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ZIRCALOY CLADDING DEFORMATION IN A STEAM ENVIRONMENT WITH TRANSIENT HEATING*

R. H. Chapman, J. L. Crowley, A. W. Longest and G. Hofmann†

Engineering Technology Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

MASTER

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†Guest Scientist from Karlsruhe Nuclear Research Center for period August 1975 to August 1977.

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R. H. CHAPMAN, MANAGER
MULTIROD BURST TEST PROGRAM
OAK RIDGE NATIONAL LABORATORY

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BY

R. H. CHAPMAN, J. L. CROWLEY,
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TEST PARAMETERS SIMULATE NUCLEAR FUEL RODS AND LOCA CONDITIONS

- INTERNAL ELECTRICAL HEATER
- 915 mm "UNIFORM" HEATED LENGTH
- 25–30°C/sec CLAD HEATING RATE
- 47 cm^3 GAS VOLUME
- SUPERHEATED STEAM ENVIRONMENT
- 770–19150 kPa BURST PRESSURE RANGE
- 1170–690°C BURST TEMPERATURE RANGE

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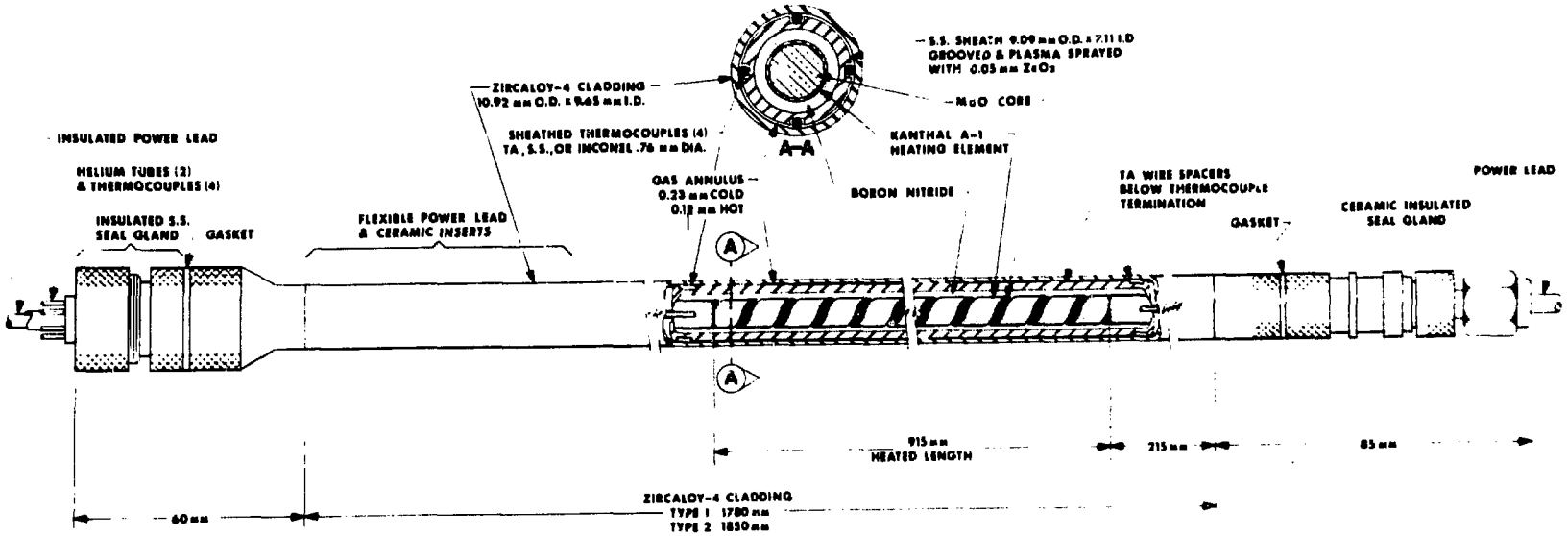
ELECTRICALLY HEATED TEST ASSEMBLY PROVIDES REALISTIC SIMULATION OF NUCLEAR FUEL ROD



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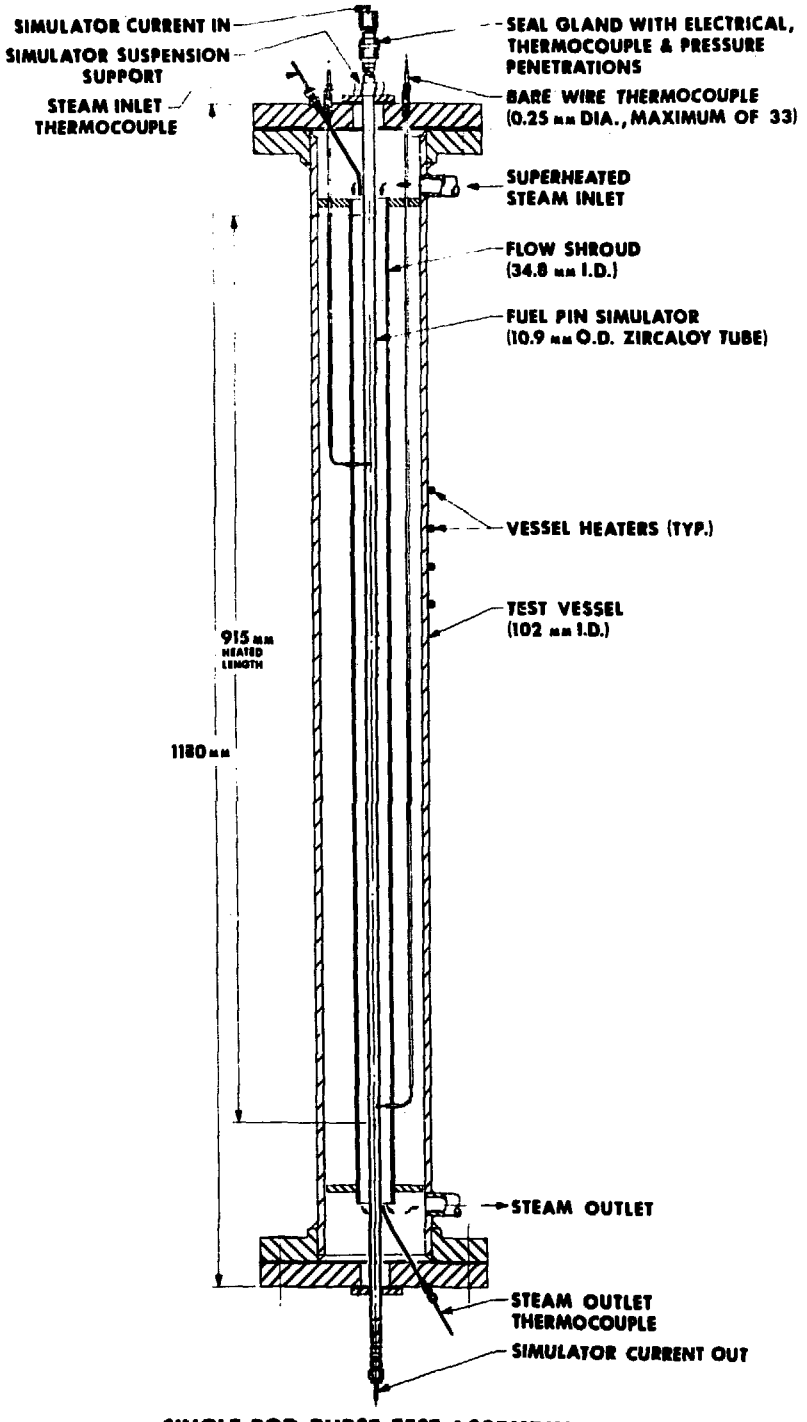
TESTS CONDUCTED IN CONTROLLED ENVIRONMENT WITH WELL DEFINED BOUNDARY CONDITIONS



SINGLE ROD BURST TEST ASSEMBLY

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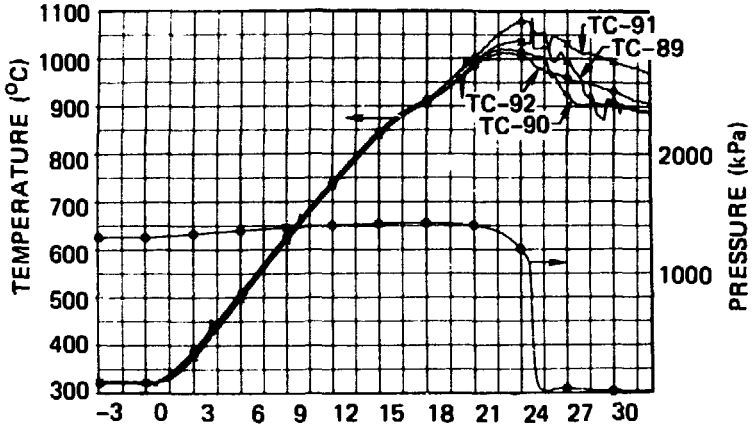
TRANSIENT TEST INCLUDES PRESSURE AND TEMPERATURE VARIATIONS



SR-13 TRANSIENT TEST

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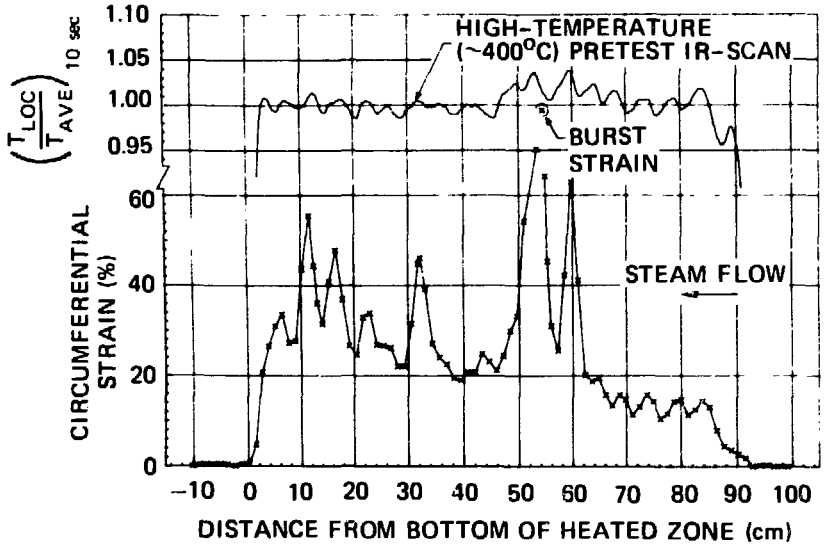
ZIRCALOY DEFORMATION IS SENSITIVE TO LOCAL TEMPERATURE VARIATIONS



SR-13 DEFORMATION PROFILE

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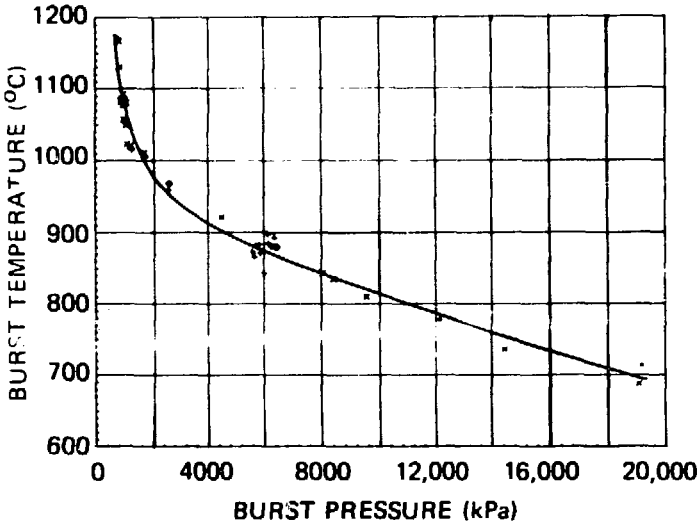
BURST TEMPERATURE CORRELATES WITH BURST PRESSURE AND IS SENSITIVE TO SMALL DIFFERENCES AT LOW PRESSURE



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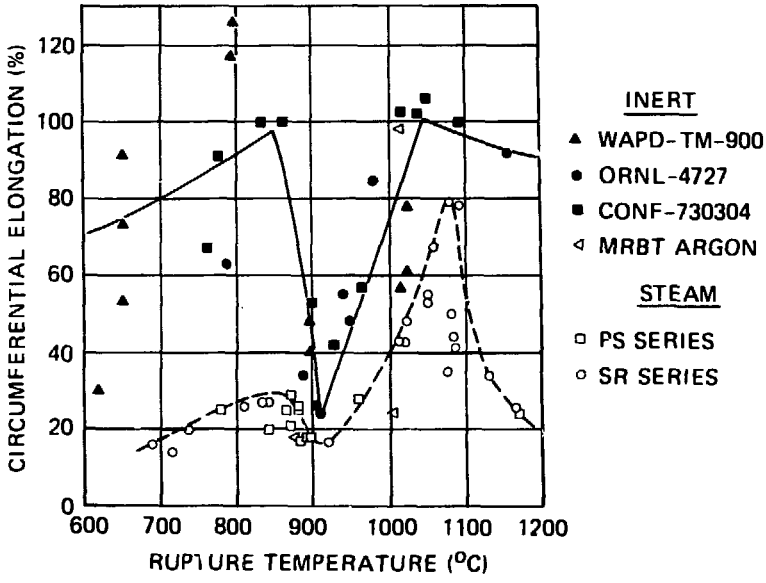
DEFORMATION WITH INDIRECT HEATING IS LESS IN STEAM THAN IN AN INERT ENVIRONMENT



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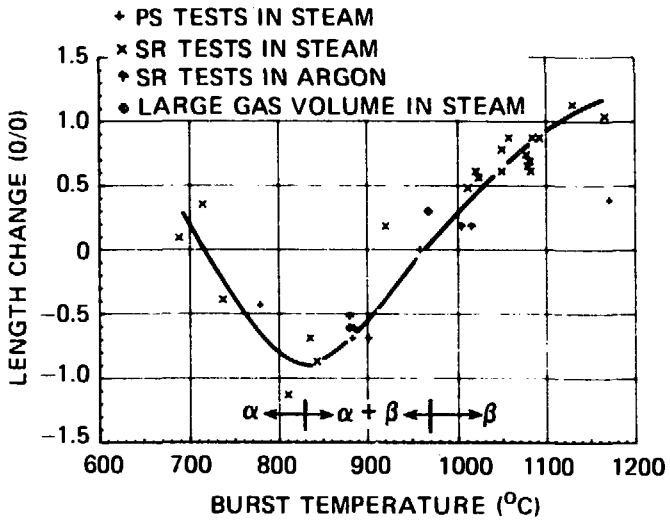
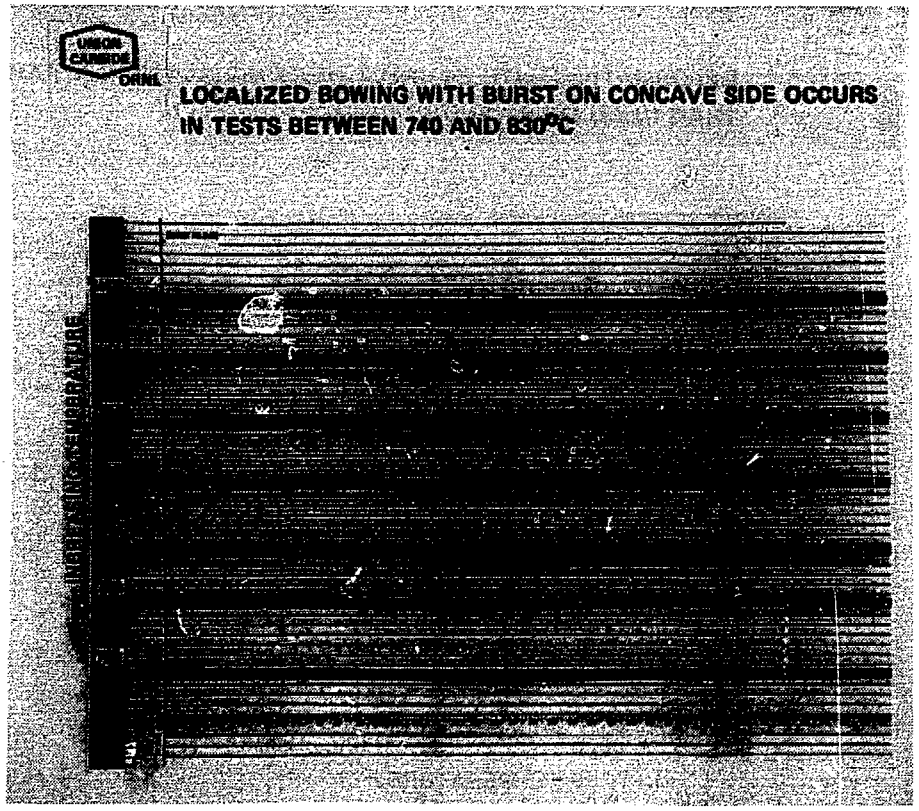
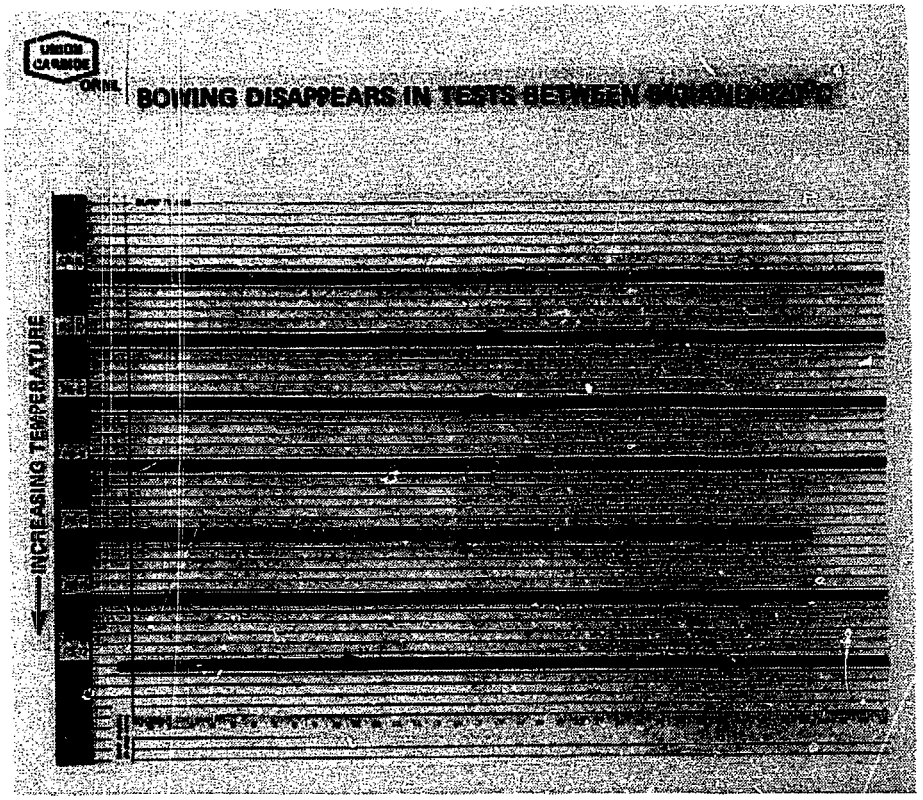
TUBE AXIAL DEFORMATION DEPENDS ON TEST TEMPERATURE



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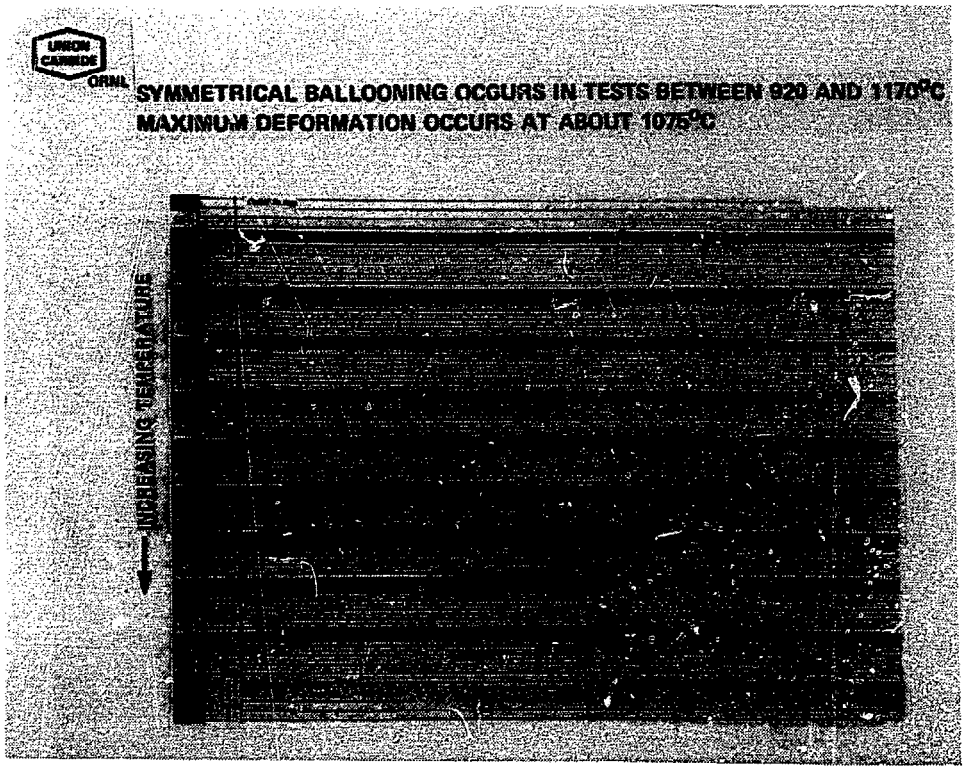
INCREASING TEMPERATURE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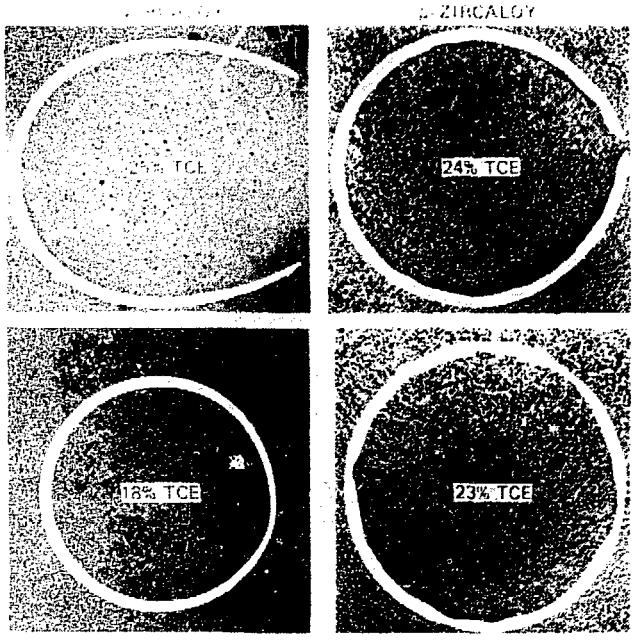
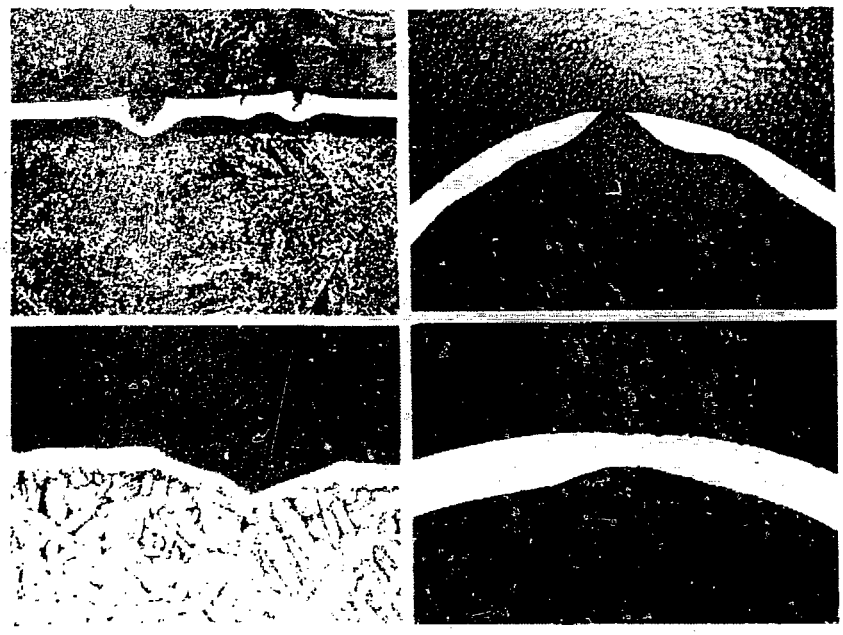
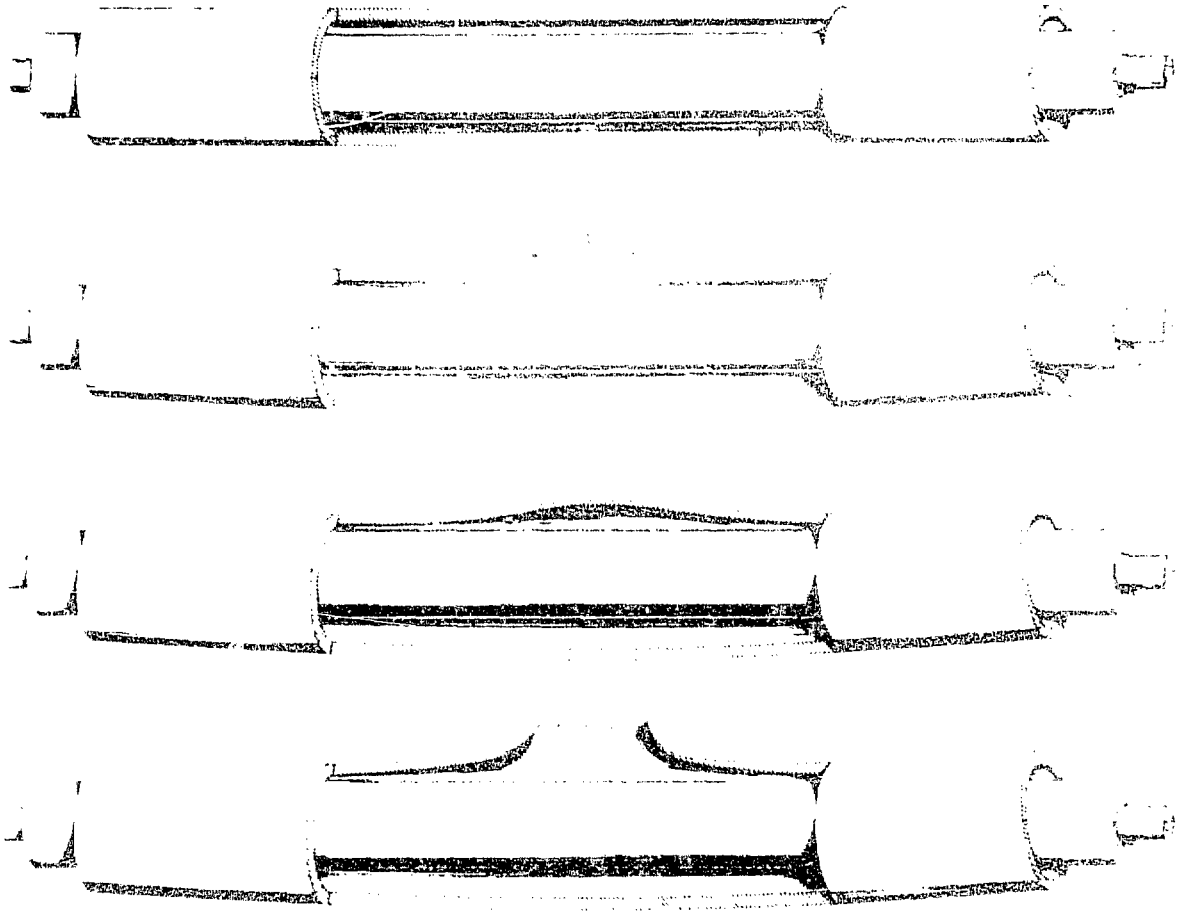
SYMMETRICAL BALLOONING OCCURS IN TESTS BETWEEN 920 AND 1170°C
MAXIMUM DEFORMATION OCCURS AT ABOUT 1075°C
INCREASING TEMPERATURE

...ERENT MECHANISMS CAUSE LOCAL DEFORMATION
AND ... TOTAL CIRCUMFERENTIAL ELONGATION



...DEFORMATION OCCURS IN β-ZIRCALOY BY OXIDE CRACKS
... AND WIDENING WITH SIMULTANEOUS NECKING ON
... SURFACE UNDER CRACKS





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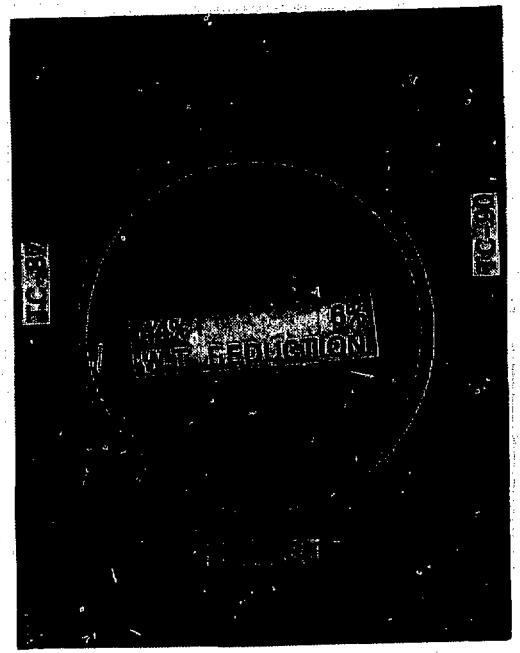
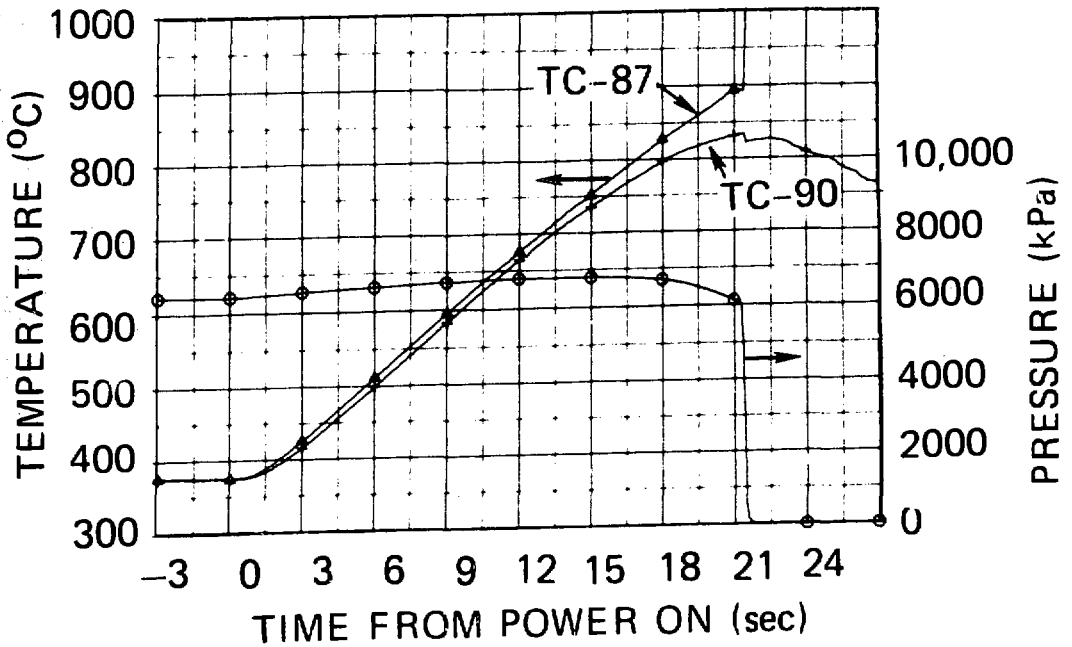
DEFORMATION CORRELATES WITH LOCAL TEMPERATURE





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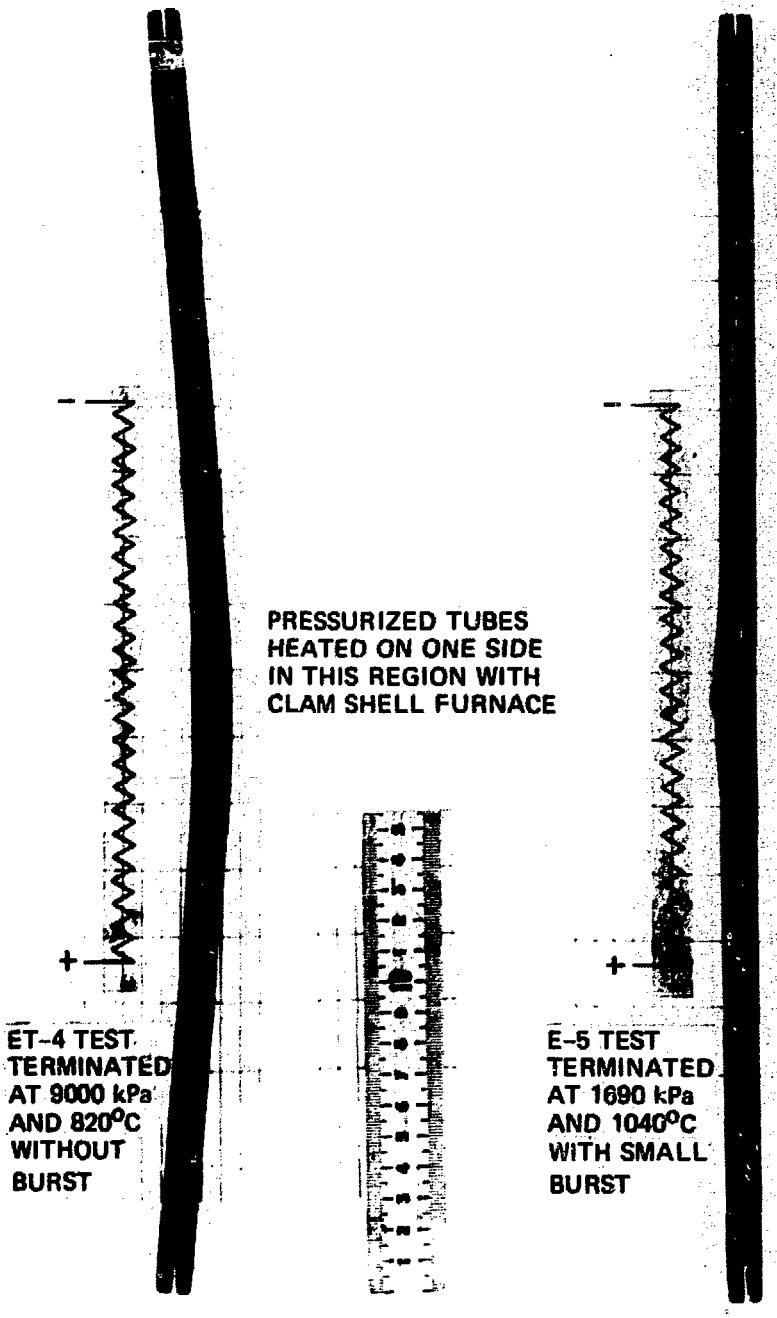
TEMPERATURE GRADIENTS ARE SUFFICIENT TO CAUSE BOWING IN DEFORMING α–ZIRCALOY TUBES



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SUMMARY

ZIRCALOY-4 TUBES RAMP HEATED IN STEAM AT 25-30°C/S WITH INTERNAL HEATERS SHOW

- IN α-ZIRCALOY
  - TEXTURE EFFECTS AND TEMPERATURE GRADIENTS LOCALIZE DEFORMATION
  - DEFORMATION SENSITIVE TO SMALL TEMPERATURE VARIATIONS
  - THE MORE UNIFORM THE TEMPERATURE THE GREATER THE DEFORMATION

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SUMMARY

- IN $\alpha + \beta$-ZIRCALOY
  - DEFORMATION MECHANISMS NOT YET CLARIFIED
  - MINIMUM DEFORMATION

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SUMMARY

- IN β–ZIRCALOY
  - TEMPERATURE GRADIENTS LESS IMPORTANT
  - CRACKS IN OXIDE AND NECKING OF INSIDE TUBE SURFACE LOCALIZE DEFORMATION
  - DEFORMATION IS FUNCTION OF TIME VS TEMPERATURE PARAMETERS
  - MAXIMUM DEFORMATION OCCURS ABOUT $1075^{o}C$

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SUMMARY

- LESS DEFORMATION THAN FOR UNIFORMLY HEATED TUBES IN INERT ENVIRONMENT
- LARGE BALLOONING ($\geqslant$ 32% TCE) DOES NOT OCCUR OVER EXTENDED LENGTHS (L/D $\lesssim$ 20)
- CORRELATION OF BURST TEMPERATURE–PRESSURE DATA WITH ANALYTICAL FUNCTION FOR $800 \leqslant P \leqslant 20000$ KPA AND $1170 \geqslant T \geqslant 690^{o}C$