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September 1964

FINAL REPORT

EML-24

CORE INSULATION ASSEMBLY THERMAL TEST
(Title Unclassified)

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Astronuclear Laboratory
Westinghouse Electric Corporation

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Westinghouse Electric Corporation
Astronuclear Laboratory
P. O. Box 10864
Pittsburgh 36, Pennsylvania 15236

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H.F.C. TIC, date SEP 11 1973

PREPARED BY:

K. P. Kiefer
K. P. Kiefer

Core Components & Thermal Experiments

APPROVED BY:

E. A. Watjen

E. A. Watjen, Supervisor
Core Components & Thermal Experiments

W. G. Roman
W. G. Roman, Manager

Engineering Mechanics

R. S. McCreary
R. S. McCreary, Manager

Experimental Engineering

W. G. Roman
W. G. Roman, Manager

Reactor Engineering, NERVA Project

/als

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TABLE OF CONTENTS

	<u>PAGE</u>
1.0 SUMMARY	1
2.0 INTRODUCTION	2
3.0 PURPOSE	3
4.0 OBJECTIVES	4
5.0 CONCLUSIONS	5
6.0 RECOMMENDATIONS	6
7.0 TEST COMPONENTS AND SPECIMENS	7
8.0 TEST EQUIPMENT	8
9.0 TEST PROCEDURE	9
10.0 DISCUSSION OF RESULTS	12
11.0 REFERENCES	16

LIST OF ILLUSTRATIONS

<u>FIGURE</u>	<u>TITLE</u>	<u>PAGE</u>
1	Cements Tested for Use on Pyro-Tile	17
2	Temperature Gradient Across Pyro-Tile	18
3	Temperature Gradient Across Pyro-Tile	19
4	Temperature Gradient Across Pyro-Tile	20
5	Temperature Gradient Across Pyro-Tile	21
6	Pyro-Tile Surface Temperature Versus Thermal Gradient	22
7	Temperature Gradient Across Core Insulation Components	23
8	Pyrometer - Thermocouple Versus Ampere Curve	24
9	Maximum Gap Between Filler Strips and Insulating Tile	25
10	Filler Strip Pyro-Tile Test Setup #1	26
11	Filler Strip, Pyro-Tile Test Setup #2	27
12	EML-24 Test Setup	28
13	View Showing Pressure Vessel Head Separated From Vessel	29
14	Components and Thermocouple Installation for Test Setup #1 at Conclusion of Testing	30
15	Components and Thermocouple Installation for Test Setup #2 at Conclusion of Testing	31
16	Core Insulation Components and Heating Element At Conclusion of Test Setup #1	32
17	Core Insulation and Heating Element Components At Conclusion of Test Setup #2	33
18	Pyro-Tile and Filler Strips at Conclusion of Test Setup #2	34
19	Comparison of New and Tested Pyro-Tile	35
20	Comparison of New and Tested Pyro-Tile	36
21	Comparison of New and Tested Pyro-Tile (Tested in excess of 4500°F)	37
22	View Showing Filler Strips at Conclusion of Testing	38

1.0 SUMMARY

- 1.1 Pyro-tile surface temperatures in excess of 4500°F, and thermal gradient across the tile of 1800°F to 2000°F have been achieved. In addition six thermal cycles from 500°F to 4000°F were completed. Each cycle consisted of a thermal ramp from 500°F to 4000°F in an elapsed time of three minutes. Return from 4000°F to 500°F also required approximately three minutes. Testing was conducted with the core components and pyro-tile subjected to plunger loadings from 0 lb per plunger to a maximum of 100 lb per plunger - in a helium atmosphere of 5 psig.
- 1.2 Inspection of the tile and core insulation components after test indicated that they were in satisfactory condition.

2.0 INTRODUCTION

2.1 Full scale reactor operation at 100 percent power and 100 percent flow results in pyro-tile - fuel element interface temperatures of 4500°R (Reference 3). Information, concerning mechanical behavior of the core insulation components, when subjected to reactor operational thermal conditions, gradients and shock, is needed to substantiate design analysis and is the basis of this testing.

3.0 PURPOSE

3.1 The purpose of this test is to establish the validity of the analysis of the core insulation assembly configuration, including plunger, seal segment, filler strips and pyro-tiles under design operating thermal gradient, thermal shock and plunger loading conditions. Reactor operation at 100 percent power and 100 percent flow results in pyro-tile surface temperatures of approximately 4500°R. Structural failure of the core insulation components, especially the pyro-tile, could cause increased thermal gradients to be imposed upon the filler strips, seal segments, plungers, and inner reflector as well as exposing some of the aforementioned components to temperatures in the range where hydrogen corrosion is very high. Either of these eventualities could lead to ultimate failure of the reactor.

4.0 OBJECTIVES

- 4.1 Determine the actual thermal gradients obtained across the pyro-tile and core insulation subassembly.
- 4.2 Determine the ability of the pyro-tile to withstand the stresses created by simulated temperature gradients and thermal shock under design plunger loading.

5.0 CONCLUSIONS

- 5.1 Thermal gradients across pyro-tile of 1800°F to 2000°F were obtained when subjected to a 4500°F surface temperature. The gradient across the remaining core insulation subassembly was approximately 260°F.
- 5.2 Results of this testing clearly demonstrated the structural ability of the core insulation components to successfully withstand the stresses created by simulated temperature gradients and thermal shock under design plunger loading.
- 5.3 No permanent bowing, physical change, or delamination of the pyro-tile was evident from this testing.
- 5.4 Attachment of the pyro-tile to the filler strip, with high temperature P-514 cement, indicated this method to be non-permanent. All tile were detached from the filler strip upon conclusion of high temperature testing.

6.0 RECOMMENDATIONS

- 6.1 Testing on improved alternate methods and materials of core insulation should be continued. Improved technology in core insulating techniques is desirable for continued reactor development.
- 6.2 Future studies should be conducted on pyro-tile to compare calculated strains due to reactor thermal gradients and core bundling, with tests simulating reactor thermal gradients and core bundling. Stress calculations for increased reactor output approaches the ultimate strength of the pyro-graphite tile material.

7.0 TEST COMPONENTS AND SPECIMENS

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

7.2 During this investigation all of the filler strip and pyro-tile configurations used in the NRX-A reactors were tested. Test components and the drawing numbers specifying them are as follows:

7.2.1 Filler Strip - Drawing numbers 909E401 to 909E404

909E406 to 909E410

909E414 and 909E421

909E416 to 909E419

909E425 and 909E426

7.2.2 Tile, Insulating - Drawing numbers 945C657A to 945C659A

945C669A and 945C671A

7.2.3 Plunger, Lateral Support - Drawing number 963B984

7.2.4 Segments Seal - Drawing numbers 977D843 to 977D845

8.0 TEST EQUIPMENT

- 8.1 A pressure vessel, housing a graphite electrical resistive heating element (simulating high temperature fuel elements) suitable water-cooled electrodes, holding fixtures and instrumentation, was incorporated to obtain the test parameters (see Figure 13).
- 8.2 Thermal gradients were induced in the pyro-tiles by a combination of the graphite heating element in contact with the front face of the pyro-tiles and a copper cooling jacket behind the support system. Cooling water was circulated through the jacket to act as a heat sink and simulate the inner reflector of the reactor. The entire testing system was enclosed within the pressure vessel permitting helium flow. All connections, including electrical power, cooling water and instrumentation was carried through one head of the pressure vessel. The electrical power to the heating element was conducted by water-cooled copper tubing. Access to the instrumentation in the pressure vessel interior was provided by Conax fittings in the head. Helium gas was introduced into the pressure vessel through one head and exhausted through the opposite head after passing through and along the lateral support system. Spring loads on the lateral support system plungers were simulated by pneumatic diaphragms loading the ends of the plungers. Initial work determined the relationship between the power input and the cooling actions of the helium flow and cooling water flow.

9.0 TEST PROCEDURE

- 9.1 Test specimens were prepared according to drawing number NT 700101. Pyro-tile were used without modification. Filler strips, seal segments and plunger pins required some modification. Pyro-tile were cemented to filler strips following specification grade hardware procedure. One end of the tile is cemented with P-514 graphite cement and the opposite end with Armstrong C-7 compound. Refer to T-S 909E640 for cementing and curing procedures.
- 9.2 Specimens were clamped together with a special machining fixture described on drawing number NT 700101 sheet number 2, having a curvature to conform to that of the reactor filler strips. Chromel-Alumel thermocouples and special high temperature tungsten-tungsten rhenium, tantalum sheathed thermocouples were installed according to Figures 10 and 11.
- 9.3 Test components were assembled including all electrical, cooling and instrumentation according to drawing number NT 700101. See Figure 12. The vessel was purged with helium until an oxygen level of less than one percent was obtained. Two test runs were completed.
- 9.4 The initial test contained a pyro-tile setup as shown in Figure 10. This test was conducted to gain core insulation temperature gradient data and tile behavior of the various reactor filler strip, pyro-tile configurations. Structural integrity of the tile was verified with

WANL-TME 902

respect to the stresses created by the thermal gradients that tend to cause bowing under maximum design plunger loading.

- 9.5 The second test was run to determine the effects of thermal shock upon structural ability of the tile to withstand both thermal loading and sufficient mechanical plunger loading to hold the tile flat against the filler strip to within .004 in. See Figure 9.
- 9.6 A strain-gaged installation was attempted to determine the magnitude of tile bowing. Attempts at cementing high temperature gages on the pyro-tile proved unsuccessful. Strain gage installations used BLH EPY-400 cement and Baid type 600 series strain gages. During checkout runs to obtain strain versus temperature data this installation was satisfactory to 600°F, but during testing these gages proved unsatisfactory. Future tests will utilize mechanical means of measuring tile bowing. Figure 1 is a record of the cements and procedures used in an attempt to secure a satisfactory high temperature bond to pyro-graphite.
- 9.7 Both tests were run using the D. C. power facilities of the Fluid Flow Laboratory. Element heat was obtained by application of current in pre-determined steps. A typical schedule follows:

RUN NO.	SYSTEM APPLIED - AMPERES	EXPECTED ELEMENT TEMPERATURE
1	1000	500°F
2	1500	1000°F
3	1875	1500°F
4	2250	2000°F
5	2500	2500°F
6	2750	3000°F
7	3000	3500°F
8	3250	4000°F
9	3500	4500°F
10	3750	5000°F

WANL-TME-902

The thermal shock testing was conducted by the application of current in one step to bring the element temperature to 4000°F. Upon reaching this temperature current was cut and the element allowed to cool to 500°F. The test included six cycles, three simulating maximum plunger loading from the lateral support springs of 65 lb per plunger, and three simulating the additional loading caused by the pressure drop across the reactor of 100 lb per plunger. Approximately three minutes were required for temperatures to achieve the 500°F to 4000°F ramp. Time versus temperature readings were not possible for this testing due to loss of the high temperature thermocouple. Temperature readings were taken with an optical pyrometer.

10.0 DISCUSSION OF RESULTS

- 10.1 Pyro-tile surface temperatures in excess of 4500°F, and thermal gradients across the tile of 1800°F to 2000°F have been achieved. Thermal shock was also accomplished, within the maximum capabilities of the test facilities, as an approximate 6 min cycle from 500°F to 4000°F and return. Testing was conducted with the core components and pyro-tile subjected to design minimum and maximum plunger loading from the lateral support springs of 34 and 62 lb per plunger, and at 100 lb per plunger simulating an additional 3.6 psi of gas loading. Calculations indicate bowing of the tile under these loads of .022 in., .011 in. and .004 in. respectively at a thermal gradient of 3150°R. Refer to Figure 9. This testing did not reach this gradient, therefore, bowing of the tile under the plunger loadings employed would be somewhat less. Inspection of the tile and core insulation components after test indicated no evidence of cracks, delamination, permanent bowing or set, or other physical change.
- 10.2 Figures 10 and 11 are a representation of the core insulation components tested. Virtually all of the pyro-tile filler strip combinations found in the NRX-A2 reactor were contained in these assemblies. The initial test was prematurely concluded because of failure of the graphite heating element. During the final period, with 16 volts and 3500 amps applied, instrumentation indicated arcing of the element. The failed element is shown on Figure 16. Examination of the element after test indicated that failure was due to an extremely high temperature in the area adjacent to the ends of the pyro-tile. This high

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WANL-TME-902

temperature area is clearly visible and shows a well defined necked-down section. This area is also vulnerable to gas impurities and to moisture present in the inert gas supply. Ultimate failure began at the element edge and proceeded across the element to about one third of the cross section, then failed by cracking the remainder of the distance in the area just under the edge of the pyro-tile causing an arc to be drawn to several of the tiles. Final cracking was caused by the eccentricities of the simulated plunger loading.

10.3 Figures 2 through 6 are plots of the temperature gradient data obtained on the "Hot" and "Cool" faces of the pyro-tile. Tungsten-tungsten rhenium thermocouples were used on the high temperature faces of the pyro-tile and chromel-alumel thermocouples were used at the filler strip - pyro-tile interface. Loss of instrumentation occurred at about 2900°F on the high temperature thermocouples and at approximately 1800°F on the cool side. Voltage and current values were monitored at the time of loss of instrumentation and at all preceding points. After the loss of thermocouple instrumentation, at a power level of 3000 amps and 12.9 volts, two additional points were run to a maximum of 3500 amps and 16 volts. These additional points made possible the extrapolation of the data to the 16 volt level. Figure 8 is data from the final test run of this project where an optical pyrometer was used in addition to the high temperature thermocouples. This curve demonstrates the close agreement between the pyrometer and thermocouple and verifies previous testing which indicated maximum pyro-tile surface temperatures in excess of 4500°F.

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- 10.4 Figure 6 is a plot of the thermal gradient across the pyro-tile versus the pyro-tile surface temperature. As indicated by the curve, the gradients ranged from 1800°F to 2000°F in these testing facilities at a surface temperature of 4500°F.
- 10.5 Figure 7 is a plot of the thermal gradient across the entire core insulation system. A very slight gradient of 40° occurs across the filler strip, with a substantially higher gradient of 250° across the seal segment at the higher temperatures.
- 10.6 Reactor Analysis calculations presented in the Reactor Analysis Data Book, WANL-TME-840, show that the maximum temperature gradient across the insulation tiles is 2770°F. Reactor operation at 76 percent power and 100 percent flow results in gradients of 2340°F across the tile. Gradients to 2300°F were experienced during this testing. Test gradients were somewhat lower than calculated values and were attributed to the construction of the test fixture, allowing current to flow through the pyro-tile causing heating of the tile itself and thus lowering the gradient.
- 10.7 Lateral support pressure sufficient to hold a tile flat against a fuel element at a temperature gradient of 2770°F calculates a compressive stress on the hot surface and tensile stress on the cold surface of 5180 psi (Reference 2). The minimum tensile strength of pyrolytic graphite at 1500°F is above 7000 psi. Bowing of the tile tends to reduce this stress.
- 10.8 Based on this testing, the core insulation components demonstrated their ability to withstand temperatures to 4500°F and temperature

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WANL-TME-902

gradients of 2300°F. No permanent bowing, delamination of physical
change was evident resultant from the test parameters.

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11.0 REFERENCES

- 11.1 "Stress Analysis Lateral Support System" prepared by J. Swanson;
WANL-TME-682, Westinghouse Astronuclear Laboratory, June 30, 1964.
- 11.2 "Evaluation of NRX-A2 Core Insulation Region" prepared by J. Swanson;
WANL-TME-856, Westinghouse Astronuclear Laboratory, July 28, 1964.
- 11.3 "Reactor Analysis of NRX-A Thermal and Fluid Flow Analysis, Volume III"
prepared by Reactor Analysis Department, WANL-TNR-128, Westinghouse
Astronuclear Laboratory, September 1963.

FIGURE 1
CEMENTS TESTED FOR USE ON PYRO-TILE

1. Allen PBX Cement - holds well at several hundred °F but flakes off when taken over 500-600°F. This is especially true if a gage has been mounted with this cement. Several curing procedures were tried. First, the pre-coat was completely cured and then the gage was cemented down. Secondly, the pre-coat was dried but not cured and then the gage was laid, and then cured.
2. Bean Type-H Cements - same as Allen PBX.
3. Astro Ceram Cement - A similar approach as for Allen PBX. This cement did not hold at all. Completely inadequate for strain gage work.
4. Sorriesen Cement - About the same as Astro Ceram. Held slightly better but still inadequate.
5. Great Lakes 514 Graphite Cement - This was tried as an attempt to obtain a better surface so that one of the ceramic cements could be used. The usual curing procedure was used except that it was not carbonized. The cement was so soft that it could be easily brushed off.
6. Flame Spray - This behaved similar to Allen PBX. It could be flaked off in large pieces. This process works well on regular graphite.
7. BLH EPY-400 - This cement works very well up to 550-600°F. This was the only cement tested that will give satisfactory results at even this temperature.

WANL-TME-902

FIGURE 2
TEMPERATURE GRADIENT ACROSS PYRO-TILE

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PYRO-TILE THERMAL GRADIENT (°F)

FIGURE 9
MAXIMUM GAP BETWEEN FILLER STRIPS
& INSULATING TILE - STATION 50
(Temperature Gradient Across Tile = 3150°F)

FILLER STRIP PYRO-TILE TEST SETUP #1

FIGURE 10

FILLER STRIP, PYRO-TILE TEST SETUP #2

FIGURE 11

FIGURE 12
EML-24 TEST SETUP

FIGURE 13
VIEW SHOWING PRESSURE VESSEL
HEAD SEPARATED FROM VESSEL

FIGURE 14
COMPONENTS AND THERMOCOUPLE INSTALLATION
FOR TEST SETUP #1 AT CONCLUSION OF TESTING

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FIGURE 15
COMPONENTS AND THERMOCOUPLE INSTALLATION
FOR TEST SETUP #2 AT CONCLUSION OF TESTING

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FIGURE 16
CORE INSULATION COMPONENTS AND HEATING
ELEMENT AT CONCLUSION OF TEST SETUP #1

FIGURE 17
CORE INSULATION AND HEATING ELEMENT COMPONENTS
AT CONCLUSION OF TEST SETUP #2

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FIGURE 18
PYRO-TILE AND FILLER STRIPS AT
CONCLUSION OF TEST SETUP #2

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FIGURE 19
COMPARISON OF NEW AND TESTED PYRO-TILE
(DARK WIDE LINE CAUSED BY CONTACT WITH METAL SHEATH OF THERMOCOUPLE)

FIGURE 20
COMPARISON OF NEW AND TESTED PYRO-TILE

FIGURE 21
COMPARISON OF NEW AND TESTED PYRO-TILE
(TESTED IN EXCESS OF 4500°F)

FIGURE 22
VIEW SHOWING FILLER STRIPS AT CONCLUSION OF TESTING
(NOTE EXCELLENT CONDITION. PYRO-TILE TESTED IN EXCESS OF 4500°F)