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WANL-TME-656

January 16, 1964

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COMPONENT TEST A-11
PHASE II FLOW INDUCED VIBRATION TEST
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Astronuclear Laboratory

March 5, 1964

Subject: WANL-TME-656 dated 16 January 1964, "Component Test A-11
Phase II Flow Induced Vibration Test"

Dear Mr. Schroeder:

Transmitted herewith are three (3) copies of the subject report.

This report is transmitted for your information.

Respectfully,

N. G. Baught. ^{jr}

H. F. Faught
Program Manager
NERVA Nuclear Subsystem

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cc: Mr. R. Wilke, SNPO-C Resident Office at WANL

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SUMMARY

A seven cluster core which simulated the basic design features of the NRX-A reactor was modified in an attempt to provide a dynamically unstable model by including some features which promote instability. This A-11, Phase II seven cluster core configuration was flow tested over the range of 0.06 to 0.41 pps of hydrogen with core inlet pressures from 30 to 186 psia. Motion pictures taken at 250 frames per second of the nozzle end of the seven fuel clusters in conjunction with oscillograph traces from a displacement sensor mounted on one of the bottom support blocks showed that flow induced vibrations did not occur during either transient or steady-state conditions.

Interstitial pressure data and core longitudinal pressure distribution data for the lateral support and seal system were obtained at various test conditions.

COMPONENT TEST A-11
PHASE II - FLOW INDUCED VIBRATION TESTS

1.0 INTRODUCTION

This report summarizes the results of the second of a series of tests completed in the A-11 test program. These tests, comprising Phase II of the test program, consisted of flow testing a seven cluster prototype reactor model to obtain information concerning core behavior, pressure distribution in the lateral support and seal system, and interstitial pressure data. The flow tests were carried out at the Westinghouse Astronuclear Hydrogen Experimental Facility (WANHEF) located at Waltz Mills. Test conditions were selected to evaluate the behavior of the core configuration with a dome end seal and reduced bundling forces.

A total of nine flow tests were completed utilizing ambient temperature hydrogen at flow rates extending from .06 to .41 lb/sec (3 to 22% of design flow). The core inlet pressure varied from 30 to 186 psia. Test duration was of the order of one minute for each test. The seven cluster core was monitored with pressure gages, a displacement sensor, microphones, and photographic equipment; in order to evaluate audio data, pressure and pressure distribution data.

The Phase II test core was assembled with available parts and incorporated modifications intended to duplicate the instability characteristic of the KIWI B-4A construction as far as possible. This duplication was limited to the reduction of the spring bundling forces, the ventilation of the seals to render them ineffective, and the elimination of the core banding feature. Features in the Phase II test core which could not be modified to simulate the KIWI B-4 construction were: the large contact areas of the seal segment rings with the graphite barrel (resulting in

high frictional damping) and the support of filler strips at the dome end of the core (rather than the nozzle end as in the NRX-A1). In addition, the A-11 test core was mounted so that the flow was downward compared to upward in the KIWI B-4. A comparison of the similarities and differences of Phase II core model of NRX-A and KIWI B-4A configuration is shown on Table I.

The results of the tests indicated that: (1) flow induced vibrations did not occur with the modified NRX-A configuration at flow rates extending from 3 to 22 percent of design values; and (2) in order to simulate the instability characteristics observed in the KIWI B-4A tests it will be necessary to make major modifications in the A-11 Test Model to more closely simulate the KIWI B-4A configuration.

2.0 TEST RIG

A photograph of the A-11 test rig assembly is shown in Figure 1 and a drawing showing the basic assembly details is shown in Figure 2. The basic configuration tested consisted of a prototype core fitted within a pressure vessel. Core components included a lateral support and seal system, inner reflector, top support plate, support rings, and a seven cluster core. The following is a description of the test rig.

2.1 Core:

The initial core consisted of a seven cluster assembly utilizing reactor grade hardware. The fuel elements were Oak Ridge Y-12 uncoated, graphite elements and the bottom support blocks were of the uncoated, interlocking type without alignment sleeves. Brazed tie rods were used and

TABLE I

GEOMETRY COMPARISON OF THE PHASE II MODEL WITH
NRX-A DESIGN AND KIWI B-4A CONFIGURATION

	Phase II Model	KIWI B-4A Configuration	NRX-A Design
Lateral Support System	Dome end and nozzle end seal including 16 in-effective seal rings.	Dome end seal.	Controlled seal schedule with .007, .009, and .011 slot depth including 2 ineffective seal rings.
Core Bundling System	Coil springs - uniform low pre-load bundling of .1 - .2 psi.	Coil springs - low and uniform pre-load bundling of .13 psi.	Leaf springs - uniform high pre-load bundling of 3.8 psi.
Core Peripheral Area	Filler strips - supported at nozzle end. Seal segments contains filler strips.	Filler strips resting on bottom support blocks. Slot assembly supported at dome end contains filler strip.	Same as Phase II model.
Core Band	None	None	Filler blocks at dome end supported by band. Band pre-load 6 psi.
Filler Strips	Continuous - one piece supported at nozzle end.	Continuous - one piece supported at dome end.	Two pieces - filler strips and filler blocks filler strip supported at nozzle end.
Rig Attitude	Flow direction - downward.	Flow direction - upward.	Flow direction - downward.

the fuel element flow passages were orificed with 0.0255 inch diameter orifices. Filler strips were specially designed for the seven cluster core and fabricated from grade HLM-85 graphite. There were no pyrotils on the filler strips. The finished outside diameter of the assembled seven cluster core was 6.75 inches.

2.2 Inner Reflector:

The inner reflector was designed to accommodate the small diameter core and lateral support and seal system. The reflector was fabricated from a single block of grade H4LM graphite and was not impregnated to reduce porosity. The inner surface of the reflector contained the lateral support system, seal grooves while the outer surface had a series of openings for the lateral support system spring components and the instrumentation pressure taps and lines.

The inner reflector was supported by a special stand on the core discharge end and spring loaded at the core inlet end. An "O" ring seal was located on the top surface of the inner reflector support stand. The inner reflector used in the Phase I tests was modified slightly because of the failure which occurred during the Phase I test series. The modifications were as follows:

1. Longitudinal channels used for containing the extension tubes of the various pressure taps were machined the entire length of the reflector to provide adequate pressure communication between the core inlet plenums and the reflector-shell annulus located below the upper support liners.
2. The outside diameter of the reflector was decreased from 13.500 inches to 13.475 inches to increase the clearance fit between the reflector and shell support liners.

3. Additional "O" ring grooves were machined around the periphery of the reflector and were located to align with the vessel support liners. "O" rings installed in these grooves were used as bumpers to support the reflector and prevent reflector movement within the vessel during flow tests. The longitudinal channels are considerably deeper than the "O" ring grooves, hence, the "O" ring did not impair communication across the outer periphery of the inner reflector.

Utilizing this configuration the outside of the reflector barrel would experience static core inlet pressure during steady-state runs. The bottom ring seal was subjected to the full core pressure gradient while the inside of the reflector experienced the axial core pressure gradient of the lateral support system.

It should be noted that the pressure on the outside of the inner reflector may be slightly lower than the core inlet pressure due to the pressure drop across the diffuser-top support plate and the top support plate-core spring seals.

2.3 Lateral Seal and Support System:

The lateral seal and support system of the seven cluster model had the full complement of 18 segment seal rings. The configuration of the segments was similar to the NRX-A design employing the outer "V" grooves and inner vertical leakage flow slots.

In all A-11 models, the NRX-A lateral support leaf springs were replaced with coil springs. The coil springs were used because of space limitations on the periphery of the inner reflector graphite cylinder. In the core spring design, the plenum behind the seal segment communicates with the spring chamber by way of the plunger pin, however, the spring

chamber is sealed from the outside surface of the inner reflector with a threaded aluminum plug fitted with an "O" ring. This precludes any gas leakage across the inner reflector, i. e., plunger pin leakage.

Each seal band in the lateral support system had six seal segments and each segment was spring loaded by two coil spring-plunger pin assemblies. The coil springs used in the tests had a spring rate of 1 - 2 lbs/in and were designed to exert a 0.53 - 1.05 pound pre-load force per pin. This resulted in a pre-load core bundling pressure of approximately .1 to .2 psi based on total core area. In Figure 3, a Phase II and Phase I plug-spring-pin assembly is presented to show the difference in spring geometry.

The flow slots on the inner surfaces of the seal segments were grooved over 66.5% of the core circumference. There were a total of 36 flow channels per seal ring, equivalent to one flow channel per filler strip. The flow channels had a uniform width and were distributed such that each channel spans a filler strip gap. The depth of the flow slots were selected in accordance with the schedule shown in Table II. As noted, there were no flow slots in the seal segments for Seal 2 as this was the dome end seal. Figure 4 shows typical Phase II seal segments without flow slots for the dome end seal ring Number 2. Figures 5 and 6 show typical Phase II seal segments for seal rings 17 and 18, as compared with the Phase I seal segments for the same seal rings.

2.4 Filler Strips and Filler Blocks:

Single section filler strips 53.250 inches long, fabricated from grade HLM-85 graphite spanned the core assembly of the Phase II model. Filler blocks which were used in the Phase I assembly were not incorporated in the Phase II core.

2.5 Core Band:

The inlet of the core assembly was not banded in order to simulate the unrestrained condition characteristic of the KIWI B-4A configuration.

TABLE II

PHASE II - SEAL SEGMENT FLOW SLOT SCHEDULE

Seal Number	Slot Depth - Inches	Remarks
1	.060	Seal 1 and 17 have butt joints.
2	.000	No flow slots.
3 - 16	.060	
17	.060	Seal 17 did not have the .050-inch slots on the bottom surface of the seal segment, typical of Phase I seal ring.
18	.060	Seal 18 did not have the .050-inch slots on the top surface of the seal segment, typical of Phase I seal ring.

2.6 Core Support Plate:

The core support plate was an aluminum plate containing coolant holes and openings to accept the tie rod nuts and locking devices. A circumferential spring seal was provided between the core support plate and the core. This seal was used to direct the hydrogen flow to the core and maintain a pressure differential between the core plenum region and the outer surface of the inner reflector. In the NRX-A design, there is a positive pressure differential between the outer surface of the inner reflector and the core inlet plenum. In the seven cluster Phase I test the spring seal between the core support plate and the diffuser was removed.

Axial support for the core support plate was provided by the outer support ring. The outer support ring is a stainless steel ring fitted with a flange supported by the pressure vessel flange. An inner support ring was retained by the core support plate and a spring load was applied between it and the inner reflector. All loads imposed on the core support plate were transmitted to the pressure vessel.

2.7 Pressure Vessel:

The pressure vessel consists of two body sections; the short section containing the inlet diffuser and the long section containing the core proper. The body sections and closures are attached to one another by circumferential bolted flanges. The completed vessel is provided with a support trunnion so that the vessel can be rotated to relocate the inlet and discharge ends. The vessel was designed for vertical mounting in the downward firing mode but can also be used in an upward firing mode. The vessel was fabricated of type 304 stainless steel and was designed for a pressure of 1125 psia.

2.8 Assembly Clearances:

After the filler strips and filler blocks were installed in the seven cluster assembly, the core was tightly banded with hose clamps. The cylindrical surface of the core was checked for discontinuities and variations using a blank seal segment. Feeler gages and micrometers were used to measure slot clearances and filler strip and filler block gaps. These values, in conjunction with the flow slot measurements for the seal segments, were used to establish the lateral seal analytical model of the Phase II test core.

3.0 INSTRUMENTATION

The instrumentation used for the Phase II tests was limited to selected audio and pressure measurements, a displacement sensor, and a photographic record of the core. The instrumentation schematic showing the location of the measuring stations is shown in Figure 7. The following is a description of the instrumentation.

3.1 Microphones:

Two microphones, Glennite Model MA-299501 (P-420M-6), located at the core inlet and outlet were used to measure the intensity of the sound pressures. The sound pressure signal generated from the microphone was sent through a dual channel pre-amplifier (EICO, HF-85 Stereo Pre-Amp) where the signal was conditioned. The output signal of the pre-amp was transmitted through triaxial cables and the conditioned signal recorded on a Westinghouse Model 22RS Stereo Tape Recorder. The output signal of the downstream microphone was connected to a speaker in parallel with the tape recorder in order to monitor the sound during tests.

3.2 Pressure Gages:

Absolute pressures were measured at the core inlet, core outlet, and outside of the inner reflector plenum and differential pressures were measured in the lateral support and seal system. Calibrated Heise gages 0 - 400 psig

were used to measure the core inlet and the core discharge pressures on the upstream side of the restricting flow nozzle. Both gages incorporated dial followers to indicate peak pressures. A standard pressure gage was used to measure the inner reflector plenum pressure. Differential pressures in the lateral seal system were measured using Barton Model 200 differential pressure indicators. Twelve gages were used which had a range of 0 - 30 psig.

Table III summarizes the location of these gages.

Midwest differential pressure gages (0 - 20 psig) were used to measure core interstitial pressures at a plane 48 inches from the core inlet. Figure 10 shows the location of the interstitial pressures and includes a typical installation schematic.

All of the pressure gages were mounted on a panel board and a 70 mm automatic camera was used to record pressure data. The camera photographed the gage panel at approximately two second intervals. A clock with a sweep second hand was located on the panel for a time reference.

3.3 Core Photography:

A Milliken, Model DBM5BE, 16 mm high speed motion picture camera was used to photograph the bottom of the core during the flow tests. Camera speed was 250 fps. A Sylvania Sun Gun Photolight was used to illuminate the core during the test.

3.4 Temperature:

A thermocouple type temperature indicator was used to measure exhaust gas temperature at the restricting nozzle orifice. The instrument, a Thermo-O-Meter gage, -50° to 1000° F, was located on the gage panel with the pressure gages.

TABLE III

PHASE II - DIFFERENTIAL PRESSURE MEASUREMENTS

<u>Barton Gage Number</u>	<u>Differential Pressure Measurements</u>
1	Core Inlet Heise Gage and Core Inlet
2	Core Inlet and Seal 1
3	Seal 2
4	Seal 3
5	Seal 4
6	Seals 5 - 8
7	Seal 9
8	Seals 10 - 11
9	Seals 12 - 13
10	Seals 14 - 16
12	Seal 17 to Core Outlet Heise Gage

3.5 Displacement Sensor:

A Crescent Engineering Company, Model No. 100-3K-1S, linear variable differential transformer (LVDT) in conjunction with an oscillograph was used to monitor the displacement of one of the bottom support blocks during the tests. The location of the displacement sensor relative to the core center-line is shown on Figure 8.

4.0 TEST PROCEDURE

The operating procedure used for the A-11, Phase II tests is outlined in the standard operating procedure included in Appendix A of the Phase I report. The tests were conducted at the Waltz Mill Test Facility. A schematic of the experimental flow system is shown in Figure 9. High pressure hydrogen gas, supplied from tube-trailers, flowed through a pressure control valve, and entered the test vessel at a specific pressure. The gas then flowed vertically down through the reflector-core assembly, passed through a shutoff valve, flowed through a critical flow nozzle, and discharged directly to the atmosphere through the exhaust system. The duration of the tests were 35 seconds to 71 seconds. Test data were recorded during the transient start-up period as well as during the steady-state conditions.

5.0 PHASE II TESTS

The purpose of the hydrogen flow tests was to determine if the A-11, Phase II core configuration was susceptible to flow induced vibration, to obtain sufficient pressure data to determine the lateral support and seal system pressure distribution at various flow rates, and to determine the core interstitial pressure distribution. Hydrogen gas was supplied to the system from two tube trailers connected in parallel. The capacities of the trailers used were 63,000 SCF and 115,000 SCF.

A total of nine hydrogen flow tests were conducted on the Phase II test program. All of the tests were conducted using the same core model positioned in a downward firing mode. Two series of tests were conducted.

The first series of tests, A-11-II-GH₂-1 through A-11-II-GH₂-6 were conducted at low core inlet pressures and mass flow rates with the pressure controlled with the upstream pressure control valve, PCV-2. Pressure control valve, PCV-2, is a 1/4" Annin valve specifically designed to control at low pressures and flow rates. The Phase II core configuration was subjected to low pressure-low mass flow rates to determine the conditions at which flow induced vibration begin and to prevent damage to the model in event vibrations are induced. After completing five tests at flow rates extending from .06 to .17 pps it was evident that the model was dynamically stable at the low flow conditions.

In order to verify the stability at higher flow rates a second series of tests were completed. These were conducted using pressure control valve, PCV-1, and installing a larger flow nozzle. The pressure control valve, PCV-1, is equipped with a quick opening operator and as a result, the test model experienced sharp pressure pulses when hydrogen flow was initiated. Three hydrogen tests A-11-II-GH₂-7 through 9 were conducted with two different flow nozzles incorporated in the system. Higher core inlet pressures and flow rates were obtained without any indications of flow induced vibrations. A typical pressure-time curve for these tests is shown in Figure 11.

6.0 DISCUSSION OF RESULTS

A summary of the Phase II flow tests including core pressures, core differential pressures and mass flow rates is shown in Table IV. Mass flow rates from 0.06 to 0.41 pps at core inlet pressures extending from 30 to 186 psia and core pressure drops varying from 6 to 70 psi were obtained with two different flow nozzles. Flow nozzles with diameters of 0.743 inches and 1.1814 inches were purposely selected for these tests.

TABLE IV

PHASE II - HYDROGEN FLOW TESTS

Test Number	Core Inlet Pressure psia	Core Differential Pressure psi	Mass Flow Rate lb/sec
1	30.4	6.0	0.06
2	42.4	10.0	0.08
3	51.4	13.0	0.10
4	78.4	14.0	0.16
5	78.4	14.0	0.17
7	186.4	32.0	0.40
8	122.3	66.0	0.36
9	134.3	70.0	0.41

The flow pressure data obtained is shown in Figure 12. In Figure 13 the Phase II data were plotted together with the proposed operating conditions for the NRX-A1 reactor. Core pressure drops were calculated and are shown in Figure 14 compared with the NRX-A1 predicted pressure drop curve.

The NRX-A1 data presented here is based on an average fuel element orifice diameter of 33.6 mils. The Phase II test model incorporated the 25.5 mil diameter orifices.

The longitudinal core pressure distribution was calculated from the differential pressures measured across various lateral support seals. The experimental results are tabulated in Table V.

Figure 15 shows the measured lateral support seal pressure distribution at the mass flow rates obtained with the 0.743 inch diameter flow nozzle incorporated in the system. The pressure distribution at the flow rates obtained with the 1.1814 inch diameter flow nozzle is shown in Figure 16.

From the curves it was noted that there were two seals which were effective, one at the dome end and one at the nozzle end. The dome end seal was designed into the system to simulate the dome end seal characteristic of the KIWI B-4 configuration. An effective nozzle end seal was not preplanned into the system. This seal was made effective by the even interface surfaces provided between the bottom of the filler strip projection and the top surface of the segment seals in row 18. The segment seal in row 18 did not have the flow slots machined in the top surface. These flow slots, in conjunction with the vertical flow slots, are required to render this seal ineffective.

Interstitial static pressures were measured at a plane 48 inches from the core inlet. The interstitial pressure measurements are shown in Table VI and are presented at this time only as preliminary data.

TABLE V
TEST A-11, PHASE II CORE PRESSURE DISTRIBUTION DATA

Test Number	Flow Nozzle Diameter Inches	Gas Temperature T-2 °R	Core Inlet Pressure P-1 psia	P _x - Station Pressure - PSIA P _x = (P-1) - (ΔP _x) x - Core Station - Inches												Upstream Flow Nozzle Pressure P-2 psia	Calculated Mass Flow Rate ṁ lb/sec	Outside Reflector Support Pressure P-3 psia	Core Pressure Drop psi
				0	4.3	7.2	10.0	12.8	24.0	26.8	32.5	38.1	46.3	52.0					
A-11-II-GH ₂ -1	.743	536	30.41	30.41	30.41	25.91	25.78	25.78	25.53	25.53	25.4	25.4	25.15	24.4	24.41	.0615	14.41	6.0	
A-11-II-GH ₂ -2	.743	535	42.41	42.41	42.41	36.78	36.65	36.65	36.15	36.02	36.02	36.02	36.52	34.27	32.41	.0817	34.41	10.0	
A-11-II-GH ₂ -3	.743	528	51.39	51.39	51.39	45.39	45.26	45.13	44.88	44.75	44.5	44.25	44.75	41.5	38.36	.0975	34.39	13.0	
A-11-II-GH ₂ -4	.743	528	78.39	78.26	78.26	70.63	70.5	70.5	70.	69.87	69.49	69.24	68.49	64.19	64.39	.163	74.39	14.0	
A-11-II-GH ₂ -5	.743	528	78.39	78.14	78.14	70.64	70.51	70.51	70.01	69.88	69.5	69.25	68.62	64.12	64.39	.166	74.39	14.0	
A-11-II-GH ₂ -6	.743	Unstable Flow Condition Caused by Pressure Control Valve, PCV-1, Cycling.																	
A-11-II-GH ₂ -7	.743	520	186.36	185.86	185.86	172.86	172.73	172.6	171.6	171.35	170.6	169.6	169.1	154.85	154.36	.395	179.36	32.0	
A-11-II-GH ₂ -8	1.1814	525	122.3	121.8	121.8	106.3	106.17	105.92	104.62	104.24	103.24	101.99	99.99	*	56.3	.362	114.29	66.0	
A-11-II-GH ₂ -9	1.1814	530	134.29	133.79	133.79	118.29	118.16	117.9	116.66	116.28	115.28	114.03	112.03	*	64.29	.412	129.29	70.0	

*Differential Pressure Exceeded Range of Barton Pressure Indicator.

TABLE VI
 A-11, PHASE II AMBIENT HYDROGEN FLOW TESTS
 INTERSTITIAL PRESSURE MEASUREMENT

Test Number	Station Pressure P_x x = 48 Inches psia	P_r - Pressure - psia $P_r = (P_x) + (\Delta P_r)$			
		r - Radius - Inches			
		0.38	1.00	1.73	2.45
A-11-II-GH ₂ -1	25.2	x	25.2	x	25.2
A-11-II-GH ₂ -2	35.5	x	35.5	x	35.5
A-11-II-GH ₂ -3	43.3	x	42.3	x	42.3
A-11-II-GH ₂ -4	68.5	x	70.3	x	66.5
A-11-II-GH ₂ -5	68.6	x	70.1	x	66.6
A-11-II-GH ₂ -7	169.1	x	176.6	x	162.1
A-11-II-GH ₂ -8	100.0	x	109.0	x	93.0
A-11-II-GH ₂ -9	112.0	x	123.75	x	105.0

x - Post test inspection showed that the adhesive bonding the tube to the element leaked.

During the Phase II tests the core photography and the displacement sensor mounted on an end support block showed no core movement with the exception of Test A-11-II-GH₂-8, Figure 11. At the start of the test the displacement sensor indicated a radially inward movement of 0.002 inches. However, the indication of core movement by the displacement sensor was inconclusive because of the mounting arrangement of the sensor. The contact surface between the displacement sensor follower and side of the support block and the clearance between the sensor body and its core was such that a longitudinal movement could result in the same output signal.

The experimental data obtained from the nine hydrogen flow tests showed Phase II core configuration to be dynamically stable and free of flow induced vibrations. Analysis of the data obtained from the Phase II tests indicated that the high degree of stability noted for this configuration was due primarily to the positive bundling of the core achieved by a nozzle end seal and the high frictional forces which retarded the radial movement of the seal segments.

In order that the model be unstable, it is necessary that the established pressure-flow conditions initially displace the seal segments radially outward in order to have sufficient radial clearances between adjacent parts, i. e. fuel element clusters and filler strips to permit freedom of movement relative to one another.

In the Phase II core configuration the existing design features and the established flow conditions were such that they tended to retard any radial outward movement. A summary of these design features and flow conditions follows.

6.1 Pressure Bundling Forces:

A preliminary analysis of the circumferential pressure area force acting on the core assembly was conducted based on the longitudinal core pressure distribution and the interstitial pressure data. A force balance on the core assembly for Run No. A-11-II-GH₂-8 showed that a net circumferential pressure area force of approximately 600 pounds acted radially

inwards at a plane 48 inches from the core inlet. This force is equivalent to a 7.0 psi bundling pressure at the nozzle end of the core.

6.2 Frictional Retarding Forces:

Two sources which tend to retard core motion are as follows:

1. Segmented seal rings 1 through 18 had the "V" groove on the back surface of the seal segments. Since the grooved segments are loaded at an angle by the tapered pins, a static frictional force of approximately 1.2 pounds per ring is generated between the bottom surface of the seal rings and the bottom surface of seal groove in the inner reflector.
2. Since the weight of the filler strips is transmitted to seal ring 18 by the projection at the nozzle end of the filler strip, a relatively high frictional force is generated at the nozzle end of the core assembly which tends to retard any radially outward movement. This frictional force increases with the addition of the pressure area force obtained as a result of the pressure drop across the ends of the filler strip during any established flow condition. Assuming a value of coefficient of friction of 0.2 (WANL-TME-325, p. 20) a frictional force of approximately 200 pounds was calculated for Run No. A-11-II-GH₂-8 based on the weight of the filler strips and the net pressure force acting on the surface area at the ends of the filler strips. If, however, the filler strips are assumed to be interlocked with the cluster assembly such that the core assembly becomes one integral piece, the frictional force is increased to approximately 500 pounds.

CONCLUSION

The Phase II flow, which basically simulated a NRX-A model with a reduced bundling load, and a dome end and nozzle end seal with fifteen intermediate seals ineffective, proved to be dynamically stable under flow conditions up to 22% of design flow with a maximum pressure drop of 70 psi.

The high degree of stability of this configuration was due to the combination of the pressure bundling force induced by the nozzle end seal and the frictional force of the lateral support system which tended to retard outward movement of the internal components of the core.

RECOMMENDATIONS AND FUTURE WORK

The following recommendations are proposed based on the results of the Phase II tests.

1. Modify the A-11, seven cluster core to simulate the basic design features of the KIWI B-4A configuration.
2. Test the model at pressure-flow conditions equivalent to the conditions at which KIWI B-4A was tested and establish flow induced vibrations.
3. Once instability is established determine the limits of stability.
4. Develop methods for eliminating or reducing flow induced vibrations.

Tests of a seven cluster core model incorporating a dome end seal and a top supported core assembly with a lightly bundled core are planned.

NOMENCLATURE

DP	= differential pressure
d	= flow nozzle diameter (inches)
H	= high pressure side
L	= low pressure side
$\dot{m}$	= mass flow rate (lb/sec)
M	= microphone
ΔP	= pressure differential (psid)
P	= pressure (psia, psig)
t	= time (seconds)
T	= temperature ($^{\circ}$ R) ($^{\circ}$ F)
x	= core station (inches)
r	= radius (inches)
ϕ	= displacement (inches)

Subscripts

e	= exit
i	= inlet
max.	= maximum
x	= core station
r	= radial station measured from model centerline

TEST NUMBER NOMENCLATURE

FIGURE 1

A-11 FLOW INDUCED VIBRATION TEST RIG

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

FIGURE 2. FLOW INDUCED VIBRATION TEST RIG

Plunger Plug - Spring - Pin Assembly

Phase II

Phase I

FIGURE 3

PLUNGER PLUG-SPRING-PIN ASSEMBLY

Phase II - Typical Dome End Seal Segments

Front View
Showing filler
strip contact
surface

Top View

FIGURE 4
PHASE II, TYPICAL DOME END SEAL SEGMENTS

Typical Seal Segments from Seal Ring Number 17

Phase II

Phase I

FIGURE 5

TYPICAL SEAL SEGMENTS FROM SEAL RING NUMBER 17

Typical Seal Segments from Seal Ring Number 18

Phase II
Front View

Note: Absence of
flow slots on top
surface of seal
segment

Phase II
Top View
showing contact
surface of filler
strip shoulder

Phase I

FIGURE 6
TYPICAL SEAL SEGMENTS FROM SEAL RING NUMBER 18

FIGURE 7

A-11, PHASE II TEST RIG SCHEMATIC

Atomic Energy Act - 1954

WANL-TME-656

LVDT

REFLECTOR

7°

FIGURE 8

Atomic Energy Act - 1954

FIGURE 9
 FLOW INDUCED VIBRATION TEST SCHEMATIC

FIGURE 10
 CORE PLAN SHOWING PRESSURE TUBE ARRANGEMENT

FIGURE 11
 TYPICAL PRESSURE-TIME AND DEFLECTION-TIME TRACE

FIGURE 12
EXPERIMENTAL FLOW-PRESSURE DATA

FIGURE 13
 EXPERIMENTAL FLOW-PRESSURE DATA FOR FREEDOM OF VIBRATION

FIGURE 14
PRESSURE DROP FOR VARIOUS CORE INLET PRESSURES

FIGURE 15
 MEASURED LATERAL SUPPORT SEAL PRESSURE DISTRIBUTION

FIGURE 16
MEASURED LATERAL SUPPORT SEAL PRESSURE DISTRIBUTION