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February 1966

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Westinghouse Astronuclear Laboratory

**PROGRESS REPORT ON
ENGINEERING MECHANICS LABORATORY
TESTING OF CORE SUPPORT BLOCK**

(Title Unclassified)

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**PROGRESS REPORT ON
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SECTION 1

INTRODUCTION

This report describes the progress made on development testing of support blocks in connection with the initiation of cracks in the seat area. The cracking of support block seats came to light after a detailed post-test inspection of the NRX-A3 reactor revealed pockets of corrosion in the counterbore seat area. Many of the regular and irregular support blocks sectioned at the test site were found to have circumferential cracks in the seat area near the 0.02 inch radius. These cracks expose uncoated graphite to the hydrogen atmosphere, and thus corrosion takes place. This reaction could affect the load bearing area of the support block and restrict the operating interval of the reactor. Figure 1-1 shows a typical crack involved in this study.

A four part testing program was instituted at WANL during July 1965 to solve this problem. The following list explains this program.

- 1) Exploratory tests were performed to investigate all of the variables involved and isolate the main contributors to the initiation of seat cracks. These explorations resulted in establishing tests that were then used as a basis for comparison of designs.
- 2) Tests of conceptual designs were conducted to provide information necessary for selection of support block configurations capable of development for the NRX-A5 and NRX-A6 reactors.
- 3) The NRX-A5 design was selected to be the best design of support block and components that could be accomplished within the available time. Development testing of support blocks and mating components to aid in the final definition of the design was accomplished.
- 4) A skirtless block concept was selected for NRX-A6. The support block and associated hardware were tested and developed with the intent of including an NRX-A6 block design in the NRX-A5 reactor.

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Figure 1-1. Core Support Block Showing a Typical Crack in the Seat Area

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SECTION 2

EXPLORATORY TESTS

Laboratory tests were conducted in the high temperature loading furnace of the Engineering Mechanics Laboratory and on the Wiedemann test machine at room temperature for the purpose of duplicating the support block seat cracks. The test objective was to determine the significant parameters involved in cracking of the blocks and use the results as a basis for evaluating new designs. Some of the tests performed are shown in table 2-1 with a brief description of the results.

The exploratory tests resulted in the identification of three tests which could be used to evaluate new support block designs. These tests also indicated that load and temperature are the most significant parameters in causing cracks in the support block seat area. The three tests originally selected are described as follows:

- 1) Load applied at constant temperature of 4150°R or 4300°R . Under these conditions the NRX-A3 support block showed a crack threshold at a 1500 pound loading.
- 2) Constant load through a temperature cycle. The NRX-A3 support block developed a crack under a 700 pound load held constant during a heatup to 4150°R (or 4300°R) and cooldown to room temperature. The maximum temperature was held for ten minutes with five scfm of hydrogen flowing through the block center bore. During cooldown a flow of argon was used.
- 3) Load applied at room temperature using a Wiedemann test machine. Under this condition the NRX-A3 support block had fine cracks after testing to 2000 pounds and incipient cracks after testing at 1500 pounds.

The three tests were used to evaluate support block design concepts for the NRX-A5 and NRX-A6 reactors. Eventually test 1) with the load applied at constant temperature was deleted from the list since it did not add to the other two tests and gave an indication of a higher load at steady-state temperature than was possible under reactor conditions.

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TABLE 2-1

EXPLORATORY TEST SUMMARY

TEST TYPE	TEST METHOD	TEST RESULTS (NRX-A2/A3 DESIGN)
Load Applied at Temperature	Support block loaded in furnace and held in place with 100 lb load. Temperature increased to 4150°R and load applied for desired time. Load reduced to 100 lb for cooldown. Hydrogen flow at 5 scfm used during constant temperature.	Fine cracks developed in seat radius (0.020 inch) for loads of 2000 lb and above. Indications of cracking at loads of 1500 lb.
Time/Temperature Cycle	Support block loaded at 2600°R for 10 minutes, then cooled and examined. Test repeated to a maximum temperature of 3500°R and repeated again to 4150°R.	No cracking found for loads of 800 lb (0.20 inch radius)
Cryogenic Tests	Support block loaded at temperature of 140°R for periods up to 10 minutes.	No cracking for loads of 800 lb
Sudden Load Application	Support block loaded at temperature of 4150°R at a rate of 0.2 in./min	No cracking for peak load of 1000 lb
Step Loading at Room Temperature	Support block loaded in steps at room temperature. Inspection with 30X microscope followed each load increment.	Cracks occurred at loads as low as 1500 lb for NRX-A3 blocks
Load Cycling	Support block loaded between 0 and 800 lb cycles at room temperature	Some cracking developed after accumulating 12 cycles
Sequential Tests	Support block cycled at 800 lb load at room temperature and followed with 500 lb load at temperature.	No cracks developed for sequential loading.
Pressure Effects	Blocks were strain gaged, loaded at 800 lb and placed in a pressure vessel. Hydrogen pressure was increased to 650 psi	250 and 300 microinches per inch of strain recorded. Very fine cracks on NRX-A3 blocks
Constant Load Through Temperature Cycle	Support block loaded in furnace to desired load at room temperature. Temperature increased to 4150-4300°R and held for 10 minutes. Hydrogen flowed through specimen for 10-30 minutes at constant temperature. Load maintained during cooldown.	NRX-A3 blocks found cracked after test with load of 800 lb but not after loads of 500 lb. Later tests on NRX-A4 blocks showed that cracking occurred for loads of 700 lb but not at 600 lb.

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SECTION 3

TESTS OF CONCEPTUAL DESIGNS

The NRX-A5 support block design is essentially an NRX-A4 block with modification. This limitation existed because the NRX-A5 blocks had been machined and inspected at the time of this development and were awaiting coating at the WANL Astrofuel Facility. The NRX-A6 design had no similar limitations since machining of these blocks had not yet begun.

Four main types of support block configurations were tested. Variations on each of the four main types were:

- 1) Radiused blocks. Variations of the radius between the block counterbore and the support washer seat. The radii tested were: 0.020 (NRX-A4), 0.060, 0.090, and 0.125 inch (figure 3-1).
- 2) Reduced length blocks. This variation was obtained by removing material from the exit end of the block while maintaining the original dimension between the washer seat and the inlet end. Blocks were tested with 0.375 inch and 0.75 inch reductions in length. The 0.75 inch block had no counterbore on the exit end and became known as a "skirtless block".
- 3) Blocks with material removed from around the outside of the inner row of flow holes. This variation was tested in two different configurations. One case had been cut to a 0.750 inch depth to correspond to the depth of the seat. The other was cut to a 1.0 inch depth so that the cut would be below the seat (figure 3-3).
- 4) Blocks with undercuts around the counterbore and seat area. This variation was tested in a variety of configurations and blended radii (figure 3-4).

The tests of the conceptual block designs led to the selection of a basic 0.060 inch seat radius for the NRX-A5 design. This design had a basic crack strength of about 900 pounds in the thermal cycle test and 2500 pounds in the room temperature test with a pyrographite washer. This radius (0.060 inch) could be incorporated in existing blocks by undercutting the seat an additional 0.060 inch. This required that a 0.310 inch washer be used in place of the 0.250

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inch to make up the difference caused by the shorter seat. The release of the basic block design permitted additional development of the NRX-A5 design through evaluation of new washer designs and materials.

The most promising of the conceptual designs was the skirtless block which was modified by machining 0.750 inch off the exit end. Tests indicated that this block could not be cracked at room or elevated temperatures by loads applied through regular hardware. The design was conditionally selected for the NRX-A6 reactor but was contingent on development of protection cups and related hardware that would be used on the exit end of the block.

Over 250 blocks have been tested in exploratory and development tests since the beginning of the investigation. In a number of the geometrical variations, cracking strength was materially improved. The initial objective was to relieve the sharp 0.020 inch fillet radius in the seat area; however, there was an optional limit to this approach. As the radius was increased beyond 0.060 inch, the reduction in seat bearing area resulted in higher bearing stresses that lower the crack initiation strength of the support block.

Several cracked support blocks were taken from the NRX-A3 reactor and tested at room and elevated temperature to arrive at a quantitative determination of their relative strength. At elevated temperature, one support block survived an 8000 pound load and another block with a badly corroded seat failed at 5730 pounds. At room temperature, the average failure load of five blocks was 3722 pounds. The five blocks tested were selected on the basis of appearance so that the test included the best and poorest of the specimens available. For comparison, five support blocks returned from the NRX-A2 reactor averaged 4138 pounds at room temperature. The results of the NRX-A3 support block strength tests are shown in figure 3-5. Even though corrosion had occurred in the blocks, there was no substantial weakening of the structural integrity.

Since corrosion of the support block in the fillet radius area was felt to be related to the size of the initial crack, an effort was made to determine any measurable flow through an induced crack. This proved to be unrelated to reactor performance since it took 2000-3000 pounds of loading and over 20 psi pressure differential across the crack to allow a measurable

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flow of hydrogen or helium through the crack. When flow was measurable, there was a cascading effect where one psi additional pressure multiplied the flow several times.

The experiments were repeated at room temperature on cracked, uncracked, and post NRX-A3 blocks. There were a number of uncracked blocks that flowed more gas through the material by seepage than the post NRX-A3 blocks. In general, a cracked or uncracked block did not affect the total flow of gas. A much closer correlation was determined with the total weight of the block. The lighter blocks proved to be more permeable and permitted greater gas flows than the heavier blocks.

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FIGURE 3-1

AN EXAMPLE OF A BLOCK WITH A RADIUS SEAT
THIS BLOCK HAD A 0.125 INCH RADIUS

FIGURE 3-2

AN EXAMPLE OF A REDUCED LENGTH BLOCK. THIS ONE WAS
REDUCED 0.750 INCH TO REMOVE THE COUNTERBORE COMPLETELY

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CONICAL DESIGN

SPLINE DESIGN

FIGURE 3-3
EXAMPLES OF BLOCKS WITH MATERIAL REMOVED
AROUND THE OUTSIDE OF THE INNER ROW OF FLOW HOLES

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A ONE INCH DEEP BY 0.250 INCH WIDE GROOVE
WAS MACHINED INTO THIS BLOCK

A 0.060 INCH GROOVE WAS MACHINED
IN THE SEAT AREA OF THIS BLOCK

FIGURE 3-4

EXAMPLES OF BLOCKS WITH UNDERCUTS
AROUND THE COUNTERBORE OR SEAT AREA

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BLOCK HT 1660
ULTIMATE LOAD 3480 LBS

BLOCK HT 1593
ULTIMATE LOAD 4130 LB

BLOCK HT 1692
ULTIMATE LOAD 3680 LB

BLOCK HT 1938
LOAD DROPPED OFF
AT 3620 LB

BLOCK 1776
ULTIMATE LOAD 4025 LB

BLOCK 1906
ULTIMATE LOAD 3400 LB

Figure 3-5. Results of Ultimate Load Tests on Post-Test NRX-A3 Support Blocks

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SECTION 4

NRX-A5 SUPPORT BLOCK DEVELOPMENT TESTING

The release of the NRX-A5 support block with the 0.060 inch radius at the seat area was the first step in development of the design. The next step was to determine the optimum washer design that could be included in the NRX-A5 reactor. This meant that testing of the support blocks had to be completed long before production quantities could be made available. For this reason NRX-A4 blocks were reworked into the NRX-A5 configuration to get an early start on development testing of the basic design.

The first NRX-A5 blocks were tested with 0.310 inch thick ATJ support washers to eliminate frictional effects resulting from different coefficients of expansion between the seat and the pyrographite washer. The selection of ATJ graphite as the washer test material, was based on design stress analysis which showed that crack initiation was affected by three main factors. The main factor was the axial tensile stress in the radius that results from the bearing stress in the seat. Other factors were 1) the frictional effects at the support washer and seat interface and 2) the stresses resulting from thermal gradients across the crack area. The ATJ washer eliminated friction from consideration as a factor in crack initiation. The original support washer had a 0.070 inch radius to remain clear of the 0.060 inch radius of the support block seat and is 0.310 inch thick to compensate for the increased seat depth of the NRX-A5 block. This configuration has a room temperature crack initiation strength of 1650 pounds. Figures 4-1 and 4-2 illustrate the typical mode of failure for the configuration. Note that the circular crack in the washer and pyro cup is of the same diameter as the molybdenum cone. In this configuration the ATJ washer could not be loaded enough to cause damage to the support block seat without first failing in compression. This was true at both room and high temperature. At temperature, the combination had a crack initiation load of 900 pounds when tested in the thermal cycle. This was identical to earlier tests where a pyrographite washer was used and indicates that frictional effects are not significant in crack initiation.

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FIGURE 4-1

ULTIMATE LOAD 1640 LB

FIGURE 4-2

ULTIMATE LOAD 1680 LB

TYPICAL RESULTS OF ATJ SUPPORT WASHER TESTS AT ROOM TEMPERATURE

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Most of the development tests on support washers were completed on uncoated parts to eliminate delays in processing of the test specimens. Coated washers complicated the testing at temperature because they could not be removed from the seat, and the assembly had to be sectioned to determine whether or not the block had cracked. The test results showed that welding had no effect on the crack initiation load of the support block. Welding of coatings took place on both ATJ and pyrographite coated washers. This was further evidence that frictional effects due to differential expansion are not significant in the NRX-A5 design.

The testing of support washers in the NRX-A5 design pointed up the need for close dimensional control of the specimens. This was particularly true of the 0.070 inch radius that provided clearance in the vicinity of the block radius. Contact between the washer and block in the radius would invariably result in premature cracking of the block. The load had to be transferred from the washer to the flat portion of the seat without interference at the radius. Any irregularities in machining or blending of the radius would result in low cracking loads on the support block. The use of pyrofoil washers minimized these problems.

PYROFOIL DEVELOPMENT

Pyrofoil washers were conceived as a way of spreading the load over a wider area and to overcome the machining difficulties and irregularities between the washer and support block. The material was available in 0.01 inch thick sheets and was punched out in the form of thin washers, ten of which were used to attain an acceptable thickness. Under test conditions of steady load through cycled temperature, an immediate improvement in cracking strength was noted in the NRX-A5 design support block. This amounted to an increased loading of approximately 50 percent over the combination of block and washer without pyrofoils. When the washer radius was increased to 0.090 inch instead of 0.070 inch, the thermal cycle cracking load was raised to approximately 1500 pounds. Pyrographite support washers were used in all of these tests. The post-test appearance is shown in figure 4-3.

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Figure 4-3. Typical Post-Test Condition of Pyrofoil Washers

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Early tests using pyrofoils were concerned only with distributing the load uniformly over the support block seat. This was accomplished because, under pressure, the material molds itself to the shape of the container. In reviewing these results, it was suggested that the pyrofoil could also be used to provide a seal around the pyro sleeve used in the center bore of the support block. This was accomplished simply by cutting the center hole so that a slight interference fit was obtained. The foils were then assembled over the pyro sleeve and compressed into the seat. The result was that the foils firmly gripped the pyro sleeve and provided an effective seal against the free flow of hydrogen between the support washer and the outer diameter of the pyro sleeve. The pyrofoil material has long been in use in furnace tests as a high temperature gasket material and has proven effective during corrosion tests of support blocks where it was used to block certain flow channels.

In assembling support block clusters for reactor use, a technique has been developed for putting a group of ten pyrofoil washers between the support block seat and the support washer with the pyro sleeve in place. A 700 pound load is applied which compresses the washers around the pyro sleeve and molds them to the shape of the fillet radius area. The thickness of the molded group is between 0.050 to 0.060 inch and is compensated by decreasing the thickness of the support washer to the original 0.250 dimension. The molded pyrofoil group tends to stay in place until pried out. After temperature and load have both been applied, the loose foils become coherent.

Tests at room temperature with pyrofoil washers have not produced a detectable improvement in cracking strength over a plain washer-support block combination. However, during temperature cycling there is an evident and significant difference.

The ultimate strength of support blocks using pyrofoil is somewhat lower but not inconsistent with the reduced seat bearing area of a 0.060 inch fillet radius. Figure 4-4 shows a typical mode of failure for a support block using pyrofoil and a regular pyrographite washer.

HYDROGEN CORROSION TESTS

Early in the program it was apparent that data was needed on the rate of corrosion versus the pressure differential across the crack. These tests require close control of variables

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Figure 4-4. Typical Mode of Failure for Support Blocks Tested to Ultimate

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to maintain low pressure differentials across the crack areas. This discussion covers only the corrosion work performed by the Engineering Mechanics Laboratory which was followed by more extensive corrosive testing of blocks and cluster in the Fluid Flow Laboratory.

In these tests, all of the flow holes were plugged except for one of the innermost row. Hydrogen was then permitted to flow freely through one hole but was prevented from flowing freely in the rest. A small pressure differential was maintained between the hydrogen inlet pressure and the furnace pressure so that in effect, a differential across the crack was obtained. The test was followed by sectioning, polishing, and photographing of the blocks for measurement and observation of the corroded areas. Photomicrographs of the blocks are shown in figure 4-5. Note that the corrosion of the crack area is always greater in the closed hole where the pressure differential was higher. These results were scaled upwards in terms of known reactor parameters for comparison with known reactor results.

Considerable success was achieved in duplicating the shape and appearance of blocks taken from the NRX-A3 reactor and sectioned similarly. The redeposit of vaporized niobium in the cracked areas hindered, to some extent, the calculations conducted by the Reactor Analysis Group. (See figure 4-6.) To avoid this vapor, which probably originated upstream of the support block in the coated graphite furnace components, tungsten tubes have been installed to avoid any contact of impure hydrogen gas with niobium carbide on furnace parts. Figure 4-5 and 4-6 show the simulations attained.

FOIL CORROSION

Since the use of pyrofoils had improved the cracking strength of support blocks, it was important to know how they would withstand a hot hydrogen atmosphere. No evidence of pyrofoil corrosion had been detected in crack determination tests; so the pyro sleeve was removed and five scfm of five psig hydrogen gas at 3600°R was passed through the exposed inner diameter of the washers for one hour. Three types of pyrofoil were used and a comparison made on weight loss. Without the pyro sleeve the weight loss averaged between 20 and 22 percent. With the pyro sleeve, the weight loss was reduced to less than 0.1 percent. Figure 4-7 shows a comparison of the washers.

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HT1642 TWO PSI

HT1801 FIVE PSI

HT1472 TEN PSI
FLOW CHANNEL ON RIGHT

Figure 4-5. Simulation of NRX-A3 Support Block Corrosion

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HT1642 TWO PSI
NON-FLOW CHANNEL

HT1642 TWO PSI
FLOW CHANNEL
NOTE REDEPOSIT OF COATING

HT1801 FIVE PSI
FLOW CHANNEL

HT1801 FIVE PSI
FLOW CHANNEL
SHOWING REDEPOSIT OF COATING

Figure 4-6. Simulation of NRX-A3 Support Block Corrosion

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Figure 4-7. Comparison of Pyrofoil Washers After Corrosion Test

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The results above were confirmed by one of the more extensive tests repeated at the WANHES facility by Fluid Flow Laboratory personnel, with hydrogen at 4400°R and 560 psi pressure flowing through the block at 500 scfm. A total run of 41 minutes and 47 seconds was made in two consecutive tests. The pyrofoils were held in place with a coated graphite bolt, nut, and washer which were severely attacked during the process. The weight loss of the pyrofoils was again around 20 percent but would have been smaller if the graphite bolt had been able to keep pressure applied. In all cases, loss of area matched the loss of weight closely in percentage which indicates that the attack was directly on the exposed surface and not interstitially. Figure 4-8 shows the post-test conditions. Note that the support washer can hardly be distinguished from the foils.

Pyrofoil corrosion tests have also been completed by the Fluid Flow Laboratory and will be reported in a separate document.

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Figure 4-8. Condition of Pyrofoils After Corrosion Test

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SECTION 5

NRX-A6 SUPPORT BLOCK DEVELOPMENT TESTS

The support block design selected for the NRX-A6 reactor is shown in figure 5-1. The assembly consists of a support block with no counterbore at the exit end (skirtless). In place of the counterbore, a protection cup is used to protect the insulating cup and metal components from direct impingement of hydrogen. The protection cup was designed to replace the counterbore of previous designs and was made of ATJ material with coating on all surfaces. A thin (0.150 inch thick) support washer of ATJ material was used at the inside of the cup for load distribution.

The first ATJ protection cups and support washers were fabricated from sketches taken from the incomplete detailed drawings. These cups were tested in the uncoated condition to get an early start on testing of the design. A standard support block was machined down so that the counterbore was completely removed to simulate the NRX-A6 block. These components were tested under load at both room temperature and in the thermal cycle test.

Tests of uncoated cups and washers showed that a load of between 1500 and 1600 pounds was necessary to crack the cup in the thermal cycle test. This represents a considerable improvement over the cracking load for the NRX-A4 block design which developed a crack at a 700 pound load under the same conditions. The ultimate failure of the cup at 4300°R was 4340 pounds and the failure at room temperature was from 2100 to 2560 pounds. The specimens used in these tests are shown in figures 5-2 and 5-3. The support block was not damaged in either of these tests. It was found, however, that when an ATJ support washer was loaded through the standard insulating cup and washer, the support washer tended to fail in compression with the insulating cup being punched through by the insulating washer.

Another factor that became apparent was that any physical contact between the support washer and the fillet radius of the cup at temperature caused the cup to crack at low loadings. Because of this, all cups and washers were inspected for quality after manufacture to eliminate

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Figure 5-1. NRX-A6 Support Block and Tie Rod Assembly

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Figure 5-2. NRX-A6 Cup Test at Room Temperature - 2100 Pound Load

Figure 5-3. NRX-A6 Cup Test at Room Temperature - 2560 Pound Load

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any specimens whose radii or points of tangency were not within tolerance. More diametral clearance is required with ATJ material washers since they tend to deform permanently under load at temperature.

Testing was continued with coated hardware made and checked within close dimensional tolerance, and the cracking load of the cup was established between 1500 and 1600 pounds for the cycled temperature tests. In tests with coated components at temperature, the washer and cup cannot be separated without destroying them due to a weld which holds them firmly together. The cup can be separated from the reacting support block, but pieces of graphite are frequently pulled away from the block during the process after testing at high loads.

At room temperature the ATJ washer cannot be loaded above 1800 pounds without failure. This occurs before any damage is done in the cup. At high temperature, as mentioned previously, it deforms under loading and surface cracks form on the inside diameter. Sections taken through the welded cup and washer show radial clearances in the order of 0.001 inch between the washer outer diameter and the cup wall. In one or two cases, it has been evident that the side wall and washer outer diameter have made actual contact during the test. The weld formation between the washer and cup is shown in figure 5-4.

This design has eliminated any cracking or damage to the support block itself in the range of loads tested. The failures are either in the washer or cup. This has been found in approximately 30 tests involving the cutdown support block. Reuse of the same block from test to test has not impaired the usefulness of the block.

Some exploratory tests were run on the cup design using pyrographite washers and also using pyrofoil washers under ATJ support washers. When pyrographite washers were used, the cups cracked under 1000 pound loading in the thermal cycle test, but there was no distortion or damage to the washer. Further testing with slightly smaller pyrographite washers may eliminate any possibility of contact on the outer perimeter; however, this has not been attempted.

When pyrofoils were used with ATJ washers, both the washer and cup failed under loading of 1500 pounds at temperature. Similarly at room temperature, the cup broke at 1080

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THIS SPECIMEN WAS LOADED TO 1500 LBS. THROUGH
THE CONSTANT LOAD THERMAL CYCLE. THE WASHER

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HAD 14 MILS DIAMETRAL
CLEARANCE BEFORE THE TEST

WASHER/CUP CONTACT
ON LEFT SIDE

WASHER/CUP CLEARANCE
ON RIGHT SIDE

MACROSCOPIC PHOTO OF
SECTIONED CUP AND WASHER

WASHER/CUP DEFORMATION IN
RADIUS OF LEFT SIDE

SEAT AREA COATING CONDITION

Figure 5-4. Photomicrographs of NRX-A6 Corrosion Cup and Washer Tests

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pounds loading. From the room temperature test, it was apparent that radial pressure from the deformed pyrofoils was pushing out the thin walls of the cup. A high temperature test was run with smaller diameter pyrofoils, but the failure of the ATJ washer in compression during the temperature cycle terminated the test. It is apparent that the 0.150 inch ATJ washers will not endure compression unless their loading is reacted against a stiffer surface than the pyrofoil material.

Ultimate strength of the NRX-A6 design at high temperature is characterized by failure of the cup and washer without harm to the block. Figure 5-5 illustrates the mode of failure for these components after testing to 4340 pounds at 4300°R. Note that the ATJ corrosion cup, support washer, insulating cup, and insulating washer have all failed during the test.

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Figure 5-5. NRX-A6 Support Block and ATJ Cup After Testing to Ultimate

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SECTION 6

PLANS FOR FUTURE DEVELOPMENT TESTING

The entire program for development testing of support blocks has required close coordination between design, analysis, and test groups. This relationship will be continued during future work to answer some of the remaining questions and provide improvements in analytical and experimental data.

At this stage of the development program, it is not positively known why pyrofoil washers improve the crack resistance of the support block in the fillet radius. Under loading and temperature, the pyrofoil conforms and molds to the shape of its container, and the deflection under load is greater than that of the graphite washer. However, at room temperature, surface strains measured by strain gages are not appreciably changed when pyrofoils are used nor does the cracking load at room temperature show any marked improvement.

A larger radius washer loading the pyrofoils produces substantial improvement at temperature over a smaller radius washer. It has been determined by photoelastic studies and strain gage results that the highest strains and consequently stresses are concentrated on the surface of the fillet radius area. The strain gage measurements are plotted on figure 6-1. These studies have revealed that the strain decreases by a factor of ten or more at a surface depth as small as 0.030 inch. The surface stress is linearly proportional to the seat loading at room temperature and can be extrapolated to a cracking condition from non-cracking loads which agree with test results.

The pyrofoils help to center the load and alleviate any eccentricity in the loaded components caused by tolerance buildups. To some extent, they redistribute the loading and undoubtedly prevent spikes or high concentrations. There is some evidence from photoelastic studies that the principal strain relationships are altered but no quantitative measurements are available. Figures 6-2 and 6-3 show changes in coloring achieved by the use of pyrofoils that indicate a trend toward equalizing the principal stresses with the pyrofoils at 1000 pound loading. Test results indicate that the foils provide major gains during thermal cycle tests but only small gains at room temperature.

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Figure 6-1. Longitudinal Strain Curve for NRX-A5 Support Block

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COMPARISON OF DISTRIBUTION OF PRINCIPAL STRAINS WITH AND WITHOUT
PYROFOIL IN THE SEAT AREA. THE TEST SPECIMEN IS A SUPPORT BLOCK
SECTIONED AT THE INNER ROW OF FLOW HOLES WITH PHOTOSTRESS PLASTIC
MOUNTED TO THE SECTIONED AREA

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6-3

STRAIN DISTRIBUTION WITH
PYROFOIL

STRAIN DISTRIBUTION
WITHOUT PYROFOIL

Figure 6-2. The Bottom of the Support Block Seat is Indicated by the Dark Line
on the Scale on the Left of the Block

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The difference in results between tests run at room temperature and at high temperature is not entirely explainable in terms of observed results. At room temperature, by easing the curvature of the fillet radius and lapping the surface of the fillet radius and lapping the surface of the washer to the support block seat, over 4000 pounds of loading can be withstood by the block without cracking. This same combination failed at 800 pounds loading in the constant load thermal cycle test. Without special geometric alteration, the standard NRX-A3 block will crack between 1500 and 2000 pounds at room temperature. At high temperature, it takes about 2000 pounds to crack an NRX-A3 block if the load is applied after the block reaches temperature. On the other hand, between 600 and 700 pounds will crack an NRX-A3 block if the load is applied and held while coming up to temperature and maintained through temperature to cooldown. Under these same conditions, between 800 and 900 pounds will crack an NRX-A5 block.

The addition of pyrofoils underneath the support washer raises the high temperature cracking load to between 1200 and 1300 pounds for the NRX-A5 block. In addition, increase the washer radius to 0.90 inch brings the strength up to 1500 pounds without cracking when the load is held during the temperature cycle. However, at room temperature the addition of pyrofoils does not change the cracking load or show any lessening of strain measurements in the highly stressed areas.

From these results, it is obvious that a temperature phenomenon must be the significant factor in changing the test results between room and high temperature, and that this phenomenon is not entirely a characteristic of the reactor operating temperature. The cracking of the fillet radius occurs at a temperature between 4300°R and room temperature, and on the basis of one or two tests, is believed to be under 2500°R.

Two main possibilities exist for an explanation of the behavior. One is thermal stress and the other is a substantial change in graphite strength properties over the interval spanned by the temperature rise of the block. The first hypothesis fits in very well with the block's environment in the reactor where high thermal ramps and large gradients can exist throughout the block. Graphite is very resistant to thermal stress damage because it is a very high conductor of heat. It is possible to exceed the gradients that are capable of causing thermal damage in

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the laboratory, but this requires special test techniques. The present Engineering Mechanics furnace cannot obtain high gradients from radiant heating alone since it takes at least three quarters of an hour to bring a block to temperature and two and one-half hours to cool it. Even with gas flow it is difficult to attain more than a 100°F gradient through the block. Thus, while not positively eliminating thermal stress as a partial factor, the rewards from exploring this area do not look promising.

The other possibility of material property change is less understood. The tensile stress and strain of graphite at high and low temperatures has been well documented and the ultimate strength at intermediate temperatures has been shown on published charts. However, the stress versus strain relationship at intermediate temperatures in the upper capabilities of mechanical strain measurement and the lower limits of optical strain measurement do not seem to be well covered.

Recently, a prepublication document from the National Carbon Company has shown that ATJ graphite is quite anisotropic in the strain properties of "with" and "across the grain" directions around 1500°C. (See figure 6-4). Since the support block fillet radius is stressed in both directions, it is quite possible that the fillet radius curve becomes distorted as the constant load produces unequal displacements in the axial and circumferential directions (maxima and minima of each direction do not coincide for intermediate temperatures). High localized stresses could result from the new geometry caused by warping experienced during heatup and cooldown.

With pyrofoils between the rigid support washer and support block, photoelastic studies have indicated a change in relationship between the principal stress directions, but no quantitative data has been obtained. Furthermore, the increased local yielding possible at the pyrofoil surface would tend to redistribute the load more evenly to an altered reacting surface.

To procure further information on the observed results, it is planned to test the blocks at intermediate temperatures and measure axial displacement of the seat areas for comparison with room and high temperature results.

The temperature of minimum resistance to axial loading, once determined, can be

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With-Grain Tensile Strain Contour Plot, Stress vs.
Temperature, ATJ Graphite

Across-Grain Tensile Strain Contour Plot, Stress vs.
Temperature - ATJ Graphite

Figure 6-4. With Grain and Across Grain Tensile Strain Contour
Plot Versus Temperature - ATJ Graphite

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used as a focal point for testing future fixes and theoretical analyses. The equipment to work in the critical temperature range can be more closely specified and an optimum geometry determined that may or may not be improved by pyrofoils. In any case, it is necessary to determine which of the temperature governed properties to concentrate on for future testing goals.

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