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Westinghouse Astronuclear Laboratory

CORE INSULATION THERMAL TEST

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FOREWORD

The material contained herein covers activities conducted in accordance with Engineering Mechanics Laboratory Test Specification Number EML-68, entitled Core Insulation Thermal Test. This is the account of the work performed and conclusions drawn from testing.

ABSTRACT

The Core Insulation Development Program was initiated to investigate characteristics of pyrotile insulation as to bow, structural integrity, and thermal gradient when subjected to reactor temperatures and bundling pressures. Other forms of core insulation were to be tested as they became available.

All test parameters were met or exceeded, and specification pyrotile through NRX-A4 was proven to be satisfactory. Pyrofoil 0.010 inch thick was tested as a possible replacement for pyrotile. Ten layers forming an insulation barrier 0.100 inch thick satisfactorily withstood maximum reactor temperature and temperature differentials.

TEST OBJECTIVES

1. Measure the amount of tile bowing resulting from thermal gradients and core bundling pressures that simulate reactor operation. Measured data to be compared to calculated values to confirm analytical methods.
2. Test filler strips and pyrotile to maximum reactor temperatures, thermal gradients and core bundling pressures to determine their structural integrity.
3. Investigate alternate methods and materials for core insulation as they become available.

TEST CONCLUSIONS

1. Tile bowing resulting from reactor thermal gradients and core bundling pressures confirms the analytical methods employed. Measured data compared with calculated values are well within acceptable limits taking into account test measurement capability and pyrotile material variations.
2. Filler strip segments and pyrotile exhibit satisfactory structural ability when subjected to temperatures, thermal gradients and core bundling pressures in excess of these reactor parameters. No permanent bowing or delamination of the tile was evidenced.
3. Layers of pyrofoil tested as a possible replacement for pyrotile satisfactorily demonstrated ability to withstand reactor maximum temperatures and temperature differentials.

TEST RECOMMENDATIONS

1. Consider the analysis employed for obtaining tile bow due to reactor thermal gradients and bundling pressures to be satisfactory.
2. Consider the structural integrity of the filler strip and pyrotile adequate for maximum reactor temperatures, thermal gradients and bundling pressures.
3. Based on this testing consider pyrofoil as a possible replacement for pyrotile as a peripheral core insulation material.
4. Continue testing alternate methods and materials for core insulation as they become available.

BACKGROUND

Temperature gradients as high as 3140°R across the pyrotile insulation during reactor operation were estimated. Later estimates place this figure somewhat lower at approximately 2900°R . Previous testing attained gradients of 2000°R and strain gages were unsuccessful in measuring tile bow due to the thermal gradient.

The testing reported herein achieved gradients across the pyrotile to a maximum of 3700°R . Simulated fuel element temperature at this gradient was 5448°R . Tile bowing was measured with a linear displacement transducer at the above maximum gradient in six descending gradient values to 1150°R . Inspection of the test tile and filler strip components after test indicated all components to be in excellent condition keeping in mind that the expected parameters of full power reactor operation were exceeded.

Reactor maximum temperature on the hot face and the temperature differential across the pyrofoil insulation was exceeded. The test pieces were in excellent condition following this test.

TEST COMPONENTS AND SPECIMENS

The core insulation assembly consists of filler strips, pyrotiles, plungers and seal segments. Thermal insulation of the reactor from the lateral support system is accomplished by the use of one-eighth inch thick pyrolytic graphite tiles. Due to the low thermal conductivity characteristics of pyrolytic graphite perpendicular to the plane of deposition, high thermal gradients are achieved between surfaces. By virtue of their position in the reactor, the tiles are laterally loaded and compressed between the outer core elements and the filler strips by the lateral support system.

During this investigation the following specification hardware was incorporated into the tests involving tile bow and thermal gradient.

Filler strip segment	-	Drawing Number	909E524H01
Tile, insulating	-	Drawing Numbers	909E524H03 909E524H07 909E524H09

Pyrofoil 0.010 inch thick manufactured by High Temperature Materials, Inc., and designated by their part number, Grafoil-HP-100, was investigated for insulating capability.

TEST EQUIPMENT

The core insulation program was set up to measure the amount of tile bowing that results from thermal gradients across the tile. This bowing is naturally affected by the core bundling pressure in the reactor. The test setup includes provisions for varying the bundling pressure and for measuring the amount of tile bow under known gradient conditions. The general arrangement used in these tests is shown in figure 9. Power is supplied by the five 1000 ampere direct current power supplies shown in the background. The test specimens are mounted inside the pressure vessel shown in the background.

Thermal gradients are induced in the pyrotiles by a combination of a graphite heating element (simulating high temperature fuel) in contact with the front face of the pyrotilite and a copper cooling block behind the filler strip segments. Figures 5 and 6 are views of the internal components showing the heating element assembly, placement of tiles, filler strips, copper heat sink blocks and copper electrodes. The linear displacement transducer shown at the bottom is used to measure the total tile bow under simulated bundling conditions. Figure 7 shows the side view of the test setup with the pressure pistons used to apply the bundling pressure. In operation tile bow is measured by pressurizing the pistons while simultaneously measuring the total deflections of the tile. For each temperature gradient obtained, the bundling pressure was varied from approximately 4 psi to 48 psi with data continuously recorded on an X-Y chart recorder system.

The entire system was enclosed within the pressure vessel permitting operation with various gas atmospheres, vacuum or pressure. All connections including electrical power, cooling water and instrumentation were carried through one head of the vessel. Access to the instrumentation in the vessel was provided by Conax fittings in the head. An optical pyrometer viewed the heating element through a view port in the stationary end of the vessel. the pyrometer served as a check on thermocouple readings taken within the heating element and a check of gradient along the length of the element test area. Tungsten-Tungsten Rhenium thermocouples were used to measure temperatures over 2,400°R and Chromel-Alumel thermocouples were used below this value. The pyrometer was used for ranges above thermocouple capability.

Initial work determined the relationships between the power input and the cooling actions of inert gas flow and cooling water flow. The relationship between piston pressure and simulated core bundling pressure was also determined. Calibration of the linear displacement transducer was conducted and variables of temperature, pressure and magnetic field were investigated.

TEST PROCEDURE

All test specimens consisted of specification grade hardware. Portions of filler strips containing complete pyrotils were used for testing. WANL drawing NT701452A, sheet 4, contains machining details for the specimens. Complete test rig assembly and details are contained on WANL drawing NT701452A, sheets 1 through 4.

The following procedure was followed in the conduct of the test.

1. Assembled the rig according to WANL drawing NT701452A, sheet 1.
2. Leak-checked all connections, including electrical power, cooling water and instrumentation.
3. Installed LVDT and standard Chromel-Alumel thermocouples and special high temperature thermocouple according to sketches and drawings.
4. Prepared test specimens by cementing one end of pyrotil to filler strips with Armstrong C-7 compound. Refer to WANL drawing 909E640.
5. Placed specimens on heating element and assembled all test components.
6. Made all electrical and plumbing connections in preparation for testing.
7. Connected all recording equipment, calibrated, etc., in preparation for check run.
8. Purged pressure vessel with helium until an oxygen level of less than one percent was obtained. Closed off the exhaust and brought pressure to a maximum five psi. The exhaust pressure valve was then opened until the desired helium flow rate of approximately one cfm was established.
9. Pre-tests were run to establish performance of the rig. Element temperature versus applied voltage and amperage was plotted. Inspection of components at 2500°F, 3500°F and 4500°F intervals was conducted to establish sufficient coolant water requirement and proper function of rig.

The tests were run in three phases (after completion of the checkout runs) as outlined below.

- A. NRX-A2 Pyrotile bowing versus thermal gradient and bundling pressure.
- B. NRX-A3 and NRX-A4 Pyrotile bowing versus thermal gradient and bundling pressure.
- C. Comparison of pyrotile and pyrofoil as to high temperature insulating ability.

Parameters of the Test

1. Thermal gradients to 3000°R across pyrotile.
2. Pyrotile surface temperature to 5000°R .
3. Simulated bundling pressures to 48 psi.

Test Data Obtained

1. Curves showing thermal gradient and simulated bundling pressure versus tile bowing.
2. Evidence of tile structural integrity at maximum tile surface temperature thermal gradient and core bundling pressures.
3. Curve giving thermal differentials achieved across faces of pyrotile and pyrofoil.

TEST RESULTS

All test parameters and objectives of this test have been achieved or exceeded. Below is a tabulation showing a comparison of the initial objectives with the parameters actually obtained during testing.

<u>Parameter</u>	<u>Test Objective</u>	<u>Achieved Values</u>
1. Maximum tile temperature	5000°R	5448°R
2. Thermal gradient across tile	3000°R	3700°R
3. Bundling pressure	8 - 18 psi	4 - 48 psi

Figure 1 is the plotted data obtained on specification pyrotile as contained in NRX reactors A1 through A4. Figure 2 is the same curve enlarged to include only the core bundling pressure range found in the NRX-A reactors. As shown by the curves in the range of reactor bundling pressures (8 - 18 psi) very close correlation exists between the calculated curve of 3140°F and the experimental 3255°F curve. Extrapolation of either curve to exactly match gradients would bring these curves to even closer proximity. Deviation of the experimental and calculated occurs primarily at bundling pressures of less than 8 psi. This family of curves can be used in calculations where the gaps left by peripheral pyrotiles would be important. It can be noted that the range of bundling pressures found in the reactor provides a steep increase in peripheral gaps caused by the tile bowing at the lower bundling pressures.

Figure 3 is the plotted data obtained on specification pyrotile as contained in NRX reactors A3 and A4. Concern over the structural ability of the tile to withstand reactor environments prompted this testing. This configuration of overlapping tile contains at each end abrupt steps that were thought to be likely to break from tensile stress as high as 7000 psi. No tile failures were experienced in testing of this configuration despite environments exceeding reactor conditions. Gradients as high as 3672°R, bundling pressures to 48 psi and maximum temperatures to 5110°R were achieved for this testing. The curve of these tests is similar to the previous curves except that the slope is steeper at low bundling pressures. This is due to the dual elastic rate created by the physical configuration of the tile. As the thermal section is flattened under the increasing bundling pressure the stiffer heavier section increases the rigidity thereby abruptly changing the slope of the curve. Rates of bowing versus bundling pressure are about equal in the range of reactor temperatures and bundling pressures.

An insulation configuration consisting of ten layers of 0.010 inch thick pyrofoil was tested. Figure 4 is a plot of the results. Curve 1 plots results of pyrotile insulation testing for comparison with curves 2 and 3 which represent the pyrofoil tests. The results illustrate the pyrofoil is about 20 percent more conductive than the tile, however, this is approximately proportional to the difference in thickness between the two. This comparison is approximate as heat flux was not established for this testing. Fuel element temperatures and thermal differentials

across the insulation were the simulated controlled reactor parameters. The difference between curves 2 and 3 illustrate the benefit in increased insulation characteristics derived from low bundling pressures. Voids and increased contact resistance present between pyrofoil layers at the lower bundling pressures would probably account for this.

Figures 12, 13 and 14 are photos of test hardware at the conclusion of testing. All were subjected to temperatures in excess of 5000°R , thermal gradients in excess of 3000°R and bundling pressures to 48 psi. All specification hardware was in excellent condition following the test. No delamination or permanent bowing of the pyrotile could be detected and filler strip components were also in excellent condition. The darkened edges shown on the pyrotile could be wiped away with a soft cloth and were probably resultant deposits from inert gas impurities. The pyrofoil was also in excellent condition following tests. The fine dots located on the core face are indentations made by thermocouple contact.

Testing of alternate methods and materials of core insulation as it becomes available can effectively be evaluated with the facilities and technology gained during this program. Continuing objectives (using the facilities designed for this testing) include a study of corrosion and/or erosion rates of the core peripheral area due to hydrogen inflow leakage.

Figure 1 Pyrotilite Bow Due to Thermal Gradient (Extended Bundling Pressure Range)

Figure 2 Pyrotile Bow Due to Thermal Gradient (Reactor Bundling Pressure Range)

Figure 3 Pyrotile Bow Due to Thermal Gradient (NRX-A3 and NRX-A4
Pyrotile in High Peripheral Fuel Element Corrosion Areas)

- 1) PYROTILE - 4 TO 36 PSI BUNDLING PRESSURE
- 2) PYROFOIL - 4 PSI BUNDLING PRESSURE
- 3) PYROFOIL - 12 TO 36 PSI BUNDLING PRESSURE

Figure 4 Thermal Gradient Versus Insulation Surface Temperature

Figure 5 Core Insulation Development Test Setup

Figure 6 Cross Section of Core Insulation Development Test Rig (End View)

Figure 7 Cross Section of Core Insulation Development Test Rig (Side View)

Figure 8 Laboratory Setup for Core Insulation Development Test

Figure 9 Laboratory Setup for Core Insulation Development Test

Figure 10 Pressure Vessel Opened

Figure 11 Insulator Cap Removed

Figure 12 Specification Hardware Tile and Filler Strip Segments,
and Heating Elements

A3 PYROTILE

HOT SIDE

COOL SIDE

Figure 13 NRX-A3 and NRX-A4 Pyrotile and Filler Strip Segments

PYROFOIL

Figure 14 Pyrofoil Test Pieces at Conclusion of Testing

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