.

¹ Ambient temperature hydrogen flow points.

TITLE CORE PERIPHERY MODEL TEST 64DT-212 (THERMALIZED PYROFOIL WRAPPER CORROSION TEST)	
DOCUMENT NO. WANL - TME 2735		DATE September, 1970	
ABSTRACTThe cyclic corrosion resistance capability of an R-1 type periphery featuring a multiple layer Z-liner pyrofoil wrapper was experimentally measured. The results obtained from this investigation indicate that a full length wrapper of this type has a low probability of achieving the ten hour lifetime R-1 reactor requirement. Good agreement was realized between the measured test data and the predicted thermal hydraulic conditions. The corrosion damage to the pyrofoil wrapper was more than predicted. Examination of the wrapper O.D. disclosed that no measurable corrosion damage occurred at temperatures below approximately 2400°R. (CRD)			
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