LOCA Simulation Program

A Summary of Test Results

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Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

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This handout is a compilation of viewgraphs used in the presentation of summary results for the LOCA Simulation Program to the Advisory Committee on Reactor Safeguards on May 27, 1983. This experimental program was performed in the National Research Universal (NRU) Reactor located at the Chalk River National Laboratory (CRNL).

It should be noted that extensive qualification and analysis of the data and results of the tests presented have not been performed. However, the data presented have been examined and evaluated to the extent necessary to assure that the results are valid and consistent.

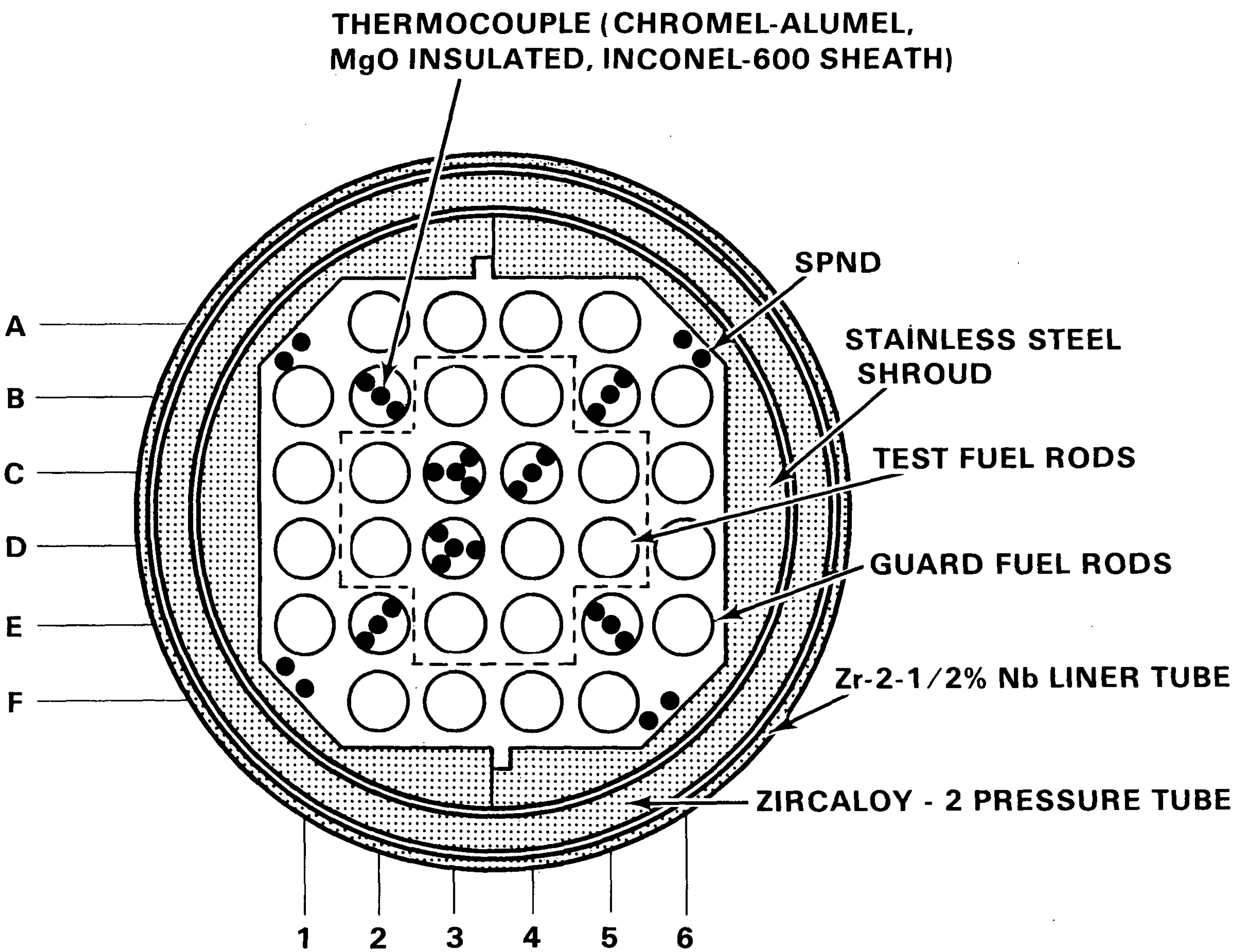
TEST OBJECTIVES

PERFORM SIMULATED LOCA EXPERIMENTS USING FULL LENGTH LWR FUEL RODS TO STUDY CLADDING MECHANICAL DEFORMATION, FLOW BLOCKAGE, AND COOLABILITY

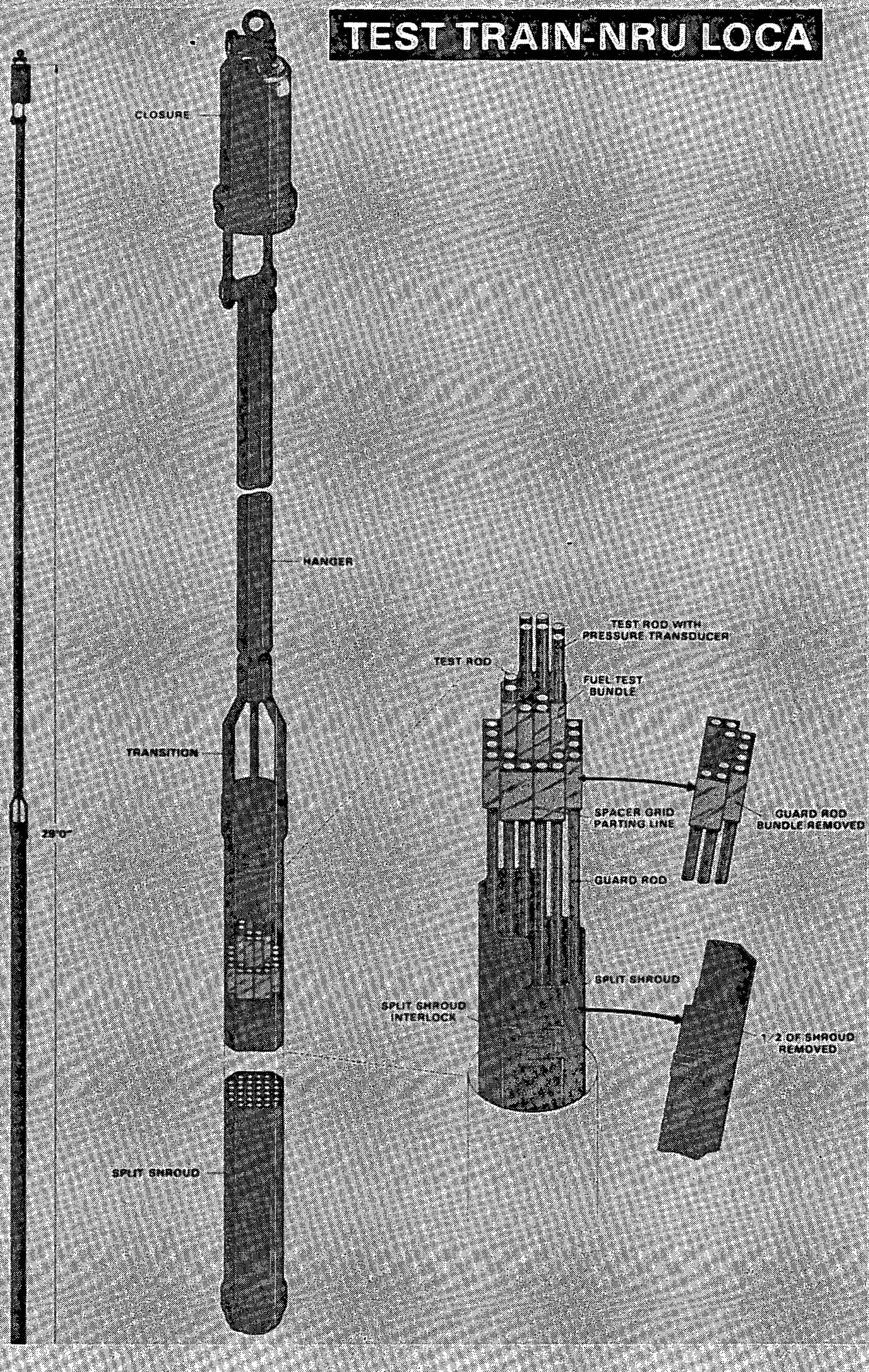
- TH-1, 2, AND 3 PROVIDED A BROAD THERMAL-HYDRAULIC DATA BASE FOR NONDILATED RODS

- MT-1 THROUGH MT-4 PROVIDED A THERMAL-HYDRAULIC AND MECHANICAL DEFORMATION DATA BASE TO COMPARE NONDEFORMED RODS TO DEFORMED AND RUPTURED RODS

LOCA TEST ASSEMBLY CROSS SECTION



TEST TRAIN-NRU LOCA



INSTRUMENTATION SUMMARY

INSTRUMENT	MT-1	MT-2	MT-3	MT-4
THERMOCOUPLES				
FUEL CENTERLINE	7/1*	7/0	12/1	5/0
FUEL CLADDING I.D.	32/11	31/1	48/3	61/8
FUEL CLADDING O.D.	27/6	27/6	0	2/0
SPACER GRID	15/1	15/3	12/1	15/1
CARRIER	6/0	6/1	10/1	11/1
SHROUD	41/8	41/6	44/0	54/8
HANGER TUBE	4/0	4/0	4/0	4/0
FUEL ROD BRAZE	0	0	4/0	2/0
TOTAL	132/27	131/17	134/6	154/18
FUEL ROD PRESSURE				
PRESSURE SWITCHES	9/4	9/0	8/7	0
PRESSURE SENSORS	2/2	2/2	4/3	12/0
NEUTRON FLUX DETECTORS				
SPNDS	24/8	24/8	24/6	11/0
FLUX WIRES	0	0	0	1/0
LIQUID LEVEL DETECTORS				
DISPLACEMENT	1/1	1/1	0	0
DIFFERENTIAL PRESSURE	0	0	0	1/0
TDR	0	0	0	1/0

*TOTAL/FAILED

TEST FEATURES

FEATURE	TH-1	MT-1	MT-2	TH-2	TH-3	MT-3	MT-4
TEST DATE	OCT 1980	APRIL 1981	JULY 1981	OCT 1981	NOV 1981	NOV 1981	MAY 1982
NUMBER OF TESTS	27	1	4	14	3	6	4
DESIRED CLADDING TEMPERATURE, K (°F)	≤1389 (2040)	≤1172 (1650)	1033-1089 (1400-1500)	1033-1103 (1400-1525)	1089-1172 (1500-1650)	1033-1089 (1400-1500)	1033-1200 (1400-1700)
FUEL ROD PRESSURIZATION MPa (psia)	0.101 (14.7)	3.21 (465)	3.21 (465)	0.101 (14.7)	0.101 (14.7)	3.90 (565)	4.62 (670)

TEST FEATURES

FEATURE	TH-1	MT-1	MT-2	TH-2	TH-3	MT-3	MT-4
PRECONDITIONING	YES	YES	YES	YES	YES	YES	YES
PREPROGRAMMED REFLOOD USING LCS	YES	YES	YES	YES	YES	YES	YES
TEMPERATURE FEEDBACK CONTROL OF REFLOOD USING DACS	NO	NO	NO	YES	YES	YES	YES
SHROUD	NEW	NEW	MT-1	MT-1/ MT-2	MT-1/ MT-2/ TH-2	NEW	MT-3
GUARD RODS	NEW	NEW	MT-1	MT-1/ MT-2	MT-1/ MT-2/ TH-2	NEW	MT-3
TEST RODS	NEW	NEW	NEW	NEW	TH-2	NEW	NEW

TEST CONDITIONS

PARAMETER	TH-1	MT-1	MT-2.2	TH-2.14	TH-3.03	MT-3.06	MT-4.04
TWO PHASE FLOW DURING RUPTURE	DOES NOT APPLY	YES	YES	DOES NOT APPLY	DOES NOT APPLY	YES	NO
REFLOOD DELAY TIME, S	10-80	32	36	7	7	9	57
AVERAGE TIME TO RUPTURE, S	DOES NOT APPLY	70	65	DOES NOT APPLY	DOES NOT APPLY	133	55
REFLOOD RATE, cm/s (in/s)	2.0-27.2 (0.8-10.7)	5.3 (2.1)	1.3-13.7 (0.5-5.4)	1.3-5.1 (0.5-2.0)	1.0-5.6 (0.4-2.2)	1.0-5.6 (0.4-2.2)	0-5.1 (0-2.0)
AVERAGE ROD POWER, kW/ft	~0.36	0.39	0.39	0.37	0.35	0.39	0.37
TEST DURATION,[a] min	<6	3.2	4.7	5.5	6.5	4.5	18.7

[a] TIME FROM STEAM OFF TO REACTOR TRIP

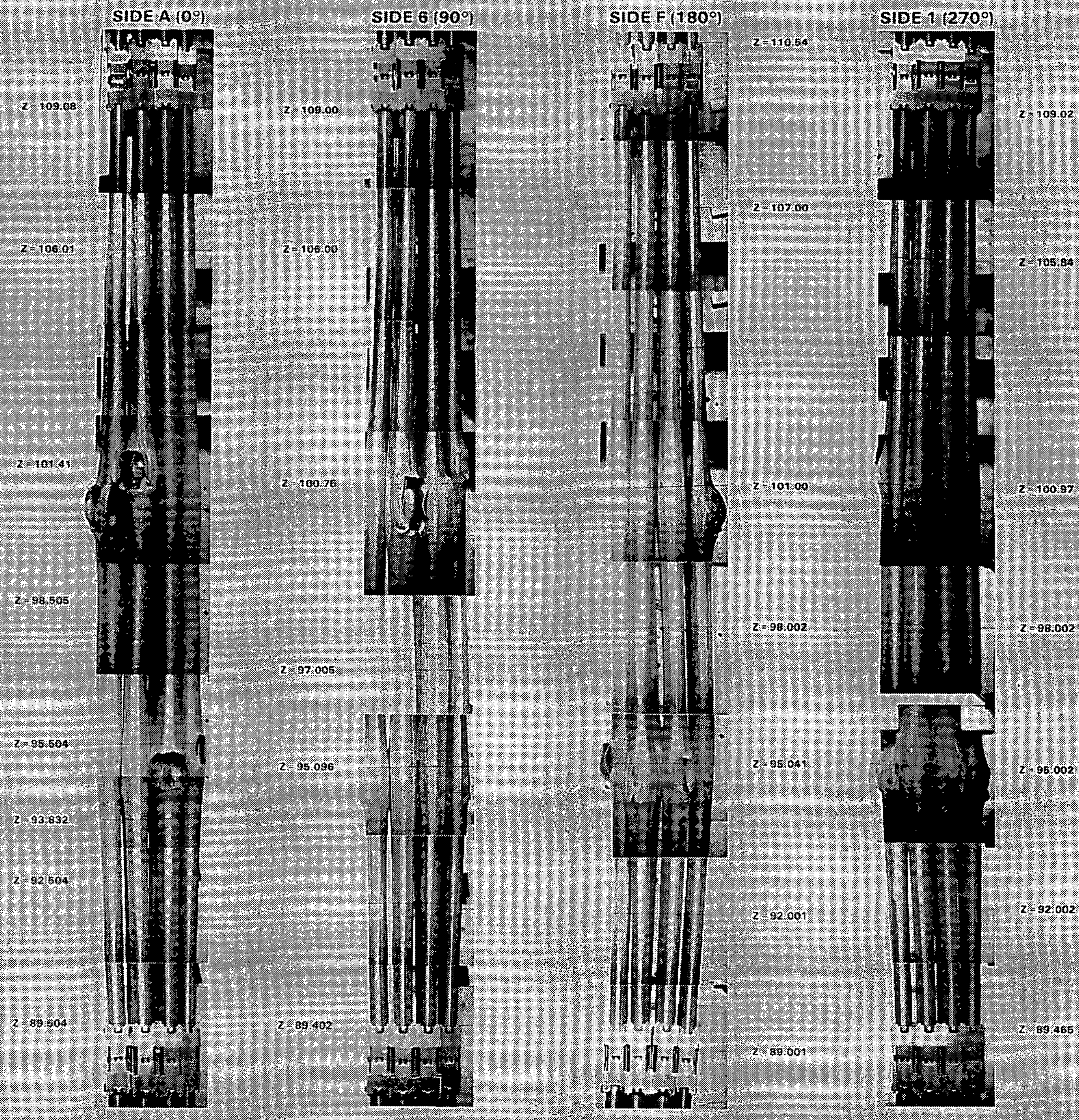
DERM FEATURES

- TELEVISION (VIDEO TAPE)
- PHOTOGRAPHY (35mm)
  - BUNDLE
  - SINGLE FUEL RODS
- TEST ASSEMBLY DISASSEMBLY
- TEST ASSEMBLY REASSEMBLY/RECONSTITUTION
- SINGLE ROD PROFILOMETRY (LVDT)
  - 11 PROBE GAUGE HEAD
    - RADIAL ACCURACY $\pm$ 1 MILL
    - RADIAL PRECISION $< \pm$ 1 MILL
    - ANGULAR ACCURACY $\pm$ 1°
    - ANGULAR PRECISION $< \pm$ 1°
  - ROTARY GAUGE HEAD
    - RADIAL ACCURACY $\pm$ 1 MILL
    - RADIAL PRECISION $< \pm$ 1 MILL
    - ANGULAR ACCURACY $\pm$ 2°
    - ANGULAR PRECISION $< \pm$ 0.01°
  - CARRIAGE
    - X & Y POSITION ACCURACY $\pm$ 1 MILL
    - X & Y POSITION PRECISION $< \pm$ 1 MILL
    - Z POSITION ACCURACY $\pm$ 50 MILL
    - Z POSITION PRECISION $< \pm$ 50 MILL

TEST ROD DILATION TEMPERATURE AND STRAIN

TEST	MAXIMUM CLADDING TEMP. K, (°F)	AVERAGE RUPTURE TEMP. K, (°F)	AVERAGE RUPTURE TIME, S	AVERAGE PEAK RUPTURE STRAIN, %	NUMBER OF RUPTURED TEST RODS
MT-1	1148 (1606)	1145 (1601)	70	43	6 OF 11
MT-2	1161 (1630)	1156 (1623)	65	43	8 OF 11
MT-3	1126 (1567)	1067 (1461)	133	47	12 OF 12
MT-4	1459 (2166)	1094 (1511)	55	72	12 OF 12

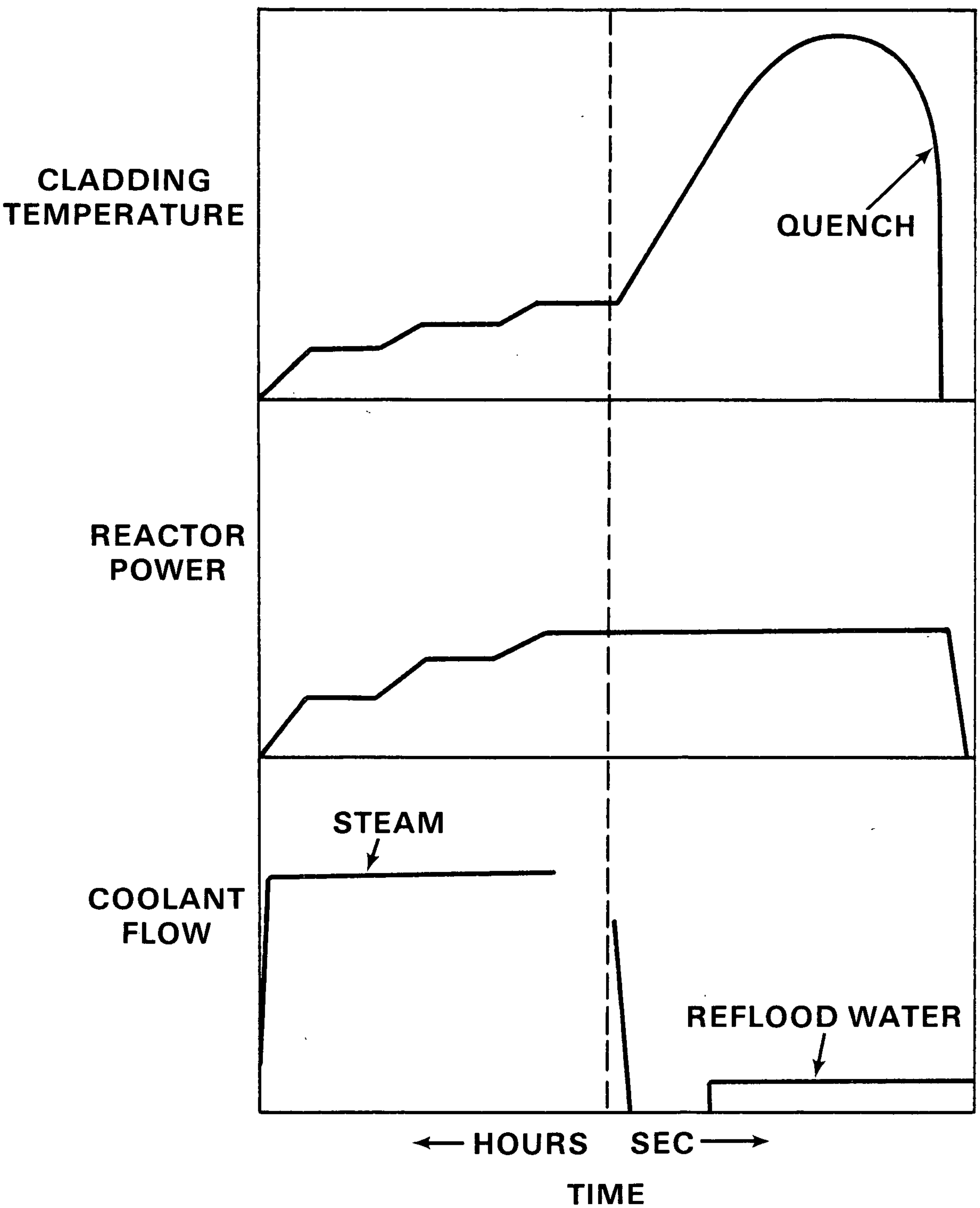
MT-4 TEST BUNDLE RUPTURE REGION



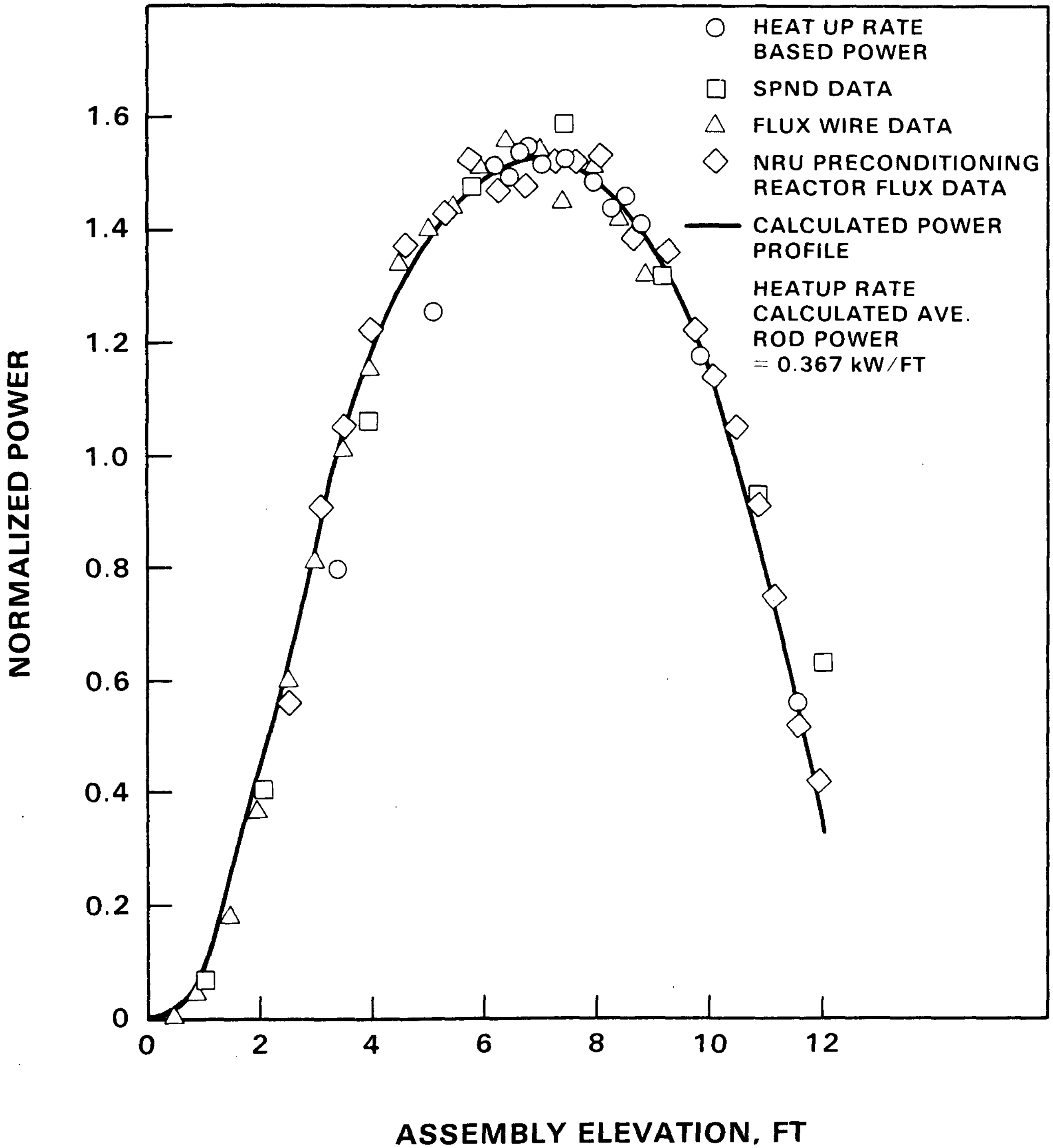
LOCA EXPERIMENT RESULTS

- STRAIN AND BLOCKAGE
- COMPARISON WITH NUREG-0630
- TEMPERATURE BEHAVIOR OF BALLOONED RODS
- HEAT TRANSFER COEFFICIENTS OF BALLOONED RODS
- CONCLUSIONS

LOCA OPERATIONAL SEQUENCE



MT-4 AXIAL POWER PROFILES



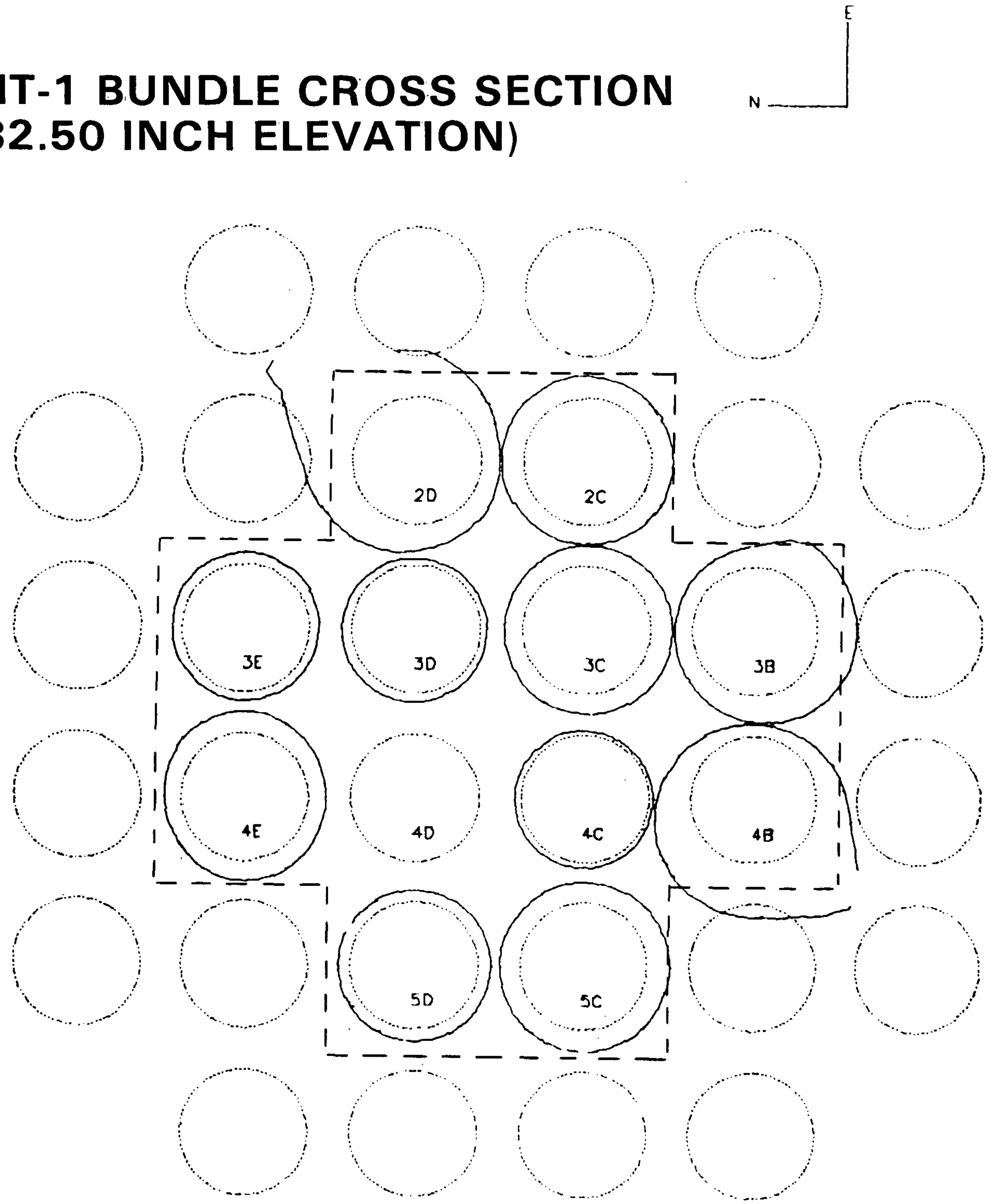
PEAK CLADDING TEMPERATURES FOR EXPERIMENT TH-1

TEST NO.	REFLOOD RATE, in/sec	DELAY TIME, sec	PEAK CLADDING TEMP AT START OF TRANSIENT, °F	PEAK CLADDING TEMP AT START OF REFLOOD, °F	PEAK CLADDING TEMP AT TURNAROUND MEASURED, °F	PEAK CLADDING TEMP AT TURNAROUND FLECHT-TRUMP, °F	PEAK CLADDING TEMP AT TURNAROUND THERM, °F
TH-1.01	3.8	28 (1)	871	881	1403	1350	1365
TH-1.04	3.8	37	853	1336	1487	1400	1445
TH-1.05	1.9	7	858	907	1364	1400	1370
TH-1.06	10.5 (2)	19	873	1101	1223	1100	1150
TH-1.07	1.9	19	891	1154	1578	1500	1420
TH-1.08	1.4	11	891	1010	1676	1700	1500
TH-1.09	1.3	22	865	1158	1881	1800	1580
TH-1.10	1.9	30	895	1314	1665	1600	1525
TH-1.11	1.4 (3)	11	817	962	1696	1700	1500
TH-1.12	3.8	37	843	1330	1589	1400	1425
TH-1.13	7.6	37	845	1408	1526	1400	1395
TH-1.14	7.6	32	858	1368	1477	1300	1300
TH-1.15	9.5	66	795	1666	1758	1800	1720
TH-1.16	3.8	51	836	1500	1707	1600	1605
TH-1.17	3.8	66	817	1599	1788	1800	1800
TH-1.18	2.9	52	844	1480	1756	1700	1675
TH-1.19	2.9	46	862	1451	1673	1600	1620
TH-1.20	5.9	51	847	1460	1611	1600	1580
TH-1.21	3.8	36	833	1304	1579	1400	1425
TH-1.22	7.6	52	866	1486	1611	1600	1575
TH-1.23	2.9	51	848	1532	1788	1700	1675
TH-1.24	5.9	52	861	1556	1688	1600	1580
TH-1.25	1.4	20	872	1138	1802	1800	1565
TH-1.26	1.2	3	797	800	1644	1700	1530
TH-1.27	1.0	3	943	966	1991	1900	1650
TH-1.28	2.0	50	911	1604	1991	1800	1735
TH-1.29	1.4	32	940	1371	1898	1900	1670
TH-1.30	0.7 (4)	5	929	998	2040		

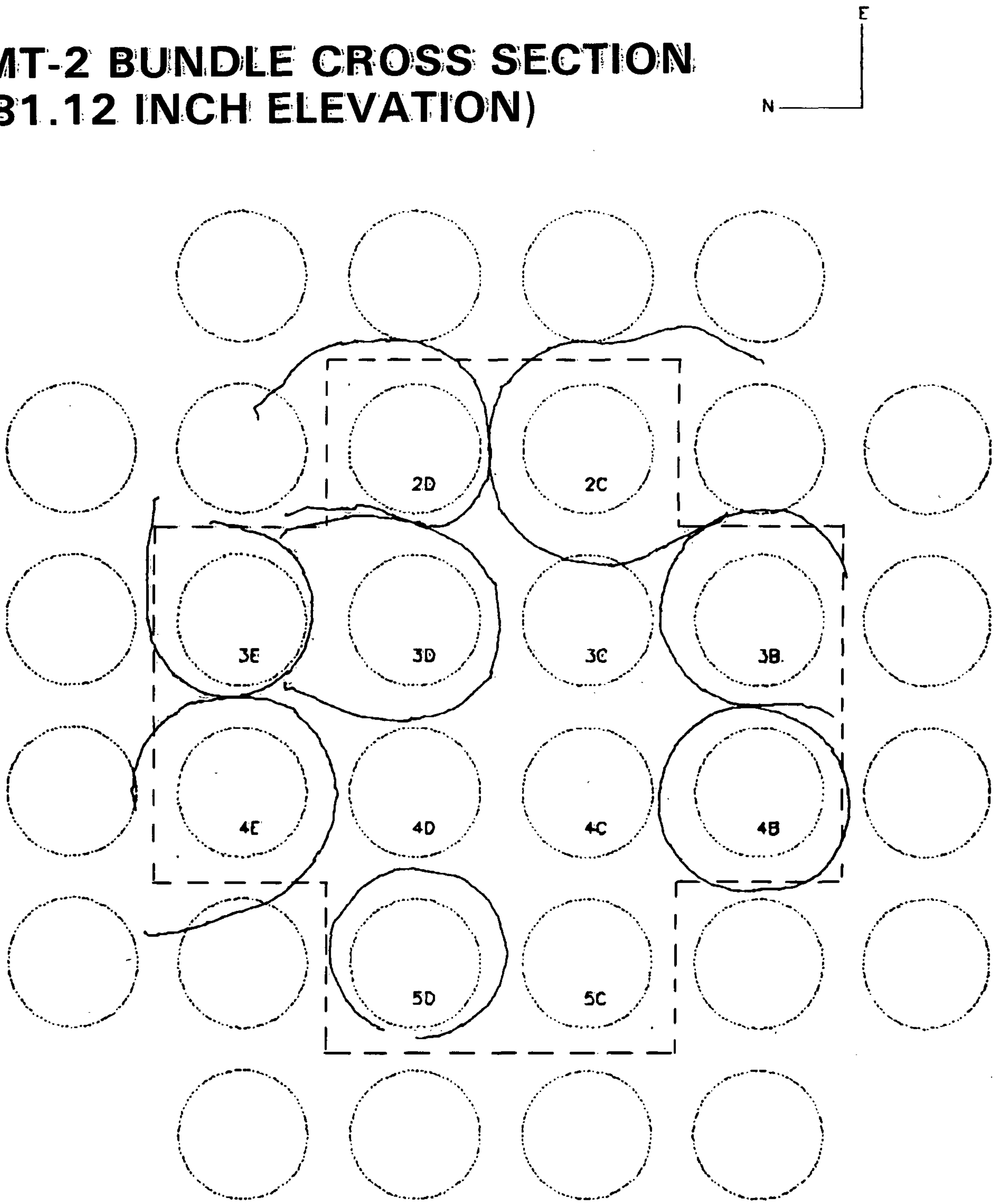
(1) UNPLANNED DELAY CAUSED BY PROBLEMS IN PREFILL
(2) MALFUNCTIONING EQUIPMENT CAUSED GREATER REFLOOD RATE THAN PLANNED
(3) 1st TWO SECONDS OF DATA MISSING
(4) REACTOR TRIPPED AT ~ 1850 °F

STRAIN AND BLOCKAGE RESULTS

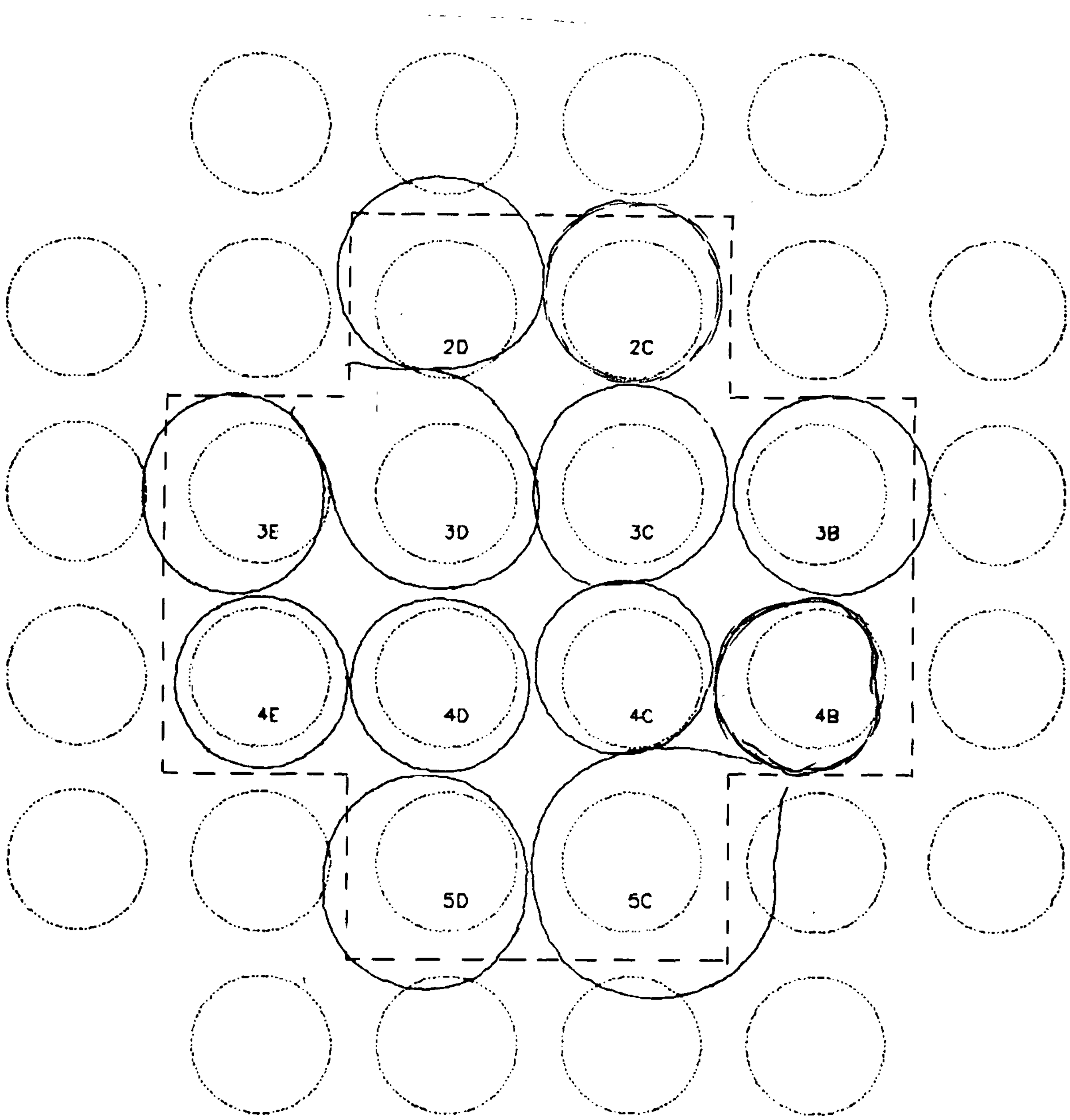
MT-1 BUNDLE CROSS SECTION (82.50 INCH ELEVATION)



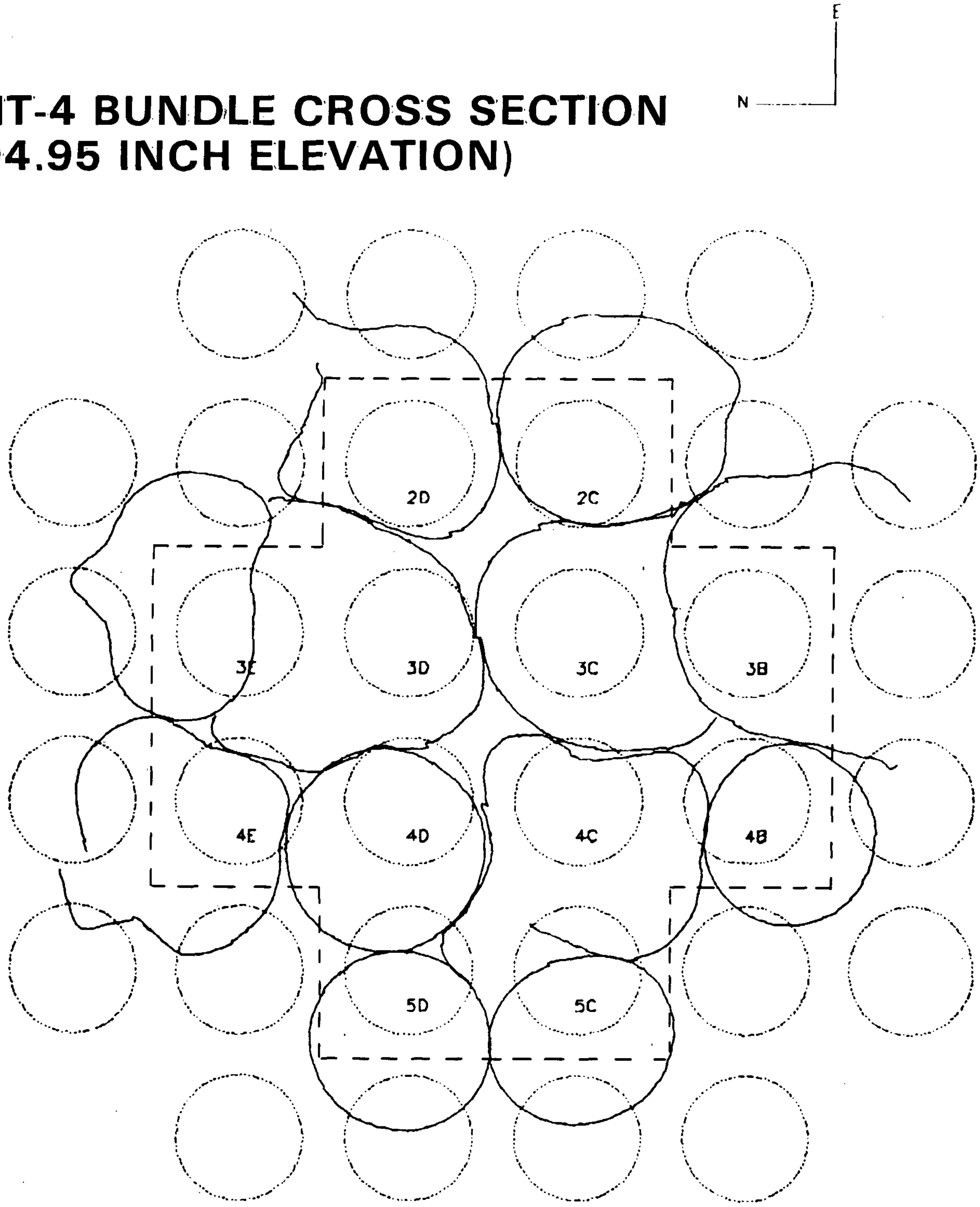
MT-2 BUNDLE CROSS SECTION (81.12 INCH ELEVATION)



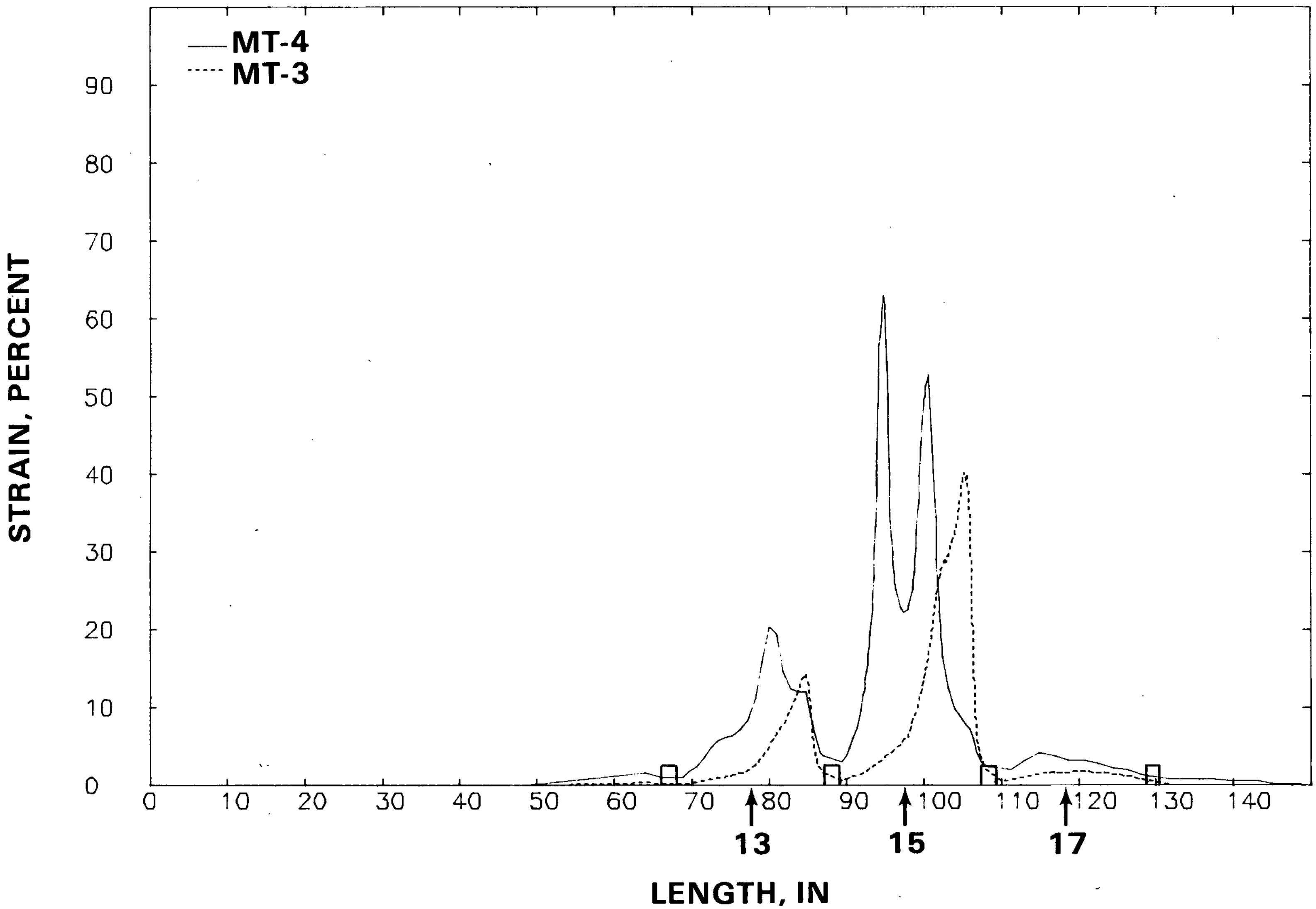
MT-3 BUNDLE CROSS SECTION
(105.09 INCH ELEVATION)



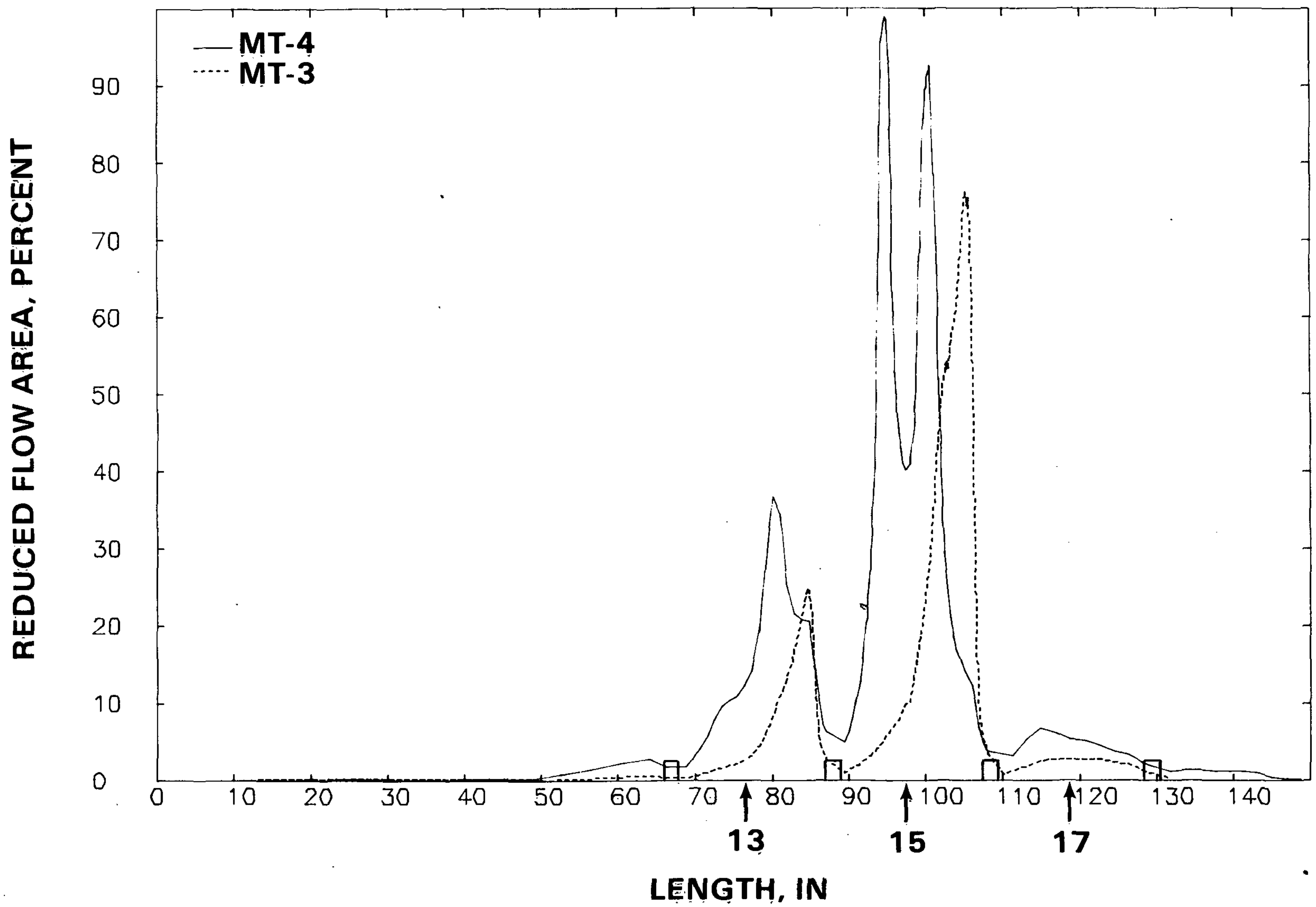
MT-4 BUNDLE CROSS SECTION (94.95 INCH ELEVATION)



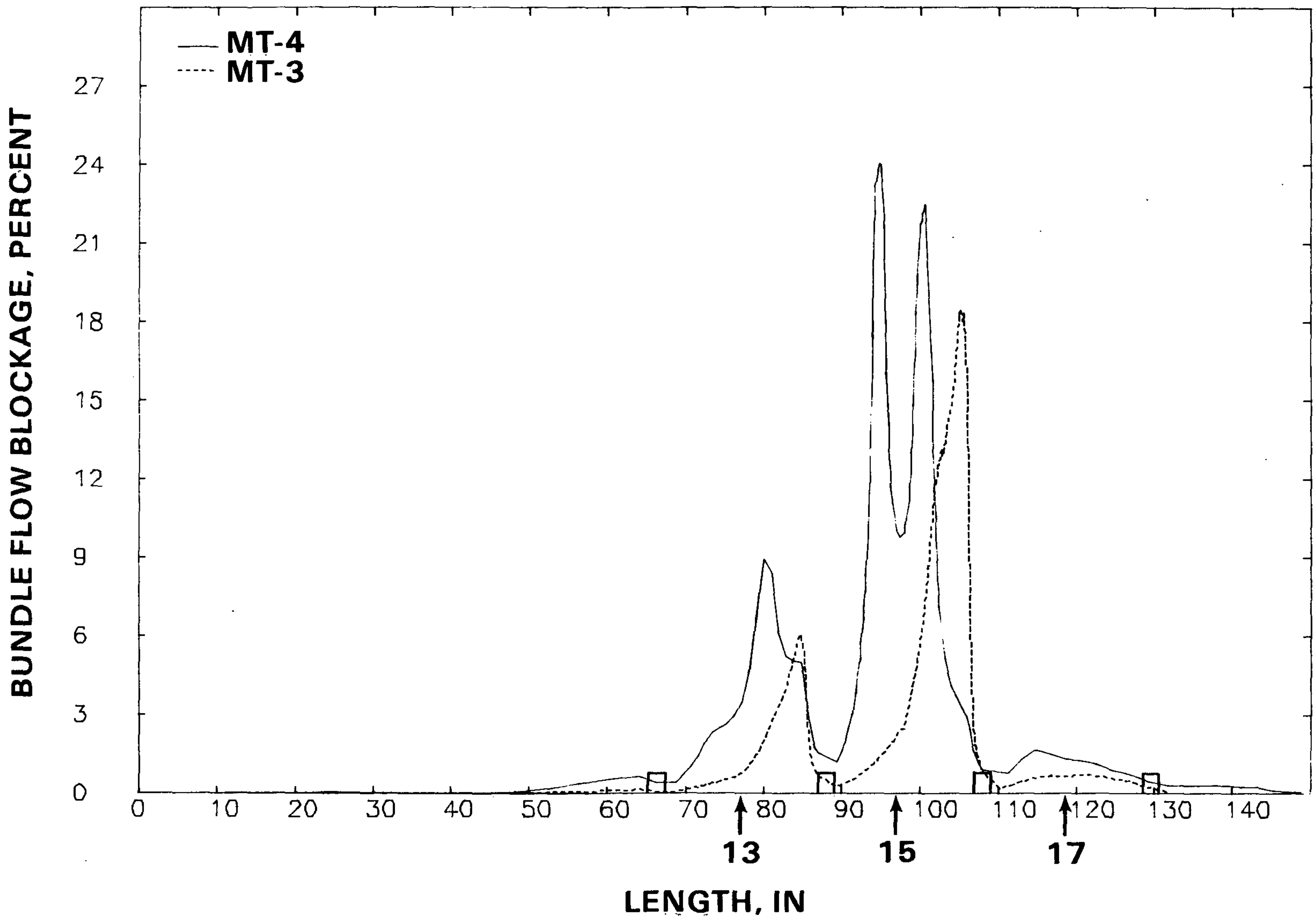
CLADDING STRAIN DISTRIBUTIONS



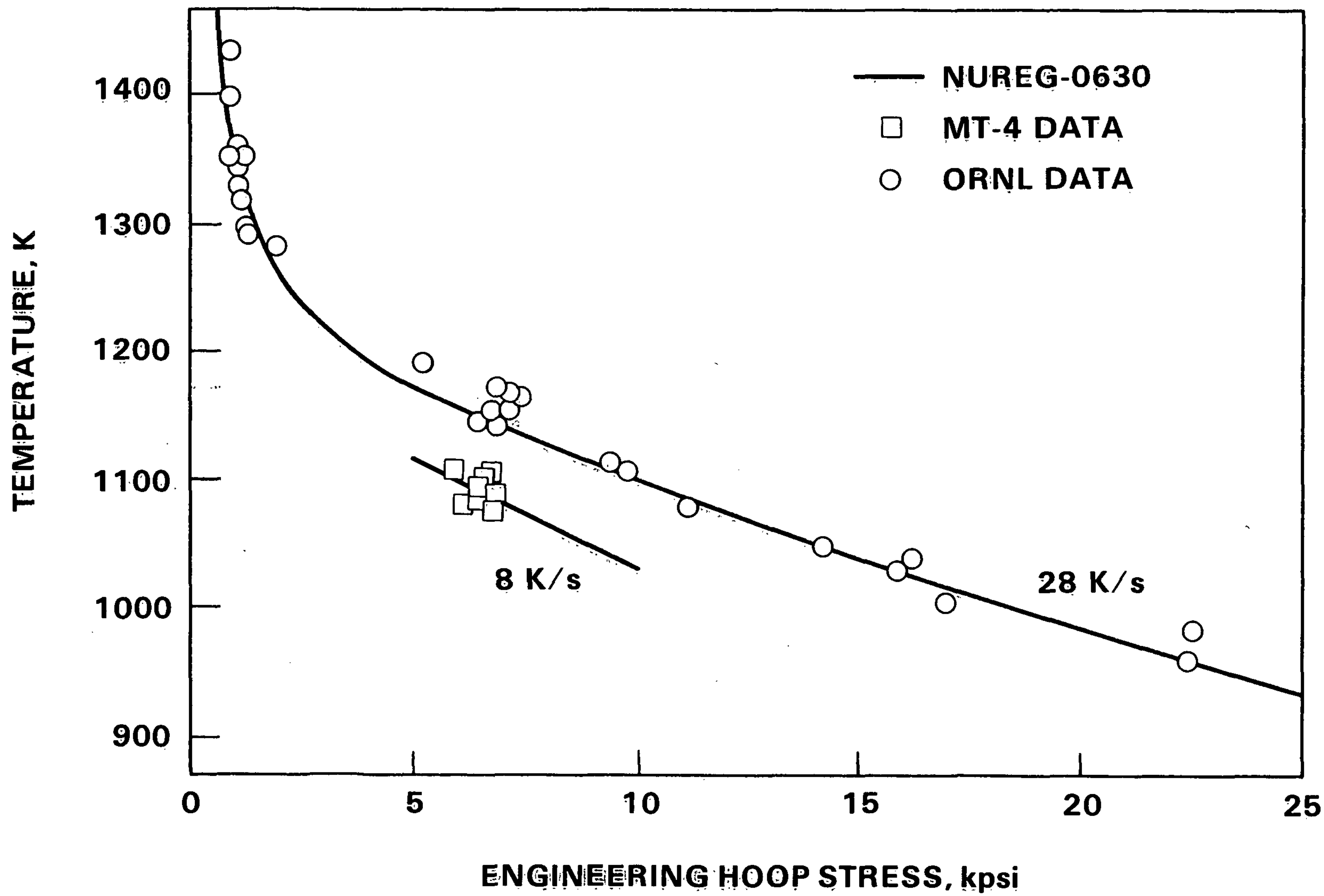
TEST ROD FLOW BLOCKAGE DISTRIBUTIONS



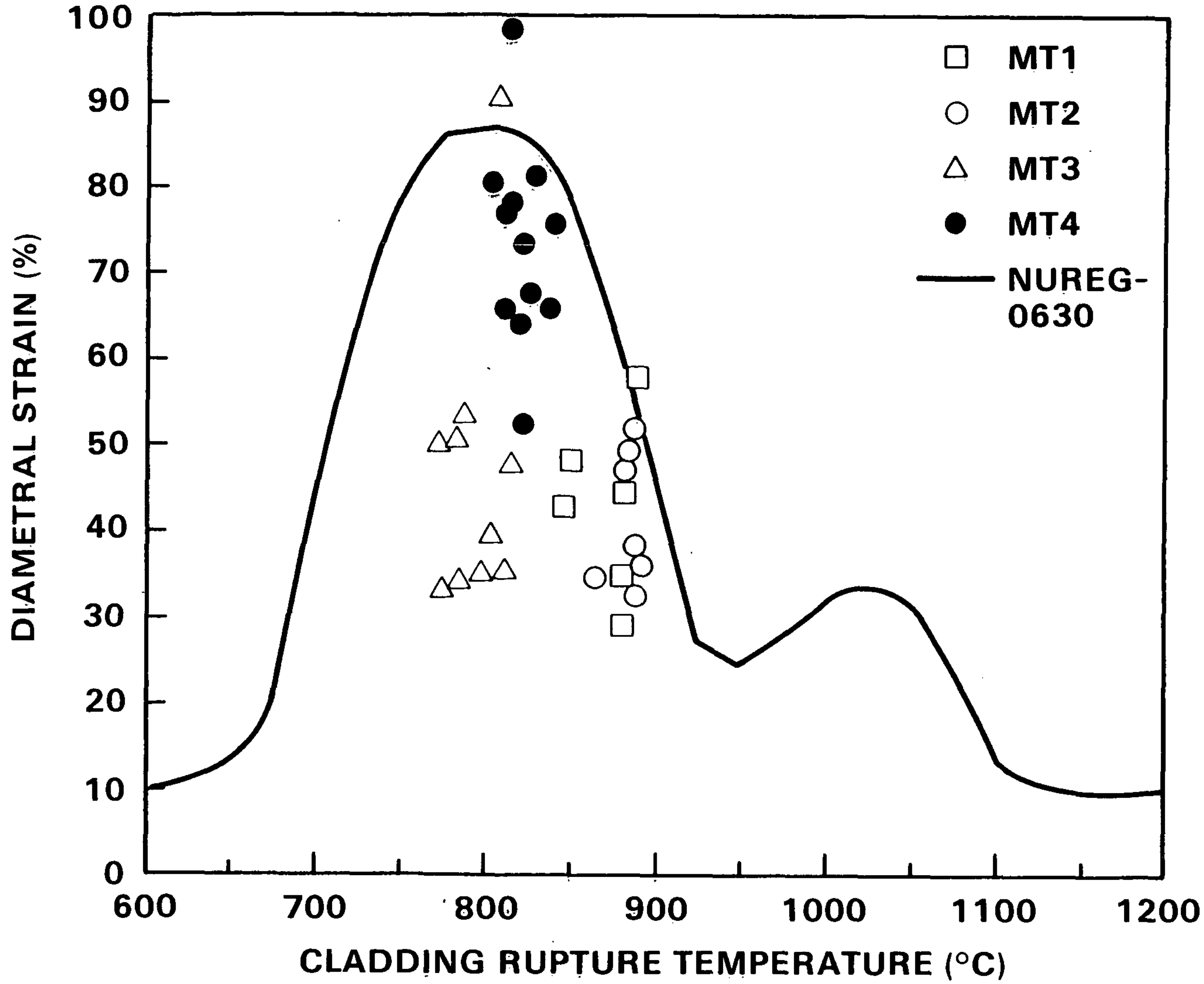
BUNDLE FLOW BLOCKAGE DISTRIBUTIONS



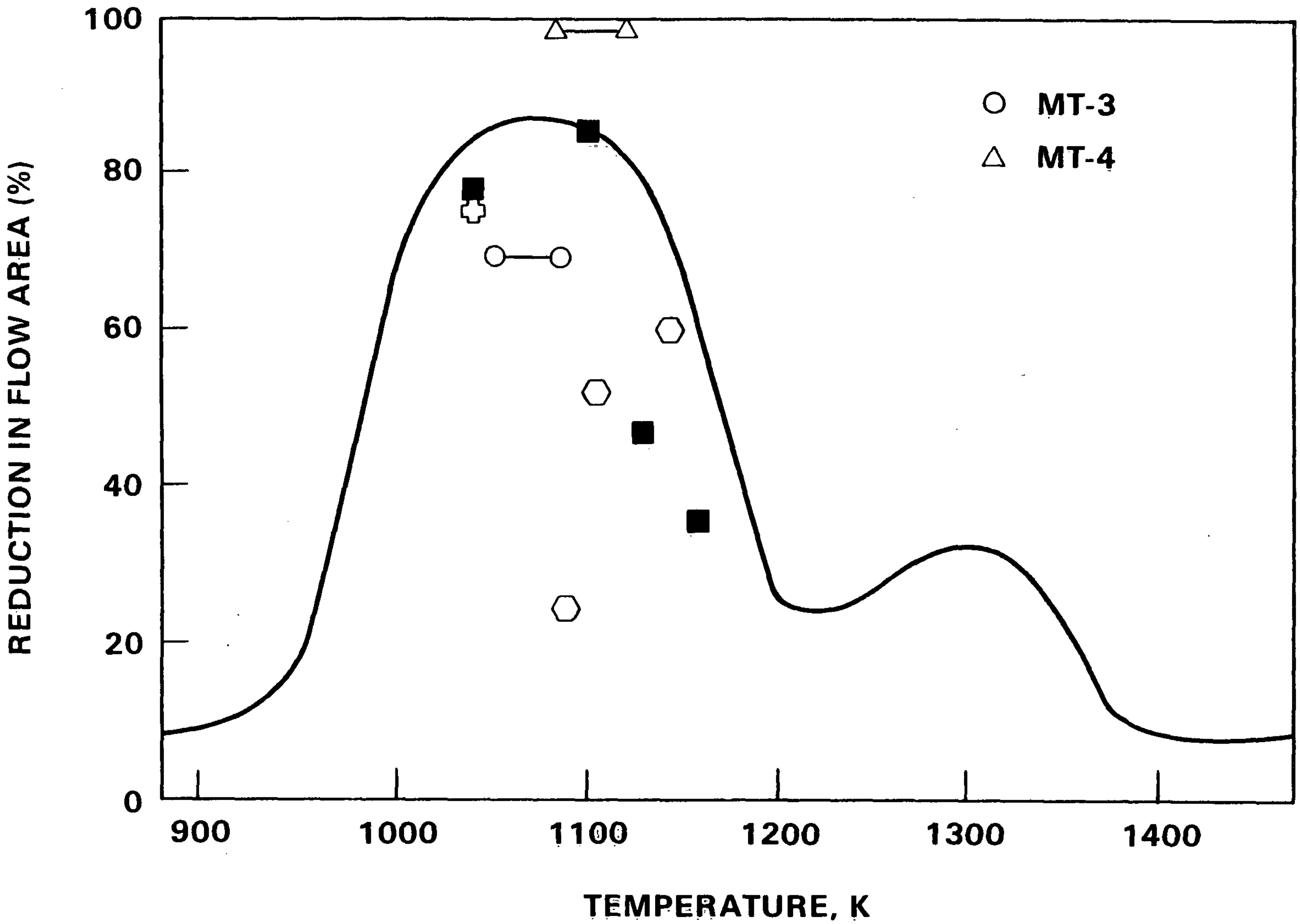
RUPTURE TEMPERATURE VERSUS ENGINEERING HOOP STRESS COMPARISONS



DIAMETRAL CLADDING STRAIN VS. RUPTURE TEMPERATURE



REDUCTION IN LOCAL FLOW AREA VERSUS RUPTURE TEMPERATURE (≤ 10 K/s)

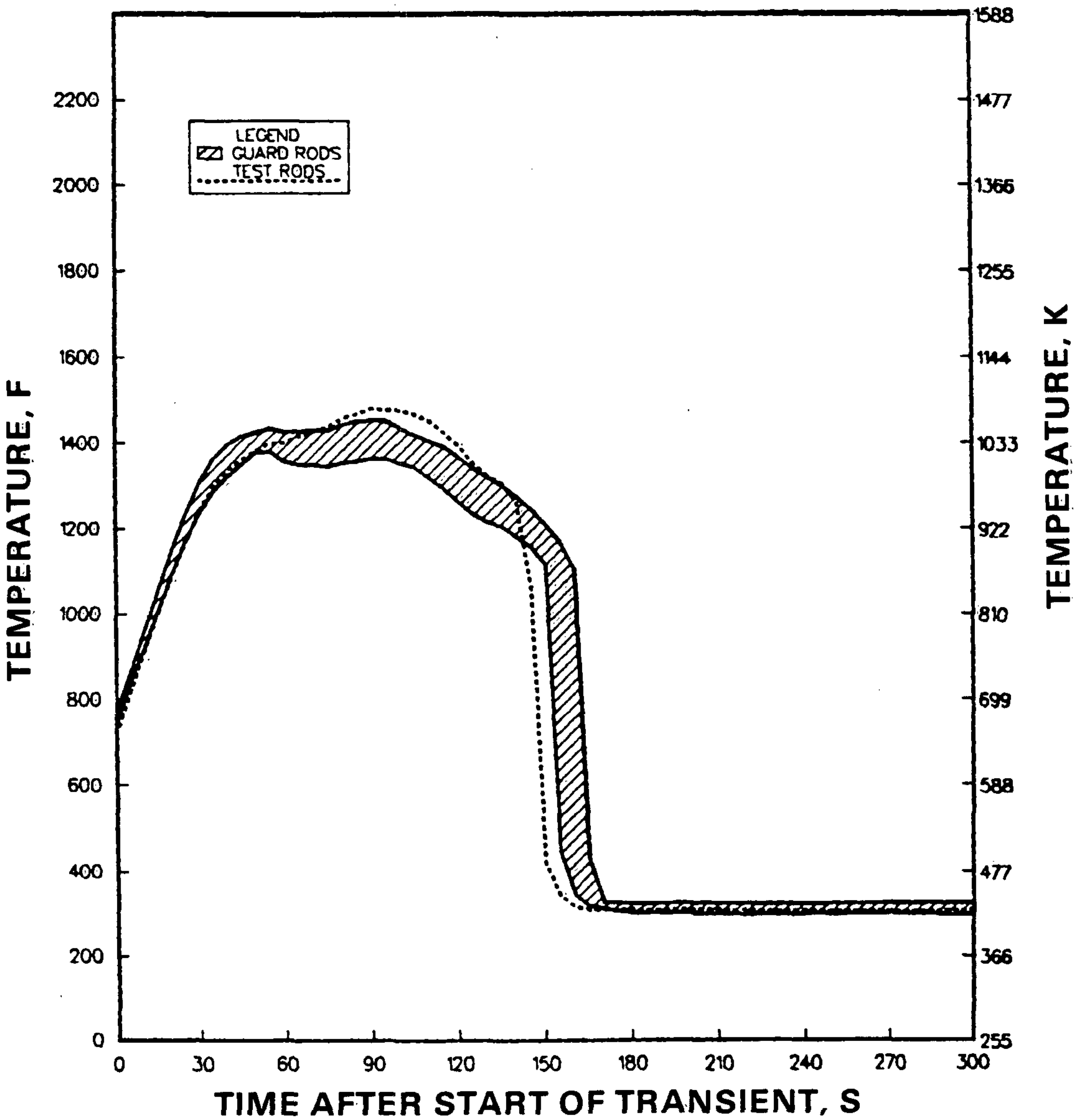


STRAIN AND BLOCKAGE SUMMARY

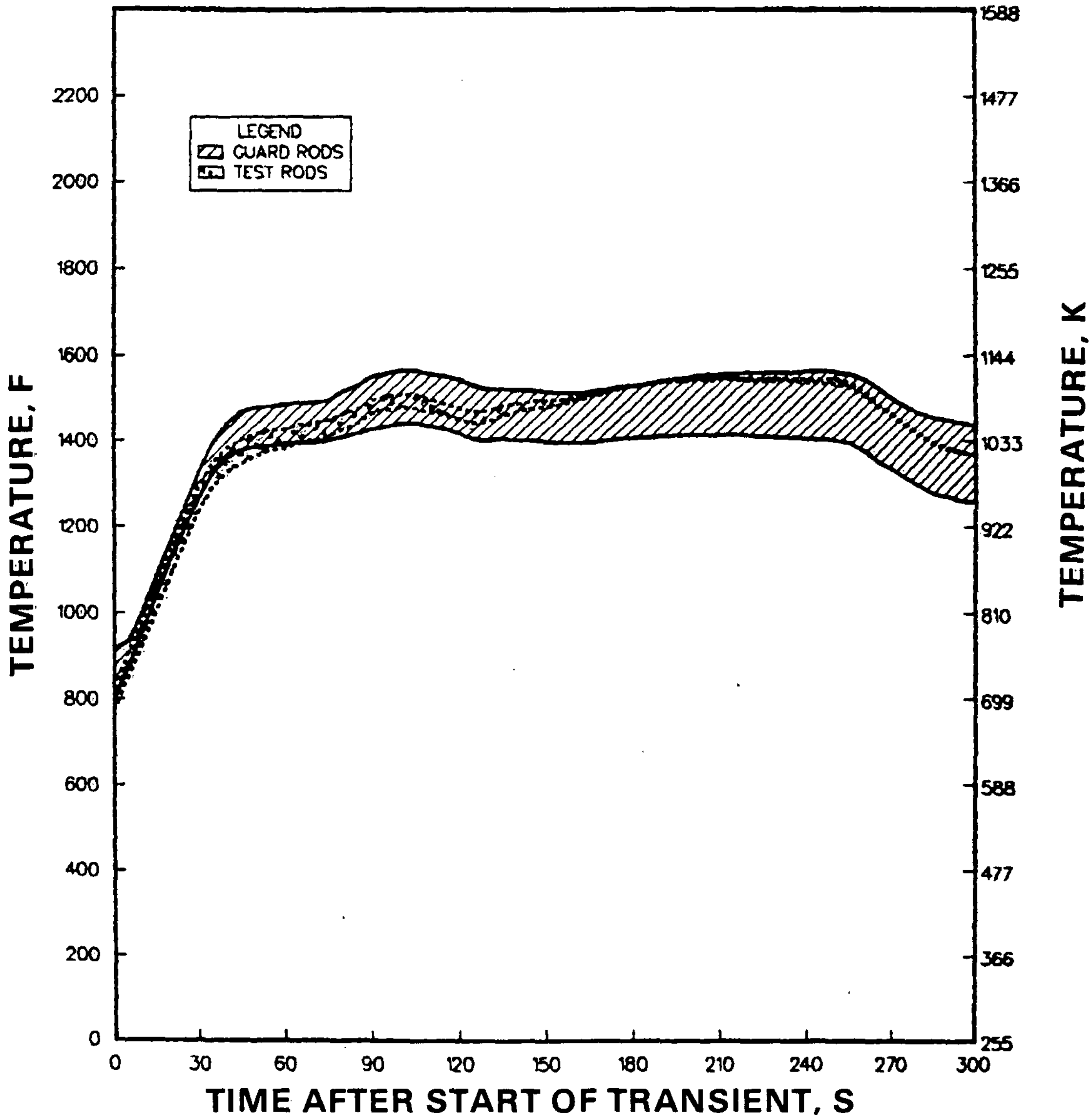
- STRAIN AND BLOCKAGE ARE BOUNDED BY NUREG-0630
- STRAIN AND BLOCKAGE ARE QUITE COPLANAR
- GRIDS AFFECT STRAIN AND BLOCKAGE BECAUSE OF
  - MECHANICAL CONSTRAINT
  - HEAT TRANSFER INCREASE

TEMPERATURE BEHAVIOR

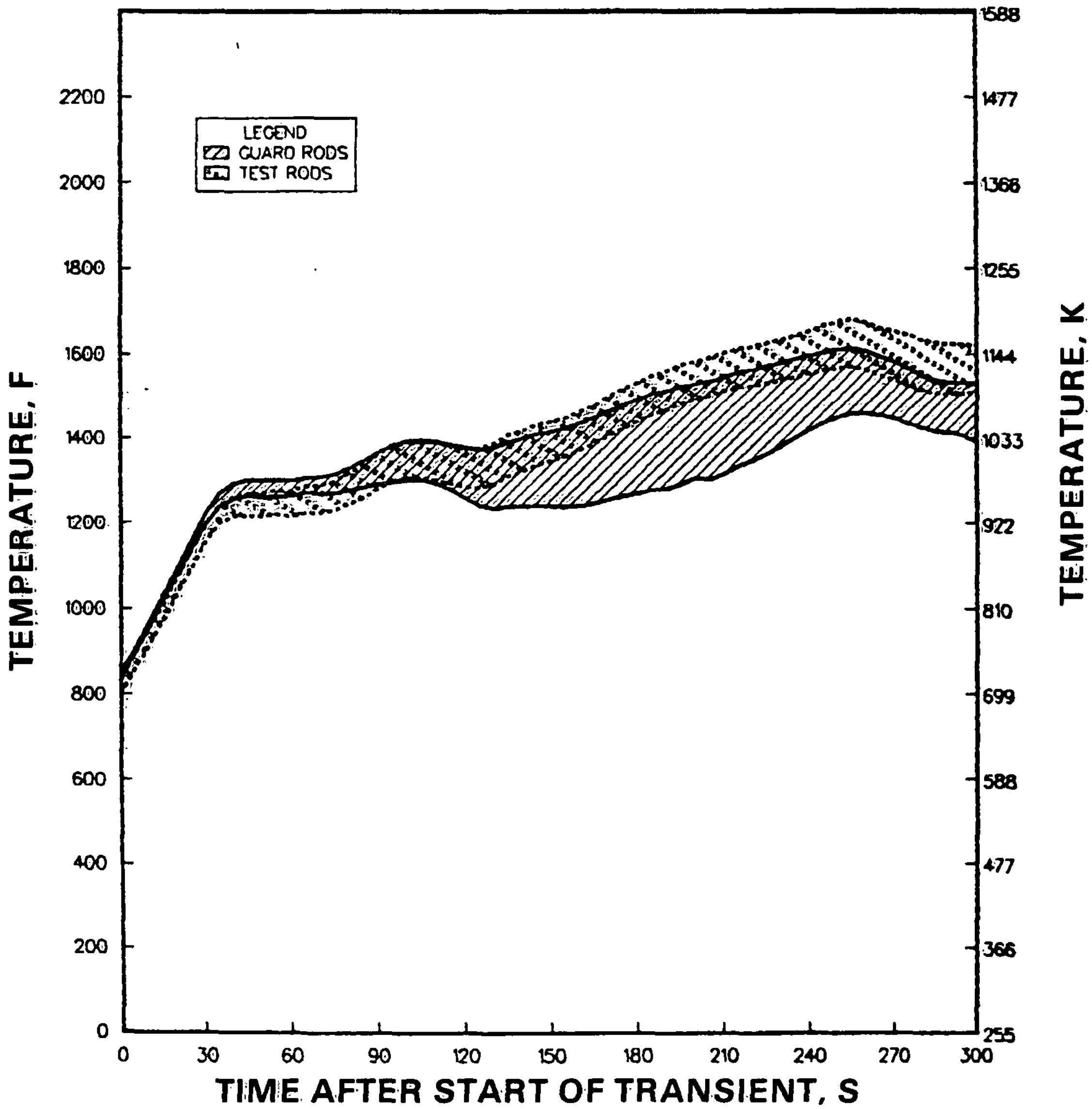
TH-2.14 TEST AND GUARD ROD TEMPERATURES (76.3 INCH ELEVATION)



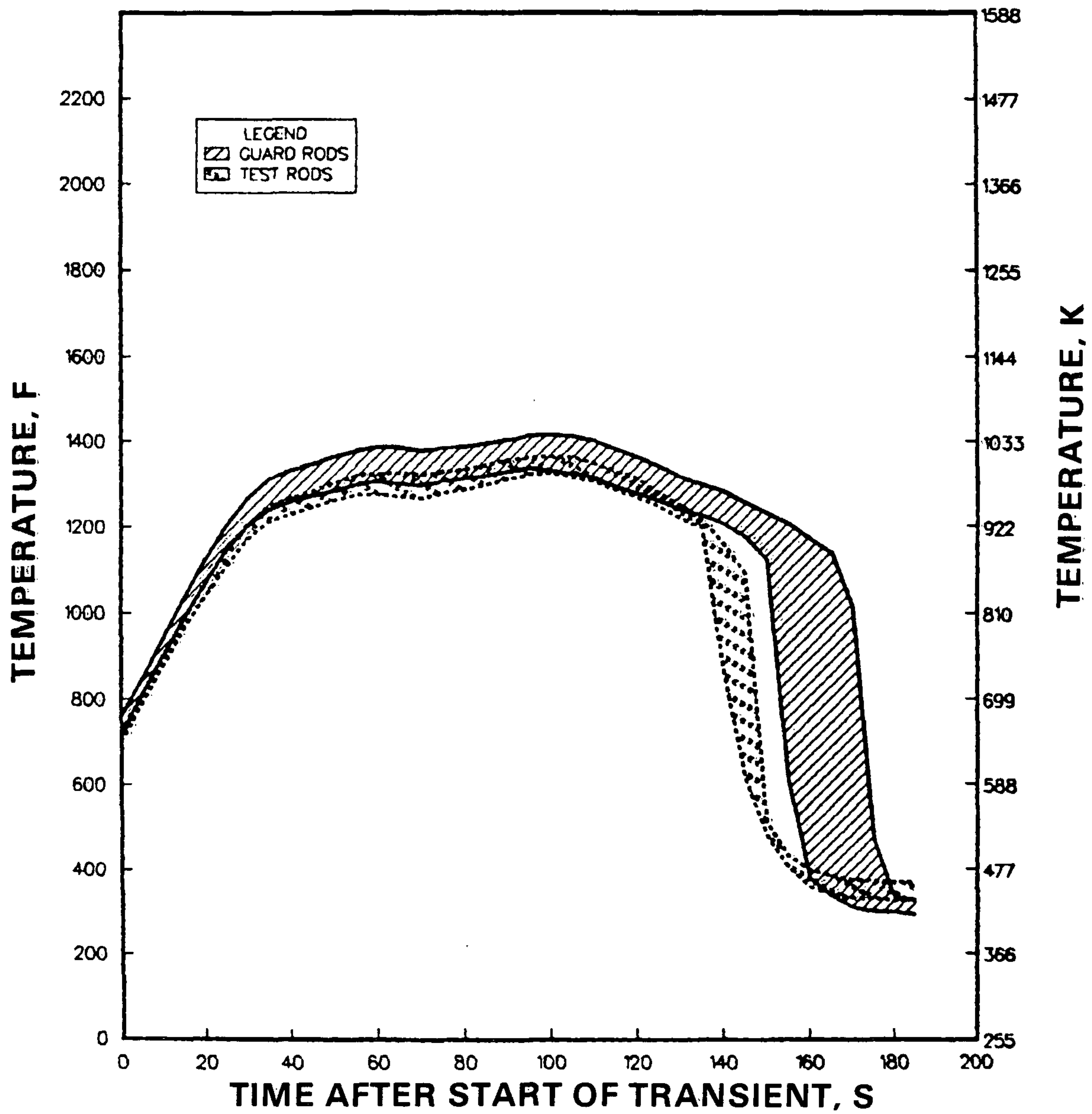
TH-2.14 TEST AND GUARD ROD TEMPERATURES (97.3 INCH ELEVATION)



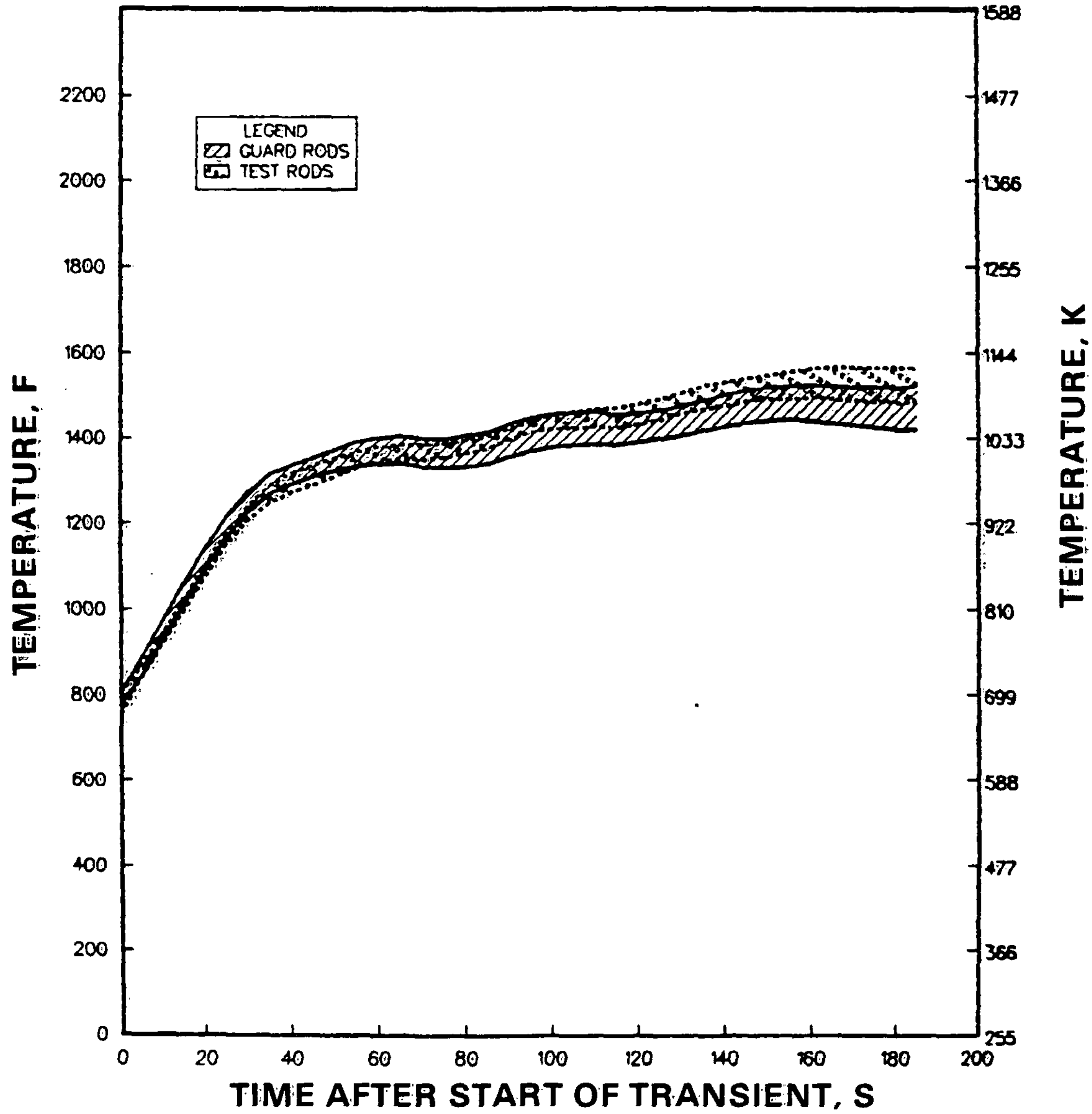
TH-2.14 TEST AND GUARD ROD TEMPERATURES (118.3 INCH ELEVATION)



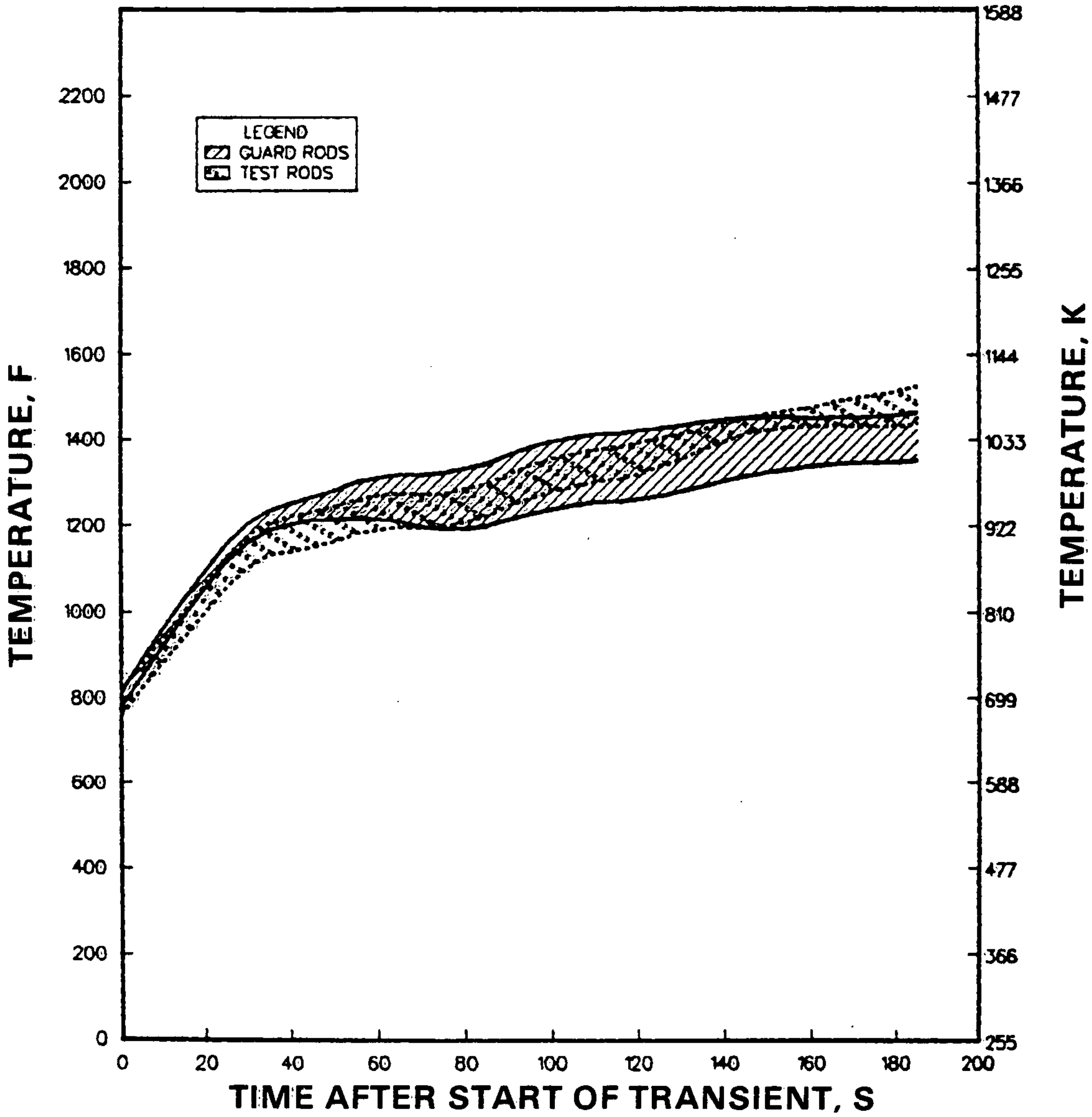
MT-3 TEST AND GUARD ROD TEMPERATURES (76.3 INCH ELEVATION)



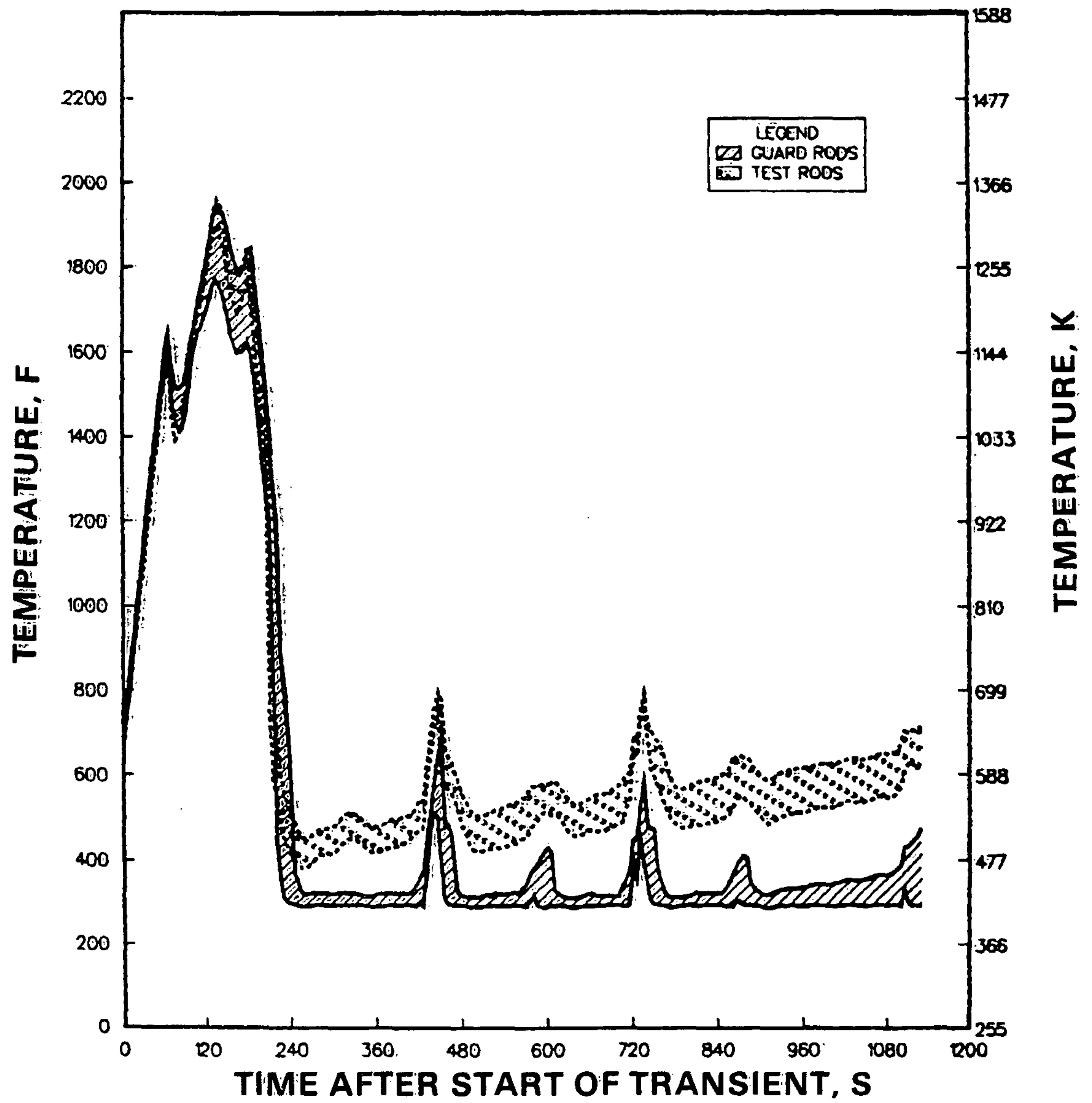
MT-3 TEST AND GUARD ROD TEMPERATURES (97.3 INCH ELEVATION)



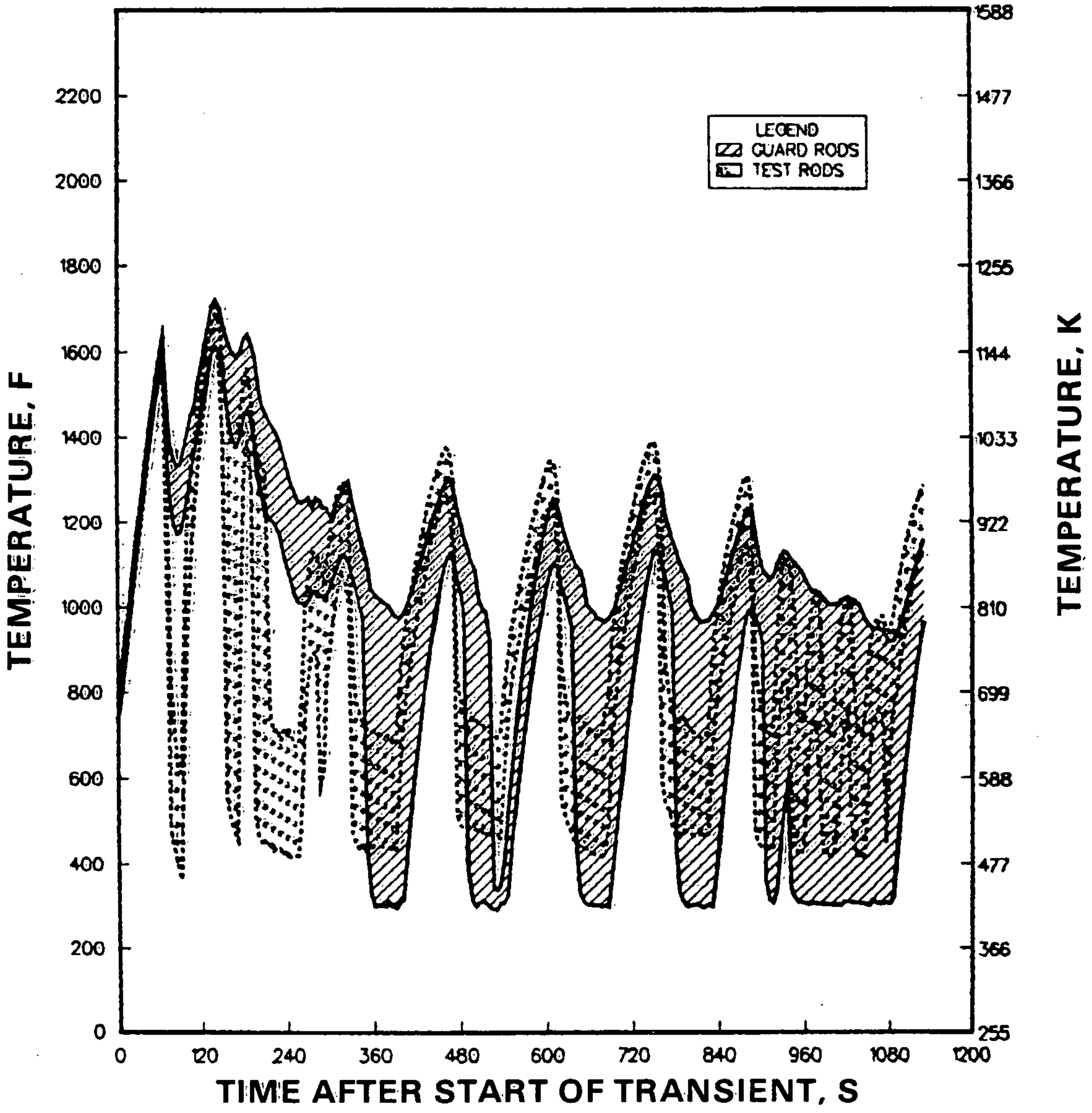
MT-3 TEST AND GUARD ROD TEMPERATURES (118.3 INCH ELEVATION)



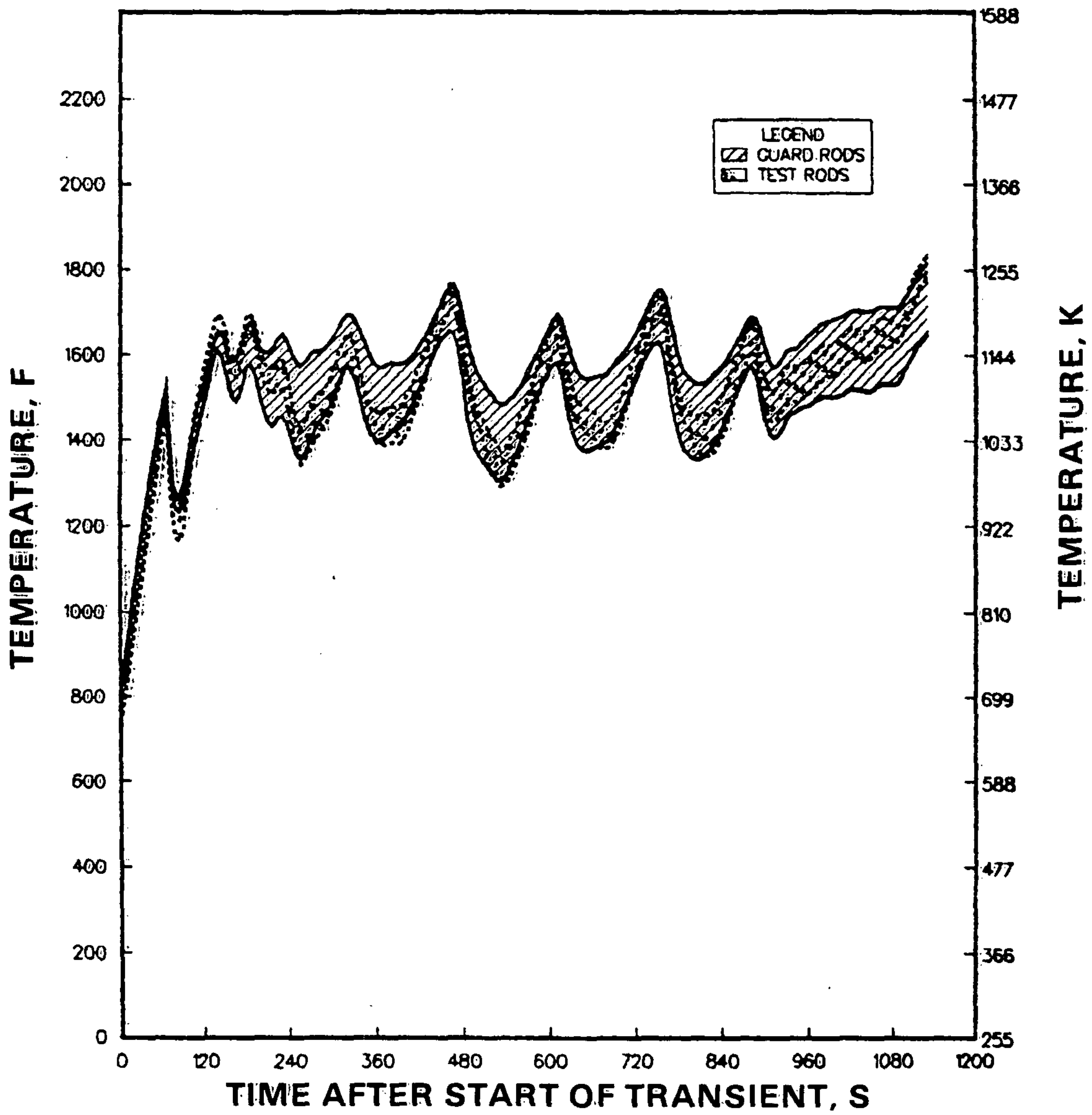
MT-4 TEST AND GUARD ROD TEMPERATURES (76.3 INCH ELEVATION)



MT-4 TEST AND GUARD ROD TEMPERATURES (97.3 INCH ELEVATION)



MT-4 TEST AND GUARD ROD TEMPERATURES (118.3 INCH ELEVATION)



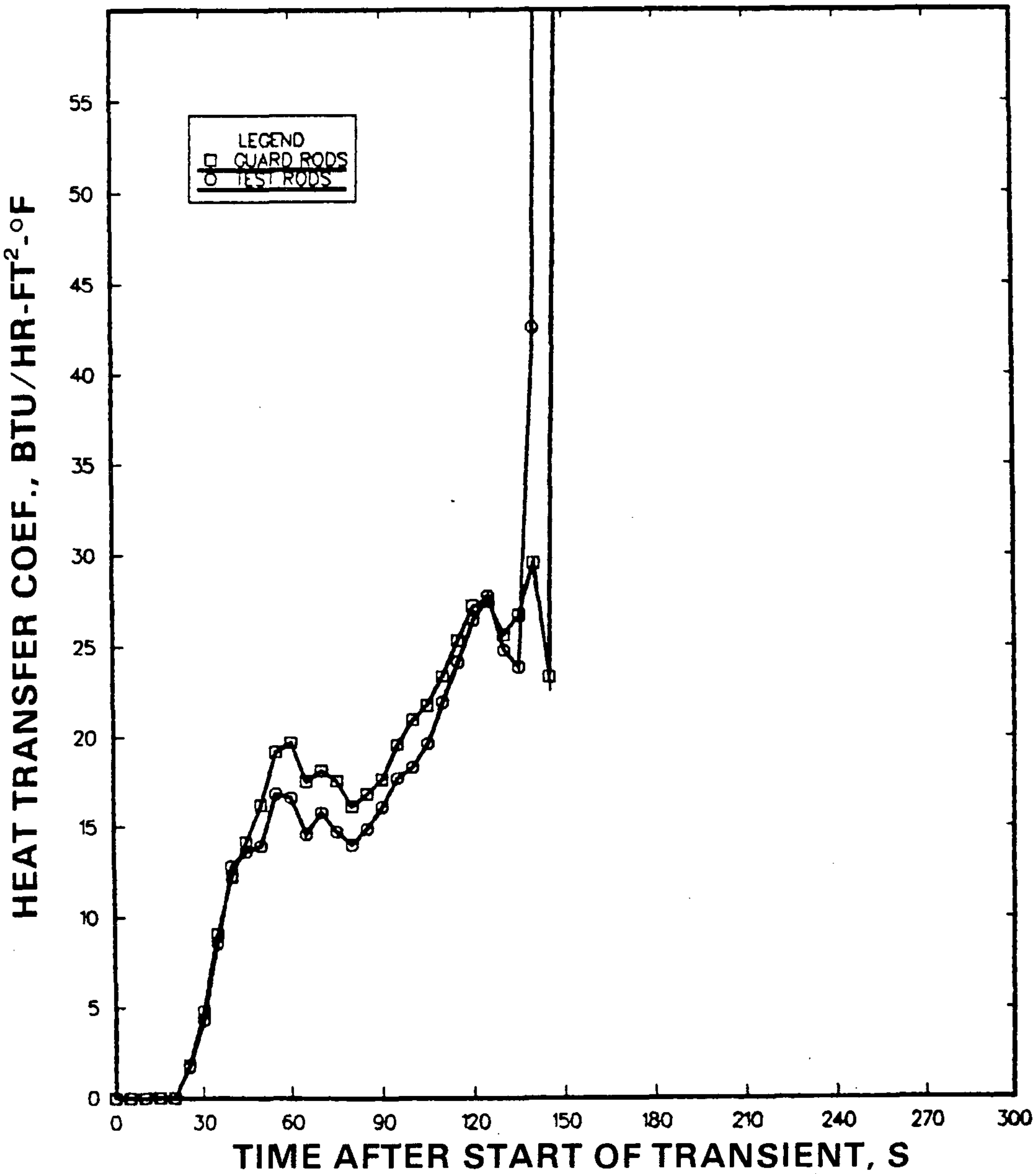
HEAT TRANSFER COEFFICIENTS

EFFECTS OF BLOCKAGE ON HEAT TRANSFER

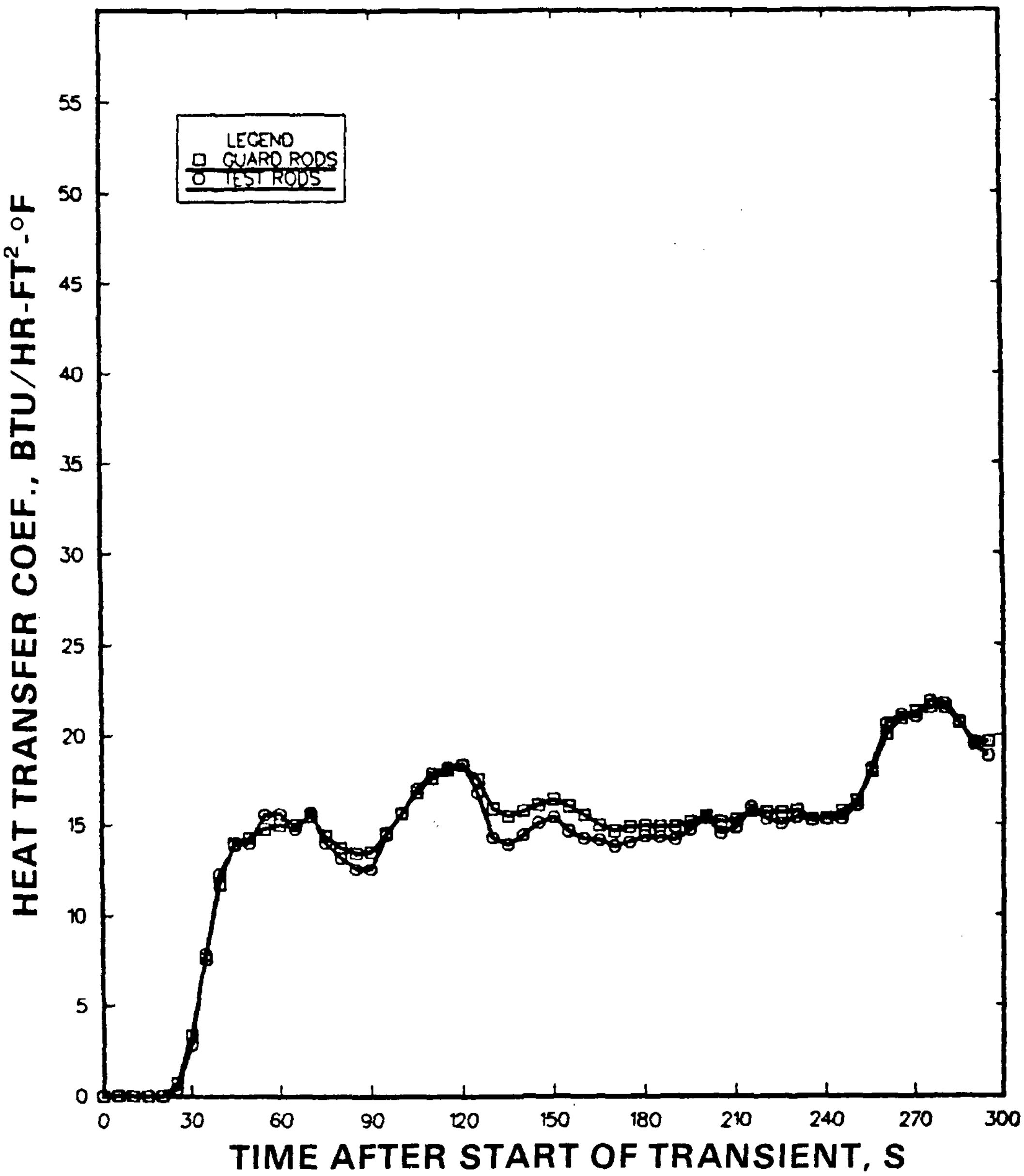
- BYPASS EFFECT AND LOCAL FLOW STARVATION WOULD TEND TO DECREASE HEAT TRANSFER

- INCREASED VELOCITY AND TURBULENCE WOULD TEND TO INCREASE HEAT TRANSFER

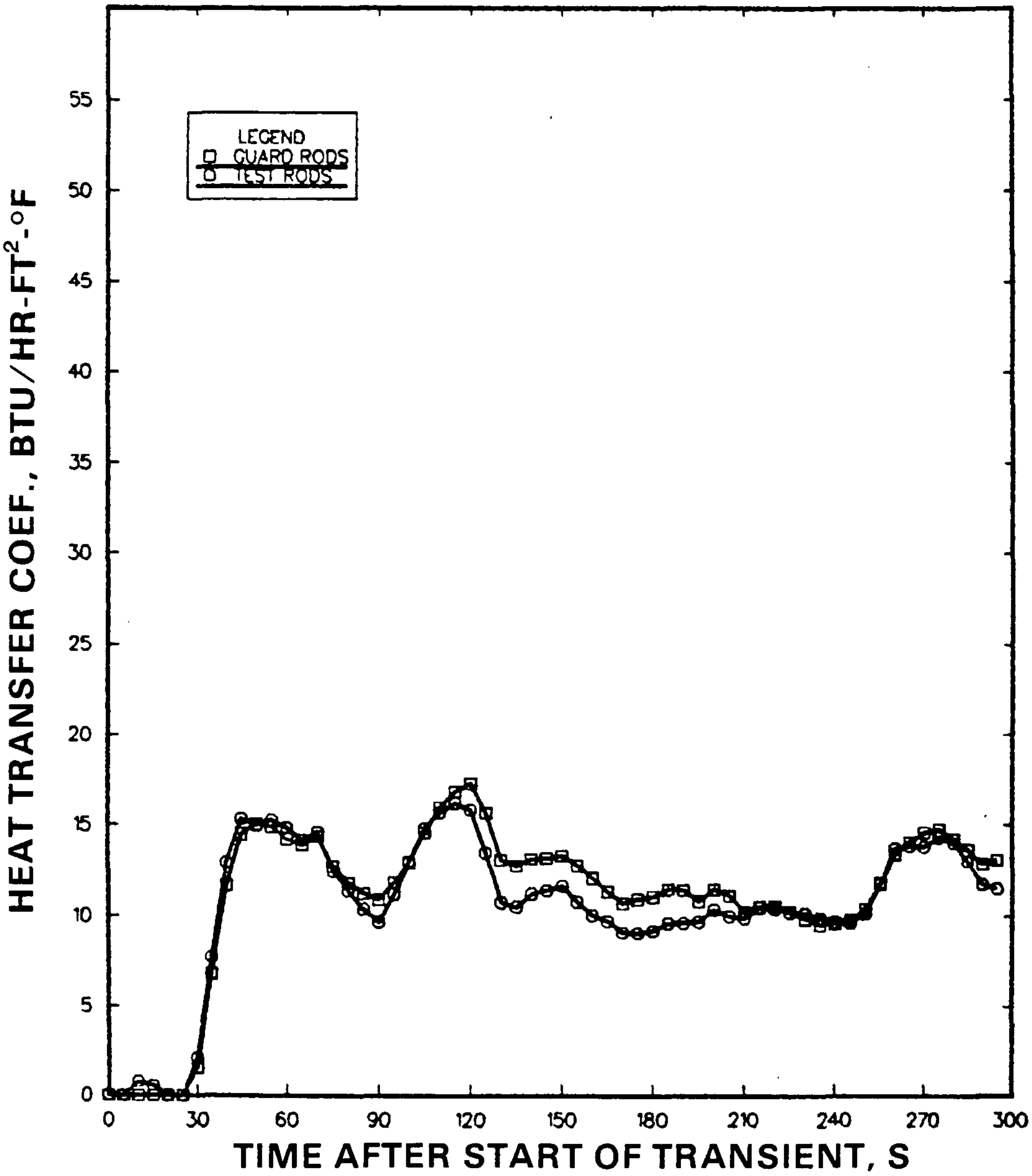
TH-2.14 CALCULATED HEAT TRANSFER COEFFICIENTS (76.3 INCH ELEVATION)



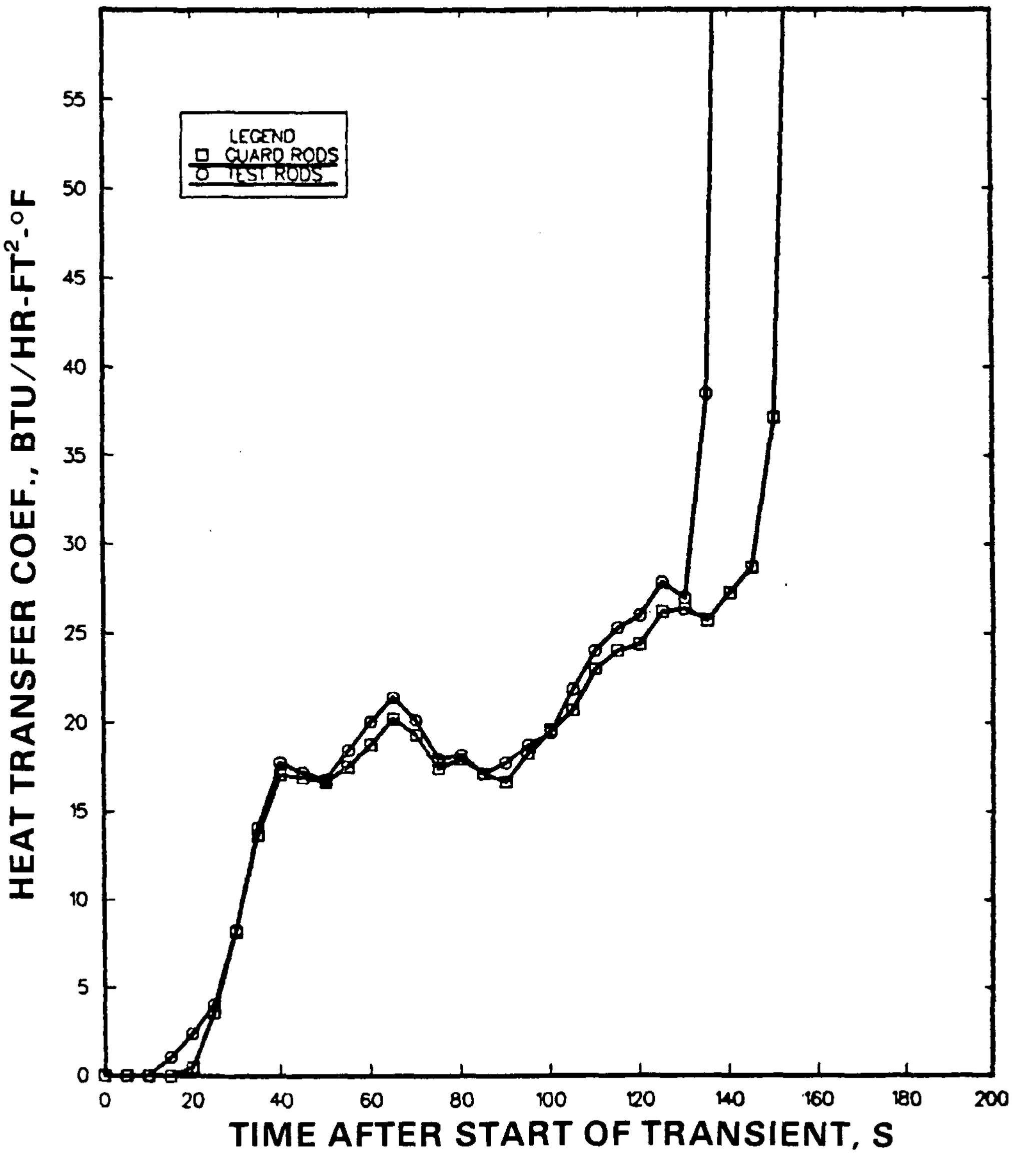
TH-2.14 CALCULATED HEAT TRANSFER COEFFICIENTS (97.3 INCH ELEVATION)



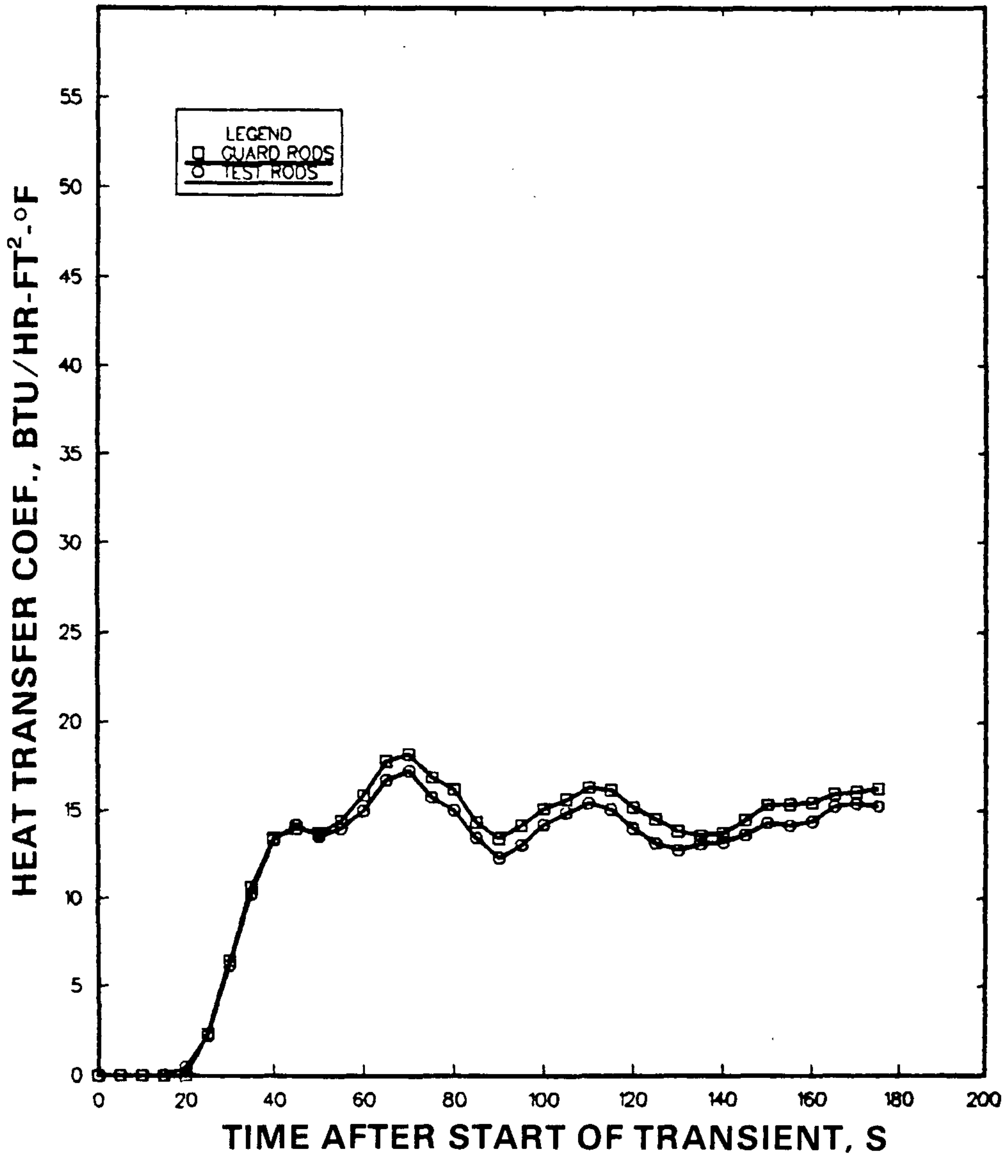
TH-2.14 CALCULATED HEAT TRANSFER COEFFICIENTS (118.3 INCH ELEVATION)



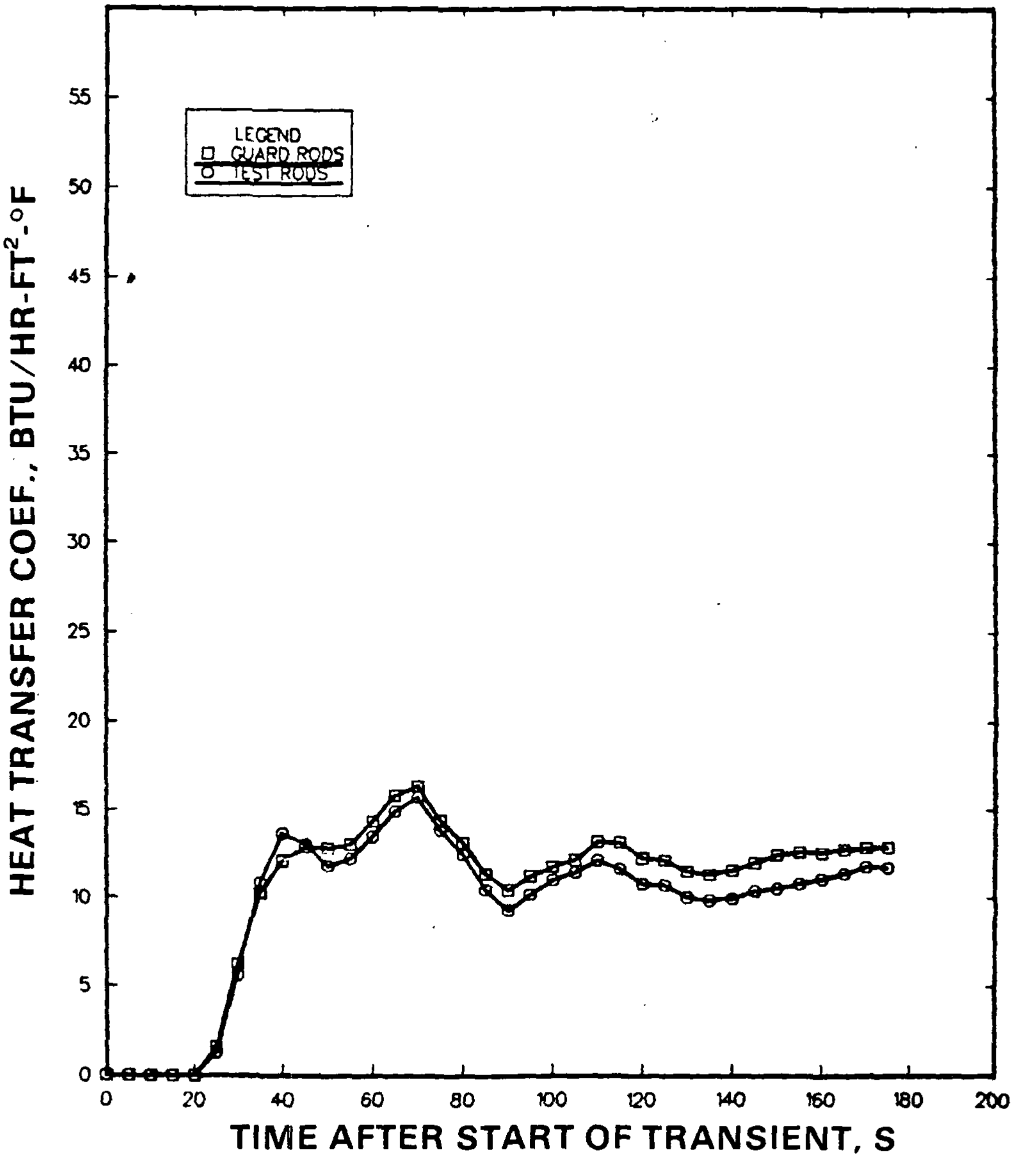
MT-3 CALCULATED HEAT TRANSFER COEFFICIENTS (76.3 INCH ELEVATION)



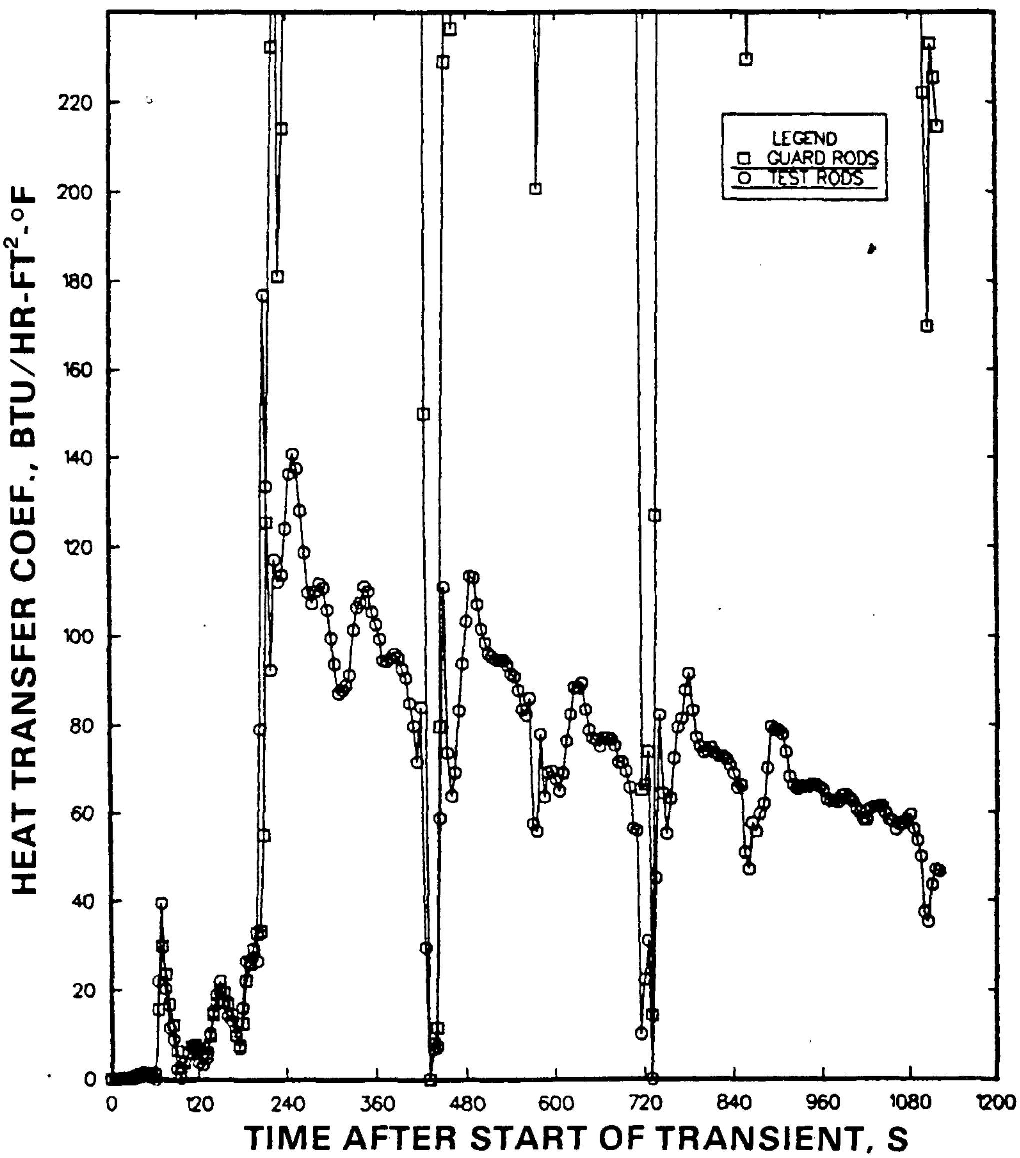
MT-3 CALCULATED HEAT TRANSFER COEFFICIENTS (97.3 INCH ELEVATION)



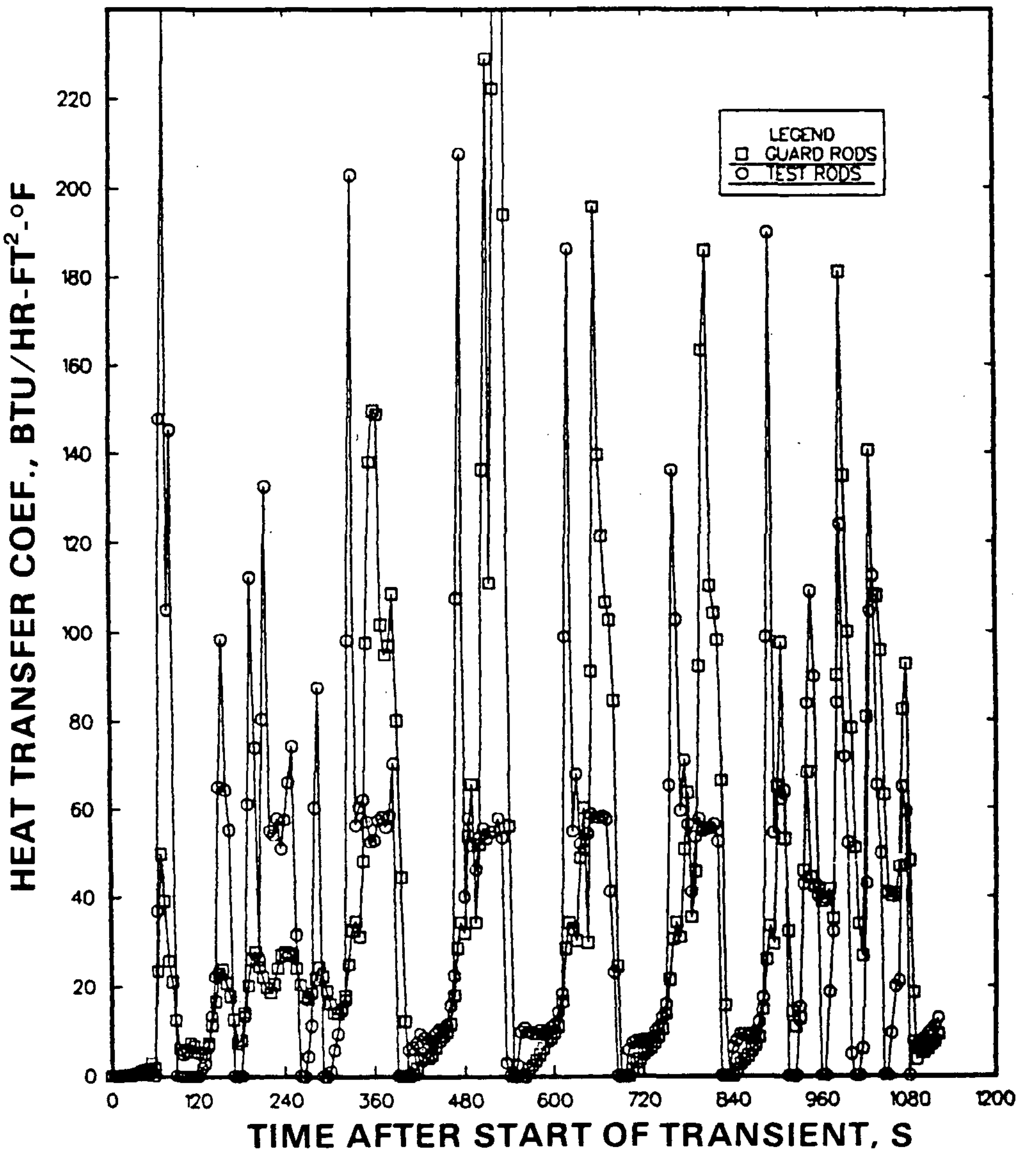
MT-3 CALCULATED HEAT TRANSFER COEFFICIENTS (118.3 INCH ELEVATION)



MT-4 CALCULATED HEAT TRANSFER COEFFICIENTS (76.3 INCH ELEVATION)



MT-4 CALCULATED HEAT TRANSFER COEFFICIENTS (97.3 INCH ELEVATION)



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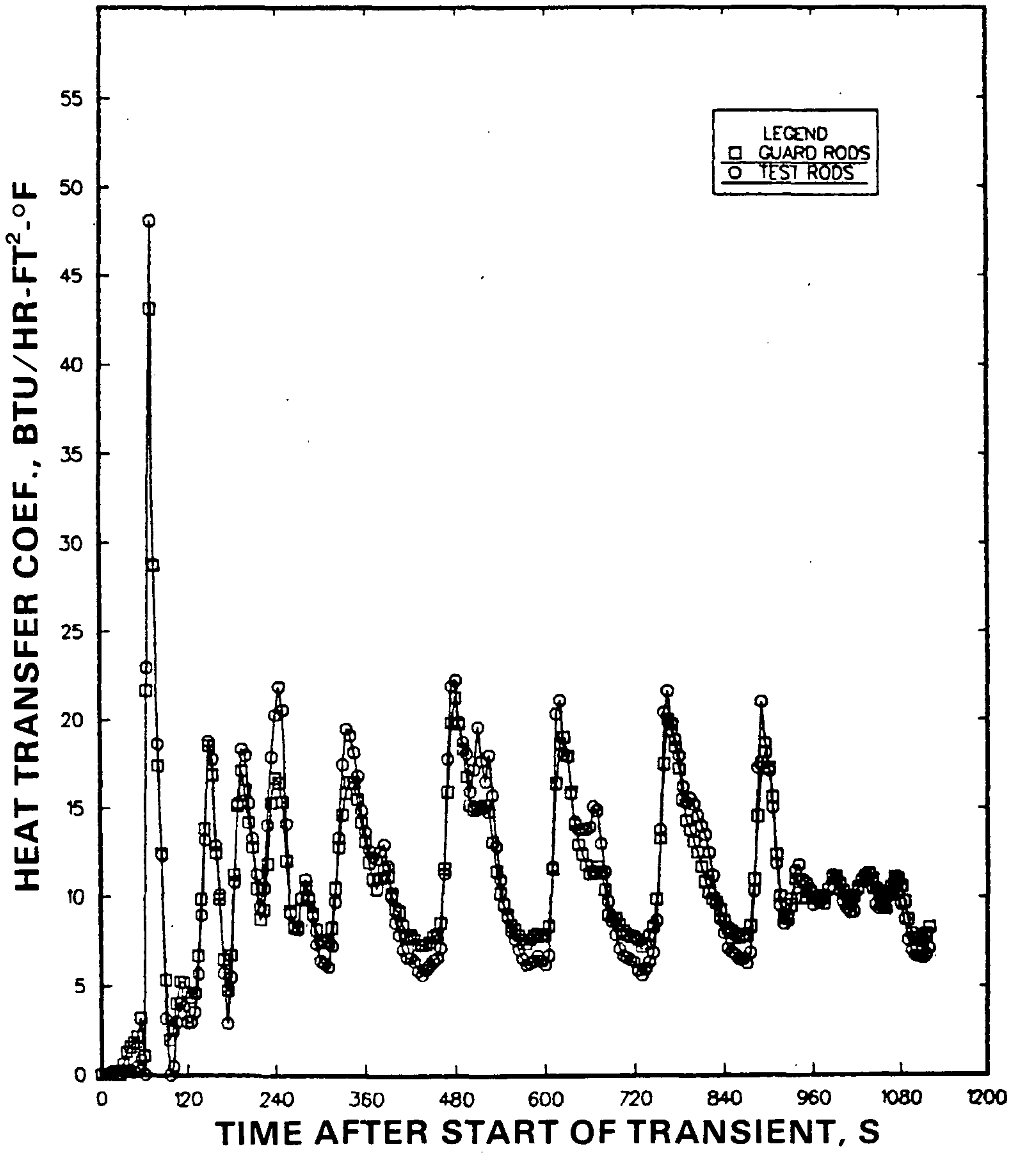

AVERAGE HEAT TRANSFER COEFFICIENT (BTU/HR - FT^2-°F)

TH214	TEST RODS	GUARD RODS	RATIO
LEVEL 13 (76.3 IN.)	16	17	0.94
LEVEL 15 (97.3 IN.)	15	15	1.00
LEVEL 17 (118.3 IN.)	11	12	0.92
MT3			
LEVEL 13 (76.3 IN.)	22	17	1.29
LEVEL 15 (97.3 IN.)	13	13	1.00
LEVEL 17 (118.3 IN.)	10	12	0.83
MT4			
LEVEL 13 (76.3 IN.)	69	340	0.20
83.3 IN.	98	--	-
LEVEL 15 (97.3 IN.)	39	46	0.84
103.3 IN.	27	--	-
LEVEL 17 (118.3 IN.)	11	11	1.00

OUT

HEAT TRANSFER SUMMARY

MT-3 flooding rate less than TH 2.14

- MT-3 HEAT TRANSFER COEFFICIENTS ARE SAME AS THOSE FOR TH-2.14

difference between guard & test rods

- MT-3 SHOWS NO SIGNIFICANT DIFFERENCE IN HEAT TRANSFER COEFFICIENTS BETWEEN TEST AND GUARD RODS

OUT

- MT-4 HEAT TRANSFER COEFFICIENTS IN THE BLOCKAGE ZONE ARE GREATER THAN THOSE FOR TH-2.14

- MT-4 GUARD RODS IN THE BLOCKAGE ZONE DISPLAYED HEAT TRANSFER COEFFICIENTS GREATER THAN THOSE FOR THE TEST RODS

Effective Blockage is less than Local Blockage.

CONCLUSIONS

CONSISTANT

- DATA ARE BOUNDED BY NUREG 0630

- DATA SHOW THAT BLOCKAGE DOES NOT DECREASE HEAT TRANSFER COEFFICIENTS

- DATA FROM MT-4 SHOW IMPROVED HEAT TRANSFER IN BLOCKAGE ZONE