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WANL-TME-2746
September 1970

DATA ITEM T-119

STRUCTURAL TESTING
OF SECONDARY SUPPORT
ASSEMBLY (U)

DEVELOPMENT TEST REPORT

MASTER

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DATA ITEM T-119

STRUCTURAL TESTING OF SECONDARY SUPPORT ASSEMBLY (U)

DEVELOPMENT TEST REPORT

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Approved By:

J. G. Gallagher
J. G. Gallagher, Manager
NERVA Design Engineering

INFORMATION CATEGORY	
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ABSTRACT

(CRD) This work describes the structural testing and analysis performed to evaluate the tensile, compressive and flexure characteristics of the secondary support assembly at the cold end of a NERVA graphite cluster. The graphite elements were manufactured from GLF flour per PDS 30136-2.

(CRD) A series of seven tests were to be conducted by loading the cold end of a prototype cluster assembly to failure. These tests are:

1. Tensile load at room temperature
2. Tensile load at 140°R
3. Tensile load at 1700°R
4. Tensile load at room temperature with flexure
5. Tensile load with cycled temperature
6. Compressive load at room temperature
7. Flexure load at room temperature

(U) This report covers the completed tests 1, 4 and 7 and their analyses. The results of tests 2, 3, 5 and 6 will be reported upon completion of the test as data become available.

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1.0 INTRODUCTION

(CRD) This work presents the test results and data analysis for room temperature testing conducted on the secondary support assembly of the cluster cold end. The discussions include tensile, flexure and combined tensile and flexure testing. Three assemblies with graphite elements were tested in each respective test series, and all central elements contained the instrumentation hole.

1.1 TEST IDENTIFICATION

1.1.1 Type of Report

(U) This report is periodic.

1.1.2 Scope of Test Document

(U) TS:58 DE-217-2

1.1.3 Functional Category of Test

(U) Development.

1.1.4 Contractor

(U) Westinghouse Astronuclear Laboratory (WANL/14683) under Subcontract NP-1,CY 1970

1.1.5 Test Facility

(U) Engineering Mechanics Department, Building 8, test dates July 10 to July 28, 1970.

1.2 PURPOSE OF TEST

(CRD) The purpose of this test was to determine the tensile, compressive and flexural characteristics of the secondary support assembly planned for use in the R-1 reactor at the cold end of the cluster assemblies.

2.0 REFERENCES AND ASSUMPTIONS

2.1 SPECIFICATIONS

CEI No. EC-677558 paragraphs 3.1.1 and 3.1.1.1.4

2.2 SCOPE OF TEST DOCUMENTATION

TS:58 DE-217-2

2.3 TEST PLAN

DRM 51624 "Test Plan for Secondary Support Assembly Structural Test"

2.4 ANALYSIS REFERENCES

2.4.1 DRM 53164 - AXF Material Properties

2.4.2 DRM 51230 - AXM Material Properties

2.4.3 WANL-TMI-1974 - Theory and Application of Fracture Mechanics

2.4.4 WANL-TME-2734 - Stem Assembly Structural Test

2.5 ASSUMPTIONS

It is assumed that the results obtained will be useful in verifying techniques for preducting failure loads.

3.0 DESCRIPTION OF TEST ARTICLE

(CRD) Cluster cold end secondary support assemblies, with four inch long graphite elements, consisting of the hardware listed in Table 1 and shown in Figure 1* were the test specimens. A short liner tube was used to maintain the hanger tongues in position.

TABLE I **

SECONDARY SUPPORT ASSEMBLY LIST OF PARTS - QUANTITIES
ARE SHOWN AS REQUIRED PER CLUSTER

388D572H01	Central Element Specimen	1	
100E512H01	Cluster Plate	1	
388D438H01	Hanger	1	
388D440H01	Threaded Sleeve	1	
388D442H02	Slotted Sleeve	1	
577F505H01	Screen Retention Plate	1	*
577F509G04	Element - Orifice Assembly	6	
800C655H01	Support Collar	6	
800C656H01	Element Support Nut	6	
800C657H01	Support Key	2	
800C666H01	Belleville Washers	12	

*An additional plate will be used as a spacer in place of the poison plate.
Group numbers are shown per ECO 16582.

* All Figures are numbered consecutively 1 through 25 in Section 7.0, ILLUSTRATIONS.

** Tables are numbered I through V and are dispersed through the text.

4.0 SUMMARY OF TESTS.

4.1 NARRATIVE

(CRD) A series of seven tests are to be conducted by loading the cold end of a prototype cluster assembly to failure. The tests are as follows:

1. Tensile load at room temperature
2. Tensile load at 140°R
3. Tensile load at 1700°R
4. Tensile load at room temperature with flexure
5. Tensile load with cyclic temperature
6. Compressive load at room temperature
7. Flexure load at room temperature

(U) The progress in this report covers the completion of tests 1, 4 and 7. The results of tests 2, 3, 5 and 6 will be reported as data become available.

4.1.1 Tensile Load at Room Temperature

(U) Three secondary support assemblies were instrumented with load cells and tensile tested to failure. The load cells, see Figure 2, were threaded and bonded in the aft end of the four inch long elements. Bonding the load cells to the elements with Armstrong A-2 adhesive was required in order to make the fixture end of the elements stronger than the test end. The clusters were assembled per Drawing 939J698.

4.1.2 Tensile Load at Room Temperature with Flexure

(CRD) Bundled clusters, assembled per Drawing 939J698, were supported aft of station zero. The hanger's forward end was laterally displaced 60 mils, and a tensile load to failure was applied at the aft end of the four inch long elements.

4.1.3 Flexure Load at Room Temperature

(U) Three bundled clusters, assembled per Drawing 939J698 and shown in Figure 3, were flexure tested at room temperature.

4.2 TEST CONDITIONS

4.2.1 Tensile Load

(CRD) The test was conducted at room temperature in a loading fixture shown on Figure 4. The test set up is shown in Figure 5. Clusters were positioned in the fixture with the forward end of the hanger supported at the base of the fixture, and the cluster spring was preloaded to 60 pounds. Each element was loaded equally and simultaneously in tension by means of seven hydraulic cylinders. A hydraulic modulator provided the uniform pressure. The calibrated output signal from the load cells was recorded on an eight channel Brush recorder. Three displacement transducers positioned 120 degrees apart recorded displacement and assured axiality of loading.

4.2.2 Tensile Load with Flexure

(CRD) The tensile load to failure with flexure test was conducted at room temperature in a loading fixture shown on Figures 6 and 7. Clusters were positioned in the test fixture with the forward end of the hanger supported at the base of the fixture, and the cluster spring was preloaded to 60 pounds. The cluster was bundled aft of station zero by a fixture consisting of three bolts with toggle pads on each element outer face. Each bolt was torqued to 10 lb-in. The bundling load was distributed on the cluster by using graphite strips between the elements and the toggle pads as shown on Figures 7 and 8. The traction was approximately 325 psi compression between the graphite strips and elements.

(CRD) The forward end of the hanger was deflected laterally 60 mils with respect to station zero, and each element was loaded equally and simultaneously in tension by means of seven hydraulic cylinders. A hydraulic modulator provided the uniform pressure. The calibrated output signal from the load cells was recorded for the first test - Assembly 7, by a Brush recorder. A VIDAR data acquisition system was used to record data from the second and third tests - Assemblies 8 and 9. Three displacement transducers positioned 120 degrees apart recorded displacement and assured axiality of loading. Lateral deflection (60 mils) of the hanger's forward end was monitored by three displacement gages.

4.2.3 Flexure Load

(CRD) The flexure load test consisted of supporting a bundled cluster assembly aft of station zero with the forward end of the assembly acting as a cantilever beam. The Bundling consisted of the 325 psi described above. Figure 9 shows the flexure test setup in the Universal Testing Machine. A closeup and a schematic of the test setup is shown in Figures 10 and 11. The tensile spring load of 60 lbs. was applied by a calibrated spring. Flexure loading was applied at the forward end of the hanger. The ram speed was 20 mils per second for all tests. Forward motion of the cluster was prevented by the bundling force and by bolting the aft end of the four inch long elements to a plate which in turn was bolted to the fixture as shown on Figure 11.

(CRD) Deflections were monitored by two displacement transducers and a displacement gage. One displacement transducer was located at the forward end of the hanger and in line with the flexure load; the other, was located at the cluster plate and monitored the lateral movement. The displacement gage was used as a visual aid and provided a displacement verification. Flexure loads for the 100 mil displacement runs were monitored by a 100 pound load cell. The 100 pound load cell was changed to one with a 1000 pound capacity when loading to failure.

4.3 TEST RESULTS

4.3.1 Recorded Data

4.3.1.1 Tensile Test

(U) Tensile test results of the secondary support assembly, at room temperature, are presented in Table II.

4.3.1.2 Tensile Load with Flexure

Test results of the secondary support assembly subjected to tensile load with flexure at room temperature are presented in Table III.

4.3.1.3 Flexure Load

(CRD) Recorded data for the secondary support assembly flexure test is presented in Table IV. Figure 12 shows a plot of deflection at the forward end of the hanger and at the cluster plate versus the flexure load applied at the forward end of the hanger for the 100 mils deflection condition. The deflection versus load plot of Assembly No. 5 Run No. 4 is typical, and it was subjected to four cycles of 100 mils deflection. A plot of the flexure load to permanent deformation for Assembly 4 is shown in Figure 13.

4.3.2 Discussion of Data

4.3.2.1 Tensile Test

(CRD) All failures occurred in the threads. The central elements failed about two inches away from the cluster plate, and the 19 hole elements failed at the jet orifices in the last thread engaged. The mode of failure is shown in Figures 14, 15, 16 and 17. In the first test (Assembly 1) the central element failed at a load of 170 pounds. Loading was continued, and the 19 hole elements failed at loads from 345 to 435 pounds. In the second and third tests (Assemblies 2 and 6), the central elements failed at 425 and 440 pounds. The 19 hole elements failed at loads from 370 to 430 pounds. See Table II.

TABLE II

RESULTS - TENSILE TEST OF SECONDARY SUPPORT
ASSEMBLY AT ROOM TEMPERATURE

Element Description	Assembly 1		Assembly 2		Assembly 6	
	Serial No.	Failure Load (lbs)	Serial No.	Failure Load (lbs)	Serial No.	Failure Load (lbs)
	001-101		001-101		001-101	
Central	606-2	170	605-4	425*	785-2	440
19 Hole	1048363-7	370	1048357-3	400	1048363-2	390
19 Hole	1048365-4	405	1048365-8	387	1048335-8	370
19 Hole	1048363-6	420	1048357-4	388	1048335-4	405
19 Hole	1048365-9	345	1048357-1	385	1048363-1	425
19 Hole	1048365-6	435	1048357-5	400	1048335-2	430*
19 Hole	1048365-3	405	1048357-11	390	1048335-1	415

*This channel of brush recorder failed during test. Failure loads were obtained from pressure (monitored by pressure transducer) and force factor (obtained from cylinder calibration).

TABLE III
RESULTS-TENSILE LOAD WITH FLEXURE OF SECONDARY
SUPPORT ASSEMBLY AT ROOM TEMPERATURE (CRD)

Element** Description	Assembly 7		Assembly 8		Assembly 9	
	Serial No.	Failure Load(lbs)	Serial No.	Failure Load(lbs)	Serial No.	Failure Load(lbs)
Central-1	001-1017 85-3	270	001-101 7855	325	001-1017 85-06	330
19 Hole - 2	1048367-10	430	1048362-1	355	1048366-4	330
19 Hole - 3	1048363-5	445*	1048361-1	373	1048367-3	555
19 Hole - 4	1048365-10	415	1048362-2	390	1048367-1	507
19 Hole - 5	1048367-6	420	1048365-2	378	1048366-3	335
19 Hole - 6	1048367-7	480	1048363-4	420	1048366-6	330
19 Hole - 7	1048367-2	420	1048367-4	375	1048361-4	330

* This channel of Brush Recorder failed during test. Failure load was obtained from pressure (monitored by pressure transducer) and force factor (obtained from cylinder calibration).

** Element location with respect to the direction of deflection is shown in the sketch below:

Direction of Deflection

4.3.2.2 Tensile Load with Flexure

(CRD) As in the tensile test, failures obtained from clusters subjected to tensile load with flexure occurred in the elements. The central elements failed at the threaded sleeve in the last thread engaged. The regular (19 hole) elements failed in the jet orifices, also, in the last thread engaged, with one exception. A regular element failed approximately a quarter inch away from the load cell end (see Figures 20, 21 and 22). The mode of failure for the three assemblies tested is shown in Figures 18, 19, 20, 21 and 22. The central elements, manufactured with a 100 mil instrumentation hole, failed at loads from 270 to 330 pounds. Regular (19 hole) elements failed at loads ranging from 330 to 555 pounds. See Table III.

4.3.2.3 Flexure Load

(CRD) Specimen examination after deflecting 100 mils, at the forward end of the hanger, showed no permanent deformation. The first test run for each specimen showed that the deflections from 14 to 34 mils at the forward end of the hanger were due to free play and slack between mating components. The second test run to 100 mils showed deflections of 3 to 14 mils, at the forward end of the hanger. Again, after examination no permanent deformations were noted. Several additional tests were performed to 100 and 200 mils deflection. See Table IV.

(CRD) Deformation of the hanger and bending of the liner tube was determined to be the mode of failure from flexure loading the forward end of the hanger. Figure 23 shows Assembly No. 5 in the test setup without the spring after it was deflected 715 mils. The modes of failure of Assemblies 3, 4 and 5 are shown in Figures 24 and 25, and are described in Table IV.

TABLE IV
SECONDARY SUPPORT ASSEMBLY FLEXURE TEST RESULTS

Cluster Assembly Number	Test Run No.	Deflection at Maximum Load		Load (lbs)	Deflection after Unloading		Comments
		at Hanger (mils)	at Cluster Plate (mils)		at Hanger (mils)	at Cluster Plate (mils)	
3	1	100	0.5	57	24*	0	Performed visual inspect.
3	2	100	0.5	66	11	0	Performed visual inspect.
3	3	596	10	178	***	8	Deflected to .596 in.
4	1	100	1.5	32.5	14*	1	Performed visual inspect.
4	2	100	0.6	35.5	3	0	Performed visual inspect.
4	3	100	0.6	37.0	1	0	Performed visual inspect.
4	4**	890	16	208	348	3	Deflected to .890 in.
5	1	100	2	38.5	34*	2	Performed visual inspect.
5	2	100	2	55	9	1	Performed visual inspect.
5	3	100	2.5	58.5	3	1	Performed visual inspect.
5	4**	100	2	59	2	1	Performed visual inspect.
5	5	200	3.5	85	62	1.5	Performed visual inspect.
5	6	200	5	110	6	1	Performed visual inspect.
5	7	715	15	173	540	10	Deflected to .715 in.

*After deflecting 100 mils and examining the hardware showed no permanent deformation. The deflections obtained at the forward end of the hanger are due to free play and slack between mating components.

**Deflection versus load graphs for these runs are shown in Figures 5 and 6.

***Test was discontinued when the displacement transducer at the forward end of the hanger slipped after deflecting 596 mils.

(CRD) The analyses include the stress and strength models of room temperature tension, flexure and tension with flexure for the cluster cold end attachments.

5.1 ANALYTICAL MODELS

(CRD) The analysis is modeled about the fact that experimental test results demonstrated that cold end attachment failures occurred in the threaded regions of the graphite simulated central and fuel elements. The graphite of GLF flour used to make these specimens was PDS 30136-2. Due to the unavailability of material property data on this type graphite, the analysis as suggested by the Materials Department assumes that the material properties can be estimated by those of unfueled unirradiated AXM, PDS 30134 and 30135.

(U) The analytic models include discussion of the stress model and the respective (strength) failure criteria model which combine to form a stress/strength model. When a failure criteria is mentioned the applicable values that govern the strength of that material in its respective geometric configuration are given statistically as a mean value and a standard deviation. Alternate stress/strength models are discussed so that when comparisons are made between predictions and results (Section 5.2), these stress/strength models will be evaluated against the experimental evidence to make an assessment if one model is more applicable than another for a given set of conditions.

5.1.1 Tensile Load at Room Temperature

5.1.1.1 Central Element Model Cold End Attachment

(CRD) The stress in the central element at the cold end threaded attachment is modeled by finite elements and by the simple membrane stress equation F/A which is the tensile force per loaded cross-sectional area. The finite element stress calculation is compared to a maximum stress theory allowable, and the membrane stress is to be compared with an allowable fracture mechanics stress.

5.1.1.1.1 Membrane Stress/Strength Model

(U) With the notation of (mean value, standard deviation), (3920,830) psi is the expected failure stress (strength) for fracture mechanics based upon the following model from reference 2.4.3, WANL-TMI-1974, Theory and Application of Fracture Mechanics. The fracture stress is to be compared to the membrane stress.

Single Edge Notch in Sheet of Finite Width Subjected to a Uniform Stress

$$S = \frac{K_{IC}}{\sqrt{\pi a} g(a/b)}$$

$$g(.017/.057) = 1.29$$

(CRD) The assumed flaw size, a , is the central element thread depth. The value of $K_{IC} = (1180, 250)$ psi - $\sqrt{\text{in}}$ is from DRM 53164, AXF Material Property Data, reference 2.4.1 due to the unavailability of K_{IC} data on AXM and by suggestion from the Materials Department. The central element instrumentation hole as well as the "cylindrical" shape of the element are neglected in this model.

5.1.1.1.2 Finite Element Stress/Strength Model

(CRD) The axisymmetric finite element model shown below with prescribed boundary conditions elastically calculates principal stresses. The maximum stress at the central element thread root is to be compared with the expected failure stress of (3200,500) psi by maximum stress theory. The pair of numbers represents the mean value and standard deviation of AXM ultimate tensile strength from reference 2.4.2, DRM 51230, AXM Material Properties.

(CRD)

5.1.1.2 Fuel Element Model at Cold End Attachment

(CRD) The stress in the 19 hole element at the cold end threaded attachment is modeled with the same theories applied to the central element.

5.1.1.2.1 Membrane Stress/Strength Model

(CRD) Based on the same fracture mechanics model shown in Section 5.1.1.1 the allowable fracture mechanics stress for the 19 hole element geometry is (3250,690) psi. The assumed flaw size for the calculation was ($a = .032$), the thread depth. The 18 non-threaded holes and the "cylindrical" shape of the element are neglected in this model. The expected stress by fracture mechanics is to be compared to the membrane stress.

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5.1.1.2.2 Finite Element Stress/Strength Model

(U) The axisymmetric finite element model within the region of interest is shown below with prescribed boundary conditions. The principal stresses are elastically calculated.

(CRD) The maximum stress at the thread root is to be compared with the expected failure stress of (3200,500) psi by maximum stress theory. The pair of numbers represents the mean value and standard deviation of AXM ultimate tensile strength from reference 2.4.2, DRM 51320, AXM Material Properties.

5.1.2 Tensile Load at Room Temperature with Flexure

(CRD) The next two sections contain a combination of qualitative and quantitative analysis based on the experimental test results. The discussions in Sections 5.1.2.1 and 5.1.2.2 are

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presented as a justification to use the same models as previously discussed to evaluate the tensile and tensile with flexure test data. The following discussions indicate that a 60 mil hanger flexure and cluster bundling have little or no effect on the tensile failure loads in this test.

5.1.2.1 Central Element Model Discussion

(CRD) The comparison of the failure loads given on Tables II and III for the central elements would indicate, with the exception of the 170 pound failure listed in Table II, that the 60 mil flexure could have induced additional stress in the centrals. Based on the Figure 12 load versus deflection curve and a 6 inch moment arm an estimate of a 60 mil flexure induced stress at the last engaged central element thread is 60 psi. This assumes the moment is transmitted along the entire threaded sleeve and therefore can be considered an over estimate. There is one other difference between the test conditions of tension and tension with flexure. With pure tension there was no bundling load applied. The bundling load applied on the cluster subjected to tension with flexure was approximately 325 psi normal surface traction on the six outer fuel surface faces of the cluster. With no bundling and with equal tensile forces applied to the central and respective 19 hole elements the central should elongate more than the 19 hole elements due to a lesser cross-sectional area. Friction with the adjacent 19 hole elements in a bundled condition would tend to retard this elongation, and the net result would be additional tension on the 19 hole elements and less on the central elements at the location of interest with respect to what actually was being measured. In other words, with bundling the fuel could have carried more load at the threads than indicated on Table III, and central may have carried less load at its threads than that indicated on Table III. The average measured fuel failure load from Table III (tension with flexure) is 402.5 pounds and that from Table II (tension-no bundling) is 398 lbs. This comparison contradicts the previous discussion on bundling effect. The average measured central element failure load from Table III is 308 pounds, and that from Table II is 345 pounds. This comparison also contradicts the previous discussion on bundling effect. Based on these observations and on the failure load inconsistency when comparison is made between flexed and non-flexed specimens the effect of flexure and bundling will be neglected, and the results from both tensile and tensile with flexure testing will be combined to better estimate a statistical failure load for the central element subjected to tensile loading.

5.1.2.2 Fuel Element Model Discussion

(CRD) The tensile test data shown on Table II gives an average failure load of 398 pounds for the 19 hole element. The failure loads presented in Table III for tension with 60 mils flexure and bundling average out to be 402 pounds. Again the comparative difference indicates that flexure and bundling in this test has little or no effect on the tensile failure load, and as a result the failure loads from both the tensile and tensile with flexure testing will be combined to better estimate a statistical failure load for the 19 hole element subjected to tensile loading.

5.1.3 Flexure Load at Room Temperature

5.1.3.1 Central Element Model at Cold End Attachment

(CRD) The stress in the central element due to flexure of the hanger is computed by the relationship $S = Mc/I$. This is a bending stress equation. It is assumed that the bending moment is transferred to the region of last thread engagement, and the stresses may be compared to the allowables in Section 5.1.1.1.

5.1.3.2 Fuel Element Model at Cold End Attachment

(CRD) The stress in the 19 hole elements is also computed by the bending stress equation, and may be compared to the allowables given in Section 5.1.1.2.

5.2 COMPARISON OF PREDICTIONS AND RESULTS

5.2.1 Room Temperature Tensile Stresses From Test Data

(CRD) The tensile failure loads are to be combined from both the tensile and tensile with flexure testing to comply with the previous discussions that showed flexure and bundling to have little or no effect upon failure loads.

5.2.1.1 Central Element Stress From Test Data

(CRD) The test data on Tables II and III for central element failure loads combines statistically by the method of maximum likelihood applied to a normal distribution to be $F = (327,91)$ lbs. Using this load and a deterministic finite element model FEATS 594-5/18/70, the peak stress at the last engaged thread root is: $S = (2450,680)$ psi. In the simple tensile stress calculation the cross-sectional area for an element with an instrumentation hole is $A = (.240, .0034)$ in.². With

these values the calculated failure stress based on the experimental failure load is:

$$S = \frac{F}{A} = (1360, 380)\text{psi}$$

5.2.1.1.1 Central Element Modeling Evaluation

(U) The model is defined as previously discussed in Section 5.1 as the agent which statistically combines the calculated failure stress with an expected failure stress to form a stress/strength model. The "calculated failure stress" is that stress which is computed from a stress criterion which in this work is either the finite element or the average stress method in which the imposed boundary conditions are the experimentally determined failure loads from component testing. The "expected failure stress" is the material strength relative to a failure theory which in this work is either maximum stress theory or fracture mechanics, and these are determined from a material property test program.

(U) A comparison of the probability density functions can be made between the calculated stress at failure based on failure loads and the expected failure stress (strength). If the probability of calculated failure stresses exceeding expected failure stresses is greater than .5 the model is conservative, and if that probability is less than .5 the model is non-conservative. When that probability is .5 the calculated mean failure stress is identical to the expected mean failure stress. A conservative model would predict reliabilities less than the true value, and a non-conservative model would predict the opposite.

5.2.1.1.2 Finite Element/Maximum Stress Theory Model Evaluation

(CRD) The finite element model evaluates the peak stress at the thread root, and the computed stress will be compared with the maximum stress theory allowable.

Expected Failure Stress = (3200,500) psi

Calculated Failure Stress = (2450,680) psi

P = Probability (Normal probability density functions are assumed)

$P[(\text{Calculated Failure Stress}) > (\text{Expected Failure Stress})] = .2$

This result indicates that at these stress levels the assumed model is fairly non-conservative.

This is not to imply that in general the finite element method is non-conservative.

5.2.1.1.3 Average Stress/Fracture Mechanics Model Evaluation

(CRD) The fracture mechanics model is based on an average stress, and the allowable is to be compared to the predicted F/A value.

Expected Failure Stress = (3930,830) psi

Calculated Failure Stress = (1360,380) psi

With the assumption of Normal Probability functions:

$$P [(Calculated Failure Stress) > (Expected Failure Stress)] = .002$$

This probability indicates with respect to failure criteria that the assumed fracture mechanics method is even less conservative than the maximum stress theory method. The primary reason for this non-conservatism is the high average cross-sectional expected failure stress and the relatively low calculated average cross-sectional stress.

5.2.1.1.4 Central Element Design Reliability

(CRD) The previous discussion on model evaluations indicates that both models are non-conservative, and therefore, if used, would result in design reliabilities that are higher than the true value. As a result the design reliability should be computed by a direct comparison of failure loads with operating loads. The expected operating load (stem failure) at the central element cold end attachment is (84,5) lbs., and the observed failure load was (327,91) lbs. Based on normal distributions a design reliability of .996 is computed.

5.2.1.2 Fuel Element Stress From Test Data

(CRD) The fuel elements failed at the last engaged thread on the orifice. The statistical failure load computed from the data on Tables II and III was: $F = (400,47)$ lbs. Using the loads in a deterministic finite element model, FEATS 640-9/4/70, the peak stress at the last engaged thread root is (8000,940) psi. The minimum cross-section for the 19 hole element is $A = (.334, .0036) \text{ in.}^2$, and with the experimental failure load, the calculated failure stress by F/A is (1200,140) psi.

5.2.1.2.1 Model Evaluation for 19 Hole Element

- (U) The models are to be evaluated by comparing the calculated failure stresses based on failure load measurements with the expected failure stresses by the guidelines set forth in Section 5.2.1.1.1.

5.2.1.2.2 Finite Element/Maximum Stress Theory Model Evaluation

- (CRD) The peak stress calculated at the last engaged thread root is compared to the expected failure stress by maximum stress theory with assumed Normal probability density functions.

Expected Failure Stress = (3200,500) psi

Calculated Failure Stress = (8000,940) psi

$$P \left[(\text{Calculated Failure Stress}) > (\text{Expected Failure Stress}) \right] = .957$$

This probability is very large compared to .5 indicating that the finite element/maximum stress theory model is very conservative.

5.2.1.2.3 Average Stress/Fracture Mechanics Model Evaluation

- (CRD) The expected failure stress by fracture mechanics is compared to the average F/A stress calculation.

Expected Failure Stress = (3250,690) psi

Calculated Failure Stress = (1200,140) psi

$$P \left[(\text{Calculated Failure Stress}) > (\text{Expected Failure Stress}) \right] = .002$$

Since this probability is much less than .5 the assumed fracture mechanics model is quite non-conservative.

5.2.1.2.4 Fuel Element Design Reliability

- (CRD) The model evaluation discussion indicates that the finite element method would predict design reliabilities somewhat less than the true value, and the fracture mechanics model would predict the opposite. The design reliability is computed by comparing the failure load (400,47) lbs. with the operating load (85,2) lbs. Based on normal probability density functions a reliability of .911 is computed.

5.2.2 Stress from Room Temperature Flexure Test Data

(CRD) The data on Table IV presents the flexure load conditions. Most of the testing was for the 100 mil hanger deflection condition. The load required to induce this deflection was (49,12) lbs. If a hanger length of 4.53 inches is used as a moment arm, the reaction moment in the cluster is $M = (222,54) \text{ in-lbs.}$ In the region of the central element threads the location of the stressed fiber at the maximum distance from the neutral axis is $C = .377 \text{ in.}$, and the cluster moment of inertia about the neutral axis is $I = .965 \text{ in}^4$. By the stress equation MC/I , the central element could experience (87,21) psi due to the flexure load. The maximum fuel element stress could be (261,63) psi since the stressed fiber distance is $3C$ from the neutral axis. These stresses are small compared to the material strength, and post-test examination revealed no element failures and no permanent deformation of the cold end attachments. For a comprehensive analysis of flexure effects upon cold end attachments reference should be made to 2.4.4.

6.0 CONCLUSIONS

(CRD) The room temperature tensile and tensile with flexure testing of the cluster cold end attachments indicated that failures of the graphite elements are more probable than failures in the metallic attachments. A probabilistic comparison between the operating loads and the failure loads gave reliabilities of .996 and .9₁₁ for the central and 19 hole elements respectively. The support element failure location was at the thread root of last engagement with the threaded sleeve, and the 19 hole element failures occurred at the last thread root engaged with the orifice. A qualitative extrapolation to reactor operating conditions can be made. With central elements of the same graphite used in this test the reliability at steady state operation could be slightly higher than .996 because the graphite strength increases with temperature, and an estimate of an average support element temperature in the thread vicinity at steady state is 609°R which is slightly higher than room temperature. The reliability of the 19 hole elements would decrease from .9₁₁ in a reactor because the loaded fuel elements are somewhat weaker than the unfueled 19 hole elements. Extrapolations to a composite core would have to be made on a strength comparison for a particular composite which may or may not exhibit higher strength than this graphite depending on the composition and the manufacturing process.

The analysis and the test results show that cluster bending stress, induced by a 60 mil hanger flexure, is small and has little or no effect on the tensile failure load. With a 100 mil hanger flexure the bending stress in the cluster is still small, and that flexure does not result in permanent deformation of the cold end attachments.

6.1 CENTRAL ELEMENT

(CRD) The specification requirements in EC-677558 paragraph 3.1.1.1.4 for emergency mode operational requirements would require that the central element in conjunction with the cold end attachments be capable of supporting the cluster loads in the event of stem failure. The statistical considerations presented in Section 5.2.1.1.4 show that the design reliability is .996 with respect to the central element emergency support function. Design improvement could be obtained by modifications that would reduce the observed failure load coefficient of variation. One such possible modification would be support elements without instrumentation holes and/or an increase of web thickness in the vicinity of the threaded sleeve, requiring a reduction in the sleeve outside diameter and seal insertion from the cluster aft end.

6.2 19 HOLE ELEMENTS

(CRD) The fuel elements have no support function themselves; but the attachments to the fuel elements are required to support them at the cold end. The fuel elements load the cold end attachments in tension by their own weight and by core pressure drop forces. The probabilistic treatment of the failure load data and the operating load at the orifice/fuel thread interface gave a reliability of .9₁₁. On this basis that aspect of the design should be considered adequate.

6.3 COLD END ATTACHMENTS

(CRD) The room temperature tensile loads in all cases resulted in element failures which indicate that the cold end attachments possess a higher load carrying capability than the graphite. With flexure loads only, the hanger and liner tube experienced permanent deformation at deflections far in excess of those expected during reactor operation. Even at this condition the flexure induced moment in the cluster did not cause any graphite failures. For a comprehensive analysis of flexure effects upon the liner tube reference should be made to 2.4.4.

6.4 ENGINEERING COMPONENT REQUIREMENT COMPARISON

(U) Table V makes a comparison between test hardware performance and the performance requirements of the cluster hardware per Specification No. EC-677558.

TABLE V
COMPONENT REQUIREMENTS

CLUSTER HARDWARE FUNCTIONAL CHARACTERISTICS - SPECIFICATION EC 677558 - DATED JULY 1970	COMMENTS
3.1.1.1.2.1 <u>Core Element Support Function</u> - The Cluster Hardware shall provide axial support for the core elements during operating conditions when subjected to the loads specified in the Loads Environment section of this specification, and shall transfer these loads to the core support plate.	The orifice attachment provides axial support for the 19 hole elements. The testing showed the orifice to be stronger than the graphite.
3.1.1.1.2.1.1 <u>Deflection Capability</u> - The CH shall be capable of accommodating the following maximum deflections between the core support plate and the core elements: (a) Distance between the core support plate centerline and the core centerline at the forward face of the core, inches -(TBD) (b) Relative distance between the forward face of the core support plate and the aft face of the core, maximum between any two clusters, inches -(TBD)	Flexure loads in excess of those expected during reactor operation resulted in hanger and liner tube permanent deformations, but did not cause cluster graphite failures.
3.1.1.1.2.1.3 <u>Core Support, Malfunction</u> - The Cluster Hardware shall be capable of: (a) Supporting or transferring to adjacent clusters, the full cluster axial loads in the event of a failure of an individual support stem. This support shall be affected with the relative motion between the failed cluster and the adjacent clusters of no more than TBD inches.	Based on central element loads induced by a stem failure, the graphite support elements showed a .997 design reliability. A reliability improvement may be possible by elimination of the central element instrumentation hole.
3.1.1.1.4 <u>Emergency Mode Operational Requirements</u> - The performance characteristics of the CH supporting Emergency Mode requirements (3.1.1.1.5.3) of CP-677555 are included within the range of performance requirements of the Normal Mode Operational Requirements specified herein except that the thermal-hydraulic characteristics of the CH shall be in accordance with Table 3(c).	No comments on the thermal-hydraulic characteristics.

7.0 ILLUSTRATIONS

Figure 1. Secondary Support Components Before Assembly

Figure 2. Secondary Support Assembly After Assemblage

Figure 3. Specimen, Secondary Support Assembly

Figure 4. Loading Fixture for Secondary Support Assembly Structural Test
(Shown after Failure)

Figure 5. Test Setup for Secondary Support Assembly Structural Test

Figure 6. Secondary Support Assembly Tensile Load
with Flexure Test Setup at Room Temperature

Figure 7. Secondary Support Assembly Tensile Load with Flexure Test Showing Bundled Cluster and Fixture

Figure 8. Secondary Support Assembly Tensile Load with Flexure Test -
Part of Fixture is Removed

Figure 9. Secondary Support Assembly Flexure Test Setup in Universal Testing Machine

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Figure 10. Closeup of Secondary Support Assembly Flexure Test Setup in Universal Testing Machine

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Forward End
 of Hanger

Figure 11. Secondary Support Assembly Loading Schematic for the Flexure Load at Room Temperature Test

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Figure 12. Secondary Support Assembly Flexure Test

Deflection at Forward End of Hanger and Cluster Plate versus Load for the 0.10 inch Deflection Test (Assy. No. 5, Run No. 4)

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Figure 13. Secondary Support Assembly Flexure Test
Deflection at Forward End of Hanger and
Cluster Plate versus Load (Assy. No. 4, Run No. 4)

Figure 14. Mode of Failure - Tensile Test at Room Temperature

Figure 15. Mode of Failure -
Secondary Support Assembly Tensile Test at Room Temperature
(Test 1, Assembly 1)

Figure 16. Mode of Failure -
Secondary Support Assembly Tensile Test at Room Temperature
(Test 1, Assembly 2)

Figure 17. Secondary Support Assembly Tensile Test Mode of Failure (Assembly 6)

Figure 18. Mode of Failure - Tensile Load with Flexure - Secondary Support Assembly Number 7

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Figure 19. Mode of Failure - Tensile Test with Flexure - Secondary Support Assembly Number 8

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Figure 20. Secondary Support Assembly No. 7, in Test Fixture
After Tensile Test with Flexure

Figure 21, Mode of Failure -
Tensile Load with Flexure Test-
Secondary Support Assembly No. 9

Figure 22. Mode of Failure of Regular Element From Secondary Support Assembly No. 9 after Tensile Load with Flexure

Figure 23. Secondary Support Assembly Showing Deformation of Hanger After Loading to Failure

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ENGINEERING MECHANICS LABORATORY
W59849
Date 7-24-70 Data Pg.
Test No 7 Run No
Specimen SEC. SUPP. ASS'Y.
Test FLEXURE TEST
AFTER TEST

Figure 24. Secondary Support Assemblies after Flexure Test - Mode of Failure

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Figure 25. Secondary Support Assemblies after Flexure Test - Mode of Failure

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TITLE STRUCTURAL TESTING OF SECONDARY SUPPORT ASSEMBLY	
DOCUMENT NO. WANL-TME-2746		DATE Sept. 30, 1970	
ABSTRACT This work describes the structural testing and analysis performed to evaluate the tensile, compressive and flexure characteristics of the secondary support assembly at the cold end of a NERVA graphite cluster. (CRD)			
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