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AN ASSESSMENT OF THE INFLUENCE OF SURFACE THERMOCOUPLES ON THE BEHAVIOR OF NUCLEAR FUEL RODS DURING A LARGE BREAK LOCA

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A second series of thermocouple effects tests[1] (TC-3) is being conducted in the Power Burst Facility (PBF) at the Idaho National Engineering Laboratory (INEL). These tests are designed to evaluate the influence of external surface thermocouples on the behavior of nuclear fuel rods during a large break loss-of-coolant accident (LOCA) experiment, which includes partial or total rod rewet during blowdown. Questions have been raised with regard to possible effects[2-4] of surface thermocouples on the thermal behavior of in-pile and out-of-pile test rods. This issue was highlighted by the recent large break LOCA test results obtained at the Loss-of-Fluid Test[5] (LOFT) facility at the INEL where measured cladding temperatures were significantly lower than expected and a core rewet was measured early in the system depressurization. The key questions are: (a) did the external thermocouples accurately measure cladding temperatures, and (b) did the external thermocouples cause the core rewet early in the depressurization?

The TC-3 test series, currently being conducted at the PBF, is an extension of the TC-1[1] tests with four LOFT-type fuel rods contained in individual flow shrouds. The fuel rods are symmetrically positioned within a test train in the PBF in-pile tube in an environment similar to the LOFT test environment. Two rods are each instrumented with four LOFT cladding outside surface thermocouples, with junctions located near the high power region of the fuel rods. All four rods are instrumented with internal thermocouples, with junctions at the same axial level as the external thermocouples. By comparing the response of the internal and external thermocouples, the behavior of fuel rods during a LOCA with and without external thermocouples is being examined.

Surface thermocouples were found to influence fuel rod cladding temperatures during both the blowdown and reflood phases of the first test of this series, TC-3A. During blowdown, the TC-3A results verify the earlier TC-1 results with the surface thermocouples (a) slightly delaying the onset of critical heat flux (CHF) and (b) slightly improving cladding surface heat transfer. Peak temperatures measured during the TC-3A blowdown were reduced by about 10% (about 100 K) due to the presence of external thermocouples. Similarly, peak temperatures measured during the TC-1 blowdowns were generally about 100 K lower due to the combined thermocouple effects of delayed CHF and improved cladding surface heat transfer. The surface thermocouples also influenced the cladding quench and rewet times during the reflood phase of both the TC-1 and TC-3A tests. In general, the fuel rods with external thermocouples quenched 3 to 12 seconds before the fuel rods without external thermocouples. In addition, some external thermocouples did not properly measure the cladding temperature response as was evident by momentary quenching and reheating of the surface thermocouples prior to the actual rod quench.

The TC-3 test series extends the results of TC-1 by providing data for evaluation of thermocouple effects during the apparent two-phase rewet that occurred early in the LOFT blowdowns. Based on TC-3A data, the external thermocouples did not significantly influence the fuel rod thermal response during the blowdown quench. The cooling rates of both the fuel and cladding during the blowdown quench were similar for the rods with and without surface thermocouples. However, the external thermocouples did not exactly measure the cladding surface temperature. The preliminary test data during the TC-3 blowdown quench indicates that the external thermocouples quenched about four times faster than the cladding quenched. The results also indicate that thermal decoupling of the cladding and fuel was apparently significant, allowing the cladding to rapidly quench during the blowdown, regardless of the presence of external thermocouples. This thermal decoupling of fuel and cladding demonstrates the importance of in-pile experiments or out-of-pile experiments where the fuel-to-cladding gap is properly simulated.

Future PBF thermocouple tests will be designed to further quantify the influence of surface thermocouples during a blowdown quench with variations in the degree of quench which should encompass the range of conditions that occurred in the LOFT L2 test series.

REFERENCES

1. T. R. Yackle, et al., Loss-of-Coolant Accident Test Series Test TC-1 Test Results Report, EGG-TFBP-5068, May 1980.

2. G. Class, et al., "Concerning the Pretests Conducted at COSIMA for the Influence of Outside Mounted Thermocouples", KfK Report 06.01.07P03A, PNS-Nr., August 1979 pp. 402-79.

3. R. C. Gottula, LOFT Transient (Blowdown) Critical Heat Flux Tests, TREE-NUREG-1240, April 1978.

4. G. L. Shires, et al., An Experimental Study of the Effect of External Thermocouples in Rewetting During Reflood, AEEW-R 1357, April 1980.

5. D. L. Reider, Quick Look Report on LOFT Nuclear Experiment L2-3, QLR-L2-3, Project No. P394, May 1979.

AN ASSESSMENT OF THE INFLUENCE OF SURFACE THERMOCOUPLES ON THE BEHAVIOR OF NUCLEAR FUEL RODS DURING A LARGE-BREAK LOCA (TC-3 RESULTS)

by
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OUTLINE

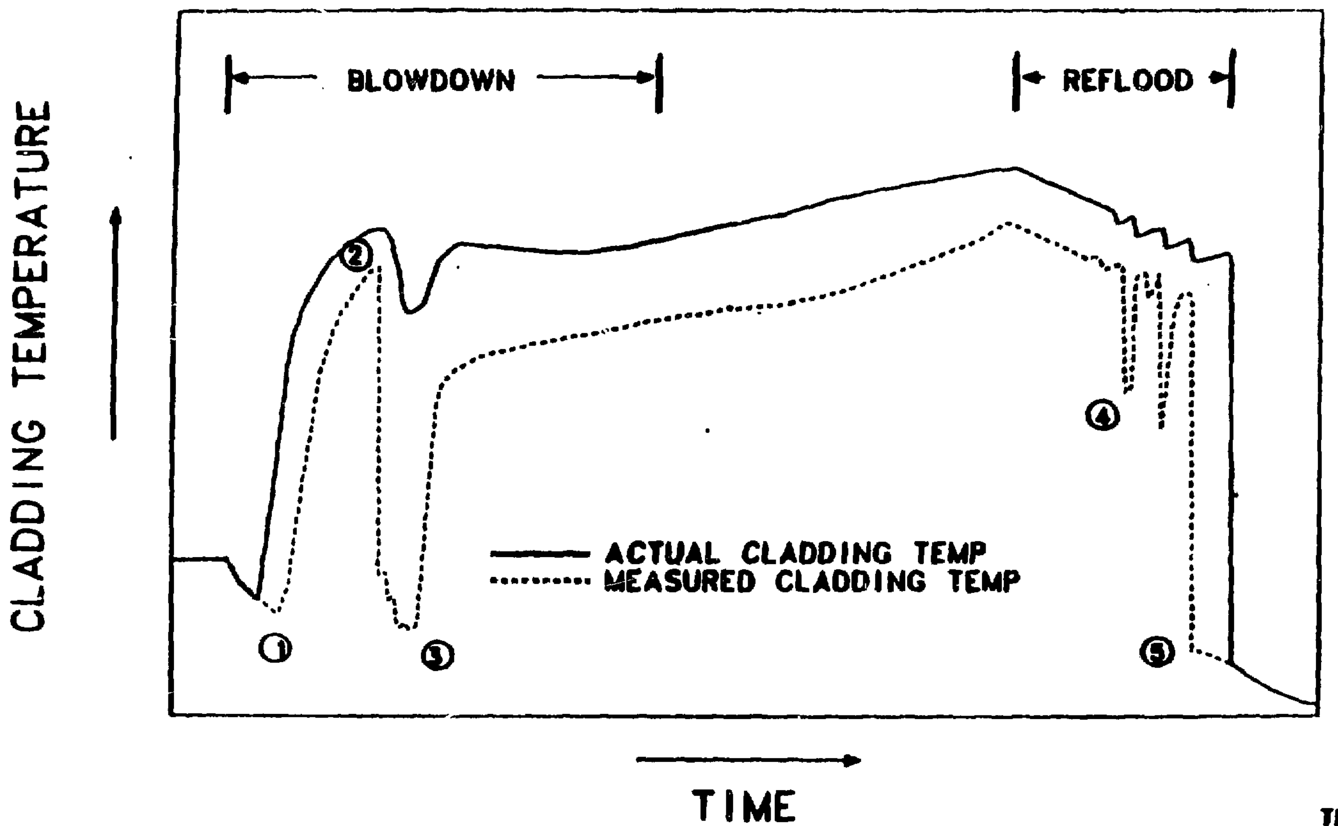
- OBJECTIVES
- TEST DESIGN AND CONDUCT
- TC-3 THERMOCOUPLE EFFECTS
- CONCLUSIONS

TRV-2

TC-3 TEST OBJECTIVES

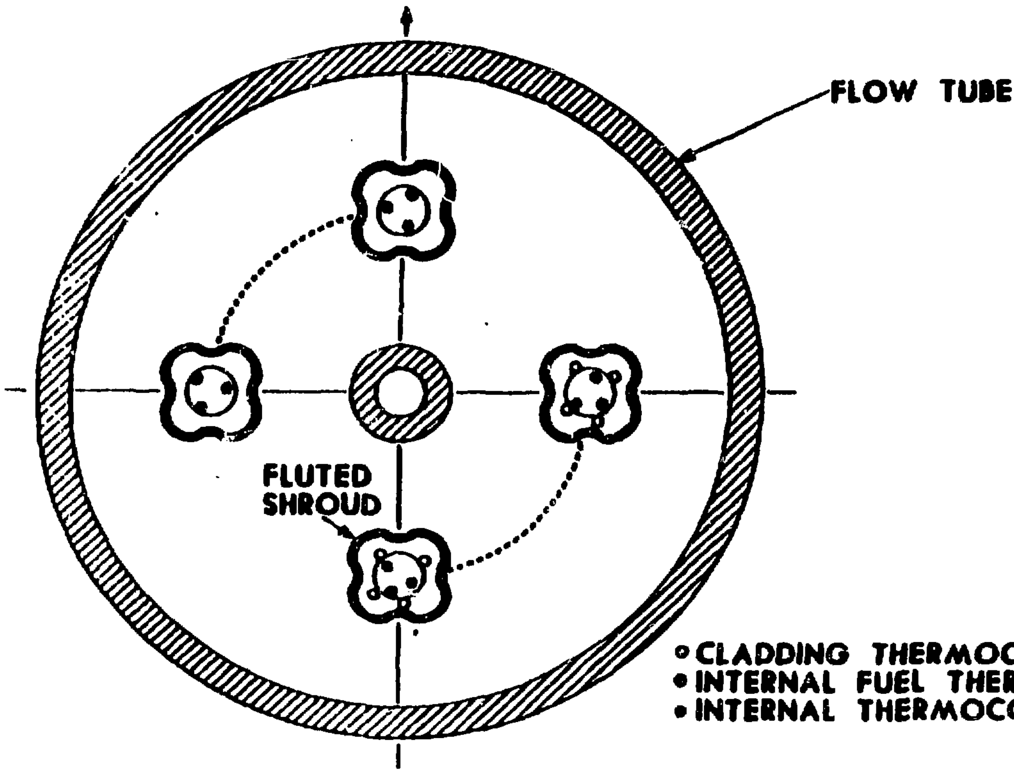
- DO CLADDING SURFACE THERMOCOUPLES INFLUENCE FUEL ROD THERMAL BEHAVIOR DURING A LOCA?
- DO CLADDING THERMOCOUPLES ACCURATELY MEASURE CLADDING TEMPERATURES?

LOCA THERMOCOUPLE EFFECTS



TRY-5

TC-3 GEOMETRY



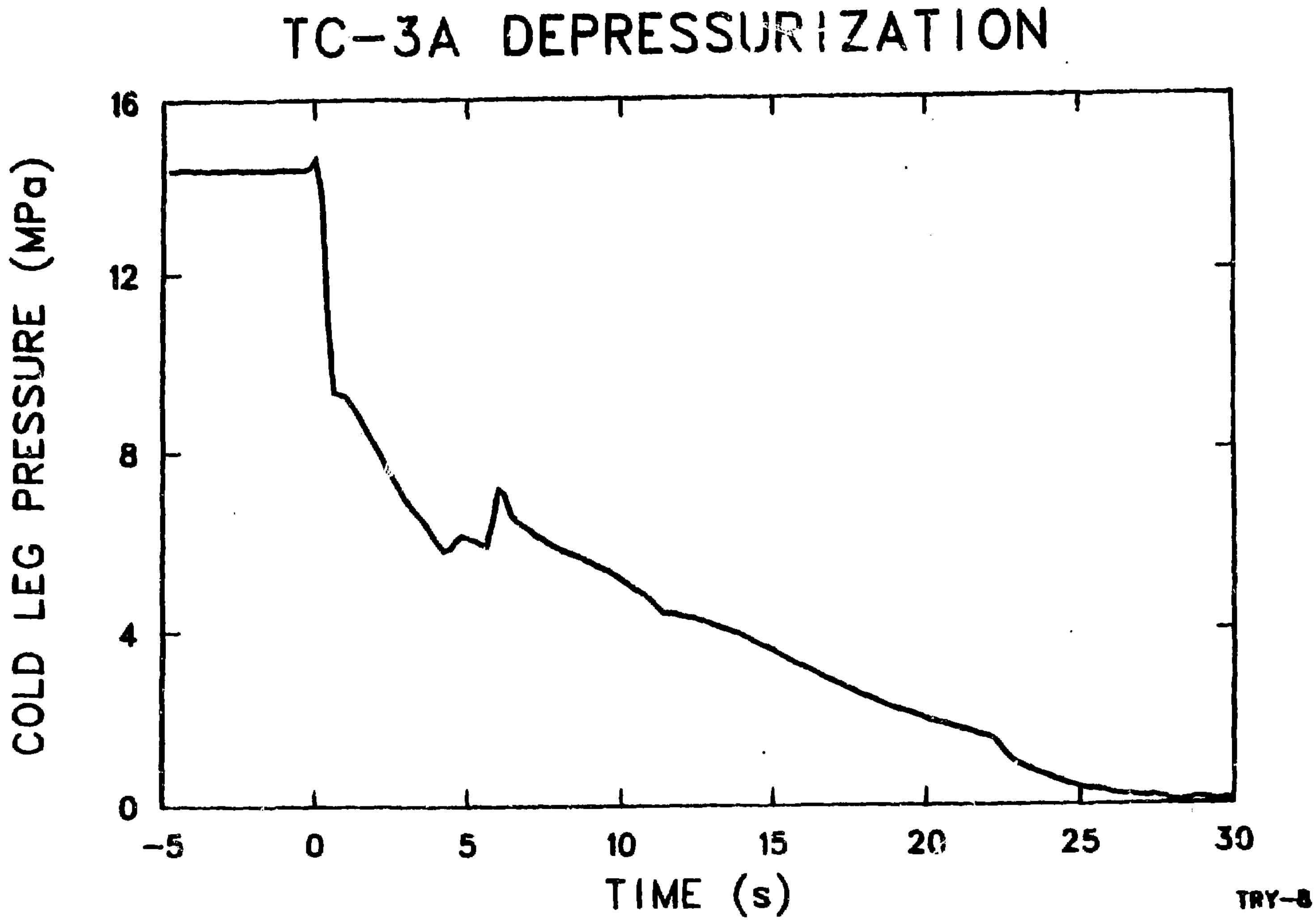
∘ CLADDING THERMOCOUPLES
• INTERNAL FUEL THERMOCOUPLES (NOT WELDED)
• INTERNAL THERMOCOUPLES (WELDED)

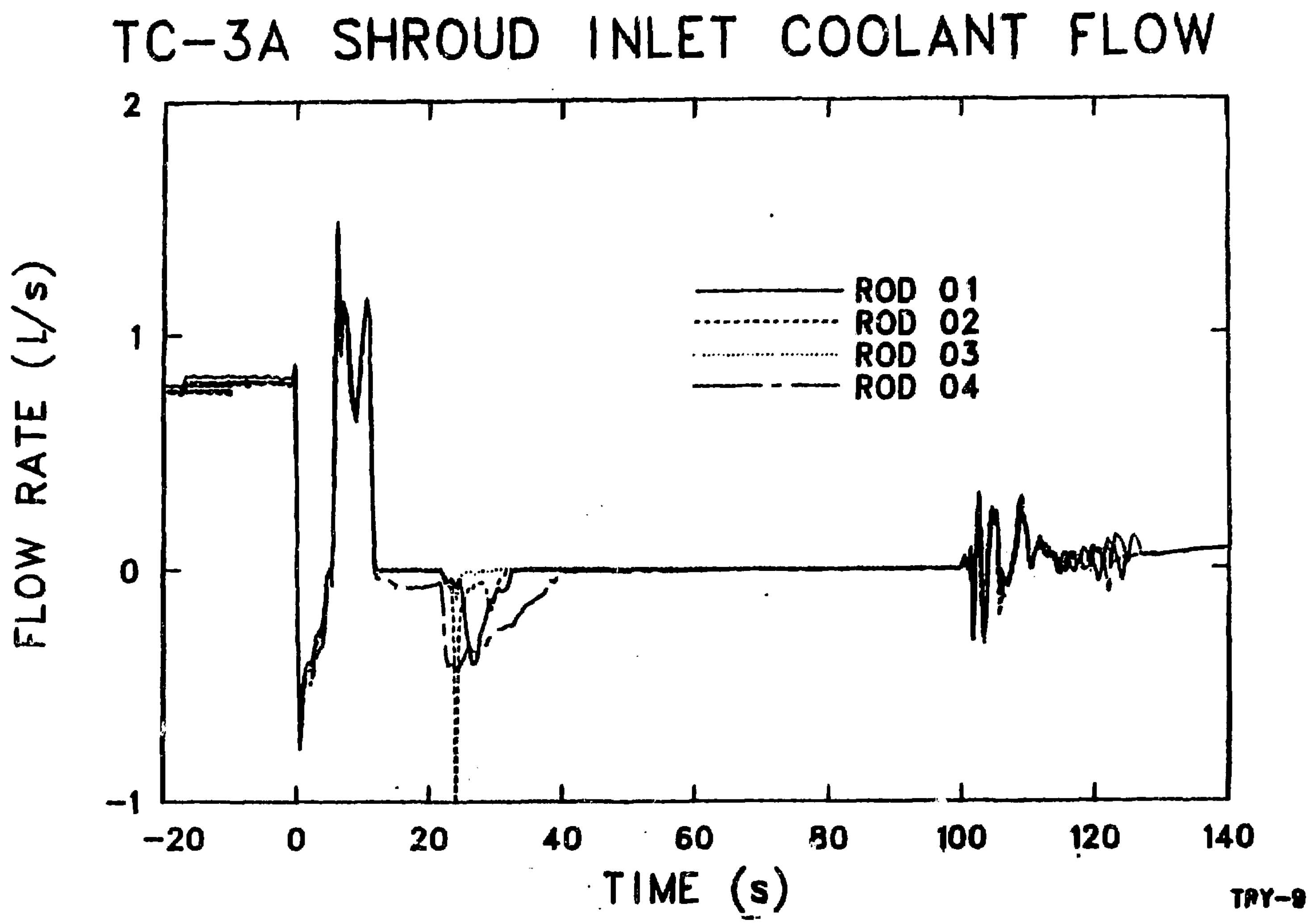
TRY-6

TC INITIAL CONDITIONS

POWER	~50 kW/m
INLET TEMPERATURE	600 K
SYSTEM PRESSURE	15.5 MPa
COOLANT FLOW	0.8 l/s

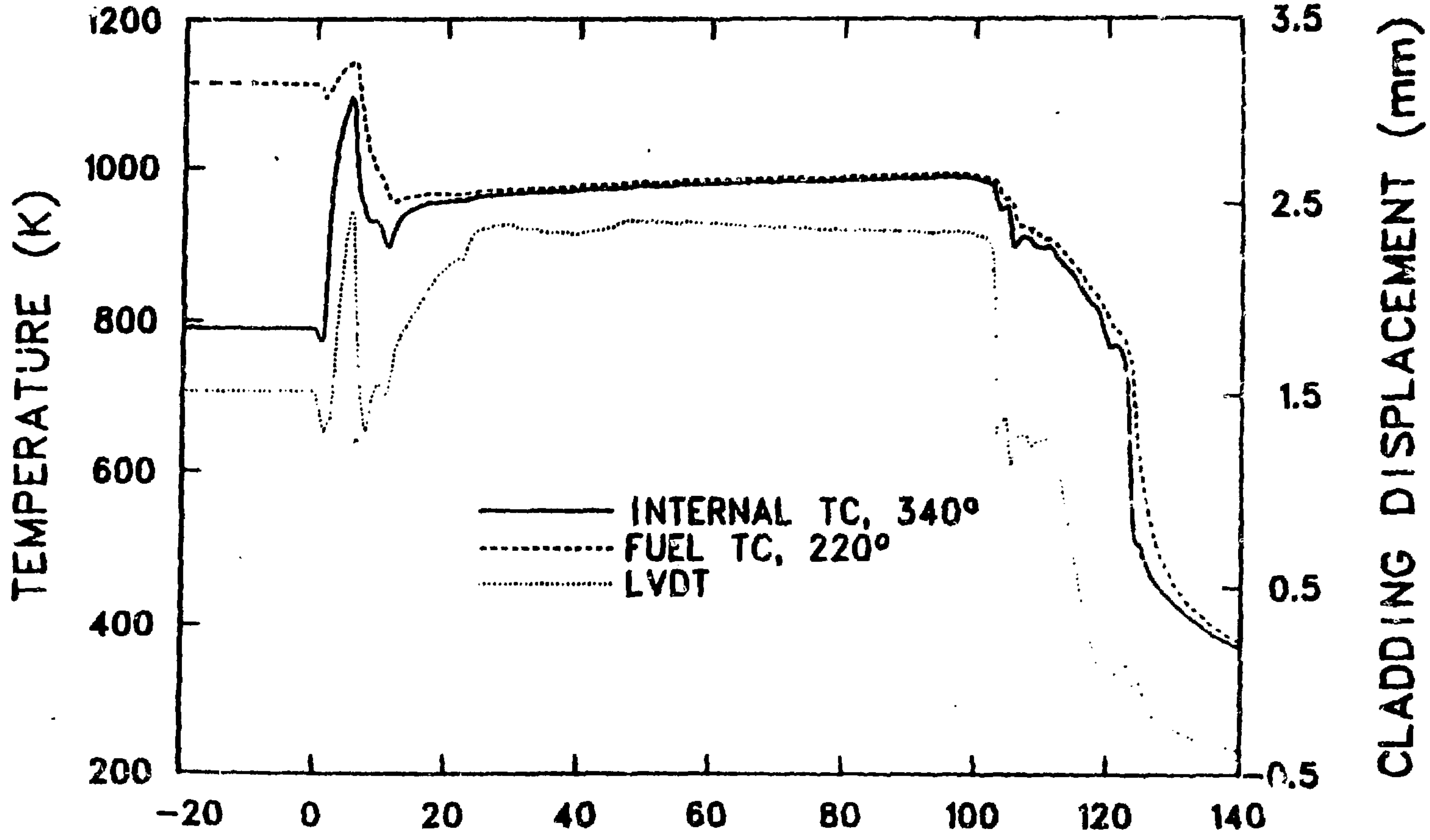
TRY-7


TC-3A DEPRESSURIZATION
COLD LEG PRESSURE (MPa)
16
12
8
4
0
-5
0
5
10
15
20
25
30
TIME (s)
TRY-8



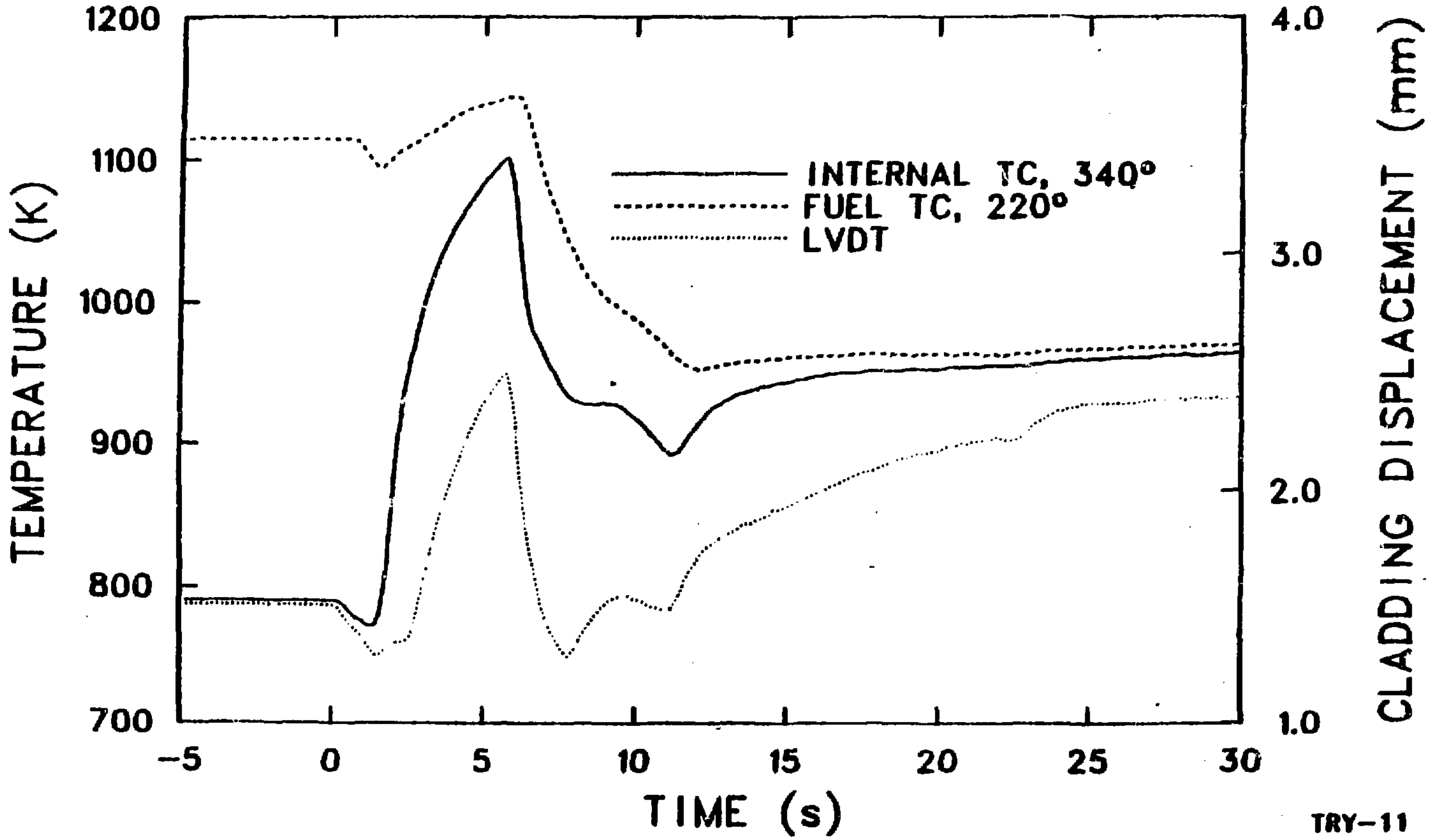
TC-3A SHROUD INLET COOLANT FLOW
FLOW RATE (L/s)
2
1
0
−1
ROD 01
ROD 02
ROD 03
ROD 04
−20
0
20
40
60
80
100
120
140
TIME (s)
TRY-9

TC--3A ROD 1 WITHOUT SURFACE TCS

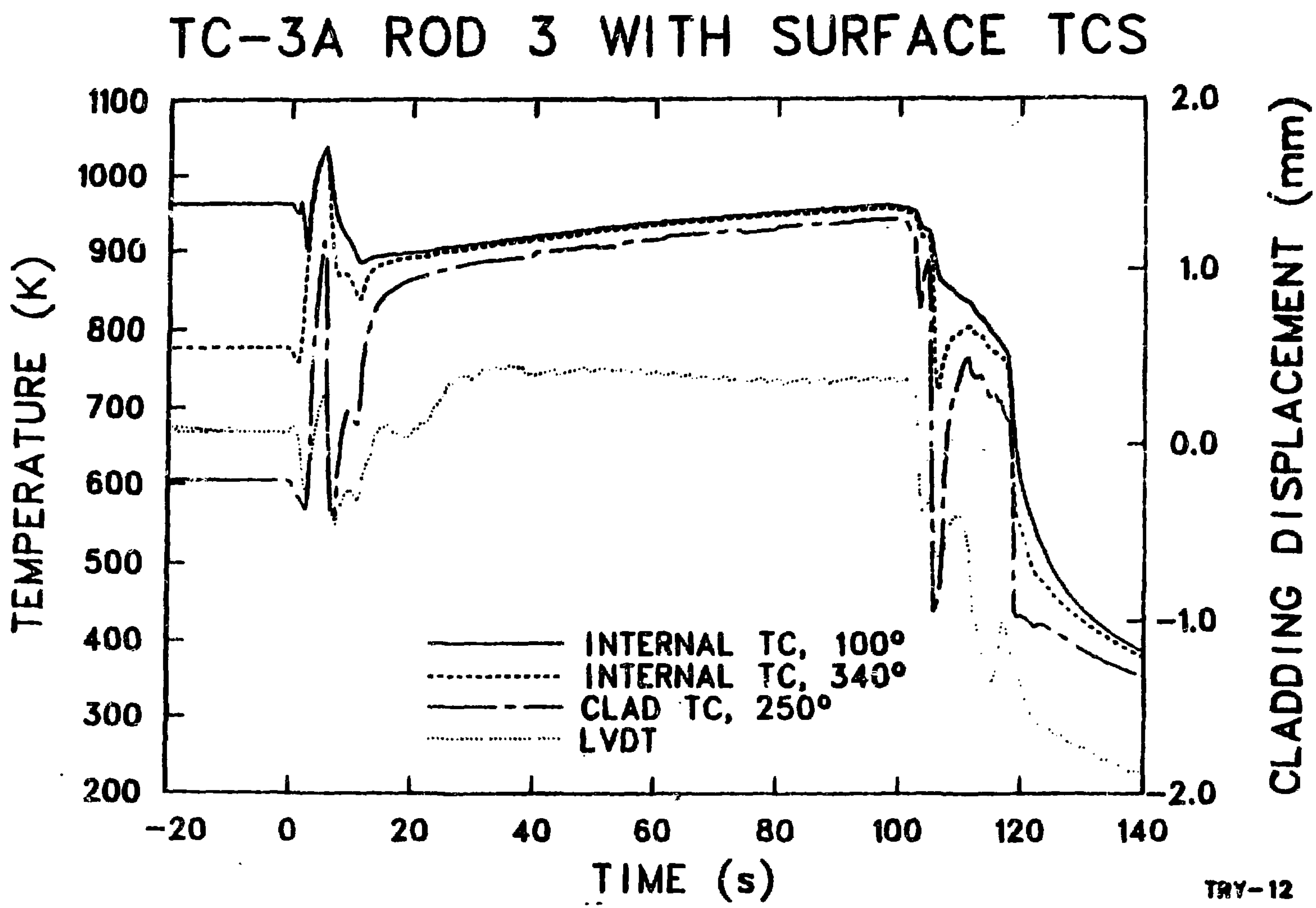


TRY-10

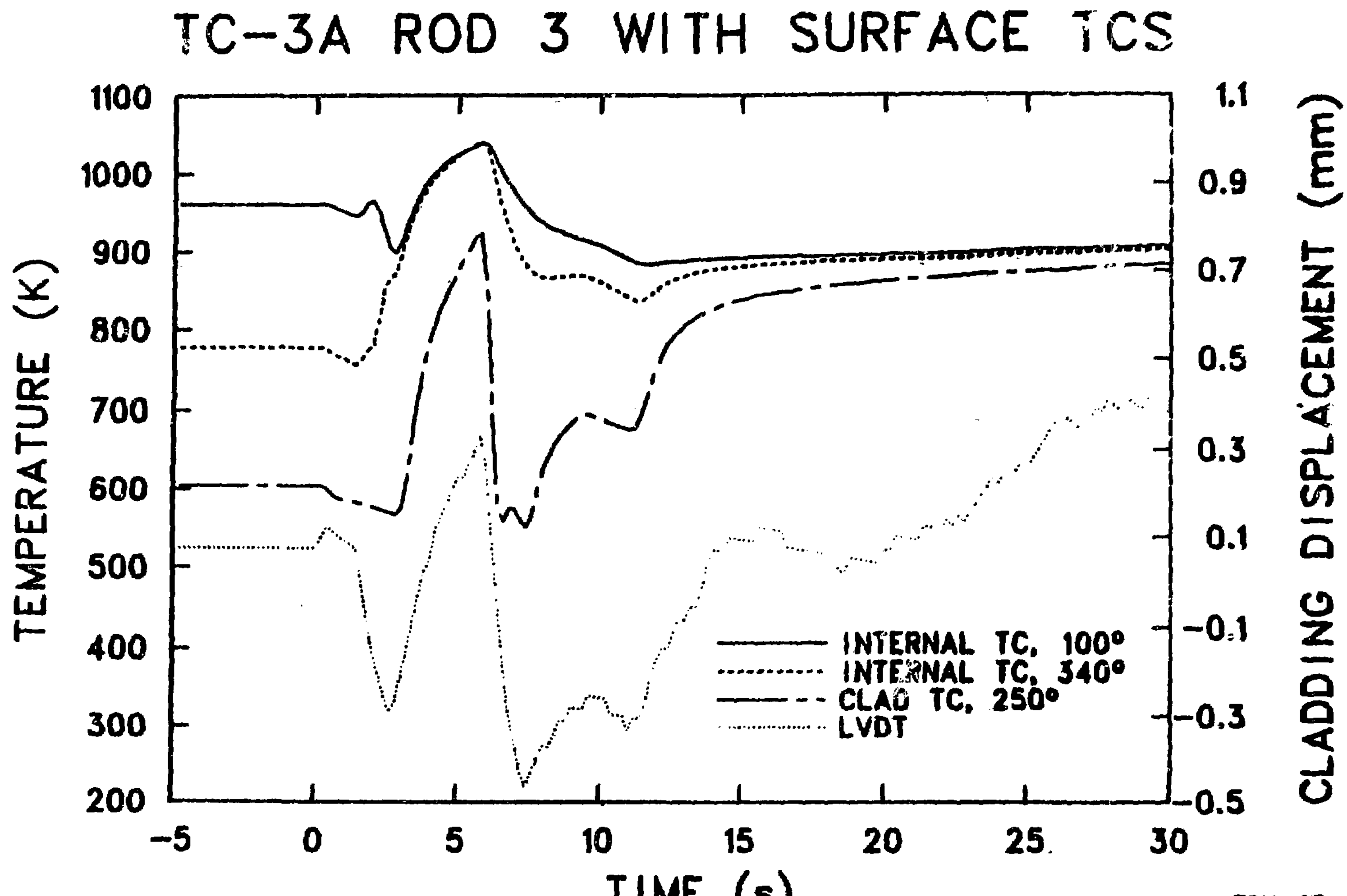
TC-3A ROD 1 WITHOUT SURFACE TCS



TRY-11


TC-3A ROD 3 WITH SURFACE TCS
TEMPERATURE (K)
1100
1000
900
800
700
600
500
400
300
200
CLADDING DISPLACEMENT (mm)
2.0
1.0
0.0
−1.0
−2.0
−20
0
20
40
60
80
100
120
140
TIME (s)
INTERNAL TC, 100°
INTERNAL TC, 340°
CLAD TC, 250°
LVDT

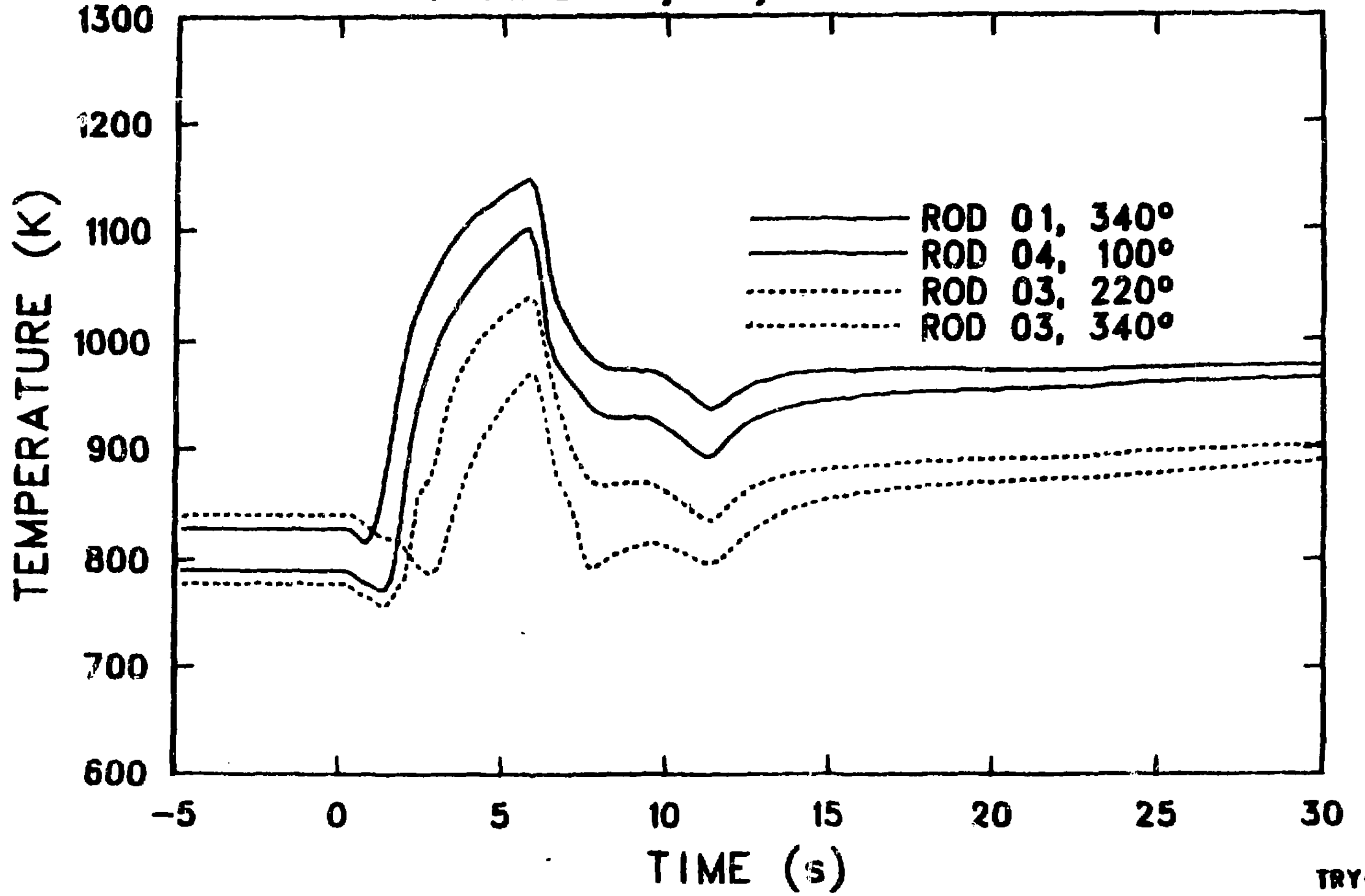
TRY-12



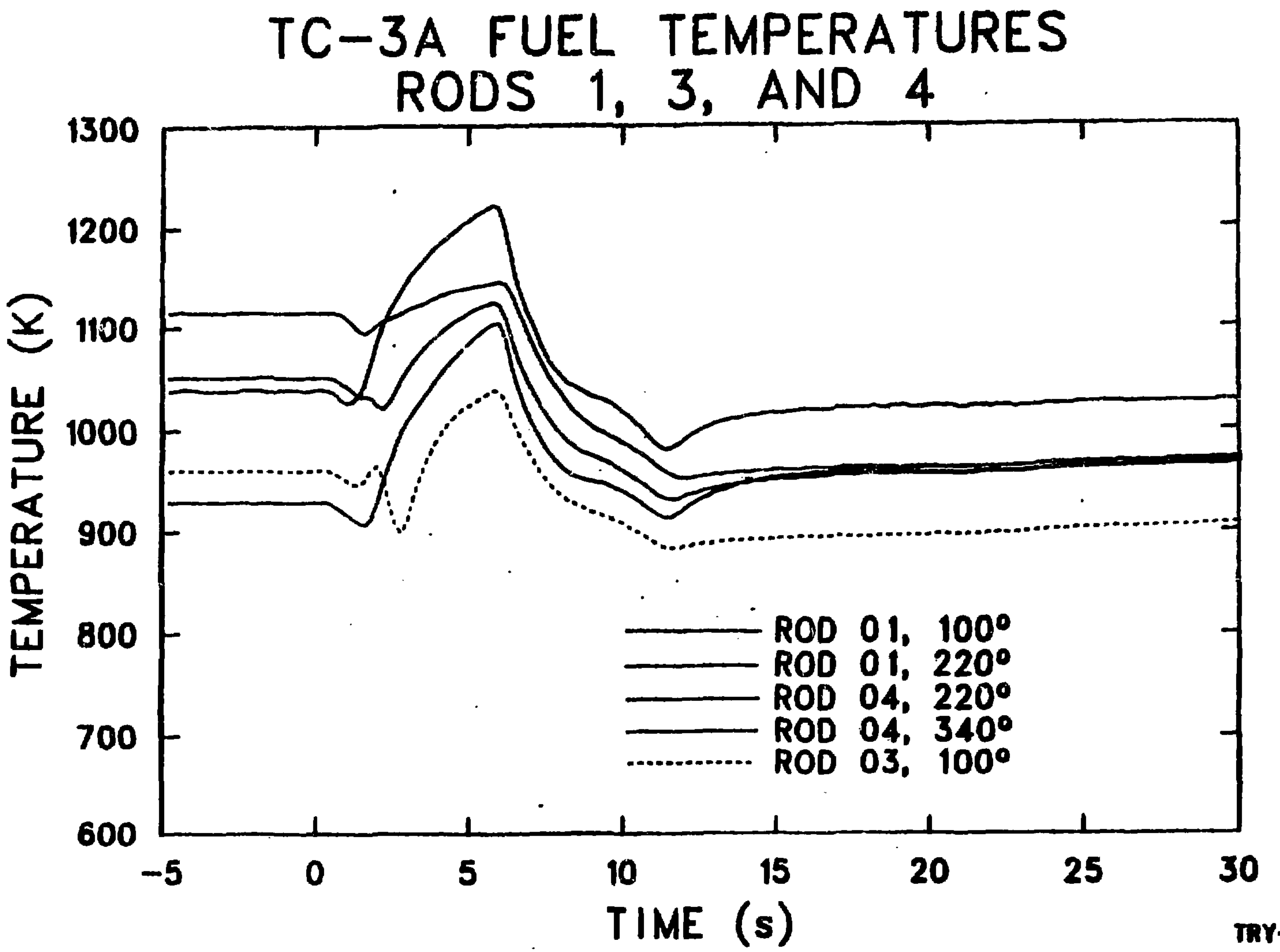
TC-3A ROD 3 WITH SURFACE TCS
1100
1000
900
800
700
600
500
400
300
200
TEMPERATURE (K)
1.1
0.9
0.7
0.5
0.3
0.1
−0.1
−0.3
−0.5
CLADDING DISPLACEMENT (mm)
−5
0
5
10
15
20
25
30
TIME (s)
INTERNAL TC, 100°
INTERNAL TC, 340°
CLAD TC, 250°
LVDT

TRY-13

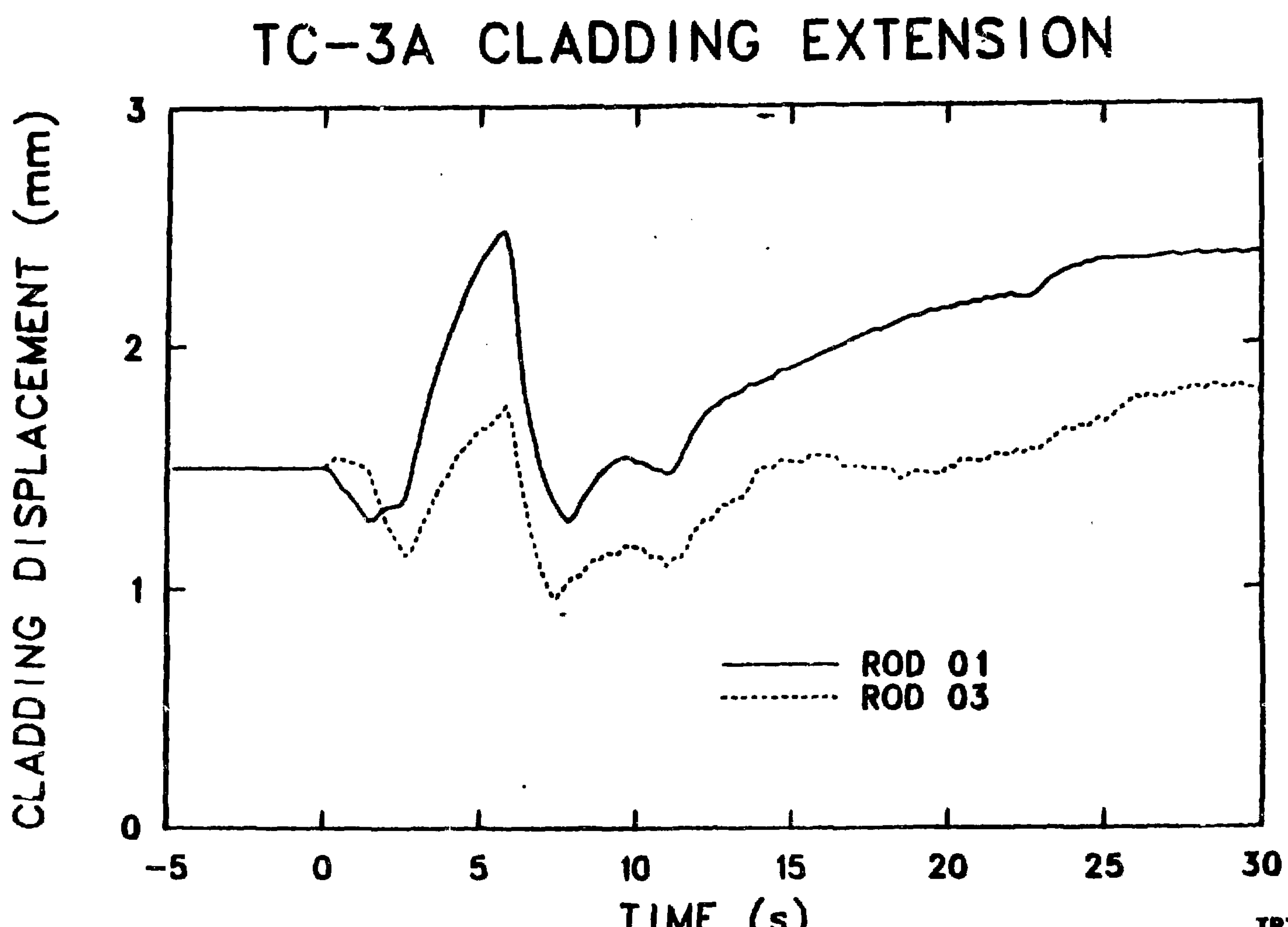
TC-3A INNER CLAD TEMPERATURES
RODS 1, 3, AND 4



TRY-14


TC-3A FUEL TEMPERATURES
RODS 1, 3, AND 4
TEMPERATURE (K)
1300
1200
1100
1000
900
800
700
600
-5
0
5
10
15
20
25
30
TIME (s)
ROD 01, 100°
ROD 01, 220°
ROD 04, 220°
ROD 04, 340°
ROD 03, 100°

TRY-15

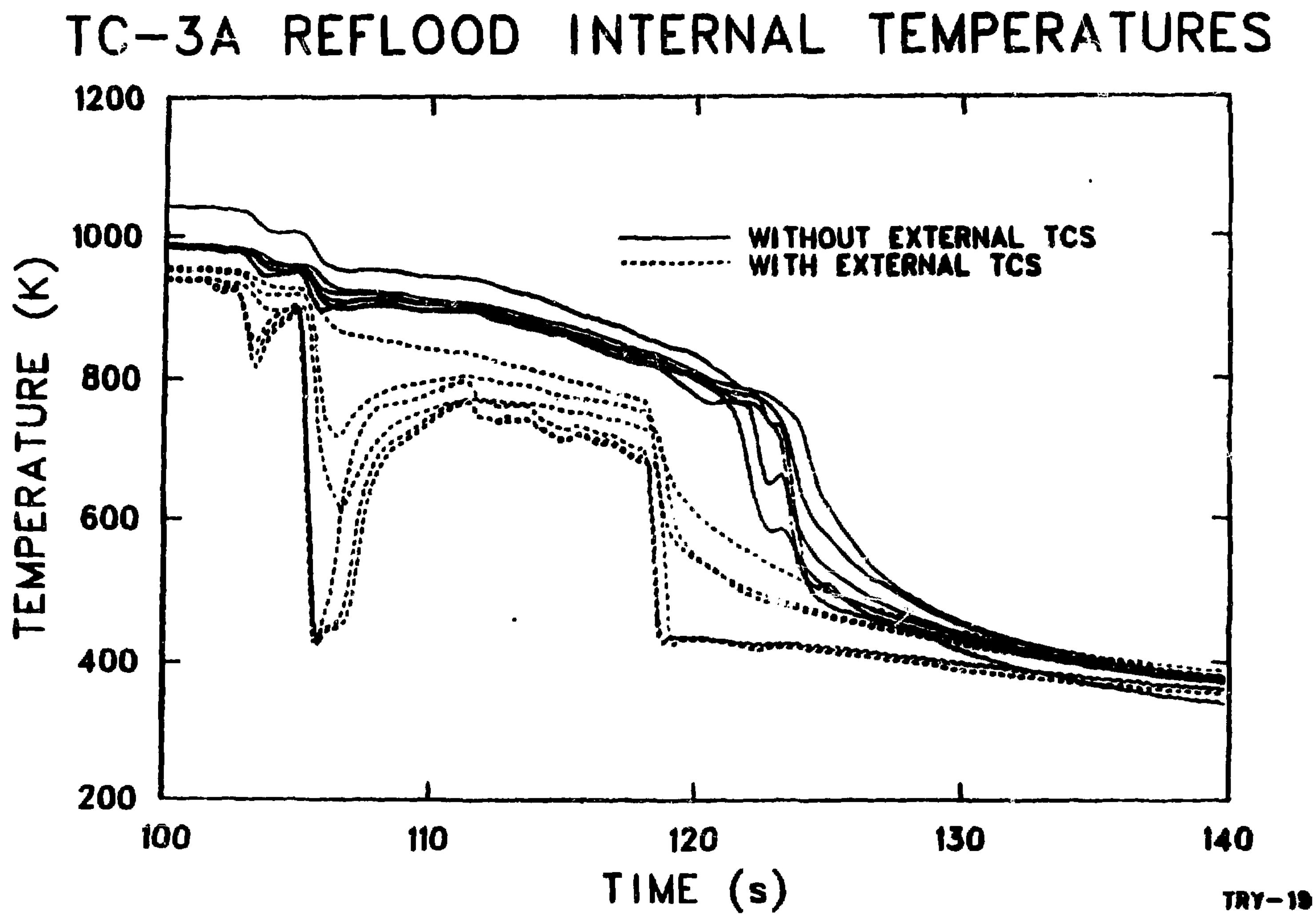

TC-3A CLADDING EXTENSION
CLADDING DISPLACEMENT (mm)
3
2
1
0
-5
0
5
10
15
20
25
30
TIME (s)
ROD 01
ROD 03

TRY-16

ROD COOLDOWN RATES DURING THE TC-3A BLOWDOWN QUENCH

	CLADDING TCs (k/s)	CLADDING LVDT (k/s)	FUEL TCs (k/s)
ROD 01	NONE	145	70
ROD 03	570	125	80
ROD 04	NONE	---	85

TRY-17


TC-3A REFLOOD INTERNAL TEMPERATURES
WITHOUT EXTERNAL TCS
WITH EXTERNAL TCS
TEMPERATURE (K)
1200
1000
800
600
400
200
100
110
120
130
140
TIME (s)
TRY-19

CONCLUSIONS

- PEAK CLADDING TEMPERATURES DURING BLOWDOWN REDUCED ABOUT 10% DUE TO EXTERNAL THERMOCOUPLES INFLUENCE ON
    - CHF
    - SURFACE HEAT TRANSFER
- NO MAJOR DIFFERENCES IN ROD THERMAL RESPONSE OCCURRED DURING BLOWDOWN QUENCH DUE TO EXTERNAL THERMOCOUPLES

TRY-9C

CONCLUSIONS (CONT'D)

- EXTERNAL THERMOCOUPLES DID NOT EXACTLY MEASURE CLADDING SURFACE TEMPERATURE
    - QUENCHED ABOUT 4 TIMES FASTER THAN CLADDING
- EXTERNAL THERMOCOUPLES INFLUENCED CLADDING QUENCH DURING REFLOOD
    - MOMENTARY REWETS
    - EARLY QUENCH (3 - 12 SEC)

CONCLUSIONS (CONT'D)

- THERMAL DECOUPLING OF FUEL AND CLADDING IS SIGNIFICANT DURING A LOCA ALLOWING CLADDING TO COOL ABOUT 2 TIMES FASTER THAN FUEL DURING THE BLOWDOWN QUENCH
  - DEMONSTRATES CONSERVATISM BETWEEN SOME OUT-OF-PILE AND IN-PILE EXPERIMENTS

TRY-22