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Westinghouse
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SNPO-C

WANL-TME-2738
SEPTEMBER 1970

DATA ITEM T-119

PERIPHERY AXIAL LOAD
TEST (U)

MASTER

FINAL REPORT

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DATA ITEM T-119

PERIPHERY AXIAL LOAD TEST (U)

FINAL REPORT

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

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ABSTRACT

(U) This report presents an evaluation of structural load tests of primary and secondary support load paths of periphery filler strips and axial support hanger assemblies for the R-1, 10 hour reactor.

(CRD) A total of 62 axial load tests are evaluated. The tests represent variations in configuration and material for six different failure modes. Strengths measured to resist these failure modes include:

1. Axial support strength of the filler strip body and forward end.
2. Axial support strength of the filler strip aft end circumferential keys.
3. Axial support strength of the filler strip aft end insulation retention ledge.
4. Axial support strength of filler strip hanger assemblies for the following

configurations:

- (a) A double ball joint forward end hanger support design (939J806, Core Periphery for R-1)
- (b) A forward end eccentric support design for groups of filler strips on a common hanger (939J287, Core Periphery for R-1).
5. Pull out strength of the double ball joint hanger assembly forward end threaded connection to the support plate.
6. Cyclic load and pull out strength of the hanger assembly ball socket interface.

(CRD) The significant conclusion of the test data and the analysis is that the 939J806 filler strip and hanger assembly design will sustain reactor axial loads if the peripheral fuel to insulation interface coefficient of friction is below .20.

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1.0 INTRODUCTION

1.1 TEST IDENTIFICATION

1.1.1 Type of Report

This is a complete Final Report.

1.1.2 Applicable Scope of Test Document

The applicable Scope of Test Document Number is 64DE-073-3, Scope of Test for Periphery Axial Load Test.

1.1.3 Functional Category of Test

This is a Development Test.

1.1.4 Contractor

The Westinghouse Astronuclear Laboratory (WANL/14683), under Subcontract NP-1, CY-70, is the contractor.

1.1.5 Test Facility, Location and Dates of Test

These tests were performed at the Westinghouse Astronuclear Engineering Mechanics Laboratory, Building 8; February 15, 1969 through July 17, 1970.

1.2 PURPOSE OF TESTS

The objective of these tests was to determine the axial load capability of filler strips in the R-1 reference design. The areas of specific interest were:

- a) The ultimate strength of the filler strip primary and secondary axial support arrangements.
- b) The ultimate strength of the filler strip periphery insulation support arrangement.
- c) The ultimate strength of the filler strip hanger assembly.
- d) The pull-out strength of the filler strip hanger assembly.

- e) The ultimate strength of the filler strip hanger assembly ball-socket interface and its integrity when subject to cyclic loading.
- d) The sliding capability between the ball and socket surfaces in a vacuum environment at vacuum levels of 10^{-8} torr. *

* This series of tests was not completed by direction of the SNPO-C monitor (WANL memo NPE-HNM-1258, dated 5-25-70, Minutes of Monthly Status Review Meeting). Based on C.O. 70-8 which called for vacuum levels of 10^{-9} torr, the monitor felt 10^{-8} torr testing was not meaningful. Equipment limitations in the Engineering Mechanics Laboratory prevented running the vacuum level to 10^{-9} torr at this time.

2.0 REFERENCES AND ASSUMPTIONS

2.1 REFERENCES

2.1.1 Specifications

EC-677564 - Part I Performance/Design and Qualification Requirements for Core
Periphery Forming a Part of CP-677555 Nuclear Subsystem

WANL PDS 30020-3 - Purchasing Department Specification for Graphitite G

WANL PDS 30038-6 - Purchasing Department Specification for Inconel 718

2.1.2 Data Item Description

Form 9 - Data Item Description, T-119, dated April 2, 1969

2.1.3 Scope of Test Document

64DE-073 - Periphery Axial Load Test for R-1

Revision 0 - January 3, 1968

Revision 1 - September 16, 1968

Revision 2 - May 28, 1969

Revision 3 - April 2, 1970

2.1.4 Data Release Memorandum

51621A - Test Plan Document - October 28, 1969

51629 - R-1 Periphery Axial Load Tests - July 2, 1969

51636 - Filler Strip Forward End Support Hanger Assembly Axial Test
Results - October 3, 1969

51637 - Ultimate Strength Test Results for the Filler Strip Secondary Axial
Support Arrangement - October 28, 1969

51639 - Ultimate Strength Test Results of the Filler Strip (711J556B) Tile
Retention Ledge - October 28, 1969

- 52553 - Ultimate Strength Test Results for a Modified Filler Strip Secondary Axial Support Arrangement - June 30, 1970
- 52558 - Ultimate Strength Test Results for a Modified Filler Strip Primary Axial Support Arrangement - July 17, 1970
- 52982 - Filler Strip Forward End Support Hanger Assembly Cyclic and Ultimate Axial Load Tests - August 10, 1970
- 52993 - Core Periphery Axial Load Test Input to T-119 Document - September 2, 1970
- 52069 - Filler Strip Ball Joint Hanger, Resistance to Pullout of Link - September 30, 1969
- 51140 - Filler Strip Stress Analysis - March 4, 1969

2.1.5 Drawings

- WT701766 - R-1 Periphery Axial Load Tests
- 100E097 - Filler Strips Support, R-1 Periphery Axial Load Test
- 100E098 - Group H-4 Assembly, R-1 Periphery Axial Load Test
- 100E712 - Group H-2 Assembly, R-1 Periphery Axial Load Test
- 100E738 - Group H-7 Assembly, R-1 Periphery Axial Load Test
- 100E075 - Filler Strip Secondary Axial Load Test
- 388D813 - Specimen Test Filler Strip and Hanger
- 101E073 - Filler Strip Primary Axial Load Test
- 939J806 - Core Periphery for R-1
- 939J287 - Core Periphery for R-1
- 711J556 - Axial Load Test Filler Strips
- 711J559 - Axial Load Test Filler Strips

2.2 ASSUMPTIONS

The primary assumptions made in these test series are:

That useful data could be obtained by performing the filler strip ultimate strength tests in a small test fixture simulating only a small portion of a core periphery.

That useful test data could be obtained by performing both filler strip and hanger assembly tests at room temperature.

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3.0 DESCRIPTION OF THE TEST ARTICLE

3.1 FILLER STRIP TEST SPECIMENS

Test specimens for the filler strip primary and secondary axial support tests consisted of approximately eight inch long forward and aft end sections, respectively, of selected filler strips of the 939J806 periphery design and of selected filler strip groups of the 939J287 periphery design (see Figures 3-1 through 3-5). The selected filler strip specimens (Drawing No. 711J559 and 388D813) of the 939J806 periphery design were those of the maximum and minimum cross-sectional areas and moments of inertia about a centroidal axis. These specimens were fabricated from both Graphitite G and Carb-I-Tex Grade 700 materials. The selected filler strip groups of the 939J287 periphery design included filler strips (Drawing No. 711J556) of maximum, minimum and intermediate cross-sectional areas and moments of inertia about a centroidal axis. These specimens were fabricated from Graphitite G only.

Test specimens for the periphery insulation support test consisted of aft end sections of the same filler strips of the 939J287 periphery design as described above.

In all, filler strip tests loads were applied to specimens by means of an adhesive bond. No modifications were made to the filler strip cross-sectional geometry. A detailed identification of the test specimens appears in Appendix I.

3.2 FILLER STRIP HANGER ASSEMBLY TEST SPECIMENS

The filler strip hanger assembly (Drawing No. 100E517) of the 939J806 periphery design was subjected to an ultimate strength test unmodified. However, to perform cyclic and ultimate strength tests on the ball-socket interface, a fixture adapter thread was machined on a reduced aft retainer pin diameter (Drawing No. 388D813). The hanger assembly specimen is shown in Figure 3-6.

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Figure 3-1. Typical Filler Strip Forward End Specimens (939J287 Periphery) Before Testing

Figure 3-2. Typical Filler Strip Forward End Specimens
(939J806 Periphery) Before Testing

Figure 3-3. Typical Filler Strip Aft End Specimens
(939J287 Periphery) Broken Before Test

Figure 3-4. The Secondary Axial Support Arrangement
(939J287 Periphery) - Lateral Support Side View

Figure 3-5. The Secondary Axial Support Arrangement
(939J806 Periphery) - Lateral Support Side View

4.0 SUMMARY OF TESTS (U)

4.1 ULTIMATE STRENGTH TEST OF THE FILLER STRIP PRIMARY AXIAL SUPPORT ARRANGEMENT (U)

4.1.1 Narrative (U)

(U) Two filler strip primary axial support designs were investigated. These designs are shown in the layout drawings 939J806 and 939J287 and schematically in Figure 4-1. The laboratory test procedure consisted of applying axial tension loads colinear with the centroidal axes of the filler strip specimens to determine the ultimate strength and mode of failure in the forward region (see Figure 4-2). Filler strip specimens of the 939J806 periphery were tested individually while filler strip specimens of the 939J287 periphery were tested in groups.

4.1.2 Test Conditions (U)

(CRD) Test specimens were assembled in a fixture simulating the core axial and lateral support of the filler strips over approximately the forward eight inches of the referenced periphery designs. The forward three rows of the lateral support system were simulated using one spring with the NRX-A6 spring rate of 262 lb/in for each row. These springs applied to the filler strips a pressure of 10 psi, representing the mechanical bundling pressure of the forward end seal segments. Approximately twenty-seven layers of pyrofoil sheets represented the 155 mil thick core wrapper. The laboratory setups and loading schemes appear in Figures 4-3, 4-4, and 4-5.

(U) The laboratory test setup for the grouped filler strip design (Figure 3-1, 939J287) also simulated the reactor loading distribution among the filler strips of a group. The filler strips were loaded simultaneously, but individually by separate hydraulic cylinders. The ratios between the applied loads were controlled by a hydraulic load maintainer to closely approximate those determined from expected nominal reactor loads.

(U) Filler strip strains were measured at the location indicated in Figure 3-1.

Filler Strip Forward End Design 711J556B
 Periphery Design 939J287

Filler Strip Forward End Design 711J559A
 Periphery Design 939J806

Figure 4-1. Filler Strip Primary Axial Support Arrangements Tested

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Figure 4-2. Loading Schematics for the Primary Axial Load Tests

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Figure 4-3. Test Fixturing for the Filler Strip (939J287
Periphery) Forward End Test

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Figure 4-4. Filler Strip Specimens (939J287 Periphery)
Assembled in the Test Fixture

Figure 4-5. Fixture Setup for the Filler Strip Primary Axial Support Test (939J806 Periphery)

4.1.3 Test Results for the Primary Axial Support (U)

4.1.3.1 Recorded Data (U)

(U) Continuous time recordings of applied test loads and filler strip displacements and strains were made. The loads at failure and the filler strip strains near or at failure were recorded in Tables 4-1 and 4-2. Original data records are available in Engineering Mechanics storage. Photographs of failed test specimens appear as Figures 4-6 through 4-8.

4.1.3.2 Discussion of Data (U)

(CRD) The tabulated data show that test failure loads exceeded the corresponding expected nominal reactor loads for all filler strips of both periphery designs tested. The ratio of the test failure load to the expected nominal reactor load can be compared for each of filler strips 1 and 2 (Graphitite G only) of the two different periphery designs tested. This ratio is more than twice as great for the filler strips of the 939J806 periphery as compared to those of the 939J287 periphery. This result can be attributed to the more desirable design features of the former periphery design; most significantly, individual support of each filler strip, eliminating moments in a plane tangent to the core circumference.

(CRD) Filler strip specimens of the 939J806 periphery failed at the structural interface between the hanger assembly and the filler strip. Filler strip specimens of the 939J287 periphery design failed in the minimum cross section at the transition point. Detailed descriptions of the failure modes appear in Tables 4-1 and 4-2.

4.2 ULTIMATE STRENGTH TEST OF THE FILLER STRIP SECONDARY AXIAL SUPPORT ARRANGEMENT (U)

4.2.1 Narrative (U)

(U) Two filler strip secondary axial support designs were tested. These designs are shown on layout drawings 939J806 and 939J287 and schematically in Figure 4-9.

(CRD) The laboratory test procedure consisted of applying axial loads to adjacent pairs of filler strip specimens. One filler strip was loaded against its neighbor - the load being transferred by the interlocking circumferential key and slot. The neighboring filler strip reacting the

TABLE 4-1
 ULTIMATE STRENGTH TEST RESULTS FOR THE FILLER STRIP PRIMARY AXIAL
 SUPPORT ARRANGEMENT OF THE 939 J806 PERIPHERY DESIGN

Filler Strip No. Material (711J559)	Test Run	Expected**	Test Failure Load (lbs)	Filler Strip Surface Strains Near Failure* (μ in/in.)					Failure Description
		Nominal Reactor Load(lbs)		1	2	3	4	5	
Filler Strip 1 - Graphitite G	1	91	275	1550	450	50	4000	925	Combined tensile and shear failure. Multiple fracture surfaces in the vicinity of the key-filler strip load interface (Figure 4-6).
	2		205	650	400	50	1200	850	
	3		225	625	500	50	1300	850	
	4		225	525	425	25	1450	975	
Avg=233									
Filler Strip 1 - Carb-i-tex 700	5	91	135	325	125	125	900	500	Shear failure along the Carb-i-tex laminations emanating from the key-filler strip load interface (Figure 4-7).
	6		125	175	75	0	500	450	
	7		160	375	50	775	800	500	
Avg=140									
Filler Strip 12 - Graphitite G	1	171	670	750	1250	500	1000	2200	Tensile fracture normal to the filler strip centroidal axis at the key- filler strip load interface (Figure 4-6).
	2		1075	875	2300	425	950	2375	
	3		1140	550	1150	375	400	2650	
	4		1075	475	850	525	1150	2550	
Avg=990									
Filler Strip 12 - Carb-i-tex 700	5	171	850	575	550	325	550	1125	Shear failure along the Carb-i-tex laminations emanating from the key- filler strip load interface (Figure 4-7).
	6		895	325	650	350	650	1050	
	7		890	500	600	350	625	1275	
Avg=878									

*These measurements do not include the steep strain gradients or strain peaks occurring immediately prior to or at failure.

** Nominal axial reactor loads are determined with the insulation wrapper retention ledge at the filler strip aft end unloaded and a coefficient of friction of .10 between the filler strip and wrapper.

TABLE 4-2

ULTIMATE STRENGTH TEST RESULTS FOR THE FILLER STRIP PRIMARY AXIAL
SUPPORT ARRANGEMENT OF THE 939J287 PERIPHERY DESIGN

Filler Strip Group	Filler Strip Number (711J556)	Minimum Cross Sectional Area (in. ²)	Nominal ** Reactor Load (lbs.)	Test Failure Load (lbs.)	Strains at Failure (μ in./in.) Location (See Figure 1):				Failure Description
					1	2	3	4	
H2	6	.426	165	495	No Strain Data Taken				Typical failure *
	7	.426	165	378					Typical failure
H4	11	.200	104	120	350	675	1310	280	Typical failure with slight curvature (Figure 4-8).
	12	.537	171	505	500	920	1400	865	Typical failure
	13	.495	174	515	715	2860	1870	925	Typical failure
H7	20	.210	112	230	700	770	1340	730	Typical failure plus Key Slot Damage
	21	.422	156	720	565	630	535	685	Typical failure
	22	.210	112	260	600	770	2070	730	Typical failure plus Key Slot Damage
H10	29	.427	154	615	660	895	1460	745	Typical failure
	1	.107	91	122	225	435	1580	440	Typical failure
	2	.197	125	168	20	310	1280	465	Typical failure

*Tensile fracture normal to the applied load occurring in the minimum cross section at the transition point (radius) of the filler strip specimen.

**Nominal axial reactor loads are determined with the insulation wrapper retention ledge at the filler strip aft end unloaded and a coefficient of friction of .10 between the filler strip and wrapper.

Figure 4-6. Failures in Graphitite G Test Specimens
(939J806 Periphery)

Figure 4-7. Shear Failures in Carb-I-Tex Grade 700 Test Specimens (939J806 Periphery)

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Figure 4-8. Core Side View of a Typically Failed Filler Strip Specimen Group (939J287 Periphery)

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Aft End of Filler Strip Design 711J556B;
Periphery Design 939J287

Aft End of Filler Strip Design 711J557A;
Periphery Design 939J806

Figure 4-9. R-1 Filler Strip Aft End Designs Under Test Evaluation

applied load was suspended from the test fixture so that its aft section was loaded in combined tension and bending (Figure 4-10).

(U) The ultimate strength and mode of failure in the aft region were thus determined. One pair of filler strips, numbers 1 and 29 of the 939J806 periphery design, was tested. One to four pairs of filler strips were tested for each group of the 939J287 periphery design investigated in the Primary Axial Support Test.

4.2.2 Test Conditions (U)

(CRD) Filler strip specimen pairs were assembled in a fixture simulating the boundary conditions over approximately the aft eight inches of a filler strip pair. Approximately 26 layers of pyrofoil sheets were used to represent a core wrapper. Radiused graphite blocks provided a rigid restraint toward the reflector side of the filler strip specimens. In addition, strips of pyrofoil along side of the test specimens were used to create the aft end seven mil gap between filler strips. It was possible, therefore, for the test specimens to experience a combined tension and bending load. The laboratory setups are shown in Figures 4-11 through 4-14.

4.2.3 Test Results (U)

4.2.3.1 Recorded Data (U)

(U) The data format consisted of load versus displacement plots for each filler strip specimen tested from the 939J806 periphery design. Continuous time recordings of the applied loads were made for filler strip specimens of the 939J287 periphery design.

(U) Displacements of the loaded filler strips were made by a dial gage. Test loads at failure were recorded in Tables 4-3 and 4-4. Photographs of failed specimens appear in Figures 4-15 through 4-20.

4.2.3.2 Discussion of Data (U)

(CRD) Test failure loads for Graphitite G specimens of the 939J806 periphery exceeded the expected nominal reactor loads. The test failure loads for the Carb-I-Tex Grade 700 specimens fell below the expected nominal reactor loads in the same loading configurations (Figures 3-2 and 3-3).

Figure 4-10. Load Configurations for the Filler Strip Secondary Support Test

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Figure 4-11. Laboratory Setup for the Filler Strip (939J287
Periphery) Secondary Axial Support Tests

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Figure 4-12. Filler Strip Fixture Internals for the Secondary Axial Support Tests

Figure 4-13. Filler Strip (939J806 Periphery) Fixture Setup Before Test with Lateral Support Bracket Aside

Figure 4-14. Filler Strip (939J807 Periphery) Fixture Setup Before Test with Front Bracket Removed

TABLE 4-3
 ULTIMATE STRENGTH TEST RESULTS FOR THE FILLER STRIP
 SECONDARY AXIAL SUPPORT ARRANGEMENT*

<u>Test Run</u>	<u>Load Configuration</u>	<u>Filler Strip Material</u>	<u>Expected Nominal Reactor Load (lbs.)</u>	<u>Test Failure Load (lbs.)</u>	<u>Failure Description</u>
1 2	FS 1 Key against FS 29 Slot	Graphitite G	91	200 200	Key shear failure in FS 1; Slot damage on FS 29 (Figure 4-15).
3 4		Carb-i-tex Grade 700	91	80 82	Key shear failure along the Carb-i-tex lamination in FS 1 (Figure 4-17).
1 2	FS 29 Slot against FS 1 Key	Graphitite G	154	205 216	Combined tension and bending failure in FS 1 (Figure 4-16).
3		Carb-i-tex Grade 700	154	126	Key shear failure along Carb-i-tex laminations in FS 1 (Figure 4-17).

*939J806 Periphery Design

TABLE 4-4
 ULTIMATE STRENGTH TEST RESULTS FOR THE FILLER STRIP SECONDARY
 AXIAL SUPPORT ARRANGEMENT
 (939J287 PERIPHERY DESIGN)

Filler Strip (FS) Grp.	Test Run No.	Load Configuration	Expected Nominal Reactor Load (lbs.)	Test Failure Load (lbs.)	Failure Description
H2	1	FS 7 Key against FS 6 Slot	165	208	Typical Failure* in FS 6
	2	FS 6 Slot against FS 7 Key	165	176	Typical Failure in FS 7
H4	1	FS 12 Key against FS 11 Slot	171	150	Typical Failure in FS 11
	2	FS 11 Slot against FS 12 Key	104	175	Typical Failure in FS 12
	3	FS 13 Key against FS 12 Slot	174	230	Typical Failure in FS 12
	4	FS 12 Slot against FS 13 Key	171	215	Typical Failure in FS 13 (Figure 4-19)
H7	1	FS 21 Key against FS 20 Slot	156	158	Typical Failure in FS 20 (Figure 4-18)
	2	FS 20 Slot against FS 21 Key	112	169	Typical Failure in FS 21
	3	FS 22 Key against FS 21 Slot	112	166	Key sheared off FS 22 Slot edge chipped on FS 21
H10	1	FS 1 Key against FS 29 Slot	91	136	Key sheared off FS 1 (Figure 4-20)
	2	FS 29 Slot against FS 1 Keyway	154	99	Typical Failure in FS 1

*A failure surface approximately normal to the centroidal axis, but, sloping downward from the fillet of the loaded edge of the key or slot close to the fillet.

Figure 4-15. Key Shear Failure of Filler Strip 1;
Load Configuration A; Graphitite G
Specimens, (939J306 Periphery)

Figure 4-16. Typical Tension and Bending Failure of
Filler Strip 1; Load Configuration B;
Graphitite G Specimens, (939J806 Periphery)

Figure 4-17. Key Shear Failure of Filler Strip 1; Load Configurations A and B; Carb-I-Tex Grade 700 Specimens; (939J306 Periphery)

Figure 4-18. Core Side View of a Typical Failure (939J287 Periphery) Through the Slot

Figure 4-19. Core Side View of a Typical Failure (939J287
Periphery) Over the Key

Figure 4-20. The Exceptional Key Shear Failure
(939J287 Periphery)

(CRD) In all except two cases, the test failure loads for the Graphitite G specimens of the 939J287 periphery were found to exceed the corresponding expected design loads. Both exceptional cases occurred when filler strip specimens of the smallest cross-sectional areas were loaded by specimens of the largest cross-sectional areas; in particular, test runs 1 and 2 for filler strip groups H4 and H10, respectively.

(CRD) The ratio of the test failure loads to the expected nominal reactor load can be compared for each of the loading configurations of filler strips 1 and 29 (Graphitite G only) from the two different periphery designs tested. This ratio is one and a half times as great for load configuration A (see Figure 4-10) and twice as great for load configuration B for filler strips of the 939J806 periphery design as compared to those of the 939J287 periphery design. This result can be attributed to two design features of the former periphery design; namely, a) the sloped key edges which reduce stress concentration and transfer load more effectively to the filler strip main cross section, and b) greater shear area between key and filler strip.

(CRD) For a given load configuration and filler strip material, the mode of failure was consistent from one test run to the second for filler strip specimens of the 939J806 periphery design. Furthermore, tests on Carb-I-Tex specimens resulted in a sheared key from filler strip 1 in both load configurations. The shear surface occurred parallel to the Carb-I-Tex laminations close to the key root.

(CRD) Test failures on the graphite specimens were different for each load configuration. Filler strip 1 exhibited a shear key failure when loaded against filler strip 29. The shear surfaces extended into the filler strips. Filler strip 29 exhibited some damage at the load reaction point. When filler strip 1 was loaded by filler strip 29, it failed in a combined tension and bending mode. The failure surface was nearly normal to the filler strip axis emanating from the key fillet.

(CRD) A typical failure occurred in the loaded filler strip (see Figure 3-2) in all except two cases for filler strip specimens of the 939J287 periphery design. The typical fracture surface was approximately normal to the filler strip centroidal axis, sloping downward from

the fillet of the loaded edge of a key or slot in the neighborhood of the fillet. In each exceptional case, the circumferential key sheared on a relatively thin filler strip specimen when loaded against a relatively thick specimen. Figure 4-20 displays the exceptional key shear failure.

4.3 ULTIMATE STRENGTH TEST OF THE PERIPHERY INSULATION SUPPORT ARRANGEMENT (U)

4.3.1 Narrative (U)

(CRD) The periphery insulation is axially supported between the fuel elements and filler strips by a ledge at the aft end of the filler strips for both 939J806 and 939J287 periphery designs. Axial loads were applied to this aft retention ledge of test specimens comprising filler strip groups H4 and H10 of the 939J287 periphery design to determine the ultimate load capability and mode of failure in the aft region. Each filler strip of a group was sequentially loaded to failure. A photograph of the loading condition appears in Figure 4-21.

4.3.2 Test Conditions (U)

(CRD) The tests were setup in a fixture simulating the core lateral support of a filler strip group over approximately its aft eight inches (see Figures 4-21 and 4-22). Loading bars 155 mils thick represented the periphery insulation and transferred loads to the entire ledge of filler strip specimens. Radiused graphite blocks provided a rigid restraint toward the reflector side of the filler strip specimens. But, radial outward bending of the filler strips was possible about the lower edge of the last seal block. The filler strip specimens were suspended from the fixture to resist the applied loads in tension.

4.3.3 Test Results (U)

4.3.3.1 Recorded Data (U)

(U) Time continuous recordings of the test loads were made. Filler strip displacements at the point of load application were measured with a dial gage. The loads at failure were recorded in Table 4-5. Original data records are available. Photographs of test specimen failures appear in Figures 4-23 and 4-24.

Figure 4-21. Internals of the Tile Retention Ledge Test Fixture

Figure 4-22. Tile Retention Ledge Test Fixture and Specimens After Test

TABLE 4-5
ULTIMATE STRENGTH TEST OF THE PERIPHERY
INSULATION SUPPORT ARRANGEMENT

<u>Filler Strip Group</u>	<u>Filler Strip Number</u>	<u>Min. Cross Section Area (in.²)</u>	<u>Failure Load (lbs.)</u>	<u>Deflection At Failure (Mils)</u>	<u>Failure Description</u>
H-4	11	.190	111	24	Typical*
	12	.537	252	14	Typical
	13	.495	156	10	Typical
H-10	29	.427	224	14	Typical
	1	.107	100	15	Typical
	2	.197	196	17	Typical

*Failure surface through ledge fillet at an inclination to the filler strip axis.

Figure 4-23. Closeup of Filler Strip Group H-4 Failures

Figure 4-24. Closeup View of Filler Strip Group H-10 Failures

4.3.3.2 Discussion of Data (U)

(CRD) Ultimate test loads ranged from 100 lbs. to 252 lbs. for test specimens of minimum and maximum cross-sectional areas, respectively.

(CRD) In all cases, the filler strip failures were typical; the failure surface occurred through the entire length of fillet of the tile retention ledge at an inclination to the filler strip centroidal axes.

4.4 ULTIMATE STRENGTH TEST OF THE FILLER STRIP HANGER ASSEMBLY (U)

4.4.1 Narrative (U)

(CRD) A test was performed to determine the ultimate strength and mode of failure of the filler strip hanger assembly (Drawing No. 100E517) of the 939J806 periphery design. This hanger assembly has two spherical joints and normally supports one filler strip. Additional neighboring filler strips may be supported when the primary axial support of these neighboring filler strips has failed.

4.4.2 Test Conditions (U)

(CRD) The test was set up in a tensile testing machine, as shown in Figure 4-25 and performed at normal ambient conditions. The upper retainer bolt of the hanger assembly was threaded into an aluminum alloy (2024) adapter, thereby simulating its interface with the aluminum alloy (2219)* support plate. The hanger retainer pin was inserted into a special steel adapter and locked into place with an Inconel key (Part No. 388D424 H11). This set-up represented the structural interface between the hanger assembly and a filler strip.

4.4.3 Test Results (U)

4.4.3.1 Recorded Data (U)

(U) A plot of load versus displacement was recorded for both the initial load and the reload. A photograph of the failed test specimen appears in Figure 4-26.

*6061 AL Alloy material subsequently replaced 2219 AL Alloy as the reactor support plate material after testing was complete. Since ultimate and yield strengths for both alloys are comparable, the threaded connection is still considered to be the weakest link.

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Figure 4-25. Filler Strip Hanger Assembly
(100E517) Axial Load Test Setup

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Figure 4-26. Filler Strip Hanger Assembly Specimen 100E517-G01

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4.4.3.2 Discussion of Data (U)

(CRD) The test specimen failed initially at 2,540 lbs. under an elongation rate of 0.020 inch per minute. A ductile failure occurred in one segment of the minimum section of the retainer pin, as shown in Figure 3-2. Immediately after the initial failure, the second segment still held a load of 1,164 lbs. The unfailed segment was then reloaded from zero pounds to failure at 1,278 lbs.

(CRD) The maximum hanger design load is 174 lbs. as noted in DRM 51945. The experimental safety factor is, therefore, 14.6.

4.5 PULL-OUT STRENGTH TEST OF THE FILLER STRIP HANGER ASSEMBLY THREADED CONNECTION (U)

4.5.1 Narrative (U)

(U) A test was performed to determine the static pull-out strength of the hanger Inconel 718 assembly retainer bolt from the aluminum alloy 2219* core support plate.

4.5.2 Test Conditions (U)

(U) The test was set up in a tensile testing machine, as shown in Figures 4-27 and 4-28 and performed at normal ambient conditions. Three Inconel 718 test specimens were machined to the exact specifications and tolerances of drawing 100E517, Hanger Assembly. Two specimens were pulled from the broad face of an Al 2219* plate, and one from its edge to determine the effect of the grain of the plate.

4.5.3 Test Results (U)

4.5.3.1 Recorded Data (U)

(U) The test failure loads were noted from the tensile machine dial indicator and were recorded in Table 4-6. Photographs of the failed specimens appear in Figure 4-29 and 4-30.

4.5.3.2 Discussion of Data (U)

(CRD) All failures apparently began after the first thread in the Inconel 718 specimens at loads of 5,800 lbs. and greater. The test results appear in Table 4-1 and Figures 3-5 and 3-6.

*6061 Al Alloy material subsequently replaced 2219 Al Alloy as the reactor support plate material after testing was complete. Since ultimate and yield strengths for both alloys are comparable, the threaded connection is still considered to be the weakest link.

Figure 4-27. Thread Pull-Out Strength Test Setup

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Figure 4-28. Hanger Assembly Thread Pull-Out Strength Test Setup

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TABLE 4-6
FILLER STRIP HANGER ASSEMBLY THREAD
PULLOUT-STRENGTH TEST

<u>Specimen</u>	<u>Test Direction; Relative to Plate Grain</u>	<u>Failure Load - F (lbs)</u>	<u>Nominal Thread Failure Stress-F/A (ksi)</u>
A	Normal	5860	175.8
B	Normal	5870	176.1
C	Along	5800	174.0

A = Minor Diameter Area = .0333 Inch²

Test Elongation Rate = .020 Inch/Minute

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Figure 4-29. Failed Inconel 718 Specimens A and B and an Intact Specimen C

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Figure 4-30. Failed Inconel 718 Specimen C

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(U) The minimum ultimate tensile strength of Inconel 718 specified in PDS 30038-6 is 170 ksi. A typical average ultimate strength is 185 ksi. The test results indicate, therefore, a threaded connection design of near maximum effectiveness in developing the strength capability of the Inconel 718 stud.

4.6 CYCLIC LOAD AND ULTIMATE STRENGTH TESTS OF THE FILLER STRIP HANGER ASSEMBLY BALL-SOCKET INTERFACE (U)

4.6.1 Narrative (U)

(U) The tests were performed to determine the integrity of the ball-socket load interface of the filler strip forward end support hanger assembly (Part Numbers 100E517 G01, G02 and G03) when subjected to cyclic tension loading and to determine its ultimate strength.

(U) Four sinusoidal load conditions, as listed in Table 4-7 were applied to four hanger assembly test specimens, as described in Table 4-8.

4.6.2 Test Conditions (U)

(U) Axial loads were transmitted to the ball-socket interface by means of the thread on the upper retainer bolt and a thread machined on the aft retainer pin. A schematic of the test configuration appears in Figure 4-31. The tests were set up in a tensile testing machine (Figure 4-32) and performed at room temperature.

4.6.3 Test Results (U)

4.6.3.1 Recorded Data (U)

(U) Loads and displacements were plotted on a time continuous recorder throughout the cyclic load test. Test loads were plotted versus displacement on an orthogonal axis recorder for the ultimate strength test. Cyclic test results and ultimate failure loads were recorded in Table 4-8. Photographs of failed test specimens appear in Figures 4-33 and 4-34.

4.6.3.2 Discussion of Data (U)

(CRD) No significant variations which would indicate a loss of integrity to the hanger

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TABLE 4-7
FILLER STRIP HANGER ASSEMBLY CYCLIC LOAD TEST CONDITIONS

<u>Test Condition</u>	<u>Load Function</u>	<u>Load Range</u>		<u>Cyclic Rate</u> (cpm)	<u>Total Cycles</u>
		<u>Min</u>	<u>Max</u> (lbs)		
1	Sinusoidal	5	205	2	180
2	Sinusoidal	10	410	2	180
3	Sinusoidal	5	205	30	180
4	Sinusoidal	10	410	30	180

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TABLE 4-8
FILLER STRIP HANGER ASSEMBLY AXIAL LOAD TEST RESULTS

<u>Test Specimen</u>	<u>Tests Performed</u>	<u>Results</u>
1) 388D813H09 A86830	A) 2 cpm/205 lbs. B) 2 cpm/410 lbs. C) Ultimate Axial Load	A) No apparent damage B) damage C) Specimen failed along upper socket welds at 4160 lbs. (Figure 4)
2) 388D813H09 A86831	A) 30 cpm/205 lbs. B) 30 cpm/410 lbs.	A) No apparent damage Micrometer measurements and observation of sectioned specimens.
3) 388D813H10 A86834	A) 2 cpm/205 lbs.	A) No apparent damage Micrometer measurements only
4) 388D813H11 A86835	A) 2 cpm/410 lbs.	A) No apparent damage Micrometer measurements and observation of sectioned specimens.
5) 388D813H11 A86836	A) Ultimate Axial Load	A) Specimen loaded to 4060 lbs. when fixture adapter failed. Specimen reloaded and failed along lower socket weld at 4300 lbs. (Figure 5).
6) 388D813H10 A86833	A) Ultimate Axial Load	A) Specimen failed at 5370 lbs. at the fixture thread. No apparent damage to ball-socket interfaces.

Figure 4-31. Test Load Schematic for the Hanger Assembly Axial Load Tests

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Figure 4-32. Hanger Assembly Cyclic and Ultimate Axial Load Test Setup

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Figure 4-33. Failed and Intact Ultimate Axial Load Test Specimens (388D813H09)

Figure 4-34. Failed Ultimate Axial Load Test Specimen (388D813H11)

assembly specimens were noted from the time records of the cyclic load test. Also, there was no apparent external damage to any of the test specimens (see Table 4-7). Micrometer measurements of the upper and lower socket dimensions taken before and after testing agreed within a few tenths of a mil. Two specimens were sectioned to provide a closer examination of deformation at the ball and socket loading interfaces. No deformation was apparent on either specimen.

(CRD) When subjected to the ultimate strength test, two specimens failed along the weld lines of the sockets at loads greater than 4000 lbs. Both of these specimens were subjected to previous loads as noted in Table 4-8. A previously unloaded specimen displayed a failure in the fixture adapter threads on the aft retainer pin at 5370 lbs. No apparent damage had occurred to the ball-socket load interface. The maximum hanger design load is 174 lbs. as noted in DRM 52178. The experimental safety factor for the ball-socket load interface is, therefore, greater than 20.

5.0 ANALYSIS (U)

5.1 FILLER STRIP PRIMARY AXIAL SUPPORT (U)

5.1.1 Analytical Model (U)

(CRD) The two main links in the filler strip primary support system are the forward section of the filler strip and the hanger assembly. Structural analyses of the filler strip link were completed for the 939J287 and the 939J806 designs, referred to hereafter as the eccentric hanger and the ball joint hanger designs, respectively. Stresses were calculated at the area of minimum cross-section of the strips based on the geometrical properties and loads listed in Table 5-1. The loads listed in this table are based on an axial pressure drop of 162 psid, an average bundling pressure of 8 psi, and friction coefficients of .10 and .20 on the inboard and outboard faces of the filler strips respectively. Each of the 29 filler strips of the ball joint hanger design was analyzed as a beam on an elastic foundation with an axial load. The eccentric hanger filler strip was treated as an eccentrically loaded bar. Mechanical stresses at room temperature only were evaluated in each case.

(CRD) The results of the analysis are documented in DRM 51140 with the maximum tensile stresses being about 2150 psi for the eccentric hanger design and 853 psi for the ball joint hanger design. The Graphitite G mean ultimate tensile strength and its corresponding standard deviation as reported in DRM 51225A are 4,400 psi and 500 psi respectively. The allowable stress would therefore be $.8 (4400 - 2.3 \times 500) = 2600$ psi. The calculated stresses in the filler strips for both designs are less than this allowable stress. However, the ball joint hanger is preferable because it induces no bending stresses in the filler strips and therefore shows a significantly higher margin.

(CRD) The force required to pull the ball joint hanger out of socket in the 939J806 Hanger Assembly was calculated using a finite element computer code (FEATS). As a lower bound, pullout was assumed to occur when the area of contact between the ball and socket becomes plastic. The analysis is documented in DRM 52069, with the calculated pullout load being 2920 pounds. This pullout is considerably higher than the calculated maximum hanger load of approximately 170 pounds.

TABLE 5-1

FILLER STRIP GEOMETRICAL PROPERTIES AND LOADS

Filler Strip No.	Min Cross Sect. A_i in ²	$I_{x \times c, q_i}$ 10 ⁻³ in ⁴	WIDTH W_i (in)	$P_{\Delta P}$ lb _f	P_f lb _f *	P_{TOT} lb _f *	$\frac{P_{TOT}}{MIN A}$ psi
1	.106876	.45235	.5896	17.4	73.8	91.2	853.
2	.196686	1.57637	.7470	31.8	93.2	125.0	636.
3	.286737	4.11893	.7563	46.5	94.4	140.9	491.
4	.355825	7.33458	.7635	57.6	95.2	152.8	429.
5	.402596	10.2732	.7683	65.4	95.8	161.2	400.
6	.426164	12.0116	.7707	69.0	96.2	165.2	388.
7	.426151	12.00888	.7708	69.0	96.2	165.2	388.
8	.402581	10.27213	.7683	65.4	95.8	161.2	400.
9	.355892	7.33915	.7636	57.6	95.2	152.8	429.
10	.286787	4.12046	.7563	46.5	94.4	140.9	491.
11	.189705	2.03204	.5863	30.8	73.2	104.0	548.
12	.536920	32.40021	.6746	87.0	84.2	171.2	319.
13	.494587	19.76418	.7526	80.1	94.0	174.1	352.
14	.345764	7.46808	.7370	56.0	92.0	148.0	428.
15	.193743	1.78071	.6106	31.4	76.4	107.8	556.
16	.482555	23.20721	.6959	78.2	87.	165.2	342.
17	.335738	7.55502	.7106	54.5	88.8	143.3	427.
18	.153427	.82235	.6185	24.8	77.2	102.0	665.
19	.389697	13.02588	.6999	63.1	87.4	150.5	386.
20	.209755	2.01255	.6242	34.0	78.0	112.0	534.
21	.421616	15.9737	.7032	68.2	88.0	156.2	370.
22	.325284	9.83707	.6242	52.6	78.0	130.6	401.
23	.389697	13.02588	.6999	63.1	87.6	150.7	387.
24	.153427	.82235	.6185	24.8	77.4	102.2	666.
25	.335738	7.55502	.7106	54.5	89.0	143.5	427.
26	.482555	23.20721	.6959	78.1	87.0	165.1	342.
27	.193743	1.78071	.6106	31.4	76.4	107.8	556.
28	.345764	7.46808	.7370	56.0	92.2	148.2	429.
29	.426794	16.99709	.6768	69.2	84.4	153.6	360.

* Nominal axial reactor loads are determined with the insulation wrapper retention ledge at the filler strip aft end unloaded and a coefficient of friction of .10 between the filler strip and wrapper.

(CRD) The hanger thread pullout load was calculated assuming an equal load in each thread. The resulting calculated pullout load is 6900 pounds, which is several orders of magnitude higher than the predicted maximum hanger load. These results indicate that the filler strips are by far the weakest link in the primary support system.

5.1.2 Comparison of Predictions and Results (U)

(U) Table 5 -2 summarizes the primary support test failure loads, the expected nominal reactor loads, and the calculated stresses in the filler strips resulting from application of the failure loads for the eccentric and ball joint hanger designs. As predicted in Section 5.1.5, the failure loads for both designs are larger than the expected reactor loads, with the ball joint hanger design showing a significantly higher margin.

(CRD) It should be noted that the failures for the eccentric hanger design occurred at the minimum cross-section where the bending stresses are the largest. However, because the ball joint hanger design eliminates bending stresses in the filler, failures occur in the vicinity of the key-filler strip load interface due to stress concentrations around the slot in the filler strip. The calculated stresses at failure listed in Table 5-2 for the ball joint hanger design are therefore not the maximum stresses in the filler strip.

(CRD) As anticipated, the failure loads in the other primary axial support links are much higher than for the weak link. The average failure loads for the ball/socket and thread pullout are approximately 4100 and 5800 pounds respectively. These test loads are comparable to the corresponding calculated failure loads of 2920 pounds and 6900 pounds. The fact that the test failure loads in the ball joint were higher than the calculated failure loads indicates that the assumption that failures occur when the ball/socket area of contact becomes plastic is conservative. The calculated thread pullout loads were slightly nonconservative due to the fact that each thread was assumed to carry an equal load.

(CRD) It should also be noted that no damage was observed in the ball joint cyclic load test. The analytical results indicate that the ball joint stresses would be in the elastic range for loads under 2920 pounds, and no damage would therefore be expected at the cyclic test maximum load levels of 205 and 410 pounds.

TABLE 5-2

COMPARISON OF ULTIMATE STRENGTH TEST RESULTS FOR THE FILLER STRIP
 PRIMARY AXIAL SUPPORT ARRANGEMENTS OF THE
 939J806 AND 838J287 PERIPHERY DESIGNS

Filler Strip Number and Material	Nominal Reactor * Load (lbs.)	Average Test Failure Load (lbs.)		Calculated Stress at Failure (psi)	
		Ball Joint Hanger (939J806 Design)	Eccentric Hanger (939J287 Design)	Ball Joint Hanger (939J806 Design)	Eccentric Hanger (939J287 Design)
Filler Strip 1 Graphitite G	91	223	122	2100	1800
Filler Strip 12 Graphitite G	171	990	505	1830	4800

(*) Nominal axial reactor loads are determined with the insulation wrapper retention ledge at the filler strip aft end unloaded and a coefficient of friction of .10 between the filler strip and wrapper.

(U) The small test sample size for each filler strip geometry tested does not permit statistical treatment of the test data for reliability calculations. However, based on analysis and test results, it can be concluded that the ball joint hanger primary support design is significantly better than the eccentric hanger design, and that it is structurally adequate under the load requirements imposed by a periphery design which incorporates a pyrofoil wrapper.

(CRD) The primary support axial load requirements would be increased for alternate periphery designs with wrappers which produce higher friction coefficients at the wrapper filler strip interface. The axial loads for filler strips 1 and 29 are shown in Figure 5-1 as a function of friction coefficient at the filler strip/wrapper interface. These loads are based on the current design maximum axial pressure drop of 178 psi and the assumption that the filler strip aft end retention ledge is not loaded.

(CRD) The test failure load for filler strip No. 1, which is assumed to be the most critical filler strip, would correspond to a friction coefficient at the wrapper/filler strip interface of .62 if the retention ledge is assumed to be unloaded. The case where the retention ledge is loaded will be treated in Section 5.2.

5.2 RETENTION LEDGE (U)

5.2.1 Analytical Model (U)

(CRD) The retention ledge on the aft end of the filler strips is intended to prevent dislodged pieces of the insulation from being ejected through the nozzle. The performance of this function requires no significant load carrying capability in the ledge. However, it is conceivable that cumulative cyclic motion of the wrapper could close in the initial .5 in. of clearance between the aft end of the wrapper and the ledge. Under this condition the ledge could be loaded through the wrapper by friction forces resulting from relative motion between the fuel and the filler strips and by the axial pressure drop on the wrapper.

(CRD) Assuming that the wrapper has been displaced aft .5 in., the load on the average filler strip ledge due to pressure drop over the wrapper is 32 pounds. If the friction forces on the wrapper due to relative motion between the fuel and the filler strips are assumed to act in the aft direction over the entire length of the wrapper, the additional ledge load would be

Figure 5-1. Primary Support Axial Loads
As A Function of Wrapper/Filler Strip Friction Coefficient
With Retention Ledge Not Loaded

(CRD) approximately 114 pounds. This load is based on a bundling pressure of 30 psi, an average filler strip width, and friction coefficient of .10 (assuming slipping between first two layers of pyrofoil), and brings the total ledge load to 146 pounds. However, it is important to note that the ledge can be loaded by relative motion between the fuel and the filler strips only if the motion of the fuel is aft with respect to the retention ledge at a time after the wrapper has ratcheted aft and contacted the ledge. The relative motion between the filler strip retention ledge and the aft end of the fuel varies considerably over the reactor lifetime. The tie tube growth (aft motion of aft end of fuel) varies from .271 inch at Start of Life when the SSCV flow is at a minimum to .032 in. at End of Life when the SSCV flow is a maximum. The maximum aft motion of the retention ledge is .114 and is nearly constant over the Reactor lifetime (all displacements based on RATS 341 Computer Run). Therefore the SOL motion of the aft end of the fuel is .157 aft with respect to the retention ledge. The EOL motion of the fuel is forward with respect to the ledge tending to relieve the ledge loads. It should also be noted that the thermal growth of the fuel is .45 in. forward from the displaced position of the tie rod/pedestal. Therefore, even for the SOL conditions, there is a point of no motion between the fuel and the filler strips, forward of which the friction forces on the pyrofoil would act in the forward direction, tending to relieve ledge loads. It can be seen that if the point of no relative motion is at midlength, the net friction force on the wrapper would be zero, since the friction forces acting in the forward direction balance those acting in the aft direction. Assuming, conservatively, that the friction forces on the wrapper act in an aft direction over 3/4 of its length, the expected ledge load on an average filler strip would be approximately 89 pounds. The corresponding ledge load on the smallest filler strip (No. 1) is 64 pounds.

(CRD) Stresses in the filler strip retention ledge were calculated using a finite element computer program (FEATS). An average filler strip was modeled, with a 100 pound load applied to the ledge. The resulting stresses are shown in Figure 5-2 with the maximum tensile stress being about 1900 psi (stress extrapolated to boundary of ledge fillet). This stress is less than the Graphitite G allowable stress (80% of the 2,3 σ minimum ultimate tensile stress) of 2600 psi.

Figure 5-2. Retention Ledge Stresses - 100 Lb. Load

5.2.2 Comparison of Predictions and Results (U)

(CRD) Failure loads for the Retention Ledge ultimate strength test ranged from 100 pounds for the smallest filler strip to 252 pounds for the largest strip, with the failure loads being above the reactor loads associated with pyrofoil insulation in all cases.

(CRD) The failure load for an average filler strip is approximately 200 pounds. The calculated stress corresponding to this load is 3800 psi, showing good correlation with the mean ultimate tensile strength of 4200 psi.

(U) It can be concluded that the retention ledge appears to be structurally adequate based on the current understanding of relative motions of the periphery components.

(CRD) However, again it should be noted that the calculated loads are based on pyrofoil insulation and could be significantly increased for periphery designs with corrosion resistant insulation, due to higher friction coefficients at the fuel/insulation interface. Ledge loads as a function of friction coefficient at the fuel/insulation interface are shown in Figure 5-3 for filler strips 1 and 12. These loads are based on the assumptions that the insulation is in contact with the ledge and that the friction forces on the insulation act in the aft direction over 3/4 of its length. An average bundling pressure of 30 psi at the fuel/insulation interface and an axial pressure drop of 178 psi were assumed.

(CRD) The 100 pound test failure load for filler strip number 1 corresponds to a friction coefficient at the fuel/insulation interface of .20, indicating that the retention ledge would be a critical problem area in a periphery design with corrosion resistant insulation.

(CRD) It should be noted that the primary support load mechanisms are also altered if the insulation loads the filler strip retention ledge. The calculated primary support loads in Section 5.1 were based on the assumption that at some time in the reactor life, the friction forces on the inboard face of a filler strip (filler strip/wrapper interface) and those on the outboard face (filler strip/lateral support seal interface) would both act in the aft direction. However, when the ledge is being loaded, the friction forces at the filler strip/LSS seal interface must act in the forward direction. This is due to the fact that the fuel has to be in a hot or expanded condition

Figure 5-3. Retention Ledge Load As A Function of Fuel/Insulation Friction Coefficient

to load the ledge. The radial growth of the hot fuel causes the inner lateral support seal to slip over the outer seal in the forward direction, thereby producing friction forces in the forward direction on the filler strip, which is being pulled aft by the ledge loads.

(CRD) Part of the filler strip axial load is therefore carried by friction forces on the seal. The primary support load for this case would then be the difference between the load on the ledge and the friction force on the outboard face of the filler strip. This load is shown in Figure 5-4 as a function of the friction coefficient at the fuel/insulation interface assuming filler strip/seal interface bundling pressure of 8 psi and friction coefficients of 0.2. It can be seen that for the pyrofoil insulation ($\mu=.1$) the primary support load is less when the ledge load is carried by friction and the primary support load is therefore zero. The primary support failure load of 223 pounds for filler strip No. 1 would result from a friction coefficient of .58 at the fuel/insulation interface.

5.3 SECONDARY SUPPORT (U)

5.3.1 Analytical Model (U)

(CRD) In the event of failure of a filler strip primary support, the failed filler strip is supported by its neighbors through interlocking circumferential keys and slots. The key/slot secondary support must, therefore, carry the same design loads as the corresponding primary support structure.

(CRD) Stresses were calculated in the secondary support slot and key of a typical filler strip using a finite element computer code (FEATS). The stresses resulting from application of the required load (based on pyrofoil insulation) of 150 pounds are shown in Figure 5-5. The maximum stress is approximately 3200 psi and the design, therefore, shows no margin. Minor modifications to strengthen the interlock are, therefore, indicated by the analysis.

5.3.2 Comparison of Predictions and Results (U)

(CRD) The results of the ultimate strength tests of the 939J806 design secondary axial support arrangement are listed in Table 4-3. The average filler load for filler strip 1 key against filler strip 29 slot and for filler strip 29 slot against filler strip 1 key are 200 pounds and 210 pounds, respectively. The analytical model would predict a maximum stress of about 4260 at these load

Figure 5-4. Primary Axial Support Loads As A Function of Fuel/Insulation Friction Coefficient And With Retention Ledge Loaded

levels, showing good correlation with the mean ultimate tensile strength of 4400 psi.

(CRD) The corresponding nominal reactor loads for the pyrofoil design are 91 pounds and 154 pounds. These test results indicate that the analytical results of Section 5.3.1 are somewhat conservative. The friction coefficient at the fuel tile interface (assuming the ledge is loaded) which would produce the test failure load is .53.

(CRD) Results of the ultimate strength tests of the secondary support arrangement of the eccentric hanger design are also documented in Table 4-4. This design again showed up relatively poor, with failure loads lower than the expected nominal reactor load in two of the load configurations tested.

5.4 DISCUSSION AND DESIGN SIGNIFICANCE (U)

(CRD) Based on the analyses and test results discussed above, the 939J806 design filler strip, primary support structure, and secondary support structure appear to be structurally adequate. The requirement of extending the reactor life to ten hours made several major design changes in the core periphery necessary. Among these changes was the replacement of the pyrofoil insulation with corrosion resistant insulation. This change resulted in significantly higher friction coefficients at several of the interfaces in the periphery, thereby making the filler strip axial load requirements much more severe. Changes in the design of the filler strip axial support features have been made to accommodate these higher loads. The above conclusions on the pyrofoil design are, therefore, not applicable in all cases to the corrosion resistant design but the data has served as an aid in the design development of the periphery for the 10 hour reactor. The primary axial load capability of the filler strip body and forward end is still greater than the anticipated applied loads in two current periphery designs shown by drawings 940J442 and 940J444.

(CRD) It should be noted that filler strips made of Carb-I-Tex material were tested and showed relatively low test failure loads because of the orientation of the material laminations with respect to the applied loads. The laminations were oriented such that the key in the forward end primary support and the interlocking key-slot secondary support loads produced interlaminar shear stresses in the material. The Carb-I-Tex fillers, therefore, showed shear failures in the primary support key

Figure 5-5. Filler Strip Secondary Support Interlock Stresses - 150 Lb. Load

area and in the aft end secondary interlocking key/slot at relatively low load levels. However, these test results do not reflect the best utilization of the strength characteristics of the Carb-I-Tex material. The material's superior unidirectional strength could be used to greater advantage within the existing axial support designs by more effective orientation of laminations with respect to support interfaces.

6.0 CONCLUSIONS (U)

(U) In drawing conclusions from the test results and analysis, it should be pointed out that the test scope requirements were originally intended to provide data to confirm the adequacy of the periphery axial support design for the superseded 75 minute reactor. When design changes were implemented for the core periphery as part of the requirements directed to extending the reactor life to 10 hours all the tests were felt to be of significant importance in guiding the R-1, 10 hour periphery design which also used the basic cold filler strip.

(CRD) The strengths measured and analyzed to resist six different failure modes of two filler strip and hanger assembly designs are evaluated in terms of their capability to sustain axial reactor loads. These include:

1. Axial support strength of the filler strip body at the forward end primary support interface.
2. Axial support strength of the secondary support circumferential keys at the filler strip aft end.
3. Axial support strength of the filler strip aft end insulation retention ledge.
4. Axial support strength of the primary support filler strip hanger assemblies.
5. Pull out strength of the double ball joint hanger assembly forward end threaded connection to the support plate.
6. Cyclic load and pull out strength of the hanger assembly ball socket interface.

(U) Based on the test results and analysis, the 939J806 filler strips and ball joint hanger assemblies are preferable to the 939J287 eccentric hanger design because the elimination of moments in the ball joint hanger design was a significant improvement over the eccentric hanger design.

(CRD) The minimum test failure load for the ball joint hanger assembly was 2540 pounds. It was produced in the slotted hanger pin that engages the filler strip. This indicates that the test failure strength of the hanger pin would accommodate a ratio of axial sliding force to interface contact force of 5.6 at the insulation to peripheral fuel interface.

(CRD) The failure strengths of the ball joint and threads of the hanger assembly, would accommodate higher ratios of axial sliding force to interface contact force at the insulation to peripheral fuel interface.

(U) The Inconel 718 material of the 939J806 ball joint hanger design was subsequently eliminated from reactor application because of its susceptibility to hydrogen embrittlement. The data, however, can be ratioed to the ultimate and yield strength properties of A-286 material which is acceptable for use in NERVA reactors. Reduction of structural margin of the hanger from changing the Inconel 718 material to A-286 would be less than 20% for failures governed by ultimate strength and less than 33% for failures governed by yielding. This reduction does not affect the above conclusions significantly.

(CRD) The test failure load of the Graphitite G filler strip forward end body at the primary support interface was 223 pounds for filler strip no. 1 (the weakest strip) in the 939J806 design, and would accommodate a coefficient of friction of .58 at the insulation to peripheral fuel interface.

(CRD) The weakest link is the insulation retention ledge at the filler strip aft end. The minimum test failure load for the filler strip no. 1 ledge was 100 pounds. This would accommodate a coefficient of friction of .20 at the insulation to peripheral fuel interface.

(CRD) The test failure load of the Graphitite G secondary support circumferential key at the aft end of filler strip No. 1 was 200 pounds. This would accommodate a coefficient of friction of .53 at the insulation to peripheral fuel interface.

(CRD) The significant conclusion of the test data and analysis is that the 939J806 combined filler strips and hanger assembly design will sustain reactor axial loads if the coefficient of friction at the insulation to peripheral fuel interface is below .20. Table 6-1 shows the comparison of this result to the EC-Specification requirement.

(CRD) Use of corrosion resistant insulation in the 10 hour periphery design is expected to result in significantly higher coefficients of friction at the insulation to peripheral fuel interface. The correspondingly more severe ledge loads at the filler strip aft end would have to be alleviated by some means. Two possible means under consideration are:

1. Provide filler strip aft end tie rod support.
2. Permit the aft end insulation retention ledge to follow the axial movement of the insulation by providing axial motion flexibility in the filler strip support.

TABLE 6-1

SUMMARY - COMPARISON OF EC SPECIFICATION
REQUIREMENTS AND TEST RESULTS

EC-677564 Core Periphery Paragraph Requirements dated July 16, 1970	Comment
<p>3.3.1.12 <u>Axial Loads</u></p> <p>The core periphery shall utilize filler strips to accomplish geometry transition. The filler strips shall be capable of withstanding the axial loads imposed by combination of friction and relative motion between the insulation and the lateral support hardware of the reflector assembly and the core pressure drop.</p>	<p>Based on the current understanding of the core periphery load environment which includes an axial pressure drop of 178 psid and a maximum pneumatic and mechanical bundling pressure of 30 psi, the filler strips and ball joint hanger assemblies of the 939J806 periphery design will sustain reactor axial loads if the coefficient of friction at the periphery fuel and wrapper insulation interface is below .20.</p>

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APPENDIX A

IDENTIFICATION OF TEST SPECIMENS FOR TEST SCOPE 64DE-073,
REVISIONS 0, 1, 2, AND 3.

TABLE A-1
FILLER STRIP PRIMARY AXIAL SUPPORT TEST SPECIMEN IDENTIFICATION
(939J806 PERIPHERY)

Filler Strip Test Specimen Identification

<u>Filler Strip No/ Material</u>	<u>Test Run</u>	<u>Part Drawing Numbers</u>	<u>Part Serial Number</u>
Filler Strip 1- Graphitite G	1	388D813H01	A89111
	2		A89113
	3		A89110
	4		A89112
Filler Strip 1 - Carb-I-Tex 700	5	388D813H05	A89104
	6		A89106
	7		A89105
Filler Strip 12-	1	388D813H03	A89114
	2		A89117
	3		A89116
	4		A89115
Filler Strip 12- Carb-I-Tex 700	5		A89103
	6		A89101
	7		A89102

TABLE A-2
FILLER STRIP SECONDARY AXIAL SUPPORT TEST SPECIMEN IDENTIFICATION
(939J806 PERIPHERY)

<u>Load Configuration</u>	<u>Filler Strip Material</u>	<u>Test Run</u>	<u>Filler Strip Specimen</u>	<u>Part Drawing Number</u>	<u>Part Serial Number</u>
F. S. 1 Key against F. S. 29 Slot	Graphitite G	1	1	388D813H02	A89113
			29	388D813H12	A89120
		2	1	388D813H02	A89110
			29	388D813H12	A89118
	Carb-I-Tex Grade 700	3	1	388D813H06	A89104
			29	388D813H13	A89108
		4	1	388D813H06	A89105
			29	388D813H13	A89109
F. S. 29 Slot against F. S. 1 Key	Graphitite G	1	1	388D813H02	A89112
			29	388D813H12	A89121
		2	1	388D813H02	A89111
			29	388D813H12	A89119
	Carb-I-Tex Grade 700	3	1	388D813H06	A89106
			29	388D813H13	A89107

TABLE A-3
FILLER STRIP PRIMARY AXIAL SUPPORT TEST SPECIMEN IDENTIFICATION
(939J287 PERIPHERY)

<u>Filler Strip Group</u>	<u>Filler Strip Number</u>	<u>Part Drawing Number</u>	<u>Part Serial Number</u>
H2	6	711J556H35	A85158
	7	711J556H36	A85159
H4	11	711J556H40	A85144
	12	711J556H41	
	13	711J556H42	A85190
H7	20	711J556H49	A85148
	21	711J556H50	A85176
	22	711J556H51	A85149
H10	29	711J556H58	A85180
	1	711J556H30	A85150
	2	711J556H31	A85142

TABLE A-4
FILLER STRIP SECONDARY AXIAL SUPPORT TEST SPECIMEN IDENTIFICATION
(939J287 PERIPHERY)

<u>Filler Strip Group</u>	<u>Test Run No.</u>	<u>Filler Strip Specimen</u>	<u>Part Drawing No.</u>	<u>Part Serial No.</u>
H2	1	6	711J556 H35	A851 58
		7	711J556 H36	A851 59
	2	6	711J556 H35	A851 58
		7	711J556 H36	A851 59
H4	1	11	711J556 H40	A851 44
		12	711J556 H41	A851 44
	2	11	711J556 H40	A851 45
		12	711J556 H41	A851 45
	3	12	711J556 H41	A851 45
		13	711J556 H42	A851 90
	4	12	711J556 H41	A851 90
		13	711J556 H42	A851 90
H7	1	20	711J556 H49	A851 48
		21	711J556 H50	A851 76
	2	20	711J556 H49	A851 48
		21	711J556 H50	A851 76
	3	21	711J556 H50	A851 76
		22	711J556 H51	A851 49
H10	1	1	711J556 H30	A851 50
		29	711J556 H58	A851 80
	2	1	711J556 H30	A851 39
		29	711J556 H58	A851 87

TABLE A-5
FILLER STRIP PERIPHERY INSULATION SUPPORT TEST SPECIMEN IDENTIFICATION
(939J287 PERIPHERY)

<u>Filler Strip Group</u>	<u>Filler Strip Number</u>	<u>Part Drawing Number</u>	<u>Part Serial Number</u>
H4	11	711J556H30	A85146
	12	711J556H31	
	13	711J556H32	A85172
H10	29	711J556H58	A85180
	1	711J556H30	A85150
	2	711J556H31	A85142

TABLE A-6
FILLER STRIP HANGER ASSEMBLY TEST SPECIMEN IDENTIFICATION
(939J806 PERIPHERY DESIGN)

<u>Test Run</u>	<u>Part Drawing Number</u>	<u>Part Serial Number</u>
1	388D813H09	A86830
2	388D813H09	A86831
3	388D813H10	A86834
4	388D813H11	A86835
5	388D813H11	A86836
6	388D813H10	A86833

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	TITLE Periphery Axial Load Tests	
	DOCUMENT NO. WANL-TME-2738	DATE 9/30/70
ABSTRACT A series of tests were performed to test critical axial support interfaces of two periphery axial support designs. The structural interfaces are the primary axial hanger assembly support, the filler strip body primary and secondary support interfaces, and the insulation retention ledge at the filler strip aft end. The 939J806 ball joint hanger assembly design will sustain reactor axial loads if the insulation to peripheral fuel interface coefficient of friction is kept adequately low. Data obtained is useful for development of the periphery design for the R-1 10 hour reactor. (C-RD)		
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