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**MASTER**

YANKEE CORE EVALUATION PROGRAM  
QUARTERLY PROGRESS REPORT FOR  
THE PERIOD ENDING MARCH 31, 1970

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## SECTION 1

### SUMMARY

The mechanical testing program has been extended to study strain rate sensitivity of the Zircaloy-4 tensile properties. A few tests have been completed demonstrating the satisfactory operation of the test equipment. During this quarter, preparations were made for unit cell nuclear design calculations which will be compared with measured uranium and plutonium isotopic compositions.

## SECTION 2

### INTRODUCTION

Two experimental fuel assemblies, intended primarily for evaluating the performance of Zircaloy-4 clad  $\text{UO}_2$  fuel rods, were designed and fabricated by Westinghouse under contract with Yankee Atomic Electric Company. The assemblies were irradiated in Yankee-Rowe Core V from November 1965 to October 1966. Eighteen of the irradiated Zircaloy-clad rods were transferred to the Westinghouse Post-Irradiation Facility for post-irradiation examination.

The post-irradiation studies reported to date<sup>(1,2,3,4)</sup> have included:

- a) an examination of the general physical condition of the fuel rods,
- b) measurement of length and diameter changes,
- c) fuel burnup and fission gas release measurements,
- d) examination of fuel and clad microstructures, and
- e) measurement of the clad mechanical properties at elevated temperatures.

During this work period, the major effort consisted of continued mechanical testing to determine the strain rate sensitivity of clad tensile properties. Physics evaluation work consisted of preparation for final unit cell calculations.

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- (1) WCAP-3017-6089
  - (2) WCAP-3017-6090
  - (3) WCAP-3017-6091
  - (4) WCAP-3017-6092

### SECTION 3

#### PHYSICS EVALUATION

During this work period, preparations were made for final unit cell calculations. These calculations will be made for fuel rod 2-1 using a modified version of the LEOPARD<sup>(5)</sup> code. The resulting predicted values of uranium and plutonium isotopic compositions for rod 2-1 will be compared with the measured values obtained in fuel burnup analyses on the rod.

Flux distributions and assembly outlet temperatures obtained by in-core measurements during Core V operation have been correlated with mass spectrometric burnup analyses on fuel rod 2-1. Calculated values of average power density and moderator temperature (Table 1) obtained from these correlations will be used as in-put data for the final unit cell calculations.

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(5) WCAP-3269-26, "LEOPARD - A Spectrum Dependent Non-Spatial Depletion Code for the IBM-7094," R. F. Barry, September 1963.

TABLE 1  
SUMMARY OF IRRADIATION HISTORY OF YANKEE CORE V  
FUEL SAMPLES FROM ROD NUMBER 2-1

<u>Axial Sample Zone</u>	<u>Distance From Bottom of Fuel (Inches)</u>	<u>Burnup<sup>(a)</sup> (MWD/MTU)</u>	<u>Average<sup>(b)</sup> Power Density (kw/kg)</u>	<u>Moderator<sup>(c)</sup> Average Temperature (°F)</u>
1	82.6	7,850	24.4	548
2	64.1	13,220	41.1	542
3	45.6	14,530	45.2	530
4	27.1	14,320	44.6	518
5	9.1	10,600	33.0	506

NOTES: (a) Determined from mass spectrometric analysis for Nd-148 concentration; each value shown here is the average of values obtained for two or more burnup samples per axial zone.

(b) Estimated from flux-wire data and burnup analyses.

(c) Based on thermocouple data obtained during core operation.

## SECTION 4

### MECHANICAL PROPERTIES OF YANKEE CORE V ZIRCALOY-4-CLAD

During this quarter, the program of uniaxial tensile tests has been extended to determine the effect of strain rate on the tensile properties of irradiated Zircaloy-4 clad from Yankee Core V. Specimens of the same clad have been previously tested at 625, 650 and 675°F at a crosshead speed of .010 inches/min.<sup>(3)</sup> The current series of tests will extend the temperature range down to 600°F and use a crosshead speed of 1.2 inches/min. to obtain a strain rate about .005 sec.<sup>-1</sup>. The specimen configuration will be the same as that used in the slower strain rate tests. A timing mechanism has been incorporated into the recorder which makes a chart mark every second (See Figure 1.). This enables the strain rate to be determined throughout the test. To obtain an even higher strain rate, a second series of tests will be conducted using shorter specimens (4 inches) and a faster crosshead speed (2.0 inches/min.).

Two tests have been run at 625°F at a cross head speed of 1.2 inches/min. The stress-strain curves and strain rate history are given in Figures 1 and 2. The initial low strain rates can be attributed to elasticity in the machine. Once beyond the proportional limit, the strain rate soon becomes that calculated from the crosshead speed (.005 sec<sup>-1</sup>) assuming that the inserts give no support to the tubing between the tensile grips. Since the strain rate is constant by the time the limit of the extensometer is reached (.035-.040 inches elongation or 1.75-2.0 percent strain) and necking is minimal, it has been assumed to remain constant until the end of the test. This assumption has been used in computing the values of uniform and total elongation. The results of the first two tests are compared below with results of earlier tests conducted at a crosshead speed of .010 inches/min.

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(3) WCAP-3017-6091

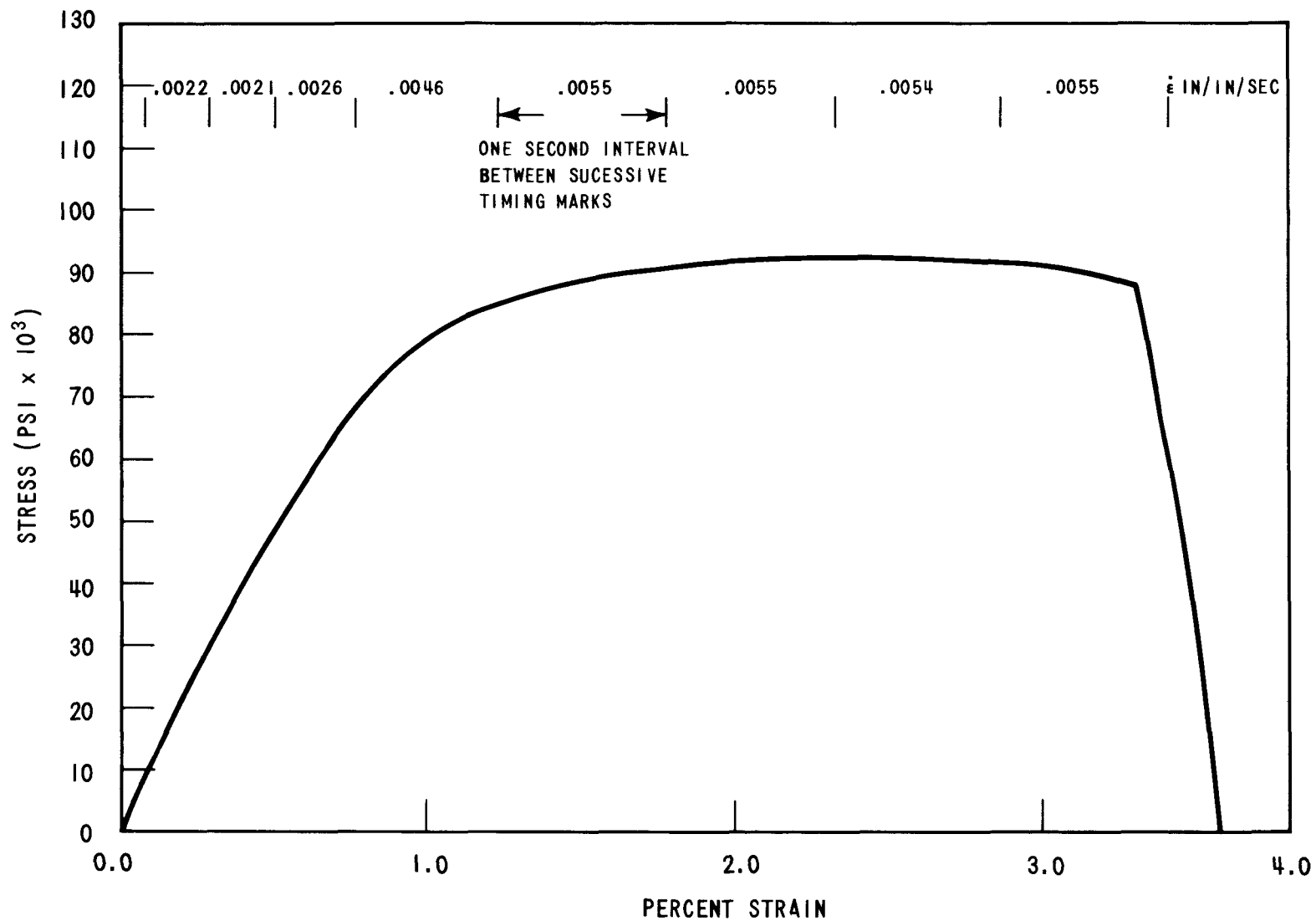


Figure 1. Specimen T1-15-2 Tested at 625°F at a Crosshead Speed of 1.2in/min.

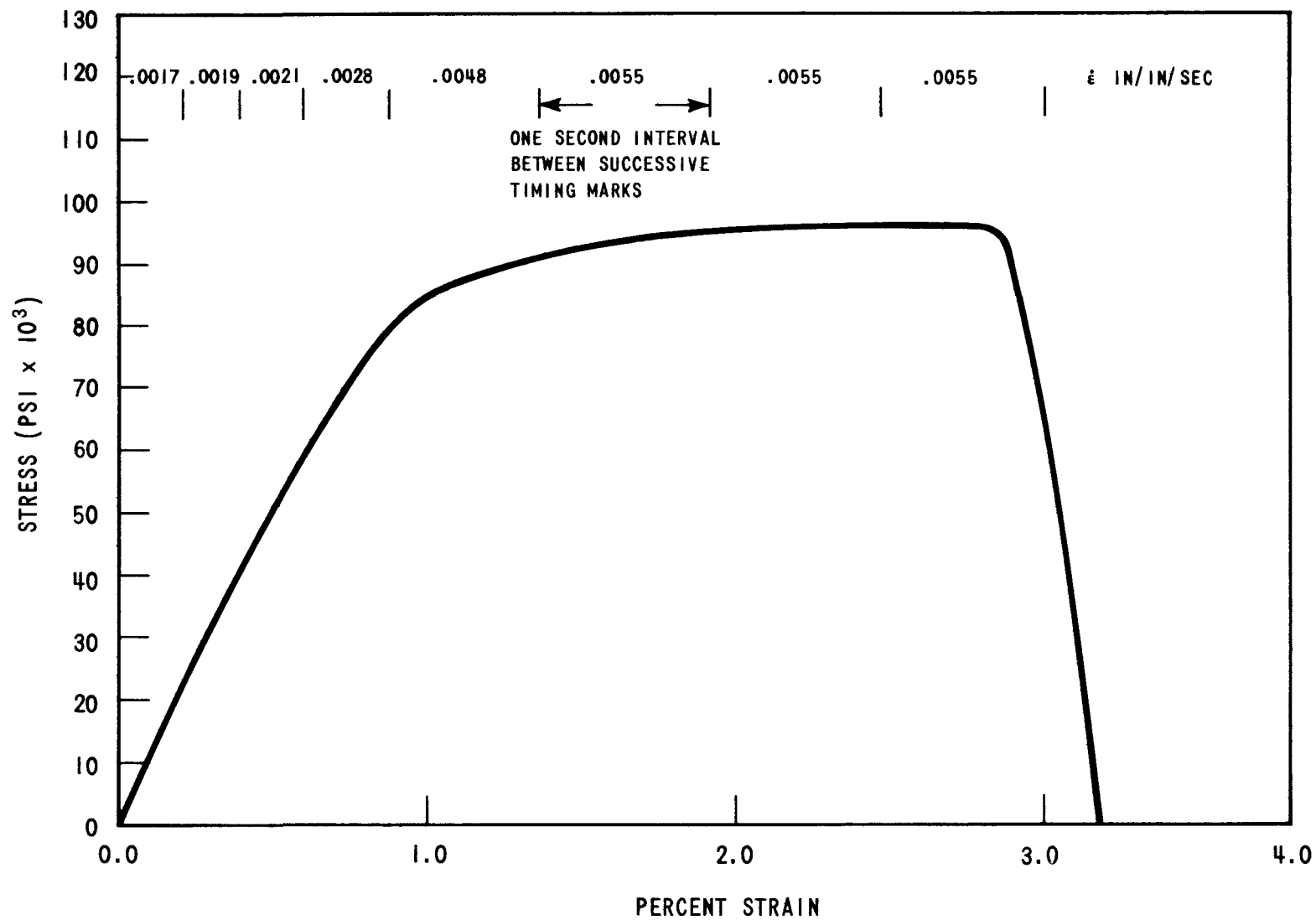


Figure 2. Specimen T1-17-1 Tested at 625°F at a Crosshead Speed of 1.2 in./min.

<u>Crosshead Speed</u>	<u>E</u> <u>(psi x 10<sup>-6</sup>)</u>	<u>0.2% Y.S.</u> <u>(psi)</u>	<u>U.T.S.</u> <u>(psi)</u>	<u>U.E. (%)</u>	<u>T.E. (%)</u>
.010 in./min*	9.7	67,000	79,000	2.5	4.4
1.2 in./min	10.7	84,990	96,370	2.5	2.9
1.2 in./min	9.3	80,760	91,120	2.9	3.3

\*Mean of 4 tests -- WCAP-3017-6091

There are, as yet, insufficient data to statistically determine any significant effects of strain rate, but the 0.2 percent yield strength and ultimate tensile strength increase with increasing strain rate, while total elongation may decrease. Modulus and uniform elongation appear to be unaffected.