LA-UR-82-2834

CONF-821037--18



MASTER

LA-UR--82-2834

DE83 000615

TITLE TRAC ANALYSIS SUPPORT FOR THE 2D/3D PROGRAM

DISCLAIMER

AUTHOR(S) Ken A. Williams

SUBMITTED TO Tenth Water Reactor Safety Information Meeting
October 12-15, 1982
Washington, D.C.



Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

# TRAC ANALYSIS SUPPORT FOR THE 2D/3D PROGRAM*

by

Ken A. Williams
Project Leader
Energy Division
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

The 2D/3D Program is a multinational (Germany, Japan, and the United States) experimental and analytical nuclear reactor safety research program having as its main purpose the investigation of multidimensional thermal-hydraulic behavior during the refill and reflood phases of loss-of-coolant accidents (LOCAs) in pressurized water reactors (PWRs). The German contribution to the program is the planned Upper Plenum Test Facility (UPTF), a full-scale facility with vessel, four loops, and steam-water core simulator. The Japanese are presently operating two large-scale test facilities as part of this program: the Cylindrical Core Test Facility (CCTF) and the Slab Core Test Facility (SCTF). CCTF is a 2000-electrically heated rod, four-loop facility primarily for investigating integral system reflood behavior. SCTF is a 2000-electrically-heated-rod, slab-core (one fuel assembly wide, eight across, and full height), separate-effects reflood facility. Both facilities are scaled on a power-to-volume basis, preserving full-scale elevations, and are much larger than any existing facilities in the United States (including LOFT). All of these facilities are instrumented better than any existing facilities: conventional instrumentation data channels alone are in excess of one thousand in each facility. The United States contribution to the program is the provision of advanced two-phase flow instrumentation and analytical support.

The Los Alamos National Laboratory is the prime contractor to the NRC in the latter activity. The main analytical tool in this program is the

---

*Work performed under the auspices of the US Nuclear Regulatory Commission.

Transient Reactor Analysis Code (TRAC), a best-estimate, multidimensional, non-equilibrium, thermal-hydraulics computer code developed for the NRC at Los Alamos.[1,2] Through code predictions of experimental results and calculations of PWR transients, TRAC provides the analytic coupling between the facilities and is extending the results to predicting actual PWR behavior.

During the previous fiscal year, the analysis program has matured to the point that it is now playing a central role in the overall 2D/3D program. The TRAC code has been used for a larger number of posttest predictions of both CCTF and SCTF experiments.[3] Through these calculations it has been demonstrated that the code is a reliable tool for predicting the thermal-hydraulic behavior resulting from the parametric variation of test conditions. Specifically, the code has been demonstrated to predict correctly the effects on core reflood resulting from the variation in system operating pressure, ECC subcooling and injection rate, core flooding rate, radial power distribution, local power peaking and the asymmetric initial stored energy of the fuel rods. The twelve experiments to be analyzed in CCTF/SCTF during the next fiscal year will further assess the code's abilities.

Both the experimental findings and the analysis results have a direct and important bearing on licensing issues. Some of the major conclusions that have come from the experiments and that have been predicted by TRAC are the following:

- o Multidimensional hydraulics are responsible for mitigating the thermal consequences of non-uniform power shapes and local power peaking.
- o Core water level stagnation occurs during reflood once the downcomer is filled.
- o Significant bypass of LPCI occurs if the flowrate is increased above the nominal rate.
- o Condensation heating of ECC to near saturation occurs due to superheated vapor exiting the steam generators.
- o Thermal effects of 56% blockages over two adjacent full-scale bundles are not significant during forced-reflood conditions.
- o Significant multidimensional flows in the core during reflood can have an important influence on the thermal response of the fuel cladding even with a symmetrical core power shape.
- o Upper plenum de-entrainment in full-scale hardware can significantly reduce steam binding.

The 2D/3D analysis program is also responsible for providing TRAC calculations of the full-scale PWR's for hypothetical intermediate to large-break LOCAs the reference US, FRG, and Japan plants. These calculations serve two important functions for this program. First, they determine prototypical initial and boundary conditions about which a range of experimental conditions can be chosen to operate the test facilities. However, the ultimate objective is to allow the overall findings (experimental, analytical, and model development) of the 2D/3D program to be related to actual PWR's. The results from the program to date are very encouraging, and can be summarized as follows. The TRAC calculations of full-scale PWR's exhibit behavior similar to that which has been observed experimentally in the CCTF and SCTF; and this same code has been demonstrated to be a reliable tool for the prediction of these experiments. These PWR calculations demonstrate that a large margin of conservatism exists in present licensing requirements for LBLOCA's. Our best-estimate calculations of these reference PWR's indicate that the peak clad temperature (PCT) occurs during the blowdown phase; the PCT is below 1000 K (1340°F).[4]

In conclusion, the analysis effort is functioning as a vital part of the 2D/3D program. Through TRAC analyses the experimental findings can be related from facility to facility; and more importantly, the results of this research program can be directly related to licensing concerns affecting actual PWR's.

## REFERENCES


1. "TRAC-PD2: An Advanced Best-Estimate Computer Program for Pressurized Water Reactor Loss-of-Coolant Accident Analysis," Los Alamos National Laboratory report LA-8709-MS, NUREG/CR-2054 (1981).

2. "TRAC-PF1: An Advanced Best-Estimate Computer Program for Pressurized Water Reactor Analysis," Los Alamos National Laboratory report (to be published).

3. "2D/3D Analysis Program Report - 1981," W. L. Kirchner and K. A. Williams, NUREG/CR-2735, June 1982.

4. "A TRAC-PD2 Analysis of a Large-Break Loss-of-Coolant Accident in a Typical US PWR." J. R. Ireland, NUREG/CR-2775, June 1982.

# TRAC ANALYSIS SUPPORT FOR THE 2D/3D PROGRAM

KEN A. WILLIAMS

PROJECT LEADER

ENERGY DIVISION

LOS ALAMOS NATIONAL LABORATORY

# LOS ALAMOS 2D/3D PERSONNEL

## STAFF MEMBERS

K. WILLIAMS - PROJECT LEADER
M. CAPPIELLO
R. FUJITA
F. MOTLEY
S. SMITH
W. KIRCHNER
B. DALY

## PROGRAMMERS

L.B. MALONE
G. THOMAS
A. BARKER-WOHLETZ

## GRAPHICS SUPPORT

M. TURNER

Los Alamos

# PRESENTATION OUTLINE

- OVERVIEW OF ANALYSIS SUPPORT
- KEY LICENSING ISSUES ADDRESSED
- SCTF ANALYSIS RESULTS WITH TRAC-PF1
- MULTIDIMENSIONAL THERMAL-HYDRAULIC BEHAVIOR IN THE SCTF & CCTF
- SUMMARY OF ANALYSIS FINDINGS RELATED TO LICENSING

Los Alamos

# 2D/3D ANALYSIS PROGRAM HIGHLIGHTS
## SLAB CORE TEST FACILITY (SCTF)

- TRAC PREDICTIVE CAPABILITES DEMONSTRATED BY BLIND PREDICTIONS OF TEN (10) SCTF TESTS TO DATE.

| ANALYSIS OBJECTIVE | SCTF TEST |
|---|---|
| SYSTEM PRESSURE EFFECTS | RUNS 506, 507, 508 |
| ECC SUBCOOLING EFFECTS | RUNS 507, 510 |
| RADIAL POWER SHAPE EFFECTS | RUNS 507, 513, 514 |
| PEAKED POWER EFFECTS | RUNS 507, 512 |
| CORE FLOODING RATE EFFECTS | RUNS 507, 511, 515 |

Los Alamos

# CYLINDRICAL CORE TEST FACILITY (CCTF)

- TRAC PREDICTIVE CAPABILITES DEMONSTRATED BY CALCULATION OF NINE (9) CCTF TESTS TO DATE.

| ANALYSIS OBJECTIVE | CCTF TESTS |
| --- | --- |
| SYSTEM PRESSURE EFFECTS----------- | RUNS 14. 19. 21 |
| LPCI FLOWRATE EFFECTS------------- | RUNS 14. 15 |
| EM RADIAL PEAKING EFFECTS-------- | RUNS 14. 38 |
| CORE FLOODING RATE EFFECTS------ | RUNS 14. 25 |
| ASYMMETRIC ROD TEMP EFFECTS--- | RUNS 14. 39 |
| SYMMETRIC MULTI-D CALCULATION WITH FINE NODALIZATION---------- | RUN 14 |
| CORE II BASE CASE PREDICTION---- | RUN 53 |

Los Alamos

# UPPER PLENUM TEST FACILITY (UPTF)

- LOOP OSCILLATION STUDIES IDENTIFIED PROBLEM AREAS FOR UPTF PROTOTYPICAL SIMULATION OF A GPWR.
- EVALUATION OF SEVERAL PROPOSED MODIFICATIONS TO UPTF LOOPS INDICATES THAT NEAR PROTOTYPICAL ECC DELIVERY CAN BE OBTAINED DURING COMBINED INJECTION. NO PROBLEMS ANTICIPATED FOR COLD LEG INJECTION TESTS.
- CORE SIMULATOR STUDIES IN PROGRESS DEMONSTRATE TRAC CAPABILITY TO MODEL FLOODING AT TIE-PLATE/UCSP.

Los Alamos

# US/J & FRG REFERENCE PWR CALCULATIONS

- NEW INPUT MODELS FOR REFERENCE REACTORS DEVELOPED IN COOPERATION WITH VENDORS.
- ALL STEADY STATE RESULTS IN CLOSE AGREEMENT WITH THOSE SUPPLIED BY VENDORS.
- LOCA CALCULATIONS PERFORMED WITH CURRENT TRAC-PF1.
- REFERENCE REACTORS LBLOCA CALCULATIONS WITH BEST-ESTIMATE TRAC CODE DEMONSTRATE LARGE MARGIN OF CONSERVATISM IN LICENSING REQUIREMENTS.

Los Alamos

# KEY LICENSING ISSUES ADDRESSED BY THE 2D/3D ANALYSIS PROGRAM (1)

- SCALING
  - GEOMETRY
  - OPERATING CONDITIONS
- MULTIDIMENSIONAL EFFECTS
  - POWER SHAPES
  - SYMMETRICAL CORE TEMPERATURES
  - ASYMMETRICAL CORE TEMPERATURES
  - FULL-RADIUS EFFECTS
  - "HOT-ROD" EFFECT
  - LOCAL POWER PEAKING (EM VALUES)

Los Alamos

# KEY LICENSING ISSUES ADDRESSED BY THE 2D/3D ANALYSIS PROGRAM (2)

- CORE RECOVERY
  - . CORE WATER LEVEL
  - . STEAM-DROPLET COOLING
  - . PARAMETRIC EFFECT OF PRESSURE
- ECCS EFFECTIVENESS
  - . NOMINAL ECCS FLOWS
  - . HIGH (200 PER CENT) LPCI FLOW RATE
  - . CONDENSATION HEATING OF ECC

Los Alamos

# KEY LICENSING ISSUES ADDRESSED BY THE 2D/3D ANALYSIS PROGRAM (3)

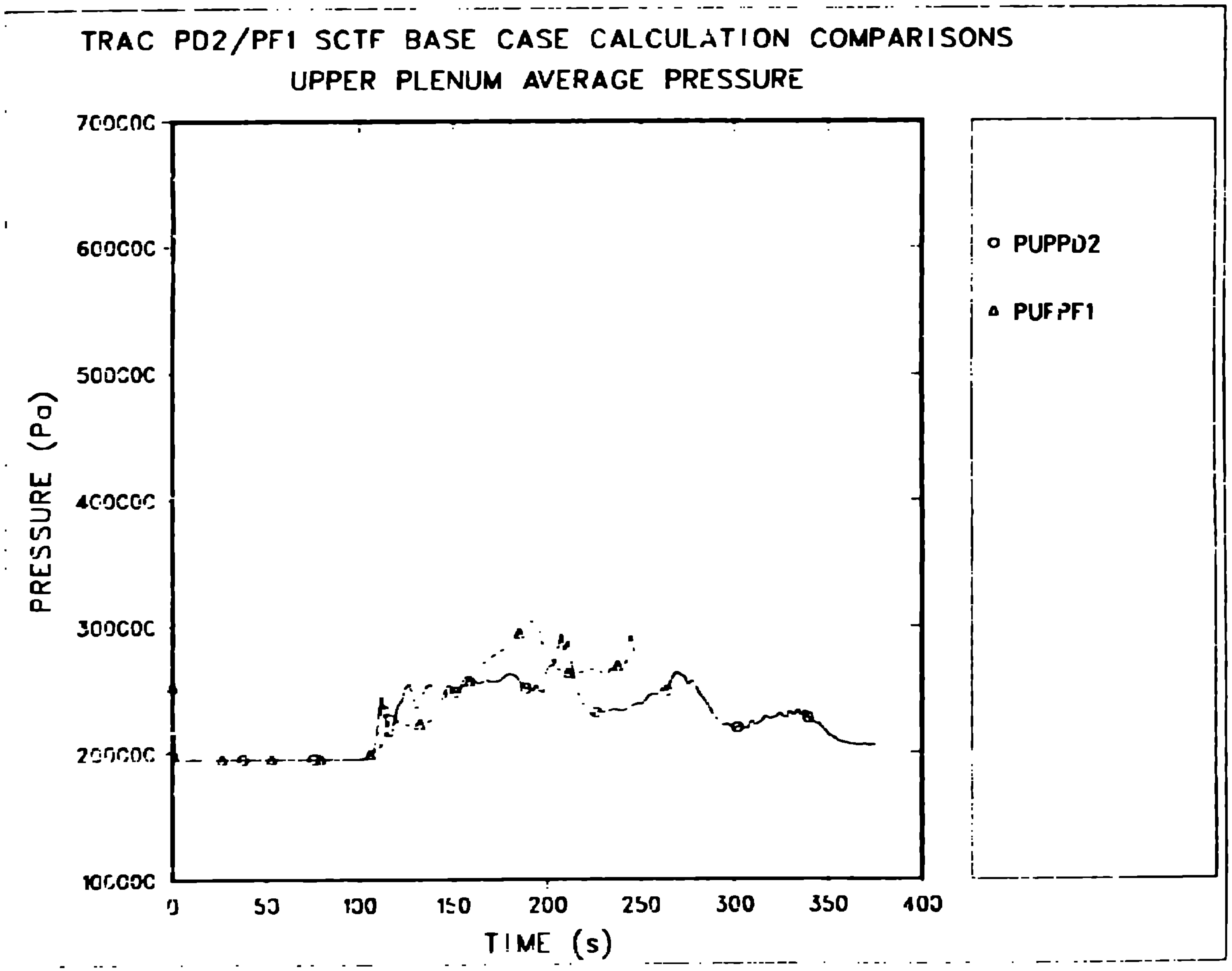
- STEAM BINDING
  - LIQUID CARRYOVER FRACTION
  - UPPER PLENUM STRUCTURAL DEENTRAINMENT
  - LOOP EFFECTS – ACTIVE COMPONENTS
- CORE BLOCKAGES
  - 50 PER CENT BLOCKAGES OVER 2 ASSEMBLIES AT CORE MIDPLANE
  - FULL-RADIUS EFFECTS

Los Alamos

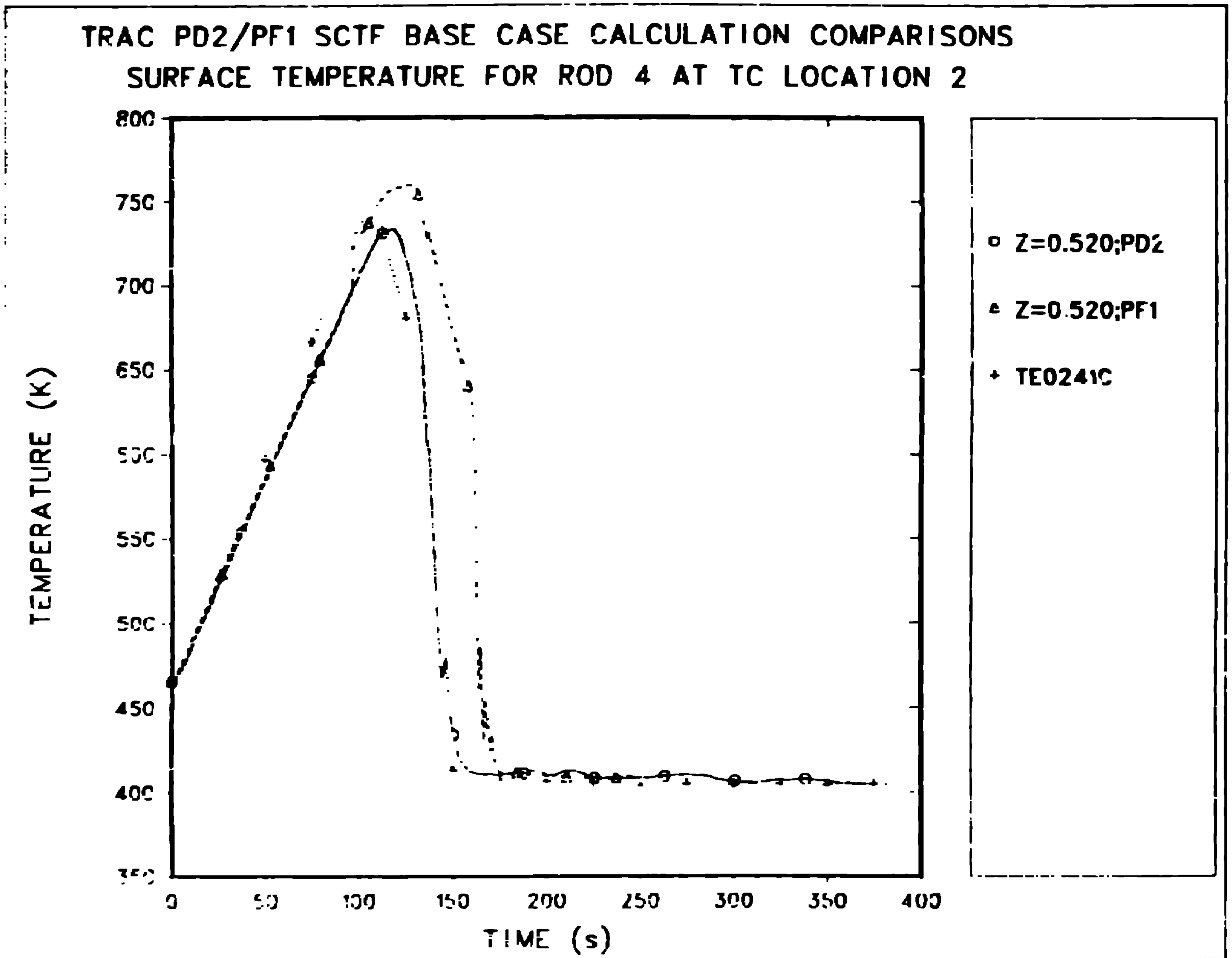
# RECENT SCTF ANALYSIS RESULTS

# WITH TRAC-PF1

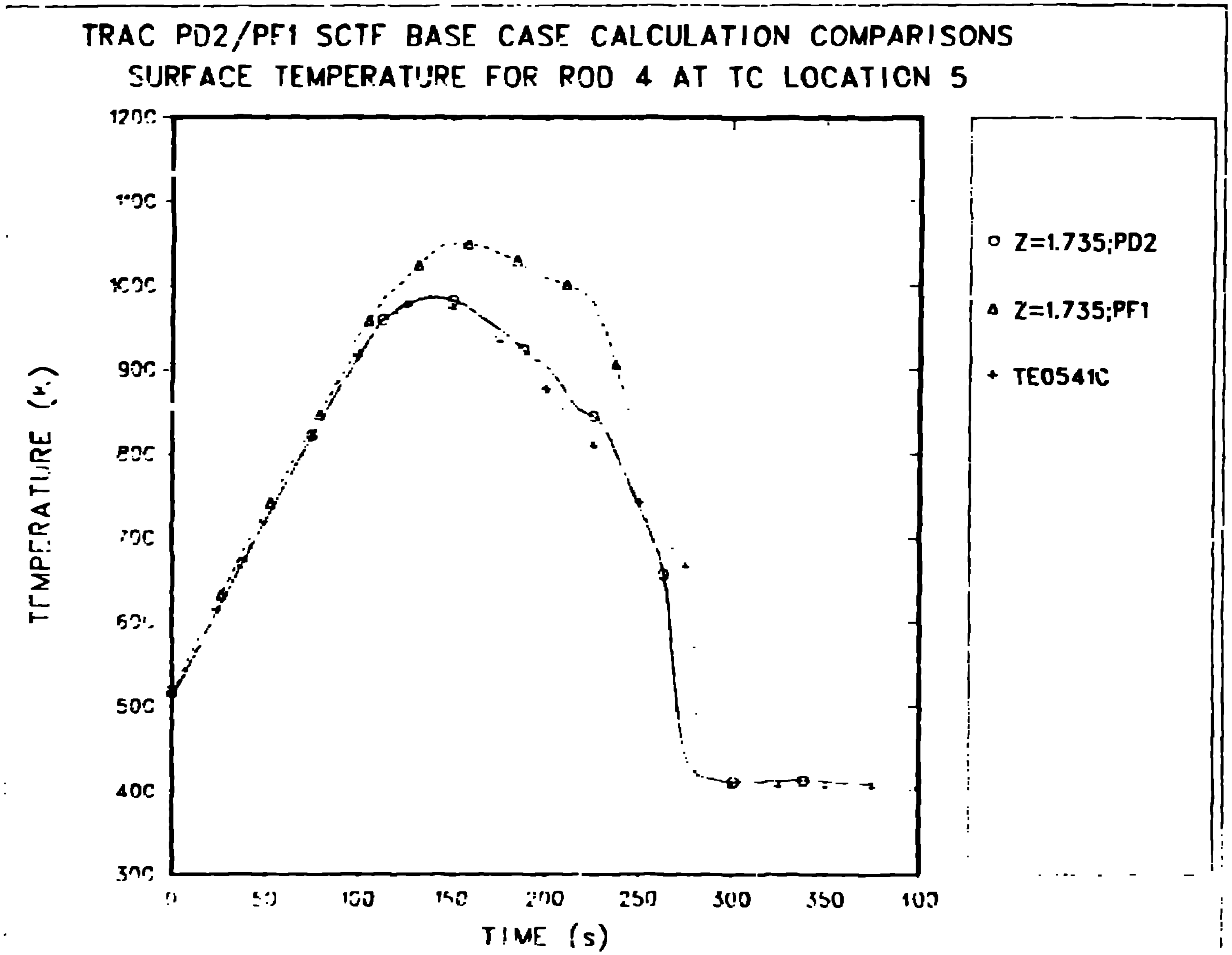
Los Alamos



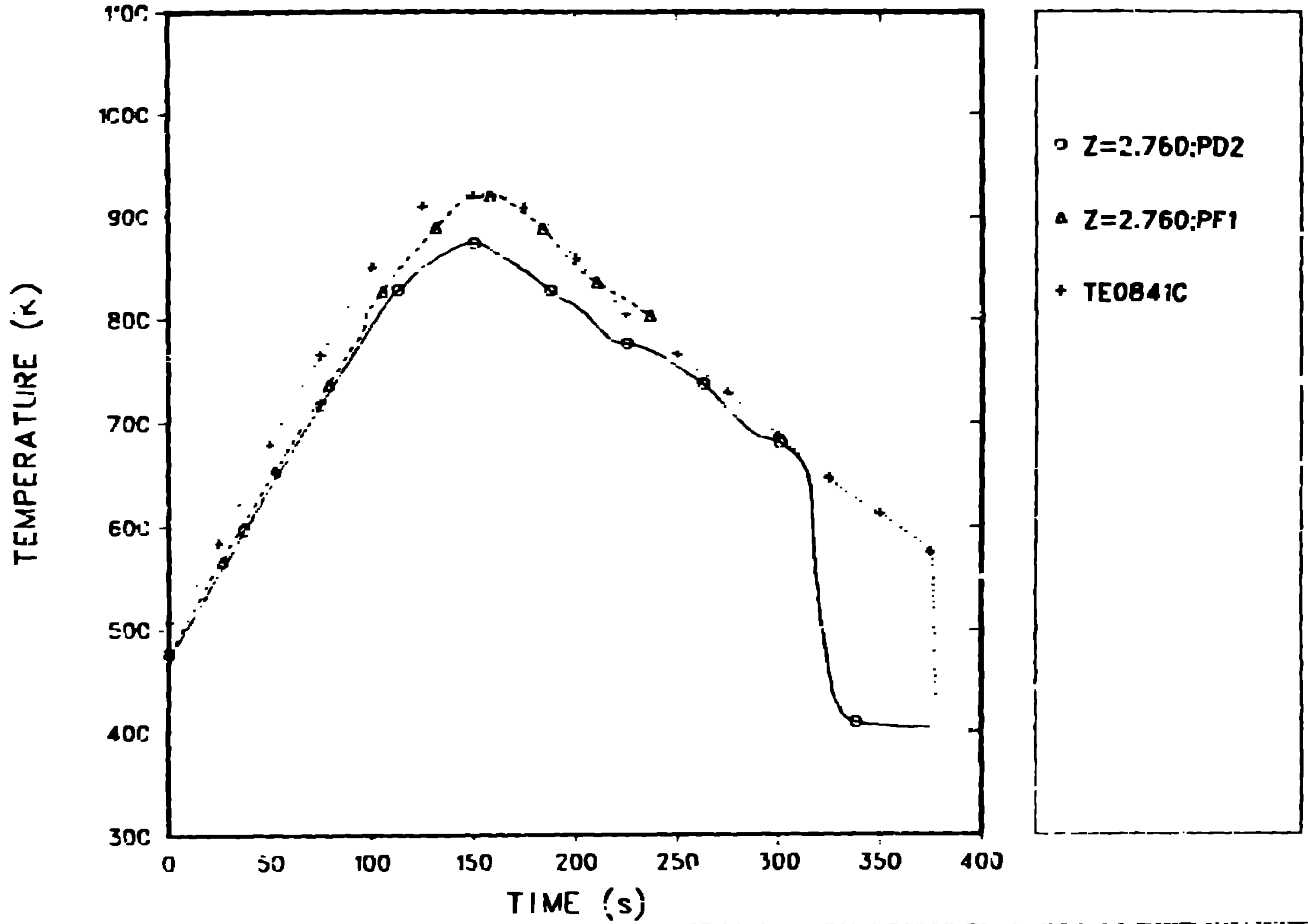
TRAC PD2/PF1 SCTF BASE CASE CALCULATION COMPARISONS
UPPER PLENUM AVERAGE PRESSURE
PRESSURE (Pa)
700000
600000
500000
400000
300000
200000
100000
0
50
100
150
200
250
300
350
400
TIME (s)
PUPPD2
PUPPF1



TRAC PD2/PF1 SCTF BASE CASE CALCULATION COMPARISONS
SURFACE TEMPERATURE FOR ROD 4 AT TC LOCATION 2
TEMPERATURE (K)
800
750
700
650
600
550
500
450
400
350
0
50
100
150
200
250
300
350
400
TIME (s)
Z=0.520;PD2
Z=0.520;PF1
TE0241C


TRAC PD2/PF1 SCTF BASE CASE CALCULATION COMPARISONS
SURFACE TEMPERATURE FOR ROD 4 AT TC LOCATION 5
TEMPERATURE (K)
TIME (s)
Z=1.735;PD2
Z=1.735;PF1
TE0541C

TRAC PD2/PF1 SCTF BASE CASE CALCULATION COMPARISONS
SURFACE TEMPERATURE FOR ROD 4 AT TC LOCATION 8

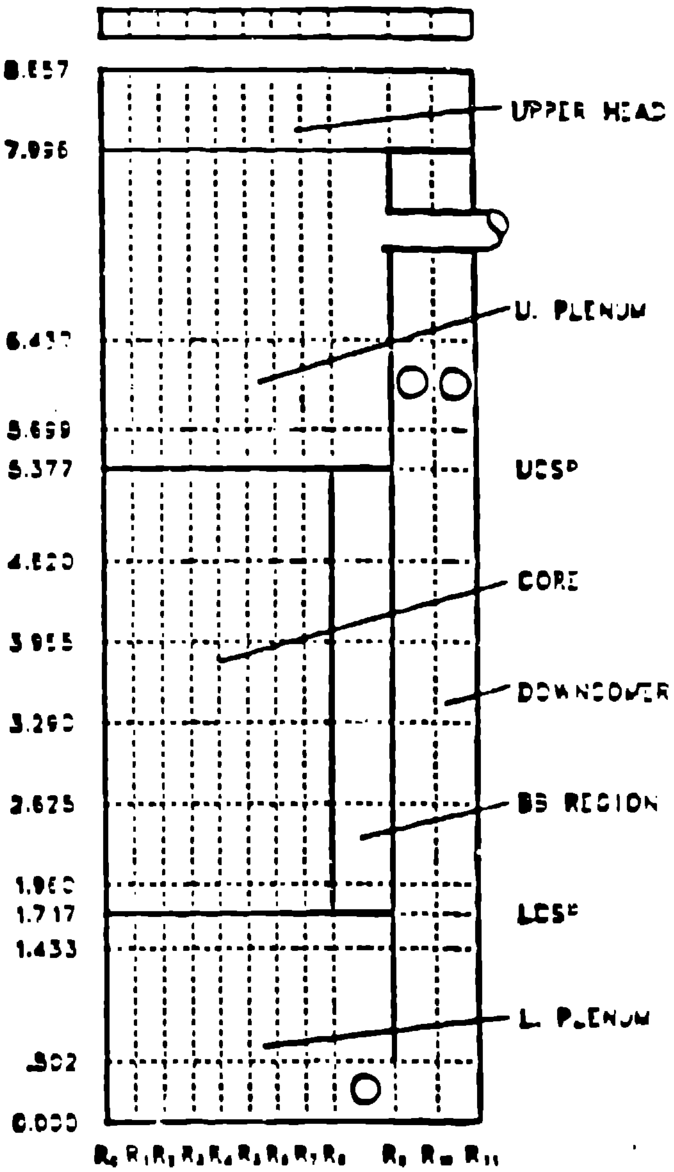


# MULTIDIMENSIONAL THERMAL-HYDRAULIC

# BEHAVIOR IN THE SCTF AND CCTF

Los Alamos

- RADIAL CORE POWER DISTRIBUTION
  - Run 507 (Base Case) – Slightly skewed profile
  - Run 513 – Uniform or flat profile
  - Run 514 – Highly skewed profile

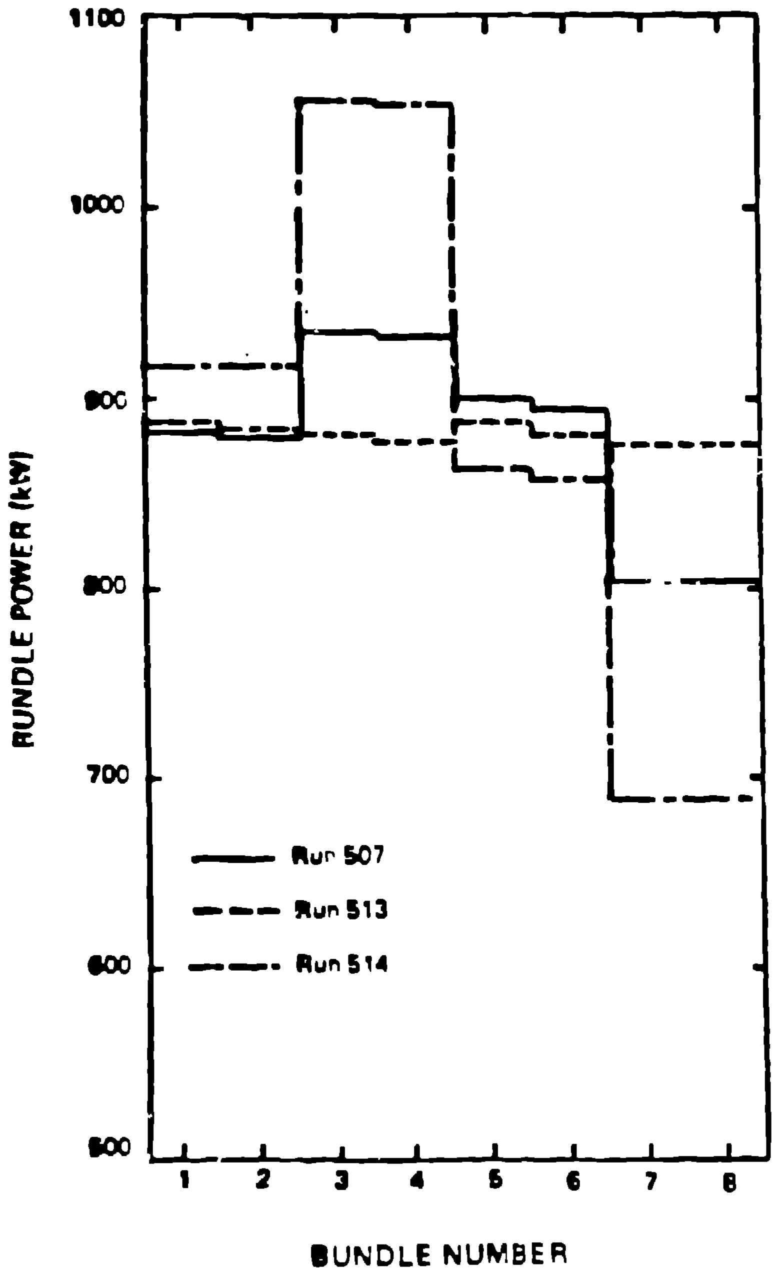



$R_1$ = .230
$R_2$ = .450
$R_3$ = .690
$R_4$ = .920
$R_5$ = 1.150
$R_6$ = 1.380
$R_7$ = 1.610
$R_8$ = 1.840
$R_9$ = 2.334
$R_{10}$ = 2.677
$R_{11}$ = 3.020

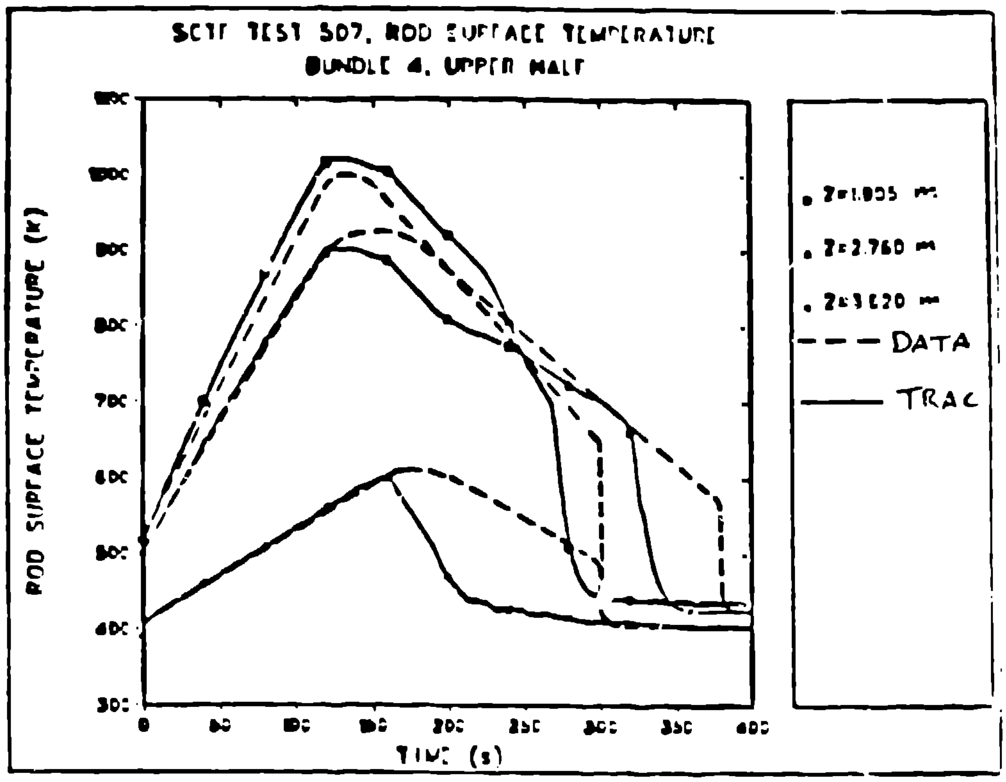
THICKNESS = .230

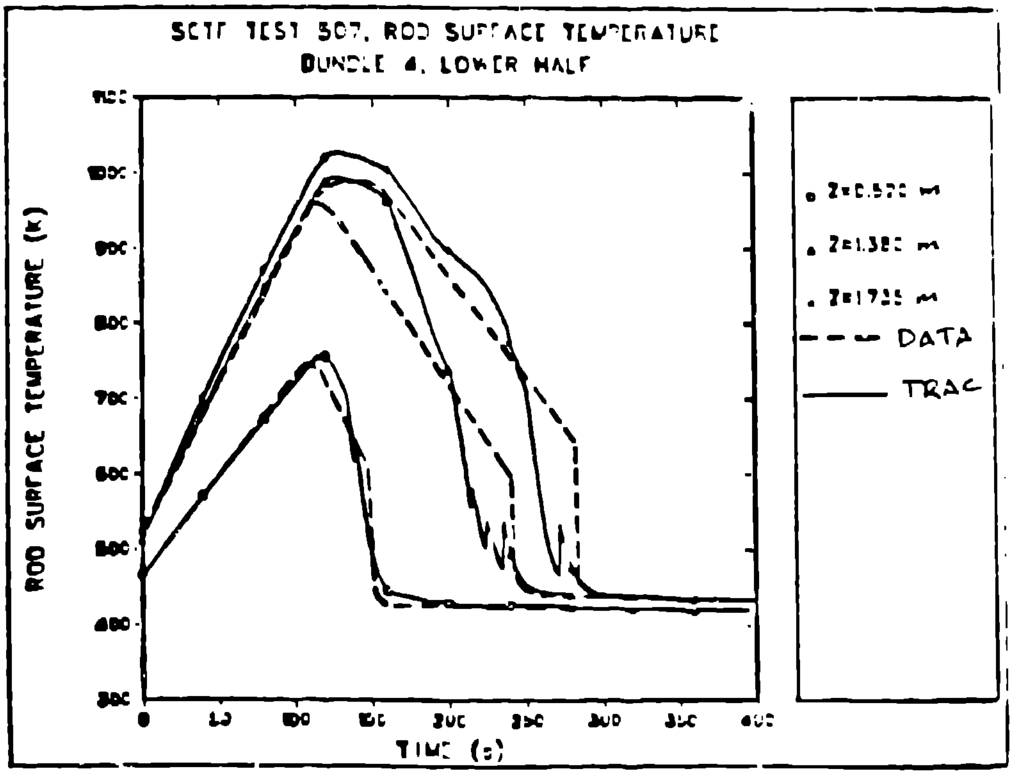
# SCTF VESSEL

SCTF vessel component noding diagram.

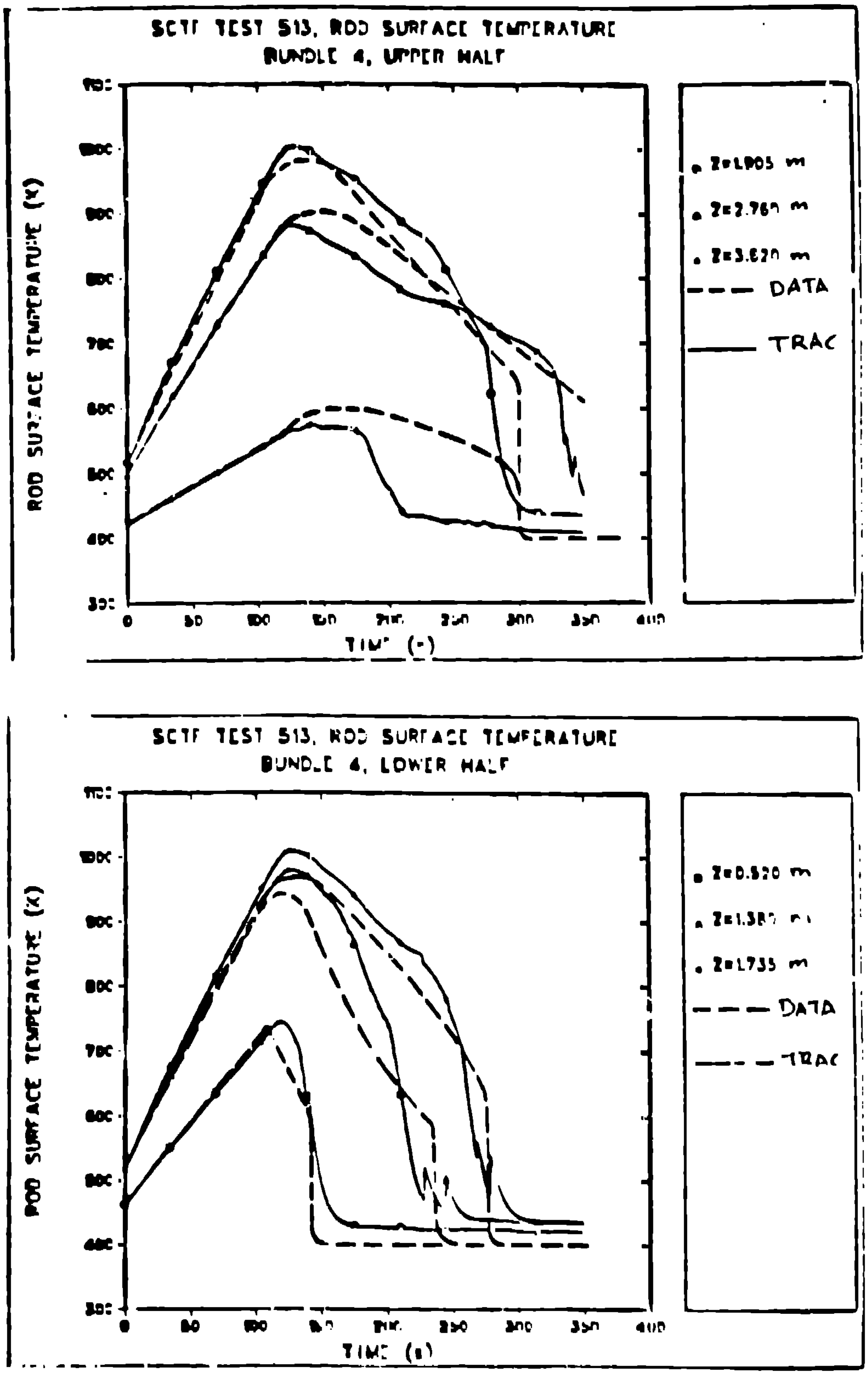



Initial core power distribution for SCTF power effects tests.

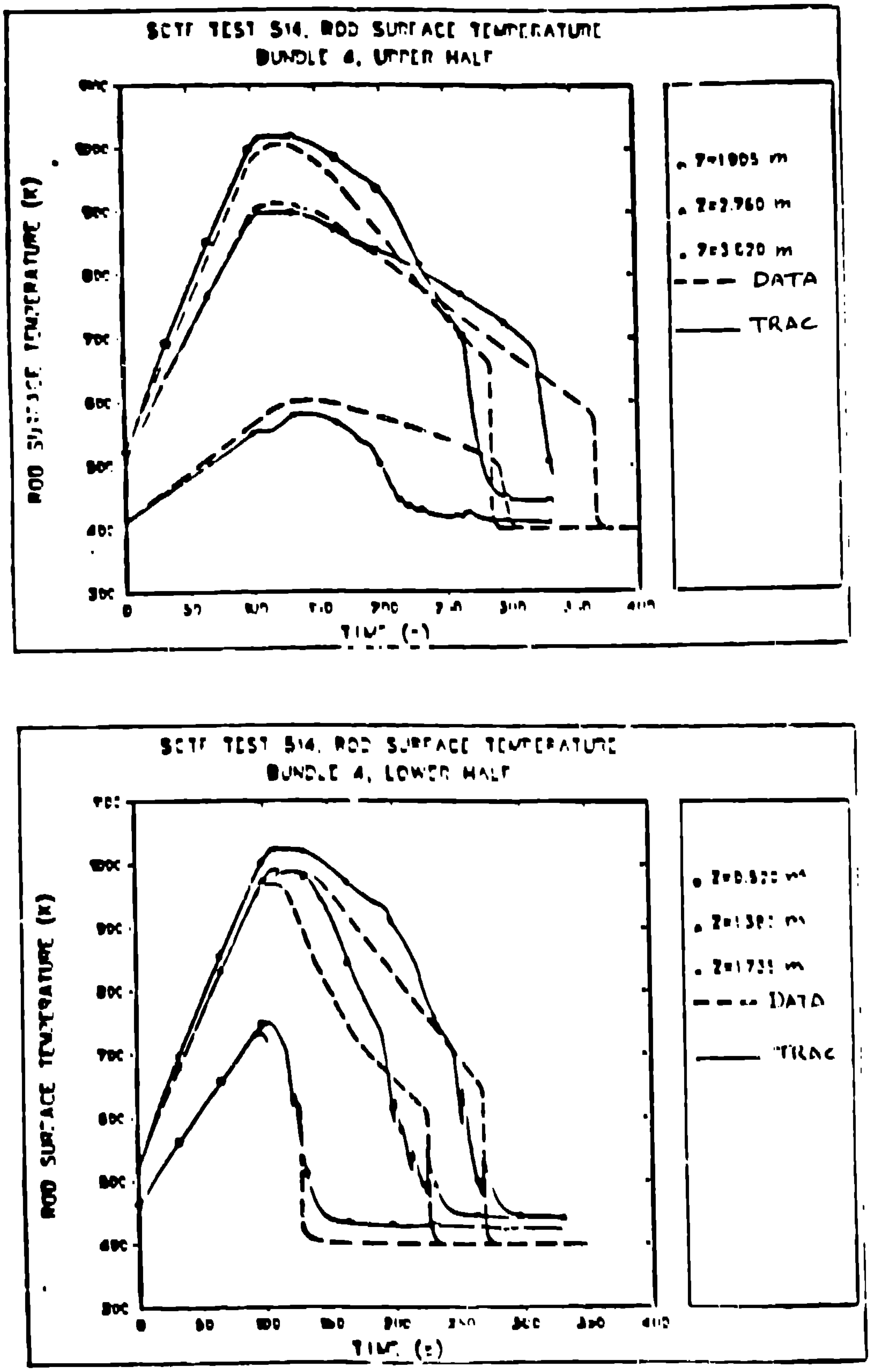


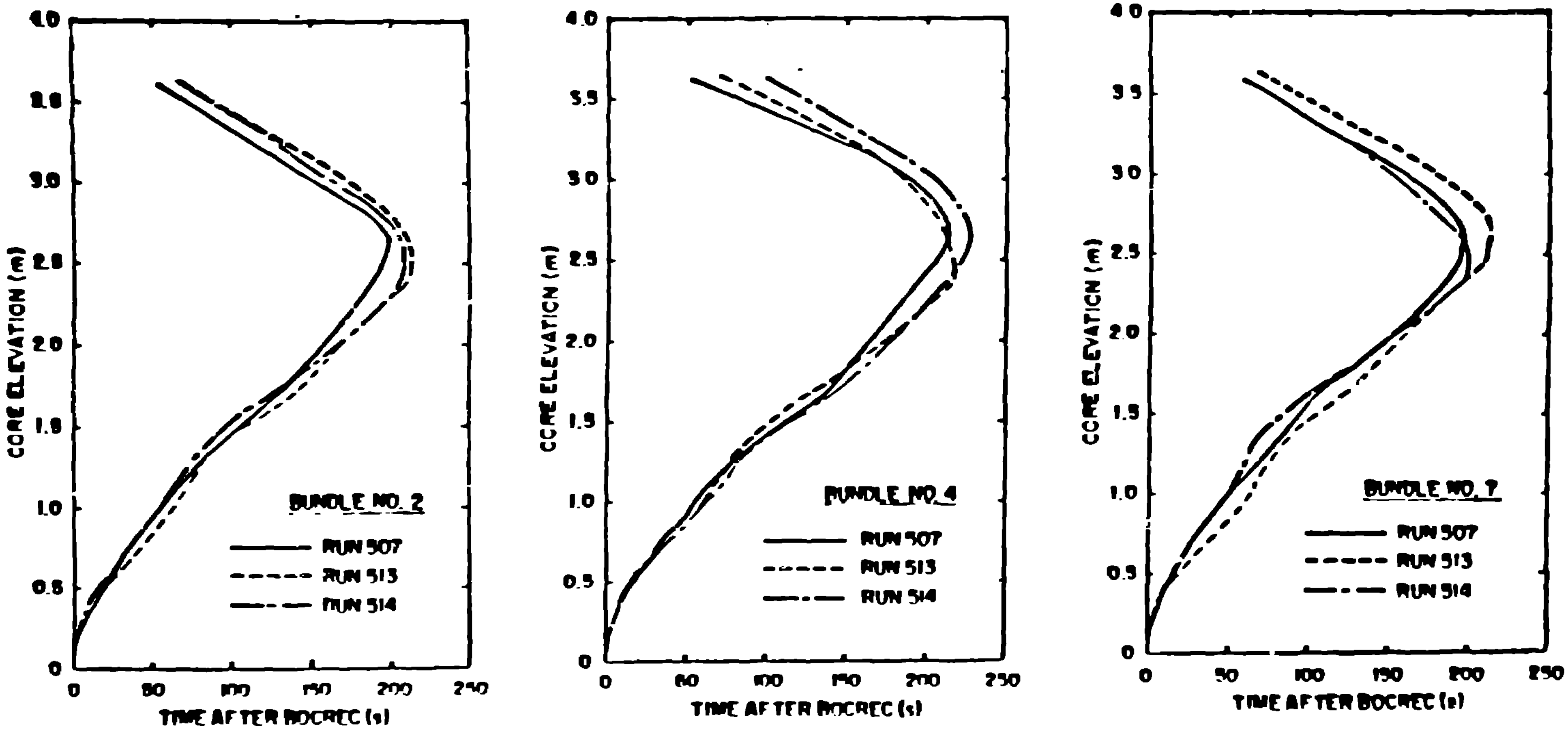

Rod surface temperatures for Bundle 4 of SCTF Run 507.



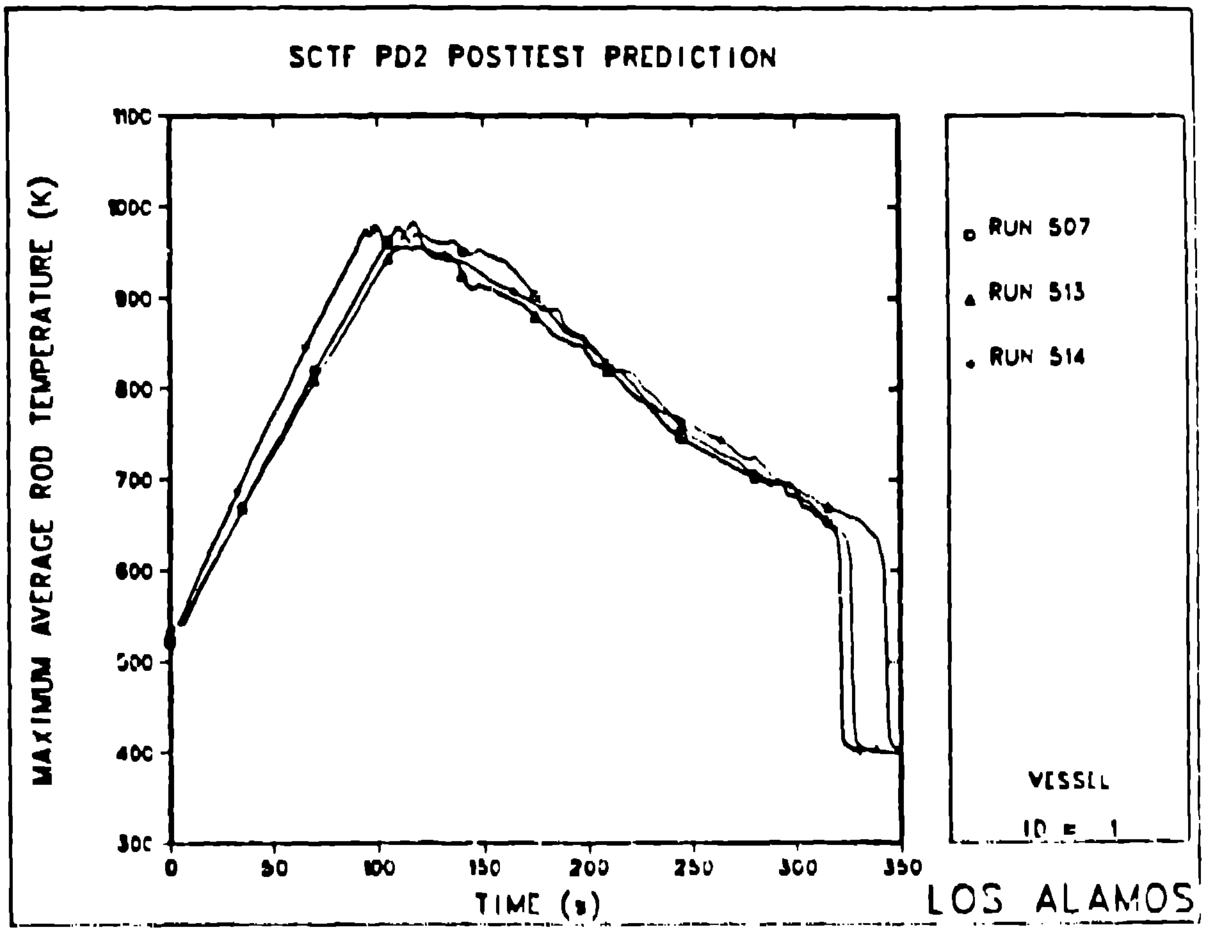

Rod surface temperatures for Bundle 4 of SCTF Run 513.




Rod surface temperatures for Bundle 4 of SCTF Run 514.




Predicted quench envelopes for SCTF power-effects tests.




Maximum rod temperatures for SCTF power-effects tests.

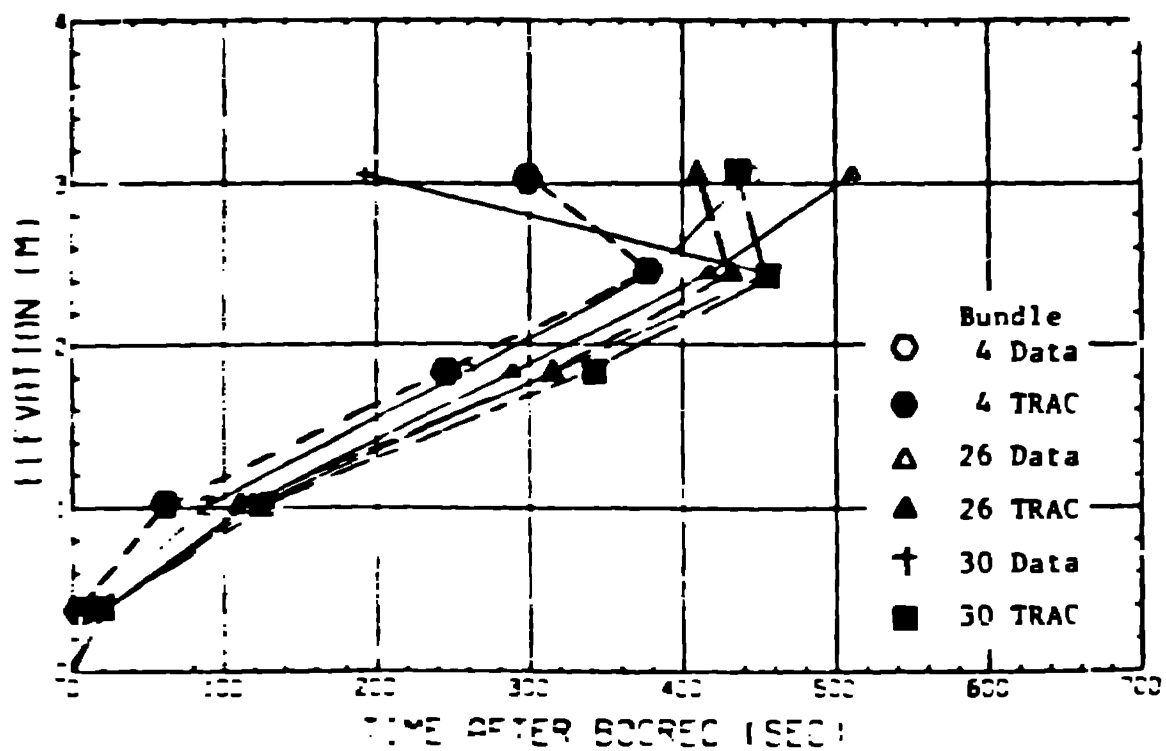
# TRAC ANALYSIS OF CCTF RUN38

INITIAL POWER--9.28 MW

LINEAR POWER--1.39 KW/M

SYSTEM PRESSURE--2.03 BAR

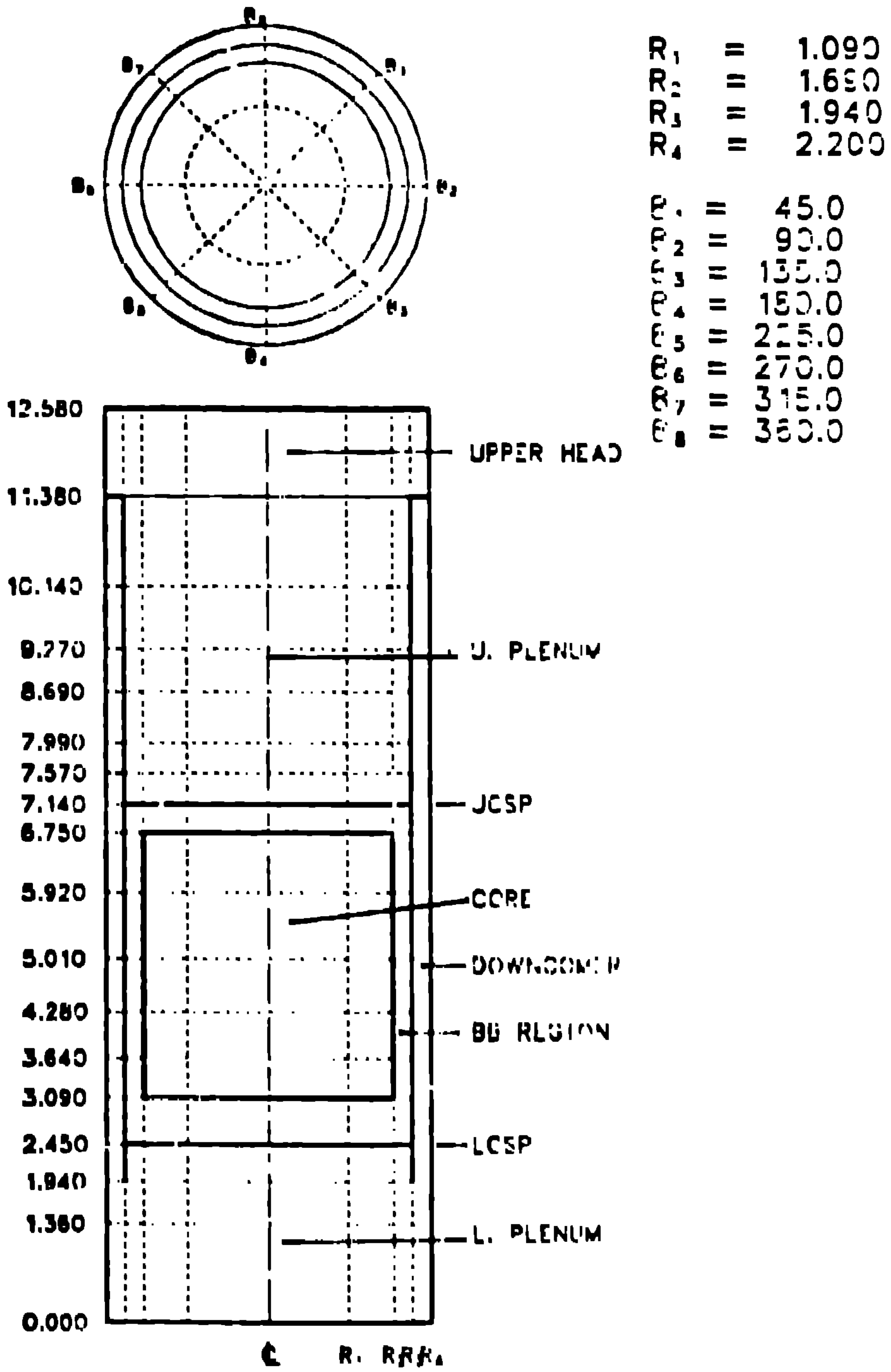
RADIAL POWER SHAPE-1.299:1.092:0.841



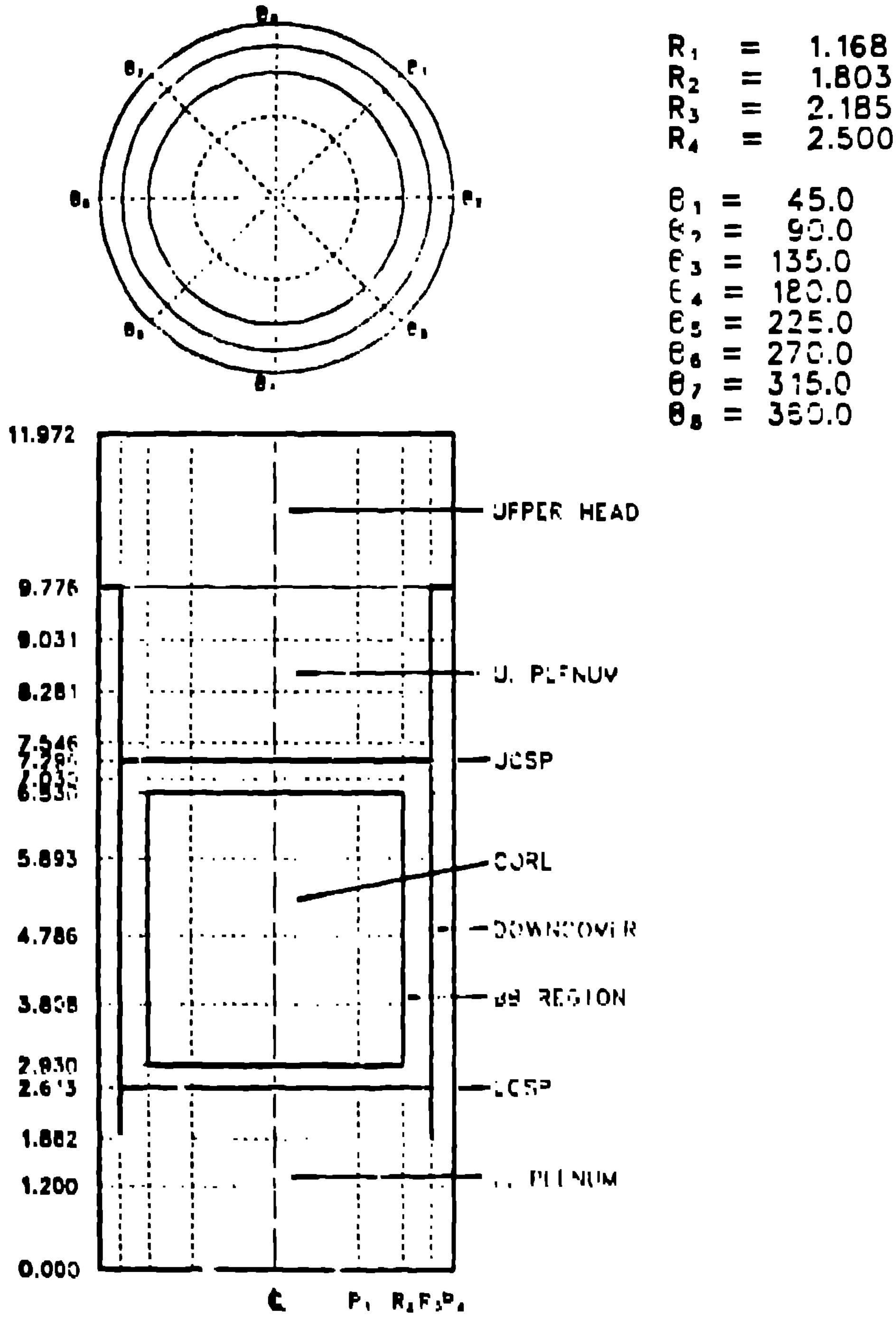

Quench envelopes (CCTF Run 38).

# FULL-SCALE PWR LBLOCA CALCULATIONS

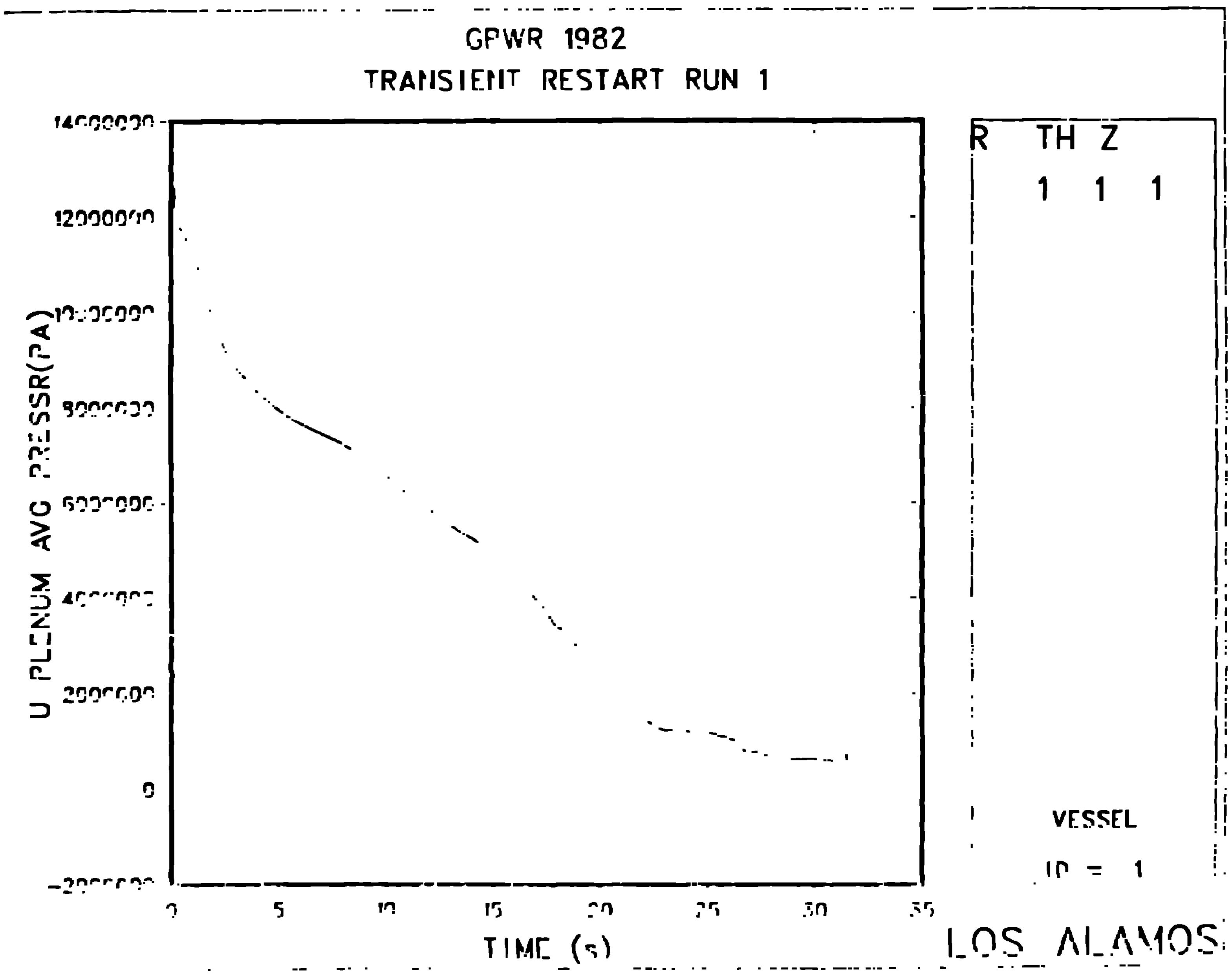
Los Alamos

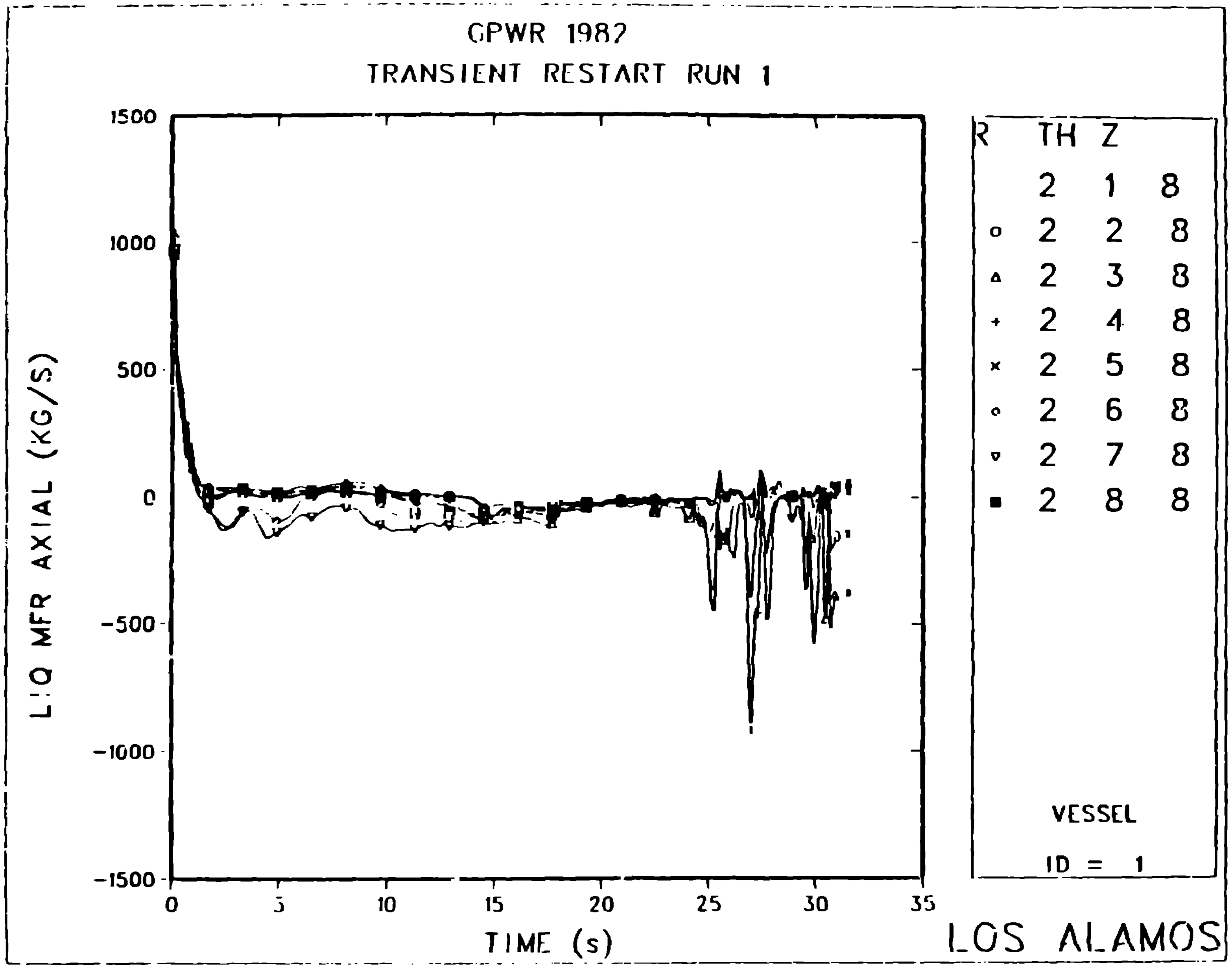



TRAC MODEL OF US/J PWR

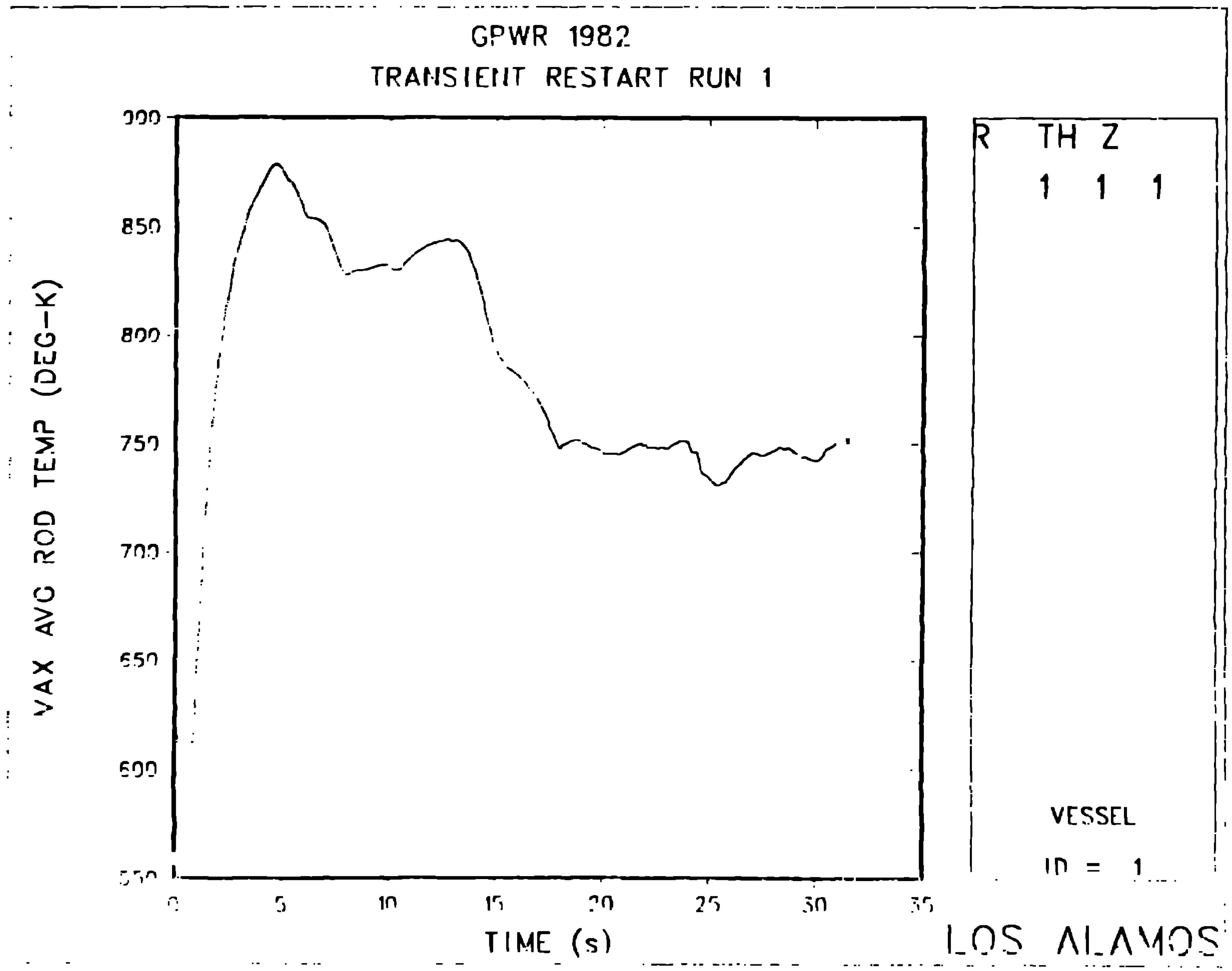


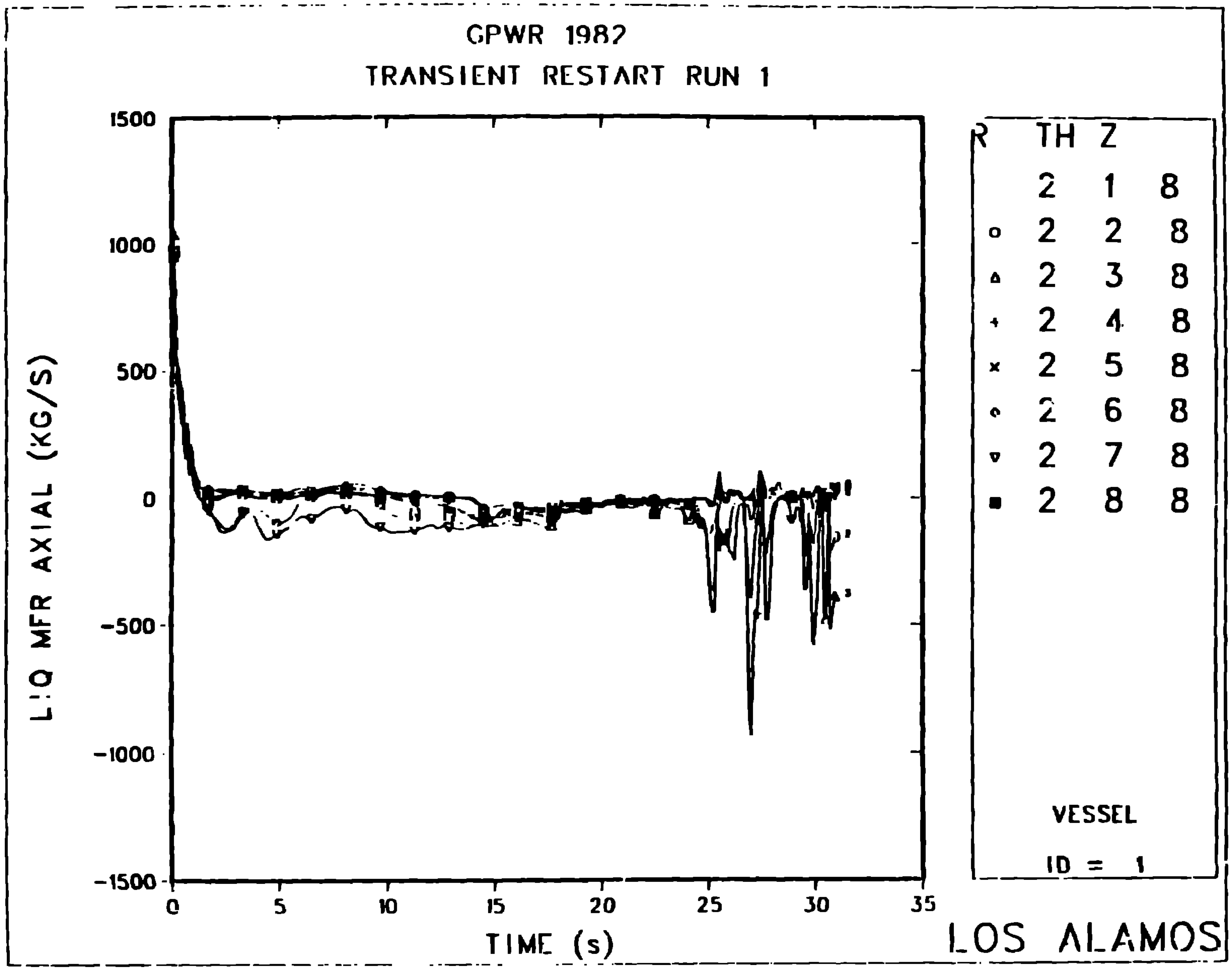

GPWR VESSEL NODING

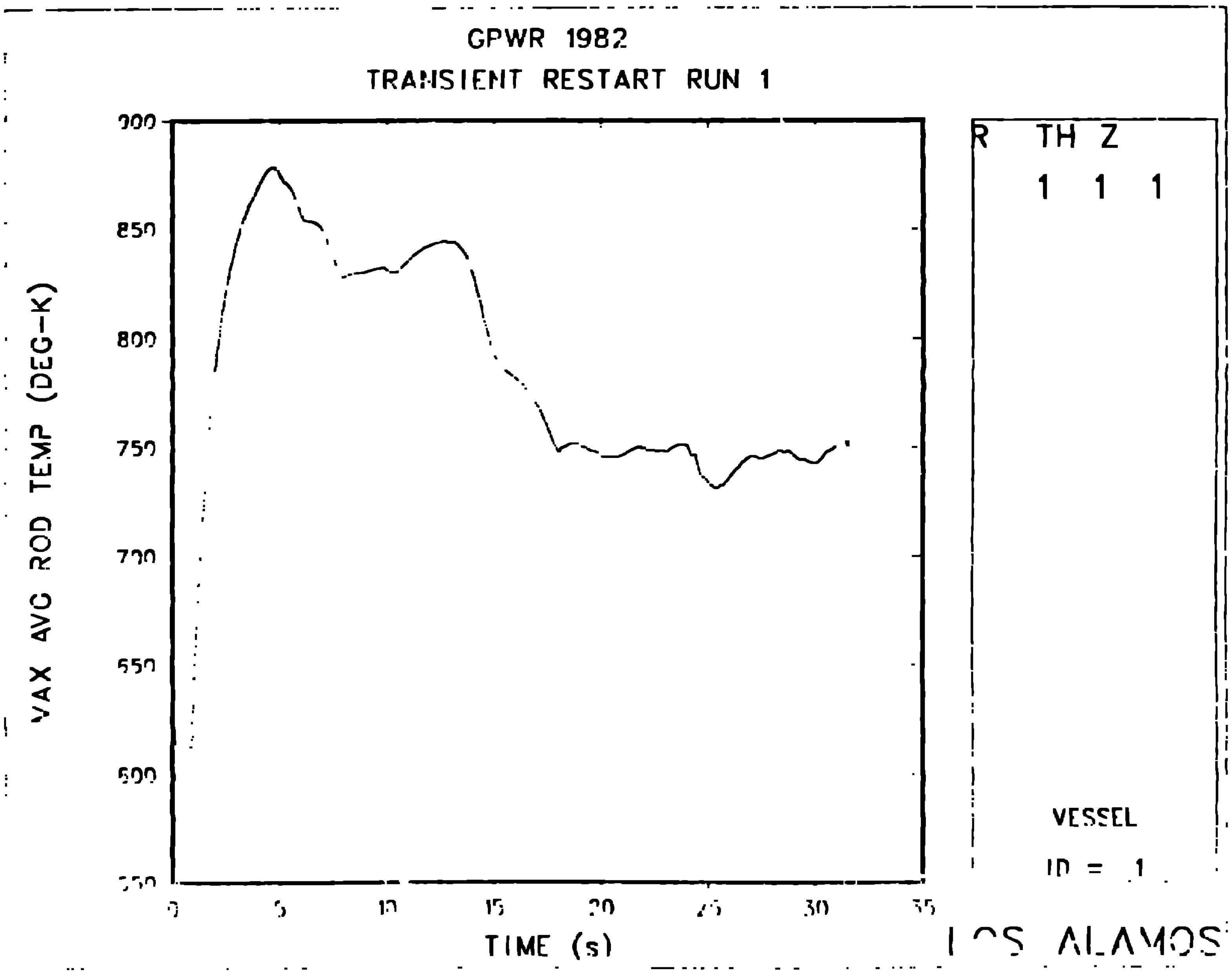

GPWR 1982
TRANSIENT RESTART RUN 1
U PLENUM AVG PRESSR(PA)
TIME (s)
R TH Z
1 1 1
VESSEL
ID = 1
LOS ALAMOS



GPWR 1982
TRANSIENT RESTART RUN 1
LIQ MFR AXIAL (KG/S)
1500
1000
500
0
-500
-1000
-1500
0
5
10
15
20
25
30
35
TIME (s)
R TH Z
2 1 8
2 2 8
2 3 8
2 4 8
2 5 8
2 6 8
2 7 8
2 8 8
VESSEL
ID = 1
LOS ALAMOS


GPWR 1982
TRANSIENT RESTART RUN 1
VAX AVG ROD TEMP (DEG-K)
900
850
800
750
700
650
600
550
0
5
10
15
20
25
30
35
TIME (s)
R TH Z
1 1 1
VESSEL
ID = 1
LOS ALAMOS


GPWR 1982
TRANSIENT RESTART RUN 1
1500
1000
500
0
-500
-1000
-1500
LIQ MFR AXIAL (KG/S)
0
5
10
15
20
25
30
35
TIME (s)
R TH Z
2 1 8
2 2 8
2 3 8
2 4 8
2 5 8
2 6 8
2 7 8
2 8 8
VESSEL
ID = 1
LOS ALAMOS


GPWR 1982
TRANSIENT RESTART RUN 1
VAX AVG ROD TEMP (DEG-K)
900
850
800
750
700
650
600
550
0
5
10
15
20
25
30
35
TIME (s)
R TH Z
1 1 1
VESSEL
ID = 1

LOS ALAMOS

# SUMMARY OF ANALYSIS FINDINGS

# RELATED TO LICENSING

Los Alamos

## REACTOR SAFETY ISSUES ADDRESSED BY SCTF ANALYSIS

- MULTIDIMENSIONAL HYDRAULICS MITIGATE SEVERE CONSEQUENCES OF NON-UNIFORM POWER SHAPES AND LOCAL PEAKING.
- IMPROVED UNDERSTANDING OF THERMAL-HYDRAULICS OF CORE REFLOOD IN FULL-RADIUS GEOMETRY.
- THERMAL EFFECT OF 50 PER CENT BLOCKAGES OVER TWO BUNDLES INSIGNIFICANT FOR FORCED REFLOOD CONDITIONS.
- SIGNIFICANT UPPER PLENUM DE-ENTRAINMENT IMPLIES REDUCED STEAM BINDING.

Los Alamos

# REACTOR SAFETY ISSUES ADDRESSED BY CCTF ANALYSIS

- MULTIDIMENSIONAL HYDRAULICS MITIGATES SEVERE CONSEQUENCES OF NON-UNIFORM POWER SHAPES.
- SIGNIFICANT REFLOOD BYPASS OF EXCESS LPCI.
- PRESSURE EFFECTS OF REFLOOD CONFIRMED.
- CORE WATER LEVEL STAGNATES DURING REFLOOD AFTER DOWNCOMER FILLS.
- CONDENSATION HEATING OF LPCI REDUCES SUBCOOING.

Los Alamos

# FULL-SCALE PWR LOCA CALCULATIONS

- US/JAPAN AND GPWR CALCULATIONS DEMONSTRATE SIGNIFICANT MARGIN OF CONSERVATISM IN LBLOCA LICENSING REQUIREMENTS.
- THERMAL-HYDRAULIC PHENOMENA PREDICTED IN LPWR'S CORRELATE WELL WITH 2D/3D EXPERIMENTAL PROGRAM RESULTS.
- PEAK CLAD TEMPERATURE OCCUR DURING EARLY BLOWDOWN PHASE WITH BEST-ESTIMATE CALCULATION. PCT LESS THAN 1000 K (1340 F).

Los Alamos