52-003

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

December 1, 1995

APPLICANT: Westinghouse Electric Corporation

PROJECT: AP600

SUBJECT: SUMMARY OF MEETING TO DISCUSS THE USE OF MAAP4 FOR AP600 PROBABILISTIC RISK ASSESSMENT (PRA) SUCCESS CRITERIA ANALYSIS

The subject meeting was held in Westinghouse's Rockville, Maryland office on October 24 and 25, 1995, between representatives of Westinghouse and the Nuclear Regulatory Commission (NRC) staff. The purpose of the meeting was to discuss details and limitations of the use of the MAAP4 code in the analysis of AP600 Level 1 PRA accident sequence success criteria. An overview of MAAP4 basic modelling, input parameters conservatisms, effect of input parameter variations, and application guidelines was provided. This meeting was part of an ongoing effort to resolve T/H uncertainty concerns raised by the staff in an August 14, 1995, letter to Westinghouse.

Highlights of the discussion are summarized below:

Peak Cladding Temperature Output:

It was noted that the peak cladding temperature (PCT) calculation does not represent the hot pin PCT. This is because the lumped radial peaking factors used in the MAAP4 core noding do not model the hot pin radial peaking factor. Therefore, the MAAP4 calculated PCT margin to the 2200°F criterion for various success sequences is not as large as it appears to be.

Accumulator:

The accumulator modelling assumes an isothermal expansion of the gas in the accumulator to calculate pressure. The staff requested that Westinghouse examine the impact of an adiabatic expansion of accumulator gases and how MAAP4 results are affected.

Condensation Effects:

The staff noted that condensation effects, especially in the core downcomer region, played a significant role in the OSU testing data. Westinghouse stated that the maximum condensation efficiency was assumed for ECCS water (MAAP4 parameter FCDDC) as recommended by EPRI. Westinghouse had not looked at the sensitivity to condensation effects and was not specifically aware of its importance in the OSU test results. The staff requested Westinghouse to assess the importance of this parameter to the AP600 design calculations.

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December 1, 1995

Benchmarking

MAAP4 uses many simplified models to address thermal-hydraulic phenomena in the accident sequences. The staff emphasized the importance of careful benchmarking to determine the adequacy of the MAAP4 application in the analysis of the success criteria. The staff requested Westinghouse to provide a written benchmarking plan for review before the next meeting.

The staff and Westinghouse agreed that the overall path to resolution on the use of MAAP4 for selecting the bounding PRA success criteria depends on a thorough benchmarking plan. The staff reiterated the importance of a well-formulated benchmarking plan which satisfies the concerns discussed in the meeting summary issued by the staff on August 14, 1995. A commitment was made to have the next meeting on T/H uncertainty following completion of a documented benchmarking plan by Westinghouse. Attachment 1 is the list of meeting attendees. Attachment 2 contains handouts provided by Westinghouse during the meeting to supplement the presentation and discussions.

Original signed by
William C. Huffman, Project Manager
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Division of Reactor Program Management
Office Of Nuclear Reactor Regulation

Docket No. 52-003

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Benchmarking

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MEETING ON THE
USE OF MAAP4 FOR AP600
THERMAL-HYDRAULIC ANALYSIS
OF PRA SUCCESS CRITERIA
OCTOBER 24 AND 25, 1995
MEETING ATTENDEES

NAME	ORGANIZATION
Jim Scobel	Westinghouse
Debra Ohkawa	Westinghouse
Cindy Haag	Westinghouse
Ralph Caruso	NRC
Walt Jensen	NRC
Giuseppe Marella (part time)	NRC
Brad Hardin (part time)	NRC
Bill Huffman	NRC
Tim Collins	NRC
Gene Hsii	NRC
Tom Kenyon (part time)	NRC
Constantine Tzanos	ANL

Attachment 1

HANDOUTS PRESENTED
AT THE OCTOBER 24 AND 25, 1995, MEETING
BETWEEN WESTINGHOUSE AND THE NRC ON
THE USE OF MAAP4 FOR AP600 THERMAL-HYDRAULIC ANALYSIS
OF PRA SUCCESS CRITERIA

Attachment 2

OVERVIEW OF MAAP4
AS USED IN
AP600 LEVEL 1 SUCCESS CRITERIA

Debra Ohkawa
Jim Scobel

October 24-25, 1995

MAAP4 Overview for AP600 Success Criteria Analyses

I. INTRODUCTION

II. MAAP4 RESULTS FOR SAMPLE 2.0" BREAK

III. REACTOR COOLANT SYSTEM

- Noding
- Natural Circulation and VFSEP
- RCS Pressure and Temperature Calculations
- Break Flow
- Effect of Selected Input

IV. CORE

- Modelling
- Heat Transfer
- Effect of Selected Input

V. "GENERIC" MODELS INTERFACING WITH RCS

- Pressurizer
- Accumulator
- Steam Generator

VI. AP600-SPECIFIC MODELS

- CMT
- ADS
- IRWST
- Effect of Selected Input

VII. MAAP4 APPLICATION GUIDELINES

INTRODUCTION

Purpose of Meeting

To provide an introduction to the MAAP4 code and how it was applied for the AP600 level 1 success criteria analyses

- Discussion of basic models
- Discussion of input
    - Level of conservatism
    - Effect on analyses

INTRODUCTION - MAAP4 Overview

- MAAP4 was developed for post-core damage accident analyses
- MAAP4 was used for pre-core damage accident analyses because
  - Upgraded T&H models in MAAP4 (compared to MAAP3B)
  - Informal comparisons with other codes were good
  - Easy to model operator actions
  - **IT IS FAST TO RUN**
- Two official EPRI versions
  - BWR
  - PWR, includes enhancements for AP600
- MAAP4 input comes from
  - Default code values
  - Parameter file
  - Input file

EXAMPLE 2.0" BREAK

Accident Assumptions

- 2.0" hot leg break on bottom of pipe
- 1 CMT
- No Accumulators
- No PRHR
- 2 stage 4 ADS lines
- IRWST gravity injection – thru one line
- Containment Isolation Failure

Sequence of Events

	Time (sec)	
Reactor trips on low pressurizer pressure	62	
CMT actuation on low pressurizer pressure	71	
VFSEP is reached	1740	
CMT transitions from recirculation to injection	1790	
CMT low-1 level setpoint is reached	2179	– (Stage 1, 2, 3 signal but fails to open valves)
Stage 4 ADS does not go off because of 100 psi interlock —> CMT low-2 level setpoint is reached	2855	
Break uncovers (hot leg empty)	3285	
Top of core uncovers	3849	
Stage 4 ADS actuates (b/c RCS pressure < 1000 psia)	3973	
IRWST injection begins	4189	
Minimum core level	4212	
Peak core temperature is reached	4465	Temp = 1081°F
Top of core recovers	4800	

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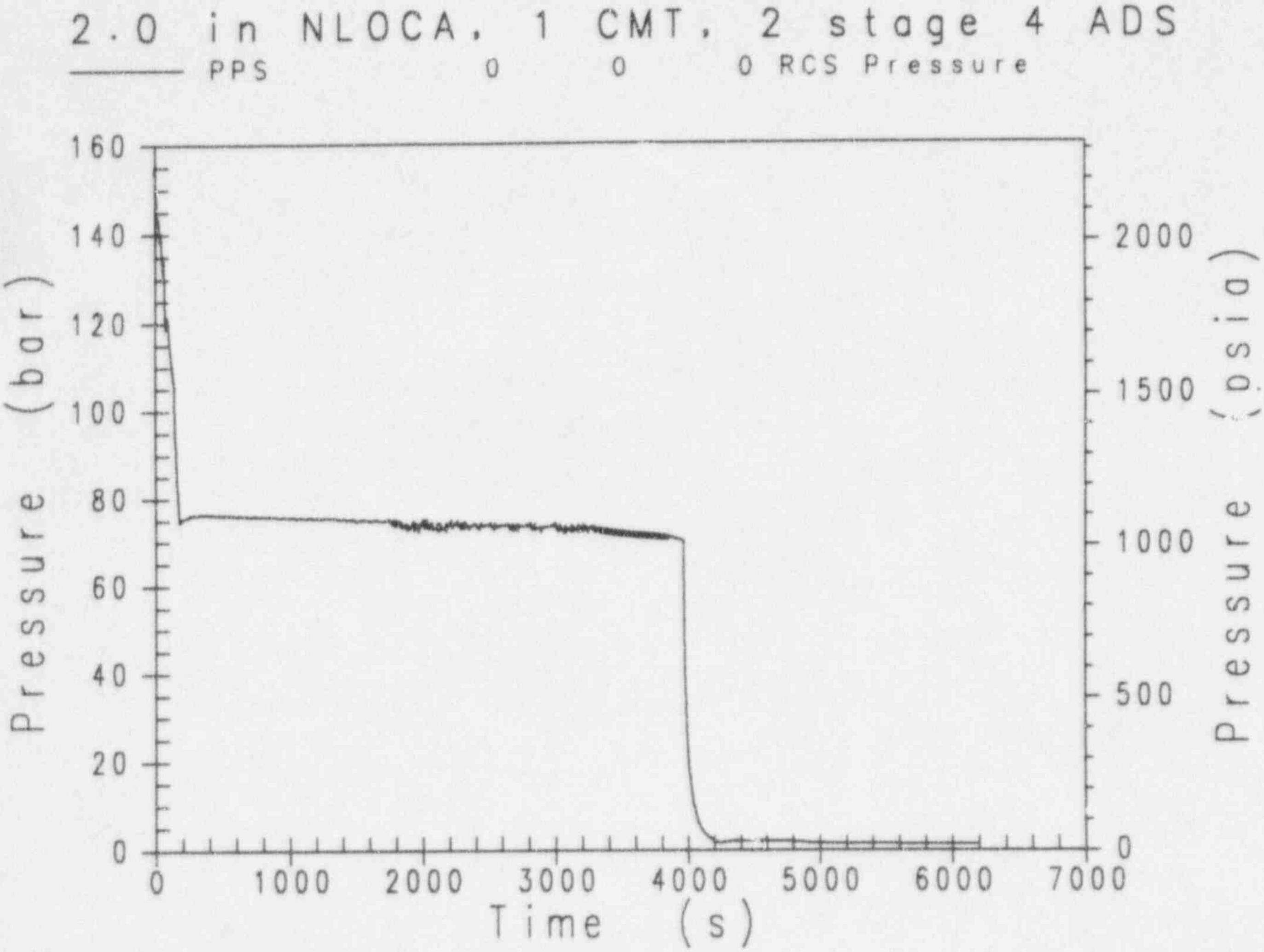

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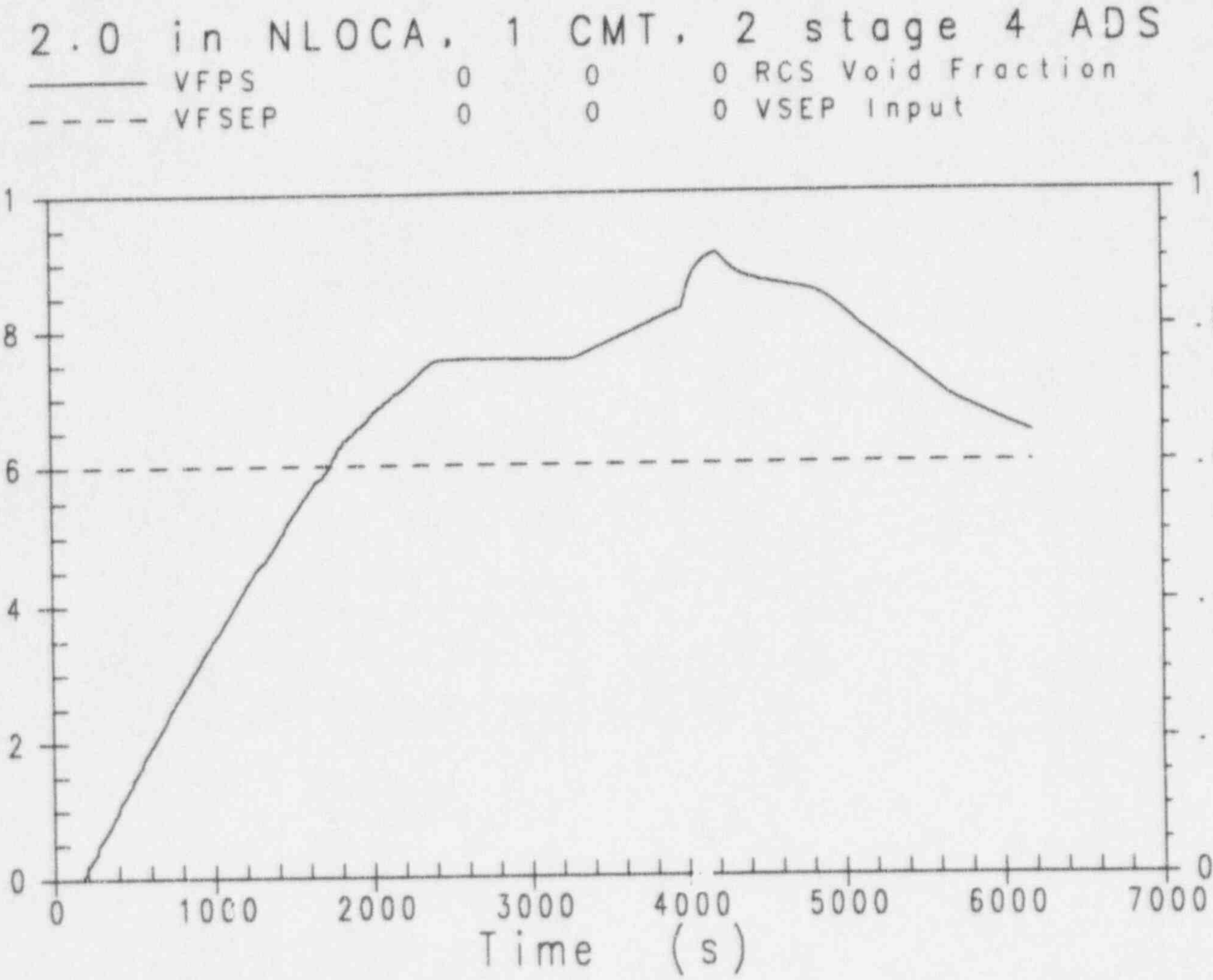

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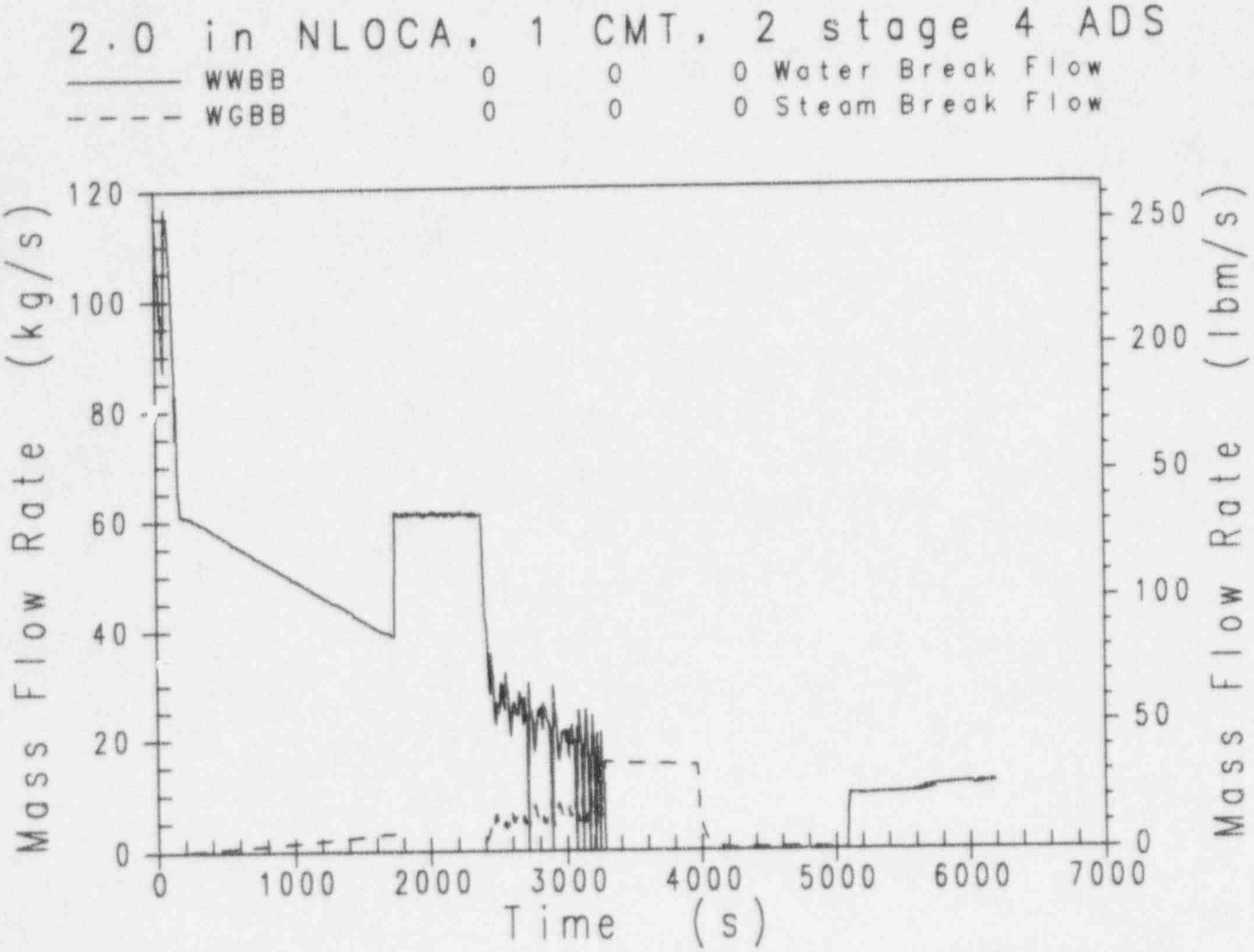

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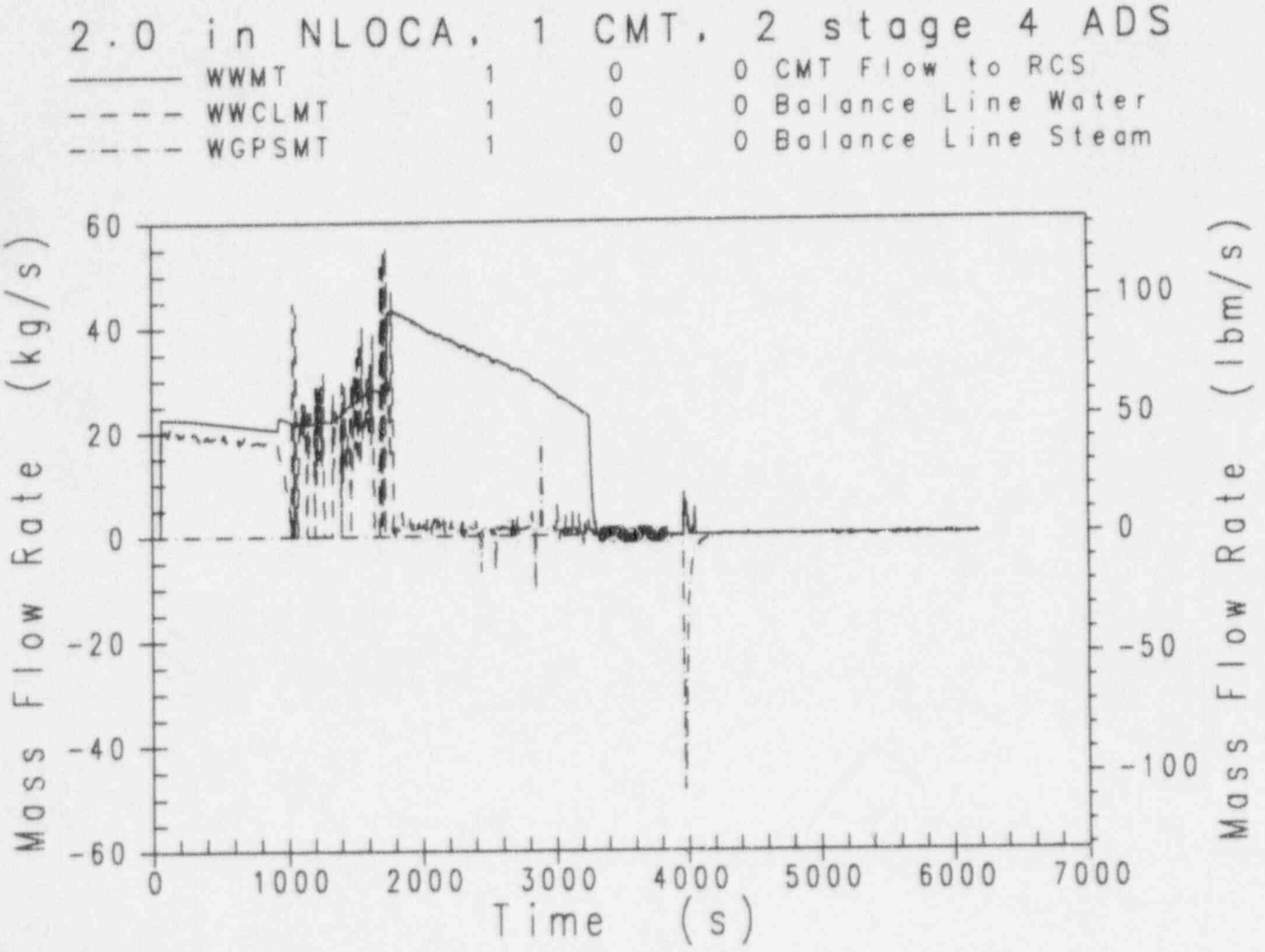

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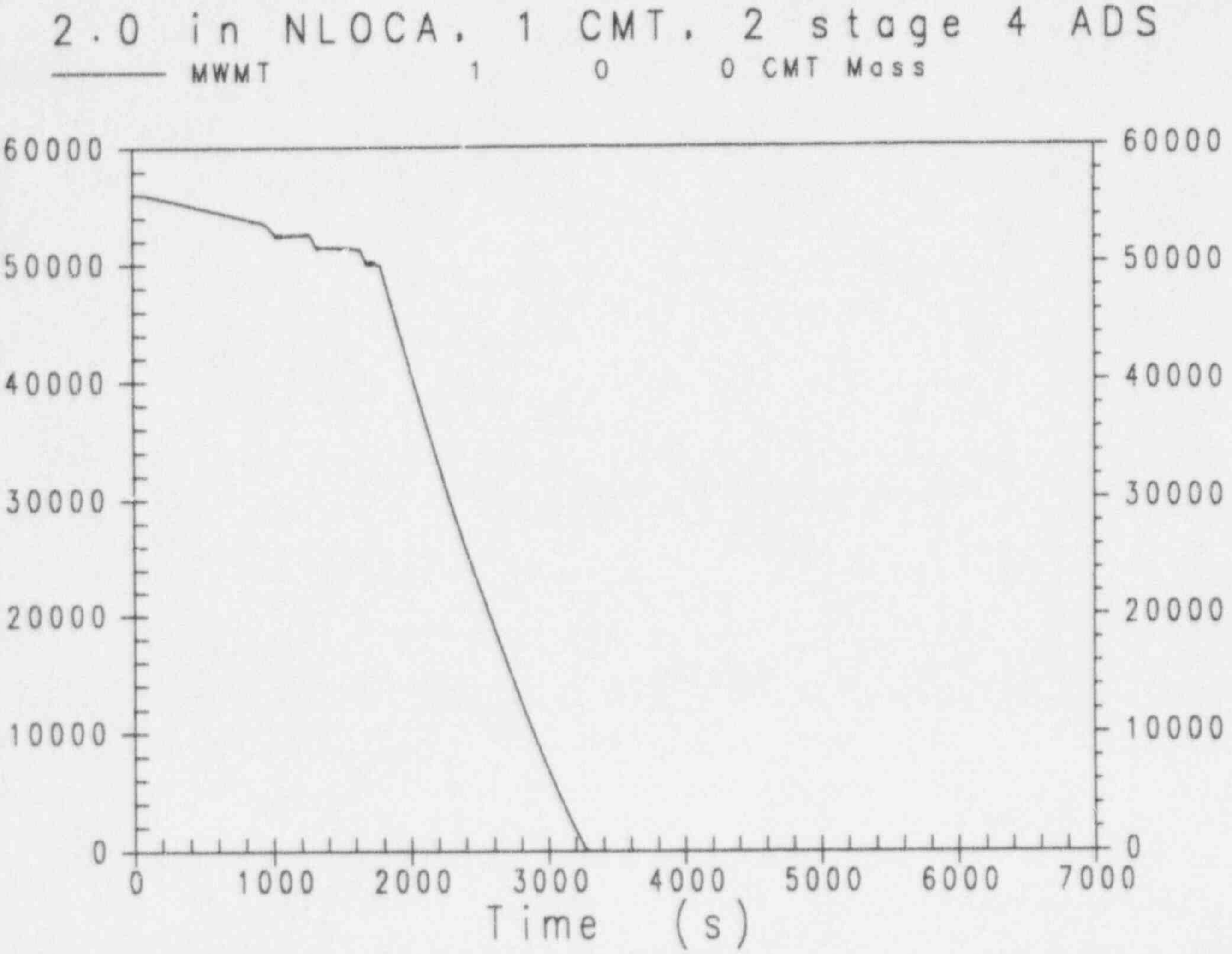

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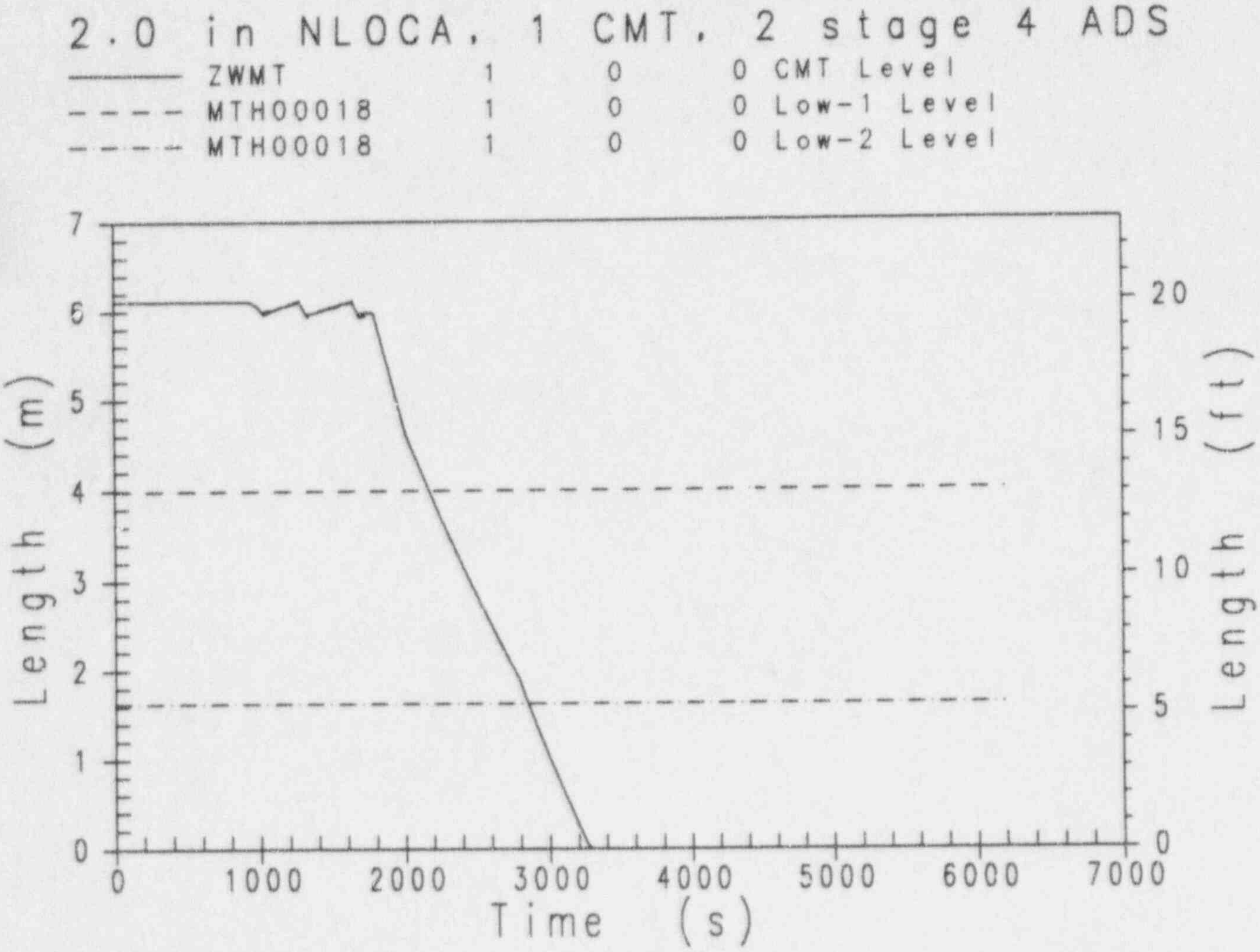

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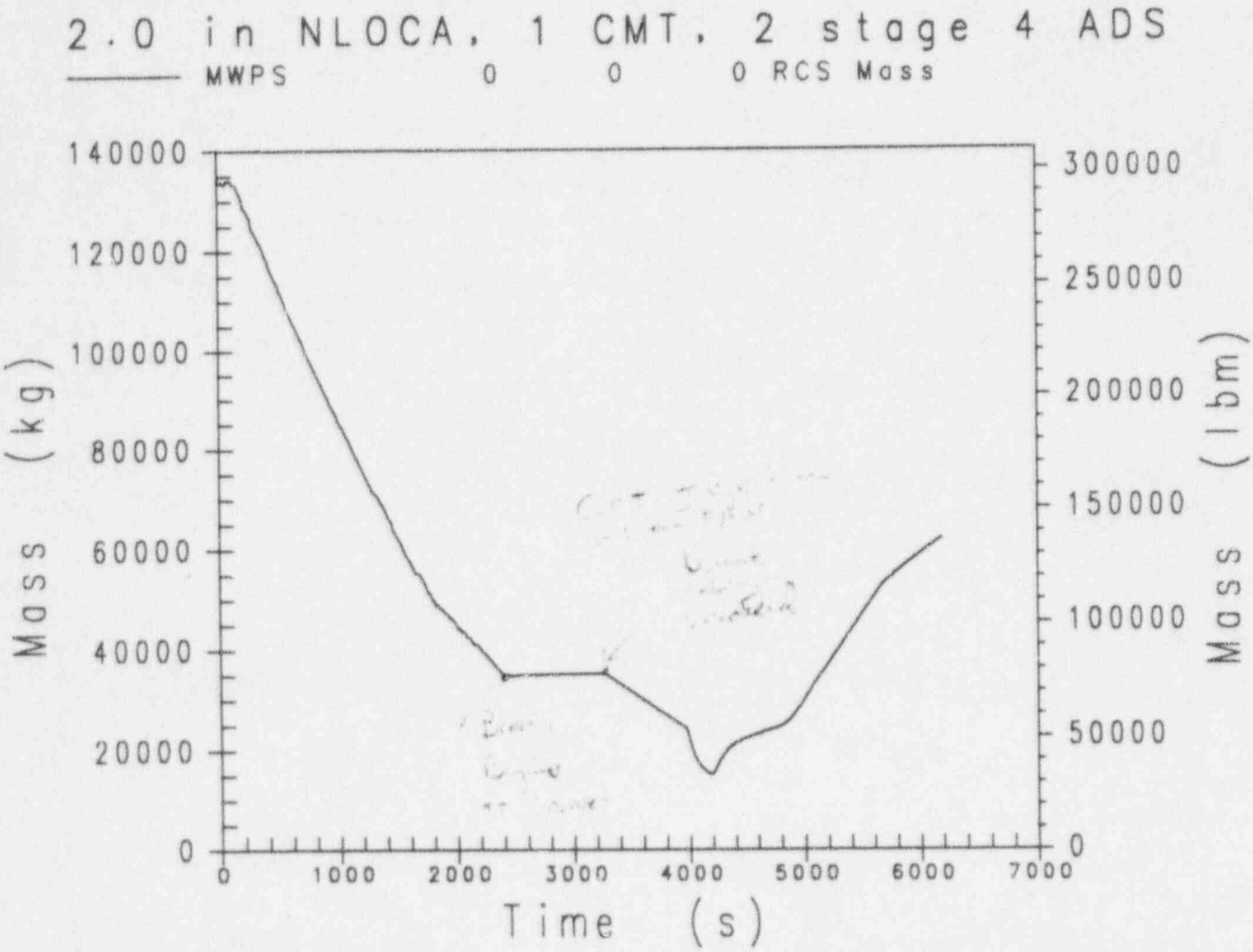

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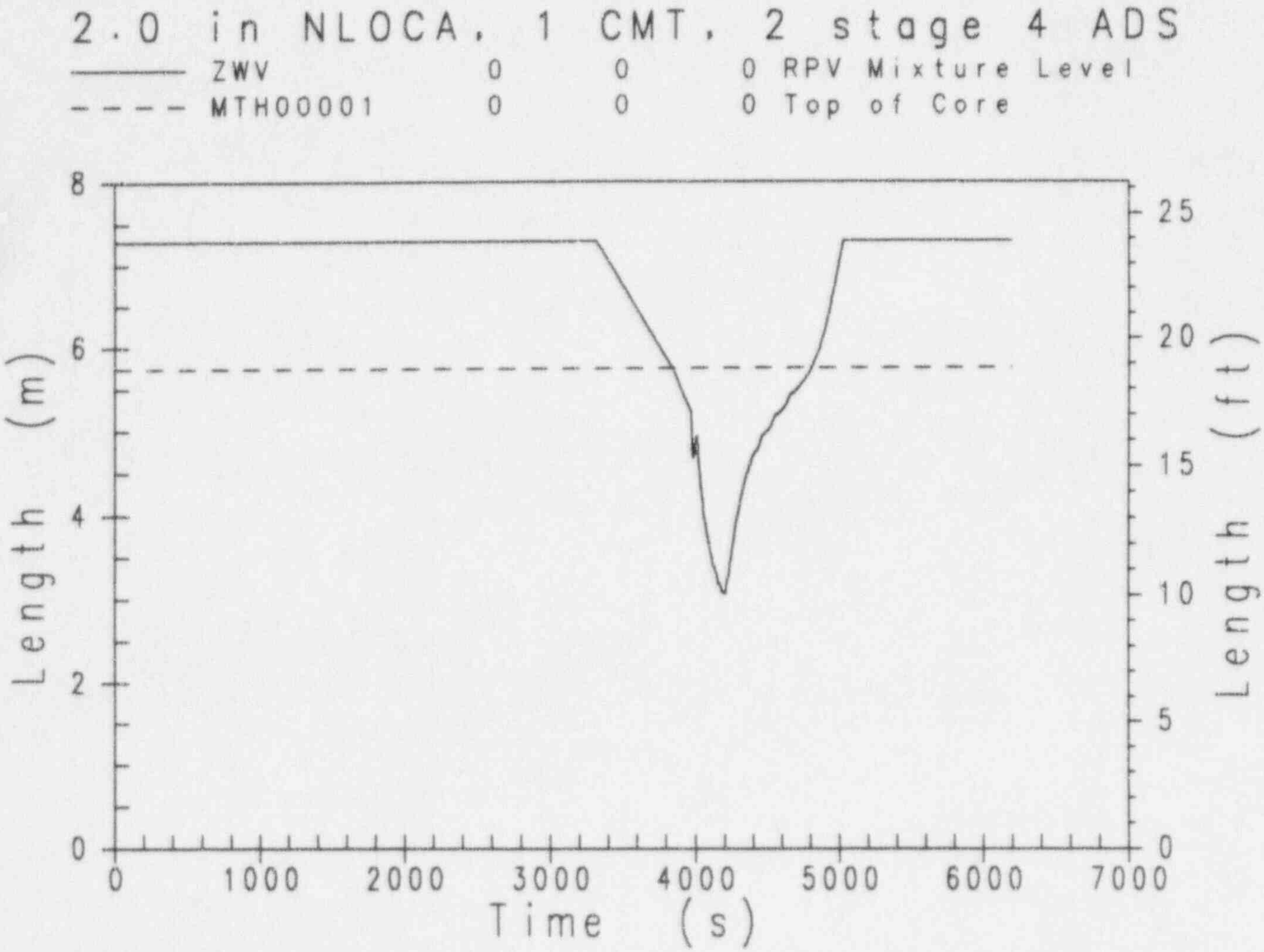

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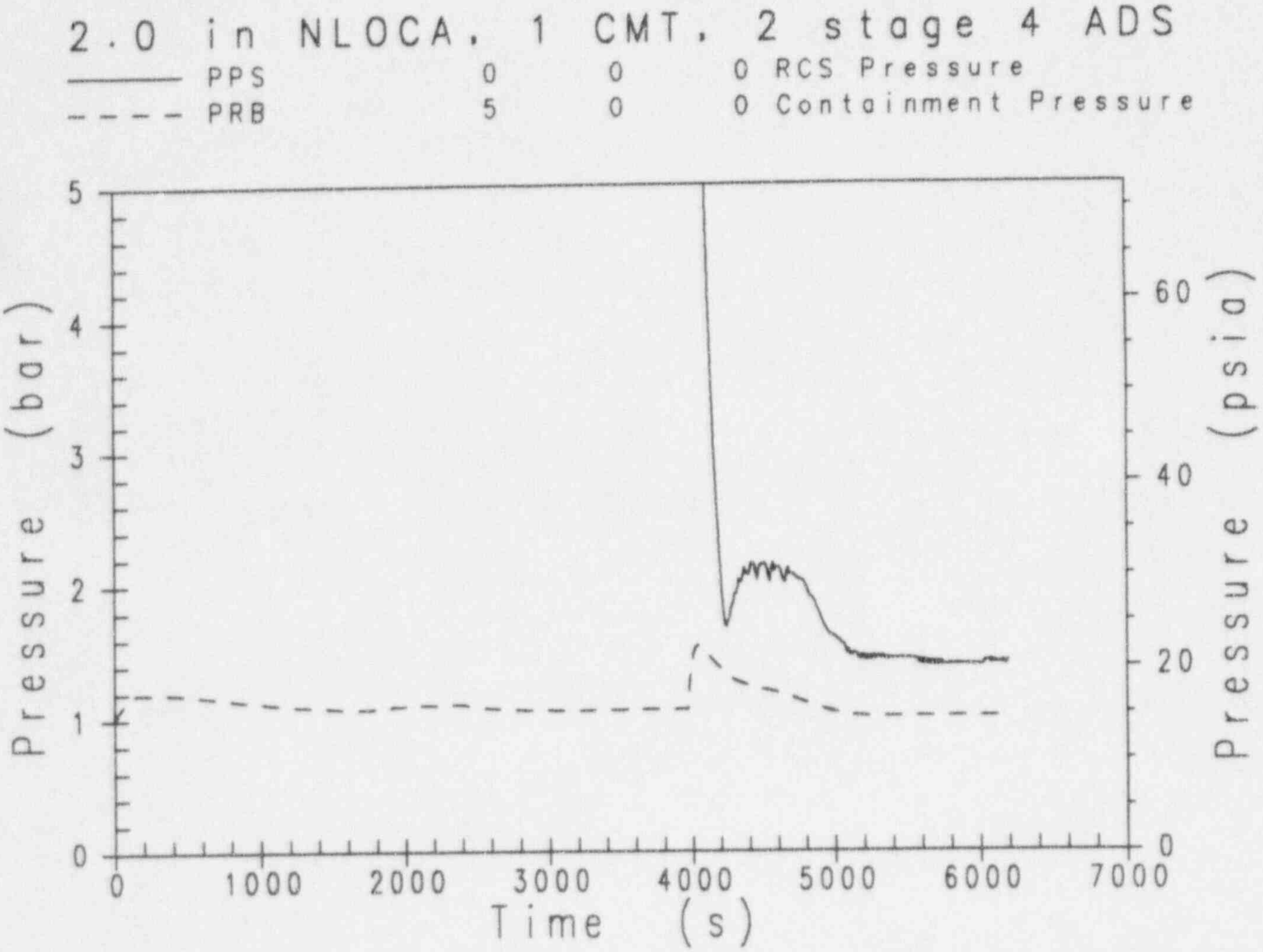

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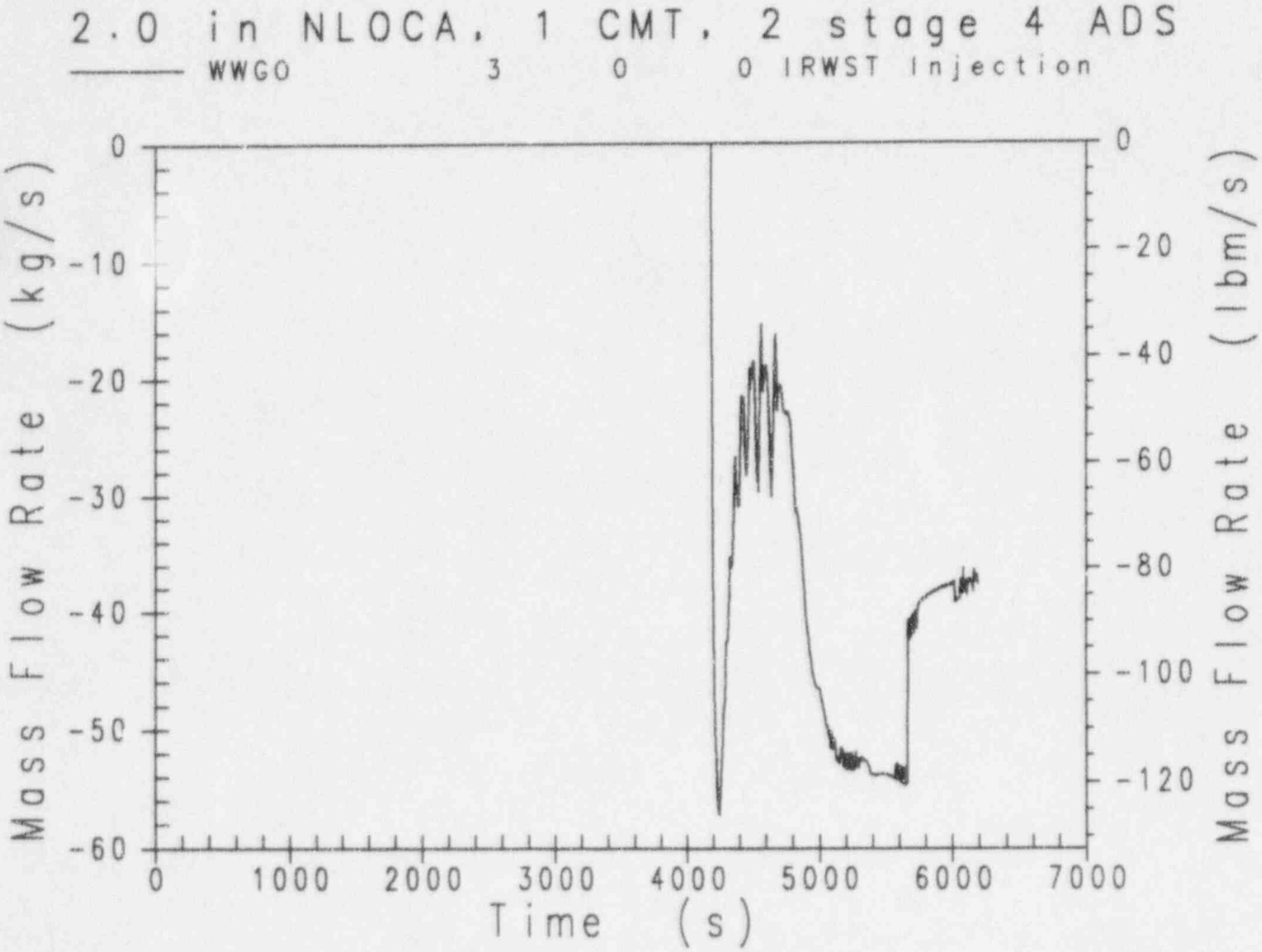

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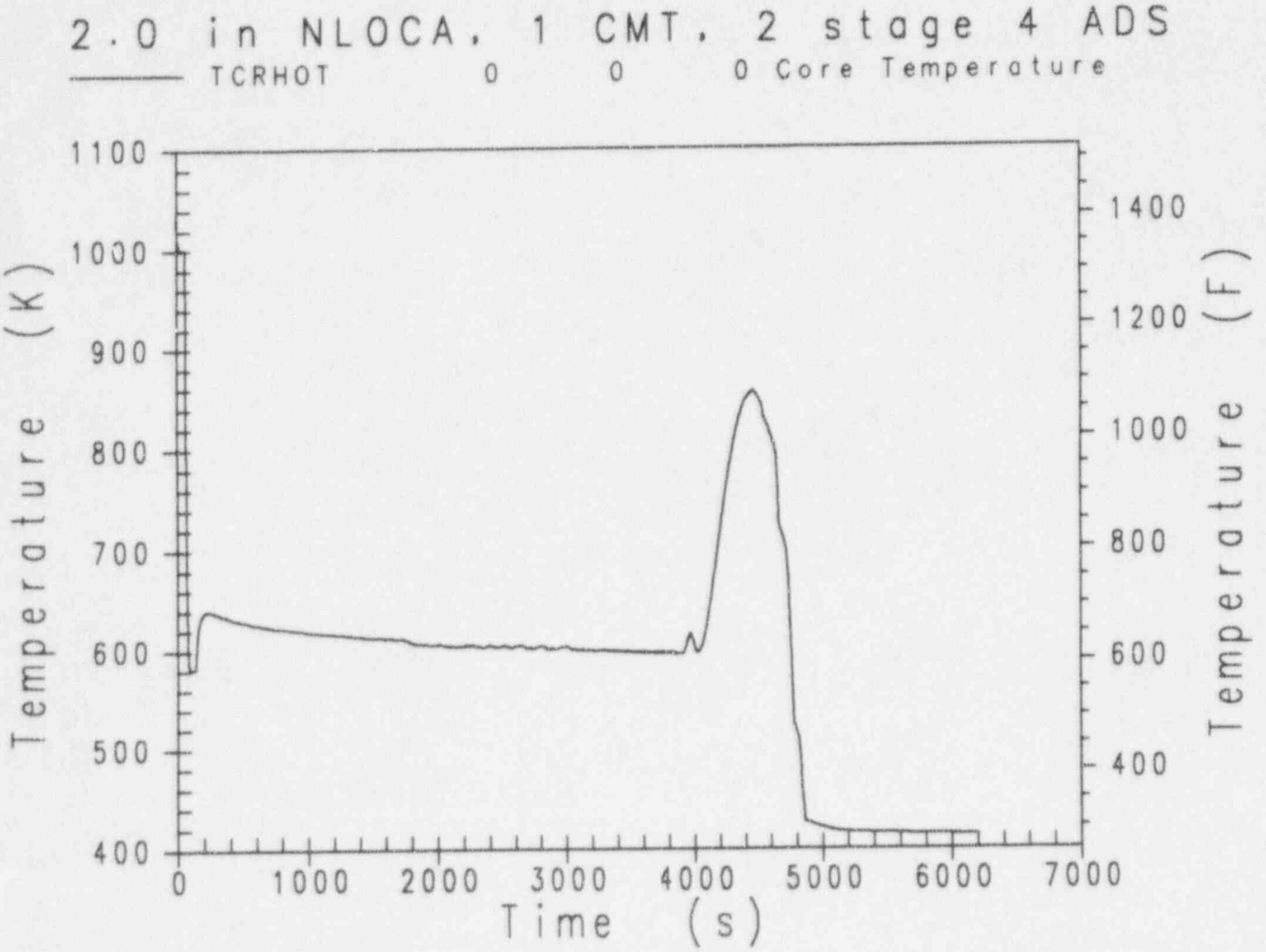

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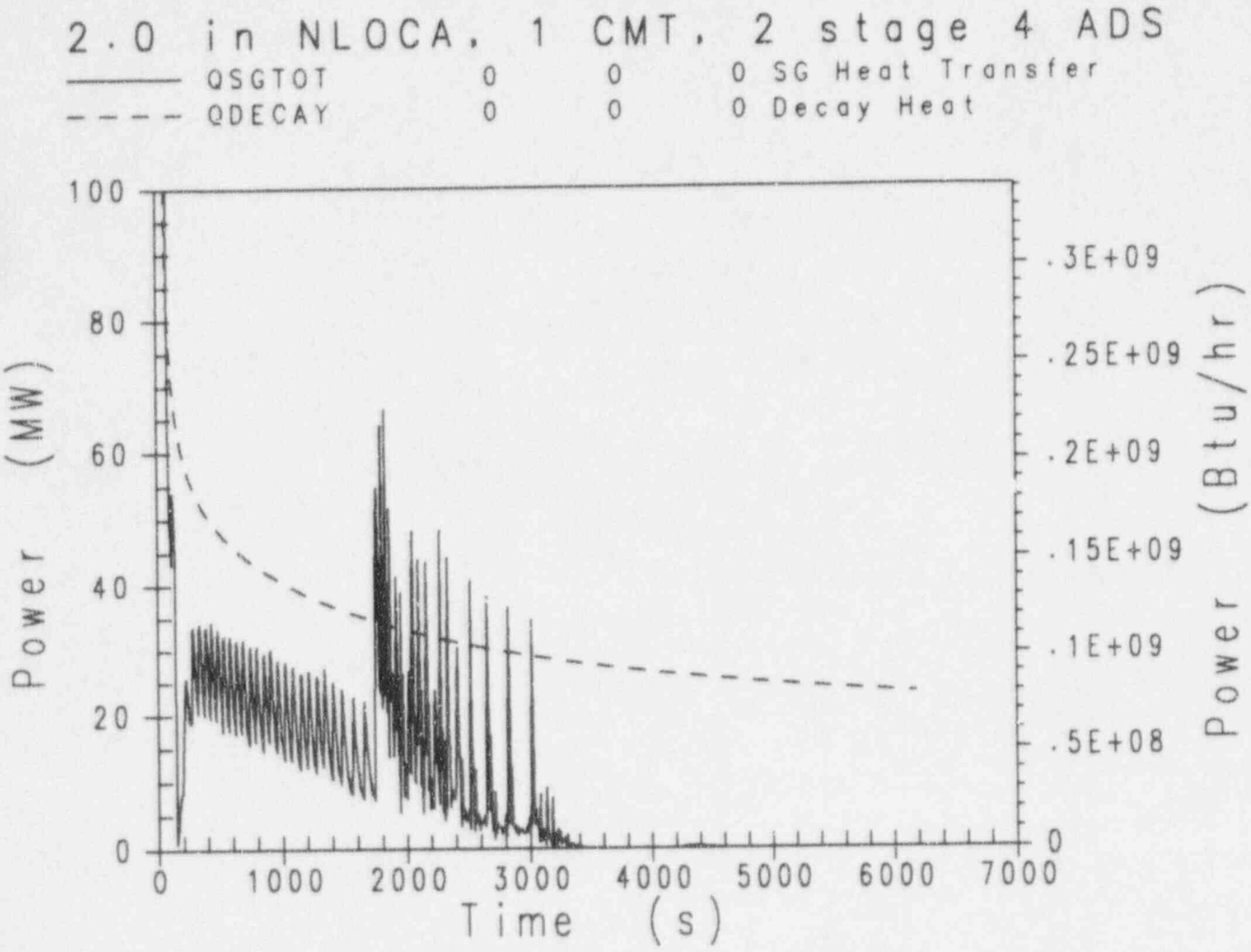

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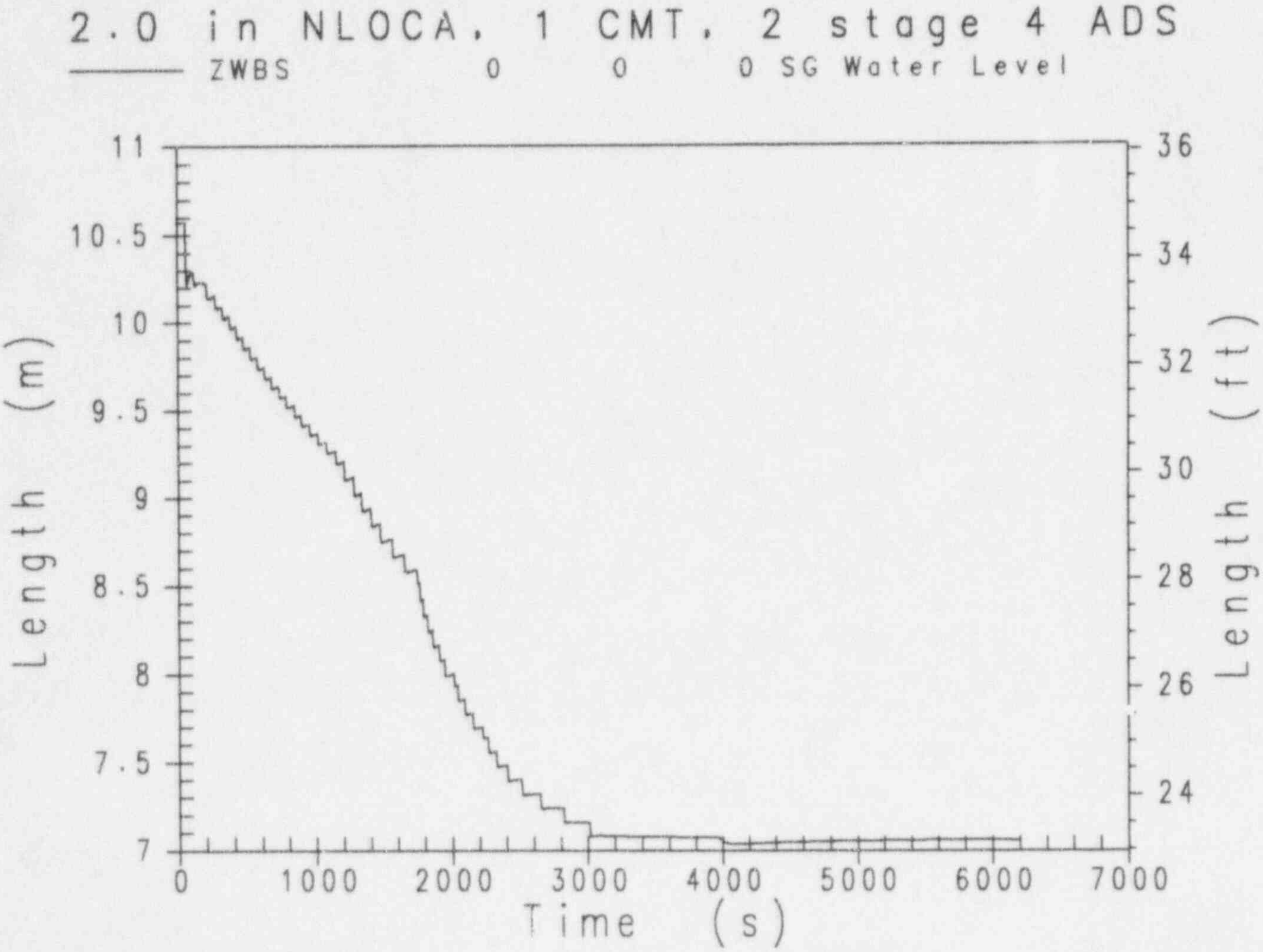

III. REACTOR COOLANT SYSTEM

MAAP4 Primary System Modeling

- Main Subroutines

PRISYS	RCS Mass, Energy, Water Distribution
FLOW	Gas Flows in RCS
PSHS	RCS Structural Heat Sinks

- 6 Water Pools

Core (inc. Hot Legs, Hot Tubes)	Downcomer (inc. Lower Head, Cold Legs)
Broken Loop Cold Tubes	Unbroken Loop Cold Tubes
Broken Intermediate Leg	Unbroken Intermediate Leg

(intermediate pools model the loop seal in coolant loop, N/A to AP600)

- 14 Gas Nodes

RPV	Core	Upper Plenum
	RV Dome	Downcomer
Loops	Broken Hot Leg	Unbroken Hot Leg
	Broken Hot Tubes	Unbroken Hot Tubes
	Broken Cold Tubes	Unbroken Cold Tubes
	Broken Intermediate Leg	Unbroken Intermediate Leg
	Broken Cold Leg	Unbroken Cold Leg

- 19 RCS Heat Sinks

RPV	Lower Core Barrel (2)	Upper Core Barrel (2)
	Upper Internals	Dome Plate (2)
	RV Wall	Dome Wall
Loops	Hot Leg Pipe (2)	Hot Tubes (2)
	Cold Tubes (2)	Intermediate Pipe (2)
	Cold Leg Pipe (2)	

- Global Pressure Assumption

MAAP4 Primary System Modeling
(continued)

- Inputs
  - Geometry of system - volumes, elevations
  - Masses of structures
  - Some control system setpoints
  - RCP coast-down curve
  - Insulation characteristics

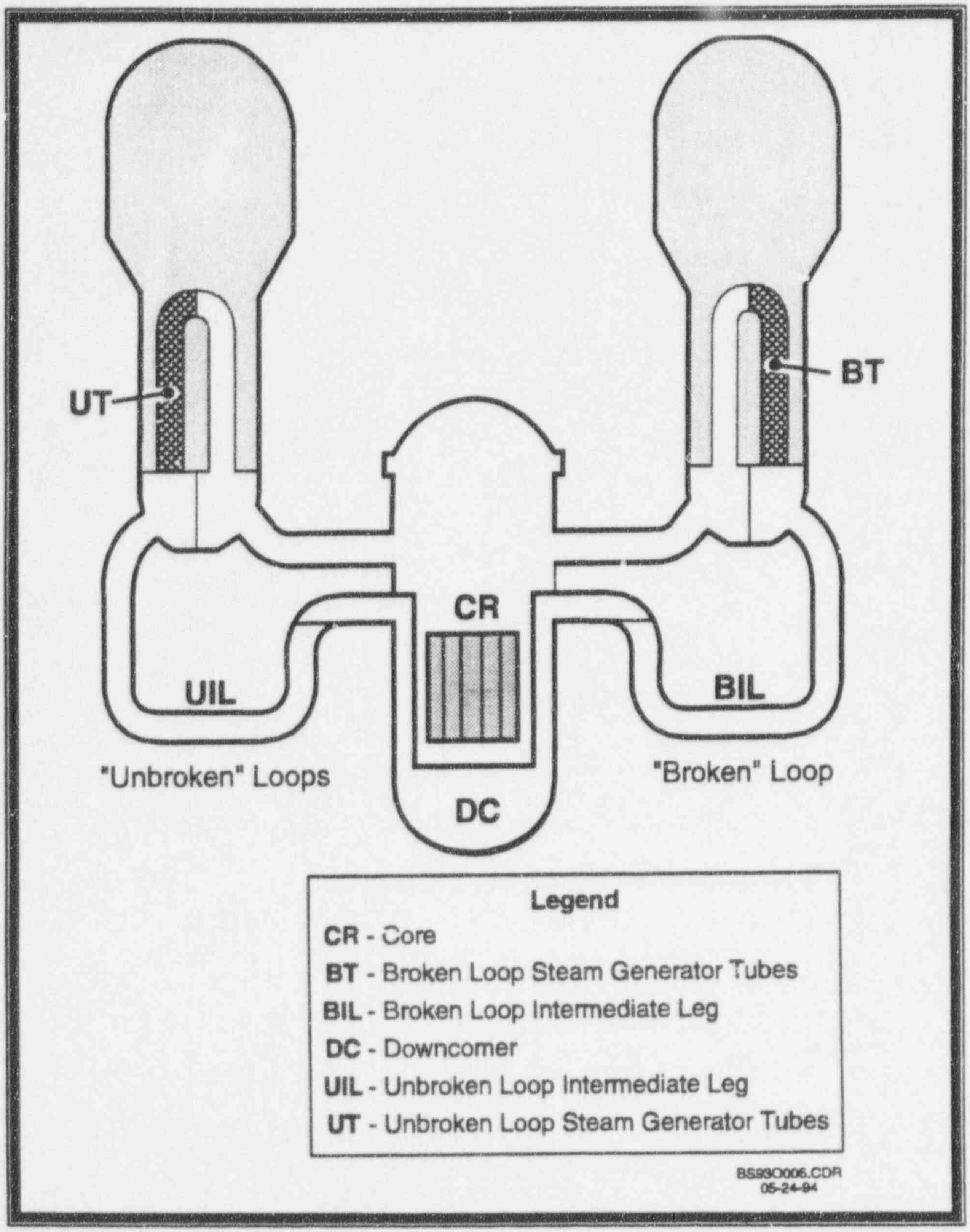

Figure 3 Primary system water pool nodes.

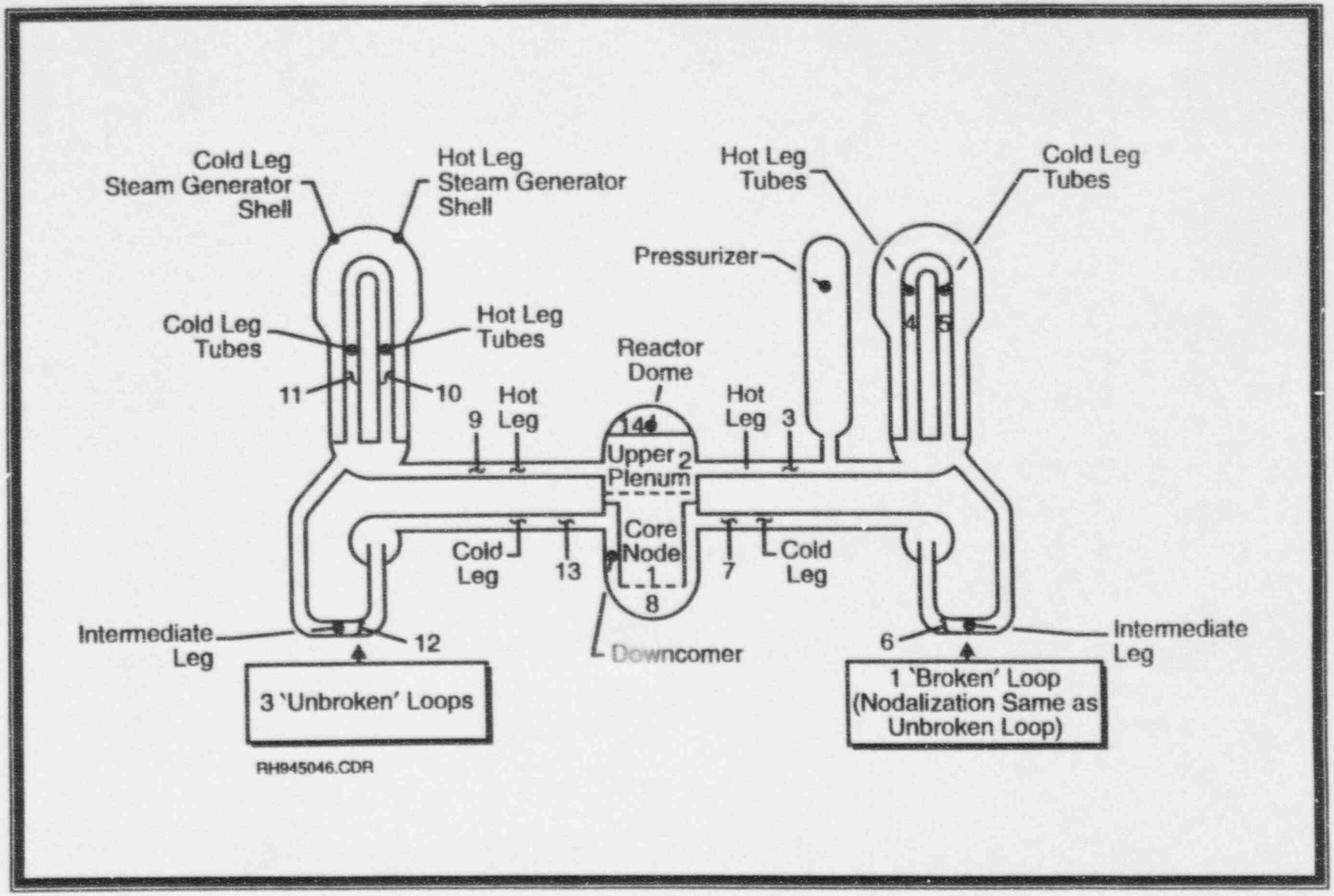

Figure 1 PWR primary system nodalization for Westinghouse 4-loop design.

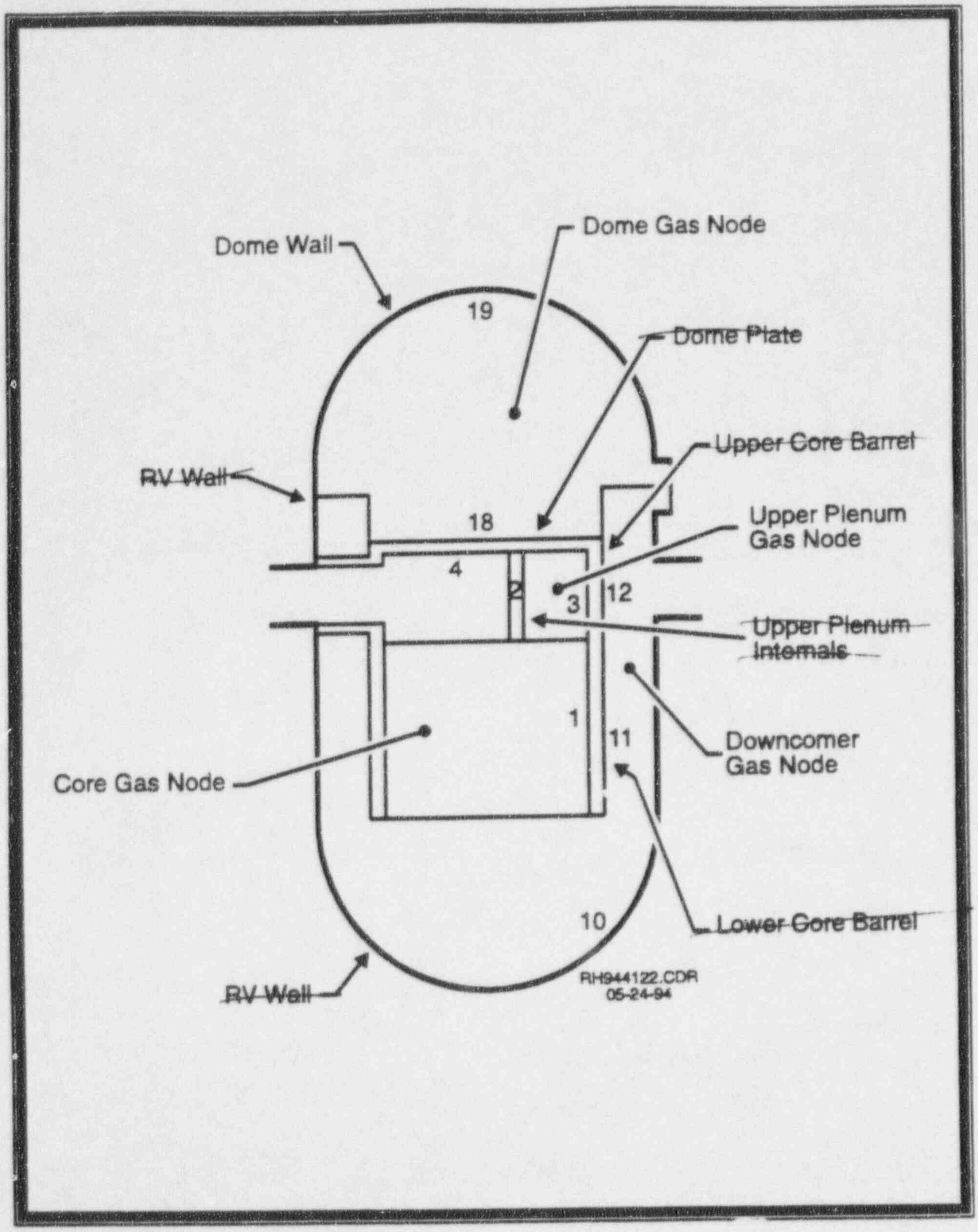

Figure 5 Heat sinks and control volumes in reactor vessel.

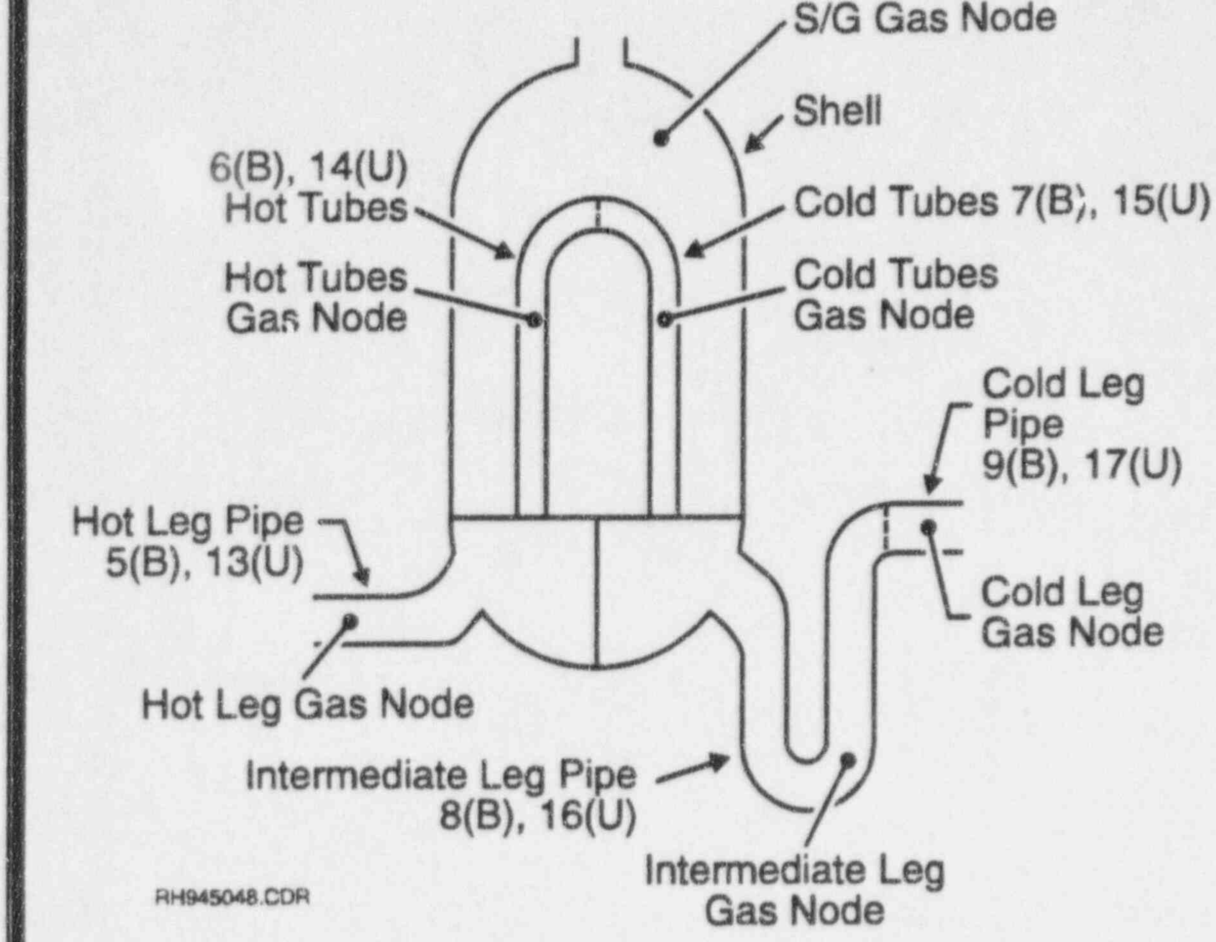

Figure 6 Heat sinks and control volumes in U-tube steam generator loop.

RCS Thermal-Hydraulic Parameters

- Parameter values are set to EPRI recommended values for Westinghouse plant. Recommendations are based on the Thermal-Hydraulic Qualification work.

- Parameters related to single and two phase natural circulation modeling

HTSTAG = 850 m^2 K/W	SG primary side film resistance when 1 or 2 phase natural circulation is occurring in the coolant loops.
VFSEP = 0.6	Void fraction above which two phase natural circulation is assumed to stop and phases separate to gas over liquid configuration
VFCIRC = 0.4	Void fraction below which it is assumed the separated system resumes 2 phase natural circulation

- Parameters related to post core uncovery natural circulation of steam and hydrogen

FFRICR = 0.1	Friction coefficient for axial gas flow in the upper plenum natural circulation model
FFRICX = 0.25	Friction coefficient for gas cross-flow in core for natural circulation model
FAOUT = 0.3	Fraction of SG tubes carrying flow "out" (away from the core) in the stratified single phase gas natural circulation flow model (not applicable to AP600, since no loop seal all tube flow is same direction)
FWHL = 0.115	Coefficient in hot leg stratified gas natural circulation model (not applicable to AP600)

- Parameters related to void fraction and calculation of the vessel water level

FCHTUR = 1.53	Churn-turbulent critical velocity coefficient (drift flux parameter)
FVOL = 2.0	Volumetric steam generation void fraction coefficient (drift-flux parameter)
FSPAR = 1.35	Sparged pool void fraction coefficient

- Parameters related to the calculation of flooding in the pressurizer and core

FCRHY = 0.3	Core hydrodynamic limit Kutateladze number for reflooding heat transfer and oxidation calculations
FFLOOD = 3.0	Flooding critical velocity coefficient
FROUPZ = 0.4	Froude number for counter-current draining of pressurizer through surge line

Void Fraction and Water Level Sensitivity Cases

Variable		Base	Minimum		Maximum	
			Input	PCT	Input	PCT
FCHTUR	Churn-Turbulent Critical Velocity Coefficient	1.53	1.0	1092	5.0	1095
FVOL	Volumetric Steam Generation Void Fraction Coefficient	2.0	0.0	634	5.0	1172
FSPAR	Sparged Pool Void Fraction Coefficient	1.35	0.0	1081	5.0	946

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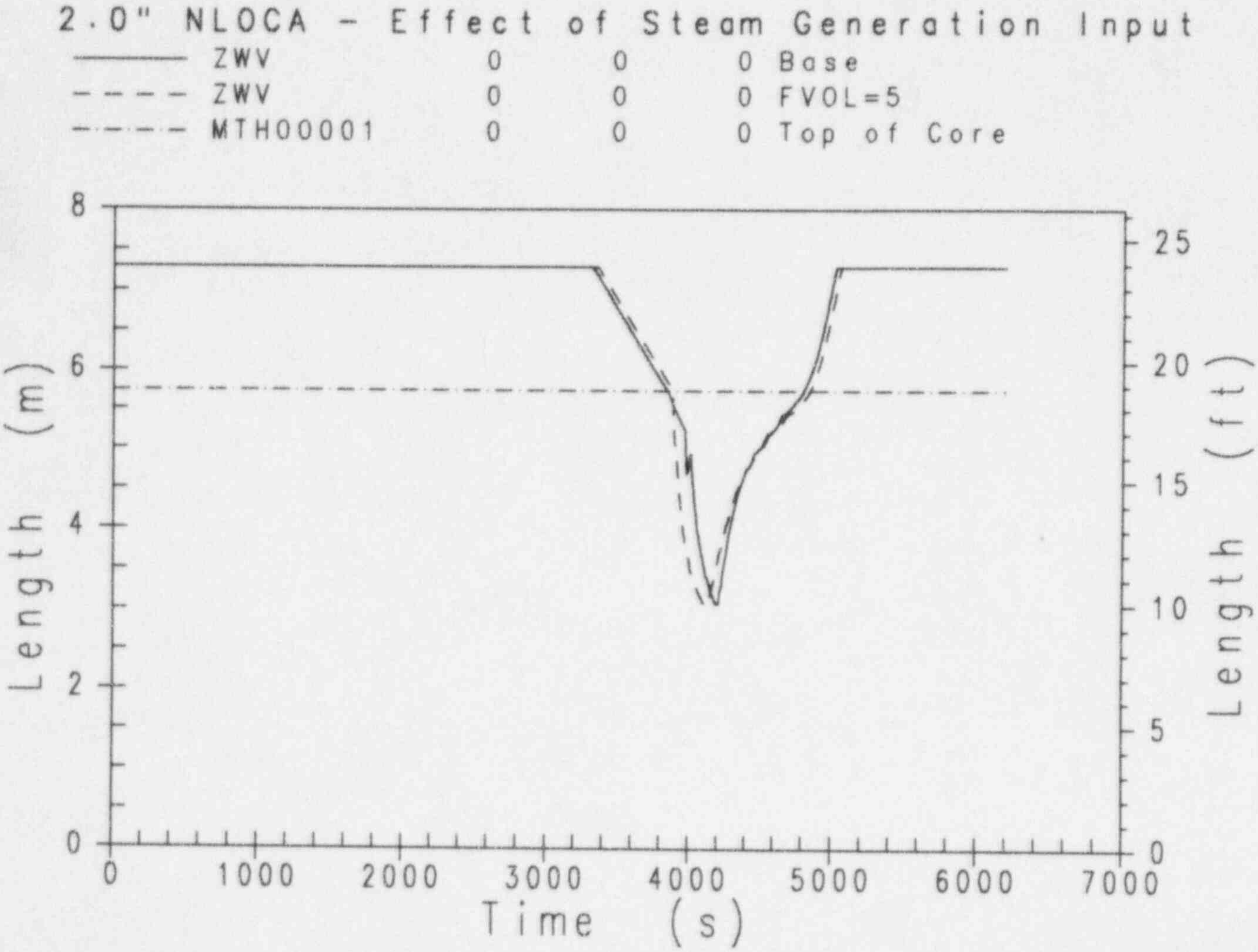

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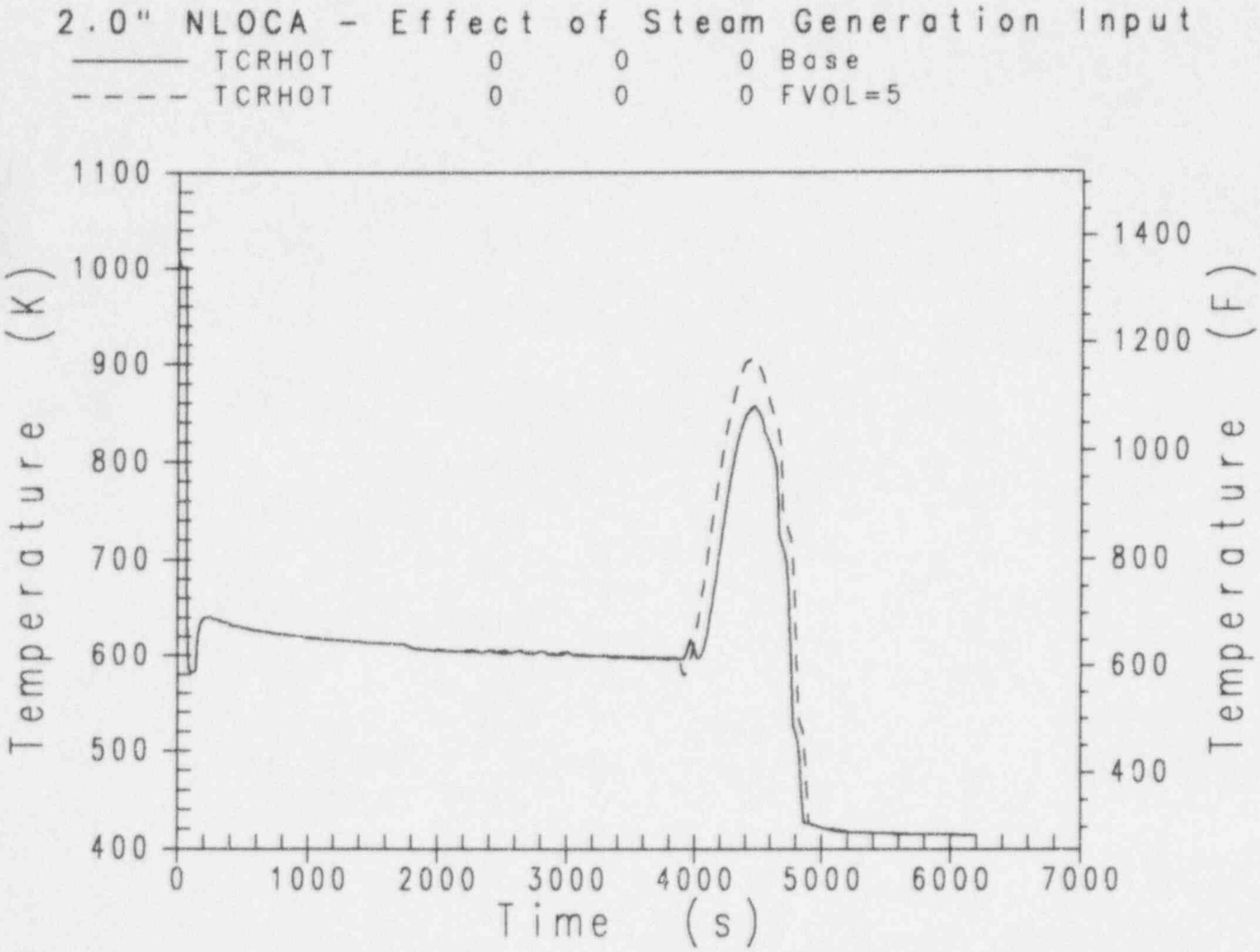
2.0" NLOCA - Effect of Steam Generation Input

Single and 2-Phase Natural Circulation in RCS

- Calculated in PRISYS
- RCPs pump primary coolant "mixture" until tripped by SI signal or by high void fraction in the loop. Coast down is modeled with user input flow vs. time table.
- RCS water and steam assumed to be mixed and circulating in the primary loops until void fraction VFPS exceeds user defined parameter VFSEP
- Phases instantaneously separate into a steam over water configuration

EFFECT OF VFSEP

Sample of Affected Output	VFSEP Input		
	0.4	0.6	0.8
VFSEP is reached	1135 s	1740 s	2480 s
CMT transitions to injection	1580 s	1790 s	2480 s
Break uncovers	3080 s	3285 s	2480 s
Core uncovers	3641 s	3849 s	4565 s
Peak core temperature	1096°F	1081°F	1061°F

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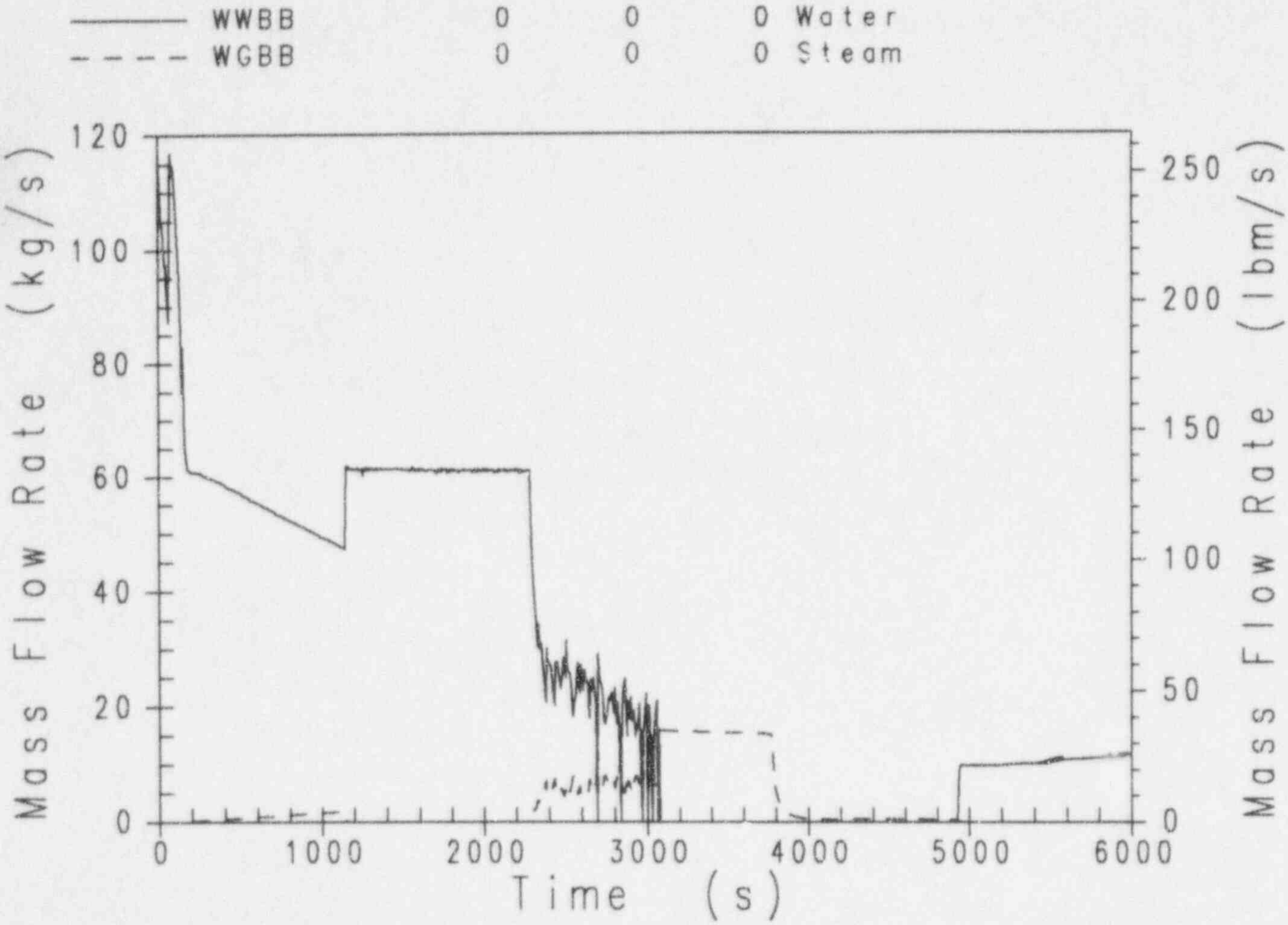
2.0" NLOCA - Break Flow for VFSEP = 0.4



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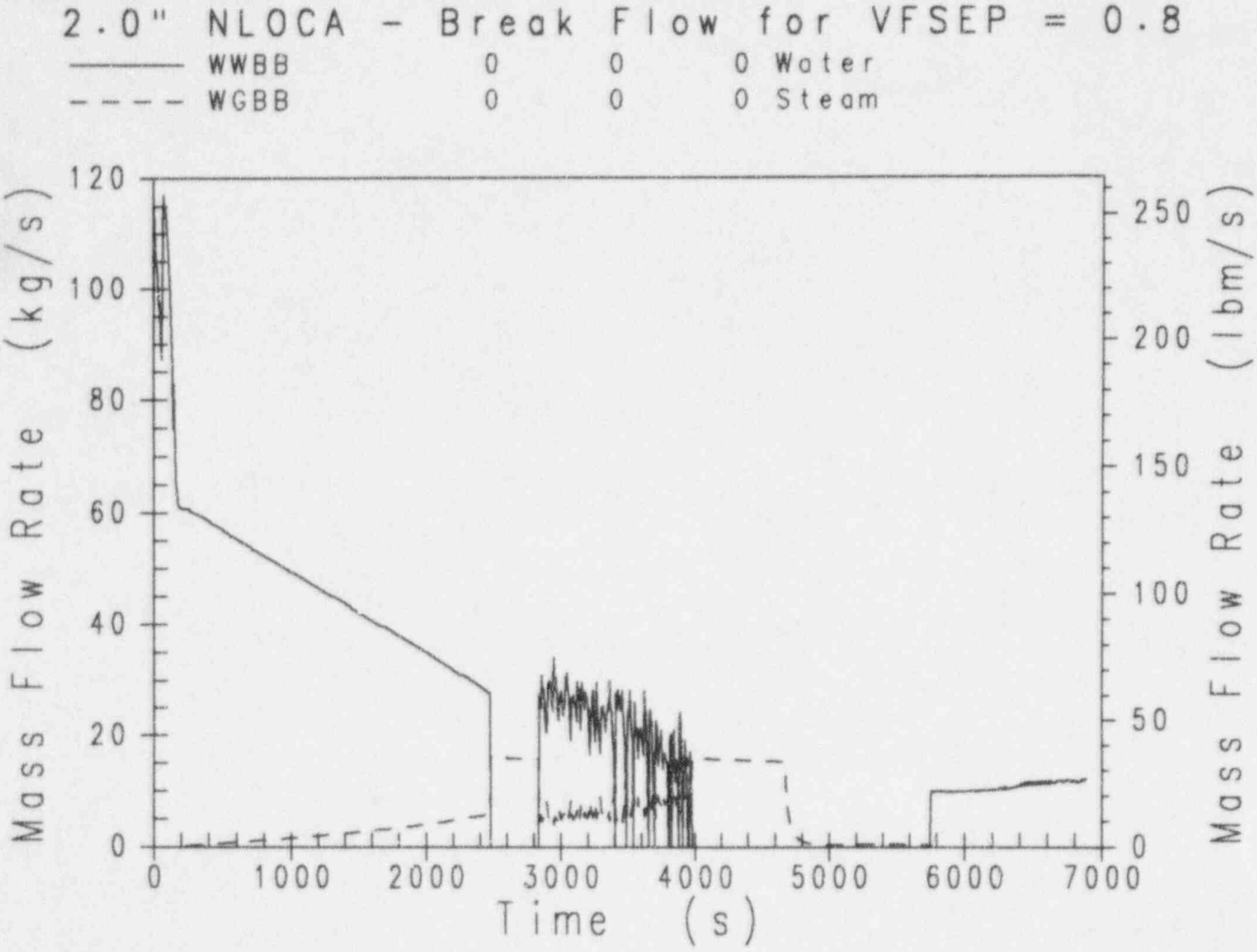

2.0" NLOCA - Break Flow for VFSEP = 0.8

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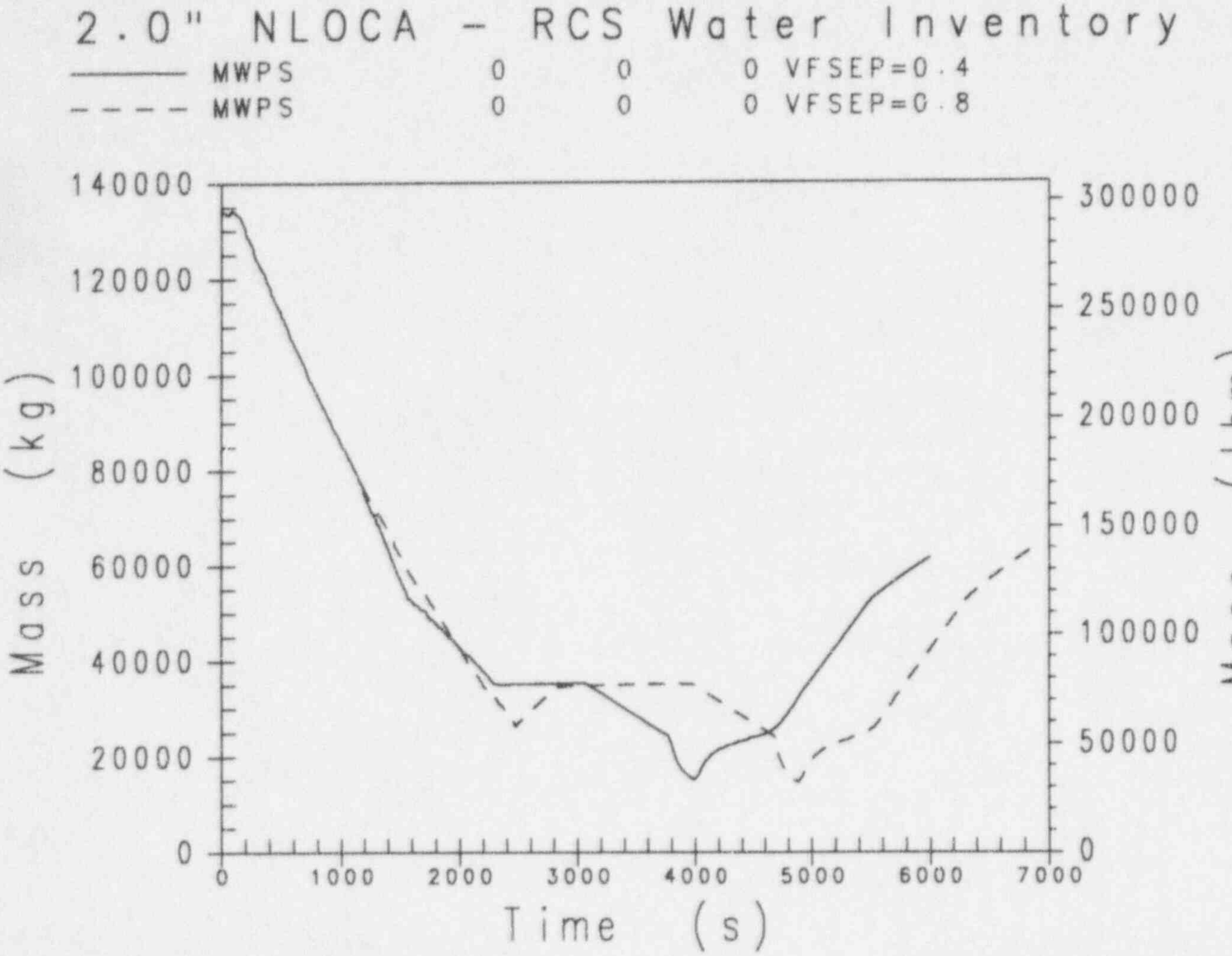

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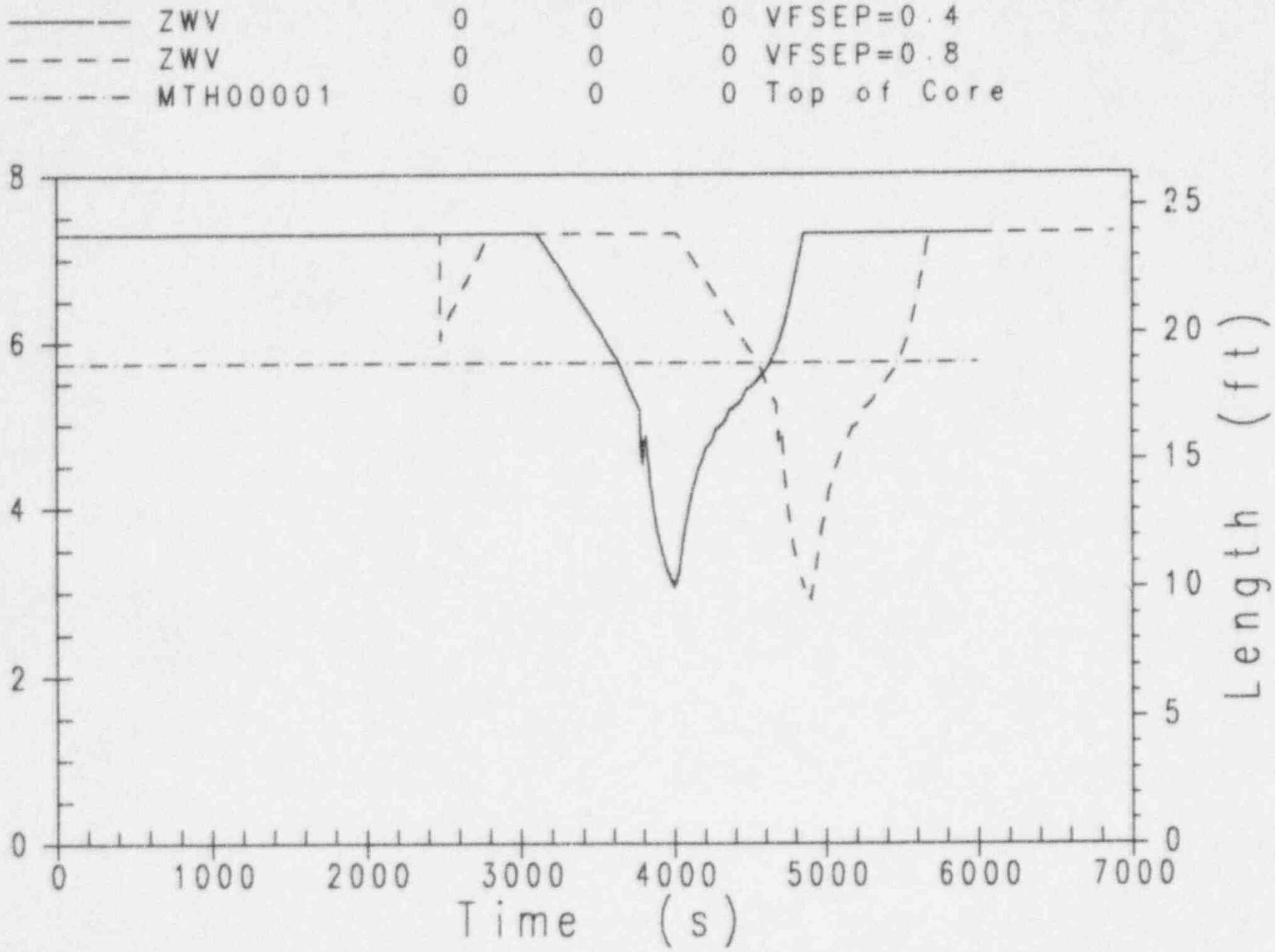
2.0" NLOCA - Mixture Level in Core



RCS Pressure and Temperature Calculation

"Coupled Mode" - small temperature differences between water pools, pressure calculated by PTCAL

- Water solid condition
  - RCS pressure equal to pressurizer pressure
  - If pressurizer is solid also, pressure required to remove "excess volume" through flowpaths (safety valves, break)
- Water pools mixed with gas phase (VFPS < VFSEP) saturated conditions determine pressure

"Uncoupled Mode" - large temperature differences between pools or phases separated (VFPS > VFSEP)

- Safety injection, heating in the core pool, superheating of gases
- Pool thermodynamics calculated by POOL subroutine
- Gas thermodynamics calculated by PTCAL subroutine for saturated or superheated conditions

BREAK MODEL

- Break model is in subroutine PRISYS, which also calls:
    - Subroutine **WFLOW** to determine mass flow rate
    - Subroutine **VFBRK** to determine void fraction entering break
- Input
    - Break Area
    - Discharge Coefficient (0.7)
    - Break Elevation
    - Break Location (Node)

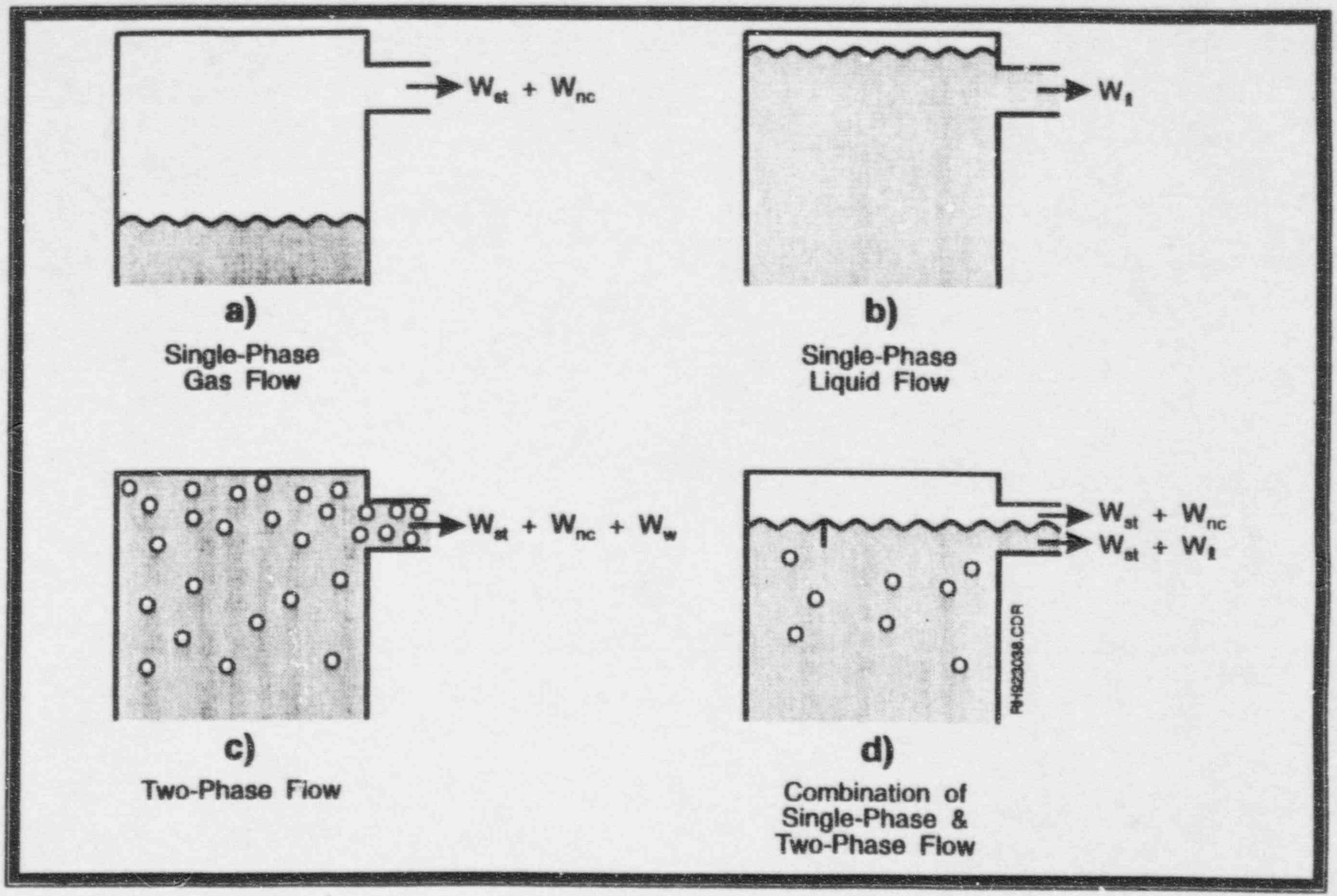


Figure 8 Various modes of discharge flow from the primary system.

BREAK FLOWRATE

Break mass flow rate is calculated in subroutine **WFLOW**.

- Simplified version of Henry-Fauske two-phase critical flow model
    - subcooled water
    - two-phase mixture

- Choked flow condition applies for majority of break flow discharge

- All water flow is a function of
    - Break area
    - Discharge coefficient
    - RCS Pressure
    - Critical pressure ratio
    - Water specific volume

- Two-phase flow is a function of
    - Break area
    - Discharge coefficient
    - RCS Pressure
    - Critical pressure ratio
    - Density of two-phase mixture
    - Void fraction of mixture
    - γ, Ratio of specific heats of steam

BREAK VOID FRACTION

Break void fraction is calculated in subroutine VFBRK.

For two-phase flow regime:

- Vertical orientation of break is assumed
- Acceleration of flow to break is accounted for by defining an effective break area that is four times the break area
    - 96% of the pressure drop from the stagnation region to the break occurs between that region having four times the break area and the break itself.

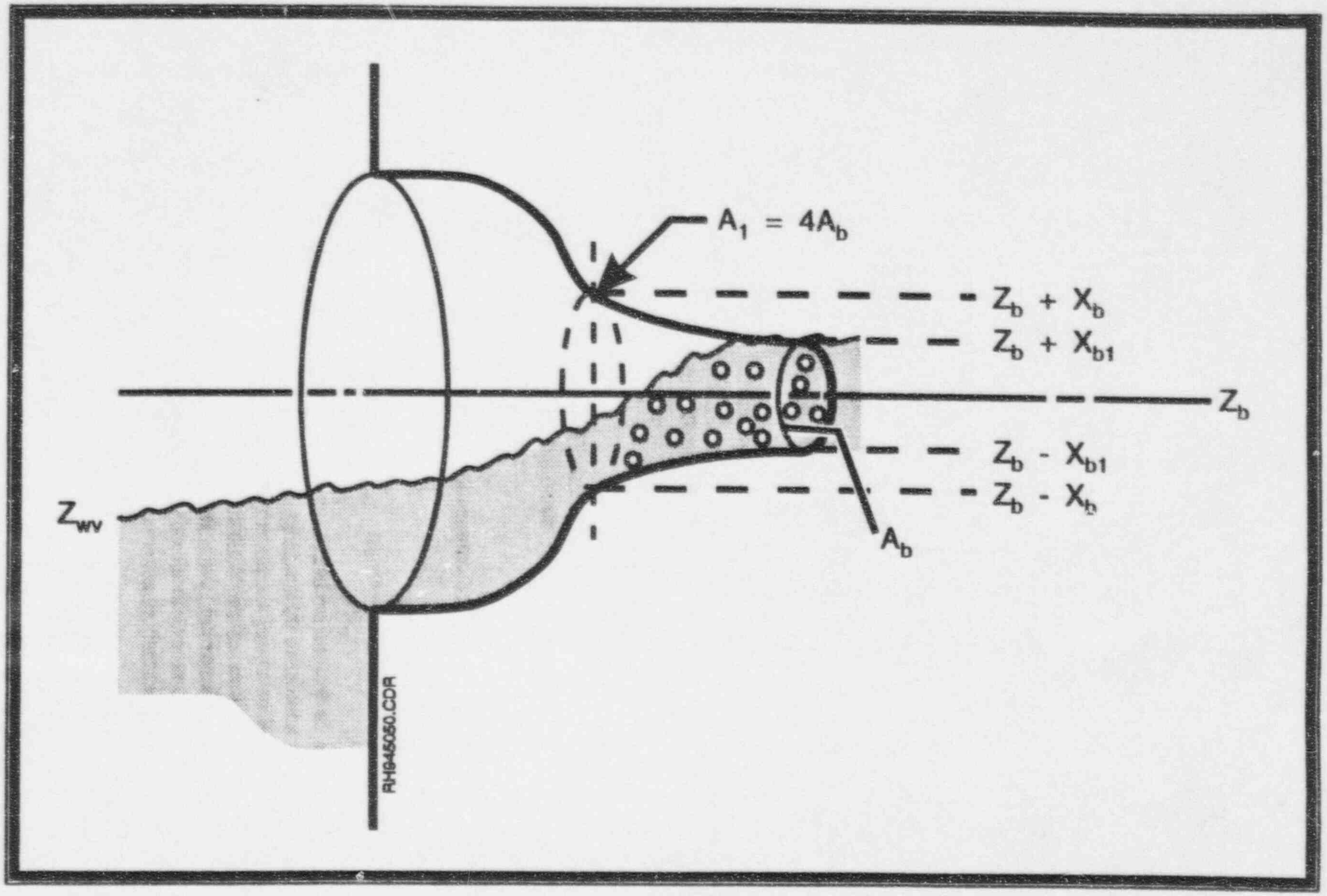


Figure 7 Characteristic dimensions used for break flow calculation.

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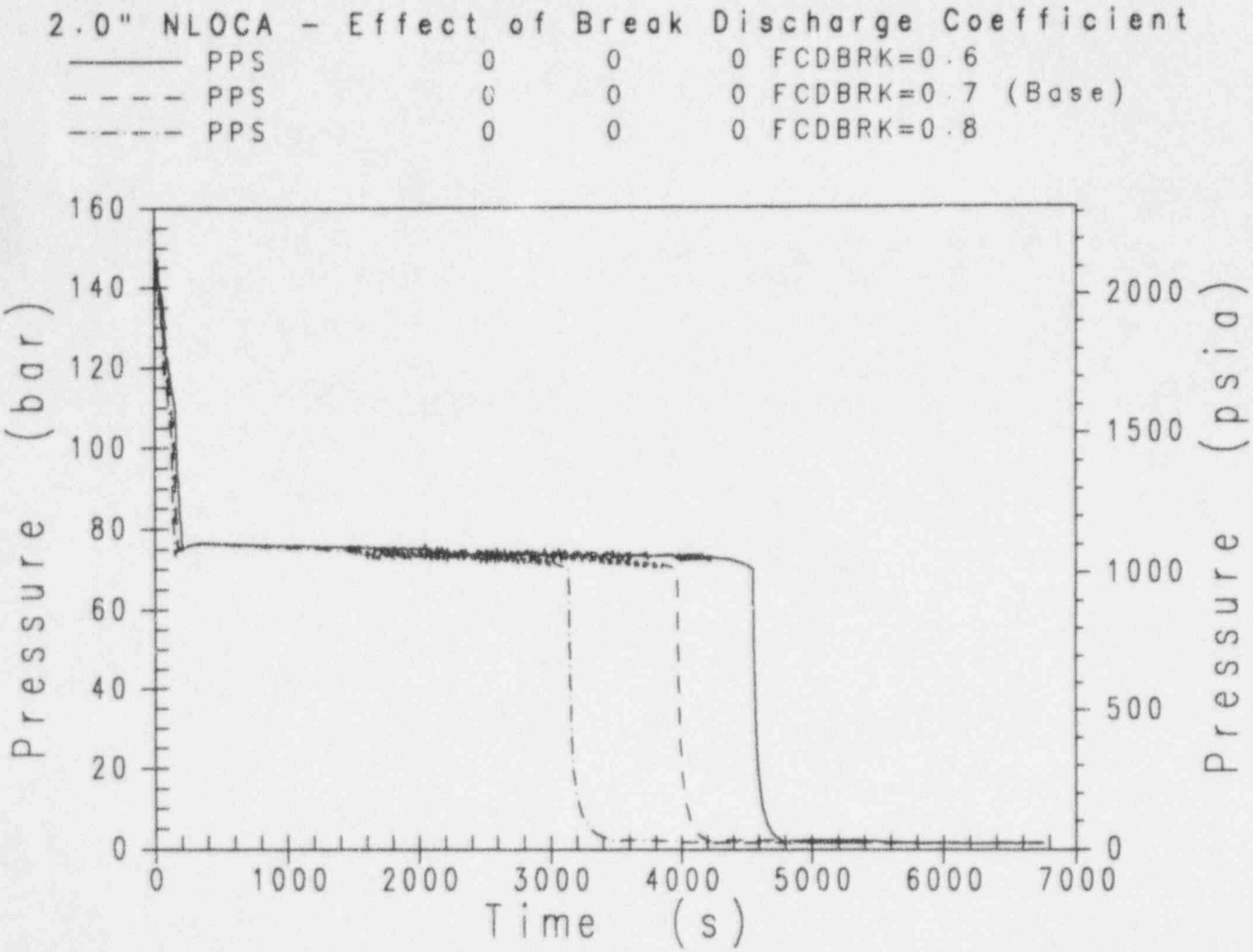

Changing the discharge coefficient has the same effect as altering the break size. These sensitivities are the same thing as analyzing 1.85", 2.0", and 2.14" breaks, if the discharge coefficient remains fixed.

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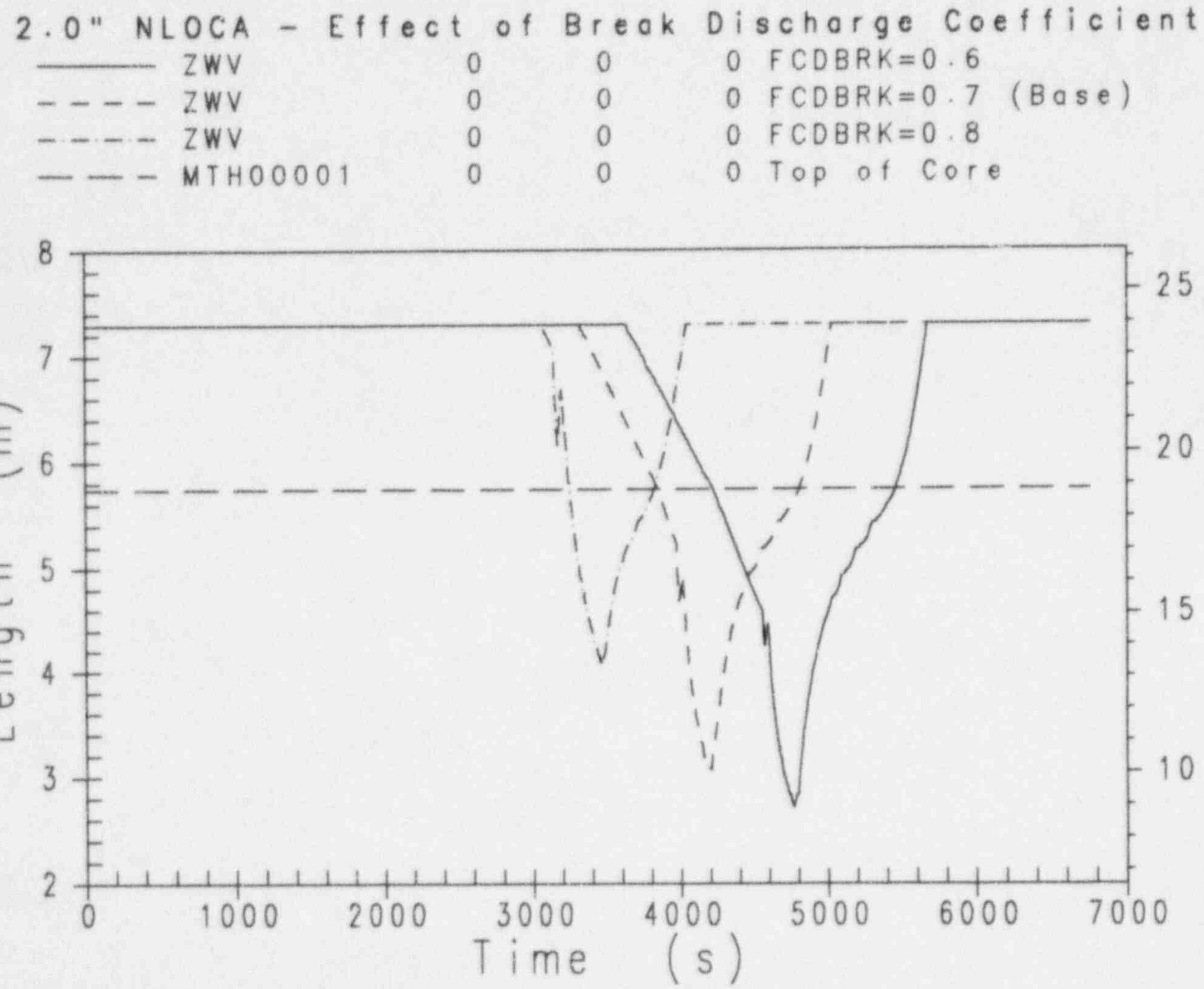

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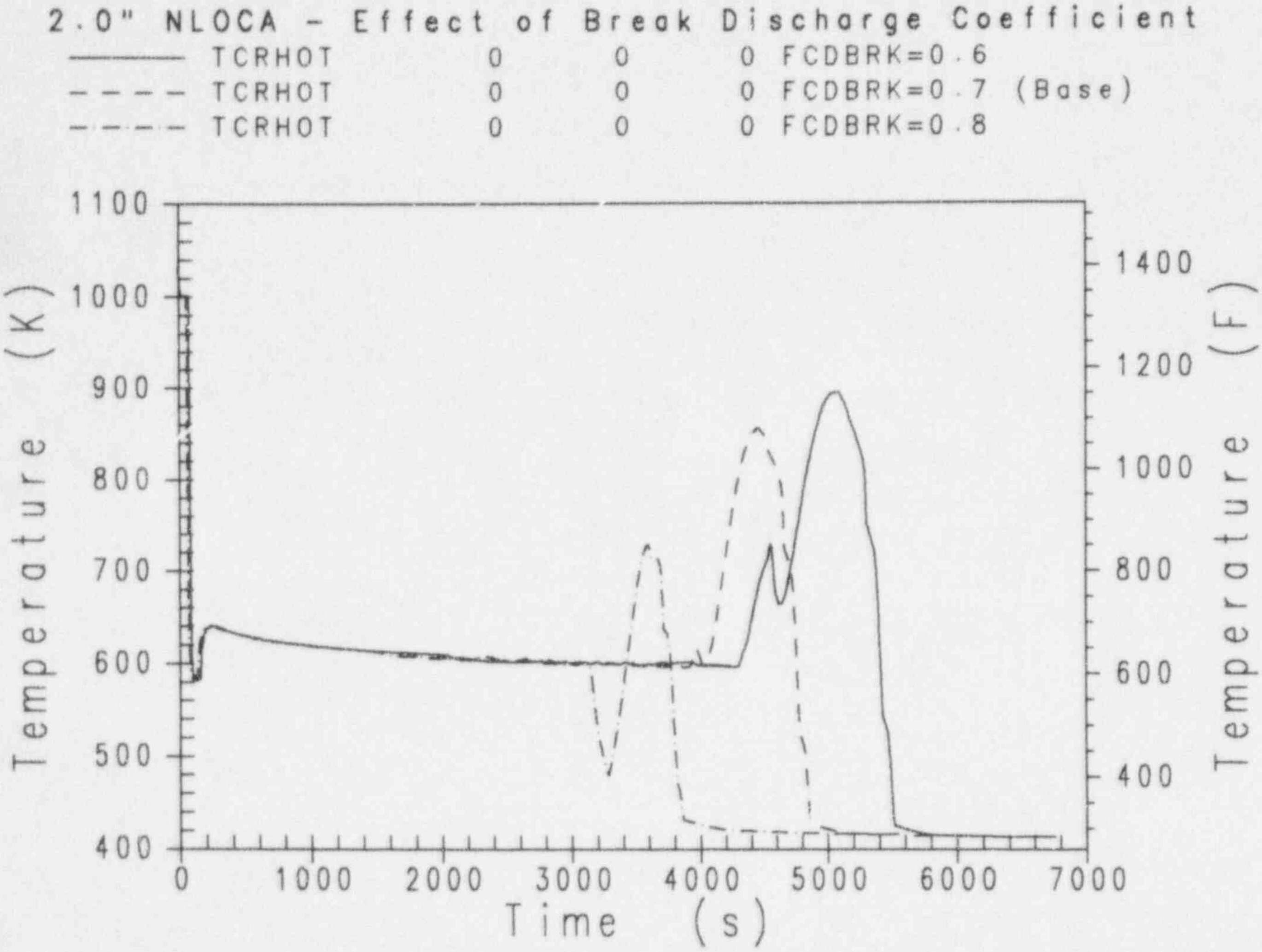


2.0" NLOCA - Effect of Break Discharge Coefficient

IV. CORE

CORE MODEL OVERVIEW

Subroutine HEATUP models the thermal-hydraulic behavior of the reactor core and the response of core components during all accident phases.

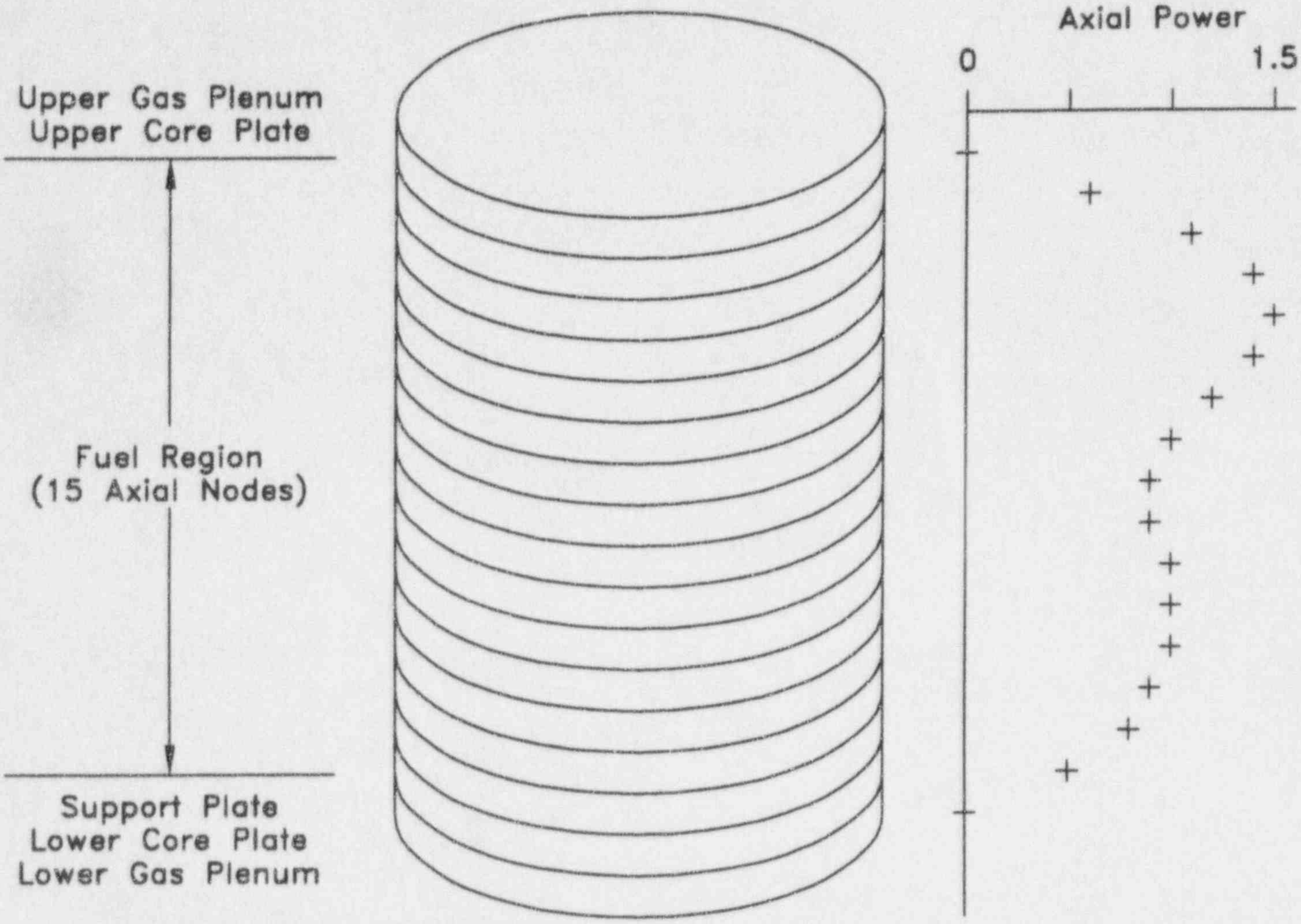
- Core is divided into a maximum of 175 nodes (25 axial rows, 7 radial rings)
  - AP600 model has 17 axial rows, 5 radial rings
- Inter-node heat transfer
  - Axial convection and conduction
  - Radial radiation (uncovered nodes only)
- Lumped mass approach is used for all mass and energy balances
- Quasi-steady state
  - Exit flows are determined by inlet flows (internal core flow rates due to pressure changes are neglected)

SUBROUTINES

The subroutines called by HEATUP that are relative to the pre-core damage state (geometry type 1) are:

TFUEL	Temperature and thermodynamic properties of fuel rod
NFCLAD	Fraction of components in the U-Zr-O mixture
TCLAD	Temperature and thermodynamic properties of fuel cladding
TCROD	Temperature and thermodynamic properties of control/water rod
COVER	Thermal-hydraulics and H_2 generation in the covered region
RATES1	Steaming rate in the core
CIRCUP	Core-to-upper plenum natural circulation
ROW	Thermal-hydraulics and H_2 generation in the uncovered region
STRETH	Fuel cladding ballooning and rupture
HTRADI	Radiation heat transfer into core nodes

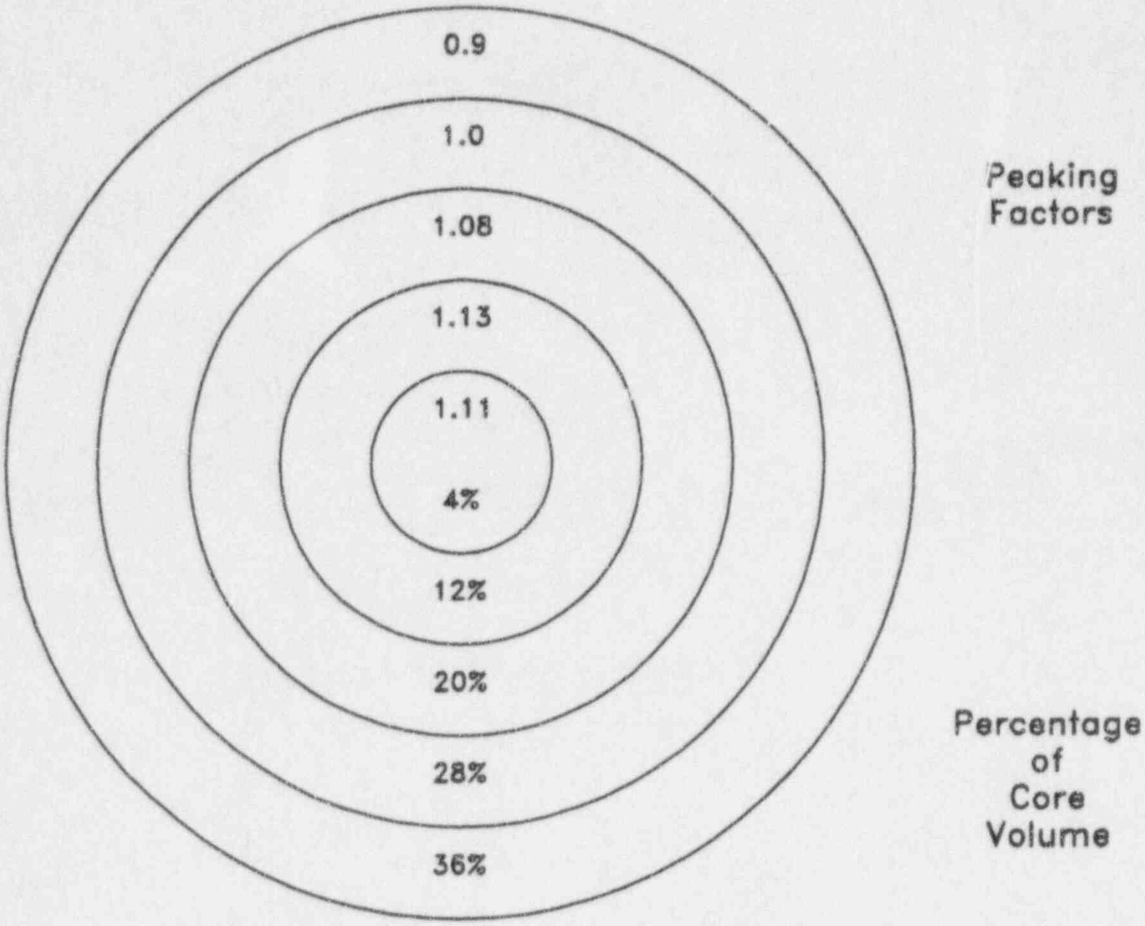
AP600 MAAP4
Axial Core Model



Total of 17 Axial Nodes

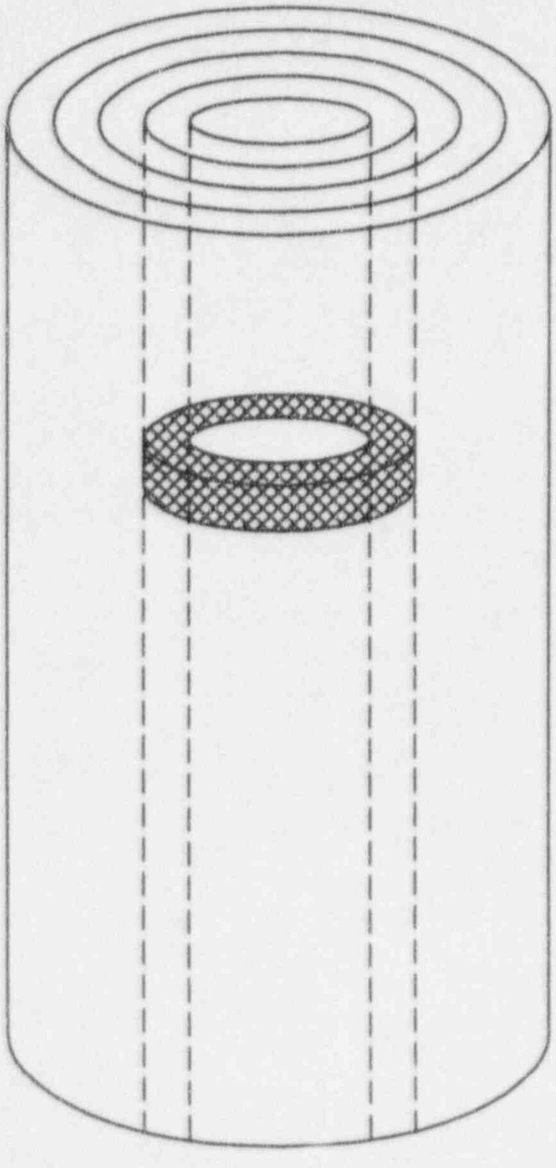
HM95-17

AP600 MAAP4
Radial Core Model



HM95-15

AP600 MAAP4
Example Core Node



Peak Power Node

- 0.8% of core volume
- 1.36% of core power

$F_Q = 1.7$

Node Contains:

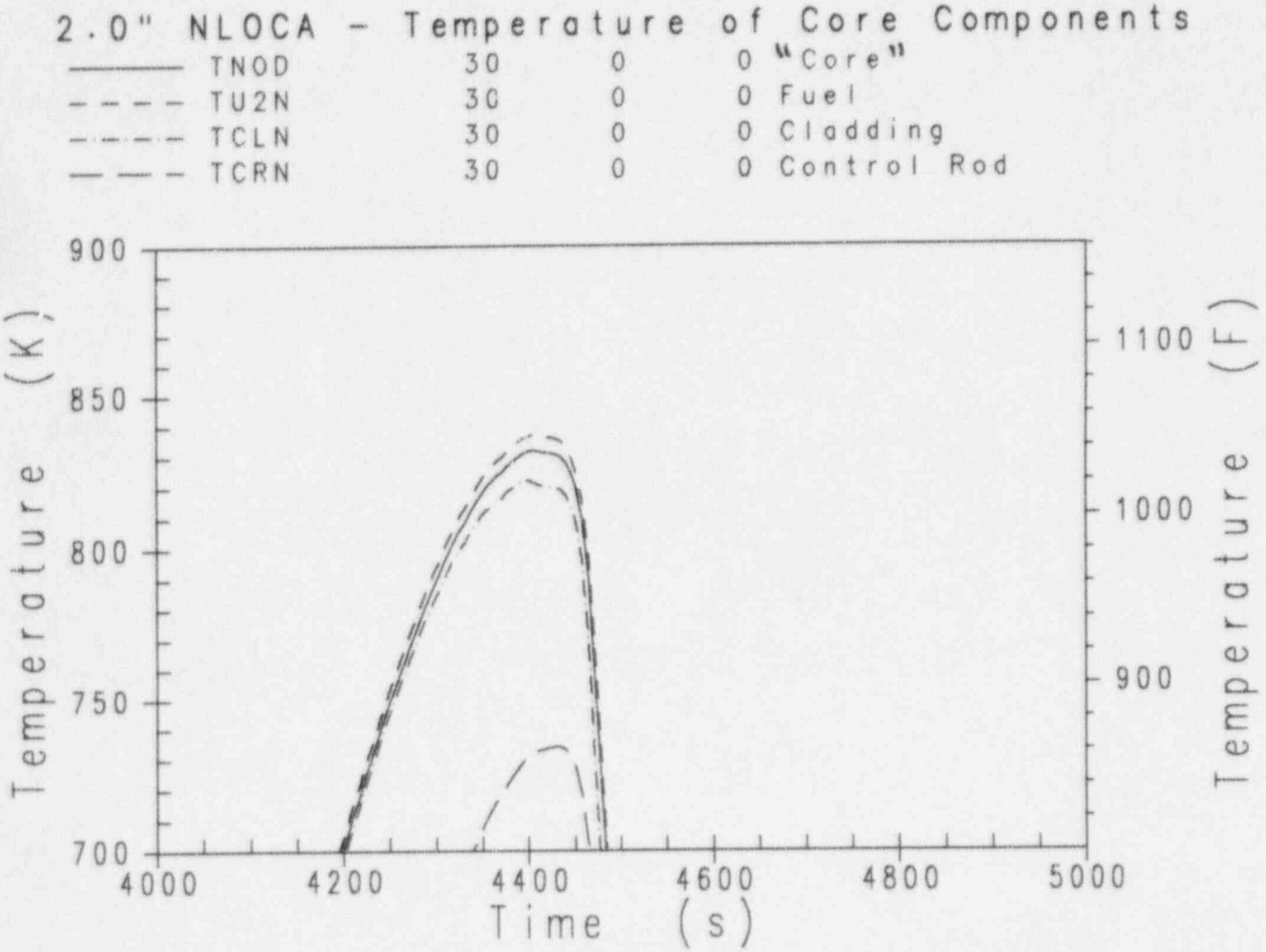
- Fuel
- Clad
- Control/Water Rod

Temperatures

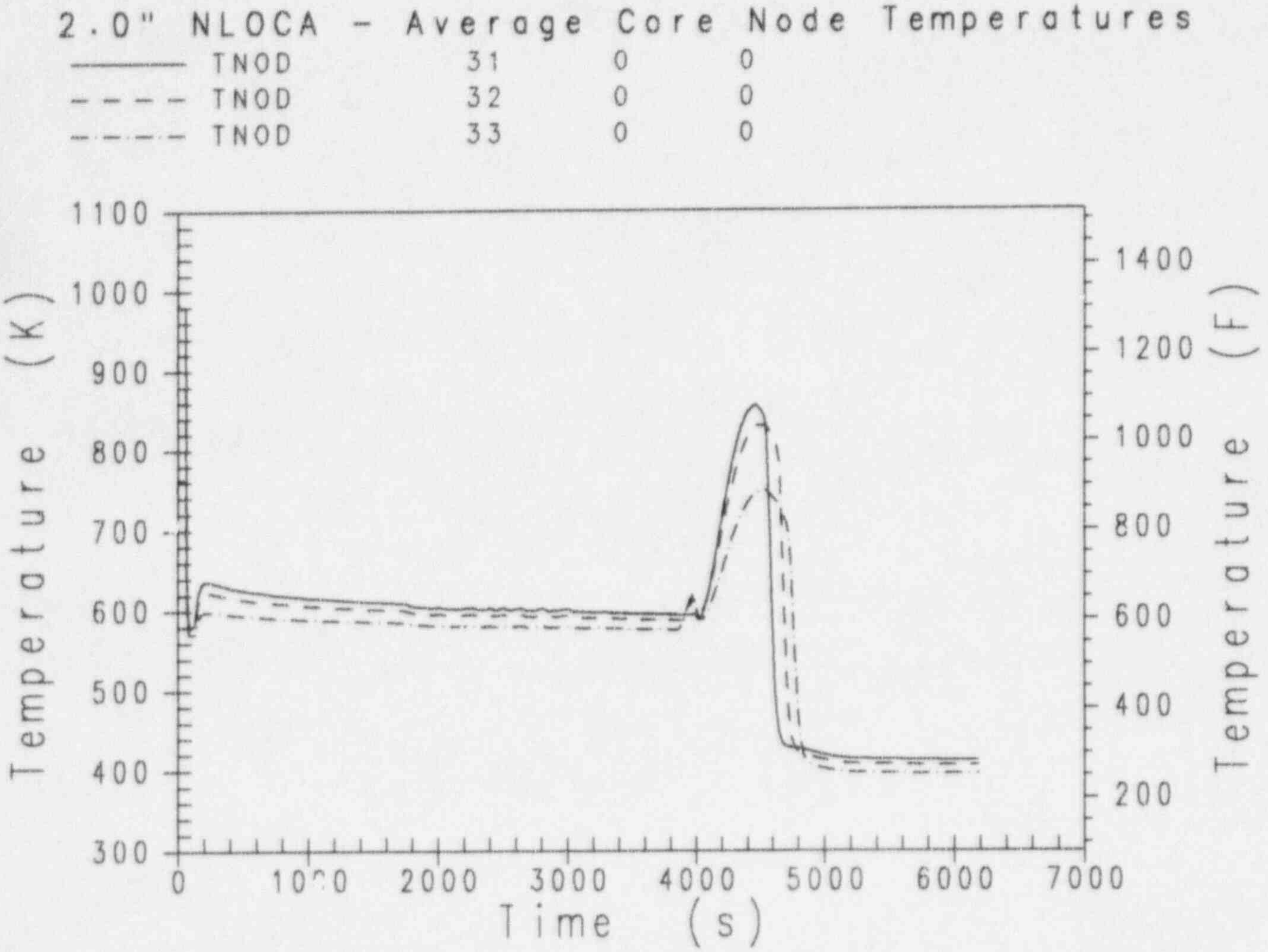
- Separate calculation for each component
- "Core Temperature" is average of 3 components, weighted by the mass

HM95-16

PRELIMINARY


2.0" NLOCA - Temperature of Core Components

PRELIMINARY



The maximum core temperature, TCRHOT, is the highest temperature from any node at a given time.

CORE HEAT TRANSFER

Heat transfer for all covered nodes is determined in **COVER** subroutine.

- Heat transfer from fuel to cladding
  - thermal conductivity of fuel (3.3 W/m-C)
  - fuel pellet-to-cladding gap conductance
    - contact heat transfer (5000 W/m^2-C)
    - radiation heat transfer ($\varepsilon = 0.85$)
    - change in fuel pin diameter is considered

- Heat transfer from cladding to water
  - convective heat transfer
    - Dittus-Boelter if pumps are running
    - film boiling heat transfer if pumps are not running (300 W/m^2-C)
  - radiation heat transfer ($\varepsilon = 0.90$)

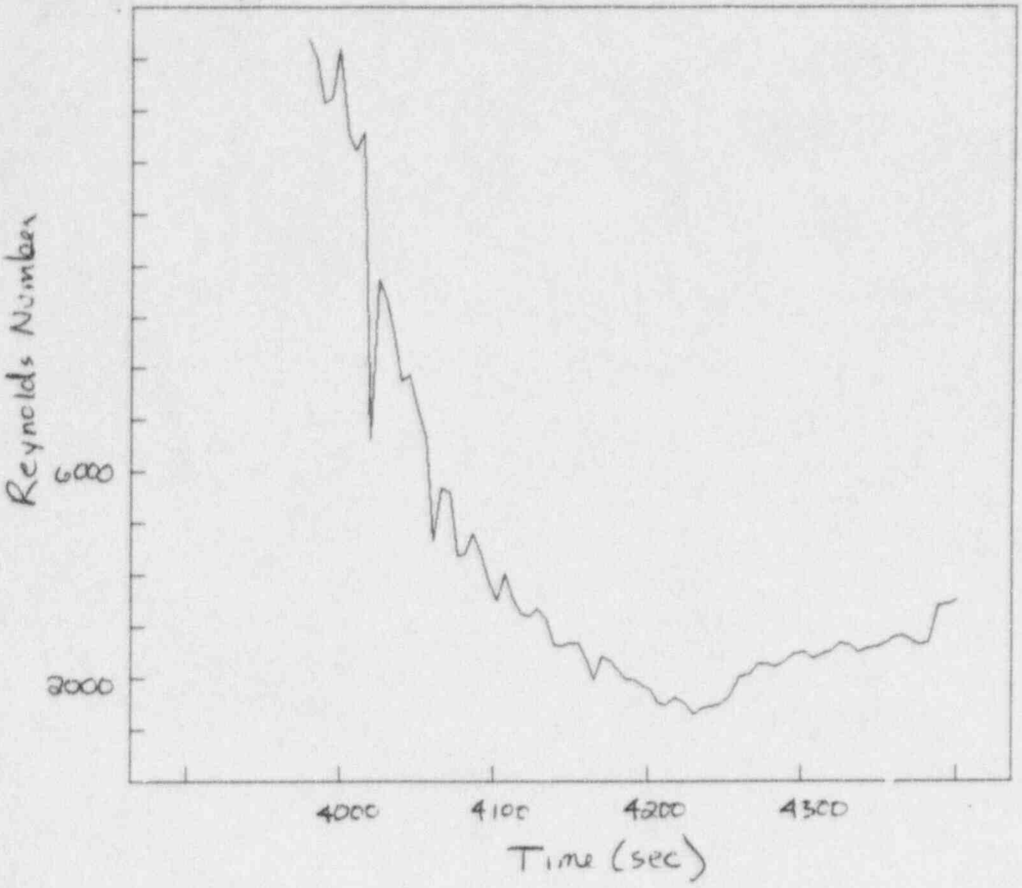
- Heat transfer from control rod to water
  - convective heat transfer (same as above)
  - radiation heat transfer ($\varepsilon = 0.90$)

- Radiation heat transfer is also considered for
  - fuel to water ($\varepsilon = 0.90$)
  - fuel to control rod ($\varepsilon = 0.85$)
  - cladding to control rod ($\varepsilon = 0.85$)

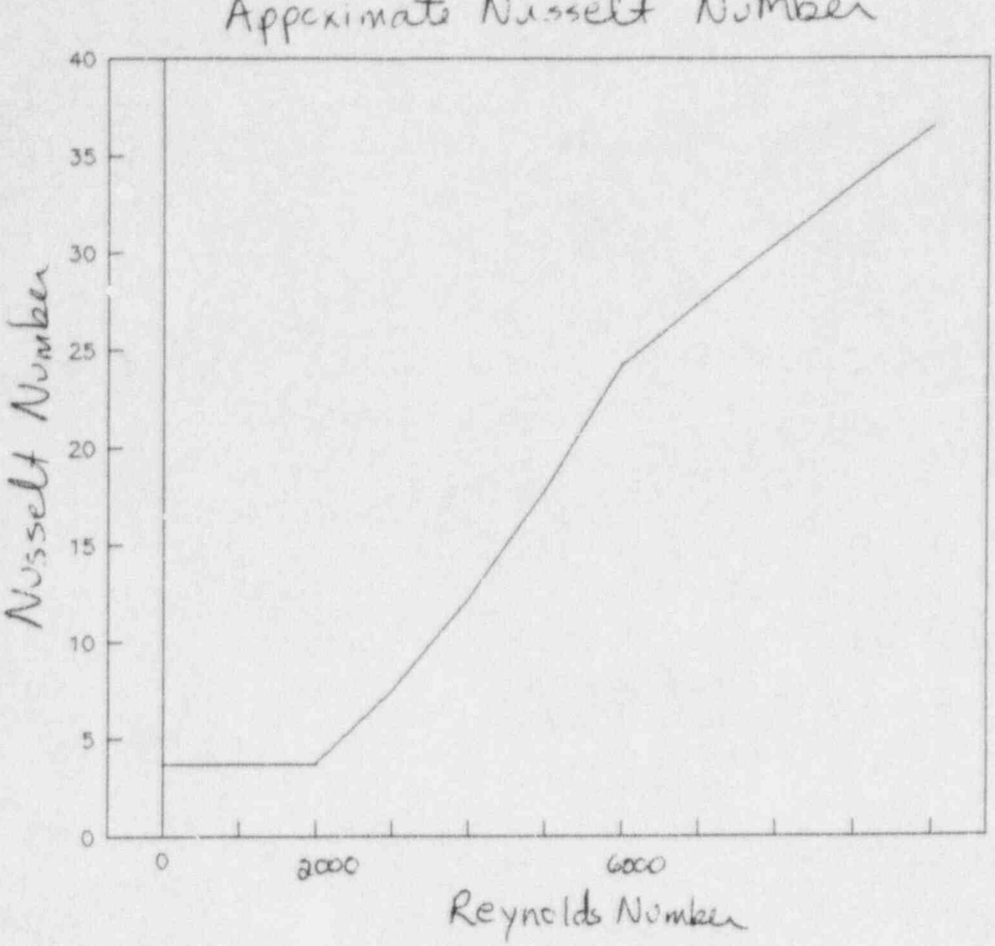
CORE HEAT TRANSFER (Cont)

Heat transfer for uncovered nodes is determined in **ROW** subroutine.

- Heat transfer from fuel to cladding same as COVER subroutine
- Heat transfer from cladding to steam
    - convective heat transfer is based on Nusselt number (h = NU*k/D)
    - radiation heat transfer ($\varepsilon = 0.6$)
- Heat transfer from control rod to steam
    - convective heat transfer is based on Nusselt number
    - radiation heat transfer ($\varepsilon = 0.6$)
- Radiation heat transfer is also considered for
    - fuel to steam ($\varepsilon = 0.60$)
    - fuel to control rod ($\varepsilon = 0.85$)
    - cladding to control rod ($\varepsilon = 0.85$)
- Inter-channel flow rates are calculated in subroutine REMIX


Approximate Reynolds Number for Uncovered Node 30

PRELIMINARY



PRELIMINARY

DECAY HEAT

- Decay heat can either be calculated or input as fraction of power vs. time

- Decay heat calculation is performed in **POWER** subroutine, called by PRISYS subroutine

- Decay heat calculation is based on best estimate 1979 ANS standard, with the following input

- Irradiation time	9.5e7 sec = 3 years
- Fuel enrichment	0.0247
- Exposure at shutdown	31205 MWD/metric ton
- Conversion ratio at shutdown	0.6
- Ratio of total capture rate to total fission rate of all fuel constituents	0.3

SENSITIVITY TO SELECTED INPUT

- Axial peaking factors
- Radial peaking factors
- Decay heat

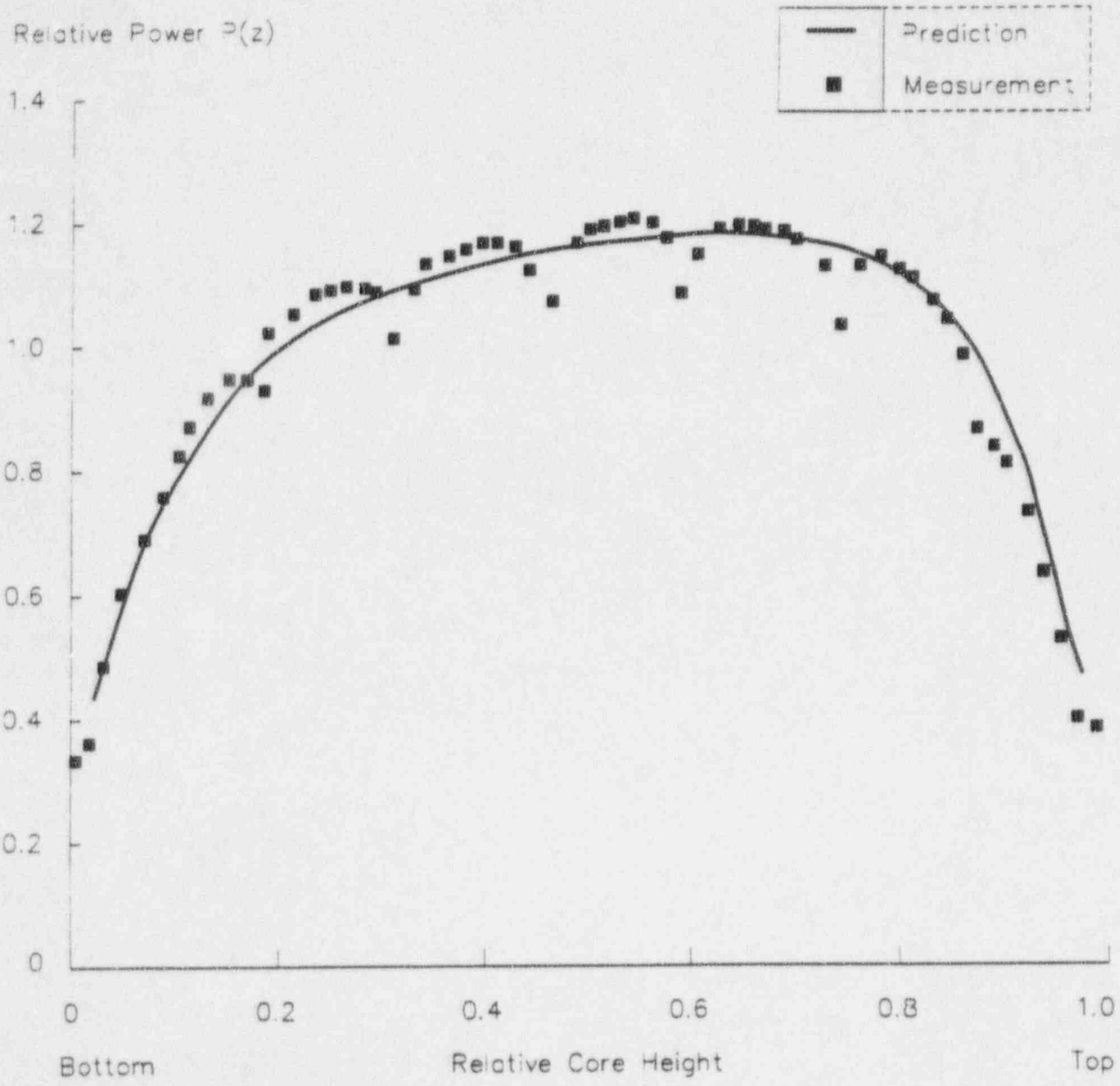
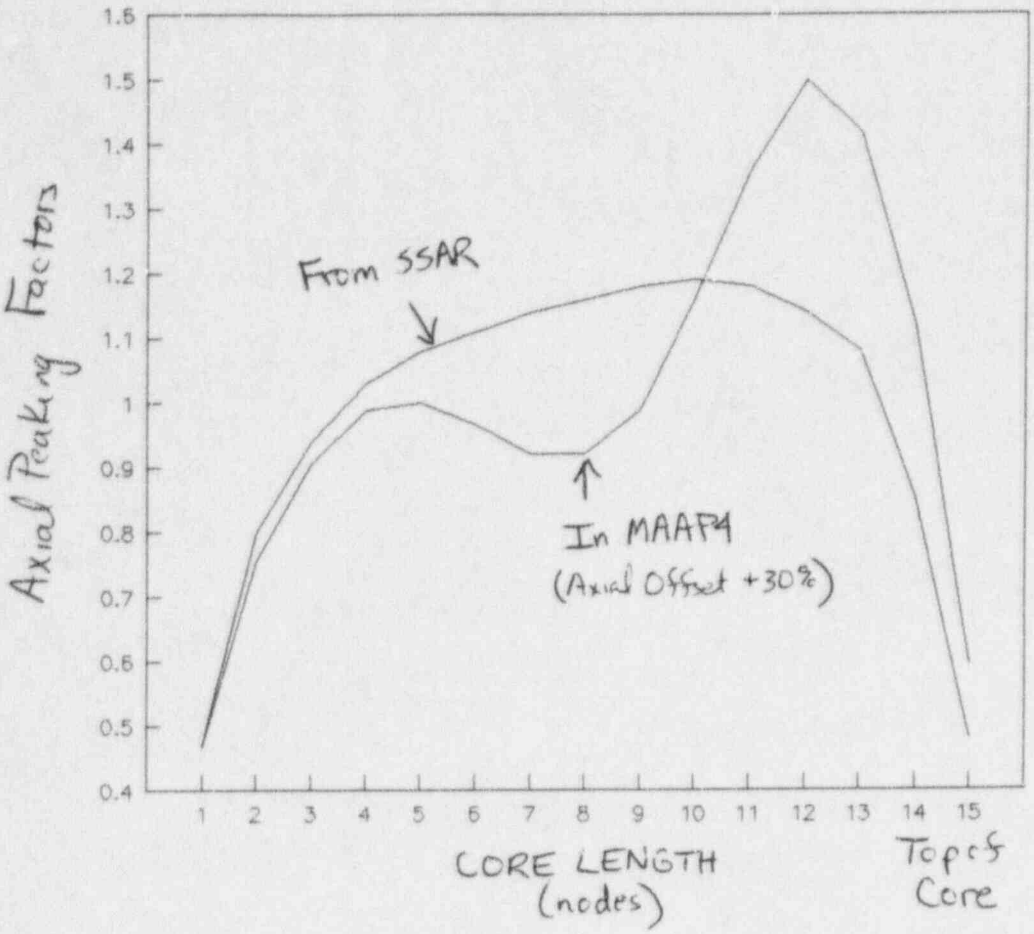


Figure 4.3-19

Typical Calculated versus Measured Axial Power Distribution

58



Axial Peaking Factors
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
From SSAR
In MAAP4
(Axial Offset +30%)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
CORE LENGTH
(nodes)
Top of Core

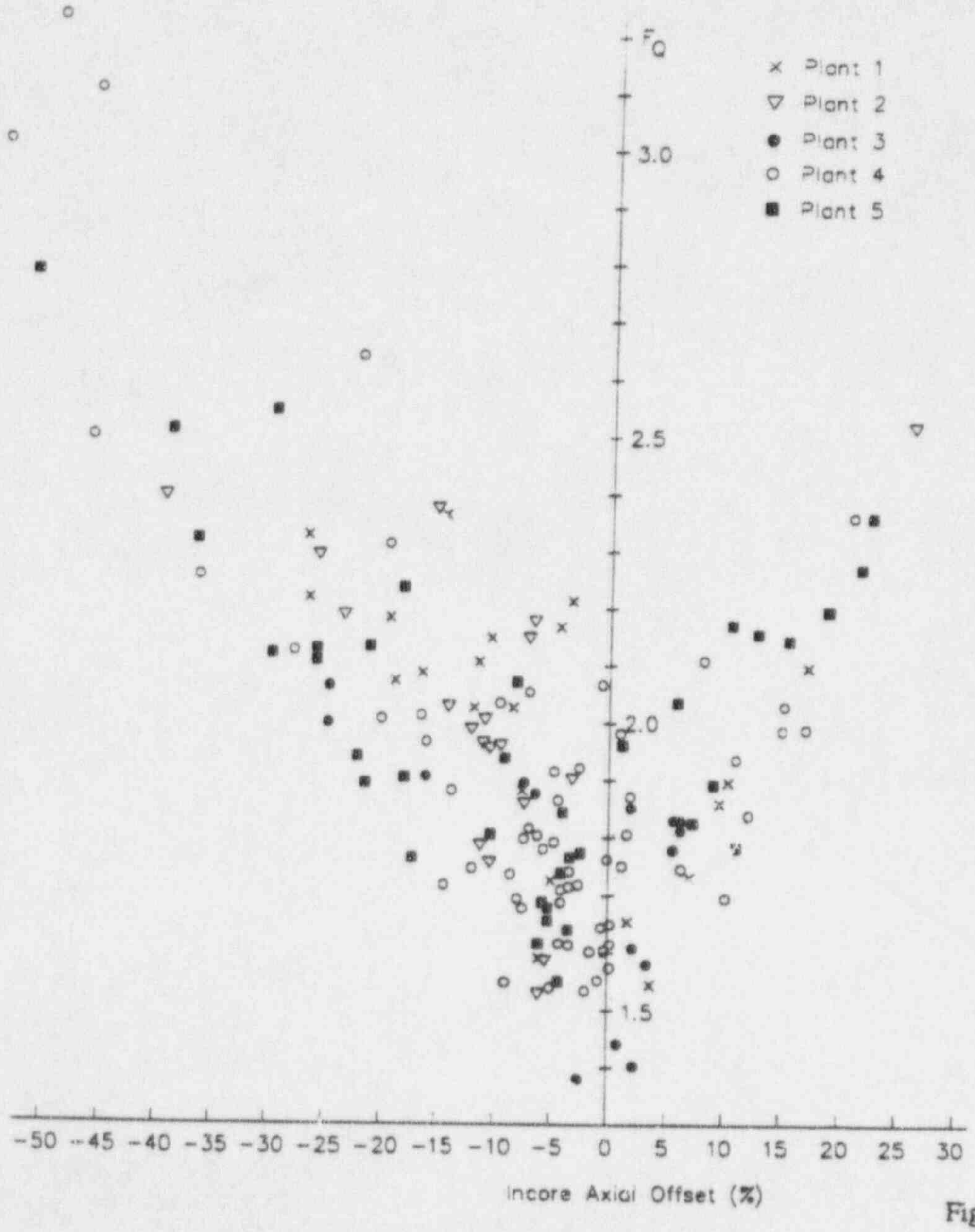
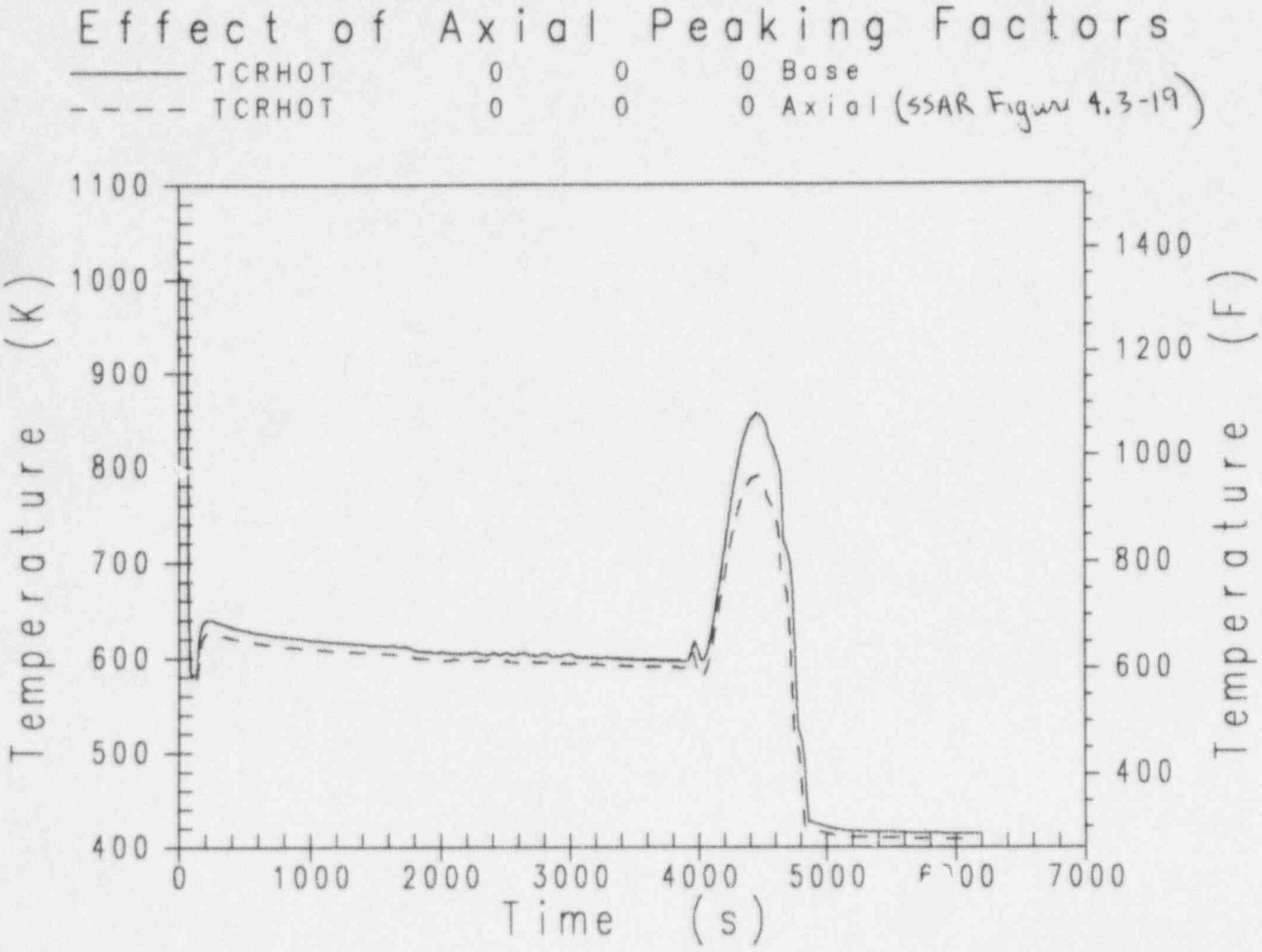


Figure 4.3-20

Measured F_Q Values versus Axial Offset for Full Power Rod Configurations

60

PRELIMINARY



1.138				
1.125	1.116			
1.085	1.068	1.072		
1.016	1.060	1.045	1.067	
1.039	1.022	1.034	1.022	1.147
0.922	1.022	1.034	0.904	0.811
1.003	0.957	0.984	0.725	

CALCULATED F-DELTA-H = 1.34

KEY: VALUE REPRESENTS ASSEMBLY RELATIVE POWER

Figure 4.3-7

Normalized Power Density Distribution Near Beginning of Life, Unrodded Core, Hot Full Power, Equilibrium Xenon

1.043				
1.186	1.060			
1.085	1.219	1.076		
1.225	1.268	1.182	1.016	
1.012	1.134	0.995	1.068	1.129
0.889	0.911	1.078	0.806	0.733
0.876	0.844	0.851	0.627	

CALCULATED F-DELTA-H = 1.35

KEY: VALUE REPRESENTS ASSEMBLY RELATIVE POWER

Figure 4.3-9

Normalized Power Density Distribution Near Middle of Life, Unrodded Core, Hot Full Power, Equilibrium Xenon

0.914				
1.064	0.930			
0.954	1.105	0.969		
1.134	1.143	1.134	0.985	
0.967	1.130	0.989	1.123	1.157
0.927	0.944	1.213	0.872	0.796
0.922	0.925	0.921	0.712	

CALCULATED F-DELTA-H = 1.30

KEY: VALUE REPRESENTS ASSEMBLY RELATIVE POWER

Figure 4.3-10

Normalized Power Density Distribution Near End of Life, Unrodded Core, Hot Full Power, Equilibrium Xenon

PRELIMINARY

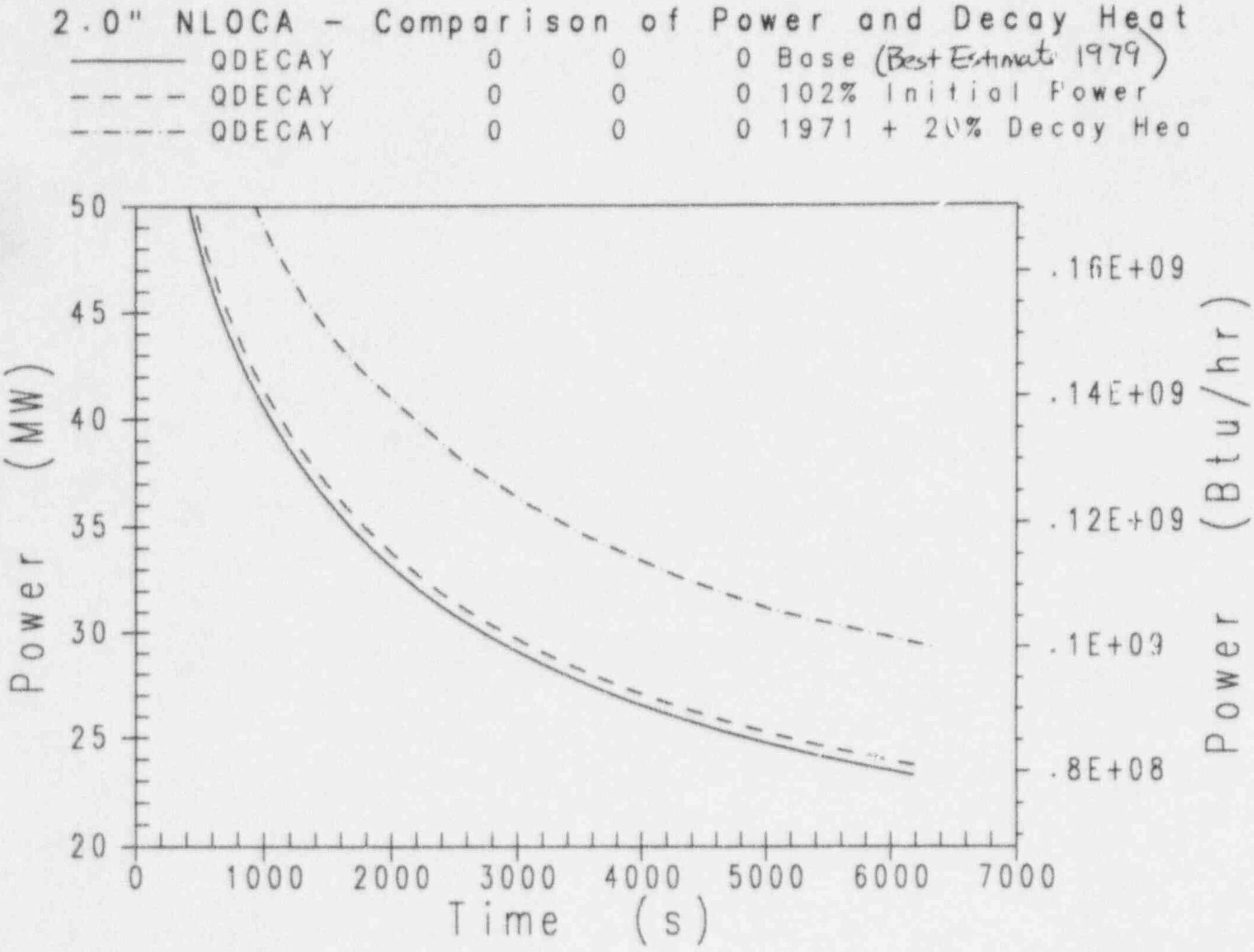
Comparison of Radial Peaking Factors

Node	Area	Used in MAAP4	Peaking Factors based on AP600 SSAR, Chapter 4		
			BOL	MOL	EOL
1	4%	1.11	1.12	1.11	0.98
2	12%	1.13	1.08	1.15	1.03
3	20%	1.08	1.05	1.17	1.10
4	28%	1.00	1.01	1.01	1.04
5	36%	0.90	0.92	0.83	0.9

Sensitivity Analyses on MAAP4 Radial Peaking Factors

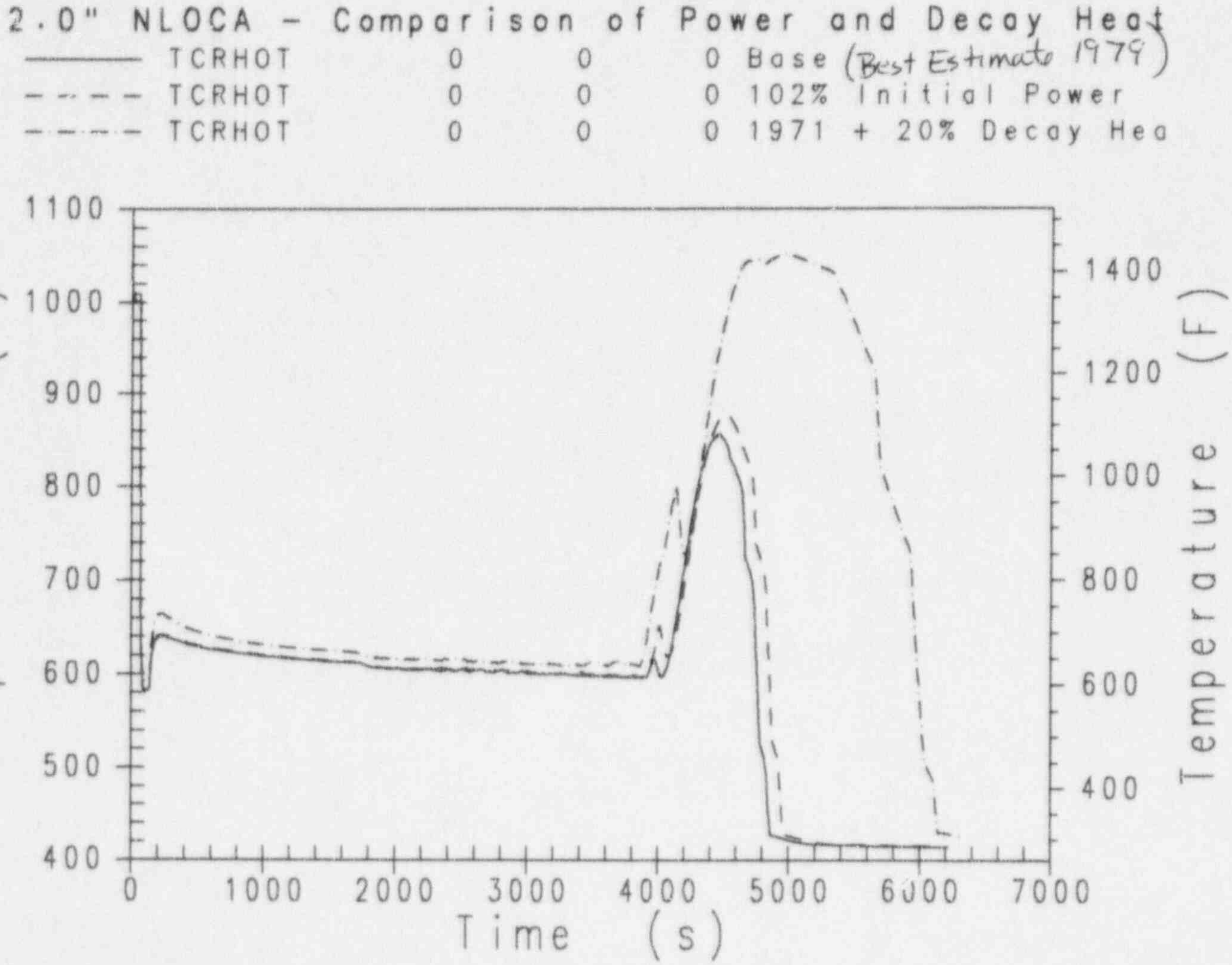
Node	Base		RAD1		RAD2		RAD3	
	Area	Peaking	Area	Peaking	Area	Peaking	Area	Peaking
1	4%	1.11	4%	1.11	<1%	1.04	<1%	1.04
2	12%	1.13	12%	1.15	6%	1.12	6%	1.12
3	20%	1.08	20%	1.17	11%	1.15	11%	1.15
4	28%	1.00	28%	1.01	17%	1.19	17%	**1.27**
5	36%	0.90	36%	0.83	22%	1.07	22%	**1.02**
6	-	-			25%	0.88	25%	**0.87**
7	-	-			19%	0.79	19%	0.79
PCT	1081°F		1092°F		1302°F		1349°F	

PRELIMINARY



2.0" NLOCA - Comparison of Power and Decay Heat

PRELIMINARY


2.0" NLOCA - Comparison of Power and Decay Heat

Pressurizer Modeling

- Subroutine PZR calculates mass and energy distribution, operation of sprays and heaters
- Subroutine FLOEXP calculates the pool thermodynamics steaming, flashing and condensation, surge line and relief flows including water draining, counter-current draining, and flooding
- Inputs
    - Geometry
    - Masses
    - Spray and heater setpoints and characteristics
    - Safety valve and ADS 1-3 characteristics

V. GENERIC MODELS INTERFACING WITH RCS

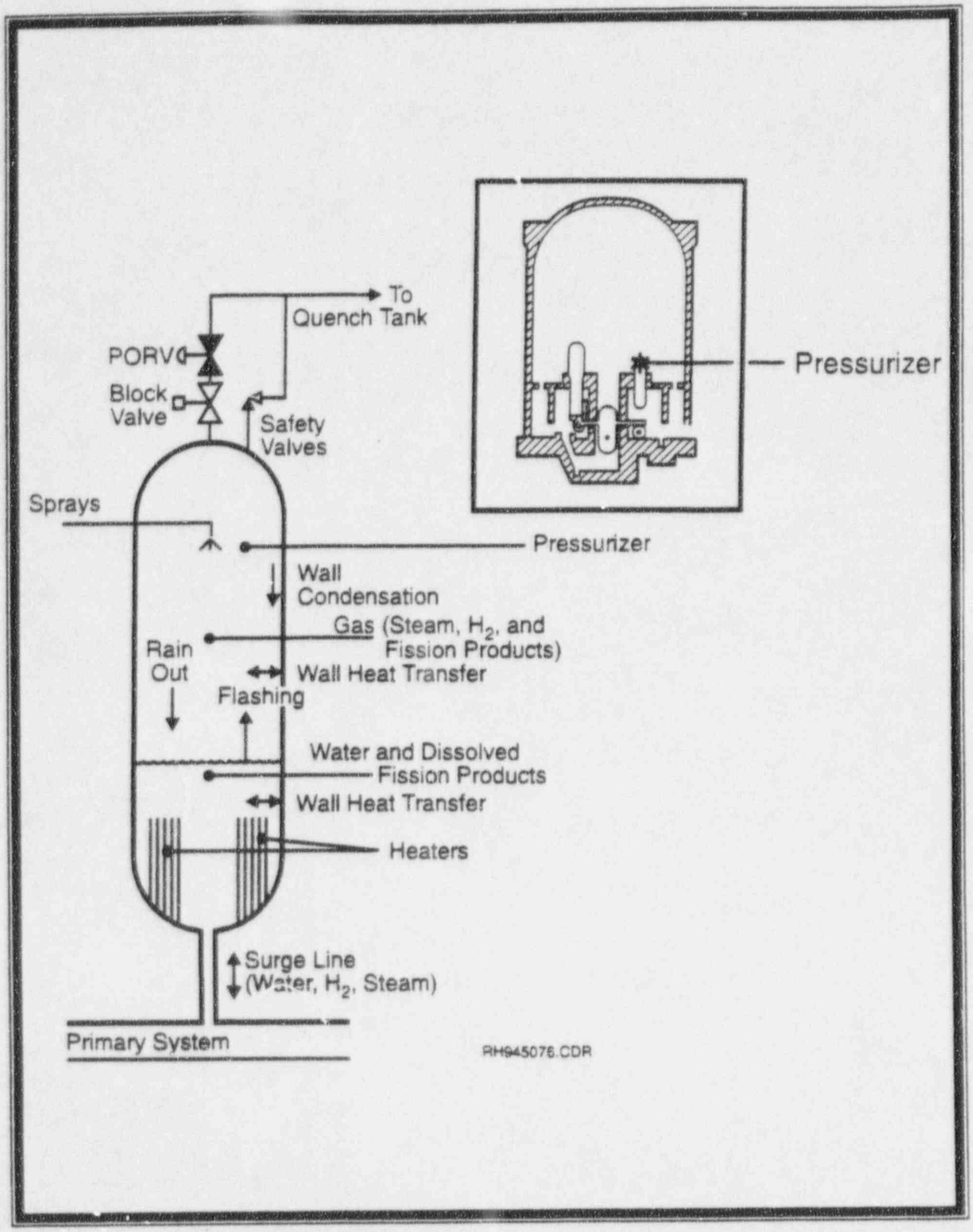


Figure 1 Schematic Description of the Pressurizer.

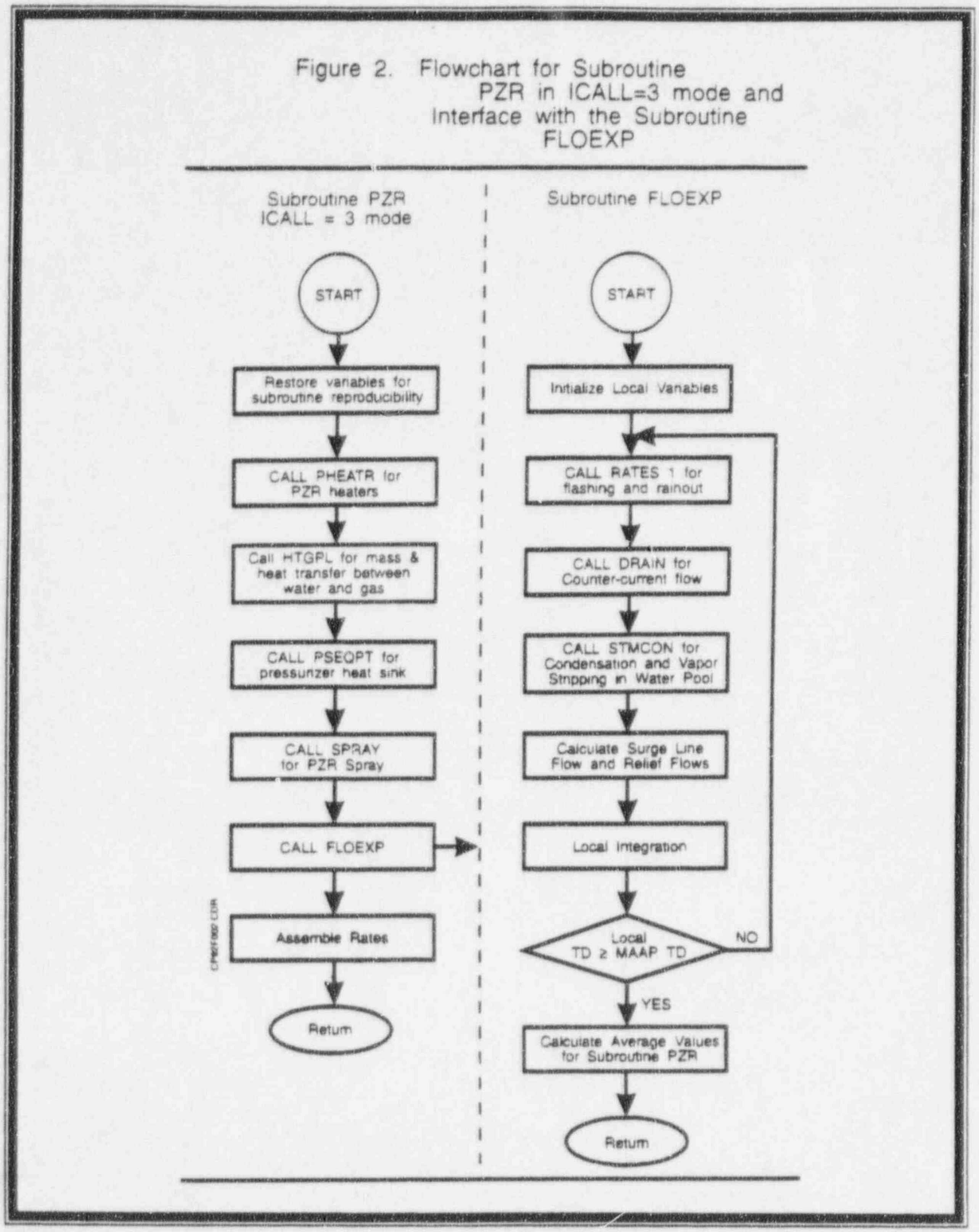


Figure 2 Flow Chart for Subroutine PZR in ICALL=3 Mode and Interface with Subroutine FLOEXP.

Accumulators

- Calculated in Subroutine ACCUM
- Inputs
  - number of accumulators
  - initial water mass in one accumulator
  - volume of one accumulator
  - initial pressure and temperature
  - L/D of the injection line
- Injects to downcomer node
- Assumes isothermal expansion of the gas in the accumulator to calculate the pressure

$$P_a = \frac{V_0}{V_{N_2}} P_0$$

- Calculates injection flow from Bernoulli equation

$$W = A_{pipe} \sqrt{\frac{2\,[P_a - P_{pe}]}{v_w}} \frac{1}{\sqrt{1 + f\ L/D}}$$

- Does not inject nitrogen into RCS

ACCUMULATOR SENSITIVITY CASES

Input	**Case**			
	Current Parameter File	**Min Accum Flow**	**Nominal Accum Flow**	**Max Accum Flow**
Pipe Diameter	0.1731 m	0.1778 m	0.1778 m	0.1778 m
Eq. Pipe Length	157 m	157 m	144 m	128 m
Initial Pressure	715 psia	650 psia	715 psia	783 psia
Water Temp.	322°K	322°K	303°K	283°K

- Sample case for this meeting does not have any accumulators modelled

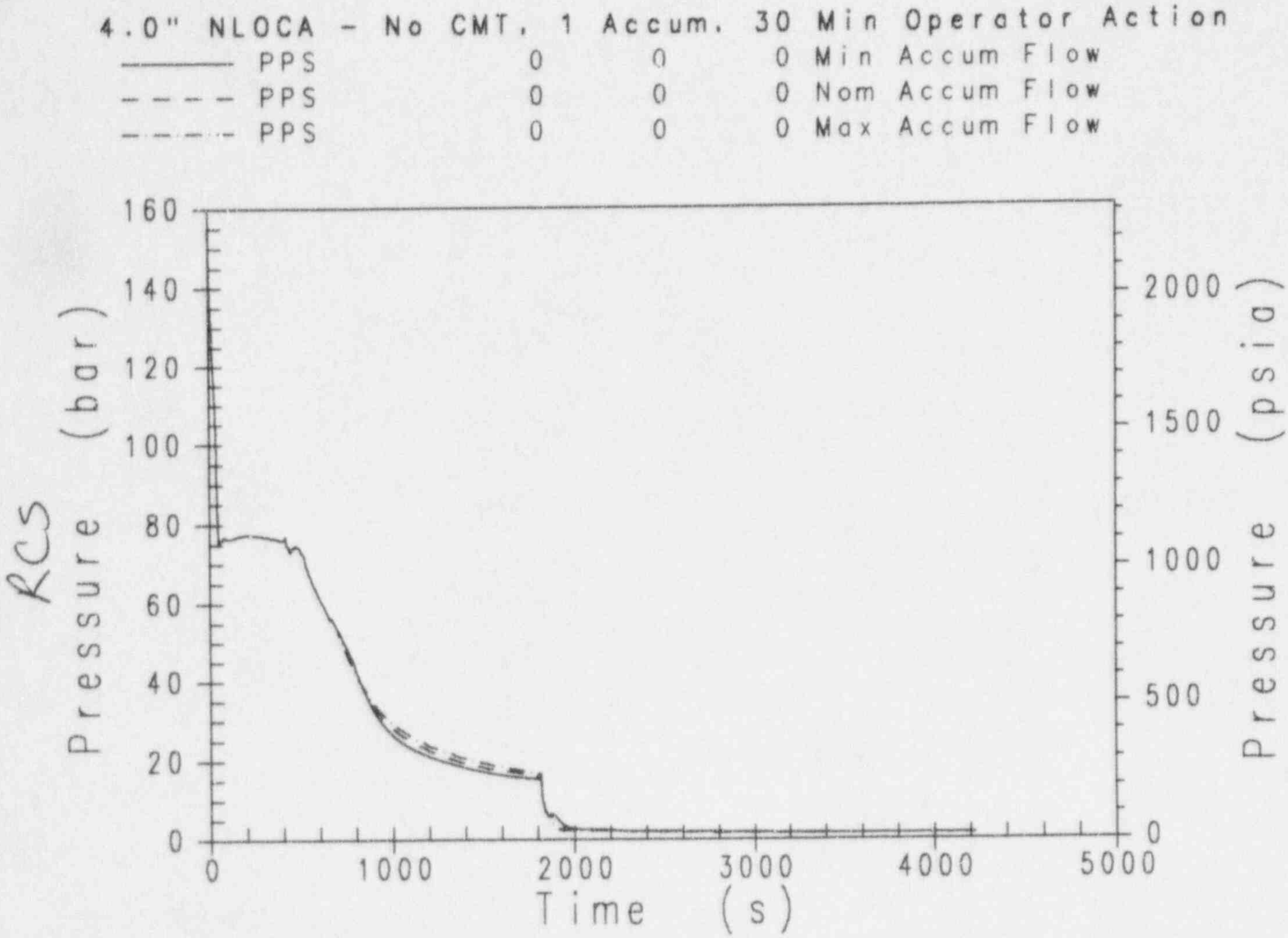
- Base case for Accumulator Sensitivity:
  - 4.0" hot leg NLOCA
  - 1 Accumulator
  - No CMTs
  - 2 stage 4 ADS (manual - operator action at 30 minutes)

- Sensitivity Results

	Peak Core Temperature (°F)
- Base (Defined Above)	1314
- Minimum Accumulator Flow	1432
- Nominal Accumulator Flow	1285
- Maximum Accumulator Flow	1165

PRELIMINARY

PRELIMINARY



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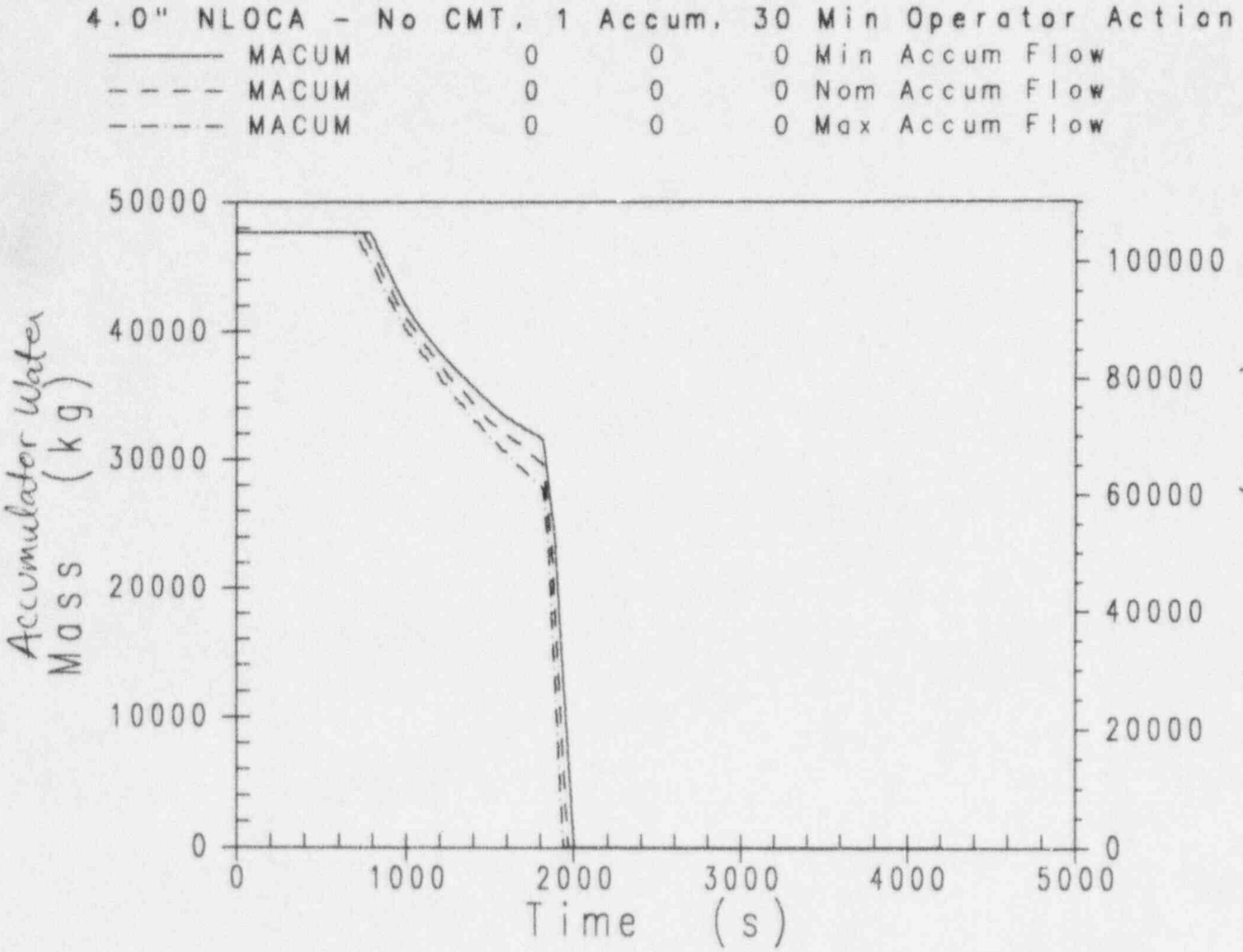

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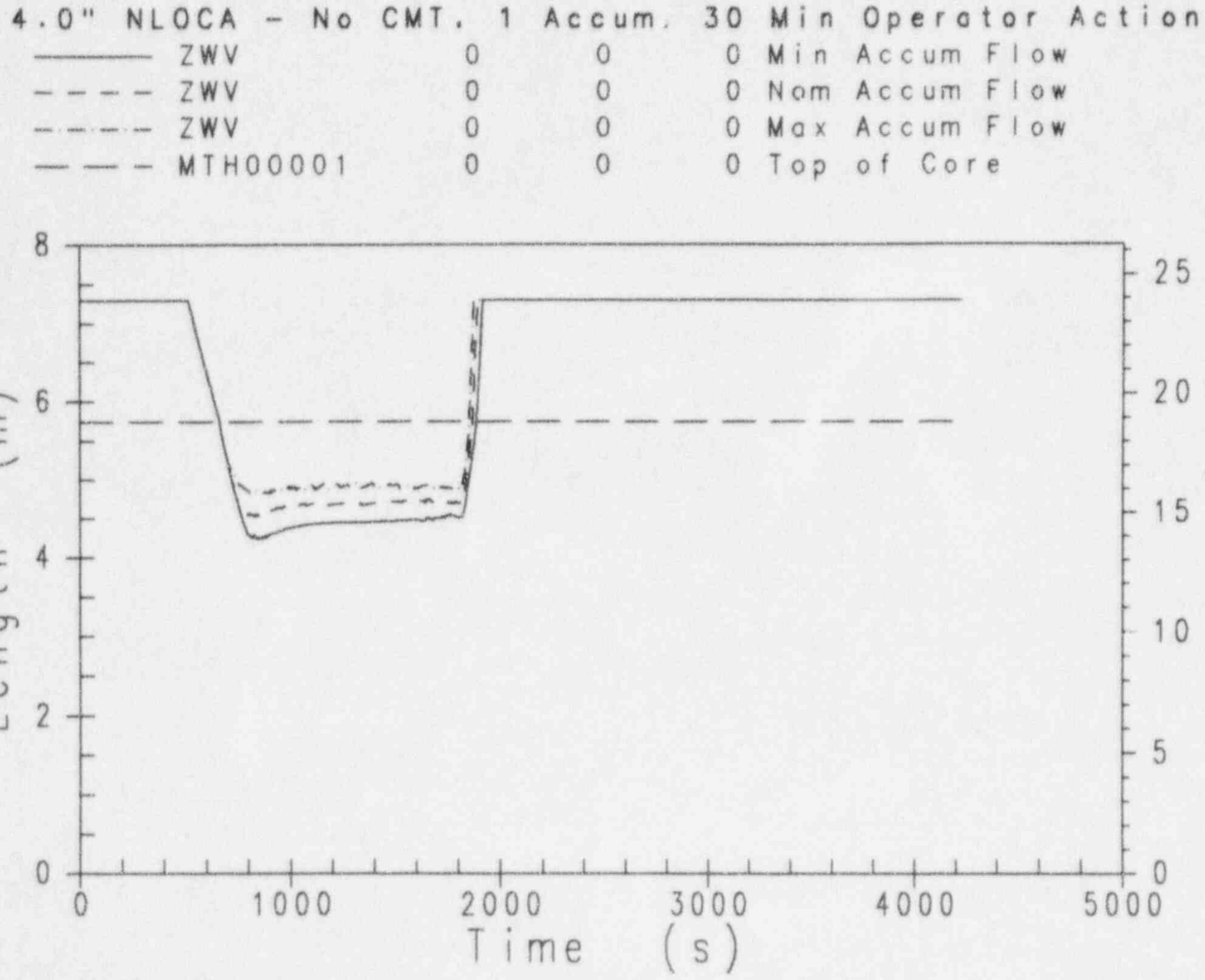
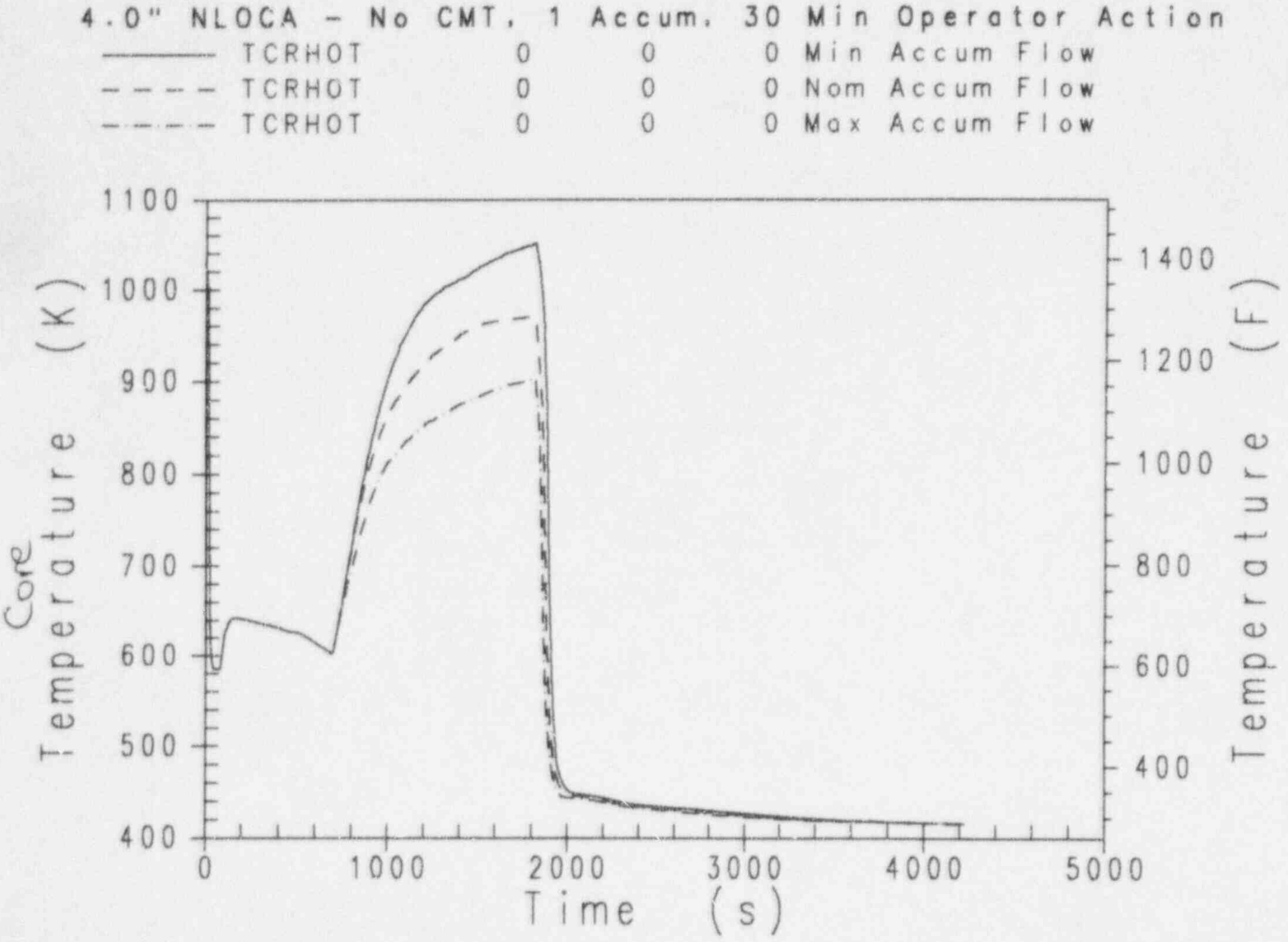


PRELIMINARY



SG Model

Subroutines **BSTGEN/USTGEN** model the thermal-hydraulic behavior in the secondary side of the steam generators.

- Secondary side of the SG is modeled as one control volume containing steam and water
- The SG model includes equilibrium and non-equilibrium thermodynamics
  - Subroutine **PTCAL** determines the pressure and temperatures using the nonequilibrium model, unless the SG is near-solid.
- Secondary side water is assumed to fill the downcomer and bundle to the same collapsed level
- SG safety valve flow rate is calculated by subroutine **GFLOW**
- Collapsed water level is determined from input of volume vs. level table
- High and low SG level setpoints are input as collapsed level
- The boiled-up water level is calculated using a drift flux model (function **VFVOL**)
  - Average bundle void fraction includes a correction factor, which is based on input vs. calculated boiled up water level

SG HEAT TRANSFER

- Heat transfer from primary side to secondary side water is calculated by subroutine **HXFRSG**

  When the primary side is homogeneous:

  - RCPs are on, subroutine **QSGCV** calculates the forced convection heat transfer coefficient using Dittus-Boelter correlation (function **HXDBW**)
  - Natural circulation, the heat transfer coefficient is user-input (HTSTAG)

  When the primary side is stratified:

  - If water is in the SG tubes
    - Subroutine **QSGCF** is used; the primary side heat transfer coefficient is based on conduction from stagnant water in the tubes
  - If steam and/or hydrogen are in the SG tubes
    - Reflux cooling, where primary side steam is drawn into the tubes from the hot leg, and condensate flows back through the hot leg to the core

- Heat transfer from primary side to uncovered tubes on the secondary side is found by subroutine **PSHS** and **PSEQPT**

VI. AP600-SPECIFIC MODELS

Core Makeup Tank Models

- Subroutine CRMKTK
  - mass and energy balance
  - flashing and rainout
  - heat transfer, condensation/evaporation between gas-water interface
  - discharge line flow
  - balance line flow

- Single node lumped parameter model

- Inputs
  - Geometry
  - Elevations
  - Discharge line area and L/D
  - Balance line area and L/D
  - Initial mass and temperature of water in CMT

- System actuation
  - "User Events" model the signals
  - "Action Blocks" model the actuation of the system

```
**
** SI SIGNALS
**
500 PPZ < 1.286E7 PA LOCK     // LOW PRZ PRESSURE SETPOINT
502 PRB(6) > 1.3583E5 PA LOCK  // HIGH CONTAINMENT PRESSURE SETPOINT
504 PBS < 4.137E6 PA LOCK      // LOW SG AND STEAMLINE PRESSURE SETPOINT
505 PUS < 4.137E6 PA LOCK
506 TWBI < 541 K LOCK          // LOW COLD LEG TEMP SETPOINT
507 EVENT 500 TRUE OR EVENT 502 TRUE
508 EVENT 504 TRUE OR EVENT 505 TRUE
509 EVENT 507 TRUE OR EVENT 508 TRUE
512 EVENT 509 TRUE OR EVENT 506 TRUE

** CMT ACTUATION LOGIC

531 ZWCPS < ZSGTS
533 ZWPZ < 2.62 M LOCK              // LOW-2 PRZ LEVEL SETPOINT (10%)
** SG Level is collapsed; corresponding 2-phase level is 10.63 m
534 ZWBS < 8.3 M LOCK               // LOW SG LEVEL WR SETPOINT (67%)
535 ZWUS < 8.3 M LOCK
536 EVENT 531 TRUE AND TGBH > 594 K LOCK  // HIGH HOT LEG TEMP SETPOINT
537 EVENT 531 TRUE AND TGUH > 594 K LOCK
538 EVENT 534 TRUE OR EVENT 535 TRUE
539 EVENT 536 TRUE OR EVENT 537 TRUE
540 EVENT 538 TRUE AND EVENT 539 TRUE
541 EVENT 533 TRUE OR EVENT 540 TRUE
542 EVENT 541 TRUE OR EVENT 512 TRUE

** ACTION 2 ACTUATES THE CMT'S
** ---------------------------

542 ACTION 2            //SI or LOW-2 PZR LEV or  LOW SG LEV and HIGH HL TEMP

    ACTION 2
            EVENT 275=1         //OPEN CMT #1 Discharge
**            EVENT 277=1         //OPEN CMT #2 Discharge
    END
```

CMT Flows

- CMT Recirculation
  - water solid CMT
  - equal volumetric natural circulation in discharge and balance line
  - sufficient water head in RCS

- CMT Injection to Downcomer
  - water head in RCS not sufficient to sustain recirculation flow
  - calculated by Bernoulli flow based on head difference

- Balance Line Flow from Cold Leg to CMT, if CMT not solid
  - water flow if RCS head > CMT head
  - no flow if water covered balance line and RCS head < CMT head
  - gas flow if balance line uncovered or if P_{CMT} > RCS head

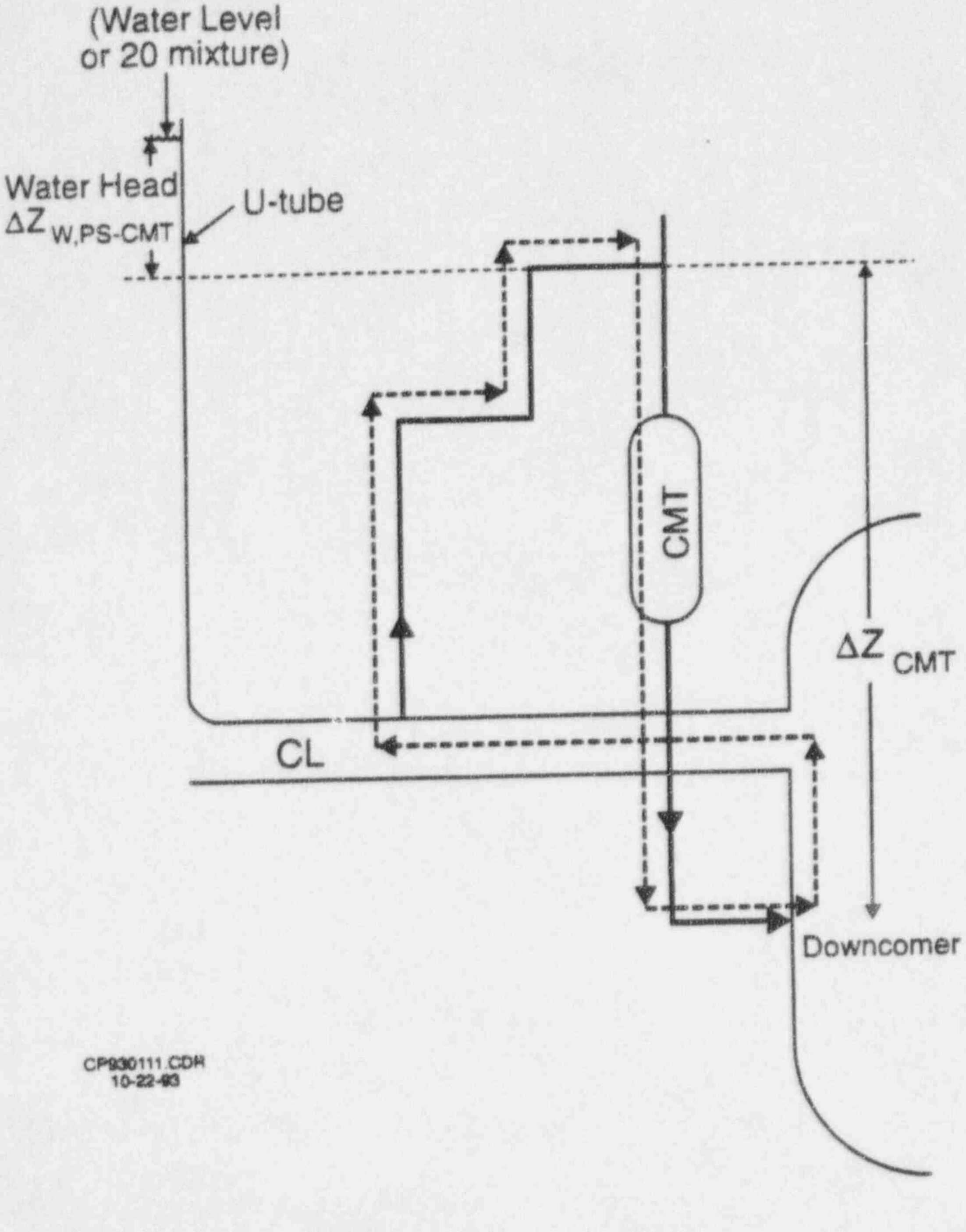
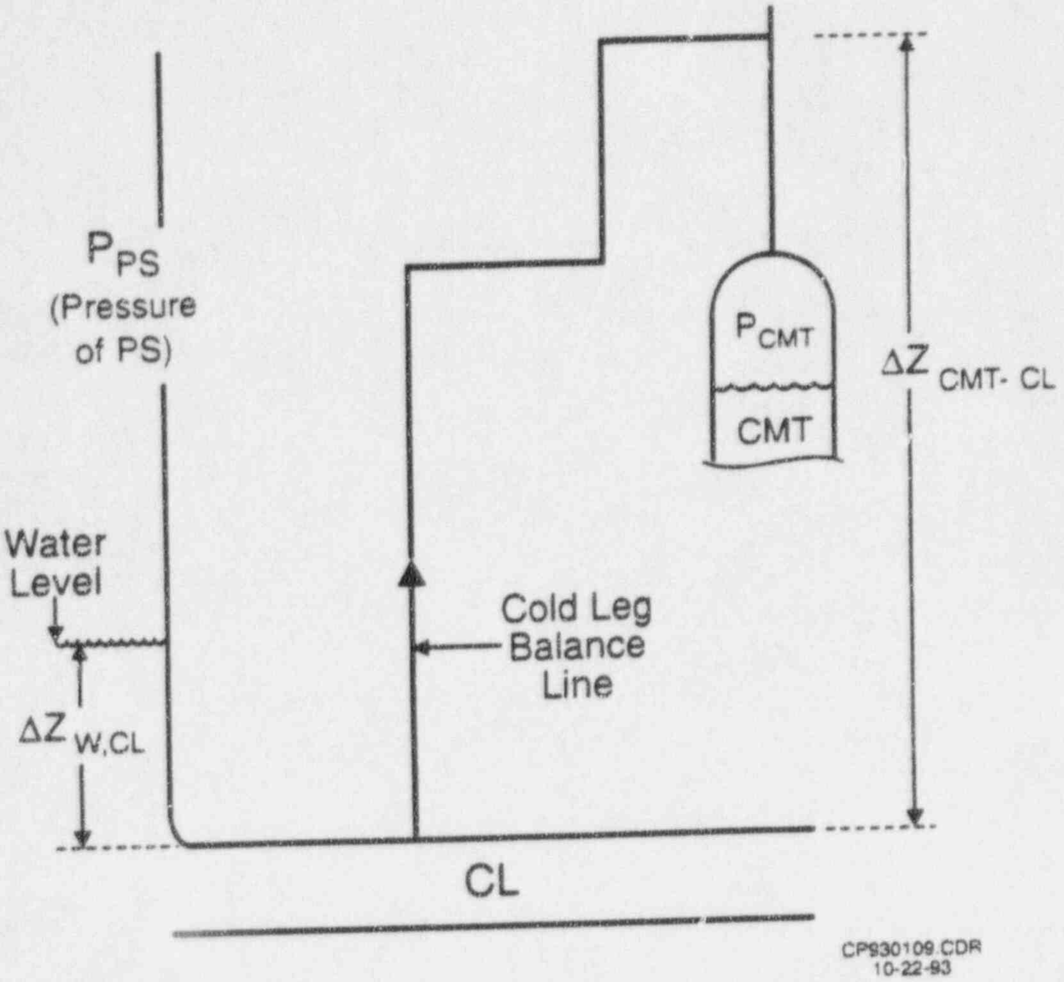


Figure 2 Natural circulation in CMT.



1) Water Flow if

$$P_{PS} + \rho_{DC}\, g\, \Delta Z_{W,CL} > P_{CMT} + \rho_{DC}\, g\, \Delta Z_{CMT-CL}$$

2) No Flow if

$$P_{CM} < P_{PS} + \rho_{DC}\, g\, \Delta Z_{W,CL} < P_{CMT} + \rho_{DC}\, g\, \Delta Z_{CMT-CL}$$

3) Gas Flow if

$$\Delta Z_{W,C} < 0 \text{ or } P_{CMT} > P_{PS} + \rho_{DC}\, g\, \Delta Z_{W,CL}$$

Figure 3 Calculation of water flow rate in the cold leg balance line.

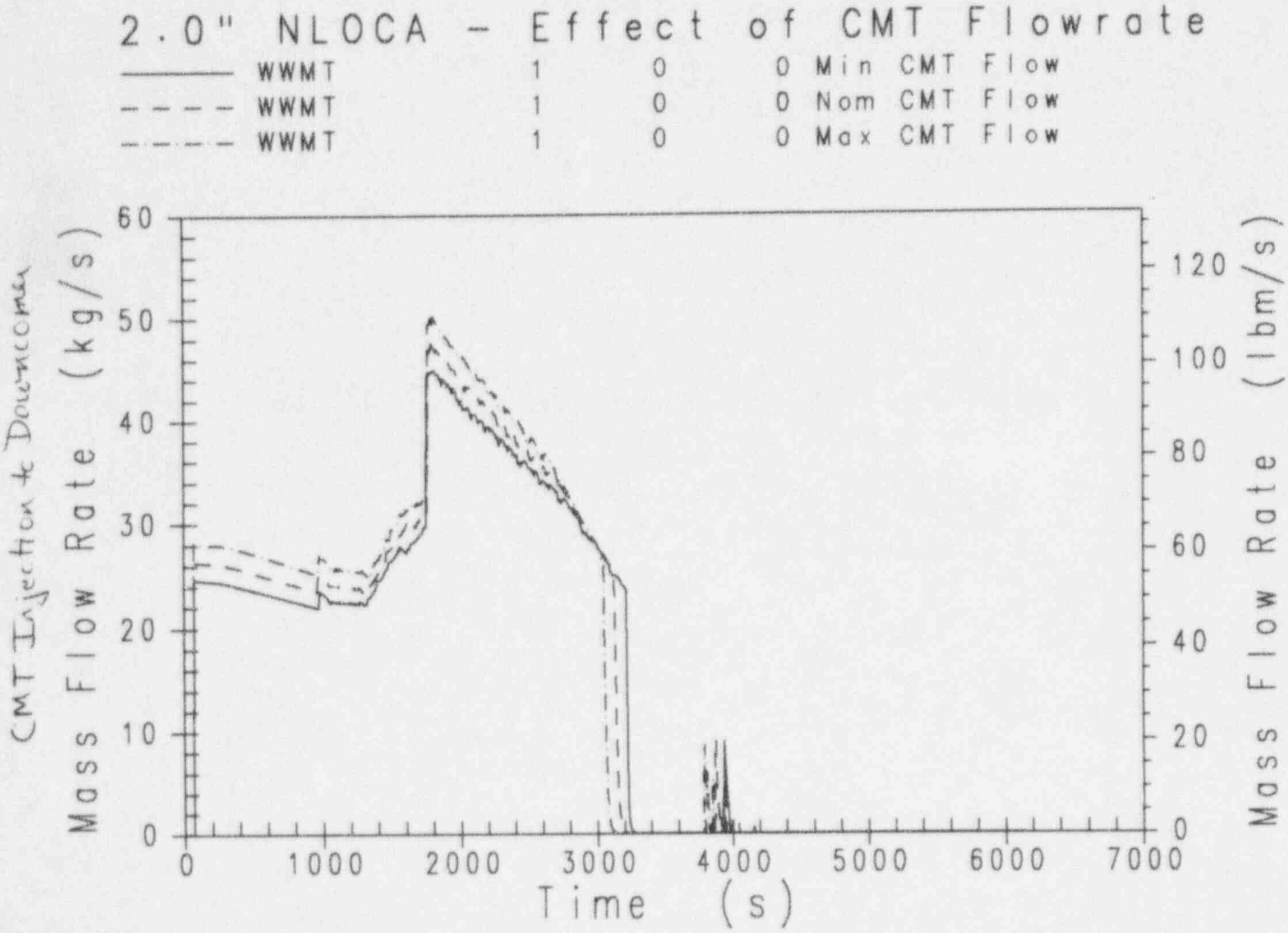
CMT SENSITIVITY CASES

Input	Case			
	Base	**Min CMT Flow**	**Nominal CMT Flow**	**Max CMT Flow**
Cold Leg to CMT	--	--	--	--
Area	2.35e-2 m^2	2.48e-2 m^2	2.48e-2 m^2	2.48e-2 m^2
L/D	556	328	295	263
CMT to Downcomer	--	--	--	--
Area	2.35e-2 m^2	2.48e-2 m^2	2.48e-2 m^2	2.48e-2 m^2
L/D	1751	1770	1592	1417
DVI L/D *	281	260	234	208
Initial Water Temperature	322.0°K	322.2°K	302.8°K	283.3°K
Peak Core Temperature	1081°F	1096°F	1106°F	1110°F

* DVI L/D is a part of the CMT to Downcomer L/D

PRELIMINARY

PRELIMINARY



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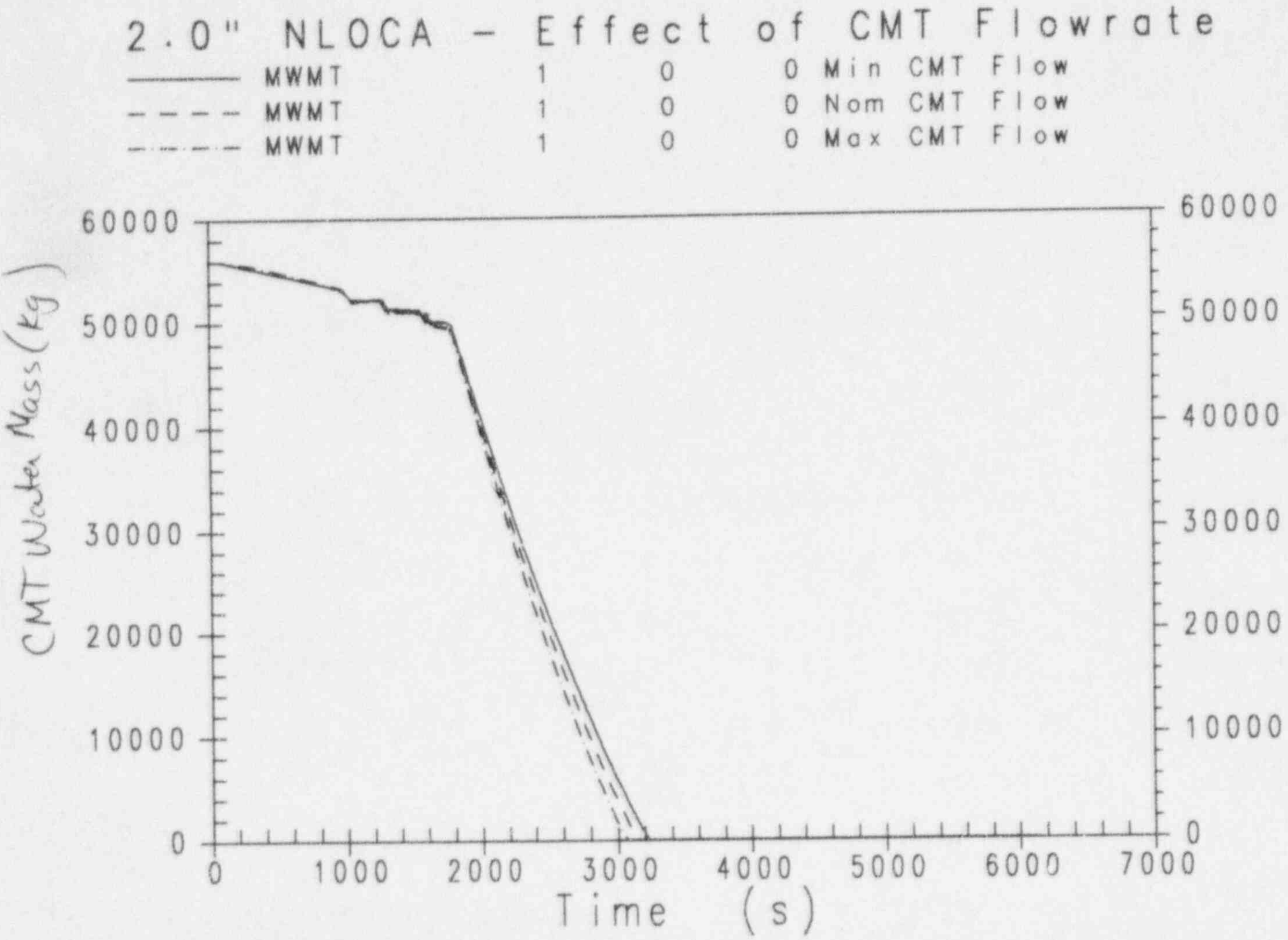

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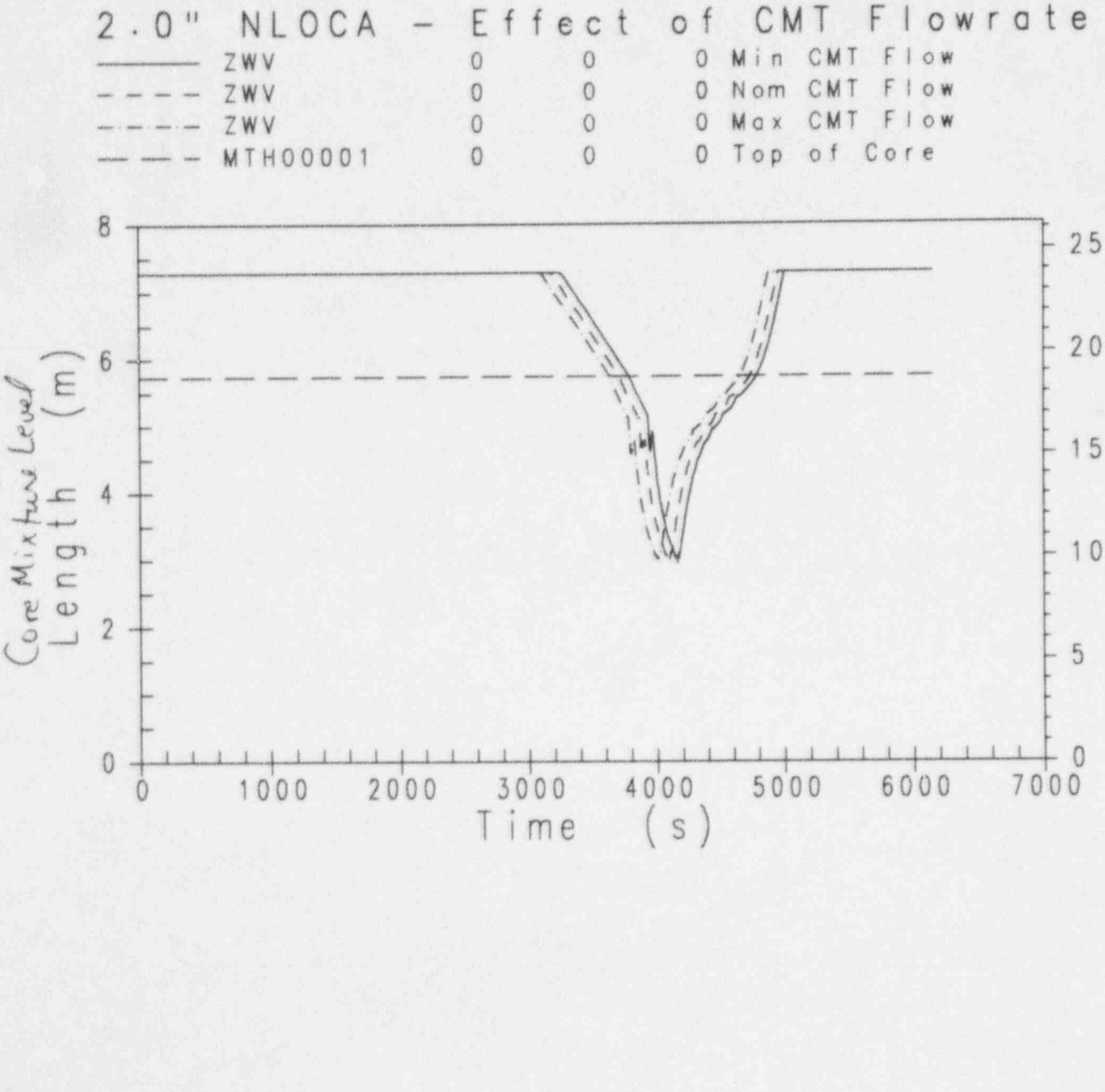

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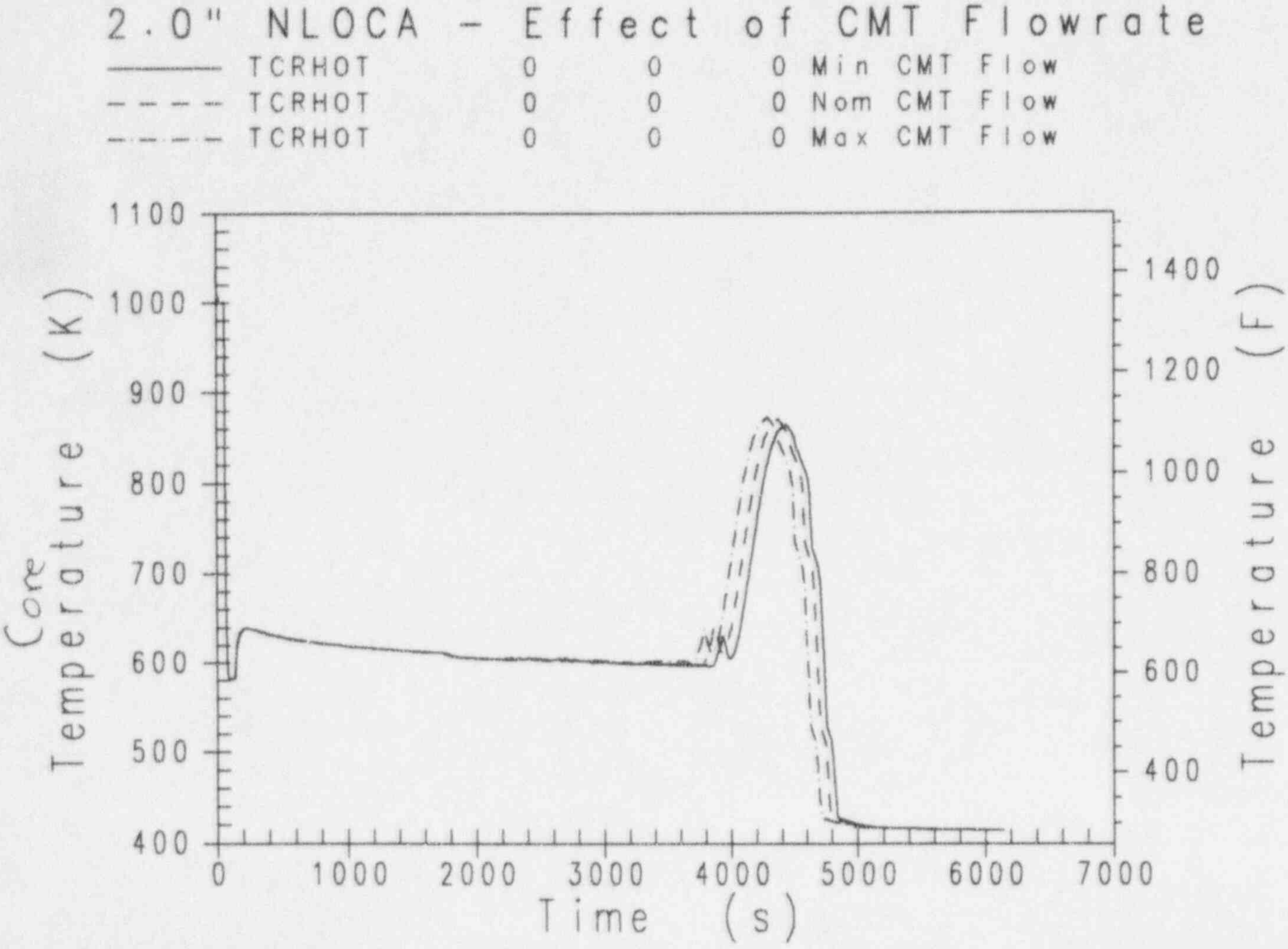


ACCUMULATOR / CMT INTERACTION

- Sample case for this meeting does not have any accumulators modelled

- If accumulator is creditted

  - it does not inject until the ADS lines are opened
  - it injects after the CMT is already empty

- To show interaction of accumulator with CMT, must analyze larger break size

- 4.0" NLOCA

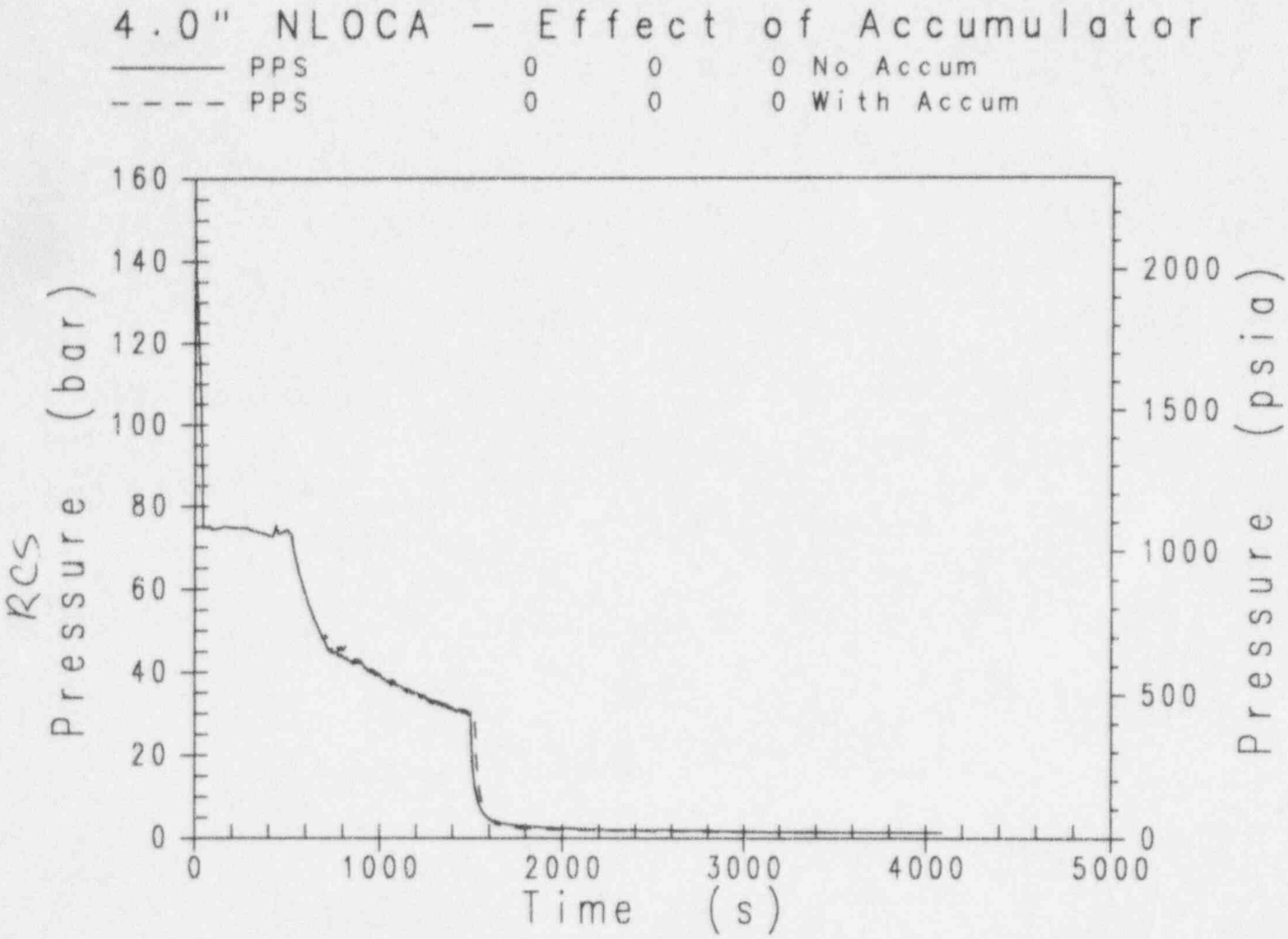
  - When accumulator injection starts, accumulator pressure gradually decreases with RCS pressure

    - Small accumulator flow rate
    - CMT flow rate is minimally impacted

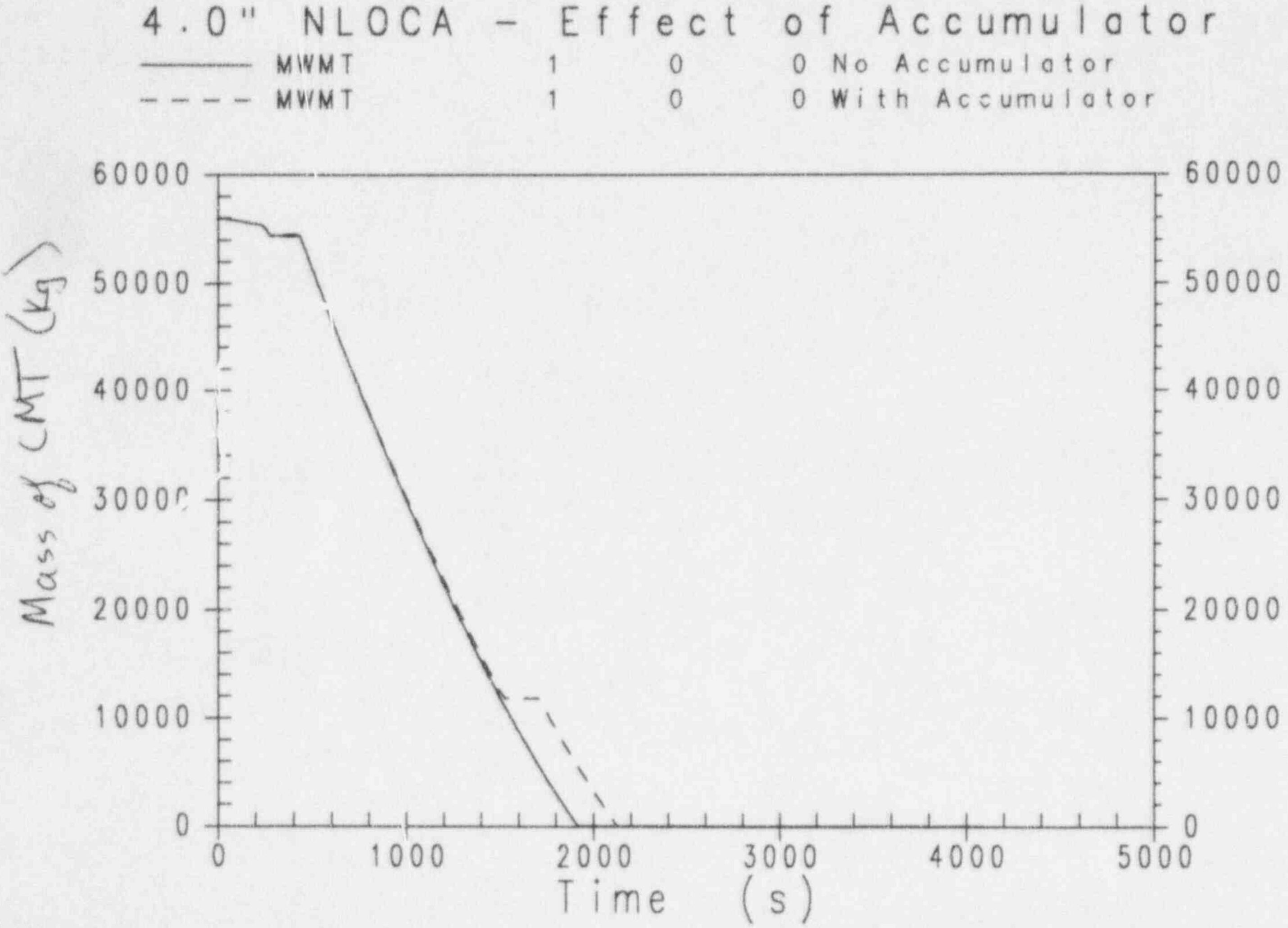
  - When ADS lines are opened

    - Large accumulator flow rate
    - CMT flow stops until accumulator empties

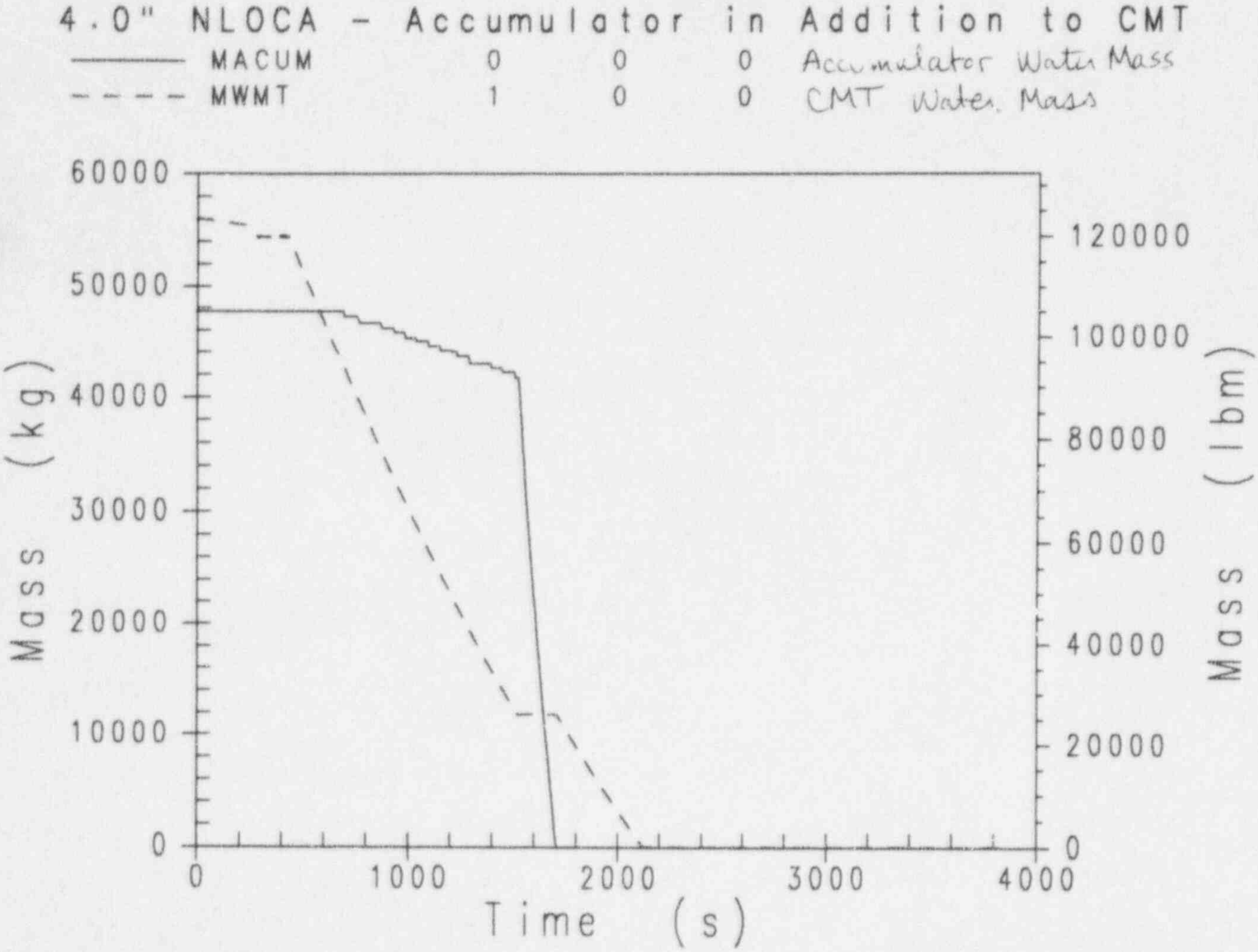
PRELIMINARY



PRELIMINARY



PRELIMINARY



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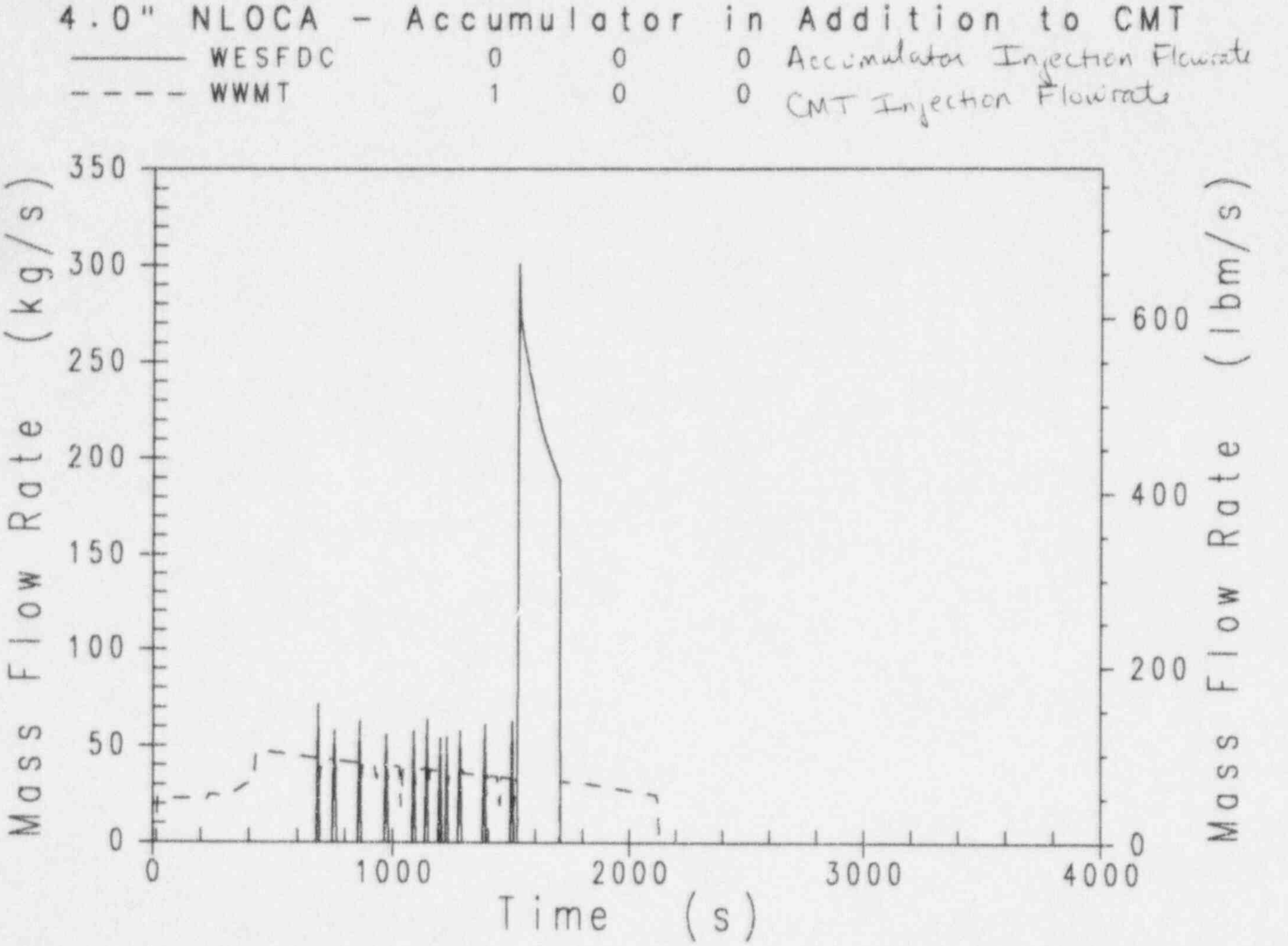

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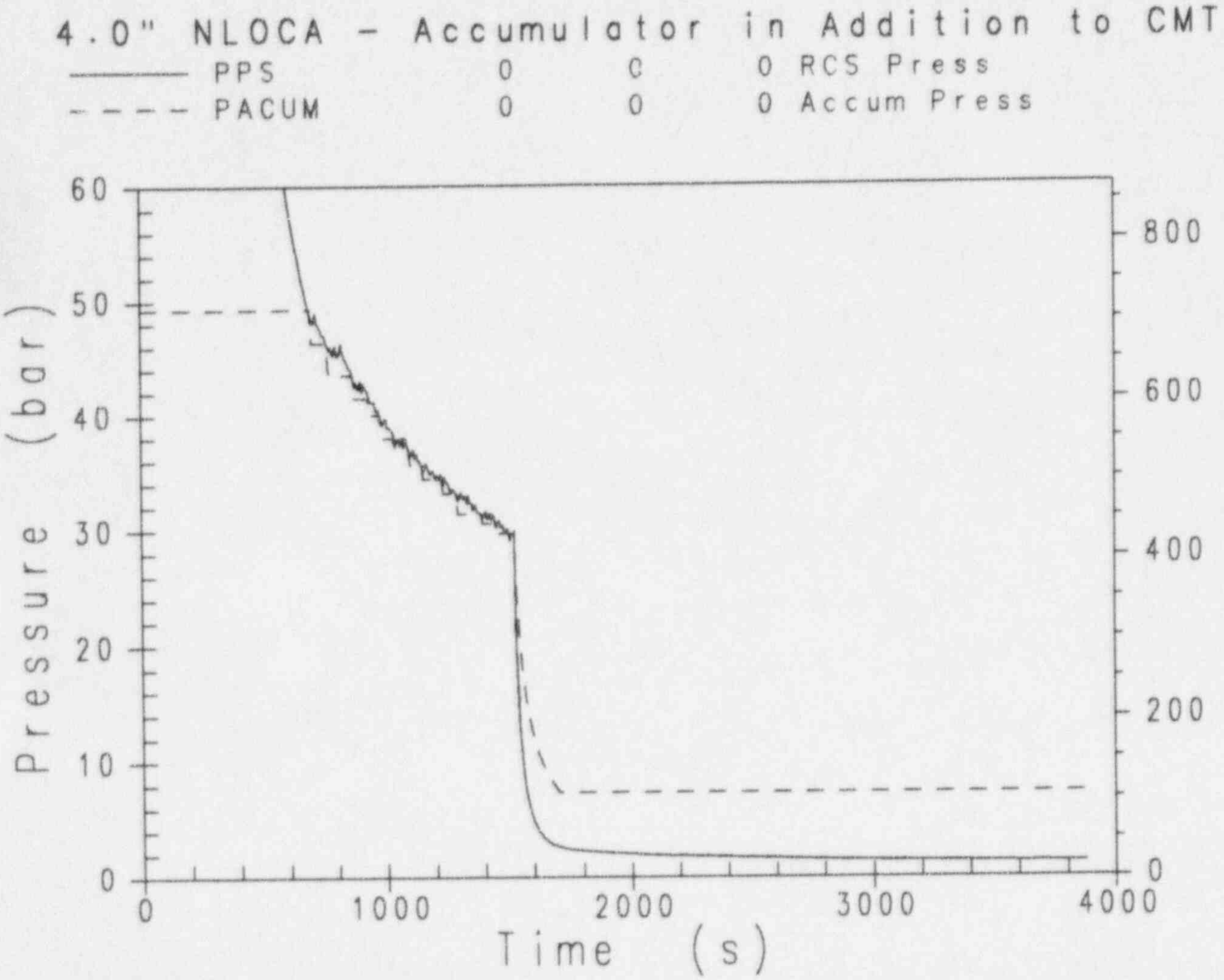


4.0" NLOCA - Accumulator in Addition to CMT

Automatic Depressurization System

- ADS Stages 1, 2, 3 modeled with the pressurizer PORV model (Subroutine FLOEXP). Flow is directed to the IRWST node in the containment.
  - Inputs
    - Discharge coefficient ($C_D = 1.0$)
    - Flow Area

- ADS Stage 4 modeled using "generalized opening", a user defined primary system/containment interface
  - Inputs
    - Elevation in RCS model
    - Elevation in containment model
    - RCS node number
    - Containment node number
    - Flow directional flag (set to allow flow in both directions)
    - Discharge coefficient ($C_D = 1.0$)
    - Flow area

- Minimum equivalent flow areas are used to model the flowpaths (as calculated by designers). Area adjusted to include losses.
  - Discharge coefficient = 1.0

- System Actuation
  - User events and timers model the system signals
    - Low CMT level event signals stage 1
    - Timer signals stages 2 and 3
    - Low-2 CMT level, timer and RCS pressure signals stage 4

  - Action blocks model the actuation of the flowpaths

ADS SENSITIVITY CASES

ADS Valves	Effective Area (in^2)	
	Minimum (Used in Base)	**Maximum**
Stage 1	4.6	7.0
Stage 2 and 3	21	26
Stage 4	38	45

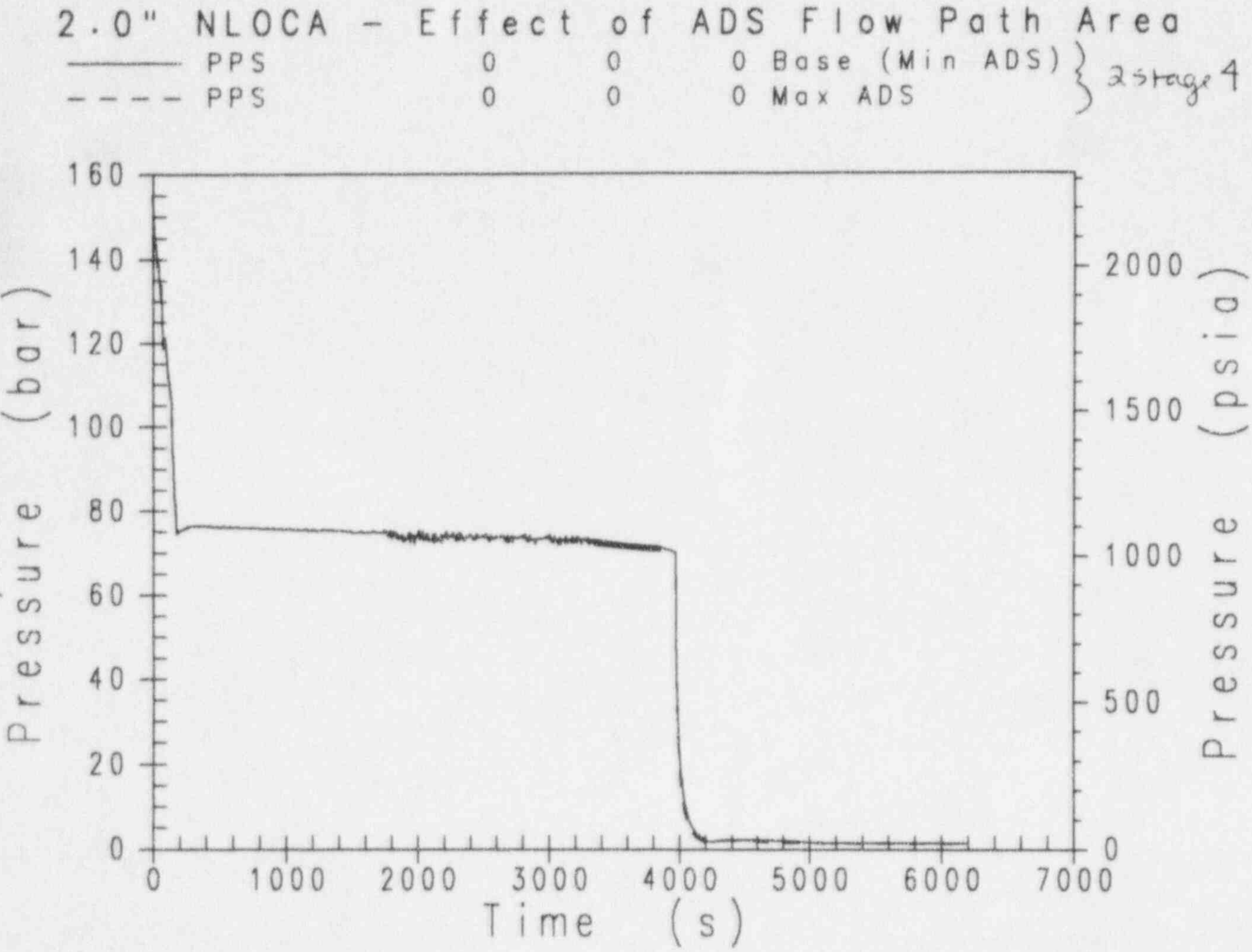
Sensitivities

Peak Core Temperature (°F)

- 2 Stage 4
  - Minimum ADS Area (Base Case) 1081
  - Maximum ADS Area 986
- All Stage 2,3
  - Minimum ADS Area 455
  - Maximum ADS Area no uncovery
- All Stage 2,3, Cold Leg Break
  - Minimum ADS Area 1321
  - Maximum ADS Area 991

PRELIMINARY

PRELIMINARY



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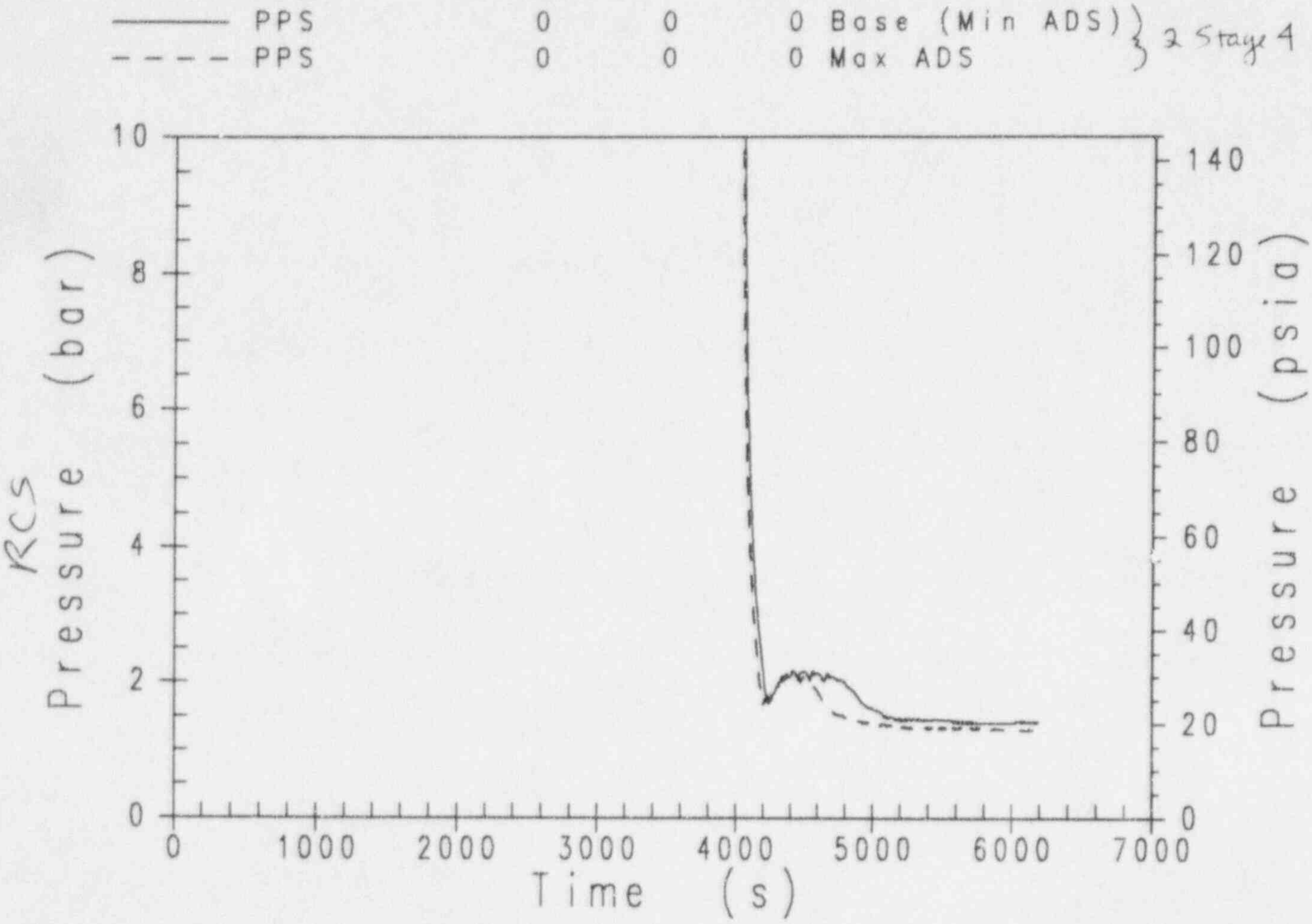
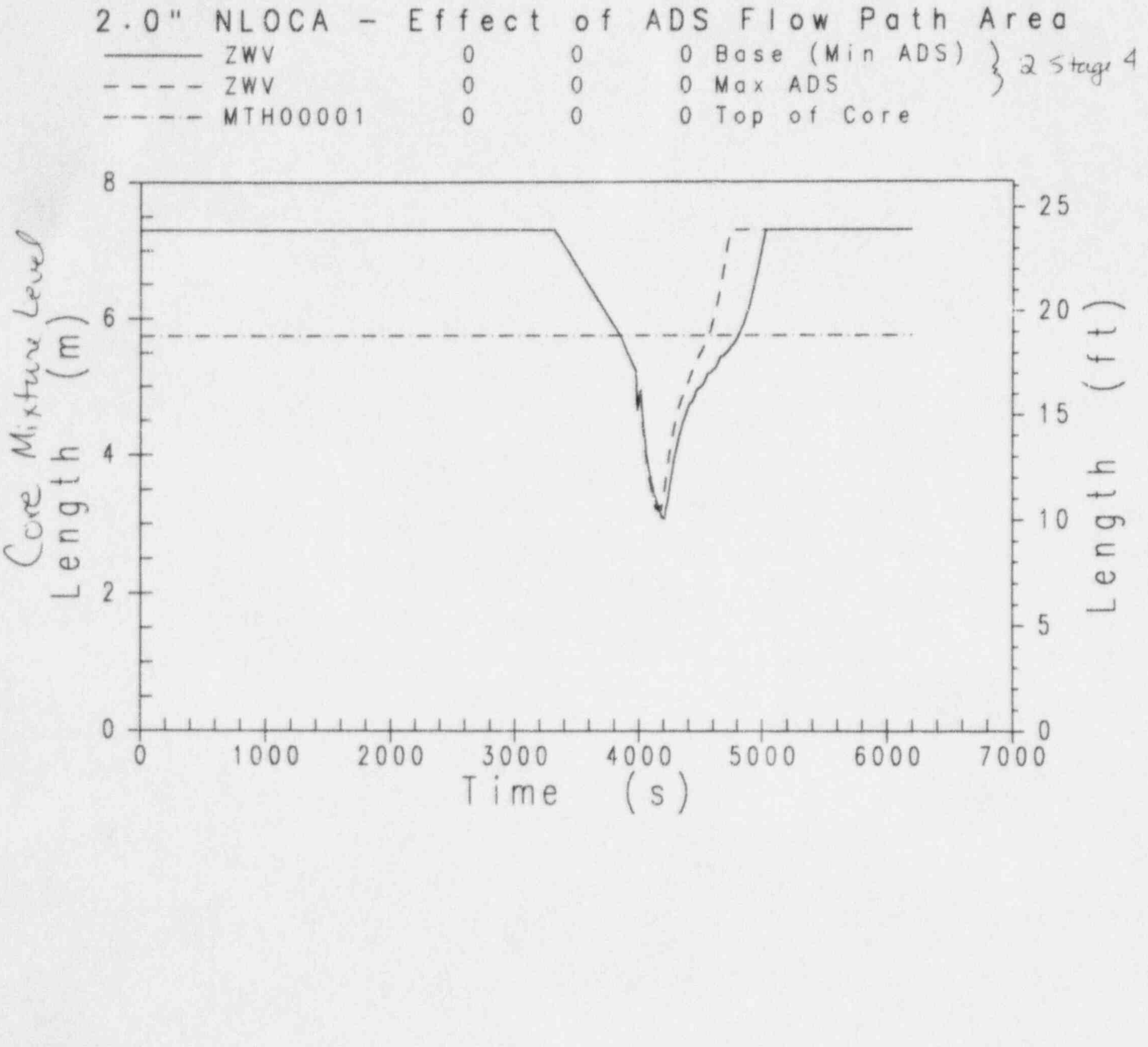
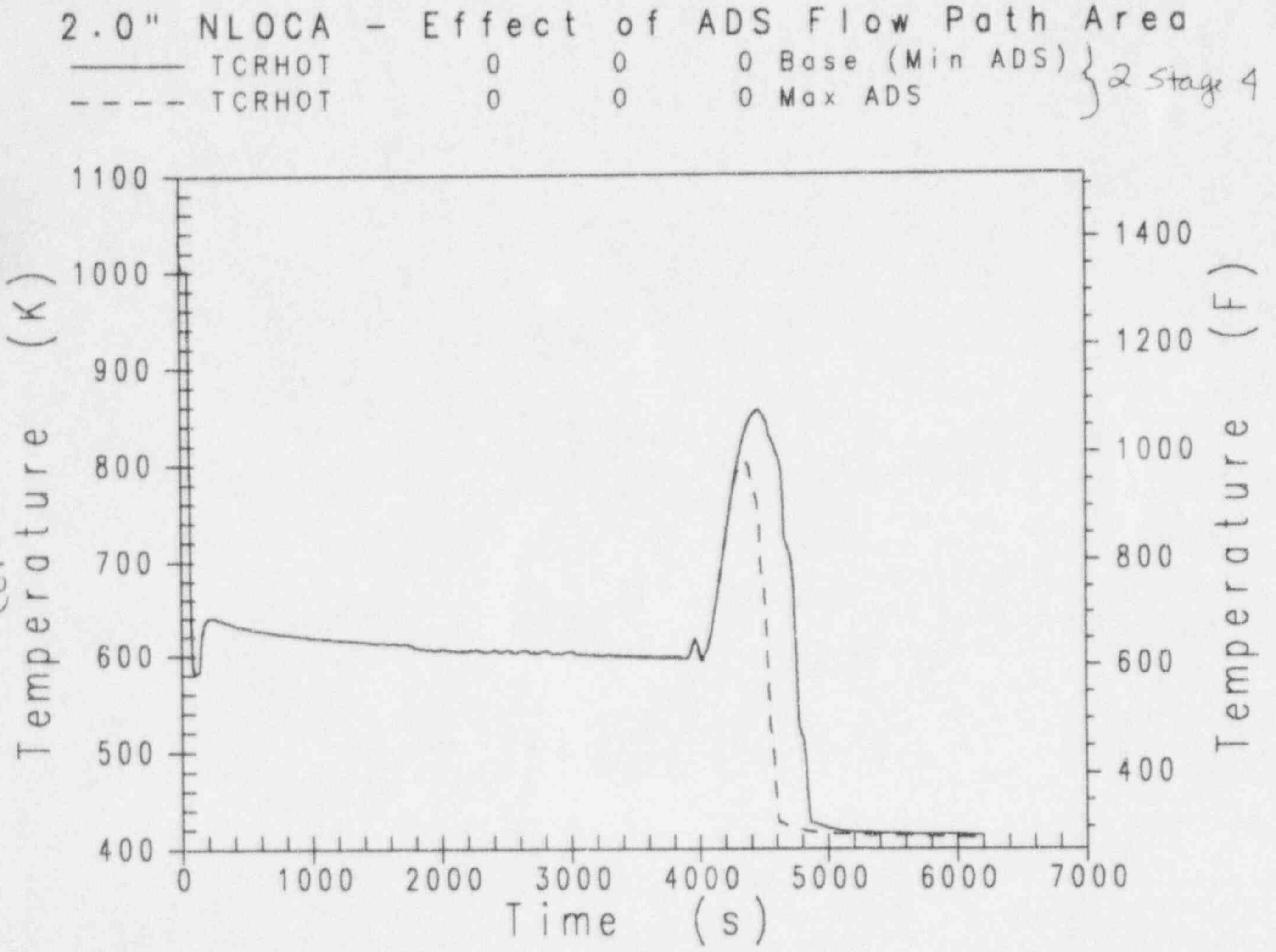


2.0" NLOCA Effect of ADS Flow Path Area

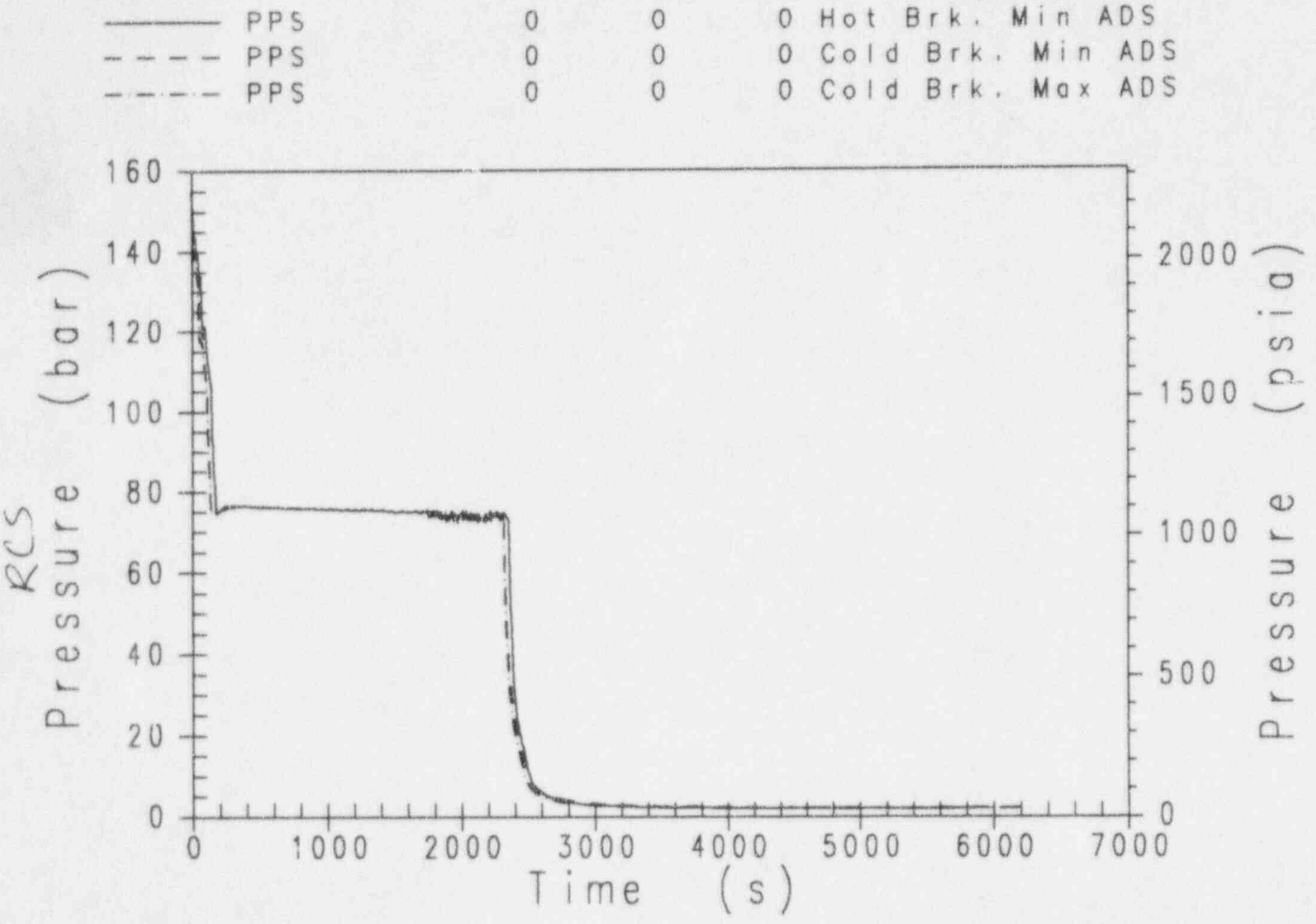
PRELIMINARY


2.0" NLOCA - Effect of ADS Flow Path Area

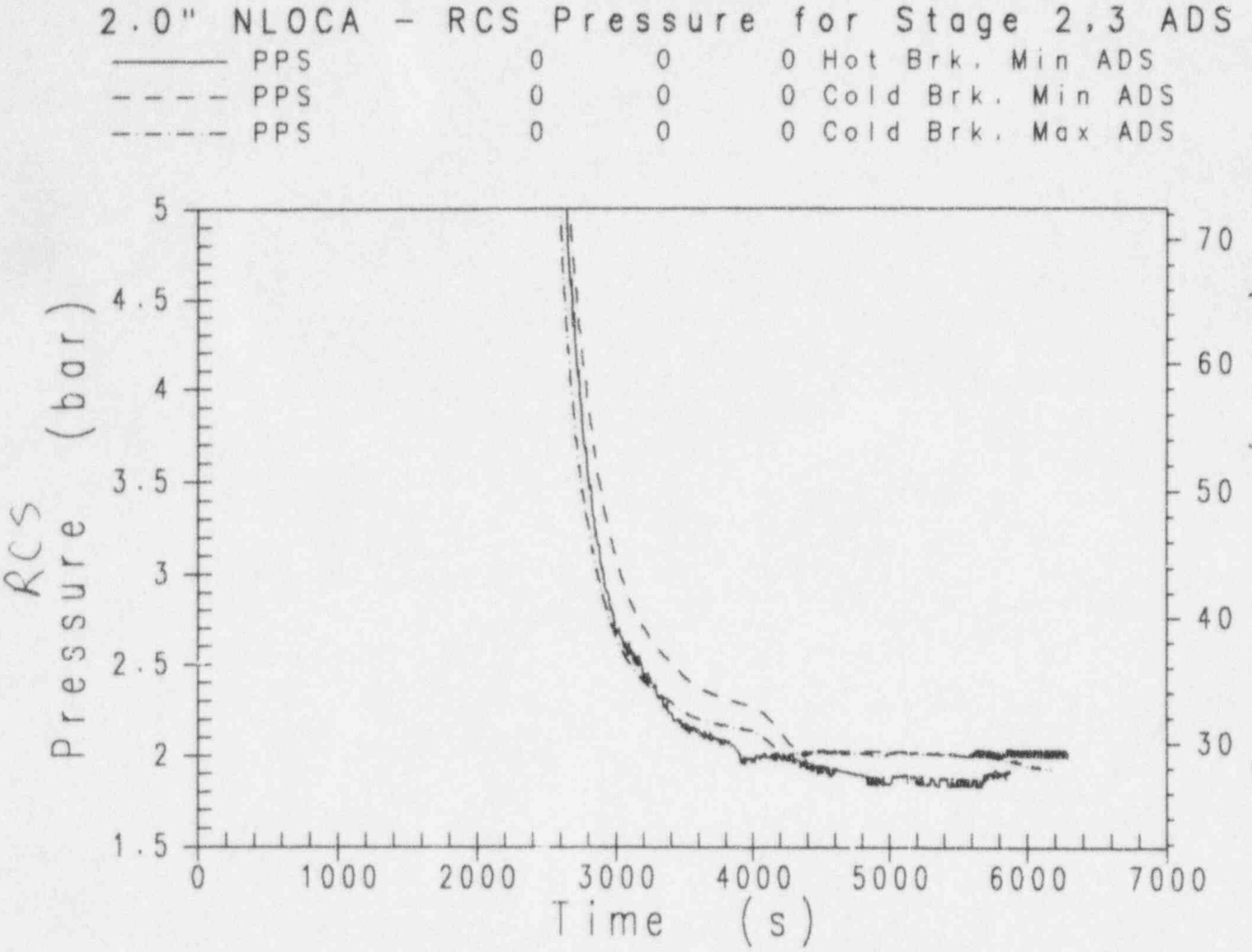
PRELIMINARY


2.0" NLOCA - Effect of ADS Flow Path Area

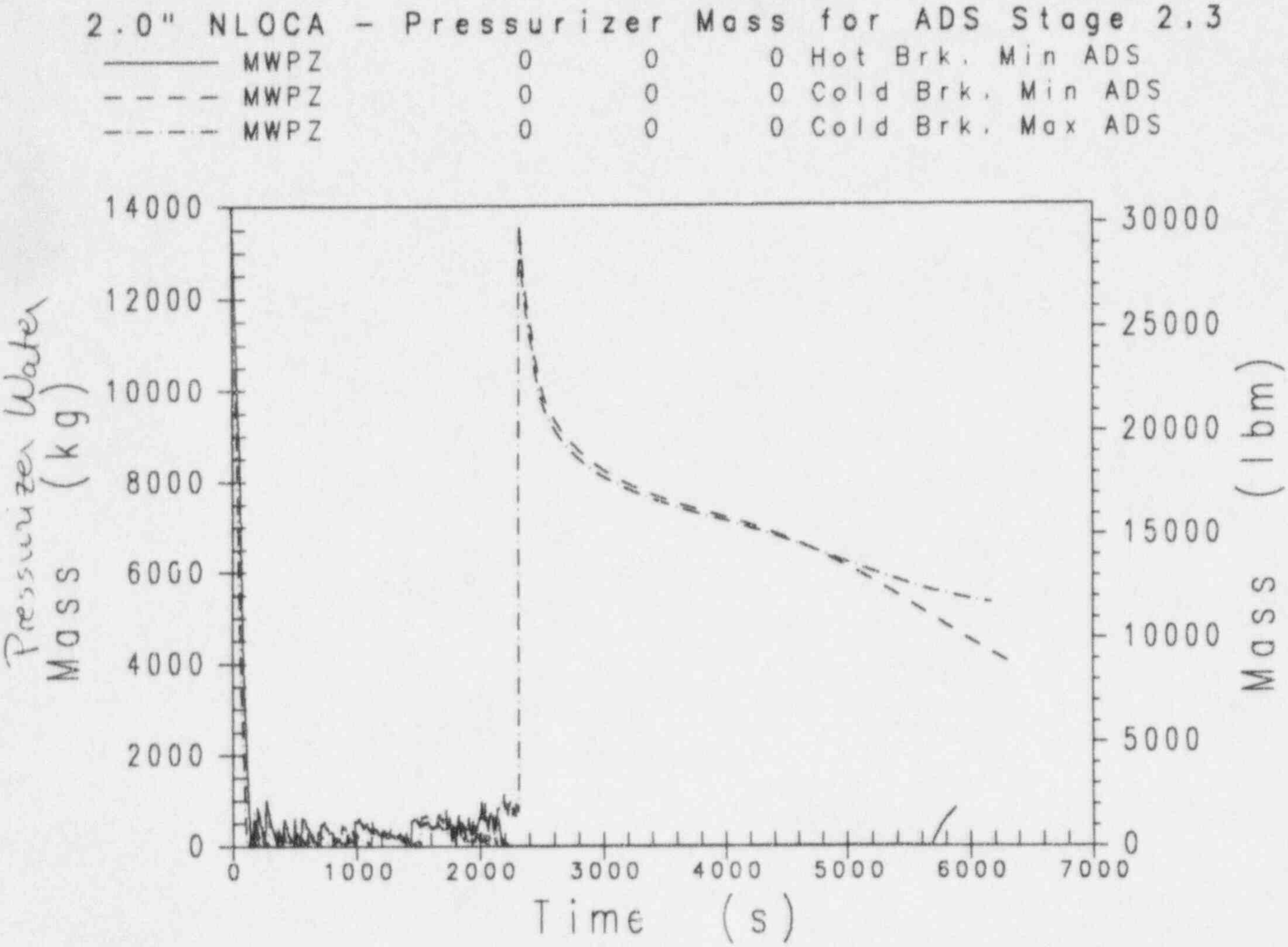
PRELIMINARY


2.0" NLOCA - RCS Pressure for Stage 2,3 ADS

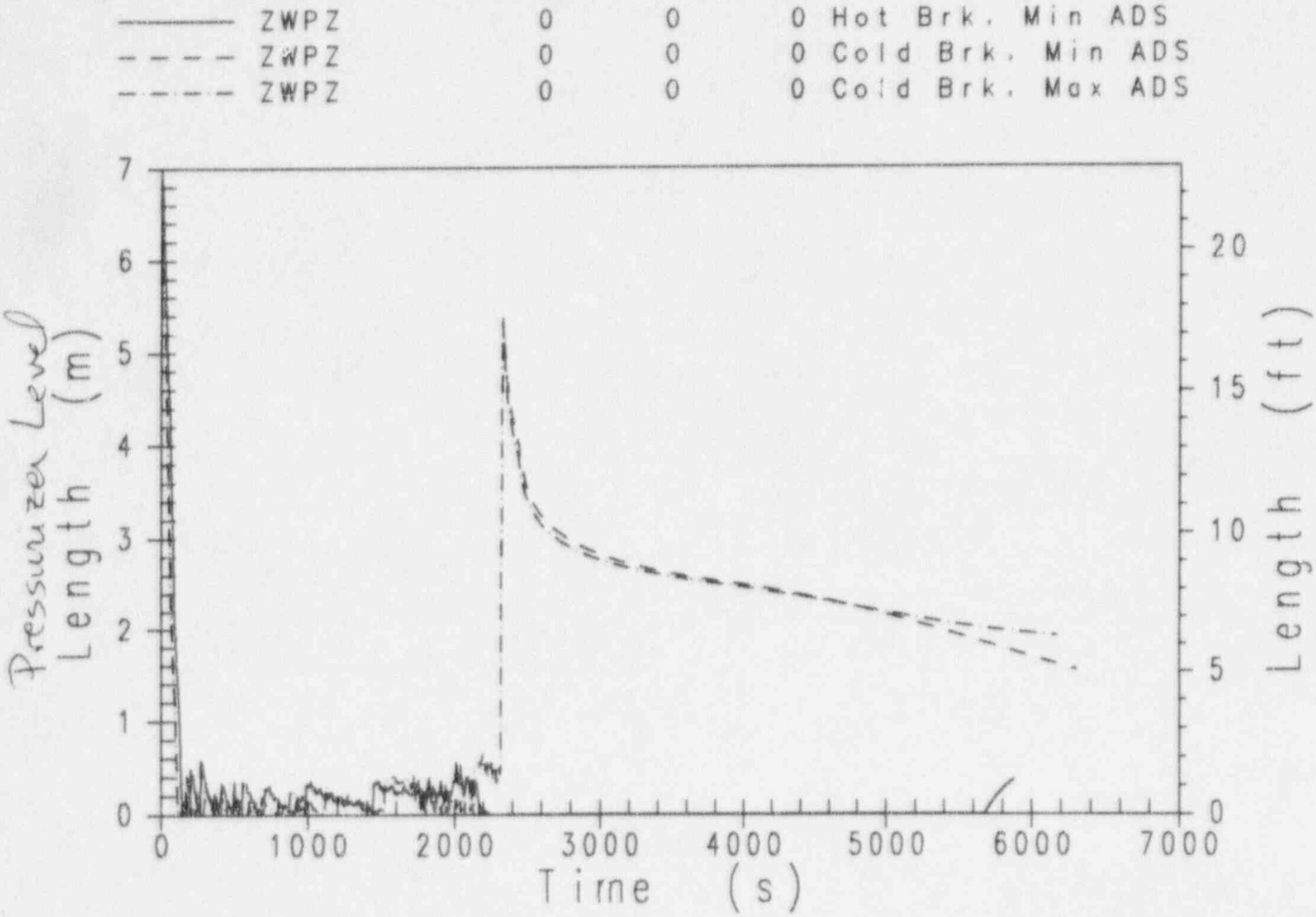
PRELIMINARY



PRELIMINARY

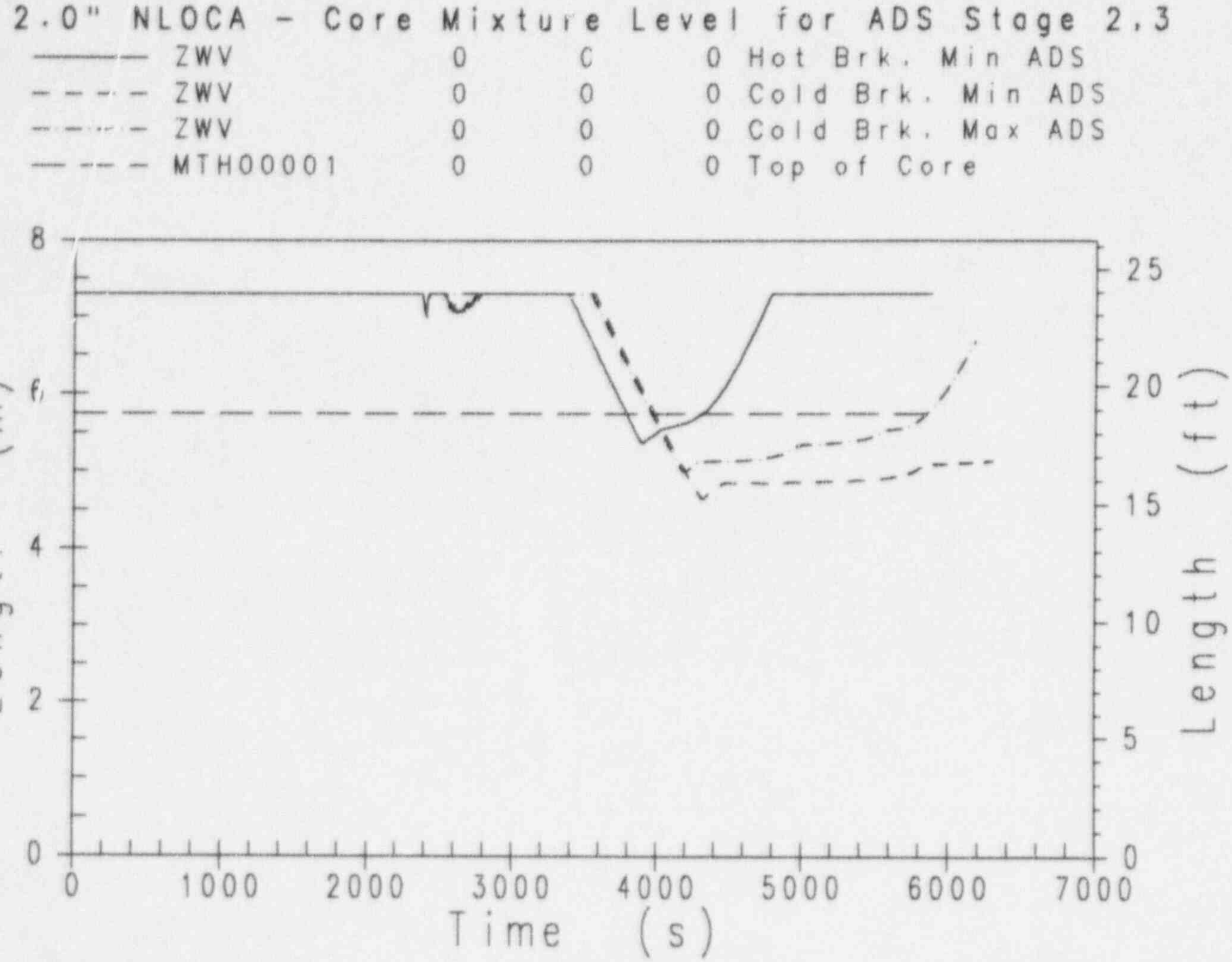


PRELIMINARY



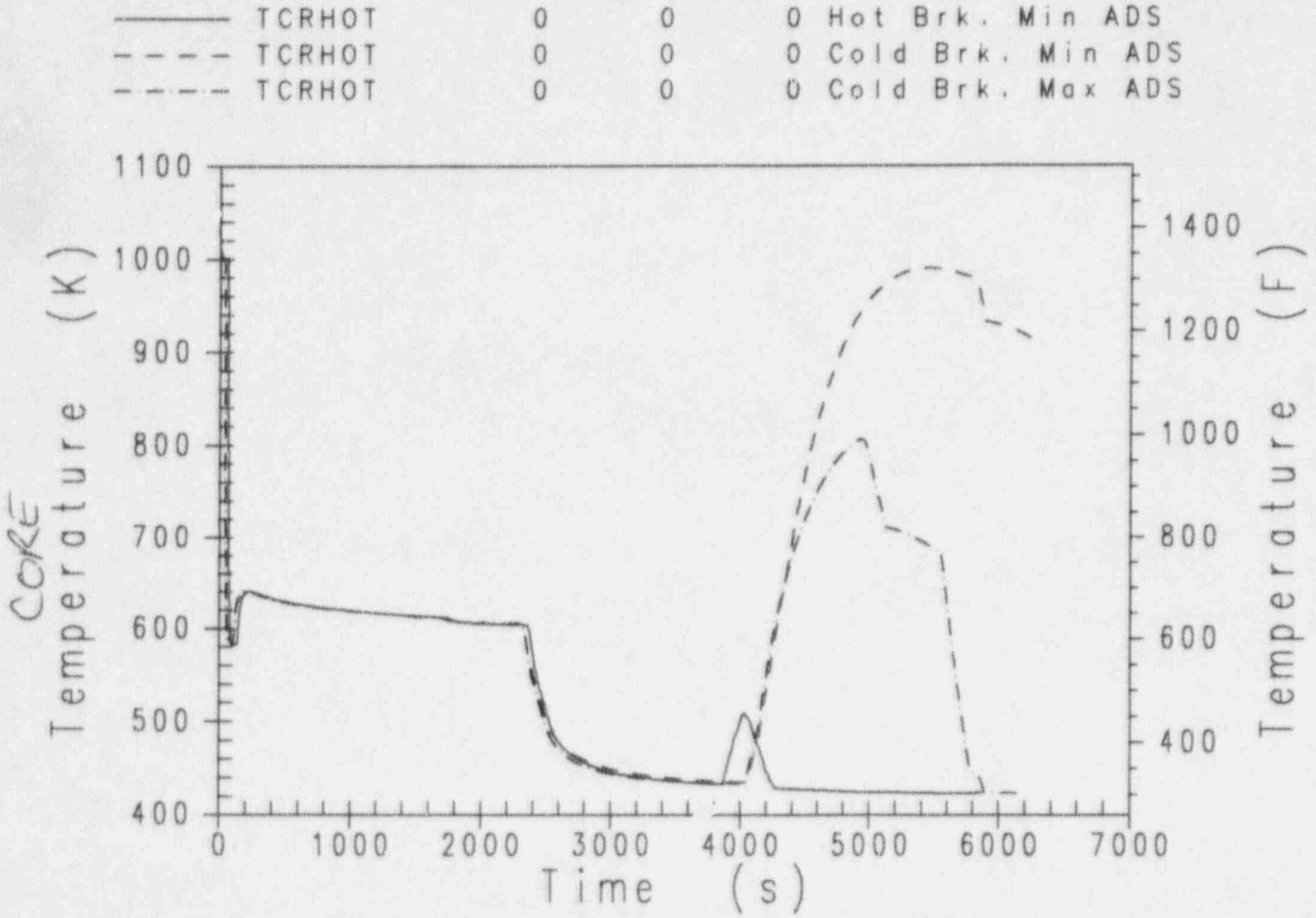
2.0" NLOCA - Pressurizer Level for Stage 2.3 ADS

PRELIMINARY


2.0" NLOCA - Core Mixture Level for ADS Stage 2,3

PRELIMINARY

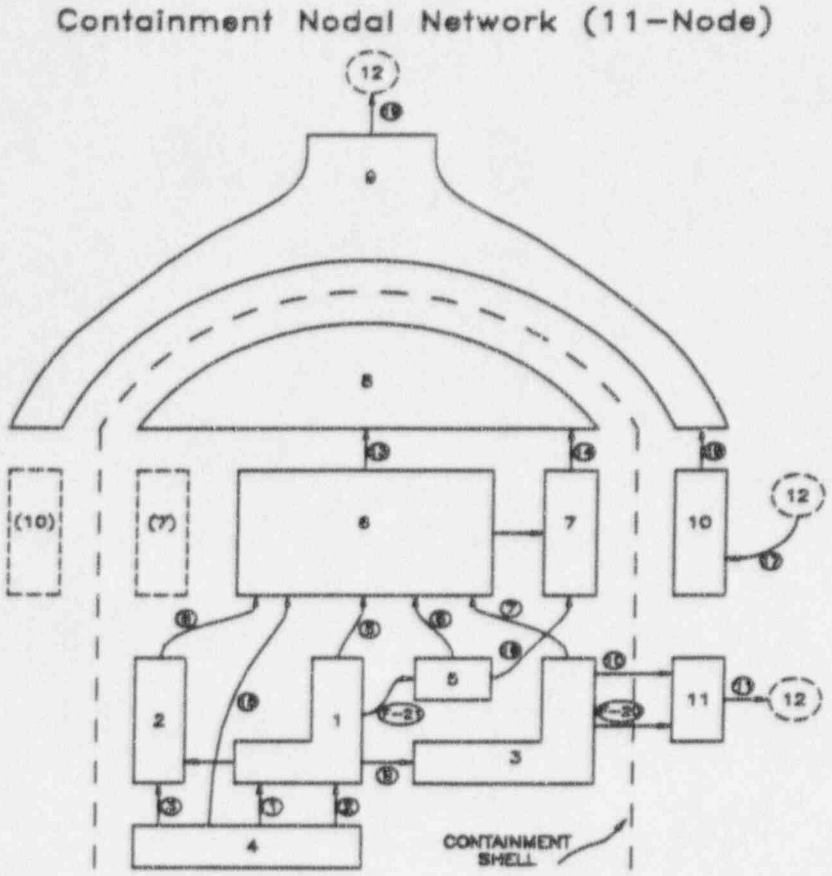
2.0" NLOCA - Core Temperature for Stage 2.3 ADS



IRWST Injection Modeling

- IRWST to downcomer DVI injection line modeled with "generalized opening"
  - Inputs
    - Elevation in RCS model
    - Elevation in containment model
    - RCS node number
    - Containment node number
    - Flow directional flag (set to allow flow into RCS only)
    - Discharge coefficient
    - Flow area

- Containment model tracks IRWST water mass, temperature and elevation



Node 1 = SG Compt 1
Node 2 = SG Compt 2
Node 3 = Low Compt, CMT, Accum
+ Valve Rooms
Node 4 = Reactor Cavity
Node 5 = IRWST Room
Node 6 = Upper Compt Inner Volume
+ Refueling Canal

Node 7 = Upper Compt Outer Volume
Node 8 = Upper Compt Dome
Node 9 = PCCS Dome
Node 10 = PCCS Annulus
Node 11 = Middle Annulus
Node 12 = Environment

Figure 44-1

AP600 MAAP4 Containment Model Nodalization

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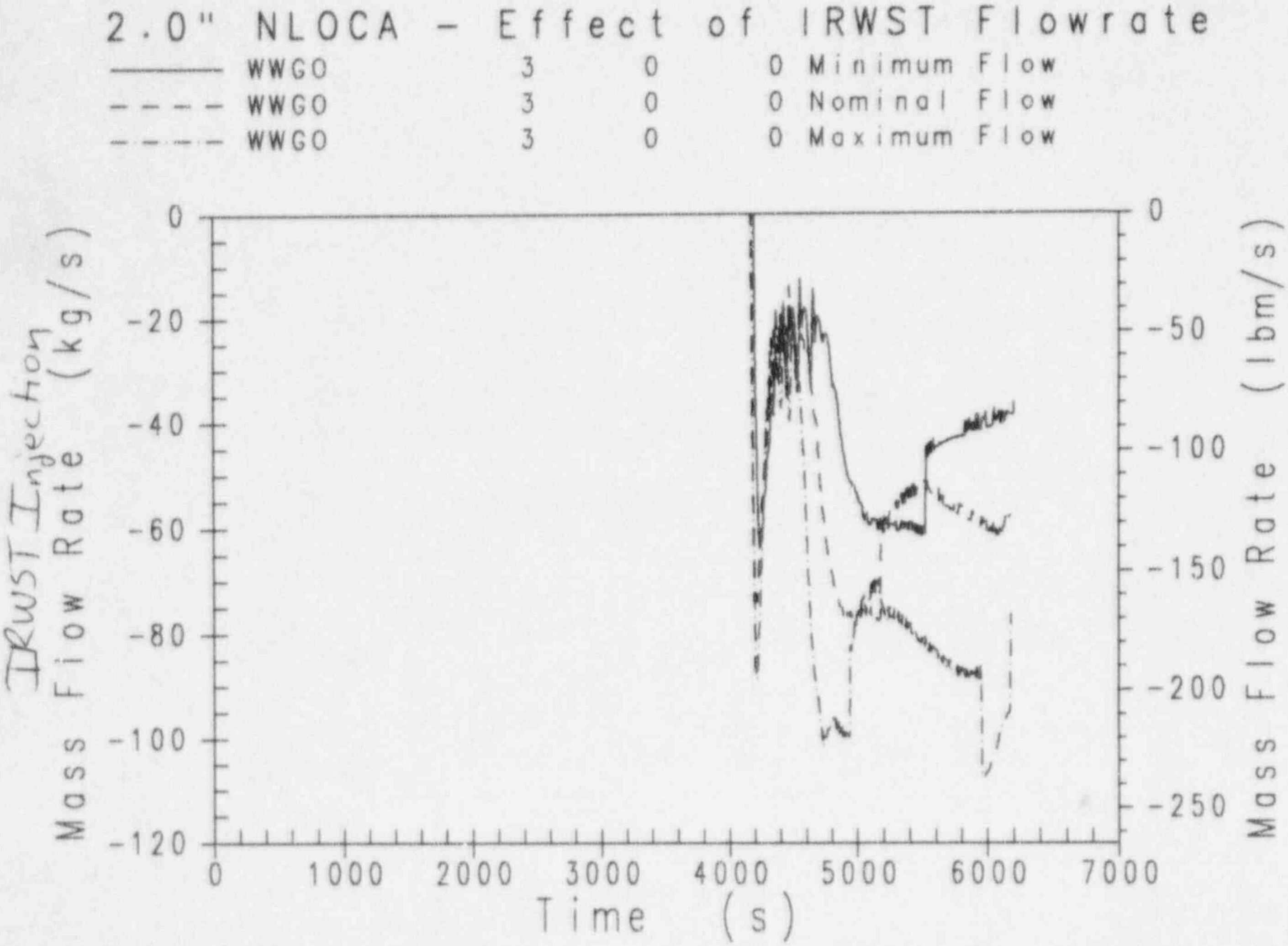
IRWST SENSITIVITY CASES

Input	Case			
	Base	**Min IRWST Flow**	**Nominal IRWST Flow**	**Max IRWST Flow**
Area	0.01364 m^2	0.0248 m^2	0.0248 m^2	0.0248 m^2
Discharge Coefficient	0.365	0.2327	0.2663	0.3205
Area * C_D	4.98e-3	5.77e-3	6.66e-3	7.95e-3
Initial Water Height	10.52 m	10.21 m	10.51 m	10.81 m
Initial Water Temperature	322.0°K	322.2°K	302.8°K	283.3°K
Peak Core Temperature	1081°F	1061°F	1016°F	978°F

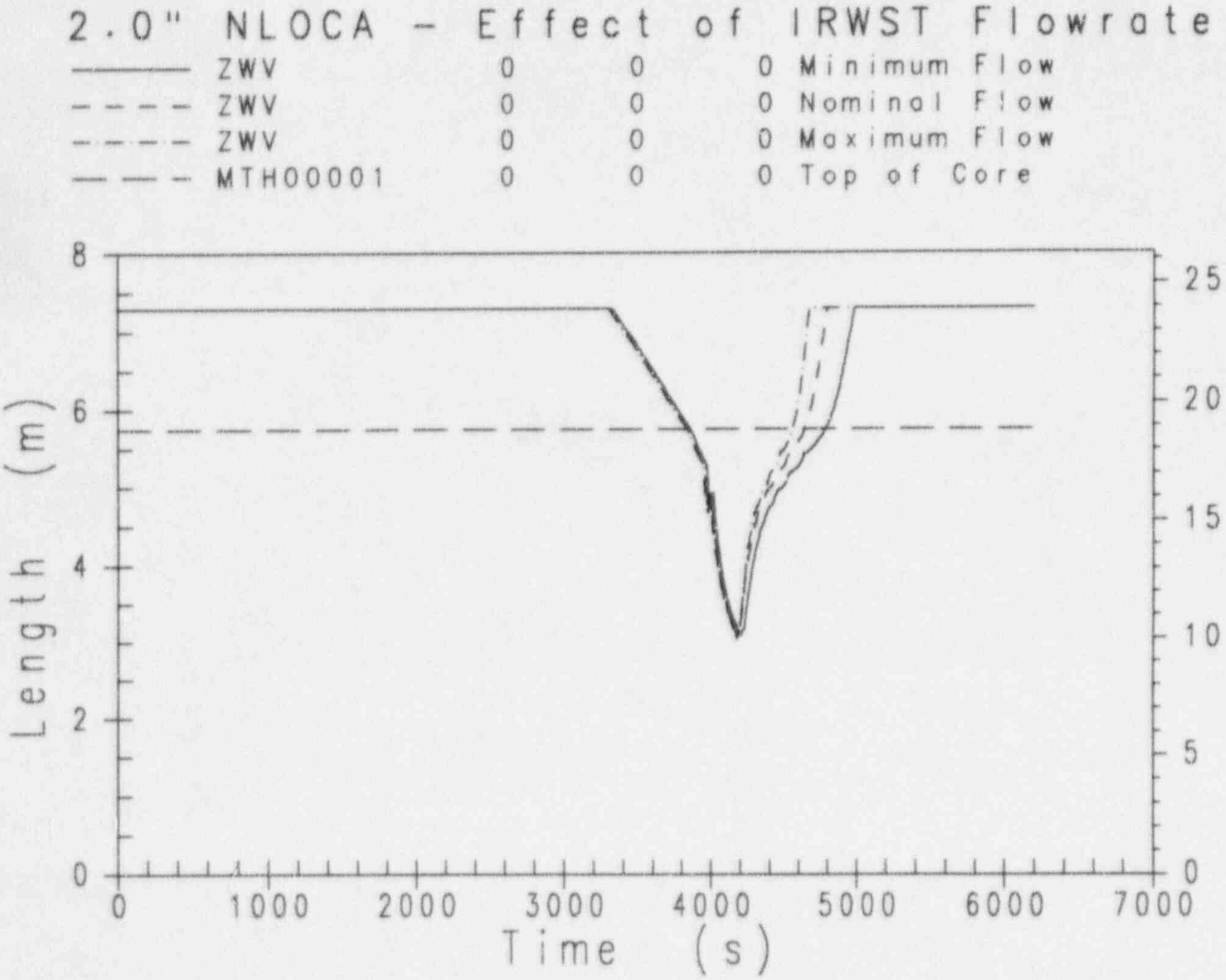
PRELIMINARY

PRELIMINARY

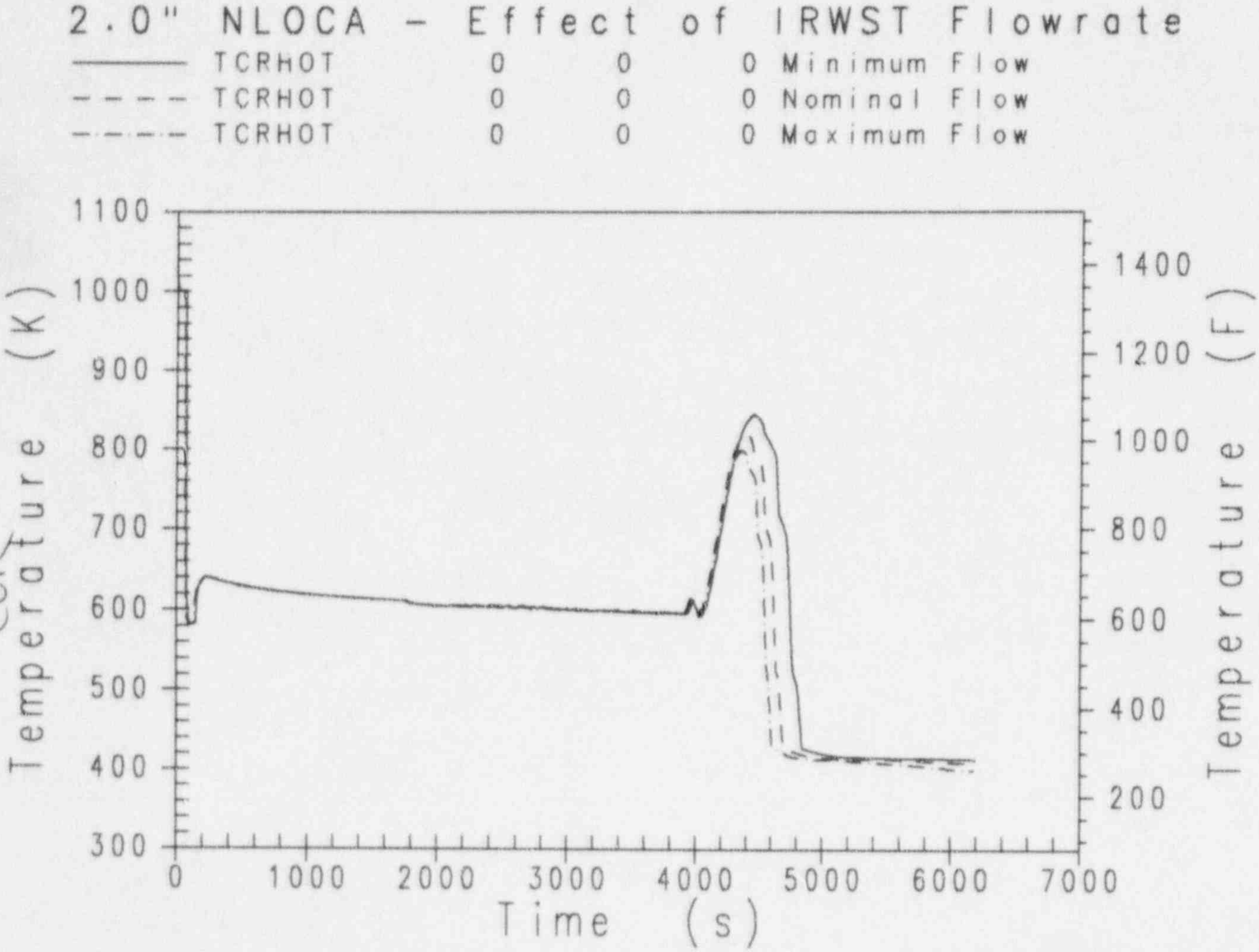


2.0" NLOCA - Effect of IRWST Flowrate

PRELIMINARY


2.0" NLOCA - Effect of IRWST Flowrate

PRELIMINARY



VII. MAAP4 APPLICATION GUIDELINES

MAAP APPLICATION GUIDELINES

- Two EPRI documents written for MAAP3.0B
    - EPRI TR-100167, "Recommended Sensitivity Analyses for an Individual Plant Examination using MAAP3.0B"
    - EPRI TR-100743, "MAAP PWR Application Guidelines for Westinghouse and Combustion Engineering Plants," June 1992.

Recommendations from EPRI TR-100167
(IPE Recommendations)

MAAP PARAMETERS IN NATURAL CIRCULATION MODEL, AFFECTING DETERMINATION OF SUCCESS CRITERIA

Variable	Suggested Value	Description	Recommended Sensitivities
VFSEP	0.6	Void fraction at which primary system natural circulation stops	No sensitivities recommended
HTSTAG	850 W/m^2/K	Heat transfer coefficient between naturally circulating water and surface of SG tube	No sensitivities recommended
FAOUT	0.3	For counter-current flow calculations, fraction of tubes carrying flow away from hot leg	No sensitivities recommended
IEVNT (208)		Event code to signify that pump suction volumes clear	
FFRICR	Approx 0.1	Friction factor for axial flow in core	No sensitivities recommended.
FFRICX	0.25	Friction factor for cross flow in core	No sensitivities recommended.
FWHL	0.115	Coefficient used to calculate hot leg counter-current flow	No sensitivities recommended.
NSAMP	10	Coefficient used to smooth out numerical oscillations in core-upper plenum natural circulation flow	No sensitivities recommended.
FCDBRK	0.7	Discharge coefficient for primary system break	No sensitivities recommended
TCLMAX	1200 K	Clad temperature at which clad rupture and gap release occurs if not already computed from clad strain model	No sensitivities recommended

Notes:
- AP600 MAAP parameter file is consistent with the suggested value for each variable
- IEVNT 208 does not apply to AP600 because there are no loop seals

Recommendations from EPRI TR-100743

- Written for analysts using MAAP to support level 1 success criteria
  - Code Overview
  - MAAP Thermal-Hydraulic Overview
  - General PWR Overview
  - Application Guidelines for Initiating Event
    - Loss of Feedwater
    - Small LOCA
    - Medium and Large LOCA
    - Steam Generator Tube Rupture
    - Main Steamline Break
- For each initiating event, provides summary of experience, cautions and recommended sensitivity calculations
  - Typical IPE Applications
  - Key Phenomena and Models
  - Key Input Parameters
  - Typical Sequence of Events
  - Typical Input Decks
  - Industry Experience
  - Recommended Sensitivity Analyses
  - Conclusions

TRANSIENTS
Loss of Feedwater

- Experience with MAAP is generally quite good
- Cautions
  - Monitor PORV flow for anomalies if pressurizer nearly solid (This concern has been fixed in MAAP4)
  - Surge line flow model is simple, and no comparison exists for two-phase natural circulation in RCS
  - ECCS flow calculations should be checked against pump delivery data that includes friction in piping
  - Stopping main feedwater pumps does not allow for pump coastdown, which could impact SG dry-out time
- Recommended Sensitivities
  - Consider variations in operator actions, including RCP trip and reactor trip
  - Vary the number of PORVs and ECCS pumps creditted

TRANSIENTS
Steamline Break

- Very little experience in modelling SLB with MAAP; this event rarely plays a major role in IPEs

- Cautions

  - MAAP does not entrain liquid in steam flow

  - Steam and feedwater control systems in MAAP are simple

  - During rapid SG depressurization, the flashing model may be unable to keep up with the depressurization rate. An artificial superheat may be seen in the pool temperature.

  - Reactor physics are not modelled in MAAP

- Recommended Sensitivities

  - Consider varying:

    - Initial SG inventory
    - Maximum timestep
    - Operator actions
    - Break size

SLOCA

- Extensive experience with MAAP benchmarking against semiscale, MIST, RELAP, RETRAN, TMI
- Cautions
    - Be aware of isothermal accumulator discharge, which has been known to cause "autocatalytic accumulator discharge"
    - Watch out for cases with anomalous gas or water flow through the pressurizer PORV (this concern has been fixed in MAAP4)
    - Be aware that the results may be sensitive to break subcooling
- Recommended Sensitivities
    - Maximum condensation "efficiency" assumed on ECCS water (MAAP parameter FCDDC)
    - VFSEP, although sensitivity studies involving a limited number of sequences have not shown any pronounced sensitivities
    - Operator actions that affect timing of injection and RCS depressurization

MLOCA

Definition:

  - LOCAs in which the effects of heat transfer to the SGs are minor
  - Thermal-hydraulic conditions do not "degrade" until after typical decay heat conditions are reached

- Benchmarking experience includes small end of medium LOCA size spectrum
  - No new concerns for MAAP modelling
- Caution that accumulator discharge is isothermal so that the discharge rate will be overpredicted
- Recommended sensitivities
  - Variations in break area, elevation and location
  - Variations in accumulator resistance
  - FCDDC, maximum allowed condensation effectiveness

SGTR

- Experience with MAAP comparisons against semiscale experiments and RETRAN; MAAP is judged to be an appropriate tool for SGTR analysesl
- Cautions
  - Check MAAP results carefully when they invoive a nearly-solid pressurizer
- Recommended Sensitivities
  - Operator actions
  - Same issues as SLOCA