~~CONFIDENTIAL~~

Q-70-714

Westinghouse
Astronuclear
Laboratory

Records

WANL-TME-2734
SEPTEMBER 1970

MASTER

DATA ITEM T-119

STEM ASSEMBLY STRUCTURAL
TEST (U)

FINAL REPORT

DISTRIBUTION OF THIS REPORT IS UNCLASSIFIED

DISCLAIMER

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

DISCLAIMER

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

(87)

~~CONFIDENTIAL~~

Westinghouse Astronuclear Laboratory

NOTICE

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

Subcontract NP-1
CODE IDENT NO. 14683

WANL-TME-2734
SEPTEMBER 1970

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

Classification cancelled (or changed to)

by authority of

by H.A.C. TIC, date SEP 11 1972

DATA ITEM T-119

SPECIAL REVIEW	Reviewer	Class	Date
DETERMINATION	DBW	U	4-16-82
Class: <u>U</u>			

STEM ASSEMBLY STRUCTURAL

TEST (U)

FINAL REPORT

APPROVED BY:

J. G. Gallagher, Manager
NERVA Design Engineering

INFORMATION CATEGORY	
<u>C-1</u>	
<u>R. Lammie</u>	<u>8-28-70</u>
AUTHORIZED CLASSIFIER	DATE

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~ATOMIC ENERGY~~

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

PAGE BLANK

ABSTRACT

Multiple tests were conducted on fabricated assemblies to determine the structural adequacy of the components and to verify the analytical techniques for predicting structural adequacy. These tests consisted of tensile, pressure, flexure, and vibration tests on components and complete stem assemblies. The liner tubes were made from type 316 stainless steel and the support stems from Inconel 718*.

The results showed that the components are structurally adequate at the conditions tested and that a high margin of safety exists. The tests also confirmed that the analytical techniques are valid since there is good agreement between predicted effects and experimental results.

The room temperature tensile tests on the support stems resulted in an average yield load of 2370 lbs. and an average ultimate load of 2790 lbs. The room temperature pressure tests on the liner tube assembly resulted in an average ultimate pressure of 4470 psig.

A comparison between the strength of rolled thread specimens and ground thread specimens was made. The ground Inconel 718 thread specimens were found to be stronger than the rolled thread specimens. Ultimate loads on ground threads averaged 6532 lbs. at room temperature and 5198 lbs. at 1760°R. Ultimate loads on rolled threads averaged 5461 lbs. and 4598 lbs. at room temperature and 1760°R, respectively.

*Subsequent to this series of tests, a decision was made to use A-286 as the material for the stems, liner tube, nut and cap. This T-119 records the experimental verification of the analytical techniques. These same techniques will be used for analyzing the A-286 hardware designs.

PAGE BLANK

TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
	ABSTRACT	iii
	TABLE OF CONTENTS	iv
	LIST OF ILLUSTRATIONS	vi
	LIST OF TABLES	viii
1.0	INTRODUCTION	1-1
	1.1 TEST IDENTIFICATION	1-1
	1.2 PURPOSE OF TEST	1-2
2.0	REFERENCES AND ASSUMPTIONS	2-1
	2.1 SPECIFICATIONS	2-1
	2.2 SCOPE OF TEST DOCUMENT	2-1
	2.3 DATA RELEASE MEMORANDUMS	2-1
3.0	DESCRIPTION OF TEST ARTICLE	3-1
4.0	SUMMARY OF TESTS	4-1
	4.1 NARRATIVE	4-1
	4.2 TEST CONDITIONS	4-3
	4.3 TEST RESULTS	4-6
5.0	ANALYSES	5-1
	5.1 TENSILE TEST OF SUPPORT STEM AND NUT	5-1
	5.2 TENSILE TEST OF ROLLED THREADS	5-3

TABLE OF CONTENTS (CONTINUED)

<u>Section</u>		<u>Page</u>
5.3	TENSILE TEST OF GROUND THREADS	5-3
5.4	PRESSURE TEST OF LINER TUBE AND CAP ASSEMBLY	5-4
5.5	CYCLIC PRESSURE TEST OF LINER TUBE NUT AND CAP ASSEMBLY	5-5
5.6	VIBRATION TEST OF STEM ASSEMBLY	5-6
5.7	FLEXURE TEST OF STEM ASSEMBLY	5-6
5.8	CYCLIC PRESSURE WITH FLEXURE AND TENSION OF STEM ASSEMBLY	5-7
6.0	CONCLUSIONS	6-1
7.0	APPENDIX	
A	TEST HARDWARE	A-1
B-1	FIXTURE DRAWINGS	B-1
B-2	TEST EQUIPMENT	B-2

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
4-1	Support Stem Schematic, Part Number 388D434H01E	4-11
4-2	Support Stem Tensile Test Set-up in Universal Testing Machine	4-12
4-3	Support Stem's Failure Modes	4-14
4-4	Typical Plot of Load vs Elongation of Full Length Stem (Reference: 388D434)	4-15
4-5	Typical Load Versus Surface Strain from Gages at Forward and Aft Ends of Support Stem	4-16
4-6	Schematic of Short Length Stem With Ground and Rolled Threads	4-17
4-7	Short Length Stem Test Setup in Universal Testing Machine for the 1760°R Test	4-18
4-8	Failure Mode of Rolled Threads Tested at Room Temperature	4-19
4-9	Failure Mode of Rolled Threads Tested at 1760°R	4-20
4-10	Failure Mode of Ground Threads Tested at Room Temperature	4-22
4-11	Failure Mode of Rolled Threads Tested at 1760°R	4-23
4-12	Stem Assembly	4-25
4-13	Burst Pressure Test Set-up	4-26
4-14	Mode of Failure of Liner Tube Nut and Cap Assembly (original)	4-27
4-15	Mode of Failure of Modified Liner Tube Assembly	4-30
4-16	Liner Tube Nut and Cap Assembly Instrumented with Strain Gages	4-31
4-17	Strain Gage Instrumentation of Closure Cap. Six 90° Rosettes were Used	4-32
4-18	Test Set-up for Cyclic Pressure Test of Liner Tube Nut and Cap Assembly.	4-33
4-19	Typical Pressure Versus Strain Recorded on Liner Tube	4-35
4-20	Typical Pressure Versus Strain Recorded on Closure Cap	4-36

LIST OF ILLUSTRATIONS (CONTINUED)

<u>Figure</u>		<u>Page</u>
4-21	Stem Assembly Specimens Used for the Vibration Test	4-37
4-22	Stem Assembly and Tube Arrangement	4-38
4-23	Test Fixture and Specimen	4-39
4-24	Test Fixture Mounting on C-50 Shaker	4-40
4-25	Stem Assembly Tensile Load Calibration	4-41
4-26	Data Acquisition and Recorder	4-42
4-27	Test Fixture and Mounting at Forward End of Stem Assembly	4-43
4-28	Data Recorded for Stem Assembly Number 2	4-44
4-29	Data Recorded for Stem Assembly Number 3	4-45
4-30	Schematic of Flexure Test Set-up for Complete Stem Assembly	4-46
4-31	Flexure Test Set-up in Universal Testing Machine	4-47
4-32	Liner Tube Strain Versus Deflection	4-48
4-33	Typical Permanent Deformation After Flexure Testing	4-49
4-34	Schematic of Cyclic Pressure with Flexure and Tension Test of Complete Stem Assembly	4-50
4-35	Test Set-up in Universal Testing Machine for Cyclic Pressure With Flexure and Tension of Complete Stem Assembly	4-51
4-36	Typical Load Versus Elongation Graph of Stem Assembly Cyclic Pressure with Flexure and Tension Test.	4-52
5-1	Allowable Nominal Pressure Drop Across SS 316 Liner Tube Versus Liner Tube Temperature	5-10
5-2	Closure Cap Assembly	5-11
5-3	Closure Cap Analytical Model	5-11
5-4	Closure Cap Strain Gage Locations	5-12
5-5	Liner Tube Bending Stresses for Elastic Support Conditions	5-13
5-6	Support Stem and Liner Tube Deflections	5-14
5-7	Support Stem Bending Stresses Including Liner Tube Interference Force	5-15

LIST OF TABLES

<u>Table</u>		<u>Page</u>
4-1	Support Stem Tensile Test Results	4-13
4-2	Short Length Stems Tensile Test - Rolled Threads	4-21
4-3	Short Length Stems Tensile Test - Ground Threads	4-24
4-4	Burst Pressure Test of Liner Tube Nut and Cap Assembly	4-28
4-5	Liner Tube Diameters Before Pressurizing to Failure and Diameter Changes After Testing	4-29
4-6	Recorded Strain From Liner Tube Circumferential Gages	4-34
4-7	Cyclic Pressure with Tension and Flexure Test - Loads, Loads Elongations and Maximum Diameter Changes After Testing.	4-53
5-1	Support Stem Loads for the Full Flow Condition and a Wide Open SSCV	5-9
5-2	Theoretical and Experimental Strains on Surface of Closure Cap	5-9
6-1	Summary of Test Results	6-3

1.0 INTRODUCTION

1.1 TEST IDENTIFICATION

This report describes the tests performed to determine the capability of the support stem assembly to carry tensile, pressure, flexure and vibration loads. Also, the comparative strengths of rolled and ground threads were tested.

1.1.1 Type of Report

Final report.

1.1.2 Scope of Test Document

56DE-207-2, Stem Assembly Structural Tests.

1.1.3 Functional Category of Test

A series of eight types of tests were conducted at room temperature. Tests on thread specimens were conducted at a temperature of 1760°R also. These tests were:

- 1) Tensile Test of Stem and Nut
- 2) Tensile Test of Rolled Threads
- 3) Tensile Test of Ground Threads
- 4) Pressure Test of Liner Tube Nut and Cap
- 5) Cyclic Pressure of Liner Tube Nut and Cap Assembly
- 6) Vibration Test of Stem Assembly
- 7) Flexure Test of Stem Assembly
- 8) Cyclic Pressure with Flexure and Tension of Stem Assembly.

1.1.4 Contractor

Westinghouse Astronuclear Laboratory under subcontract NP-1.

1.2 PURPOSE OF TEST

The purpose of this test was to determine the capability of the support stem assembly to carry tensile, pressure, flexure, and vibration loads so that analytical techniques for predicting structural adequacy could be verified.

Subsequent to this series of tests, a decision was made to use A-286 as the material for the stems, liner tube, nut and cap. The analytical techniques used for evaluating the 316 stainless steel hardware will be used for analyzing the A-286 hardware designs.

2.0 REFERENCES AND ASSUMPTIONS

2.1 SPECIFICATION

CEI No. EC 677558 dated July 1970, Paragraph 3.1.1.1.2.1, Core Element Support Function; 3.1.1.1.2.1.1, Deflection Capability; 3.1.1.1.2.3, Thermal-Hydraulic Characteristics; and 3.1.2.4.2.2, Loads Environment.

2.2 SCOPE OF TEST DOCUMENT

56DE-207-2 dated May 2, 1960.

2.3 DATA RELEASE MEMORANDUMS

<u>DRM Number</u>	<u>Description</u>
51623	Test Plan for Stem Assembly Structural Test
52176	Tensile Test of Short Length Stems - Rolled Threads
52177	Tensile Test of Support Stems and Short Length Stems - Ground Threads
52544	1) Burst Pressure of Liner Tube Nut and Cap Assembly and, 2) Cyclic Pressure of Liner Tube Nut and Cap Assembly
52546	Stem Assembly Vibration Test
52557	1) Cyclic Pressure with Flexure and Tension of Stem Assembly and, 2) Flexure of Stem Assembly.

3.0 DESCRIPTION OF TEST ARTICLE

Components and complete stem assemblies per drawing 388D443 were tested. Support stems were manufactured of Inconel 718 and the support nut, closure cap, and liner tube were manufactured from stainless steel 316. The assembly was electron beam welded. Specimens for the thread tests were manufactured of Inconel 718. Fifty per cent of the specimens had rolled threads and 50 per cent had ground threads.

A listing of the test hardware including serial numbers is provided in Appendix A.

4.0 SUMMARY OF TESTS

4.1 NARRATIVE

4.1.1 Tensile Test of Support Stem and Nut

Static tensile tests were performed at room temperature to determine tensile strength characteristics of full length support stems, Part Number 388D434 H01E, see Figure 4-1. Six support stems were tested. They were manufactured from age-hardenable nickel-chromium-iron containing a minimum of 50% nickel (PDS 30043-3). The support nuts were manufactured from corrosion resistant steel (AISI 316).

4.1.2 Tensile Test of Rolled Threads

Twelve short length stems with rolled threads, Part Number 388D571 H01, were tested to determine thread strength characteristics. Six stems were tested at room temperature and six at 1760°R. They were manufactured from Inconel 718 tubing in accordance with Specification PDS 30043-3. A short length stem schematic is shown in Figure 4-6.

4.1.3 Tensile Test of Ground Threads

Same as described in Section 4.1.2 except threads were ground instead of rolled.

4.1.4 Pressure Test of Liner Tube Nut and Cap Assembly

Six liner tube nut and cap assemblies, Part Number 388D443, were pressurized to failure. The liner tubes were manufactured from corrosion and heat resistant seamless steel tubing AMS 5573, closure caps and support nuts were manufactured from corrosion resistant steel AISI 316. Two electron beam welds were used to assemble the components. A schematic of the assembly is shown in Figure 4-12.

4.1.5 Cyclic Pressure Test of Liner Tube Nut and Cap Assembly

Three liner tube nut and cap assemblies were pressure cycled at room temperature. Strains in the liner tube were monitored by seven circumferential strain gages, shown in Figure 4-16, the closure cap was instrumented with six 90° rosettes and oriented to monitor

circumferential and longitudinal strains, see Figure 4-17.

4.1.6 Vibration Test of Stem Assembly

To determine the vibrational characteristics and any vibrational problems associated with the stem assembly as normally constrained within a central element and under a 70 lb. tensile load, vibration tests were conducted on three stem assemblies shown in Figure 4-21. The vibration was applied in the transverse direction at levels intended to simulate reactor startup conditions.

Each stem assembly specimen was inserted in the steel tube as shown in Figure 4-22 and then mounted on the test fixture and shaker as shown in Figure 4-24. Figure 4-22 shows a picture of the various bushings and parts used with the steel tube to simulate the central unfueled element with respect to the stem assembly.

4.1.7 Flexure Test of Stem Assembly

To determine flexure characteristics of the stem's forward end under simulated reactor conditions, four complete stem assemblies were flexure tested. A schematic diagram and a photograph of the test setup in a universal testing machine are shown in Figures 4-30 and 4-31.

4.1.8 Cyclic Pressure with Flexure and Tension Test of Stem Assembly

Complete stem assemblies were subjected to the combined loads of cyclic pressure, tension and flexure. A schematic and photograph of the test setup is shown in Figures 4-34 and 4-35. The stainless steel spacer and the grafoil seals aft of station zero (refer to Drawing 939J837) were replaced with a fixture adapter. Brass spacer tubes were positioned in an element and aligned with the aft end of the stem. The element was supported rigidly by means of a fixture which in turn was supported by six radial tie rods connected to the frame of the Universal Testing Machine. The test loading sequence consisted of (1) deflection at the forward end of the stem, obtained by displacing the clamping chucks of the loading machine's lower head; (2) the tensile load was applied; and (3) the cyclic pressure was applied through a fitting at the forward end of the stem. The flow of helium gas was controlled by a regulator.

4.2 TEST CONDITIONS

4.2.1 Tensile Test of Support Stem and Nut

The tensile tests were conducted in a Universal Testing Machine, shown in Figure 4-2. The stems were loaded so that the head of the machine moves at a constant rate of 40 mils per second. Each stem was instrumented with six strain gages, three at the forward end and three at the aft end spaced 120° apart as shown in Figure 4-1. The strain gage outputs were temperature compensated. Load versus specimen elongation and two strain gages were recorded on X-Y recorders, typical plots are shown in Figures 4-4 and 4-5. The remaining gages were recorded by using SR-4 strain recording instruments.

4.2.2 Tensile Test of Rolled Threads

The tensile tests were conducted in a Universal Testing Machine. The test setup shown in Figure 4-7 consisted of using adapters to mate with universal joints at both ends of the loading machine. Nominal test temperatures of 1760°R were obtained by using four radiant heating reflectors, with three quartz lamps each, arranged 90° apart.

4.2.3 Tensile Test of Ground Threads

Same as described in Section 4.2.2.

4.2.4 Pressure Test of Liner Tube Nut and Cap Assembly

A high pressure hydraulic pump and accumulator were used to apply a steady pressure to the specimens. Failure pressures were determined from the calibrated output signal of a 10,000 psig pressure transducer. The signal was recorded on a x-y plotter. For safety, a pressure relief valve was installed in the system and the specimens were tested in a safety enclosure. The test setup is shown in Figure 4-13.

4.2.5 Cyclic Pressure Test of Liner Tube Nut and Cap Assembly

The test setup was the same as that used for the burst pressure test except that strain recording instruments were added, see Figure 4-18. Each specimen was cycled 15 times from zero to 2600 psig. Strain data was recorded at pressure loads of 500, 1000, 1500, 2000 and 2600 psig for the first, fifth, tenth and fifteenth cycle. For cycles two to four, six to nine and eleven to fourteen, the strains were recorded at only 2600 psig.

4.2.6 Vibration Test of Stem Assembly

The vibration test of each specimen was a separate test and although the three tests were basically the same, there were small differences in the test setup. Figure 4-24 shows the additional accelerometer added for the second and third tests and the additional clamps used on specimen number three. During Tests Two and Three, silicone grease was placed around and under the steel tube to add damping to any motion between the steel tube and the test fixture. The accelerometer on the test fixture was used to determine the relative motion between the steel tube and test fixture by comparing A1 and A4. This comparison also shows the effect of the additional clamp added for specimen number three.

A strain gage was first installed inside the stem at the approximate location shown in Figure 4-23. With the stem assembly installed in the steel tube, the strain gage wire leads came out through a small hole in the end of the spring guide (see Figures 4-23 and 4-27). The stem assembly and steel tube were then hung in the vertical direction, as shown in Figure 4-25, and various loads applied with each corresponding load up to 70 lbs. The 70 lb. load was then duplicated by using the spring as shown in Figure 4-27. This was repeated for each specimen just prior to testing to insure an accurate 70 lb. tension on the stem.

After calibration of the 70 lb. load, the stem assembly and steel tube were mounted on the test fixture and shaker as shown in Figure 4-24. The center accelerometer (A2) was used as the control accelerometer. The input acceleration (A2) was 1.5g from 5 Hz to 34 Hz and 2.0g from 34 Hz to 500 Hz except for displacement limitations of the shaker from 5 Hz to 6 Hz when values slightly less than 1.5g were obtained. The frequency range was covered at a logarithmic rate such that the range of 5 Hz to 500 Hz

and back to 5 Hz was covered in 6.8 minutes. This cycle was repeated three times for each specimen so that each stem received 20.4 minutes of vibration testing.

During the testing, the strain gage, frequency, and various accelerometers were recorded on the FM Tape Recorder and monitored on the Oscilloscope shown in Figure 4-26. This provided a means of checking the validity of the data going on the tape and then reproduction at a later time with an X-Y Recorder.

After each specimen was tested, it was again checked for static strain to determine how close it was to the original strain imposed by the 70 lb. tensile load. Each specimen was examined closely for damage or permanent set and the dimples were measured with a micrometer and compared to previous readings.

4.2.7 Flexure Test of Stem Assembly

The stem assembly was supported aft of station zero by brass tubes that replaced the stainless steel spacer and the grafoil seals. The brass tubes were positioned in an element and the element was supported rigidly by means of a fixture. The forward end of the support stem was rigidly fixed to a simulated support plate which was restrained from rotation. The forward end of the liner tube was fixed by means of a brass fitting to the simulated support plate. Testing was conducted in a Universal Testing Machine, the flexure loading was applied at the center of the stem's forward end threads.

Test instrumentation consisted of a 100 lb. load cell and a 1/2 inch displacement transducer to monitor load and deflection. X-Y plots of load versus deformation were recorded. The liner tubes were instrumented with a longitudinally oriented strain gage located forward of station zero on the top of the liner (see Figure 4-30). Load and deflection were recorded at the center of the stem's forward end threads.

4.2.8 Cyclic Pressure with Flexure and Tension Test of Stem Assembly

Each stem assembly was tested twice. The test setup was the same for both tests but the loads for the second test were increased by a factor of 1.35. The first test consisted of deflecting the forward end of the stem by 60 mils, loading to 1200 lbs. in tension and cycling the pressure from zero to 500 psig. Loads for the second test were 81 mils

deflection, 1620 lbs. tension and cyclic pressure from zero to 675 psig. Under these loading conditions, four complete stem assemblies were each pressure cycled 15 times. The first stem assembly tested, No. A86705, was rejected by Quality Control and was used to check out the test fixture.

4.3 TEST RESULTS

4.3.1 Recorded Data

4.3.1.1 Tensile Test of Support Stem and Nut

Test results for each stem: failure load, elongation, failure location, ultimate strength, yield strength and percent elongation are presented in Table 4-1.

4.3.1.2 Tensile Test of Rolled Threads

Recorded data for the short length stems with rolled threads is presented in Table 4-2.

4.3.1.3 Tensile Test of Ground Threads

Recorded data for the short length stems with rolled threads is presented in Table 4-3.

4.3.1.4 Pressure Test of Liner Tube Nut and Cap Assembly

Recorded data for the pressure test of the liner tube nut and cap assembly is presented in Tables 4-4 and 4-5.

4.3.1.5 Cyclic Pressure Test of Liner Tube Nut and Cap Assembly

Recorded data for the cyclic pressure test of liner tube nut and cap assembly is presented in Table 4-6 and in the graphs of Figures 4-19 and 4-20.

4.3.1.6 Vibration Test of Stem Assembly

Figures 4-28 and 4-29 show the acceleration and peak strain levels for specimens two and three. As is readily seen, the additional clamps used for specimen number three greatly reduced the response of the steel tube which resulted in a reduction of peak strain.

This Page is UNCLASSIFIED

4.3.1.7 Flexure Test of Stem Assembly

Recorded data for the flexure test of stem assembly is presented in the graph of Figure 4-32.

4.3.1.8 Cyclic Pressure with Flexure and Tension of Stem Assembly

Recorded data for the cyclic pressure with flexure and tension test of stem assembly is presented in Table 4-7 and the graph of Figure 4-36.

4.3.2 Discussion of Data

4.3.2.1 Tensile Test of Support Stem and Nut

The test results for each stem failure load, elongation, failure location, ultimate strength, yield strength and percent elongation are presented in Table 4-1. All failures occurred at 4.4 to 7.7 inches away from the stem's aft end. The failure mode is shown in Figure 4-3. Failure loads ranged from 2695 to 2880 lbs. and elongations, over the entire stem's shank length of 60.3 inches, ranged from 3.40 to 3.70 inches giving 5.65 to 6.14 percent elongation. The calculated average yield stresses and ultimate stresses were determined to be 169,000 psi and 199,000 psi. At the stem's forward end, a linear strain relation was obtained up to 2200 pounds and a strain of 5,700 microinches per inch was recorded at failure. At the aft end, a linear strain relation was obtained up to 1900 lbs. and a strain of 5,000 microinches per inch. At failure, aft end surface strains, exceeded the X-Y plotter calibration of 50,000 microinches per inch.

4.3.2.2 Tensile Test of Rolled Threads

Rollled threads tested at room temperature failed in the range from 5280 to 5670 lbs. and elongated 0.083 to 0.087 inch. All failures occurred in the threads. The mode of failure is shown in Figure 4-8. At 1760°R, failure loads and elongations ranged from 4270 to 5030 lbs. and 0.092 to 0.133 inch. Again, at 1760°R, all failures occurred in the threads at the last thread engaged, see Figure 4-9. Results for each test are tabulated in Table 4-2.

(THIS PAGE IS UNCLASSIFIED)

4.3.2.3 Tensile Test of Ground Threads (U)

(U) Ten short length stems with ground threads were tested. The five tested at room temperature failed in the range of 6320 to 6680 lbs. and elongated from 0.100 to 0.177 inch. The five tested at 1760°R failed at lower loads, 5030 to 5380 lbs., but elongated more, from 0.132 to 0.275 inch. Except for one stem, tested at 1760°R, all failures occurred in the threads. The mode of failure for the room temperature test is shown in Figure 4-10 and for the 1760°R in Figure 4-11. Results for each test are tabulated in Table 4-3.

4.3.2.4 Pressure Test of Liner Tube Nut and Cap (U)

(U) Burst pressures ranged from 4400 to 4550 psig. All failures occurred in the tapered section at the forward end of the liner tube, wall thickness 12 mils. Burst pressures, failure locations and calculated circumferential tensile stress for each assembly is given in Table 4-4. For a wall thickness of 12 mils, the ultimate circumferential tensile stress ranged from 70,000 to 72,400 psi. Table 4-5 gives the liner tube diameters before testing and the diameter changes after testing. Modes of failure are shown in Figure 4-14.

(U) The six liner tube nut and cap assemblies, used in the above test, were modified by removing about ten inches from the forward end of the liner tube where failures had occurred. The modified specimens were repressurized and higher failure pressures from 5290 to 5770 psig were obtained. For a wall thickness of 15 mils, the modified specimens showed an ultimate circumferential tensile stress from 69,000 to 73,500 psi. All failures occurred in the liner tube about onch inch from the liner support nut weld, except one that failed at about eight inches from the weld. Burst pressures and diameter changes for the original and modified specimens are summarized in Tables 4-4 and 4-5. Failure modes for the modified specimens are shown in Figure 4-15.

4.3.2.5 Cyclic Pressure Test of Liner Tube Nut and Cap Assembly (U)

(C-RD) Calculated strain from $\epsilon = Pr/t E$ at a pressure of 2600 psig and for a liner wall thickness of 0.012 inch is 1380 microinches per inch. At the same pressure, but for liner wall thickness of 0.015 inch, the calculated strain is 1150 microinches per inch.

(C-RD)

Experimentally obtained surface strains from liner tube circumferential gages are summarized in Table 4-6. At a pressure of 2600 psi and for $t = 12$ mils, the recorded surface strain ranged from 1725 to 1730 μ in/in; for $t = 15$ mils the strain ranged from 825 to 1455 μ in/in. Typical pressure versus strain plots for liner tube and closure cap are shown in Figures 4-19 and 4-20. The liner tube exhibited a linear strain to pressure relation of values less than approximately 2000 psig. At a pressure of 2600 psig the highest strain, 1730 microinches per inch, was obtained at gage station 10C of the liner tube (wall thickness 12 mils).

(U) Strains in the closure cap ranged from 400 μ in/in. in compression and 640 μ in/in. in tension. Compressive strains were obtained from longitudinal gages located on the closure cap support nut weld. The maximum strain, on the closure cap, of 640 microinches per inch at 2600 psig was obtained from circumferentially oriented gages (30C) located on the closure cap.

(U) In addition to the 15 cycles up to 2600 psig, each assembly was pressurized to 3500 psig. The maximum deformation of 0.0064 inch was measured with a micrometer at a location on the liner tube diameter five inches from the forward end.

4.3.2.6 Vibration Test of Stem Assembly (U)

(U) The maximum unit strain of the stem during the entire test was about 150 μ in/in. peak as shown in Figure 4-28. This means that the vibration caused a vibratory strain in addition to the static strain caused by the 70 lb. tensile load. This corresponds to .018 in. peak to peak total displacement of the 60 inch stem. As can be seen from Figure 4-29, the additional restraining of the steel tube reduced the maximum peak strain to around 40 μ in/in. This is a more realistic value because the movement of the steel tube was closer to the input. Close comparison of the curves plotted in Figures 4-28 and 4-29 reveals that there was a 6-10 db difference between A1 and A4 for stem number two and only 4-6 db for number three which means there was a 2-4 db reduction in the relative motion between the test fixture and the steel tube.

(U) In no way did the test indicate any kind of problem associated with vibration of the stem assembly. The strain levels are not considered to be abnormal and the post-test

This Page is UNCLASSIFIED

inspection showed no change in the stem or dimple measurements. The static strain did change slightly but this corresponds to a displacement change of the spring. Figure 4-21 shows the three test specimens after the vibration tests with no adverse effects.

4.3.2.7 Flexure Test of Stem Assembly

A plot of the liner tube surface strain versus deflection for tests No. 2, 3, and 4 is shown in Figure 4-32. Test No. 1 was conducted without strain gage instrumentation. Loads were applied incrementally, strain gage data was recorded and the specimens were examined for deflection. Permanent deformations were noted at loads of 21, 21, 22 and 28 lbs. of deflection of 0.25, 0.30, 0.30 and 0.41 inch. Figure 4-33 shows a typical deflection; a bend of about 1° was obtained at station zero.

4.3.2.8 Cyclic Pressure with Flexure and Tension of Stem Assembly

The maximum diameter change, measured with a micrometer, was 2.2 mils. This change was obtained on the stem assembly rejected by Quality Control. The other three assemblies showed a maximum diameter change from 0.5 to 0.8 mils which can be considered as insignificant since the deviation is within the accuracy of the micrometer. A summary of the test results is presented in Table 4-7. The graph of Figure 4-36 shows the relation of load versus elongation.

In order to indicate the design margins, the specimens were pressure cycled 15 additional times from zero to 675 psig with a deflection at the stems forward end of 0.081 inch and a tensile load of 1620 lbs. After the 15 cycles, the maximum liner tube diameter changes ranged from 0.3 to 1.6 mils. The test results are presented in Table 4-7.

(THIS PAGE IS UNCLASSIFIED)

**Astronuclear
Laboratory**

4-11

CONFIDENTIAL
RESTRICTED DATA

Atomic Energy Act - 1954

(THIS PAGE IS UNCLASSIFIED)

Figure 4-2. Support Stem Tensile Test Setup in Universal Testing Machine

(THIS PAGE IS UNCLASSIFIED)

CONFIDENTIAL
RESTRICTED DATA

Atomic Energy Act - 1954

TABLE 4-1

SUPPORT STEM TENSILE TEST RESULTS

Stem Serial No.	Nut Serial No.	Failure Load (pound)	Elongation Over Entire Length (inches)	Failure Location * (inches)	Ultimate Stress (K psi) ***	Yield Stress (K psi) ***	Percent Elongation Over Shank Length (60.3") %
A86110	A86047	2820	3.50	7.7	201	171	5.82
A86112	A86049	2790	3.70	4.4	199	169	6.14
A86116	A86048	2695	3.55	5.5	192	164	5.88
A86120	A86051	2880	3.70	4.75**	205	172	6.14
A86125	A86050	2760	3.65	4.45	197	168	6.05
A86129	A86052	2800	3.40	4.6**	200	171	5.65
Arithmetic Mean	$\bar{X}$	2790	3.58	---	199	169	5.95
Standard Deviation	σ	56.3	0.11	---	3.97	2.68	.18

* Failure Location from Aft End.

** Test Conducted with Aft End Up.

*** Calculated from $\frac{\text{Load}}{\text{Cross sectional area}}$

Note: The Gage Length used to obtain elongation was the shank length of the Stem; that is, 60.30 inches. Support Stem Cross Sectional Area of 0.014 in² was used to obtain stress.

Figure 4-3. Support Stem's Failure Modes

Figure 4-4. Typical Plot of Load vs Elongation of Full Length Stem
(Ref. 388D434)

Figure 4-5. Typical Load Versus Surface Strain from Gages at Forward and Aft Ends of Support Stem

Figure 4-6. Schematic of Short Length Stem With Ground and Rolled Threads

(THIS PAGE IS UNCLASSIFIED)

Figure 4-7. Short Length Stem Test Setup in Universal Testing Machine
for the 1760°R Test

(THIS PAGE IS UNCLASSIFIED)

Figure 4-8. Failure Mode of Rolled Threads Tested at Room Temperature

Figure 4-9. Failure Mode of Rolled Threads Tested at 1760°R

TABLE 4-2

SHORT LENGTH STEMS - ROLLED THREADS

<u>Short Stem No.</u>	<u>Failure Load (lbs)</u>	<u>Elong. (in.)</u>	<u>Test Temperature °F</u>	<u>Location of Failure</u>
A86096	5280	0.086	Room	In last engaged thread.
A86098	5280	0.086	Room	In last engaged thread.
A86099	5510	0.087	Room	In last engaged thread.
A86100	5490	0.086	Room	In last engaged thread.
A86101	5540	0.085	Room	In last engaged thread.
A86105	5670	0.083	Room	In last engaged thread.
A86097	4780	0.100	1299	In thread 0.8" from bottom end.
A86102	4270	0.133	1305	In thread 0.8" from top end.
A86103	4420	0.132	1330	In thread 0.7" from top end.
A86104	4340	0.127	1300	In thread 0.8" from top end.
A89170	5030	0.100	1300	In thread 0.8" from bottom end.
A86106	4750	0.092	1301	In thread 0.8" from bottom end.

Figure 4-10. Failure Mode of Ground Threads Tested at Room Temperature

Figure 4-11. Failure Mode of Ground Threads Tested at 1760°R

TABLE 4-3

SHORT LENGTH STEMS - GROUND THREADS

<u>Short Stem No.</u>	<u>Failure Load (lb.)</u>	<u>Elongation (in.)</u>	<u>Temp. (°F)</u>	<u>Failure Location</u>
A88944	6680	0.173	Room	Failed in last engaged thread
A88945	6620	0.177	Room	Failed in last engaged thread
A88946	6650	0.108	Room	Failed in last engaged thread
A88947	6320	0.102	Room	Failed in last engaged thread
A88949	6390	0.100	Room	Failed in last engaged thread
A88950	5380	0.275	1345	3.75 From identity end
A88951	5350	0.152	1316	In thread 0.6" from top end
A88952	5080	0.132	1320	In thread 0.6" from top end
A88953	5030	0.145	1310	In thread 0.6" from top end
A88954	5150	0.135	1300	In thread 0.6" from top end

CONFIDENTIAL
RESTRICTED DATA

Atomic Energy Act - 1954

AFT END

SUPPORT NUT

POSITION PIN

CLOSURE CAP

ELECTRON BEAM
WELDS

AFT END
THREADS
MACHINED

LINER TUBE

SUPPORT STEM

FORWARD THERADS
MACHINED

FORWARD END

Figure 4-12. Stem Assembly

CONFIDENTIAL
RESTRICTED DA

Atomic Energy Act - 1954

CONFIDENTIAL
RESTRICTED DATA

Atomic Energy Act - 1954

(THIS PAGE IS UNCLASSIFIED)

Figure 4-13. Burst Pressure Test Setup

CONFIDENTIAL
RESTRICTED DATA

Atomic Energy Act - 1954

(THIS PAGE IS UNCLASSIFIED)

CONFIDENTIAL

RESTRICTED DATA

Atomic Energy Act - 1954

This Page is UNCLASSIFIED

Astronuclear
Laboratory

Figure 4-14. Mode of Failure of Liner Tube, Nut and Cap Assembly (Original)

CONFIDENTIAL

RESTRICTED DATA

Atomic Energy Act - 1954

(THIS PAGE IS UNCLASSIFIED)

CONFIDENTIAL
RESTRICTED DATA

TABLE 4-4

BURST PRESSURE TEST OF LINER NUT AND CAP ASSEMBLY

Stem Assembly Number	Burst Pressure Original Assembly (psig)	Calculated σ_c Circum. Tensile Stress (psi)*	Failure Location*** (Original Assembly)	Burst Pres. Mod. Spec. (psig)	Calculated σ_c Circum. Tensile Stress (psi)**	Failure ⁺ Location Modified Specimen
A86152, A85640 A86087, A86055	4490	71,500	7 1/4	5650	71,900	1 1/2
A86135, A85652 A86084, A86070	4540	72,300	3 5/16	5420	69,000	1 5/8
A85649, A89349 A86064, A86074	4425	70,500	5 15/16	5290	67,500	12
A85635, A89350 A86081, A86069	4410	70,200	7 5/16	5550	70,600	1 1/2
A86077, A85639 A86057 - - - -	4400	70,000	4 7/8	5740	73,000	1 1/2
A86062, A86080 A85646, A86150	4550	72,400	5 3/16	5770	73,500	1 5/8

* The circumferential tensile stress was obtained by using nominal dimensions $t = 0.012$ " and $r = 0.191$ " from the equation $\sigma_c = Pr/t$.

** Modified specimen liner tube thickness is $t = 0.015$ ".

*** Inches from Forward End.

⁺ Inches from Aft End.

CONFIDENTIAL
RESTRICTED DATA

TABLE 4-5

LINER TUBE DIAMETERS BEFORE PRESSURIZING TO FAILURE AND DIAMETER CHANGES AFTER TESTING

Stem Assembly Number		Positions on Liner Tube in Inches Starting from Forward End of Liner											
		0	5	10	15	20	25	30	35	40	45	50	55
A85640	Dia. Before Test	4039	4044	4129	4129	4128	4131	4132	4128	4130	4130	4130	4129
	Dia. Change Orig. Assy.	---	750	63	65	65	63	60	69	67	70	68	61
	Dia. Change Mod. Assy.	---	---	---	463	462	458	440	477	473	505	508	455
A85652	Dia. Before Test	4040	4048	4126	4126	4128	4126	4127	4124	4124	4126	4124	4123
	Dia. Change Orig. Assy.	---	745	70	81	76	81	77	89	86	81	84	87
	Dia. Change Mod. Assy.	---	---	---	346	342	329	353	353	343	342	344	364
A85649	Dia. Before Test	4033	4045	4128	4126	4126	4127	4128	4129	4127	4129	4129	4128
	Dia. Change Orig. Assy.	---	149	66	72	72	73	65	70	71	67	104	64
	Dia. Change Mod. Assy.	---	---	---	250	258	258	241	249	254	246	353	263
A85653	Dia. Before Test	4036	4046	4130	4131	4128	4127	4127	4130	4129	4126	4128	4128
	Dia. Change Orig. Assy.	---	621	58	60	71	71	67	70	73	91	82	80
	Dia. Change Mod. Assy.	---	---	---	368	396	373	362	377	382	462	408	412
A85639	Dia. Before Test	4039	4040	4125	4128	4126	4128	4129	4127	4128	4128	4129	4127
	Dia. Change Orig. Assy.	---	947	73	79	82	67	60	66	62	64	65	65
	Dia. Change Mod. Assy.	---	---	---	500	490	482	444	443	458	472	505	470
A85646	Dia. Before Test	4038	4048	4127	4128	4128	4126	4128	4129	4129	4129	4128	4126
	Dia. Change Orig. Assy.	---	841	78	76	71	70	80	65	64	66	67	74
	Dia. Change Mod. Assy.	---	---	---	543	498	505	469	576	464	459	455	526

Note: 1) Liner diameters and diameter changes are given in tenths of mils.
2) Diameter changes for modified assembly are referenced to before test dimensions.

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~

~~Atomic Energy Act - 1954~~

(THIS PAGE IS UNCLASSIFIED)

Figure 4-15. Mode of Failure of Modified Liner Tube Assembly

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~

~~Atomic Energy Act - 1954~~

(THIS PAGE IS UNCLASSIFIED)

Figure 4-16. Liner Tube, Nut and Cap Assembly Instrumented with Strain Gages

Figure 4-17. Strain Gage Instrumentation of Closure Cap.
Six 90° Rosettes were Used

Figure 4-18. Test Setup for Cyclic Pressure Test of
Liner Tube, Nut and Cap Assembly

TABLE 4-6
RECORDED STRAINS FROM LINER TUBE CIRCUMFERENTIAL GAGES

Stem Assembly Number	Pressure Level (psig)	Strain in Microinches per Inch from Liner Tube Strain Gages						
		10C	11C	12C	13C	14C	15C	16C
A86060	500	252	176	220	190	186	186	Gage Out
	2600	1730	1060	1455	1350	1345	1175	
A86061	500	260	165	130	165	130	210	210
	2600	1730	845	880	1050	825	1110	1380
A86149	500	250	163	180	156	204	255	210
	2600	1725	1090	1130	1040	1200	1270	1175

WS934-1

Figure 4-19. Typical Pressure Versus Strain Recorded on Liner Tube

Pressure in PSIG

Figure 4-20. Typical Pressure Versus Strain Recorded on Closure Cap

Astronuclear
Laboratory

Figure 4-21. Stem Assembly Specimens Used for the Vibration Test

CONFIDENTIAL
RESTRICTED DATA

Atomic Energy Act - 1954

Figure 4-22. Stem Assembly and Tube Arrangement

CONFIDENTIAL
(THIS PAGE IS UNCLASSIFIED)

Figure 4-23. Test Fixture and Specimen

CONFIDENTIAL
(THIS PAGE IS UNCLASSIFIED)
4-39

Figure 4-24. Test Fixture Mounting on C-50 Shaker

Figure 4-25. Stem Assembly Tensile Load Calibration

Figure 4-26. Data Acquisition and Recorder

Figure 4-27. Test Fixture and Mounting at Forward End of Stem Assembly

Figure 4-28. Data Recorded for Stem Assembly Number 2

Figure 4-29. Data Recorded for Stem Assembly Number 3

Figure 4-30. Schematic of Flexure Test Set-Up for Complete Stem Assembly

Figure 4-31. Flexure Test Set-Up in Universal Testing Machine

Figure 4-32. Liner Tube Strain Versus Deflection

CONFIDENTIAL
RESTRICTED DATA

Atomic Energy Act - 1954

This Page is UNCLASSIFIED

Astronuclear
Laboratory

ENGINEERING MECHANICS LABORATORY

DATE 5-5-70 EML NO. _____

TEST NO. _____ RUN NO. _____

SPECIMEN STEM ASSEMBLY

TEST FLEXURE - ROOM TEMP

0 2 4

Figure 4-33. Typical Permanent Deformation After Flexure Testing

CONFIDENTIAL

(THIS PAGE IS UNCLASSIFIED)

RESTRICTED DATA

Atomic Energy Act - 1954

**CONFIDENTIAL
RESTRICTED DATA**

Atomic Energy Act - 1954

Figure 4-34. Schematic of Cyclic Pressure with Flexure and Tension
Test of Complete Stem Assembly

**CONFIDENTIAL
RESTRICTED DATA**

Atomic Energy Act - 1954

Figure 4-35. Test Setup in Universal Testing Machine for Cyclic Pressure With Flexure and Tension of Complete Stem Assembly

Figure 4-36. Typical Load Versus Elongation Graph for Stem Assembly Cyclic Pressure With Flexure and Tension Test

TABLE 4-7

CYCLIC PRESSURE WITH TENSION AND FLEXURE TEST-LOADS, ELONGATIONS AND
MAXIMUM DIAMETER CHANGES AFTER TESTING

Test	Stem Assembly Number	Deflection At Forward End (in)	Tensile Load (lbs)	Pressure* (psig)	Elongation (in)	Drop in Tensile Load when Pressure was Applied (lbs)	Liner Tube Maximum Diameter Changes (mils)
1	A86075 (Check out Test)	0.060	1200	500	0.161	96	Stem assembly rejected by Q. C. used for fixture check out. 2.2
3	A86091	0.060	1200	500	0.166	90	0.6
5	A86083	0.060	1200	500	0.146	80	0.8
7	A86088	0.060	1200	500	0.175	98	0.5
The following stems were retested to 1.35 times the original loads.							
2	A86075 (Check out Test)	0.081	1620	675	0.242	100	0.5
4	A86091	0.081	1620	675	0.230	110	0.3
6	A86083	0.081	1620	675	0.226	120	0.4
8	A86088	0.081	1620	675	0.238	110	1.6

*Pressure was cycled fifteen times from zero to the specified level.

5.0 ANALYSES (U)

5.1 TENSILE TEST OF SUPPORT STEM AND NUT (U)

5.1.1 Description of Analytical Model (U)

(C-RD) The axial load on the support stem is made up of the following components:

- a. pressure drop across core
- b. pressure drop across closure cap
- c. weight of core
- d. force developed in compressing hold-down spring
- e. friction between core and lateral support system
- f. relative thermal elongation of support stems due to thermal gradient across core
- g. relative mechanical elongation of support stems due to support plate deflection

The following design constants have been used in computing the support stem loads:

- a. cross sectional area of core = 1175 in.²
- b. cross sectional area of support stem = 0.014 in.²
- c. number of support stems = 349
- d. inside area of liner tube = 0.116 in.²
- e. hold-down spring constant = 63.5 lb./in.
- f. initial spring load = 60 lbs.
- g. coefficient of friction between core and lateral support system = 0.2
- h. lateral area of core = 6320 in.²
- i. weight of core = 4530 lbs.
- j. support stem length = 60.3 in.

5.1.2 Comparison of Analytical Predictions with Test Results (U)

(U) The support stem loads for steady state full power operating conditions based on the full flow cycle with a wide open SSCV have been calculated and are presented in Table 5-1. The load components correspond to those described in Section 5.1.1.

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~

This Page is UNCLASSIFIED

The superscript on the type of load refers to the paragraph below where the magnitude of the variable involved in the calculation is listed.

- (1) core pressure drop = 171.6 psi
- (2) closure cap pressure drop = 668 psi
- (3) spring deflection = 0.427 in.
- (4) average bundling pressure = 17 psi
- (5) mean ΔT between average and central (and peripheral) stems = 2.75°R
- (6) support plate maximum deflection 0.03 in.

The stem axial loads may vary across the core due to the support plate bow and stem temperature differences. The maximum axial load in the stems, with respect to core location, occurs in the outermost (peripheral) stems and is 844 lbs. The 99% limit load value, based on a 9.2% variation with 95% confidence, is calculated to be 1125 lbs. The test results show that the stems exhibit a linear stress-strain curve up to 1900 lbs. and have a failure range from 2695 to 2880 lbs.

5.1.3 Verification of Analysis and Design Significance

The calculated axial stem load of 1125 lbs. represents, with a 95% confidence level, the limit load below which 99% of the actual operating load values should fall. A positive margin of safety is associated with this limit load for the Inconel 718 stems at the maximum recommended operating temperature of 1300°R.

A comparison between the calculated stem loads and the experimental failure loads cannot be made directly since the experiments were conducted only at room temperature. However, the observed average failure stress at room temperature (199,000 psi) does compare very well with the material mean ultimate strength (198,000 psi) at room temperature. The expected failure stress at a temperature of 1300°R, based on the ultimate strength at that temperature, is then 161,000 psi. This corresponds to an axial load of 2250 lbs. Comparing this failure load with the 99/95% calculated limit load of 1125 indicates an adequate experimental margin.

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~

(THIS PAGE IS UNCLASSIFIED)

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~

5.2 TENSILE TEST OF ROLLED THREADS (U)

5.2.1 Description of Analytical Model (U)

(C-RD) A comparison of the thread tensile stress area (0.0351 in.^2) with the stem shank tensile stress area (0.0141 in.^2) indicates that tensile failure is less likely to occur in the threads than in the shank.

5.2.2 Comparison of Analytical Predictions with Test Results (U)

(U) The test results of the rolled threads show a failure range from 5280 to 5670 lbs. at room temperature and from 4270 to 5030 lbs. at 1760°R . Previous tests on the stem shank gave a failure range from 2695 to 2880 lbs. at room temperature.

5.2.3 Verification of Analysis and Design Significance (U)

(U) Comparing the failure range of the rolled threads with the failure range of the shank indicates that the threaded sections of the support stem are less critical than the stem shank as predicted.

5.3 TENSILE TEST OF GROUND THREADS (U)

5.3.1 Description of Analytical Model (U)

(C-RD) A comparison of the thread tensile stress area (0.0351 in.^2) with the stem shank tensile stress area (0.0141 in.^2) indicates that tensile failure is less likely to occur in the threads than in the shank.

5.3.2 Comparison of Analytical Predictions with Test Results (U)

(U) The test results of the ground threads show a failure range from 6320 to 6680 lbs. at room temperature and from 5030 to 5380 lbs. at 1760°R . Higher failure loads were obtained from ground thread specimens than from rolled thread specimens. Previous tests on the stem shank gave a failure range from 2695 to 2880 lbs. at room temperature.

5.3.3 Verification of Analysis and Design Significance (U)

(U) Comparing the failure range of the ground threads with the failure range of the shank indicates that the threaded sections of the support stem are less critical than the stem

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
AT 1054

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy~~

shank as predicted.

5.4 PRESSURE TEST OF LINER TUBE NUT AND CAP ASSEMBLY (U)

5.4.1 Description of Analytical Model (U)

(C-RD) The analytical model for the liner tube consists of a thin-wall tube subjected to an internal pressure. Two nominal thicknesses of liner tube are considered. They are 0.015" for the nozzle end and 0.010" for tapered inlet end. A statistical summation of tolerances due to eccentricities, machining, and fissure depth has been estimated to give minimum thicknesses 0.0047 in. less than the nominal values. Allowable pressure drops across the liner tube have been calculated based on the statistical minimum yield strength of SS 316. In addition, a 12% pressure drop and an 85% modeling factor of safety have been included.

5.4.2 Comparison of Analytical Predictions with Test Results (U)

(U) The analysis predicts failure of the liner tube due to bursting at the tapered inlet section. Calculations based on the conservative model described above give an allowable mean pressure drop across the liner tube of 490 psig. This value is obtained from Figure 5-1 for the minimum thickness inlet section at a temperature of 535°R.

(U) Test results indicate that all failures occurred in the tapered section at the forward end of the liner tube. Burst pressures, conducted at room temperature on a 12 mil wall thickness, ranged from 4400 to 4550 psig.

5.4.3 Verification of Analysis and Design Significance (U)

(U) A comparison between the design allowable pressure drop and the experimental failure pressure drop indicates an ultimate stress to design allowable stress ratio (classical factor of safety) of approximately 9. This large safety factor is due to the conservative assumptions built into the analytical model. Elimination of the conservative assumptions and calculations based upon the ultimate strength and a 0.012 in. wall thickness result in values very near the experimentally observed values (4920 psig).

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy~~ 1054

5.5 CYCLIC PRESSURE TEST OF LINER TUBE NUT AND CAP ASSEMBLY

5.5.1 Description of Analytical Model

The closure cap, support nut, and portions of the closure cap screw, support stem and liner tube are included in the analysis model. The complete closure cap assembly, including components not directly included in the analysis model, is shown in Figure 5-2 (Reference Drawing 940J196). The axisymmetric finite element grid shown in Figure 5-3 is used as the analytical model for determining stresses and strains with the FEATS code. The grid consists of 658 nodal points and 589 elements. The model is capable of taking internal pressure loads that represent the ΔP between the turn-around flow and the chamber, cluster loads, and thermal loads due to temperature gradients.

5.5.2 Comparison of Analytical Predictions with Test Results

A comparison is made between the strain gage readings on the surface of the closure cap and theoretical finite-element calculated values. Both longitudinal and circumferential strain values at the weld area and at a lower area on the closure cap gives good comparison agreement.

Typical strain versus pressure on the closure cap is recorded in Figure 4-20. Gages were placed on the external surface of the cap at the weld and at a lower section approximately 1/2 inch from the bottom of the cap as shown in Figure 5-4. Both longitudinal and circumferential strains were recorded.

The stresses and strains throughout the closure cap are calculated by finite-element methods using the FEATS code. Values have been calculated for the cap at a uniform temperature of 540°R and a pressure of 578 psig. The calculated strains at the element surfaces corresponding to the locations at which the strain gages were placed during the experiment are shown in Table 5-2.

5.5.3 Verification of Analysis and Design Significance

A good comparison is shown between the experimental and finite-element strains for this particular situation, i. e., $\Delta P = 578$ psig, zero cluster load, and a uniform temperature of 540°R. Finite element strains have been extrapolated to the element surface to compare with strain gage values (see Table 5-2). Thermal gradients were not imposed on the closure

cap nor was the closure cap screw included.

5.6 VIBRATION TEST OF STEM ASSEMBLY

5.6.1 Description of Analytical Model

No detailed pre-test analysis of the vibrational characteristics of the support stem assembly has been made.

5.6.2 Comparison of Analytical Predictions with Test Results

Test results indicate a 0.018 in. peak-to-peak total displacement of the 60 in. stem. This corresponds to a maximum unit strain of $150 \mu \text{ in./in.}$ peak. The corresponding peak axial stress ($E = 28.1 \times 10^6 \text{ psi}$) is 4215 psi.

5.6.3 Verification of Analysis and Design Significance

In no way did the test indicate any kind of problem associated with vibration of the stem assembly.

5.7 FLEXURE TEST OF STEM ASSEMBLY

5.7.1 Description of Analytical Model

The analytical model of the liner tube consists of a thin-wall tube supported on an elastic foundation within the core. The forward end is attached to the support plate in a flexible fashion. The flexibility ranges from rigid (constrained to move with the support plate) to free (zero end moment). The distance between supports is 7.19 in. The bending moments and stresses are calculated from standard beam equations programmed in a code called BEAM.

5.7.2 Comparison of Analytical Predictions with Test Results

Figure 5-5 gives the maximum theoretical liner tube bending stress as a function of the forward end displacement and type of support. For an end displacement of 90 mils (arbitrarily selected for comparison with test results) the maximum bending stress ranges from 22,000 to 49,000 psi, depending on the rigidity of the attachment to the support plate. The lower stress corresponds to the zero end moment support. The lateral end load range

corresponding to the bending stress range is from 5.4 to 22 lbs. Experimental results for this same displacement can be obtained from Figure 4-32 as a strain range from 485 to 660 $\mu\text{in}/\text{in.}$ for the three tests. In terms of stress, this range is from 13,300 to 18,200 psi. Permanent deformations were noted at lateral end loads ranging from 21 to 28 lbs.

5.7.3 Verification of Analysis and Design Significance

The difference between the experimental results and the theoretical results may be due to several reasons.

- (1) The theoretical stress depends upon the flexibility of the forward end support, ranging from a rigid (no rotation) condition to a zero end moment condition. The forward end of the liner tube in the experiment was fixed by means of a brass fitting to the simulated support plate. It is expected that the rigidity of the forward end in the experiment lies between the rigid and the zero end moment theoretical conditions.
- (2) The aft end of the liner tube in the theoretical model rests on a relatively stiff ($k = 58,000 \text{ lb.}/\text{in.}/\text{in.}$) foundation. The experimental aft end support consisted of brass spacer tubes that simulate the stainless steel spacer and the grafoil seals. A bend of about 1° was reported at the aft end and indicates that the experimental support was more flexible than that assumed in the theoretical model. This accounts for the higher (more conservative) theoretical stress predictions. Good agreement is shown between the theoretical and experimental lateral end loads.

5.8 CYCLIC PRESSURE WITH FLEXURE AND TENSION OF STEM ASSEMBLY

5.8.1 Description of Analytical Model

The analytical model of the support stem is very similar to the liner tube model. In addition to the liner tube model it includes an axial load and a transverse load. The transverse load represents the interference force on the support stem due to contact with the liner tube.

This force occurs only after sufficient bending of the stem assembly reduces the gap between the liner tube and the support stem to zero. This force does not contribute significantly to the liner tube bending stress since it occurs near the liner tube aft end support. The aft end support of the support stem is taken to be at the location of the first dimple, i. e., 18.7 in. from the forward end support. A sketch of the support stem assembly model is shown in Figure 5-6. The equations giving the stresses and displacements are programmed in a code called BEAM.

5.8.2 Comparison of Analytical Predictions with Test Results

The experimental stem assembly was first subjected to a 60 mil forward end deflection, 1200 lbs. axial loading, and cycling pressure from zero to 500 psig. Loads for the second test were 81 mils deflection, 1620 lbs. tension and cyclic pressures from zero to 675 psig. No strain gages were included on the support stem. An estimate of the bending stress can be obtained from the theoretically calculated values shown in Figure 5-7. At 81 mils, for an axial load of 970 lbs. and a forward end slope of 0.0031 radians, the maximum bending stress is 21,700 psi. Extrapolating this stress to conditions of 1620 lbs. and zero end slope gives an estimated bending stress of 32,000 psi.

5.8.3 Verification of Analysis and Design Significance

The test conclusion states that the stem assemblies showed no significant deformation after loading. Calculations based on a 117,000 psi axial stress (1620 lbs. load) and a 32,000 psi bending stress give a combined stress of 149,000 psi. Since the material (Inconel 718) yield strength at room temperature is 161,000 psi no permanent deformation is expected.

This Page is UNCLASSIFIED

TABLE 5-1

SUPPORT STEM LOADS FOR THE FULL FLOW
CONDITION AND A WIDE OPEN SSCV

<u>Type of Load</u>	<u>Support Stem Load, lb.</u>
Core $\Delta P^{(1)*}$	578
Cup $\Delta P^{(2)}$	77
Weight	13
Hold-Down Spring ⁽³⁾	87
Lateral Friction ⁽⁴⁾	62
Thermal Core Gradient ⁽⁵⁾	8
Support Plate Bow ⁽⁶⁾	<u>19</u>
	844

* The numbers in parentheses refer to the values listed in Section 5.1.2.

TABLE 5-2

THEORETICAL AND EXPERIMENTAL STRAINS ON SURFACE OF CLOSURE CAP

	<u>Weld Area</u> <u>(1.2 in. from bottom)</u>	<u>Lower Area</u> <u>(0.5 in. from bottom)</u>
Longitudinal Strain ($\mu\text{in.}/\text{in.}$)	-80 (-95)*	34 (35)
Circumferential Strain ($\mu\text{in.}/\text{in.}$)	17 (30)	133 (145)

* The numbers in parentheses represent the experimental strain gage readings.

(THIS PAGE IS UNCLASSIFIED)

NOMINAL PRESSURE DROP, ΔP , PSI

Figure 5-1. Allowable* Nominal Pressure Drop Across SS 316 Liner Tube versus Liner Tube Temperature

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~

~~Atomic Energy Act of 1954~~

Figure 5-2 Closure Cap Assembly (Drawing 940J196)

Figure 5-3 Closure Cap Analytical Model (Finite Element Grid)

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
~~Atomic Energy Act of 1954~~

Figure 5-4 Closure Cap Strain Gage Locations

Figure 5-5. Liner Tube Bending Stresses for Elastic Support Conditions

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
Atomic Energy Act of 1954

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~
Atomic Energy Act of 1954

Figure 5-6, Support Stem and Liner Tube Deflections

Figure 5-7. Support Stem Bending Stresses Including Liner Tube Interference Force

6.0 CONCLUSIONS

The purpose of the test was accomplished. Capability of the support stem assembly was determined and the analysis performed on the structural adequacy of the support stem assembly was confirmed. Good agreement with the experimental results was obtained in the eight tests. Analytical techniques were shown to be sufficiently accurate for predicting structural adequacy.

The results confirm that Inconel 718 support stems and Type 316 stainless steel liner tubes are structurally adequate at expected reactor conditions. The strength of the components provides a high margin of safety beyond the maximum expected operating load and pressure.

The actual yield strength of the stem (2370 lbs. average) is 100% above the 1125 lbs. axial stem load which represents with a 95% confidence level the load below which 99% of the operating values should fall. The thread section is almost twice as strong as the shank, based on the average load values. In the stem tensile tests, the average yield and ultimate strength values of 169,000 psi and 199,000 psi, respectively, compare well with the property data values of 168,900 psi and 202,600 psi.

The tests on comparative strength of rolled and ground threads for the support stems indicate that the ground thread specimens are stronger than the rolled thread specimens. At room temperature, the difference was about 20% and at 1760°R the difference was 13% of the average strengths. One ground thread specimen in the high temperature test failed in the shank at the highest test load of the series. The reason for this type of failure has not been established at this time. The fabrication history shows that heat treatment on all specimens was as specified.

Based on these results, the stem for the reference design will be specified with ground threads, but the relative merits of ground threads and rolled threads will continue to be studied by additional testing on A-286 material.

The pressure test on the liner tube and cap assembly showed that a margin of safety of approximately seven exists on the ultimate strength.

The flexure test on the liner tube assembly showed that this component is capable of accommodating a 0.078 inch lateral deflection without damage.

In the cyclic pressure test, the strains recorded at the weld on the closure cap indicate that a margin of approximately eight exists on the pressure vs. allowable stress based on a turnaround ΔP of 668 psig. This margin does not include cluster load or thermal gradient stresses.

The cyclic pressure test with flexure and tension showed no adverse effects with .081 inch deflection, 1620 lbs. tension, and 675 psig pressure. For comparison, reactor operating values are expected to be 0.078 inch deflection or less, 1125 lbs. cluster load (99/95 condition), and 668 psig maximum pressure difference. It is concluded that the stem assembly will perform adequately under expected operating parameters.

No adverse effects resulted from the vibration test. A maximum strain measurement corresponding to a stress of 4215 psi was recorded at levels to 2.0g and 500 Hz.

The dynamic design requirements for the SSA have not been completely identified at this time. However, the lateral input to the nuclear stage is defined in SNPO-C6 as being predominantly in the frequency range below 6.5 Hz with less than 0.6 g's input above this frequency. It would appear then that the dynamic input to this test is considerably above this number for frequencies above 6.5 Hz and, hence, this test input can be considered to be dynamically conservative.

Table 6-1 summarizes the test results.

TABLE 6-1. SUMMARY OF TEST RESULTS

TEST	COMPONENT	EC-677558 SPECIFICATION REQUIREMENTS*	OPERATING CONDITIONS	TEST RESULTS	
				ACTUAL YIELD LOAD	ACTUAL ULTIMATE LOAD OR PRESSURE
TENSILE	Support Stem	Paragraph 3.1.1.1.2.1 Core Element Support Function	1125 lbs. load**	2370 lbs. average	2790 lbs. average at R. T.
	Rolled Thread Specimen	Same As Above	1125 lbs. load**	-----	5461 lbs. average at R. T. 4598 lbs. average at 1760°R
	Ground Thread Specimen	Same As Above	1125 lbs. load**	-----	6532 lbs. average at R. T. 5198 lbs. average at 1760°R
PRESSURE	Liner Tube	Paragraph 3.1.1.1.2.3 Thermal-Hydraulic Characteristics	668 psig	-----	4470 psi average
FLEXURE	Stem Assembly	Paragraph 3.1.1.1.2.1.1 Deflection Capability	0.078 in. deflection (design limit)	Liner tube was permanently bent about 1° at Station 0 after deflections greater than 0.25 in.	
VIBRATION	Stem Assembly	Paragraph 3.1.2.4.2.2 Loads Environment	-----	No adverse effects were detected.	
CYCLIC PRESSURE	Stem Assembly	Paragraph 3.1.1.1.2.3 Thermal-Hydraulic Characteristics	-----	No permanent deformations after 15 pressure cycles to 2600 psig.	
CYCLIC PRESSURE WITH FLEXURE & TENSION	Stem Assembly	Paragraph 3.1.1.1.2.3 Thermal-Hydraulic Characteristics	-----	No noticeable effects except for a maximum increase of 1.6 mils on liner tube diameter.	

*All values in the specification paragraphs referenced are to be defined.

**95% confidence level that 99% of the operating loads will fall below this value.

APPENDIX A TEST HARDWARE

<u>Title</u>	<u>Part Number</u>	<u>Serial Numbers</u>
Stem Assembly	388D443 G01	A 85636 A 85637 A 86075 A 86083 A 86088 A 86091 A 86093
Stem Assembly	388D443 G02	A 85635, A 86070, A 86074 A 85639, A 86077 A 85640, A 86080 A 85646, A 86081 A 85649, A 86084 A 85652, A 86088 A 86055, A 86135 A 86057, A 86149 A 86060, A 86150 A 86061 A 86062, A 86152 A 86064, A 89349 A 86069, A 89350
Support Stem	388D434 H01	A 86110 A 86112 A 86116 A 86120 A 86125 A 86129
Liner Tube	388D436 H01	----

<u>Title</u>	<u>Part Number</u>	<u>Serial Numbers</u>
Support Nut	100E510 H01	A 86047 thru A 86052
Closure Cap	388D441 H01	----
Locking Pin	800C515 H01	----
Rolled Thread Specimen	388D571 H01	A 86096 thru A 86106 A 89170
Ground Thread Specimen	388D571 H02	A 88944 thru A 88947 A 88949 thru A 88954

APPENDIX B-1
FIXTURE DRAWINGS

<u>Drawing Number</u>	<u>Description</u>
388D377	Tensile Test Stem Assembly
100E092	Tensile Test Stem Assembly
388D378	Pressure Test Stem Assembly
100E093	Pressure Test Stem Assembly
711J805	Cyclic Pressure with Flexure and Tension
711J829	Cyclic Pressure with Flexure and Tension
711J265	Cyclic Pressure with Flexure and Tension

APPENDIX B-2 TEST EQUIPMENT

Instrumentation

<u>Description</u>		<u>Used in Test No.</u>
Universal Testing Machine	Tinius Olsen	1, 2, 3, 8
Universal Testing Machine	Wiedemann	7
"X - Y" Recorders	Electro Instruments	1, 2, 3, 4, 5, 6, 7, 8
SR4 Strain Indicators	BLH MODEL 120	1, 5, 6
Switching and Balancing Unit	BLH MODEL 225	1, 5, 6
Radiant Heating Units	Research Inc.	2, 3
Powerstat	Superior Electric	2, 3
Hydraulic Pump 30,000 psi	Sprague	4, 5
Accumulator	Sprague	4, 5
Pressure Relief Valve	Circle Seal	4, 5
Tape Recorder 14 Channel	Consolidated	6
Oscilloscope	Tektronix	6
C-50 Shaker System	M. B. Electronics	6
Millivoltmeter	Thermo Electric	2, 3

Transducers

Strain Gages	Micromasurements	1, 4, 5, 6
Thermocouples	Thermo Electric	2, 3
Pressure Transducer 10,000 psi	Alinco	4, 5
Accelerometers	Endevco	6
Displacement Transducers	Collins	7
Load Cell 100 lbs.	Transducers Inc.	7
Displacement Gages	Federal	1, 2, 3, 7, 8
Micrometer	Starrett	1, 4, 5, 6, 7

TITLE	
	Stem Assembly Structural Test	
DOCUMENT NO.		DATE
WANL-TME-2734		September 1970
ABSTRACT		
<p>Tensile, pressure, flexure, and vibration tests were conducted on stem assemblies and thread specimens to determine structural adequacy. The results showed that the components are structurally adequate with a high margin of safety.</p>		
Fold --- or Cut	DATA ITEM NO.	SECURITY CLASSIFICATION OF DOCUMENT
	T-119	
	CDRL LINE NO.	TOTAL NO. OF PAGES
		86
KEY WORDS		
<p>Stem Assembly, Structural, Liner Tube, Tensile, Pressure, Flexure, Vibration, Deflection, Rolled Threads, Ground Threads</p>		
→	AUTHOR/EDITOR	PREPARING DEPT.
	D. Polinak	Reactor Design
W Form 59943		DOCUMENT INFORMATION SUMMARY

 Fold

or Cut