Westinghouse
Astronuclear
Laboratory

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WANL-TME-2731
SEPTEMBER 1970

DATA ITEM T-119

GRAPHITE FOIL SET TEST

FINAL REPORT

MASTER

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Westinghouse Astronuclear Laboratory

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DATA ITEM T-119

GRAPHITE FOIL SET TEST.

FINAL REPORT.

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INFORMATION CATEGORY

Unclassified

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ABSTRACT

Graphite foil laminates are used in the NERVA reactor as insulation on the core side of the reflector. This insulation is pressed between the lateral support seal segments which are supported by ledges projecting from the I. D. of the reflector. Knowledge of the compression characteristics (set, deflection, and spring constant) of the graphite foil insulator, which is determined in this test, is required in order to determine the size of the lateral support components and to determine the effect on the dynamic analysis of the lateral support.

Three insulation thicknesses were evaluated in this test: .035, .050, and .080 inch. Both deflection and set characteristics were studied for temperatures ranging from room temperature up to 2000°R and pressures ranging from 25 psi to 6000 psi.

It can be concluded from this test that the graphite foil laminated insulation in thicknesses up to .080 inch can be utilized in the R-1 reactor without significantly affecting the displacement or dynamic characteristics of the lateral support system.

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1.0 INTRODUCTION

1.1 TEST IDENTIFICATION

1.1.1 Type of Report

This report is a final report.

1.1.2 Scope of Test Document

The Scope of Test document is 63DE-205-0.

1.1.3 Functional Category of Test

This test is a development test of a candidate reactor material.

1.1.4 Contractor

The Westinghouse Astronuclear Laboratory under Subcontract NP-1, CY 1970, Project 728.

1.1.5 Test Facility

The tests were performed at the WANL Engineering Mechanics Laboratory during the period of August 1969 to June 1970.

1.2 PURPOSE OF TEST

The purpose of this test is to determine the compression properties (permanent set, deflection, and spring constant) of graphite foil insulation laminates of .035, .050, and .080 inch thicknesses for mechanical pressures from 25 psi to 6800 psi and temperatures from vapor up to 2000^oR. These data are required for use in the design of the reflector and lateral support of the R-1 NERVA reactor.

2.0 REFERENCES

2.1 DRAWINGS

800C663, Rev. - Specimen, Insulating, Set Test
388D511, Rev. - Specimen, Insulating, Thermal Conductivity

2.2 SPECIFICATIONS

PDS 30097-1 Graphite Foil Insulating Laminates

2.3 DATA REQUIREMENT SHEET

WANL Data Requirement Sheet T-119

2.4 SCOPE OF TEST DOCUMENT

63DE-205-1 Graphite Foil Set Test

2.5 DRMs USED AS SOURCE INFORMATION

51622 Test Plan Release - Graphite Foil Set Test
52167 Graphite Foil Set Test - Interim Report
52179 Release of Raw Data From the Graphite Foil Set Test
52282 Graphite Foil Set Test Results - Statistical Analysis
52551 Graphite Foil Set Test - 60 Cycle Results
52981 Graphite Foil Set Test - Final Test Report

3.0 DESCRIPTION OF TEST ARTICLE

3.1 TEST SPECIMEN

The test specimens were finish machined to size from laminated graphite foil insulation, WPDS 30097-1. These laminates were made from oriented graphite foil coated with a bonding agent and laminated on a substrate and then thermalized at 2200°C minimum temperature for at least 30 minutes. The test specimens are listed in Table 3-1.

TABLE 3-1
GRAFOIL TEST SPECIMEN DESCRIPTION

<u>Item</u>	<u>Part Number</u>	<u>Quantity</u>	<u>Thickness (In.)</u>	<u>Description</u>
1	800C663 H01	10	.050	Round, 1 inch diameter (7 foil layers minimum)
2	800C663 H02	39	.080	Round, 1 inch diameter (11 foil layers minimum)
3	388D511 H01	10	.035	Round, 1 inch diameter, cut from NRX-A6 insu- lating segments (5 foil layers minimum)
4	388D511 H02	10	.035	Rectangular 1 inch x 3 inch, cut from NRX-A6 insulating segments (5 foil layers minimum)

3.2 TEST SETUP

The test fixture, assembly Drawing 100E662, is shown schematically in Figure 3-1. Photographs of the test setup are shown in Figures 3-2, 3-3, and 3-4.

Figure 3-1. Graphite Foil Set Test Schematic

Figure 3-2. Test Setup

Figure 3-3. Test Setup

Figure 3-4. Test Setup

3.3 DATA ACQUISITION

The instruments used to record foil thickness and temperature are listed in Table 3-2.

TABLE 3-2
INSTRUMENTATION

<u>Measurement</u>	<u>Transducer</u>	<u>Recorder</u>
Temperature	Cr-A Thermocouple	Mini-Mite
Foil Thickness	Optron (Disp.Mea.Dev.)	X-Y Recorder
Plunger Force	Internal Load Cell of Universal Testing Machine	Visual Read- out, X-Y Recorder

4.0 SUMMARY OF TESTS

4.1 NARRATIVE

The test was performed on the Wiedemann Universal Test Machine where compression loads were applied through the plunger-anvil arrangement shown in Figure 3-1. An electric resistance heater was used to obtain the required test temperatures which were measured by means of a thermocouple probe. The thickness of the specimen was measured before and after the test using a micrometer. The thickness of the specimen was continuously recorded using an external target for the optron.

All of the 2000[°]R tests were performed in a 6 inch by 10 inch furnace using a helium atmosphere because graphite foil oxidizes in air at this temperature. For this test setup, optical measurements of foil thickness were recorded in steps using a telescope readout during the compression cycle.

4.2 TEST CONDITIONS

4.2.1 Test Parameters

4.2.1.1 Set and Spring Rate Measurements

The following measurements were taken:

- 1) thickness before test
- 2) thickness at load and temperature
- 3) thickness after load has been removed and specimen has returned to room temperature.

4.2.1.2 One Hour Test

A constant load was maintained on each specimen for one hour. The number of specimens tested and pressure and temperature conditions for the test are shown in Table 4-1.

TABLE 4-1
NUMBER OF SPECIMENS AND TEST CONDITIONS
ONE HOUR TEST

Pressure PSI Temp.	0-25-0	0-50-0	0-100-0	0-200-0	0-3200-0	0-6800-0
Room Temp.	2	2	2	2	2	2
1000°R	2	2	2	2	2	2
2000°R	2	2	2	2	2	2
Room Temperature	3 (Six consecutive test cycles using the listed pressures for each specimen.)					

800C663H02

Pressure PSI Temp.	0-25-0	0-50-0	0-100-0	0-200-0	0-3200-0	0-6800-0
Room Temperature	3		3			3

800C663H01, 388D511H01, and 388D511H02

4.2.1.3 Sixty Cycle Test

Specimens were subjected to 60 cycles at room temperature for the pressures shown in Table 4-2. During each cycle the specimen was held at pressure for 5 minutes.

TABLE 4-2
NUMBER OF SPECIMENS AND TEST CONDITIONS
60 CYCLE TEST OF .080 THICK SPECIMENS, 800C663 H02

<u>Test</u>	<u>No. of Specimens</u>	<u>Previous History of Specimens Used for This Test</u>
60 cycles to 200 psi-held at pressure for 5 min/cycle. Recorded load vs. deflection vs. time (room temperature).	3	200 psi at room temp, .2 mil set 200 psi at room temp, .5 mil set 100 psi at room temp, .1 mil set
60 cycles to 400 psi-held at pressure for 5 min/cycle. Recorded load vs. deflection vs. time (room temperature).	3	200 psi at 1000°R, .4 mil set 25 psi at 1000°R, .3 mil set 50 psi at room temp, .5 mil set
60 cycles to 600 psi-held at pressure for 5 min/cycle. Recorded load vs. deflection vs. time (room temperature).	1	25 psi at room temp, .1 mil set
60 cycles to 1000 psi-held at pressure for 5 min/cycle. Recorded load vs. deflection vs. time (room temperature).	1	25 psi at room temp, .2 mil set

4.2.2 Test Procedure

An initial calibration was performed to measure the displacement contribution to the measured data as a result of fixture material compression and thermal expansion properties. The same fixture was used for both the 60 cycle and one hour tests. The loading rate was approximately 40 lbs/second and unloading was instantaneous. The applied pressure was calculated from the measured load in pounds and the specimen cross-sectional area.

4.2.2.1 One Hour Test

The test procedure for each of the tests listed in Table 4-1 is detailed below:

- 1) Measure thickness of foil at room temperature.
- 2) Place foil specimen on anvil.
- 3) Place plunger on foil.
- 4) Bring foil to temperature.
- 5) Start X-Y Recorder.
- 6) Apply pressure for one hour (per Table 3-2).
- 7) Remove pressure and lift plunger.
- 8) Allow foil to cool at room temperature.
- 9) Stop X-Y Recorder.
- 10) Measure thickness of unloaded foil at room temperature.

4.2.2.2 Sixty Cycle Test

The test procedure for each of the tests listed in Table 4-2 is detailed below:

- 1) Measure thickness of foil.
- 2) Place foil specimen on anvil.
- 3) Place plunger on foil.
- 4) Start X-Y Recorder.
- 5) Apply pressure for five minutes.

- 6) Remove pressure and lift plunger.
- 7) Measure thickness of unloaded foil every 10th cycle.
- 8) Perform a total of 60 cycles.

4.3 TEST RESULTS

4.3.1 One Hour Tests - Recorded Data

The test results are summarized in Tables 4-3 through 4-7. The spring rates were determined from the linear portion of the load deflection curve. Some typical data traces are shown at representative pressures and temperatures in Figures 4-1 through 4-11.

4.3.2 One Hour Tests - Discussion of Recorded Data

Permanent set of the specimen is a function of the load applied to the foil and of the specimen thickness. Temperatures in the range from room temperature to 2000°R do not appear to have any effect on the amount of set. Tests on .080 inch thick specimens show a set of less than .001 inch at pressures up to 200 psi. The set increases to approximately .020 inch at a pressure of 3200 psi and approximately .026 inch at a pressure of 6800 psi. Set at 6800 psi pressure decreases to .016 inch for .050 inch thick specimens and to .008 inch for .035 inch thick specimens. Comparison tests on circular specimens of 1 inch diameter and rectangular specimens of 1 inch by 3 inch size show less than .0003 difference in set at 200 psi pressure and no difference at 6800 psi pressure.

Tests on the .080 inch specimens show deflection is directly proportional to load up to 200 psi and not dependent on temperature. Figure 4-12 shows a plot of deflection vs.

TABLE 4-3
 TEST RESULTS 80 MIL FOIL
 (800C663H02)

Pressure PSI	Temperature	Thckns.* Before Load Mils	Thckns.* After Load Mils	Perm. Set Mils	Maximum Defl. Mils	Spring Constant lb./in.
25 Nominal	Room Temp.	81.6	81.2	.4	.6	46,000
25 Nominal	Room Temp.	81.6	81.5	.1	.5	52,000
25 Nominal	1000°R	82.0	81.8	.2	.4	55,000
25 Nominal	1000°R	81.7	81.4	.3	.4	54,000
50 Nominal	Room Temp.	81.3	80.8	.5	.8	50,000
50 Nominal	Room Temp.	82.4	82.2	.2	.5	73,000
50 Nominal	1000°R	81.7	81.4	.3	.8	53,000
50 Nominal	1000°R	82.4	82.2	.2	No Reading	
50 Nominal	2000°R	82.1	82.1	0	.9	40,000
50 Nominal	2000°R	81.9	81.9	0	.5	40,000
100 Nominal	Room Temp.	81.5	81.4	.1	1.0	83,000
100 Nominal	Room Temp.	82.6	82.5	.1	1.0	83,000
100 Nominal	1000°R	81.7	81.5	.2	.8	93,000
100 Nominal	1000°R	81.8	81.7	.1	1.6	54,000
100 Nominal	2000°R	80.9	80.6	.3	2.5	35,000
100 Nominal	2000°R	81.2	81.2	0	2.7	39,000
200	Room Temp.	82.5	82.0	.5	3.0	51,000
200	Room Temp.	81.5	81.3	.2	3.0	53,000
200	1000°R	81.5	81.0	.5	3.0	52,000
200	1000°R	81.7	81.3	.4	2.5	61,000
200	2000°R	80.9	80.8	.1	3.6	41,000
200	2000°R	81.5	81.3	.2	4.0	41,000

*Average of Five Readings.

Note: All spring constant values are for a one-inch diameter specimen.

TABLE 4-3

(Continued)

<u>Pressure PSI</u>	<u>Temperature</u>	Thckns.* <u>Before</u> <u>Load</u> <u>Mils</u>	Thckns.* <u>After</u> <u>Load</u> <u>Mils</u>	<u>Perm.</u> <u>Set</u> <u>Mils</u>	<u>Maximum</u> <u>Defl.</u> <u>Mils</u>	<u>Spring</u> <u>Constant</u> <u>lb./in.</u>
3200	Room Temp.	82.9	58.5	24.4	38	53,000 **
3200	Room Temp.	82.7	59.9	22.8	33	44,000 **
3200	1000°R	81.6	61.9	19.7	30	45,000 **
3200	1000°R	81.3	60.0	21.3	29	47,000 **
3200	2000°R	80.7	61.4	19.3	40	Not Linear
3200	2000°R	81.6	59.1	22.5	44	Not Linear
6800	Room Temp.	80.9	54.5	26.4	35	50,000 **
6800	Room Temp.	82.3	55.4	26.9	37	50,000 **
6800	1000°R	81.2	54.6	26.6	40	46,000 **
6800	1000°R	81.1	53.7	27.4	37	48,000 **
6800	2000°R	81.6	59.1	22.5	50	Not Linear
6800	2000°R	No Reading				

**Linear Portion of Curve (to approximately 1000 p.s.i.)

Note: All spring constant values are for a
one-inch diameter specimen.

TABLE 4-4
 CYCLE TESTS 80 MIL FOIL
 (800C663H02)

Pressure PSI	Temperature °R	Thckns.* Before Load Mils	Thckns.* After Load Mils	Perm. Set Mils	Spring Constant lb./in.
0-25-0	Room Temperature	80.9	80.9	0	No Reading
0-50-0	Room Temperature	80.9	80.6	.3	No Reading
0-100-0	Room Temperature	80.6	80.4	.5	83,000
0-200-0	Room Temperature	80.4	80.4	.5	85,000
0-3200-0	Room Temperature	80.4	63.6	17.3	50,000
0-6800-0	Room Temperature	63.6	55.7	25.2	Not Linear
0-25-0	Room Temperature	81.8	81.7	.1	No Reading
0-50-0	Room Temperature	81.7	81.7	.1	No Reading
0-100-0	Room Temperature	81.7	81.6	.2	48,000
0-200-0	Room Temperature	81.6	81.4	.4	Not Linear
0-3200-0	Room Temperature	81.4	64.1	17.7	≈ 50,000
0-6800-0	Room Temperature	64.1	56.1	25.7	Not Linear
0-25-0	Room Temperature	81.8	81.7	.1	No Reading
0-50-0	Room Temperature	81.7	81.7	.1	No Reading
0-100-0	Room Temperature	81.7	81.6	.2	No Reading
0-200-0	Room Temperature	81.6	81.6	.2	65,000
0-3200-0	Room Temperature	81.6	65.6	16.2	57,000
0-6800-0	Room Temperature	65.6	57.4	24.4	Not Linear

*Average of Five Readings

Note: All spring constant values are for a one-inch diameter specimen.

Note: No reading indicates failure of Data System to produce acceptable trace for interpretation due to noise level.

TABLE 4-5
TEST RESULTS 50 MIL FOIL
(800C663H01)

<u>Pressure PSI</u>	<u>Temperature °R</u>	<u>Thckns.* Before Load Mils</u>	<u>Thckns.* After Load Mils</u>	<u>Perm. Set Mils</u>	<u>Maximum Defl. Mils</u>	<u>Spring Constant lb./in.</u>
25	Room Temp.	51.3	51.3	0	.2	120,000
25	Room Temp.	51.3	51.2	.1	.2	115,000
25	Room Temp.	51.3	51.2	.1	.2	105,000
100	Room Temp.	51.9	51.8	.1	.4	195,000
100	Room Temp.	51.6	51.2	.4	.6	125,000
100	Room Temp.	51.4	51.4	0	.6	120,000
6800	Room Temp.	51.7	34.6	17.1	23	67,000 **
6800	Room Temp.	51.4	36.8	14.6	21	80,000 **
6800	Room Temp.	50.5	33.0	17.5	24	60,000 **

*Average of Five Readings

**Linear Portion of Curve (to approximately 1000 p.s.i.)

Note: All spring constant values are
for a one-inch diameter specimen.

TABLE 4-6
 TEST RESULTS 35 MIL FOIL
 (388D511H01)

<u>Pressure PSI</u>	<u>Temperature °R</u>	<u>Thckns.* Before Load Mils</u>	<u>Thckns.* After Load Mils</u>	<u>Perm. Set Mils</u>	<u>Maximum Defl. Mils</u>	<u>Spring Constant lb./in.</u>
25	Room Temp.	37.5	37.4	.1	No Reading	
25	Room Temp.	37.0	36.9	.1	.7	30,000
25	Room Temp.	37.2	37.0	.2	.7	33,000
100	Room Temp.	37.1	36.8	.3	2.5	Not Linear
100	Room Temp.	36.8	36.7	.1	2.0	Not Linear
100	Room Temp.	37.0	36.7	.3	2.2	Not Linear
6800	Room Temp.	36.4	27.9	8.5	13	Not Linear
6800	Room Temp.	35.4	27.4	8.0	12	Not Linear
6800	Room Temp.	34.7	27.5	7.2	10	Not Linear

*Average of Five Readings

Note: All spring constant values are for a one-inch diameter specimen.

TABLE 4-7
35 MIL RECTANGULAR FOIL
(388D511H02)

<u>Pressure PSI</u>	<u>Temperature °R</u>	<u>Thckns.* Before Load Mils</u>	<u>Thckns.* After Load Mils</u>	<u>Perm. Set Mils</u>	<u>Maximum Defl. Mils.</u>	<u>Spring Constant lb./in.</u>
25	Room Temp.	37.7	37.5	.2	1.5	Not Linear
25	Room Temp.	38.5	38.0	.5	3	Not Linear
25	Room Temp.	37.9	37.7	.2	2.5	Not Linear
100	Room Temp.	38.1	37.7	.4	2	Not Linear
100	Room Temp.	37.0	36.6	.4	2.5	Not Linear
100	Room Temp.	38.6	38.1	.5	3.5	Not Linear
6800	Room Temp.	37.3	29.3	8.0	No Reading	Not Linear
6800	Room Temp.	37.5	30.2	7.3	14	Not Linear
6800	Room Temp.	38.4	30.1	8.3	15	Not Linear

*Average of Nine Readings

Figure 4-1. 25 PSI 80 Mil Foil 1000°R Typical Trace

Figure 4-2. 200 PSI 80 Mil Foil 1000°R Typical Trace

Figure 4-3. 3200 PSI 80 Mil Foil Room Temperature Typical Trace

Figure 4-4. 6800 PSI 80 Mil Foil Room Temperature Typical Trace

Figure 4-5. 100 PSI 50 Mil Foil Room Temperature Typical Trace

Figure 4-6. 6800 PSI 50 Mil Foil Room Temperature Typical Trace

Figure 4-7. 100 PSI 35 Mil Foil Room Temperature Typical Trace

Figure 4-8. 6800 PSI 35 Mil Foil Room Temperature Typical Trace

Figure 4-9. 25 PSI 35 Mil Rectangular Foil Room Temperature Typical Trace

Figure 4-10. 100 PSI 35 Mil Rectangular Foil
Room Temperature Typical Trace

4-23

Figure 4-11. 6800 PSI 35 Mil Rectangular Foil
Room Temperature Typical Trace

Maximum Deflection - MILS

Figure 4-12. Maximum Deflection Versus Pressure and Temperature - 80 Mil Foil

load and also gives the estimated standard deviation. Traces from the test, as in Figure 4-3, show that the deflection is linear up to about 1000 psi pressure. Data in the tables show that the thinner specimens behave different than the thick specimens as they exhibit more deflection at low pressures. This discrepancy is probably due to the measurements being made in fractions of a mil and electrical instrument noise causes some distortion of the force-deflection curve as seen in Figure 4-1. At the higher test pressures, the deflection does vary as a function of the specimen thickness as expected. Other factors affecting the deflection results at low pressures are the foil layer interactions and the binder properties.

The spring constant for .080 inch thick specimens was statistically determined to be 54,700 lbs/in with a standard deviation of 8,680 lbs/in. Figures 4-1 through 4-6 show that the 80 and 50 mil specimens both have a constant force-deflection slope to approximately 1000 psi pressure. Figures 4-7 to 4-11 show that the 35 mil specimens do not exhibit this linear spring constant at low pressures.

4.3.3 Sixty Cycle Tests - Recorded Data

The test results are summarized in Table 4-8 and Figure 4-13.

4.3.4 Sixty Cycle Tests - Discussion of Recorded Data

Selected .080 inch thick specimens that had been previously tested to give the data in Table 4-3 were each submitted to sixty additional load cycles.

Permanent set as a function of number of cycles is given in Figure 4-13. Most of the set takes place in the first ten cycles, and it appears that the limit on set is reached in the range of 30 to 50 cycles.

Deflection data were not available for this portion of the test.

TABLE 4-8
PERMANENT SET FOLLOWING CYCLIC LOADING
80 MIL FOIL

<u>Pressure</u>	<u>Number of Cycles</u>	<u>Number of Specimens</u>	<u>Total Set * (Mils) After 60 Cycles</u>	<u>Avg. Total Set (Mils) After 60 Cycles</u>
200 psi	60	3	.66, .36, .2	.4
400 psi	60	3	.6, 1.4, .66	.88
600 psi	30	1	2.5	
1000 psi	30	1	11.9	

*Average of Five Readings at the End of 60 Cycles

Figure 4-13. Thickness Versus Number of Cycles - 80 Mil Foil (Nominal)

5.0 ANALYSIS

5.1 ANALYTICAL MODEL

The purpose of this test, in part, was to verify some of the assumptions made in the analysis of the lateral support system (LSS). These assumptions are that the effects of foil permanent set and deflection are small and can be easily accounted for in the static design and that the elastic spring constant of the foil is many orders of magnitude higher than the coil spring rate. The second assumption implies a negligible effect on the low to intermediate frequency dynamics of the LSS. These assumptions are implicit in the present formulations of the Structural Design static program LATSUP and the current form of the NSS dynamic model.

5.2 COMPARISON OF ANALYTICAL PREDICTIONS AND TEST RESULTS

As the purpose of the test was mainly to verify the design assumptions and as the load deflection curves exhibit non-linear and inelastic behavior, detailed predictions above and beyond those discussed in Section 5.1 were not made for this test. Some general trends in the data, however, were expected.

It was predicted that the foil permanent set and total deflection would increase with a hardening spring type of non-linearity with an increase in pressure and would increase linearly with an increase of foil thickness. Both foil set and total deflection were predicted to show only a small increase with increasing temperature due to mainly a decrease in the elastic and tangent moduli of the material. For the size of specimens considered, creep was predicted to be negligible.

As seen from the data of Section 4 the variation of the foil deflection and permanent set with pressure apparently follows the qualitative predictions for each foil thickness, although the set of the .080 thick foil was approximately constant for pressure up to 200 psi. As discussed in the following section, the average foil contact pressure during reactor operation is less than 25 psi although localized average pressures approach 425 psi. The effect of foil thickness on both set and total deflection is approximately linear at pressures of 6800 psi. At these pressures the foil layers are in direct contact and the response approaches that of a homogeneous body. At pressures below 200 psi, however, no consistent trend of both deflection and set with foil thickness is discernible. The magnitude of data

points is close to the system sensitivity points, so that all the data points at low pressures may contain some noise which may cloud the true trends. A review of data indicates there was no appreciable change in the foil set and deflection with an increase of temperatures to 2000°R.

The graphite foil elastic spring constant was predicted to be independent of pressure and thickness and to show a slight decrease with increasing temperature due to a decrease in the elastic modulus.

Test results fairly well substantiate these predictions. There appears to be a slight decrease in spring constant at temperatures of 2000°R. Although there are wide variations in the data, it appears that the results are independent of pressure. The data indicate a possibility of a thickness effect for very low pressures. As previously discussed in Paragraph 4.3.2, other phenomena are acting in this low pressure region. One should also note that it is very difficult to read off the initial spring constants from the curve traces.

If one assumes that the first load application above roughly 200 psi eliminates the effects of fabrication and special interlayer phenomena, then a second load application would only slightly increase the permanent set, for example. The results of this test support this contention. There appears to be no significant increase in any of the three foil test parameters, set, deflection and spring constant, with an increase in the number of applied cycles up to 60 cycles.

In summary, except for some low pressure anomalies, the test results agree well with the qualitative predictions. The next section will examine in a quantitative fashion the design significance of the test results on the present reference design.

5.3 DESIGN SIGNIFICANCE

In this section, we will consider the degree to which the graphite foil affects the LSS design. Conservatively, we will consider a reference design LSS, per Drawing 940J418, designed for INT-21 launch, a Saturn V type vehicle.

Figure 5-1. Outer Seal Segment Dimensions and Free Body Diagram

The maximum expected loads F_1 and F_2 were obtained using the computer code LATSUP.

$$F_1 = 150 \text{ lbs./plunger}$$

$$F_2 = 225 \text{ lbs./plunger}$$

Average pressures under these loads are:

$$P_1 = \frac{150}{1.4 \pi (21) \times 2/36} = 25 \text{ psi} \quad P_2 = \frac{225}{.15 \pi (21) \times 2/36} = 425 \text{ psi}$$

It appears that the 425 psi pressure will produce nearly the same permanent set as at 200 psi. Of course, the elastic deflection will be much higher.

The maximum lumped (inner and outer) seal temperature is 1180° from TNT-2/RATS runs. The foil, of course, is much cooler.

It appears conservative, for a design using .035 inch thick insulation, to use a permanent set of .4 mils under p_1 , and a permanent set of .9 mils under p_2 for 60 cycles and an average spring constant of 64,000 lbs/in for each square inch of insulation from the cyclic data of Section 4.

Elastic Deflections $\delta_{e, i}$

$$\delta_{e, 1} = \frac{p_1}{K} = \frac{25 \text{ lbs/in}^2}{64,000 \text{ lbs/in}^3} = .4 \text{ mils}$$

$$\delta_{e, 2} = \frac{p_2}{K} = \frac{425 \text{ lbs/in}^2}{64,000 \text{ lbs/in}^3} = 6.6 \text{ mils}$$

Permanent Set $\delta_{p, i}$

$$\delta_1 = .4 \text{ mils for 60 cycles}$$

$$\delta_2 = .9 \text{ mils for 60 cycles}$$

We note from the preceding sketch that a deflection of the outer seal δ_1 , would cause the inner seal to move aft $+\delta_1 \tan \beta$, whereas, an outer seal change δ_2 would cause the inner seal to slide in the outer seal with the resulting aft displacement δ_2 . Hence, the resulting displacement for analysis purposes is $\delta = \delta_1 \tan \beta + \delta_2$.

Due to the geometry of the reference design inner seal, an aftward displacement of the inner seal would increase the plunger overhang by an amount $\delta \tan 30^\circ = .577 (1.74 \delta_1 + \delta_2)$.

Plunger Motion

$$\delta_e = .577 (1.74(.4) + 6.6) = 4.2 \text{ mils}$$

$$\delta_p = .577 (1.74(.4) + .9) = .92 \text{ mils}$$

Based on analysis of previous reference designs, these deflections would produce a change in the G_{BA} value of the system of

$$\% G_{BA} \text{ reduction caused by elastic action} = .6\%$$

$$\% G_{BA} \text{ reduction caused by plastic action} = .1\%$$

Total reduction in G_{BA} caused by foil deflection	.7%
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This is negligible for analysis purposes, however, the deflection must be allowed for in the plunger design.

Finally, the foil elastic spring constant is an order of magnitude greater than that of the LSS compression spring rate so that the foil has a negligible effect on the first few dynamic modes of the LSS.

6.0 CONCLUSIONS

It can be concluded from this test that graphite foil insulation, in thicknesses up to .080 inch, can be utilized to insulate the inside diameter of the reflector without significantly affecting the displacement or dynamic characteristics of the lateral support system.

Data from this test will be utilized in the sizing of the lateral support components. For instance, in the case of the current reference design, Drawing No. 940J418, the reflector I. D. would be increased approximately .003 inch due to the radial deflection of the .035 insulation. The combination of radial and axial deflections will affect the G breakaway capability by less than 1%.

The dynamic response of the system will not be altered much since the average spring rate for this material was measured to be 64,000 lbs/in for each square inch of insulation.

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	DOCUMENT NO. WANL-TME-2731	DATE September 1970
ABSTRACT <p><i>Graphite foil laminates are used in the NERVA reactor as insulation on the core side of the reflector. This insulation is pressed between the lateral support seal segments which are supported by ledges projecting from the I. D. of the reflector. Knowledge of the compression characteristics (set, deflection, and spring constant) of the graphite foil insulator, which is determined in this test, is required in order to determine the size of the lateral support components and to determine the effect on the dynamic analysis of the lateral support.</i></p>		
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