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WANL-TME-1227
SEPTEMBER 1965

Westinghouse
Astronuclear Laboratory

**THE COMPRESSIVE MECHANICAL
PROPERTIES OF FUEL ELEMENTS
AT ELEVATED TEMPERATURES**
(TITLE UNCLASSIFIED)

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THE COMPRESSIVE MECHANICAL
PROPERTIES OF FUEL ELEMENTS
AT ELEVATED TEMPERATURES
(TITLE UNCLASSIFIED)

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TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
1	INTRODUCTION	1-1
2	CONCLUSIONS AND RECOMMENDATIONS	2-1
3	TEST SETUP AND DESCRIPTION	3-1
4	TEST RESULTS	4-1

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Test Arrangement for Fuel Element Compression Test	3-2
2	Ultimate Load and Stress on a Fuel Element as a Function of Temperature	4-3
3	Typical Compressive Failure of Fuel Specimens at a Temperature Below 4600°R	4-4
4	Typical Failure of a Fuel Specimen Due to Combined Buckling and Compression (Temperature 4800°R)	4-5
5	Buckling of a Two Inch Fuel Specimen at a Temperature of 5000°R	4-6
6	Typical Data Trace Curve of Load Versus Deflection at Various Temperatures	4-7

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Ultimate Compression Load Versus Temperature for Two Inch Fueled Elements	4-2

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ABSTRACT

An investigation of the ultimate compressive strength of fuel elements as a function of temperature was conducted. A series of tests were performed on a group of two inch long fuel elements with maximum fuel loading (Code 99). The tests were performed over the temperature range of 3600°R to 5200°R. The maximum increase in ultimate compressive stress was approximately 33 percent of the ambient temperature (530°R) ultimate stress of 12,000 psi and occurred in the temperature range from 3800°R to 4000°R. At temperatures higher than 4600°R, the ultimate stress decreased rapidly and noticeable plastic deformation was observed.

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SECTION 1

INTRODUCTION

The following is a report on the compressive testing of NERVA fuel elements at reactor operating temperatures. The purpose of the tests was to determine the mechanical properties of fuel elements under compressive loads as a function of temperature. All testing was conducted in the 6 by 10 inch furnace in the Engineering Mechanics Laboratory. The test specimens were subjected to an inert (helium) atmosphere during testing under uniform heating conditions. Data obtained included ultimate compressive load and stress versus temperature.

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SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The maximum temperature for the NERVA fuel element is 4434°R (reference WANL-TME-840A). The normal compressive load on the fuel element is approximately 80 lb at full power and flow. Data from this test shows that at a temperature of 4400°R the ultimate compressive strength of the fueled element is approximately 4800 lb or 60 times the reactor loading.

It is unlikely that elements will fail in compression; therefore, it is recommended that this data be supplemented by tensile data taken at reactor operating temperatures. This will permit greater accuracy in analyses to determine the probability of failure for reactor elements. Tensile tests are presently planned as part of the current test program and should be complete by the end of 1966.

As a result of these tests we can conclude that a transition from brittle fracture to a ductile failure mode exists in the temperature region between 4400°R and 4600°R .

SECTION 3

TEST SETUP AND DESCRIPTION

The fuel element compression tests were performed in the 6 by 10 inch furnace in the Engineering Mechanics Laboratory. This furnace uses an electrically heated radiant heat source to bring the specimen up to temperature.

The furnace is equipped with a load train to permit mechanical loading of specimens to a maximum of 10,000 pounds. The portion of the load train that is within the furnace is composed of ATJ graphite cylinders. For the fuel element compression tests, the load input portion of the train (the lower section) was connected to a water cooled loading rod. A load cell was placed so as to measure the force applied to the loading rod. Mechanical loads were applied by means of a DC powered motor and jackscrew. This system was calibrated to provide a loading rate of 0.02 inch per minute. The upper end of the load train was reacted at the top of the furnace to prevent bending. A schematic of the entire configuration is shown in figure 1.

The output of the load cell was recorded on an X-Y recorder and displayed on a digital voltmeter. The digital voltmeter was used to monitor the loading during expansion of the specimen on heating to temperature.

The test specimens consisted of two-inch long fueled elements cut from three different full length elements. The serial numbers of the full length elements from which the specimens were taken were 18778, 18816 and 18890. All of these elements had the maximum fuel loading (Code 99) with coating on the bores only.

FIGURE 1 Test Arrangement for Fuel Element Compression Test

SECTION 4

TEST RESULTS

A total of 41 compression tests were conducted on two inch long fueled specimens over a temperature range of 3600°R to 5200°R . A series of tests using the same test arrangement were performed at ambient temperatures (530°R) for comparative purposes. The results of these tests are given in table 1 where the ultimate load is given as a function of the temperature. The maximum ultimate load and stress as a function of temperature occurs at approximately 4000°R with values of 5490 lb and 16,000 psi, respectively, as shown in figure 2. A close examination of figure 2 indicates a noticeable amount of scatter in the data above 4600°R . This can be attributed to the change in failure mode as the temperature is increased above 4600°R . The mode of failure obtained in the compression tests for temperatures below 4600°R were brittle fractures as shown in figure 3. At a temperature of 4600°R and above, the mode of failure changes to a combined buckling and compressive failure as evidenced by the plastic deformation of the specimen, see figure 4. A photograph of a specimen subjected to a temperature of 5000°R is shown in figure 5.

The plastic deformation of fuel specimens experienced at temperatures above 4600°R is readily discernible from the data traces obtained during the tests. Typical data trace curves of load versus deflection at various temperatures are shown in figure 6. The deflection axis represents the total deformation of the specimen and load train combined. The load train deflection represents approximately 50 percent of the elastic deflection but is reduced to a much smaller percentage of the total deflection as plastic deformation of the specimen takes place. The mass and size of the load train being much larger in comparison to the fuel specimen does not experience plastic deformation at the loads necessary for specimen failure.

An attempt at determining the elastic modulus for the fuel specimen as a function of temperature from the load versus deflection data did not appear feasible. The load train deflection represents such a larger percentage of the total deflection that the modulus could not be determined accurately.

TABLE 1

ULTIMATE COMPRESSION LOAD VERSUS TEMPERATURE FOR TWO-INCH FUELED ELEMENTS

	TEMPERATURE ($^{\circ}$ R)										
	530	3600	3800	4000	4200	4400	4600	4800	4900	5000	5200
Ultimate Load (lbs) Test Run 1	4380	5150	5275	5670	5070	5150	4190	4190	3600	2710	2260
Ultimate Load (lbs) Test Run 2	4300	5075	5390	5240	5190	4990	4510	4160	3480	2600	
Ultimate Load (lbs) Test Run 3	4060	5300	5510	5330	5610	4900	4620	4330	3460	2690	
Ultimate Load (lbs) Test Run 4	4000		5580	5730	5500	5000	4480	3700	3600		
Average Ultimate Load (lbs)	4160	5175	5440	5490	5340	5010	4450	4095	3545	2670	

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4-3

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FIGURE 2 Ultimate Load and Stress of a Fuel Element as a Function of Temperature

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ELEM. #18778
IDENT #8

FIGURE 3 Typical Compressive Failure of Fuel Specimens at a Temperature below 4600°R

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ELEM #18778
IDENT #1

FIGURE 4 Typical Failure of a Fuel Specimen Due to Combined Buckling and Compression
(Temperature 4800°R)

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FIGURE 5 Buckling of a Two Inch Fuel Specimen at a Temperature of 5000°R

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COMPRESSIVE LOAD VS DEFLECTION CURVES AT VARIOUS TEMPERATURES

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FIGURE 6 Typical Data Trace Curve of Load Versus Deflection at Various Temperatures