~~CONFIDENTIAL~~
~~RESTRICTED DATA~~

Atomic Energy Act - 1954

RECORD COPY

~~SNPO-C~~

WANL-TME-1511

September, 1966

Westinghouse Astronuclear Laboratory

SINGLE CLUSTER CORROSION TEST SUMMARY

April 1966 to September 1966

(Title Unclassified)

RECORD COPY

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

~~CONFIDENTIAL~~
~~RESTRICTED DATA~~

Atomic Energy Act - 1954

RECORD COPY

DISCLAIMER

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

DISCLAIMER

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

CONFIDENTIAL
RESTRICTED DATA

Atomic Energy Act of 1954

Astronuclear
Laboratory

GROUP I

WANL-TME-1511

Excluded From Automatic Downgrading
and Declassification

September, 1966

78

NOTICE

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

SINGLE CLUSTER CORROSION TEST SUMMARY
April 1966 to September 1966
(Title Unclassified)

Westinghouse Astronuclear Laboratory
P.O. Box 10864
Pittsburgh, Pennsylvania 15236

by

L. A. Salvador

Classification cancelled for change to
by authority of DOC
by H.F.C. TIC, date SEP 10 1973

Approved By:

INFORMATION CATEGORY

~~CONFIDENTIAL R. D.~~

E. A. DeZubay, Manager
Fluid Flow Laboratory

9/66
Authorized Classifier Date

CLASSIFICATION REVIEW	Class.	Date
DETERMINATION	u	4-14-82
Class: <u>u</u>		

CONFIDENTIAL
RESTRICTED DATA

Atomic Energy Act of 1954

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

Table of Contents

	<u>Page</u>
Abstract	ii
List of Tables	iii
List of Figures	iv
I Introduction	1
A. General	1
B. Status of Program	1
II Test Development	5
A. Upgrading of Current Configuration	5
B. Cluster-Lateral Support Model	18
III Reactor Hardware Tests	24
A. Test Configurations	24
B. Summary of Test Results	24
IV Summary and Conclusions	68
V Bibliography	70

CONFIDENTIAL
RESTRICTED DATA
Atomic Energy Act - 1954

WANL-TME-1511

ABSTRACT

This report reviews progress on the HHT-4 Cluster Corrosion Test from April 1966 to September 1966. The results of 12 high-temperature flow tests are presented. These tests were primarily proof tests and qualification tests of the NRX-A5 skirtless support block and XE-1 exit gas thermocouple configurations. In addition, developments in the state-of-the-art of high-temperature flow testing of clusters are reviewed. These include design modifications to upgrade the present configuration as well as a new cluster-lateral support model design.

CONFIDENTIAL
RESTRICTED DATA
Atomic Energy Act - 1954

List of Tables

Table Number	Title	Page
I	HHT-4 Test Summary	25
II	Reactor Grade Components Employed in Cluster Tests	27
III	Component Identification	29
IV	Test Conditions and Results	30
V	Summary of Weight Loss Data	33

WANL-TME-1511

List of Figures

Figure Number	Title	Page
1	Cluster Corrosion Test Assembly	7
2	Experimental Cold End Chuck Assembly With Graphite Cloth	11
3	Experimental Cold End Chuck Assembly With Copper Braids	13
4	Cluster Direct Gas Inlet Plenum	17
5	Cluster-Lateral Support Model	20
6	Temperature Profiles in the Center Element	22
7	Axial Temperature Profiles for Tests HHT-4-20 through 23	32
8	Exit Gas Thermocouple Output Record (HHT-4-20a)	37
9	XE-1 Support Block and Exit Gas Thermocouple Assembly Before Test HHT-4-20a	38
10	XE-1 Thermocouple and Support Hardware After 18.3 Minutes at 4283°R (HHT-4-20a)	39
11	XE-1 Thermocouple and Support Assembly After 18.3 Minutes at 4283°R (HHT-4-20a)	40
12	Tie Rod, Molybdenum Cup, and Thermocouple Assembly from HHT-4-20a	42
13	NRX-A5 Skirtless Block After 7.3 Minutes at 4283°R (HHT-4-21a)	43
14	NRX-A5 Skirtless Block After 41 Minutes at 4283°R (HHT-4-21b)	45
15	Corrosion of the Skirtless Block (HHT-4-21b)	46
16	Protection Cup and Insulating Cup After 41 Minutes at 4283°R (HHT-4-21b)	47
17	XE-1 Support Block and Exit Gas Thermocouple Assembly Before Test HHT-4-22a	48
18	Exit Gas Thermocouple Output Record for Test HHT-4-22a, Cycle 1	50
19	XE-1 Thermocouple and Support Hardware After 24 Minutes Above 2900°R (HHT-4-22a)	52

List of Figures (Continued)

Figure Number	Title	Page
20	Tungsten Sheathed Thermocouple After Test HHT-4-22a	53
21	XE-1/NRX-A5 Support Components Prior to Test HHT-4-23a	54
22	Thermocapsule Insertion in Center Element (HHT-4-23a)	56
23	Exit Gas Thermocouple Output Record for Test HHT-4-23a	57
24	XE-1 Thermocouple and Support Hardware After 21 Minutes at 4283°R (HHT-4-23a)	58
25	XE-1/NRX-A5 Support Components After 21 Minutes at 4283°R (HHT-4-23a)	59
26	XE-1 Thermocouple and Molybdenum Cup After Test HHT-4-23a	60
27	Cluster Assembly for Test HHT-4-23b	62
28	Element Damage From Test HHT-4-23b	64
29	Exit Gas Thermocouple and Molybdenum Cup From Test HHT-4-23b	65
30	Support Components From Test HHT-4-23b	66
31	Insulating Cup, Foil Washers, and Sleeve from Test HHT-4-23b	67

WANL-TME-1511

1. INTRODUCTION

A. GENERAL

Since the publication of the previous summary report¹, the single cluster test program has continued along two avenues of endeavor. The primary utilization of the test model itself continued to be the evaluation of support blocks and related hardware in a full cluster held at approximately reactor temperature levels, at hydrogen flow rates on the order of 40 per cent of reactor cluster flow rates, and with no nuclear radiation field. The parallel endeavor was the continuing development of the state-of-the-art of electrical testing of clusters. This latter effort was directed not only to the design upgrading of the current configuration, but also to the development of a new and substantially different model to provide increased test flexibility and reliability, and an improvement in the simulation of the reactor environment.

The purpose of this report is to summarize the results of the cluster tests performed in the period between March 1, 1966 and September 15, 1966 as well as to review developments in the state-of-the-art of cluster testing.

B. STATUS OF PROGRAM

1. Support Hardware Tests

Cluster tests conducted during this period were primarily endurance proof tests and qualification tests of reactor component designs for the NRX-A5 and XE-1 reactor tests. Several of the initial tests, developmental in nature, were conducted to evaluate new electrical chucking designs. The following table summarizes the tests completed to date:

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

WANL-TME-1511

<u>Description</u>	<u>HHT-4 Test Number</u>
NRX-A5 Support Block, Pre-Cracked	12b
NRX-A5 Support Block, Uncracked and Test Development	13c
Test Development	18a, 18b, 19
XE-1 Exit Gas Thermocouple Assembly and Related Support Block Configuration	20, 22, 23a, 23b
NRX-A5 Skirtless Support Block	21a, 21b

Tests in support of NRX-A5 were required to provide forty (40) minutes operation at 4280°R in two cycles of approximately twenty minutes each. These requirements were fulfilled in the case of the prime NRX-A5 block design (foil washers in the counterbore seat area) by the results of tests HHT-4-10 and HHT-4-13 previously reported.¹ The requirements for the experimental skirtless block for NRX-A5 were fulfilled in test HHT-4-21.

An attempt to provide additional data on the endurance of a pre-cracked NRX-A5 block was unsuccessful when a temperature excursion melted the tie rod in test HHT-4-12b and damaged the support block. In addition, an attempt to provide a sixty minute endurance test of the NRX-A5 configuration in support of the XE-2/NRX-A6 back-up design failed on the initial power ramp because of a failure in the developmental chuck being employed.

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

WANL-TME-1511

The XE-1 requirements were originally specified to be twenty minutes endurance at 4280°R in at least two cycles. The requirement was subsequently changed to thirty minutes. The cycling requirement was added to simulate the results of the many power cycles included in the proposed XE-1 test plan. The design of the exit gas thermocouple assembly was altered slightly between tests to improve the design and the resulting configuration proposed for XE-1 was eventually qualified for twenty minutes in test HHT-4-23.

Requirements for NRX-A6 and XE-2 designs are for sixty minutes endurance at 4280°R in two or three cycles of twenty or thirty minutes each. These proof tests are currently being conducted.

2. Test Development

The techniques involved in the high temperature testing of complete clusters by resistance heating have been improved to the extent that twenty to thirty minutes duration tests at 4300°R exit gas temperature are repeatably attained. In addition to the advances reviewed in the previous progress report - orificing techniques, electrical contact enhancement, and lateral support system design - the following improvements reported here have added substantially to test repeatability and duration:

- "Floating" upper chuck design to permit axial expansion of the cluster.

- Expandible hot chuck design to provide radial expansion, improved electrical contact, and gas sealing.

- Hydrogen inlet plenum to separate hydrogen and helium flows.

- Improved instrumentation.

WANL-TME-1511

In addition to these innovations which have been employed in one or more of the tests reported herein, a new cluster - lateral support model design was completed. The new model is a combination of the current cluster configuration with a full length lateral support system similar to that used in the HHT-7 program for testing reactor periphery designs². Inclusion of a complete lateral support envelope around the cluster will provide improved and more uniform radial support to the elements and should permit the evaluation of fuel elements as well as support components under conditions better approximating those to be found in a reactor test. Hardware for this model is currently being procured and fabricated.

WANL-TME-1511

II. TEST DEVELOPMENT

A. UPGRADING OF CURRENT CONFIGURATION

Prior to the series of tests reviewed in this report, operation of the cluster model at exit gas temperatures near 4300° R and at about 0.10 lb/sec. hydrogen flow for twenty minutes duration had been accomplished several times. However, operation at these conditions appeared to be marginal in that the probability of two or more successive full-length twenty minute tests was relatively low. This marginal nature became quite apparent when a series of cluster tests (tests HHT-4-15c, 16a, 16b, and 17a previously reported¹ and tests HHT-4-18a, 18b, and 19 herein reported) failed during the early stages of the test.

After the series of cluster failures, no further attempts to test reactor grade hardware were made pending a complete investigation into the causes of the test aborts. The analysis of the entire series of cluster test results to date showed that several failure modes were most common:

Electrical arcing between the chucks and elements causing element breakage.

Breakage of the elements near the center element insulators.

Mid-core breakage of elements under an axial buckling load.

Arcing between the center element and fuel elements.

All of these failure modes are in some way related to the relative thermal expansion of one cluster component to that of another and the eventual failure of a component due to thermal stresses or arcing.

WANL-TME-1511

The design changes wrought by the analysis of these modes of failure were incorporated gradually over a series of about 10 tests until the cluster configuration shown in Figure 1 was finally achieved. This configuration has substantially increased the reliability of the model and represents the present state-of-the-art of cluster testing. It has provided repeated testing experience in excess of 25 minutes at or near full-power and has greatly increased the flexibility of the model to study the effects of high temperature and hydrogen atmosphere on reactor cluster hardware. The basic configuration is the same as was previously used with some important improvements which will be reviewed in the following sections.

1. Radial Supports

Thermal expansion analysis of the cluster in the radial and axial directions, based on measured axial surface temperature profiles, showed an interference between the lateral support sleeves and the fuel elements at steady - state conditions of temperature, especially near the hot end of the cluster. This interference due to the greater expansion of the elements relative to the supports resulted in high compressive stresses in the elements and high hoop stresses in the supports. On many occasions the lateral support sleeves were observed to have failed because of the overstress; and in some instances, elements were observed to have cracked between the lateral support sleeves as bowing occurred between the two "pinned" areas under the sleeves.

The lateral support sleeves were modified as a result of the thermal stress analysis to provide more room for element expansion. The use of sleeves with increased radial clearances between the elements and the sleeves eliminated the overstress and breakage of the supports. In addition, the

Figure 1
Cluster Corrosion Test Assembly

WANL-TME-1511

looser fit on the elements reduced the bundling pressure and the friction between the supports and elements. The elements were permitted to expand more uniformly under and between radial supports and the bowing problem was somewhat alleviated.

2. Center Element

Two problem areas were found to be related to the center element. The configuration employed in this model consists of a cylindrical center element with a 1/2-inch long niobium carbide-coated graphite hexagon on the hot end and a 17-inch long insulator hexagon on the cold end. The insulators are composed of beryllium oxide and boron nitride and are employed in the low temperature area of the cluster to locate the center element as well as to insulate it electrically from the fuel elements. This insulation of the center elements in the hotter areas of the cluster over the last 34-inches is accomplished by a stagnant gas gap formed between the cylindrical center element and the hexagon envelope of the fuel elements.

The first problem was associated with the ceramic insulators. It was found that depending on the axial temperature profile attained during the test, it was possible to have an interference fit between the hexagon insulators and the inside faces of the fuel elements because of differential thermal expansion. This interference fit resulted in the cracking or perforation of the elements by the relatively more abrasive ceramics. Relieving the across-flats dimensions of these insulators eliminated this problem.

WANL-TME-1511

The second difficulty arose when the unsupported 34-inch length of the center element bowed and touched the fuel elements. Since the fuel is at a positive electrical potential relative to the center element, arcing between the two surfaces can occur. This arcing and subsequent perforation of the elements on the inner surface was observed after several tests.

It was found that one of the causes of the bowing of the center element was the restriction of its axial movement under thermal expansion by the cluster plate assembly employed in this model. The dimensions of the center element and the insulator bushing used under the cluster plate were changed to prevent the interference between the two pieces.

3. Cold End Electrode

By far the most frequent cause of cluster test failure was the restriction of the axial movement of the elements as the cluster expanded thermally and the resulting breaking of elements by buckling. Calculations of the axial growth at the measured axial temperature profiles showed that the elements would expand from about 0.3 to 0.4 inches between start-up and full power conditions. Actual measurement of the axial growth by a linear displacement gage on the cold end of the cluster revealed a definite positive correlation between axial cluster growth and success. Those clusters which were free to expand on the order of 0.2 inch or more showed less tendency to fail than those in which axial growth was restricted to less than 0.2 inch. The study of dimensional clearances in the area of the cold end chuck indicated that, in many cases, the cold end chuck was not free to slide axially as expected because of "lock-up" or higher than expected frictional forces between the cold chuck and the mating surface of the cold end spacer which retains the chuck.

The obviously indicated solution was to increase the radial clearance between these two pieces. The inter-related problems of electrical contact between the two surfaces and the heat transfer from the power generating chuck to the water cooled electrode made the solution of the "lock-up" problem less amenable to an easy solution. For in order to insure good heat transfer and electrical contact between the chuck and electrode it is necessary to have relatively high contact pressures between the two surfaces.

One proposed solution was the configuration shown in Figure 2. Woven graphite cloth was wrapped on the periphery of a cold end chuck which had previously been machined to an outer diameter about 0.5 inch less than normal. The cloth acted as a cushion as well as a lubricant between the mating surfaces and was quite successful in providing a "floating" cold end arrangement. Unrestrained axial growth was observed. However, the electrical and thermal resistance through the cloth was higher than expected. As a result of the higher power generation in the chuck and the lower heat flux, the parts eventually overheated and failed.

Following this failure, several tests were conducted in the single element furnace, a similar water cooled apparatus employed in the electrical resistance heating of single fuel elements, at a current flux identical to that employed in the cluster test model. These single element tests were conducted with various size chucks and electrode spacers to determine the largest effective gap between the mating surfaces of the chuck and electrode spacer which could be employed prior to the onset of arcing. It was found that gaps of less than 15 mils were required at the given conditions of current flux, voltage, and surface conditions.

Figure 2
Experimental Cold End Chuck Assembly With Graphite Cloth

Analytical calculations showed that heat transfer from the chuck to the electrode through the gas in the gap between these surfaces would be marginal for gaps in excess of 20 mils. A radial gap of 10 mils was therefore selected for test to be well within both limiting considerations.

The configuration illustrated in Figure 3 was tested and found to provide an adequate solution to the problem. Unrestricted axial movement was attained on the power increase and decrease ramps at the beginning and end of the test cycle as well as on small power adjustments during the steady-state full-power portions of the tests. The O-ring seen near the top of the chuck was added as a centering device rather than as a seal, and the copper braids were added to reduce the effects of arcing during the initial power ramp when the maximum clearances exist between the mating surfaces. This configuration has been employed in eight successive, relatively long duration tests and has essentially eliminated the problems associated with restricted axial growth of the cluster.

4. Hot End Chuck

Perhaps the second most frequent cause of cluster test failure was found to be the arcing-induced element damage near the hot end chuck. In the present cluster configuration, the hot end chuck is held in place by a retaining nut which prevents the cluster from moving away from the electrode in the event of a gas pressure surge. Therefore, good electrical contact between the chuck and electrode is assured. The contact between the elements and chuck is adequate at full power when the elements are fully thermally expanded into the chuck; however, during the power ramp when the gap between the chuck and the elements is greatest, arcing is commonly observed to occur.

Figure 3
Experimental Cold End Chuck Assembly With Copper Braids

In the hot chuck designs previously proposed and tested, the leading edge of the chuck was tapered to increase the local electrical resistance. It was anticipated that the current flux between the elements and the chuck would, therefore, be more uniformly distributed along the surface rather than concentrated at the leading edge. The concept, at first, appeared to be sound but was subsequently found to be inadequate. Because the resistance in the leading edge of the chuck was higher than in the larger portion, a higher temperature also existed there. This temperature gradient caused the leading edge to lift away from the elements slightly and arcing occurred across the gap. The arcing, in turn, pitted, cracked, or severed the elements in that area.

An interim solution to this problem consisted of increasing the thickness of the leading edge of the chuck. This modification reduced arcing to some extent; however, a more adequate design was pursued. The configuration shown on the cluster assembly in Figure 1 was developed and was found to provide the margin of safety required in the hot chuck hardware.

The new chuck is an expandable configuration which is designed to maintain electrical contact with the fuel elements throughout all stages of thermal expansion from start-up to full-power operation. Fingers or grips cut to the cluster configuration are held in place by a graphite clip spring which maintains a light, inward radial pressure. Pyrolytic graphite foil wrapped around the grips insures good electrical contact, provides a gas seal for the helium blanket around the cluster, and provides for limited radial expansion as it compresses into the spring clip during thermal growth of the cluster. Additional graphite foil seals placed between the two sets of grips further prevent helium leakage through the chuck. The two grips are housed in a sleeve which is retained in the electrode.

Experience with this design in three successive tests of over 20 minutes duration has indicated that arcing under the grips is minimal and not damaging to the elements. Gas sealing is excellent. Element cracking in the area has essentially been eliminated.

5. Hydrogen Flow in the Cluster

It was learned in the previously reported test series that proper orificing of the elements was essential to the long duration testing of clusters. Uneven distribution of hydrogen flow through the cluster resulted in high radial thermal gradients which tended to bow and crack the elements. The use of extended orifices to insure that controlled flow of hydrogen was attained was an important improvement in the design.

In spite of the improvement, two difficulties remained. Because of the radiation heat losses from the surface of the cluster to the furnace walls, a high radial temperature gradient was established from the outside to the center of the cluster. Second, it was possible for the flow of hydrogen from the inlet plenum in the furnace to occur along parallel paths both through the cluster and through the furnace body around the cluster. The only method of limiting hydrogen flow around the cluster in the furnace body was by maintaining the pressure of the helium blanket at a slightly higher value (1 to 50 inches of water) than the hydrogen inlet pressure. This technique could result in some mixing of the hydrogen and helium at the cluster inlet.

The first difficulty was attacked by a more desirable orificing program and an improved radiation shield design. Whereas, tests prior to test HHT-4-23b employed 30 mil orifices in the outer or peripheral circle of flow channels and

33 mil orifices on all inner channels, test 23b employed 36 mil orifices on the innermost circle of channels. In addition, three of the five graphite radiation shields around the cluster were replaced by three concentric, 15-inch long molybdenum shields which are known to be somewhat more efficient in preventing heat losses from the cluster. Preliminary data obtained from thermocapsules in the center element immediately above the support block are insufficient to show improvement in reducing the radial temperature gradient. Further testing to provide more data and further optimization of the orificing program may be required.

The second problem related to hydrogen flow through the cluster was solved by the addition of a direct hydrogen inlet plenum to the orifices as illustrated on the assembly in Figure 1 and pictorially in Figure 4. This plenum is connected to the hydrogen inlet line through a flexible hose connection which is routed through a 4-inch thick instrumentation ring recently installed on the furnace body. This scheme separates helium and hydrogen flows through the furnace and insures that only hydrogen in a measured, controlled amount reaches the orifice plate and flows through the cluster.

An additional value of the direct gas inlet is the ability to vary the pressure of the helium blanket at will. In tests of support hardware in which long duration endurance of elements is desired, this pressure can be increased to provide a corrosive-inhibiting blanket around the cluster. In tests of element endurance, the pressure can be lowered to simulate the pressure differential between coolant channels and some interelement channels which is calculated to exist in a full-scale reactor test.

CONFIDENTIAL
RESTRICTED DATA
Atomic Energy Act - 1954

WANL-TME-1511

Figure 4
Cluster Direct Gas Inlet Plenum

CONFIDENTIAL
RESTRICTED DATA
Atomic Energy Act - 1954

WANL-TME-1511

B. CLUSTER-LATERAL SUPPORT MODEL

Although the cluster configuration in its present state of development is a useful tool in evaluating support blocks and related cluster hardware under conditions which approximate those in a reactor test, it is limited somewhat as a flexible tool for the evaluation of the entire cluster including the fuel elements. The basic deficiency is in the present lateral support system. Radial support along the length of the cluster is achieved through five equally spaced rings. The area between the rings is exposed to the furnace body. To prevent unnecessary damage to the graphite radiation shields in the furnace body as well as to the cluster chucks and supports, the furnace body is pressurized with helium maintained at a pressure slightly higher than the hydrogen pressure. The result is that the outside of the fuel elements are not exposed to hydrogen as they are in a reactor test and, under some conditions, the helium blanket can actually inhibit bore corrosion. This can occur when the higher pressure helium flows through the pores of the element matrix or through a pinhole in the element to purge the hydrogen away from pockets of corrosion.

For cluster tests in which the support hardware is the subject of the evaluation, this protective helium blanket is desirable in that it makes long duration tests possible by inhibiting element damage. If tests of the full cluster, including elements, are desired, the use of a helium blanket can seriously compromise the simulation of actual reactor test environments.

A second deficiency of the present design is the lack of control over the degree of radial support pressure. The lateral support rings are loaded to provide a specified radial clearance at room temperature between the elements and support sleeves so that at high temperature neither the elements nor the supports are overstressed. The

WANL-TME-1511

actual compression afforded by the sleeves is a result of the relative thermal expansion between the sleeves and the elements at steady-state full power temperature levels. It is not always possible to predict these adequately beforehand. As a result, radial support or bundling pressure can vary from test to test. This influences not only the stress level set up in the elements for a given test but also the sizes of the interelement gaps.

A new cluster-lateral support model was designed which hopefully will alleviate these deficiencies. The new model is a combination of the best features of the present cluster configuration with a lateral support system similar to that used in the HHT-7 program for corrosion tests of reactor periphery designs. Figure 5 is an assembly drawing of the new model.

The cluster, hot and cold end chucking, and furnace support hardware used in the new model are quite similar to the present cluster model designs changing only where anticipated assembly problems dictated a modification. Therefore, the cluster itself, as before, continues to be the source of power generation. This is a modification of the present HHT-7 design which employs a circular cross section, tapered heater element as the power generating source and a one-piece graphite "cluster" to simulate the filler strip to element interface.

The center element is changed substantially. Instead of a normal graphite center element, boron nitride is employed over the entire length with the exception of the coated tip which is retained to maintain the proper interface with the support block. The boron nitride electrically and thermally insulates the tie rod channel from the

Figure 5
Cluster-Lateral Support Model

WANL-TME-1511

elements. It is itself protected from the elements by 1/8-inch thick pyrolytic graphite strips on each face of the hexagon. No reactor grade insulating sleeves are employed around the tube liner. The resulting temperature profiles for the worst steady-state condition expected are shown in Figure 6. These values were calculated from measured element temperature profiles assuming a tie rod channel gas flow rate of 0.01 lb/sec and the least desirable values for specific heats and thermal conductivities. The results indicate that the boron nitride should not be damaged by high temperature. They also point out that by adjusting tie rod flow rates appropriately, exit gas temperature in the center annulus can be held well below 1200°R. It should be noted that the profiles given in Figure 6 are based on preliminary calculations. In terms of fuel interface temperature and radial thermal gradients, they do not match NRX-A5 profiles exactly. Continued analyses to specify conditions which better simulate those in a reactor test are in progress.

Radial support of the cluster is accomplished with a full length support system consisting of an annular graphite barrel, thirteen seal rings, plunger pin and spring assemblies, boron nitride filler strips, and pyrolytic graphite insulating strips as shown on Figure 5. This system will provide a more nearly constant radial support loading than is currently achieved in that the elements will be loaded by an expandible, spring-loaded system. Bundling pressure profile can be programmed by the proper selection of spring force.

The use of O-rings and pyrolytic graphite foil seals completely separates the helium and hydrogen flows in the model. The elements therefore are exposed to a hydrogen atmosphere at a pressure which is established by the relative impedances of the seal segments. The flow slots in these segments can be pre-selected to provide a highly flexible interelement pressure distribution along the length of the cluster.

Figure 6
 Temperature Profiles in the Center Element

WANL-TME-1511

Therefore, conditions approaching those at a specific location in a test reactor can be achieved.

The filler strips employed in this model are boron nitride to provide good high-temperature electrical insulation between the elements, and support system. Based on measured temperatures in HHT-7 tests,^{2, 3, 4} it is not expected that the boron nitride will be damaged by high temperatures. Thermal analyses in this area will continue in an effort to better simulate reactor conditions.

Detailed designs for components of the new model have been completed and procurement is in progress. A developmental test is planned for the future to test the model and to define problem areas which are not currently perceived. As the development of the system continues, the model should provide a new and improved technique for the high-temperature evaluation of cluster components.

WANL-TME-1511

III. REACTOR HARDWARE TESTS

A. TEST CONFIGURATIONS

The cluster tests reviewed here were conducted to evaluate NRX-A5 and XE-1 hardware designs under qualification or proof-test conditions. Thus, the test plan specified that each component design should be tested for periods of 20 to 40 minutes at steady-state, full power temperatures. Following several abortive attempts to test the hardware and the subsequent modifications reviewed above, the NRX-A5 skirtless block and the XE-1 exit gas thermocouple assembly were eventually tested as prescribed. Table I summarizes the configurations employed on all of these tests and gives the test designations and dates.

Reactor grade hardware was employed throughout the test series in accordance with the parts list in Table II. The actual component designation by lot or serial number is shown in Table III for the more critical components. In many cases, fuel elements were not of NRX-A5 or XE-1 reactor quality.

B. SUMMARY OF TEST RESULTS

The discussion of the test variable measurement and analysis given in WANL-TME-1375¹ for the previous test series in support of NRX-A4 and NRX-A5 apply to these tests and the reader is referred to this document. Basically, gas pressures, temperatures, and flow rates were monitored for the helium and hydrogen streams and material temperatures of the elements and blocks were measured by optical pyrometer. Table IV summarizes these important results for the successful tests. Data for tests 18a, 18b, 19, 12b, and 13c which failed on the initial power ramp are not given.

Table I
Test Summary

Test Number	Support Configuration	Test Date
HHT-4-12b	NRX-A5 "as built" design block, pre-cracked. Pyrofoil washers, 90 mil radius x .257 inch thick coated ATJ Support washer.	4-4-66
HHT-4-13c	Same configuration as test 12b except block was not cracked.	3-16-66
HHT-4-18a	NRX-A5 skirtless block, coated ATJ protection cup and support washer.	3-18-66
HHT-4-18b	Cycle 2 of above.	3-29-66
HHT-4-19a	Same configuration as test 18.	4-12-66
HHT-4-20a	XE-1 exit gas thermocouple assembly with NRX-A5 "as-built" block and related support hardware. Extended, perforated, tungsten coated molybdenum protection cup. Normal NRX-A5 (non-extended) insulating cup. Flanged thermocouple support. W/W-Re 26% thermocouple sheath.	4-15-66
HHT-4-21a	Same configuration as test 18.	4-20-66
HHT-4-21b	Cycle 2 of above.	5-5-66
HHT-4-22a	Same as 20a except for following: Tungsten thermocouple sheath. Non-flanged thermocouple support.	4-27-66

Table I (Continued)

Test Number	Support Configuration	Test Date
HHT-4-23a	Same as 20a except for following: Non-flanged thermocouple support. Employed insulating cup from 20a rather than a new one. Thermocaps in center element.	5-13-66
HHT-4-23b	Cycle 2 of above.	9-8-66

Table II
Reactor Grade Components Employed in Cluster Tests

Part Description	Quantity per Cluster	Part Number	Tests in Which Used
Fuel Elements	6	XE-1 Candidate or NRX-A5 Grade	All
Split Bushing	1	946 C 216 HO2	12b, 13c, 18, 19, 21
Split Bushing	1	946 C 216 H14	20, 22, 23
Compression Spring	1	978 D 695 HO1	All
Spring Shim	1 to 10	946 C 684 HO1	All
Tie Rod (Solid)	1	945 C 568 HO1	12b, 13c, 18, 19, 21
Tie Rod Assembly (Hollow)	1	978 D 576 GO1	20, 22, 23
Tie Rod Nut	1	946 C 053 HO1	12b, 13c, 18, 19, 21
Tie Rod Nut	1	946 C 670 HO1	20, 22, 23
Tie Rod Pin	1	963 B 339	12b, 13c, 18, 19, 21
Tube Liner	1	978 D 347 HO8E	All
Insulating Sleeve, Counter-sunk	1	946 C 970 HO2	All
Insulating Sleeve, Tapered	2	946 C 120 HO1	All
Insulating Sleeve, Tapered	2	946 C 121 HO1	All
Insulating Sleeve, Straight	12	946 C 969 HO1	All
Tube Liner Adapter	1	978 D 351 HO1	All
Support Cone	1	976 D 449 HO1	12b, 13c, 18, 19, 21
Insulating Washer	1	963 B 257 HO1B	All
Insulating Cup	1	944 C 889 HO1C	12b, 13c
Insulating Cup	1	978 D 626 HO1	18, 19
Insulating Cup	1	978 D 626 HO3D	20, 21, 22, 23

Table II (Continued)

Part Description	Quantity per Cluster	Part Number	Tests in Which Used
Support Washer, ATJ	1	978 D 960 HO1	18, 19, 21
Support Washer, ATJ	1	978 D 960 HO3D	12b, 13c, 20, 22, 23
Protection Cup	1	978 D 959 HO1	18, 19, 21
Pyrofoil Washers	10	947 C 043 HO1	12b, 13c, 20, 22, 23
Support Block	1	909 E 371 HI0P	12b, 13c, 20, 22, 23
Support Block	1	937 J 924 GO1	18, 19, 21
Thermocouple Support Assembly	1	978 D 579 GO2	20
Thermocouple Support Assembly	1	978 D 579 HO6D	22, 23
Tungsten-Rhenium Thermocouple	1	979 D 149 HO2D	20, 22, 23
Chromel-Alumel Thermocouple	1	978 D 186 HO1	All
Tungsten-Molybdenum Cup	1	979 D 497 HO2A	20, 22, 23

Table III
Component Identification

HHT-4 Test Number

Component	20a	21a	21b	22a	23a	23b
B Element	AC-69-29240	AC-89-29653	AC-69-23136	UN-99-96894	PF-3581 ⁺	AC-99-19374
C Element	AC-69-29213	AC-79-29378	AC-69-23103	UN-99-97565	PF-4542	AC-99-19937
D Element	AC-69-29093	AC-79-29351	AC-69-23056	UN-99-97176	PF-3337	AC-99-18679
E Element	AC-69-29321	AC-79-29363	AC-69-23138	UN-99-97435	PF-6502	AC-99-19359
F Element	AC-69-29106	AC-89-29851	AC-69-23137	UN-99-97580	PF-4714	AC-99-19442
G Element	AC-69-29108	AC-69-29256	AC-69-23060	UN-99-97262	PF-3824	AC-99-19399
Support Block	A21760	A33234	A33234	A21204	A21524	A21524
Insulating Cup	LB289*	-	-	LB1855	LB289*	LB289*
Insulating Washer	-	-	-	LB2385	-	-
Support Washer	LB2384	-	-	LB8384	LB2304	LB2304
Protection Cup	-	-	-	-	-	-
Tie Rod	-	C22H	C22H	-	-	-
Exit Gas Thermocouple	A48865	-	-	A48862	20	20
Tube Liner Thermocouple	-	-	-	-	-	-
Molybdenum Cup	-	-	-	-	-	-
Pyrofoil Washers	-	-	-	-	LB2425	LB2425

* Same cup.

⁺ Unfueled.

Table IV
 Test Conditions and Results

Parameter	HHT-4 Test Number						
	20a	21a	21b	22a Cycle 1	22a Cycle 2	23a	23b
Test Duration, min.	42.0	16.0	39.0	21.0	23.0	28.0	39.0
Equivalent Time at 4283° _R , min.	18.3	7.3	34.0	6.0	4.6	20.8	20.6
Duration at Steady-State, min.	30.0			8.0	16.0	21.5	21.5
Support Block Temperature, ° _R	3870	4160	4400	(4000)	(4000)	4260	-
Cluster Exit Gas Temperature, ° _R							
1/2 Inch From Block	4020	-	-	3850 ⁺	3750 ⁺	4270	1480 ⁺
3 Inches From Block	3565	4300	4180	-	4000	4120	4200
Element Surface Temperature, ° _R							
Station 43	4220	4820	4880	-	4300	4620	4650
Station 35	3940	4280	4520	4150	3880	4360	4590
Station 16	3520	3080	2810	2970	3320	2780	3420
Station 8	-	2600	2280	-	-	2050	2800
Tie Rod Exit Gas Temperature, ° _R	1020	1322	1160	1200	1270	1088	1020
Hydrogen Flow Rate, lbm/sec	0.0955	0.0980	0.0990	0.0981	0.1005	0.0989	0.1205
Helium Flow Rate, lbm/sec	0.0172	0.0158	0.0158	0.0167	0.0167	0.0168	0.00293
Cluster Outlet Pressure, psia	565	565	565	565	565	565	569
Cluster Pressure Drop, psi	55.0	50.0	54.0	55.0	45.0	53.0	50.0
Electrical Power Input, MW	1.54	1.74	1.76	1.78	2.06	1.81	2.13
Resistance, milliohms	7.32	8.28	8.34	8.65	9.08	7.02	8.56
Voltage, volts	106	120	121	124	137	113	135
Current, kiloamps	14.50	14.50	14.50	14.35	15.05	16.10	15.75
Tie Rod Pre-Load, lbf	300	294	328	300	300	300	320
Maximum Tie Rod Load, lbf	-	432	393	-	-	-	-
Tie Rod Orifice Diameter, mils	70	52	52	70	70	70	70

⁺ Highest temperature recorded.

WANL-TME-1511

The axial temperature profile for these tests approached the NRX-A5 profile to a higher degree than in previous tests. Figure 7 shows these profiles and compares them with the NRX-A5 material temperatures at a power factor of unity.⁵

Graphite components were weighed before and after each test when feasible and weight losses from graphite corrosion and niobium carbide coating losses were recorded. These data appear in Table V.

Several words of caution in the use of the summarized data should be noted. First, the weight loss data should not be employed directly from the table for corrosion calculations. These values reflect coating losses and depositing of material from upstream in the cluster as well as corrosion losses. Second, the equivalent time data were based on the reaction of carbon and hydrogen to form methane as a convenient method of comparing the results of two or more tests and as a simple method for determining the effects of transient operation above or below the steady-state design temperature level of 4283°R. As a result, these figures apply to graphite parts such as the insulating cups and support blocks but do not apply to thermocouples, protection cups and other non-graphite hardware. To evaluate these components, a "duration at steady-state" is given. This time represents cumulative operating time at or near the listed steady-state operating temperature. Third, the tie rod loads at full power were not recorded in every case since no strain gage instrumentation was available. These loads are estimated to be within + 50 lbf of 500 lbf maximum load. Finally, the axial temperature profiles and all electrical data should be compared with the realization that unfueled elements were employed in test 23a.

Figure 7
Axial Temperature Profiles for Tests HHT-4-20 through 23

Table V
 Summary of Weight Loss Data

Component	Loss	HHT-4 Test Number					
		20a	21a	21b	22a	23a	23b
Support Block	Grams	1.40	-	38.10 ⁺	2.00	2.20	8.00
	Per Cent of Initial	0.80	-	31.45 ⁺	1.11	1.22	4.44
Support Washer	Grams	0	-	WELD	0	0.40	0
	Per Cent of Initial	0	-	WELD	0	15.40	0
Insulating Cup	Grams	-	-	0.40 ⁺	-	0.30**	1.44**
	Per Cent of Initial	-	-	13.33 ⁺	-	10.70**	51.50**
Pyrofoil Washers	Grams	0	-	-	-0.05 ⁺⁺	0.10	0.105
	Per Cent of Initial	0	-	-	-7.70	11.10	15.00
Aft Insulating Sleeve	Grams	0	-	0.6 ⁺	0.05	-	0.083
	Per Cent of Initial	0	-	8.45 ⁺	0.71	-	11.35
Insulating Washer	Grams	0	-	0.10 ⁺	-	-0.10 ⁺⁺	0.004
	Per Cent of Initial	0	-	16.67 ⁺	-	-16.67 ⁺⁺	0.67
Center Element	Grams	-	19.2	17.3	16.8	23.7	10.8
	Per Cent of Initial	-	6.83	6.16	6.00	8.45	3.96
Six Fuel Elements	Grams	82.7	89.3	202.1	157.0	107.7	183.1
	Per Cent of Initial	2.07	2.16	5.12	3.82	2.83	4.35
Protection Cup	Grams	-	-	0.30*	-	-	-
	Per Cent of Initial	-	-	4.06*	-	-	-

- ⁺ Cumulative Loss for 21a and 21b.
^{*} Cup plus washer cumulative loss.
⁺⁺ Deposit of material.
^{**} Cumulative Loss for tests 20 and 23.

WANL-TME-1511

A more detailed discussion of the individual tests follows.

C. DISCUSSION OF INDIVIDUAL TEST RESULTS

1. HHT-4-12b and 13c

Both of these support blocks had undergone previous test cycles and were being tested to provide long term endurance checks for the NRX-A5 support system. The blocks were the NRX-A5 "as built" configuration with the exception that the 12b block was pre-cracked in the counterbore area.

Test 12b was terminated after 4.5 minutes at full power or steady-state. Arcing near the hot chuck severed the elements and the tie rod was melted. The support block was recovered but was damaged severely by the high temperature and molten metal.

Test 13c was terminated on start-up because of arcing of an experimental chuck being used. The block was not damaged severely but coating on the top surface was bonded to the elements and left the graphite of the block exposed. The block was put aside for possible future testing. Since, it was not considered worthwhile at the time to continue the evaluation with the loss of coating on the block.

2. HHT-4-18 and 19

Both tests were attempts to proof-test the NRX-A5 skirtless block configuration. Test 18a was terminated when an experimental cold chuck failed during start-up. During the second cycle, test 18b, arcing near the hot chuck

WANL-TME-1511

resulted in a test abort and damage to the block. Test 19a was also terminated after severe arcing near the hot chuck which severed the elements melted the tie rod, and critically damaged the block. None of the hardware from these tests was suitable for re-testing.

3. HHT-4-20

The qualification testing of the XE-1 exit gas thermocouple assembly was accomplished in tests HHT-4-20, 22, and 23 following the previous thermocouple tests, HHT-4-11 and 13, which were directed toward qualification of a thermocouple and support assembly for NRX-A5.

The results of the previous tests, reported in detail in WANL-TME-1375¹, failed to qualify the NRX-A5 design, primarily because of severe corrosion of the extended pyrolytic graphite insulating cup. Several changes were, therefore, made in the XE-1 design based on the knowledge gathered from the previous tests 11 and 13. These included:

- a. The use of a standard NRX-A5 insulating cup rather than the extended pyrolytic graphite cup previously employed to protect the tie rod cone and thermocouple support.
- b. Inclusion of two rows of holes near the base of the molybdenum protection cup to allow cool gas from the tie rod channel to flow outward into the annulus between the insulating cup and the molybdenum cup.

WANL-TME-1511

- c. Enlargement of the flow holes in the thermocouple support to provide additional coolant flow around the thermocouple braze joint.

In addition, a further change was made following the results of test HHT-4-20a. The flange on the radially outward face of the thermocouple support was removed in favor of a conical design which was intended to reduce heat transfer to the braze area of the thermocouple. These changes are reflected in the parts listed for each test given in Table II.

In the first cycle, HHT-4-20a, the cluster was held at steady-state for 30 minutes. However, an erroneous recorder reading resulted in the attainment of temperatures about 200°R lower than desired. The equivalent reaction time at 4283°R was 18.3 minutes. The thermocouple output was steady and continuous during the entire test, including the downward power ramp as shown by Figure 8. A comparison between the exit gas thermocouple output and that of a second W/W-Re thermocouple in the furnace outlet shows the two to be within 435°R . Correction of the cluster exit gas temperature for tie rod coolant flow brings the two indicated temperatures to within 165°R .

Figures 9, 10 and 11 show the thermocouple and support assemblies before and after the 30 minute power test. The insulating cup lost most of the coating on its outer surface but very little corrosion occurred. No cracks were noted in the molybdenum cup; however, the thermocouple sheath and support were blistered on and near the flange of the support. Conclusions regarding the nature and causes of this blistering will be discussed in a later report following metallographic analysis of the parts.

Figure 8
Exit Gas Thermocouple Output Record (HHT-4-20a)

Figure 9
XE-1 Support Block and Exit Gas Thermocouple Assembly Before
Test HHT-4-20a

Figure 10
XE-1 Thermocouple and Support Hardware After
18.3 Minutes at 4283°R (HHT-4-20a)

Figure 11
XE-1 Thermocouple and Support Assembly After
18.3 Minutes at 4283° R (HHT-4-20a)

WANL-TME-1511

The cluster for the second power cycle, HHT-4-20b, was built but was not tested because the thermocouple tip was broken during installation into the furnace. The components were, therefore, put aside for metallographic analysis and for possible inclusion in a future test. Figure 12 shows the final appearance of the molybdenum cup, tie rod cone, and thermocouple support.

4. HHT-4-21

The endurance testing of the NRX-A5 skirtless support block and related hardware was successfully completed in test 21.

Two cycles, designated HHT-4-21a and HHT-4-21b, were conducted in the cluster furnace. The first cycle proceeded normally for 16 minutes under conditions of applied power before a hot spot near the aft end of the cluster developed and required a rapid test termination to prevent damage to the block, tie rod, and other support components.

The exit gas temperature remained constant at 4300°R throughout the test at a hydrogen flow rate of 0.098 lb/sec. On disassembly of the build, no apparent damage to the graphite components was noted except for peeling of coating on the outside of the insulating cup. In addition, welding between the elements and the upstream face of the block resulted in the removal of some coating from the block. Figure 13 illustrates this coating damage.

In the second cycle, 39 minutes under power were logged. Disassembly revealed large pockets of corrosion in the block starting at the upstream

Figure 12
Tie Rod, Molybdenum Cup, and
Thermocouple Assembly from HHT-4-20a

Figure 13
NRX-A5 Skirtless Block After 7.3 Minutes at 4283°R (HHT-4-21a)

WANL-TME-1511

face. The bores, periphery, and downstream face of the block were virtually intact, indicating that the corrosion occurred because of the coating loss in the previous cycle. The protection cup and support washer showed no signs of cracking, coating loss, or corrosion; however, the two components were tightly stuck together after the test. No welding took place between the cup and the block. Significantly, the support system continued to function adequately under load in spite of the fact that weight losses were 31 per cent for the support block and 13 per cent for the insulating cup. Figures 14, 15, and 16 are post-test photographs showing the results after 41 minutes at 4283°R.

5. HHT-4-22

The exit gas thermocouple support assembly was modified somewhat by removing the flange on the leading or exposed end. A conical design was substituted to reduce the area for heat transfer to the brazed transition joint as shown in Figure 17. An additional, though unintentional, change from previous exit gas thermocouple tests was the use of a tungsten thermocouple sheath rather than a tungsten-rhenium alloy sheath.

The test plan for this test specified a 5 to 10 minute full power cycle followed by a 20 to 30 minute full power cycle. The first cycle was to effectively remove most of the coating from the outside surface of the insulating cup and the second cycle was to provide the endurance test based on the largely uncoated cup. The two cycles were designed to be within the present test capability of the HHT-4 assembly so that minimum down-time and assembly effort would be required between cycles.

CONFIDENTIAL
RESTRICTED DATA
Atomic Energy Act - 1954

Astronuclear
Laboratory
WANL-TME-1511

Figure 14
NRX-A5 Skirtless Block After
41 Minutes at 4283°R (HHT-4-21b)

CONFIDENTIAL
RESTRICTED DATA
Atomic Energy Act - 1954

Figure 15
Corrosion of the Skirtless Block (HHT-4-21b)

Figure 16
Protection Cup and Insulating Cup After
41 Minutes at 4283°R (HHT-4-21b)

Figure 17
XE-1 Support Block and Exit Gas Thermocouple Assembly Before Test HHT-4-22a

WANL-TME-1511

In the first cycle, control of power was based on the exit gas thermocouple until it indicated a temperature 3850°R . At that point, the output of the thermocouple decreased instantly to zero and furnace control was shifted to power correlations from previous tests. The resulting temperature level at steady-state is estimated to have been about 4000°R . After 8 minutes at this temperature level, the power was decreased slowly to zero. During the power decrease, the thermocouple apparently formed a new junction. The output resumed at an indicated temperature of 2480°R and followed the power decrease smoothly to zero as shown in Figure 18.

Inspection of the cluster in the furnace after Cycle 1 revealed no cracks or other indication of damage. The thermocouple sheath was blistered slightly, but otherwise, no component in the thermocouple or support assemblies appeared to be damaged. The decision was then made to restart the test as planned without a cluster disassembly and detailed inspection.

In the second cycle, the thermocouple output seen on Figure 17 was smooth and continuous up to 3750°R at which point it again dropped to zero. Furnace control was shifted to the furnace outlet thermocouple and the test was continued for about 16 minutes at or near 4000°R . During this portion of the test a high helium leak rate was attained and power had to be adjusted up and down repeatedly during the 16 minutes to stop the leak. Finally, the test was terminated when it was realized that the high leak rate was a result of broken elements. As a result of the cycling of power, temperatures in the gas stream varied between 2900°R and 4200°R . Equivalent time at 4283°R was about 11 minutes whereas the cluster was over 2900°R for about 24 minutes.

CONFIDENTIAL
RESTRICTED DATA

Atomic Energy Act - 1954

**Astronuclear
Laboratory**
WANL-TME-1511

Figure 18
Exit Gas Thermocouple Output Record for Test HHT-4-22a, Cycle 1

CONFIDENTIAL
RESTRICTED DATA

Atomic Energy Act - 1954

WANL-TME-1511

Post-test inspection revealed that several elements were broken, presumably on the down-ramp of Cycle 1. The thermocouple, molybdenum cup, and thermocouple support were melted slightly as shown in Figure 19. During disassembly the tip on the thermocouple broke near the support. The tungsten-sheathed tip is shown in an enlarged view in Figure 20. In addition to the melting, the molybdenum protection cup was cracked from the slot in the trailing edge to the first row of holes. This may have occurred during disassembly. The graphite support hardware was essentially intact with the exception of coating removal on the insulating cup.

6. HHT-4-23

As initially planned, this final test was to include all new thermocouple tie rod, and support hardware along with the insulating cup and molybdenum protection cup from test 20a. This would provide endurance data on both cups on a re-start basis since each had previously been tested for 30 minutes. The plan was not fully realized in that the molybdenum cup was cracked in the pre-loading of the tie rod during assembly of the cluster when the close fits between the thermocouple support, tie rod cone, and molybdenum cup were not achieved. Therefore, a new molybdenum cup was employed with the insulating cup from test 20a. Figure 21 shows the support hardware employed and illustrates the degree of coating removal on the insulating cup.

One of the characteristics of the cluster and furnace assemblies which, it was hypothesized, deleteriously effected the thermocouple tests was the radiation heat losses from the cluster surface to the furnace shields. These result in a thermal gradient from the outer surface of the fuel elements to the inner surface which would, in turn, result in higher exit gas temperatures

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

Astronuclear
Laboratory
WANL-TME-1511

Figure 19
XE-1 Thermocouple and Support Hardware After
24 Minutes Above 2900° R (HHT-4-22a)

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

Figure 20
Tungsten Sheathed Thermocouple After Test HHT-4-22a

Figure 21
XE-1/NRX-A5 Support Components Prior to Test HHT-4-23a

WANL-TME-1511

near the inner circle of flow channels than in the outer rows. Larger orifices are employed in these inner channels to provide more coolant flow and to attempt to lower the radial thermal gradient. However, no measurement of the effectiveness of the orificing technique was made previously. To define the maximum gradient for this test, thermocapsules were inserted into the center element at approximately the 52-inch station as shown in Figure 22.

The cluster assembly was successfully held at full power for 21.5 minutes before the power supply overheated and automatically shut down. The thermocouple recorded smoothly and continuously during the power ramp and steady-state power hold as is illustrated by Figure 23. It responded rapidly to all power increases with a corresponding temperature increase. The steady-state temperature level was about 4260°R .

Figures 24, 25, and 26 shows the post-test condition of the thermocouple and support assemblies. Very little damage is apparent except for corrosion of the insulating cup and slight blistering of the thermocouple sheath near the support. In addition some braze material from the transition joint melted and flowed along the thermocouple sheath. The total weight loss for the insulating cup was about 11 percent of its initial weight. This was largely coating loss and was the result of a total equivalent time of 39 minutes at 4283°R .

The thermocouple data indicated that the temperature on the inner surface of the elements at station 52 was from 4500°R to 4600°R . This would indicate that a gradient of, perhaps, 200 to 300°R could have existed from the tip of the thermocouple to the thermocouple support. Thus the support may

Figure 22
Thermocapsule Insertion in Center Element (HHT-4-23a)

Figure 23
Exit Gas Thermocouple Output Record for Test HHT-4-23a

Figure 24
XE-1 Thermocouple and Support Hardware After
21 Minutes at 4283° R (HHT-4-23a)

Figure 25
XE-1/NRX-A5 Support Components After
21 Minutes at 4283°R (HHT-4-23a)

Figure 26
XE-1 Thermocouple and Molybdenum Cup After Test HHT-4-23a

WANL-TME-1511

have reached a temperature of 4600°R . This observation could explain the apparent melting of braze material as well as the localized blistering on the thermocouple sheath noted on this and prior tests if one postulates the existence of low melting eutectics of tungsten, molybdenum, carbon, niobium, and other materials.

The final cycle for this test was conducted after several weeks of furnace down-time during which time many of the design modifications previously described in Section II were installed. In addition, the cluster configuration was changed somewhat. The inner row of flow orifices were enlarged from 33 mils to 36 mils and the direct gas inlet assembly shown in Figure 27 was installed. As in the previous cycle, the center element was instrumented with thermocouples. Hydrogen flow rate through the cluster was increased to 0.12 lb/sec.

During the initial power ramp in the second cycle (test 23b), the thermocouple output was continuous until a temperature of 1480°R was attained. At this point the thermocouple formed a new junction in the cooler part of the tie rod cone and indicated a temperature of about 1000°R for several minutes before an open junction was indicated. This behavior is shown by the trace on Figure 23.

The test was continued for a total time at a steady-state temperature of 4200°R of 21.5 minutes in order to evaluate the effects of long term operation on the insulating cup and other support hardware including the tie rod cone and thermocouple support. The test was eventually terminated normally after changes in the measured current and power indicated that element breakage had occurred.

Figure 27
Cluster Assembly for Test HHT-4-23b

Post-test inspection revealed that severe bore corrosion of the elements shown in Figure 28 was responsible for the breakage. It was also clear that considerable hot or molten material from the elements passed through the support block. The thermocouple support and part of the tie rod cone were partially melted. The tip of the thermocouple was severed at the base of the support. Significantly, no cracks or other signs of damage were observed on the molybdenum protection cup. Figure 29 illustrates these observations.

It is possible that much of the damage to the thermocouple and support occurred near the end of the power cycle after element breakage occurred. This would have been a result of local hot spots which would not necessarily effect the measurement of element surface temperature which remained within normal limits throughout the test. In that the exit gas thermocouple located in the furnace diffuser also was destroyed near the end of the test by the debris from the broken elements, there is no measurement of the exit gas temperature flowing around the thermocouple and support. The only available information is the 4540°R indicated by thermocapsules in the center element.

The insulating cup and other support hardware corroded to some degree but was still performing adequately at the end of the test. The block lost 6 percent of its initial mass and the insulating cup lost 51.5 percent for a cumulative time at 4300°R of about 60 minutes. The pyrofoil washers lost about 15 percent of initial mass primarily on the outer circumference. The post-test condition of these components is indicated by Figures 30 and 31.

Figure 28
Element Damage from Test HHT-4-23b

Figure 29
Exit Gas Thermocouple and Molybdenum Cup from Test HHT-4-23b

Figure 30
Support Components from Test HHT-4-23b

Figure 31
Insulating Cup, Foil Washers, and Sleeve from Test HHT-4-23b

IV SUMMARY AND CONCLUSIONS

The development of hardware designs and techniques for testing single clusters at NRX-A reactor test temperature levels continued. After several successive cluster test failures, design modifications on the support hardware resulted in a more reliable test model which operated in six successive tests for periods of 20 to 30 minutes at power. Specifically, improvements were made in the cold and hot chuck, lateral support, and center element designs to provide increased margin for radial and axial thermal expansion of the cluster while maintaining good electrical contact of the chucks and good insulation for the center element. In addition gas flow control through the cluster was improved by the addition of a direct gas inlet plenum which separates helium and hydrogen flows near the cluster inlet.

A parallel design effort was conducted to provide a more flexible cluster model. Detailed designs were completed for a new model which combines the best features of the present configuration with a complete lateral-support system similar to that employed in the HHT-7 test of reactor periphery designs. The use of a barrel, seal segments, filler strips, and load spring assemblies to provide uniform radial support of the cluster should afford a more reliable and flexible model which can be used to evaluate fuel elements as well as support systems.

Evaluations of the XE-1 exit gas thermocouple assembly were conducted in a series of tests at or near 4300°R exit gas temperature at flow rates of from 0.10 to 0.12 lb/sec hydrogen. The design was altered slightly between tests to improve the protection of the thermocouple support and transition joint. The insulating cup, molybdenum protection cup, tie rod cone, and other vital support components were found to perform adequately for 40 minutes. One

insulating cup performed even after 60 minutes at 4300°R. However, the thermocouple supports and sheath were damaged in many of the tests, particularly during the second power cycle after they had been at 4300°R for about 20 minutes in the first cycle. Analysis of these results and metallographic analyses of the tungsten and molybdenum components were in progress in order to establish the suitability of the exit gas thermocouple design for inclusion in the XE-1 test.

The NRX-A5 skirtless block was proof tested for 40 minutes at 4280°R in tests 21a and 21b. Although the block was severely corroded in the second nominal 20 minute cycle because of loss of coating on the face adjacent to the fuel element tips, the complete support system functioned adequately throughout the test.

WANL-TME-1511

V BIBLIOGRAPHY

1. WANL-TME-1375, "Single Cluster Corrosion Test Summary, August 1965 to March 1966," L. A. Salvador, R. D. Foster, L. Wagner, April 1966.
2. WANL-TME-1135, "HHT-7 Build 1 Test 1", P. Cherish, W. Painter, March 1965.
3. WANL-TME-1330, "HHT-7 Report 2", P. Cherish, W. Painter, January 1966.
4. WANL-TME-1462, "HHT-7 Filler Strip Corrosion Test Model: Test Report No. 3, Hot Buffer Type Peripheral Core Design", P. Cherish, June 1966.
5. WANL-TME-1389, "NRX-A5 Reactor Analysis Data", Thermal and Nuclear Design Department Staff, April 1966.

16