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April 1965

Westinghouse Astronuclear Laboratory

PROGRESS REPORT ON HIGH TEMPERATURE

TESTS OF CORE COMPONENTS

(Title Unclassified)

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*PROGRESS REPORT ON HIGH TEMPERATURE**TESTS OF CORE COMPONENTS**(Title Unclassified)**Prepared By:**E.A. Watjen**Approved By:**W J Rowan**W.J. Rowan**Engineering Mechanics*

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INTRODUCTION

To simulate reactor regimes upon core components, they were subjected to high temperatures, thermal gradients, and compressive loads. The environments of long-term reactor operation and restarts will be more severe than those of any previous tests. To prove the capability of the core components in these environments, the following tests were specified:

Support Block Mechanical and Thermal Testing

Fuel Element High Temperature Testing

Fuel Element Cluster High Temperature Testing

These programs called for applying ultimate mechanical loads to the test specimens at operating temperatures as high as 5000°R. Improved fixtures and refined techniques were developed to meet the new specification requirements.

Achievements of the Core Components High Temperature Tests to date have been more noticeable on short clusters and support blocks. Additional development of fixturing for testing of fuel elements has been started. High temperature testing has also been conducted on fuel elements and new cluster designs. This report documents only preliminary results of major programs conducted to date. Final reports will be issued upon completion of major phases of each test program.

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SUMMARY

Early tests of short cluster assemblies have shown that fuel element coatings tend to flake or blister on the external flats. To understand and solve this problem, further tests have been made to eliminate some of the variables. While all of the variables have not been eliminated, preliminary results indicate that loss of coating is more noticeable at temperatures above 3000°R.

Support blocks have been tested to ultimate mechanical loads at temperatures up to 5000°R. The results show that failure loads are generally higher than for room temperature tests but have a greater scatter. The lowest failure load recorded was 5600 lb at a temperature of 3460°R. For comparison, room temperature tests averaged an ultimate mechanical load of 4000 lb. All of the support blocks tested failed at loads well in excess of the design loadings.

CONCLUSIONS

1. Flaking or blistering of the niobium carbide exterior coating on the element/wafer has been investigated for the effect of mechanical load, cooldown rate, purity of atmosphere, time at temperature and maximum temperature. Tests to date have indicated that of the variables tested flaking or blistering is affected most by temperature alone.
2. The presently designed support block is capable of withstanding compressive loads in a helium atmosphere well in excess of the 560 lb reactor operating load. At 4500 °R, ultimate loads in excess of 7600 lb have been achieved.
3. Six specimens of the experimental Strip Supported Cluster averaged an ultimate load of 4000 lb at a temperature of 4500 °R.
4. Two specimens of the Fully Bonded Cluster design averaged an ultimate load of approximately 6400 lb at a temperature of 4500 °R.

RESULTS OF THE TEST PROGRAM

Support Block Mechanical and Thermal Tests

Support block testing to date has been conducted to determine the ultimate strength of the block as a function of temperature. Data has been obtained on regular support blocks drawn from quantities rejected for use in the reactor, and eleven regular support blocks from the NRX-A2 reactor. The virgin, or previously untested blocks, have been used to establish the ultimate strength and mode of failure of the support block at temperatures both above and below those contemplated for full power reactor operation. The NRX-A2 blocks were originally scheduled for the hot cell testing but were of a low enough radiation level to permit handling these blocks at the Engineering Mechanics Laboratory at Large, Pennsylvania. Six of these have been tested at operational temperatures (4300°R) and five tested under room temperature conditions. These were used to establish preliminary data on the effect of the total reactor operational environment on ultimate strength.

The high temperature support block test configuration is shown in the sketch of figure 1. The support block is placed on a graphite plunger so that compression loads are transmitted through the pyro support washer to the support block seat and then to the inlet end of the block. The compressive load is applied at the bottom of the furnace by means of a combination d-c motor and jackscrew loading system capable of operation at uniform loading rates. All of the support block testing to date has been done at a uniform loading rate of 0.02 inch per minute. The applied load is measured by a load cell placed on top of, and external to, the furnace.

Table 1 lists the support block tests completed together with the ultimate mechanical failure loads and test temperature. Note that all of the failure loads are well above the 560 lb expected during reactor operation.

Figure 1. Support Block Mechanical and Thermal Test Setup

Early tests of support blocks did not use the pyro sleeve normally located in the central hole of the support washer and block. These tests were conducted without the pyro sleeve to prevent the fragmentation type of failure that could cause breakage of the furnace heating element. The mode of failure without the sleeve begins first with a plastic deformation at the corner of the seat followed by crumbling of the area above the center hole and subsequent loss of load. A graphite shield was subsequently placed around the support block to prevent damage to the furnace heating element from fragmentation. The pyro sleeve was then included in the assembly of the test specimen to determine the effect on the mode of failure of the support block. The mode of failure, with this sleeve, was similar in the initial stage of seat separation but was followed by a conical shearing of the seat area which precipitated fragmentation of the block into many pieces. This often left a conical piece of the support block attached to the pyro sleeve after failure as shown in figure 2. The principal difference in the failure modes is that the pyro sleeve prevents the inward deformation of the center hole so that all of the energy is in shear rather than crumbling deformation. It is interesting to note that sufficient energy can be stored in the support block to cause breakage of the 5/8 inch thick wall on the graphite shield. The shield has been very successful in reducing the breakage of heating elements from flying particles.

Three support block creep tests have been run to date. Two of these tests were conducted during graphitization of the cemented repair made on the furnace heating element. This graphitization involved a six hour period at a temperature between 4300°R and 4500°R. To make maximum use of the furnace time a support block creep test was conducted simultaneously under the conditions shown in table 1. On the basis of this limited testing it appears that the loading to permit permanent deformation at reactor operating temperatures is between 2000 and 4000 lb. Additional creep tests will be conducted during the remainder of the contract year.

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Figure 2. Typical Support Block Failure Mode After Testing at 4300° R
(This block failed at a load of 7640 lb)

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TABLE 1
CHRONOLOGY OF SUPPORT BLOCKS IN 6 INCH x 10 INCH FURNACE

	Date of Test	Block Serial Number	Test Temperature	Ultimate Load (lb)	Remarks
Tests Conducted Without a Pyro Sleeve	1-14-65	HT 1115	3000°F	5600	
	1-18-65	HT 874	4000°F	8160	Deformation of load applicator leaves results in doubt.
	2-16-65	HT 1731	4000°R	8035	
	2-16-65	HT 1715	4500°R	7600	
	2-24-65	HT 1706	5000°R	8400	
Tests Conducted With a Pyro Sleeve Installed	2-26-65	HT 1720	4300°R	6450	
	3-12-65	HT 1728	4300°R	None	Test loading stopped at 9500 lb
NRX-A2 Support Blocks With Pyro Sleeve Installed	3-16-65	HT 1220	4300°R	7640	
	3-19-65	HT 1106	4300°R	6680	
	3-29-65	HT 1339	4300°R	7800	
	3-30-65	HT 1216	4300°R	7975	
	4-6 -65	HT 1437	4300°R	9300	
	4-6 -65	HT 862	4300°R	7600	
Creep Tests	1-19-65	HT 1537	4500°F	600	One hour creep test
	2-26-65	HT 1726	4300°R	2000	Six hour creep test
	3-8 -65	HT 1726	4300°R	4000	Six hour creep test

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Fuel Element High Temperature Testing

Fuel element checkout tests showed that graphite materials can be very ductile at temperatures of 5000°R (See figure 3). This was evident when a test was run on a fueled element despite the fact that misalignment of center lines of the adjacent fixturing allowed excessive bending. The test was a check of the structural integrity of the graphite blocks in the rig used to apply compressive loads to either end of the short element specimen. The test accomplished the primary objective and illustrated that graphite will bend and deform plastically under mechanical load at temperatures of 5000°R.

Three other fuel element tests have been run to date after completion of rig checkout and improved alignment. These tests took the fueled element to failure at temperatures of 4300°R and 4500°R. The elements failed in compression at loads of 5220, 5440, and 5190. The failure mode of these elements was in the conical section that is characteristic of brittle fractures under compression load.

Additional tests of fueled elements will be completed during the coming months in an effort to fully define the compressive strength of these components as a function of temperature.

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Figure 3. Fueled Element Specimen After Testing at 5000°R to Check Out the
Furnace Fixtures Shown at Either End of the Specimen
(The three inch long element was loaded to 4000 lb)

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Fuel Element Cluster High Temperature Testing

The first test of fueled, coated elements in the Short Cluster tests revealed a condition of flaking and blistering of the niobium carbide coating in the undercut area of the fuel elements (See figure 4). Subsequent tests were made in an attempt to determine the cause of this condition. They showed flaking or blistering of approximately two-thirds of the elements tested. This ratio was consistent throughout the series of tests listed on table 2. No flaking was found on any of the support blocks.

The test specimens, used in this investigation, were carefully selected from fuel elements with specification grade coatings. All of these elements had unfueled wafers cemented to the exit end in the NRX-A3 configuration (Westinghouse Astronuclear Laboratory drawing 937J321 GO7). Many of the tests used several unfueled elements that had been coated over the full length. This was done not only to check whether these elements would flake but also to conserve fueled specimens for subsequent tests.

The results of the testing indicated that: mechanical loading, time at maximum temperature, cooldown period and purity of atmosphere did not affect the degree of blistering or flaking. These variables were eliminated by conducting separate tests with and without mechanical loading, with different times at temperature, with longer cooldown periods and by testing with regular and ultra-pure helium atmospheres. None of these had any effect on the loss of coating.

Three tests were run to investigate temperature as the significant variable. These tests showed that coating loss is affected by temperature to the extent that flaking did not occur at 2460°R but did take place at 3000°R and above.

Attempts were made to correlate with element serial numbers, batch number and coating runs shown on table 3. Several elements from common coating runs were tested but no clear relationship was established in that some did flake and some did not flake. No element batch relationship could be established because there were no two elements out of the same batch. Further testing is required to properly correlate these factors.

It has been suggested that coating thickness or heat up rate may be factors. This should be further investigated.

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Figure 4. Closeup View of Short Cluster Assembly After Removal
From the Furnace

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TABLE 2
FUEL ELEMENT CLUSTER TESTS CONDUCTED

Test 1	500 lb load for five minutes at 4460°R in a helium atmosphere. Six fueled elements and one thirteen-hole element on support block HT917.
Test 2	400 lb load for fifteen minutes at 4460°R in a helium atmosphere. Six fueled elements and one thirteen-hole element on support block HT1120.
Test 3	No load - heated to 2460°R and cooled down - no flaking. Reheated to 4460°R for five minutes at no load in a helium atmosphere. Three fueled elements, three unfueled fully coated elements and one thirteen-hole element on support block HT1674.
Test 4	No load - heated to 4490°R - held for twenty minutes in an ultra-pure helium atmosphere. Three fueled elements, three unfueled fully coated elements and one thirteen-hole element on support block HT1226.
Test 5	2000 lb load for ten minutes at 4460°R in an ultra-pure helium atmosphere. Three fueled elements which were previously tested but had not flaked were retested, three unfueled fully coated elements, and one thirteen-hole element on support block HT917 (same as used in Test 1).
Test 6	Four elements and two unfueled peripheral elements heated to 3920°R for 10 minutes - no load - 5 psi ultra-pure helium atmosphere.
Test 7	Six elements heated to 3000°R (no load) for 10 minutes - ultra-pure helium atmosphere 5 psi (static).

TABLE 3
SHORT CLUSTER TEST RESULTS

Test Run	Element S/N	Batch No.	Coating Run No.	Condition
1	17792	01789	F109008	No flaking
1	18581	01855	C147008	Element flaked on one face, blistered on two other faces above joint.
1	18833	01891	C148008	Wafer badly flaked - element flaked above joint.
1	19337	01963	C152007	Wafer completely flaked, slight element flaking at joint.
1	18937	01902	C150008	Wafer completely flaked and element badly flaked above joint.
1	19173	01920	F126008	No flaking or blistering.
2	18965	01906	F126008	Wafer slightly flaked - element badly flaked above joint.
2	17094	01703	C146008	Wafer flaked on two flats - element flaked above joint.
2	17372	01695	F109008	No flaking - one small blister on element above joint.
2	14253	1385	C105004	Large blistered area on three flats - No flaking.
2	18756	01883	F123008	No flaking or blistering
2	18897	01898	C148008	Element badly flaked - wafer completely flaked.
3	19147	01917	F126008	No flaking or blistering
3	18859	01894	F124008	Wafer completely flaked - element slightly flaked.
3	18954	01905	F124008	Flaked on element above joint - no flaking on wafer
4	18873	01896	F124008	Flaked all around wafer, element flaked above joint.
4	18890	01898	C150008	Flaked all around joint and some on wafer and element.
4	16002	01581	F112005	Blistered on element and wafer.
5*	19147	01917	F126008	No flaking or blistering.
5*	17792	01789	F109008	No flaking or blistering.
5*	19173	01920	F126008	No flaking or blistering.

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TABLE 3 (CONTINUED)

Test Run	Element S/N	Batch No.	Coating Run No.	Condition
6	13512	01333	F 75 PDS 30021-B-1	Slight peeling at bottom side and bottom of wafer-end
6	14198	01273	C105004	Blistered and flaked on fueled element coating (above wafer)
6	15788	-----	-----	No flaking or blistering
6	15850	-----	-----	Badly flaked and blistered
7**	13573	01340	F 75	Minor blistering
7**	13951	-----	-----	Blistered and flaked
7**	14183	01272	C106004	Minor flaking occurred
7**	15821	-----	-----	No change
7**	15886	-----	-----	No change
7**	16909	-----	-----	Blistered and flaked

* Tested previously and had not flaked, so these were retested.

** No coating on bottom end of wafer.

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The short cluster, shown in figure 4, consists of the lower five inches of six coated, wafer-end fueled elements, an unfueled center element, and a coated support block. The elements are retained at the upper end by a close-fitting cap, shown in figure 5, that provides the only bundling for the short cluster. The lower end of the elements are in contact with the inlet end of the support block. The short cluster is placed on the bottom portion of the furnace which is then raised so that contact of the upper cap is made to complete the loading train through the assembly. The temperature of the specimen is obtained by an optical pyrometer placed so that fuel element temperature is measured just above the interface between the element and support block. The furnace is temperature controlled by a radiamatic radiation detector unit observing the specimen at a point 180° opposite the optical pyrometer. Close correlation is maintained between the radiamatic and the optical pyrometer. The furnace is cooled down by shutting off the power as soon as testing is complete. Normally it requires 1 1/2 to 2 hours before the bottom of the furnace can be lowered. A helium atmosphere is maintained during the entire warmup, test and cooldown.

Other High Temperature Testing

Testing has also been conducted on new cluster designs and tests to develop fixtures to provide bundling devices for use at high temperatures.

Tests conducted on new cluster designs included four unfueled strip supported clusters and two fueled fully bonded cluster tests. The test setup for these tests is as shown in figure 6. The graphite cap at the top is used to retain the elements in a clustered configuration. The ring placed around the cluster is the first design of a high temperature bundling fixture

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Figure 5. Fuel Element (Short) Cluster High Temperature Test Setup

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Figure 6. View Showing Arrangement of the Short Cluster Used in Tests
of Self-Supported Cluster Designs
(The graphite ring around the center was applied to provide bundling of the specimen)

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Figure 7. Typical Failure of the Strip Supported Cluster Design
(The test was conducted at 4500°R and failure occurred at 4150 lb load)

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Figure 8. Typical Failure Mode of the Fully Bonded Cluster Design
(Testing was conducted at 4500°R and failure occurred at 6650 lb)

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employing graphite cloth springs. A tie rod seat, similar to that of a support block, is machined in the lower end of the short cluster. Mechanical loading is transferred through a plunger in the load train to a support washer to the cluster seat.

The results of this test showed that the Strip Supported Cluster design is capable of an average ultimate load of 4000 lb at a temperature of 4500°R. For comparison room temperature tests, conducted on similar specimens, averaged 2467 lb for ultimate compression load. Figure 7 illustrates a typical failure mode for the strip supported design. Failure begins at the periphery of the tie rod seat, at the bottom of the photo, and progresses outwardly along a forty-five degree plane until intersection of the bond line. The bond joint then fails axially to the end of the cluster.

The results of testing on the Fully Bonded Cluster design showed that an average compressive load of 6400 lb was required to fail the cluster at 4500°R. This design included a tie rod seat similar to that of the support block and was set up in the same manner as the Strip Supported Cluster. Figure 8 shows a typical failure mode for the bonded cluster. Note that even though the failure followed the bonded joint, portions of two of the elements failed in the fueled material, indicating a close match of bond strength with element strength.

Equipment Required

The high temperature test programs were conducted in either the 6 inch diameter x 10 inch long furnace or the 6 inch diameter x 54 inch long furnace. (See figures 9 and 10.) These furnaces are resistance-heated units powered by a common silicon controlled rectifier 150 KVA power supply for operation from 440/480 VAC, 60 cycle, three phase power. The furnaces are capable of temperatures up to 5900°R, pressures from 1 psia to 35 psia and can be programmer-controlled to heat from 2500°R to 5000°R in a period of 15 minutes.

The furnaces are installed in a contaminated materials area that includes provisions for storage of fueled elements in shipping containers and in storage cabinets. Several CRIT-zones are available in the room for pretest and post-test examination of fueled specimens.

Figure 9. General Arrangement of High Temperature Test Facility
(The 6 x 10 inch furnace is shown at the center behind the large instrumentation console;
the 6 x 54 inch furnace can be seen in the high bay area to the right)

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Figure 10. 6 inch x 10 inch Furnace Showing Optical Pyrometer Viewports and the Mechanical Loading and Measuring Systems

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