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FINAL REPORT

DYNAMIC TESTS CONDUCTED ON THE SEVEN CLUSTER PARTIAL CORE

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1.0 SUMMARY

- 1.1 A seven cluster partial core assembly of unfueled elements was subjected to lateral and axial vibration as well as axial shock. The vibration tests were performed over a frequency range of 15 to 500 cps at g levels from 1 to 5 g's, however amplification of test rig inputs produced accelerations as high as 20 g's at the support block with no detrimental effect. Results from these tests revealed only minor chipping at the mating surface of the support block and fuel element. Resonant conditions were found to exist at approximately 50 cps for lateral inputs and at 70 cps for axial vibration.
- 1.2 Axial shock tests showed no detrimental effects from shock loads up to and including the 9.0 g input. The shock inputs were amplified however by the core assembly which experienced core accelerations as high as 16 g's.

2.0 INTRODUCTION

- 2.1 The principal cause of test failure during the early stages of the KIWI reactor development was attributed to core instability due to vibrations. The NERVA reactors were designed with a lateral support system to minimize vibration response. The seven cluster partial core test was required to obtain a basic understanding of the fundamental cluster resonances and response to vibration inputs.

3.0 PURPOSE

3.1 The purpose of this test is to develop a knowledge of the fundamental mechanical response of a full length fuel cluster assembly while subjected to vibration at ambient temperature and to determine the areas where structural deterioration and degradation will occur with unfueled elements.

4.0 OBJECTIVES

- 4.1 Determine the effects of lateral and axial vibration on the niobium coating of graphite components.
- 4.2 Determine the amplitude of motion and "g" load of a fuel cluster when subjected to known inputs of lateral and axial vibration and axial shock.
- 4.3 Determine the resonant frequency of the cluster for axial and lateral sinusoidal excitation.
- 4.4 Determine the extent of damage caused by various vibration and shock loadings.

5.0 CONCLUSIONS

- 5.1 The cluster assemblies are capable of sustaining relatively large "g" loadings - as high as 20 g's were recorded at the support block - without detrimental effects. From the vibrational and shock testing, no major damage was incurred during the testing, however, some fretting and chipping was experienced at the mating surfaces of the elements and support block (see Figure 4).
- 5.2 From the data recorded during lateral vibration it appears that the significant core resonance is between 50 and 60 cps. Axial vibrational tests indicate a significant cluster resonance at approximately 70 cps. Resonant points also occurred at higher frequencies but these were not as sharply defined and were of lower amplification.
- 5.3 The cluster tests in which coated elements were used reveal no extensive damage or detrimental effects. Comparison of uncoated and niobium coated elements after testing indicated no significant difference in the durability of uncoated versus coated elements.

6.0 RECOMMENDATIONS

- 6.1 In evaluating the vibrational shock performance of fuel clusters based upon the amount of damage sustained during testing, it is recommended that the clusters in their present configuration are acceptable for use at ambient temperatures.
- 6.2 It is also recommended that any future testing of partial cluster core or cluster be performed with a test rig utilizing graphite filler strip and plungers as opposed to the present plexiglass filler strips and metal plungers. The amount of error induced by noise and resonances of the filler strip and plungers would warrant the modification.

7.0 TEST SPECIMENS

- 7.1 The various test components under investigation included (a) seven full length uncoated unfueled clusters (b) one full length niobium coated unfueled cluster and (c) one full length uncoated unfueled cluster with strain gaged elements. These clusters were complete with all of their associated hardware.

8.0 TEST EQUIPMENT

- 8.1 The test fixture and assembly is shown in Figure 1 (a). Seven full length unfueled clusters are supported by a simulated section of the top support plate which incorporates actual core hardware. Plexiglass filler strips are used to simulate the adjacent clusters and lateral support. The lateral support bundling force was simulated by a series of helical springs and metal plungers that were individually set to a predetermined deflection. Each spring and plunger applied a pressure of approximately four psi to the plexiglass filler strips. An electrodynamic shaker was used to excite the specimen in the axial and lateral directions as shown in Figure 1 (b) and (c).
- 8.2 The test specimen was subjected to axial and lateral vibrational accelerations from 1 to 5 g's over a frequency range of 20 - 500 cps. Shock tests were also performed on the sand drop machine to produce an input shock that varied from 4.5 to 10 g's with a 14 millisecond duration. A typical shock input is shown in Figure 7.

9.0 TEST RESULTS

9.1 The results reported here were obtained from lateral and axial vibration tests of a seven cluster simulated partial reactor core. The seven cluster core was subjected to acceleration levels from 1 to 5 "g's" over a frequency range from 15 to 500 cps. Analysis of data is based upon information obtained from accelerometers, LVDT's, and strain gages mounted on the test specimen and fixture.

9.1.1 Data obtained from the accelerometers mounted on the support blocks of the central and an adjacent cluster during lateral excitation indicates that the seven cluster core assembly resonates laterally as a rigid unit. The shape and magnitude of the accelerometer output curves for both clusters are identical with no measurable phase shift between them. Output from the accelerometers monitoring the axial direction of the central and an adjacent cluster during lateral excitation reveals relative motion in that direction. An indication of the magnitude of this resonant coupling in the axial direction may be obtained from the amplification factor defined as the "g" response (measured at the support blocks) divided by the "g" input (recorded at the shaker). A plot of the amplification factor of the axial response for the support block during lateral excitation is shown in Figure 2. The lateral response of the central cluster, top cluster plate and input adapter is given in Figure 3. From these curves it appears that the cluster

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core resonance is approximately 50 to 60 cps. The amplification factor for the support block is approximately 6.7 and is almost three times the values obtained for the top cluster plate. The lower amplification value for the top of the cluster may be attributed to its restricted movement caused by the simulated support plate. The strain values recorded during lateral vibration were very small - approximately 20 micro-inches. An inspection of the clusters upon completion of the lateral excitation tests revealed chipping on the outer periphery of the cluster at the mating surface of the support block and elements. Observing the location of the fretting, it appears that the relative motion of the cluster in the axial direction may be the cause.

9.1.2 Clusters used in the lateral vibration tests were also used for the axial vibration tests. Results from the axial vibration tests shown in Figure 5 indicate that an axial resonant condition occurs at approximately 70 cps. The amplification factors in the axial direction at resonance (70 cps) were approximately 4.8 for the central cluster and 6.7 on an adjacent cluster. These values were computed based upon an input level of 1.0 g's.

9.1.3 Coated Cluster Test - A niobium coated cluster was inserted into the center of the seven cluster assembly and lateral and axial vibrational tests performed. The coated cluster was subjected to lateral and vertical vibrations of 3 g's for 30 minutes each

at 30 and 58 cps for a total testing time of 2 hours. The test assembly was inspected after the lateral testing and again after the vertical testing. An external visual inspection of the niobium coated cluster revealed no evidence of chipping or fretting. Disassembly of the coated cluster, however, showed some fretting of the element ends at the mating surfaces between the elements and support block. A microscopic study of the support block's top (mating) surface revealed several abrasive areas. These abrasive areas, coupled with a small relative motion between the support block and elements, could have caused the element ends to fret.

- 9.1.4 The seven cluster partial core was subjected to axial shock input from 4.5 to 9.0 g's with a 14 millisecond duration. The shock wave form is shown in Figure 7. Results from the axial shock indicated the same minor damage at the mating surface of the support block and fuel elements. An experimental plot of the input shock and the core response is shown in Figure 6. The relation between the input and response is almost linear up to 7 g's. The amplification of the shock input by the core is approximately 1.6.

10.0 APPENDIX

10.1 Test Procedure

10.1.1 Test Rig Checkout

The initial testing consisted of a checkout of the test rig minus the test components and an investigation of its resonant frequencies. The resonant frequencies in the range from 20 to 500 cps were studied to determine whether they would significantly affect the cluster assembly results.

10.1.2 Preliminary testing

An uncoated, unfueled seven cluster assembly was excited in the axial and lateral directions as shown in Figure 1 (b) and 1 (c) over a frequency range of 20 to 500 cps at various accelerations up to and including 5 g's. Instrumentation in this set of tests was limited to accelerometers mounted on support blocks and test rig. The test assembly was disassembled and the test components inspected twice during that phase of testing, once after completion of lateral testing and again following completion of axial testing.

10.1.3 Niobium Coated Cluster Testing

The central cluster was replaced by a niobium coated unfueled cluster with the other six peripheral clusters remaining uncoated. The coated cluster was subjected to lateral and axial vibrations of 3 g's at 30 and 58 cps for 30 minutes each. The coated cluster was disassembled and inspected upon completion of the test.

10.1.4 Instrumented Cluster Assembly Test

An uncoated unfueled strain-gaged cluster conforming to NRX-A1 specifications for gage locations and type was then substituted for the central cluster of the seven cluster partial core. Supplementary instrumentation consisted of accelerometers mounted on support blocks and test fixture and a triad arrangement of transducers (LVDT's) mounted to the support blocks for measuring relative radial motion between clusters. Displacement transducers were mounted on the test fixture for monitoring relative motion between the cluster assembly and test fixture.

10.1.5 Shock Tests - A simulated load was placed on the drop table and a "g" load versus drop height calibration curve was obtained. The test fixture was affixed to the drop table and a shock pulse applied to the test specimen. The shock input was varied from 4.5 to 9.5 g's with a 14 millisecond duration, see typical input - Figure 7. The test specimen was subjected to axial shock only.

FIGURE 1 (a) SEVEN CLUSTER VIBRATION TEST ASSEMBLY

FIG 1(b) AXIAL VIBRATION

FIG 1(c) LATERAL VIBRATION
WITH CLUSTERS VERTICAL

Figure 2
AXIAL RESPONSE OF THE SUPPORT BLOCK DURING LATERAL EXCITATION

a) Support Block Response

b) Top Cluster Plate Response

c) Lateral Adapter Input

Figure 3

VIBRATIONAL RESPONSE CURVES OF FUEL CLUSTER FOR A LATERAL SINUSOIDAL INPUT OF 1 g (MEASURED AT SHAKER)

FIGURE 4 FRETTING AREAS OF THE CLUSTER ASSEMBLIES

Figure 5
 VIBRATIONAL RESPONSE CURVES OF FUEL CLUSTER
 FOR AN AXIAL SINUSOIDAL INPUT OF 1 g (MEASURED AT SHAKER)

Figure 6
SHOCK INPUT VERSUS RESPONSE OF PARTIAL CORE

Figure 7 Typical Axial Shock Input and Response Recordings