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LOFT TECHNICAL REPORT

Title	LOFT Fuel Rod Cladding Critical Collapse Pressure Analysis	LTR No.	LO-14-80-068
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The critical collapse pressure of the zircaloy fuel rod cladding for the LOFT peripheral fuel assemblies was calculated in order to evaluate whether the cladding can withstand a hydrostatic test or whether the cladding is already collapsed from previous testing.

The calculations indicate that both the normal power operation preceding LOCE L3-1 and the hydrostatic test would exceed the critical collapse pressure of the fuel rod cladding with annealed zircaloy tensile properties.

NO DISPOSITION REQUIRED

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SUMMARY

The critical collapse pressure of the zircaloy fuel rod cladding for the LOFT peripheral fuel assemblies was calculated in order to evaluate whether the cladding can withstand a hydrostatic test at 21.55 MPa (3125 psig) and 394 K (250^{0}F) or whether the cladding has already collapsed after exposure at 664 K and 14.82 MPa. The peripheral fuel assembly fuel rods have been exposed to power range tests to 440 w/cm peak fuel rod linear heat rate, three large break (L1-5, L2-2 and L2-3) and two small break LOCEs (L3-0 and L3-1), and normal power operations preceding LOCE's L2-2 (330 w/cm), L2-3 (440 w/cm) and L3-1 (440 w/cm). The peak cladding temperature (874 K) measured in the peripheral fuel bundle fuel rods during L2-3 is sufficiently high to cause loss of the improved mechanical properties that existed after the cladding drawing and stress relieving process, and annealed cladding tensile properties were used in the computations.

The calculations indicate that both the normal power operation preceding LOCE L3-1 and the 21.55 MPa, 394 K hydrostatic test would exceed the critical collapse pressure of the fuel rod cladding with annealed zircaloy tensile properties.

CONTENTS

FIGURES

I. Introduction

The critical collapse pressure of the peripheral LOFT fuel rod cladding was calculated in order to evaluate whether the cladding can withstand a hydrostatic test at 21.55 MPa (3125 psig) and 394 K (250^{o}F) or whether the cladding has already collapsed. Besides the power operation during the power range testing, the peripheral fuel rods have been exposed to three large break (L1-5, L2-2 and L2-3) and two small break (L3-0 and L3-1) LOCE's with normal power operations preceding LOCE's L2-2, L2-3, and L3-1. These calculations provide a basis for estimating the current status of the cladding mechanical state for further evaluation of future LOCE testing and normal operation of the reactor.

The computation method is described in Section II with the results presented in Section III.

II. Cladding Deformation of Peripheral Fuel Rods

The evaluation of the mechanical state of the cladding was based upon determining a critical cladding collapse pressure in a manner similar to that performed by Jersey Nuclear Company for the LOFT fuel rod design.[1,2]

The critical collapse pressure Pa, for a perfectly round tube, is calculated from the equation:

$$Pa = \frac{E}{4(1-\nu^2)} \left(\frac{t}{r}\right)^3 \qquad (1)$$

where

E = elastic modulus

ν = Poisson's ratio

t = wall thickness

r = mean radius of cladding

The collapse pressure for a tube with some initial ovality is obtained from the equation:

$$P_{cr} = \frac{A - \sqrt{A^2 - 4B}}{2} \qquad (2)$$

where

P_{cr} = the critical collapse pressure

$A = \frac{\sigma_y t}{r} + P_a \; 1 + \frac{6u}{t}$

$B = \frac{\sigma_y t P_a}{r}$

σ_y = the yield strength

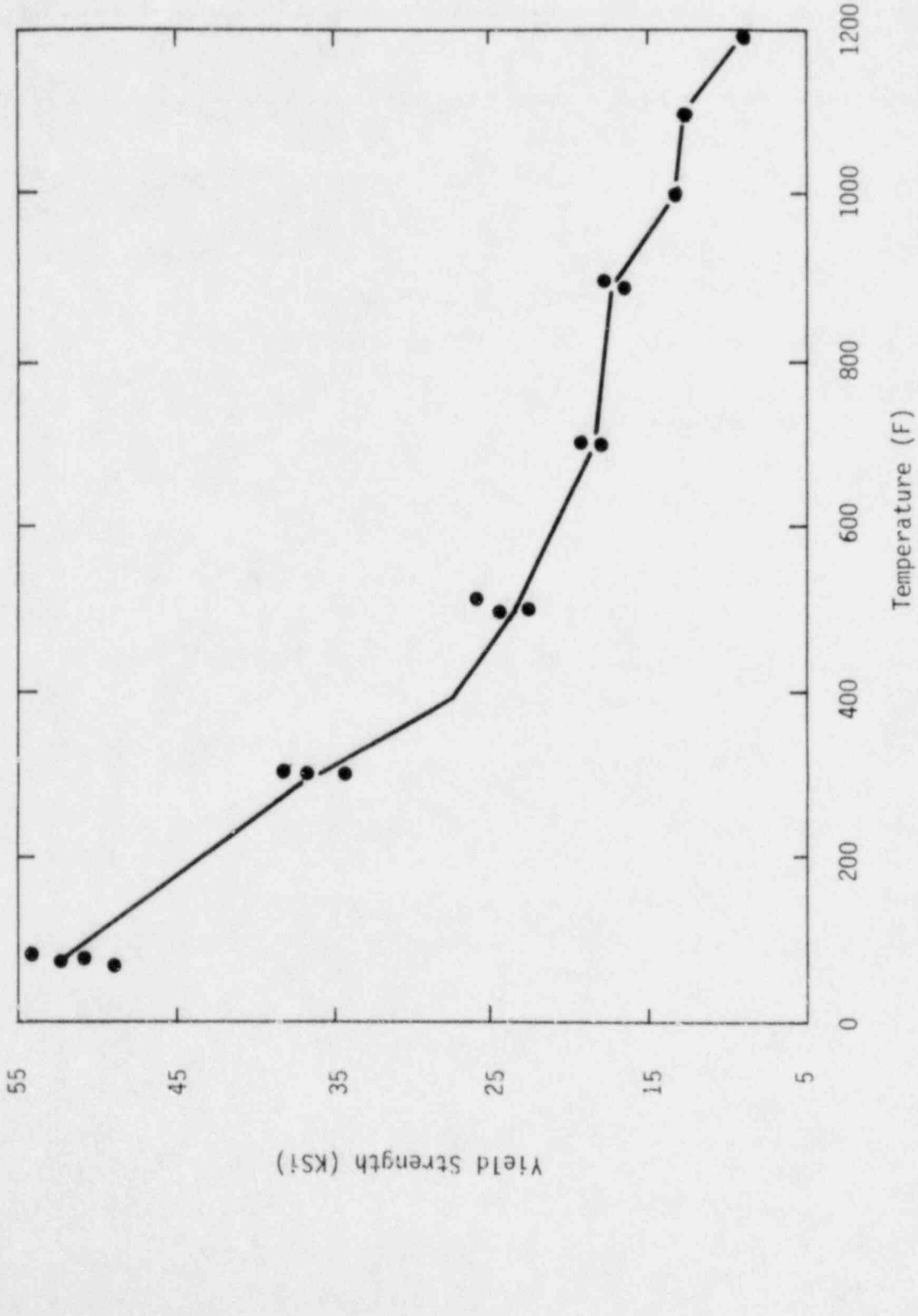
u = ovality = $\frac{OD_{max} - ID_{min}}{4}$

Equations 1 and 2 were used to evaluate the cladding deformation by comparing the critical collapse pressure with external pressures imposed upon the cladding. In performing these calculations, certain physical properties are required which require some assumptions about the cladding.

The cladding is assumed to be annealed. The peak temperatures measured during L2-3 were 852 K for module 2, 874 K for module 4, and 866 K for module 6. Instantaneous annealing temperatures for LOFT cold-worked cladding vary from 922 K based upon microhardness[3] to 866 K based upon microstructures.[4] The temperatures determined during L2-3 for the peripheral modules are sufficiently high to permit the assumption of annealed cladding. The yield strength used in Equation 2 is based upon annealed cladding and is shown in Figure 1 as a function of temperature.[5,6]

The dimensions of the cladding used in this calculation are 10.69 mm OD (0.4210 in.), 9.48 mm ID (0.3732 in.) and 0.605 mm (0.0238 in.) wall. A minimum wall thickness of 0.605 mm (0.0238 in.) is assumed with the constraint (based upon specifications) that the ID is 9.48 mm ± 0.0254 mm (0.3734 in. ± 0.001 in.). From this ID and wall thickness, the OD is 10.69 mm (0.4210 in.).

The ovality used in Equation 2 is based upon the difference between the maximum OD and minimum OD. The permissable ovality in zircaloy is 0.051 mm (0.002 in.).[7] For these calculations, ovalities of 0.041 mm (.0016 in.), 0.076 mm (.003 in.), and 0.127 mm (0.005 in.) were used to evaluate the effect of ovality.


Yield Strength (KSi)
55
45
35
25
15
5
0
200
400
600
800
1000
1200
Temperature (F)

III. Results

Assuming the cladding is free standing, the critical collapse pressures at 394 K (250^{0}F) are for 0.041 mm (0.0016 in.) ovality-25.51 MPa (3700 psig), for 0.076 mm (0.003 in.) ovality-22.70 Mpa (3293 psig), and for 0.127 mm (0.005 in.) ovality-20.01 MPa (2902 psig). For a 21.55 MPa (3125 psig) hydrostatic test at 394 K (250^{0}F), and with ovalities near the specified values for as-received tubing, the calculations show that the fuel rod cladding will not collapse. However, if the ovality has exceeded the value for permissable ovality as a result of creep-down during power operation, the cladding will collapse.

A calculation was performed to determine if the annealed cladding could withstand normal operating power conditions of 14.82 MPa (2150 psig) coolant pressure with a peak cladding temperature of 664 K (735^{0}F). The calculations show that at 664 K (735^{0}F), the critical collapse pressure for annealed cladding is 12.78 MPa (1853 psig) with an initial ovality of 0.041 mm (0.0016 in.). With the coolant pressure of 14.82 MPa (2150 psig) and the annealed cladding, the coolant pressure is sufficient to collapse the cladding.

The ovality of the cladding after 14.82 MPa (2150 psig) and a design limit of 664 K (735^{0}F) will certainly be worse than the specified value, so that an ovality of .127 mm (0.005 in.) is reasonable to expect so that a hydrostatic test at 21.55 MPa (3125 psig) and 394 K (250^{0}F) will contribute to further cladding collapse.

IV. References

1. R. A. Pugh and K. P. Galbraith, Standard LOFT Fuel Rod Design Report, JN-72-4 (March 2, 1972).

2. K. P. Galbraith and W. C. Gallaugher, Standard LOFT Fuel Rod Design Report Addendum I, JN-72-5 (March 17, 1972).

3. D. O. Hobson, The Effect of Thermal Transients on the Hardness of Zircaloy Fuel Cladding, ORNL-NUREG-TM-26 (June 1976).

4. C. S. Olsen, Postirradiation Metallurgical Techniques to Estimate LOFT Peak Cladding Temperatures, LTR 1111-54, Rev. 1 (February 15, 1979).

5. C. C. Busby and K. B. March, High-Temperature Deformation and Burst Characteristics of Recrystallized Zircaloy-4 Tubing, WAPD-TM-900 (January 1970).

6. Capsule Driver Core Inspection and Test Data, Westinghouse (December 1968).

7. ASTM-B 353-69, Standard Specification for Wrought Zirconium and Zirconium Alloy Seamless and Welded Tubes for Nuclear Service.