YAEC-1547

VERMONT YANKEE
BWR LOSS-OF-COOLANT ACCIDENT
LICENSING ANALYSIS METHOD

By

Dr. R. Thomas Fernandez
Dr. Hugo C. da Silva, Jr.

June 1986

Yankee Atomic Electric Company
Nuclear Services Division
1671 Worcester Road
Framingham, Massachusetts 01701

Prepared By: R Thomas Fernandez — 6/26/86
Dr. R. T. Fernandez, Principal Engineer — (Date)
LOCA Analysis Group

Hugo C. da Silva Jr. — 6/26/86
Dr. H. C. da Silva, Jr., Engineer — (Date)
LOCA Analysis Group

Reviewed By: Kevin E. St. John — 6/27/86
Mr. K. E. St.John, Nuclear Engineer — (Date)
Nuclear Evaluations and Support Group

Stephen P. Schultz — 6/26/86
Dr. S. P. Schultz, Manager — (Date)
Nuclear Evaluations and Support Group

Michele A. Sironen — 6/26/86
Ms. M. Sironen, Senior Engineer — (Date)
VY Nuclear Engineering Coordinator
Reactor Physics Group

Reviewed and Approved By: Ansaf Husain — 6/26/86
Dr. A. Husain, Manager — (Date)
LOCA Group

Approved By: Paul A. Bergeron — 6/26/86
Mr. P. A. Bergeron, PE Acting Director — (Date)
Nuclear Engineering Department

DISCLAIMER OF RESPONSIBILITY

ABSTRACT

This report describes the BWR loss-of-coolant accident licensing analysis method for the Vermont Yankee Nuclear Power Station. This method will be used to perform full break spectra (size and location) and cycle exposure analyses that comply with USNRC regulations contained in 10CFR50.46 and Appendix K thereto. The method basically uses the RELAP5YA LWR System Thermal-Hydraulic Analysis Computer Program developed and extensively assessed by YAEC. The extensive code assessment work has established the validity of the code to predict the complex thermal-hydraulic phenomena encountered in LWR LOCA events. In particular, the code assessment has shown that use of the evaluation model features in RELAP5YA required by Appendix K yields reliable, conservative predictions when compared to experimental results such as from TLTA and Marviken tests. Therefore reliable, conservative predictions are obtained for the Vermont Yankee LOCA licensing analyses since these same features plus additional conservative assumptions are used.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES
(CONTINUED)

LIST OF FIGURES
(CONTINUED)

LIST OF FIGURES
(CONTINUED)

LIST OF TABLES

ACKNOWLEDGEMENTS

The Vermont Yankee LOCA licensing analysis method is the result of support and cooperation from many organizations and individuals.

The Vermont Yankee, Yankee, Maine Yankee, and New Hampshire Yankee organizations provided continued financial support and motivation throughout the development of the RELAP5YA code. The RELAP5 MOD1 base computer program was originally developed and made publicly available by the USNRC and EG&G Idaho Inc. Several of the extensive modifications to the base program were achieved through assistance from Intermountain Technologies, Inc. Research programs sponsored by EPRI, USNRC, and GE provided valuable test data for the code assessment effort.

The development of the Vermont Yankee Nuclear Steam Supply System and hot channel models resulted from the technical support provided by many departments within the VYNPC and YAEC organizations. These include the following:

Vermont Yankee Nuclear Power Station

B. Buteau, P. Donnelly, J. Edelhauser, J. Pelletier, R. Lodwick, R. Wanczyk, and T. Watson.

Vermont Yankee Nuclear Training Center

A. Chesley, M. Krider, R. Slauenwhite, and D. Tuttle.

Vermont Yankee Project Office

R. Capstick, A. Doyle, H. Hyams, R. January, P. Johnson, M. Marian, S. Miller, R. Smith, and D. Yasi.

YAEC Nuclear Engineering Department

B. Baharynejed, K. Burns, J. Cronin, J. Loomis, S. Mihaiu, K. Mitchell, K. St.John, M. Sironen, R. Woehlke, and W. Yeung.

The Word Processing Center (especially Pam Vierstra, Susan Henchey, and Debbie Stanton for the excellent typing, and also Virginia Hellmuth and Danielle Golove for the excellent proofreading), Computer Services Department, and the Reproduction Department provided invaluable services during this project. Finally, this effort was achieved because of the continued support from YAEC and VYNPC management, especially from D. Hunter, A. C. Kadak, and W. P. Murphy.

We gratefully acknowledge the support from all of these individuals and organizations.

1.0 INTRODUCTION

1.1 Purpose

This report describes the BWR Loss-of-Coolant Accident (LOCA) licensing analysis method for the Vermont Yankee Nuclear Power Station. This method will be used to perform cycle independent LOCA-ECCS (Emergency Core Cooling Systems) licensing analyses that comply with USNRC regulations contained in 10CFR50.46 and Appendix K thereto. The development and application of this method has been motivated by several considerations:

a. Supporting Vermont Yankee's goal to achieve extended fuel cycles of approximately 18 months starting with Cycle 14.

b. Retaining cycle independent LOCA-ECCS licensing analysis results.

c. Utilizing new LOCA-ECCS technology, both analytical and experimental, developed by U.S. nuclear institutions over the past decade.

The Vermont Yankee Nuclear Steam Supply System (VY NSSS) and reactor core are summarized in Section 1.2. The Vermont Yankee LOCA licensing analysis method uses the RELAP5YA LWR System Thermal-Hydraulic Computer Program, summarized in Section 1.3, and two base input models. The first is the Vermont Yankee NSSS model described in Section 2.0. This model will be used to perform the break spectrum study. Minor modifications are made to the base input data to model various break sizes, locations, and single failure assumptions. The second is the Vermont Yankee Hot Channel (VY HC) model described in Section 3.0. This model uses core inlet and outlet thermal-hydraulic results from the corresponding Vermont Yankee NSSS cases as boundary conditions. This model will be used to perform the burnup study for each fuel assembly type as a function of exposure. Modifications to the base deck will account for variation of fuel assembly design and exposure conditions. Together, results from these models will be used to establish the Design Basis Accident (i.e., most limiting LOCA case) and to show compliance with the LOCA-ECCS criteria in 10CFR50.46 for the VYNPS. Three LOCA sample problems are presented in this report to demonstrate the application of the LOCA licensing analysis method to the VYNPS. Section 4.0 describes two large break cases and Section 5.0 describes a small break case.

1.2 Vermont Yankee NSSS Summary

The Vermont Yankee Nuclear Power Station is a BWR4 with a Mark I containment that began commercial operation in November 1972. Table 1.2.1 shows the rated and design operating conditions. The reactor is currently licensed to produce 1,593 MWt; however, the turbine generator unit is designed for 1,664 MWt. The plant nominally produces 540 MWe at rated conditions.

The nuclear system generally includes those systems most closely associated with the reactor vessel which are designed to contain, or be in communication with, water coming from or going to the reactor core. The nuclear system includes the following (Section 1.2 of Reference 1-1):

a. Reactor vessel

b. Reactor vessel internals

c. Reactor core

d. Main steam lines from reactor vessel to the isolation valves outside the primary containment

e. Neutron Monitoring System

f. Reactor Recirculation System

g. Control Rod Drive System

h. Residual Heat Removal System

i. Reactor Core Isolation Cooling System (RCIC)

j. Core Standby Cooling System (Emergency Core Cooling Systems, ECCS)

k. Reactor Water Cleanup System

l. Feedwater System piping between the reactor vessel and the first valve outside the primary containment.

The reactor vessel, internals, and core are shown in Figure 1.2-1. The reactor vessel has an internal diameter and height of 205 inches and 757.5 inches, respectively. The reactor vessel internals include the following components:

89 - Control rods and guide tubes

30 - Incore instrumentation tubes

129 - Standpipes and steam separators

6 - Chevron type dryers with an annular skirt

10 - Internal riser pipes connected to the jet pumps

20 - Internal jet pumps

4 - Sets of low pressure core spray pipes

A shroud that defines the lower plenum, core, and upper plenum regions

Various internal support structures for the core, jet pumps, separators, and dryers

The reactor core consists of 368 fuel assemblies. Currently, each fuel assembly contains an 8 x 8 array of 62 zircaloy clad fuel rods and two water rods within a zircaloy channel. The axial length of the fuel zone is 150 inches of which 144 inches contain enriched UO_2 and six inches at the top contain natural UO_2. Vermont Yankee has a uniquely large core bypass region (inside the core shroud and external to the fuel assemblies) for a BWR4 due to the relatively large vessel diameter and the small number of fuel assemblies. A typical BWR4 (e.g., Monticello) with a 205-inch ID vessel would have 484 fuel assemblies and a core power of 1,670 MWt. Alternatively, the Duane Arnold plant has a 183-inch vessel ID, 368 fuel assemblies, and was originally licensed for a core power of 1,593 MWt. The latter two values are the same as those for Vermont Yankee.

Each of the two recirculation loops contain the following components:

1 - 28-inch suction pipe from the vessel to the pump

1 - 20-inch RHR suction pipe and isolation valve

1 - 4-inch reactor water cleanup system suction pipe and isolation valve

1 - 32,250 gpm variable speed recirculation pump

1 - 28-inch discharge pipe from the pump to the header

1 - motor-operated discharge valve immediately downstream of the recirculation pump

1 - 17.5-inch ID throat venturi in the discharge pipe

1 - 24-inch RHR return pipe and isolation valve that also function for LPCI injection

1 - 22-inch recirculation loop header pipe

5 - 12-inch external riser pipes from the header to the vessel

Each of the two independent feedwater systems include the following components from the drywell to the vessel:

2 - 16-inch check valves (inside and outside the drywell wall)

1 - 16-inch feedwater pipe from the drywell to a tee

2 - 10-inch feedwater pipes from the tee to the vessel

During normal operation, the feedwater control system adjusts flow control valves located upstream from the drywell. The feedwater flow rate is set to match the main steam line flow rate plus an amount proportional to the difference between the desired and the actual reactor water level. If a loss of auxiliary power occurs, the condensate and feedwater pumps coast down, the flow control valves freeze in position, and the check valves close in about six seconds.

Each of the four main steam lines include the following components from the vessel to the drywell:

1 - 18-inch steam line

1 - 8.7-inch ID throat venturi

2 - Main Steam Line Isolation Valves (MSIVs; one each inside and outside the drywell wall)

1 - Pilot-operated Safety/Relief Valve (S/RV) that discharges to the wetwell suppression pool

Two of the main steam lines have a spring-loaded safety valve that discharges to the drywell. One main steam line has a 10-inch pipe and two motor-operated valves to deliver steam to the HPCI steam turbine. A different steam line has a 3-inch pipe and two motor-operated valves to deliver steam to the RCIC steam turbine. The four main steam lines then run from the drywell, through the steam line tunnel, to the main turbine. Each has a Turbine Control Valve (TCV) and a Turbine Stop Valve (TSV) immediately upstream of the turbine. The four main steam lines are cross-connected by the pressure averaging manifold upstream of the turbine valves. Also, two sets of two main steam lines each connect to a header that has five Turbine Bypass Valves (TBVs). These mechanical-hydraulically driven valves operate quickly following a change in turbine load (e.g., turbine trip).

The Vermont Yankee Nuclear Power Station has the following Emergency Core Cooling Systems (ECCSs) that are also referred to as Core Standby Cooling Systems (CSCSs):

1 - High Pressure Coolant Injection (HPCI) System that injects into one of the two main feed water lines outside the drywell wall.

1 - Automatic Depressurization System (ADS) that utilizes the four safety/relief valves to vent reactor vessel steam to the suppression pool.

2 - Low Pressure Core Spray (LPCS) Systems that inject coolant into the upper plenum directly above the core region.

2 - Low Pressure Coolant Injection (LPCI) Systems, each which injects into one of the two recirculation loop discharge pipes.

1.3 RELAP5YA Summary

RELAP5YA, a computer program for light-water reactor system thermal-hydraulic analysis, has been adapted by Yankee Atomic Electric Company for Loss-of-Coolant Accident (LOCA) analyses. RELAP5YA provides a consistent, integral analysis capability of the system and core response to LOCA events and other plant transients. YAEC will use this program as a major part of its method to analyze the entire BWR break spectrum and the PWR small break spectrum in a manner that conforms to U.S. Nuclear Regulatory Commission requirements contained in 10CFR50.46 and Appendix K. YAEC has extensively applied this program for other conservative and realistic analyses of LOCA events and transients.

The RELAP5YA hydrodynamic model is based upon a one-dimensional, two-fluid, nonequilibrium model. This model accounts for single-phase liquid and gas flows, and for velocity and temperature differences between two fluid phases that frequently occur in LWR Systems. It allows for the presence of a noncondensible gas, such as nitrogen, mixed with the vapor phase. It also allows for a dissolved nonvolatile constituent, such as sodium pentaborate, mixed with the liquid phase. The hydrodynamic model contains the necessary conservation of mass, momentum, and energy equations, thermodynamic state relations, and constitutive equations to complete the physical and mathematical description of a generalized fluid system.

The hydrodynamic model is implemented in the RELAP5YA code through the selection of hydrodynamic components. These components serve as building blocks and provide a high degree of flexibility for the user to simulate a variety of LWR and other thermal-hydraulic systems. RELAP5YA uses the concept of hydrodynamic volumes (fluid control volumes) and hydrodynamic junctions (momentum control volumes). Hydrodynamic volumes contain averaged state properties. These include primary dependent variables (ρ, X, X_n, ρ_B, u, P) and auxiliary variables (α_f, α_g, T_f T_g, X_e, and volume averaged phasic velocities). The wall heat transfer rate, vapor generation rate, and mechanical energy dissipation terms are accounted for within these volumes. Hydrodynamic junctions contain the averaged phasic velocities and properties required for the flux terms at the open ends of hydrodynamic volumes. Fluid inertia, convected momentum, gravitational forces, interphase drag, wall friction, localized pressure losses, and critical flow are accounted for within hydrodynamic junctions.

Twelve types of hydrodynamic components are available in RELAP5YA for constructing a simulation model of a thermal-hydraulic system. These components are the vehicle for entering input data, selecting user options, and applying the hydrodynamic model to fluid regions within the system or specifying fluid system boundary conditions. Five components (SNGLVOL, SNGLJUN, PIPE, ANNULUS, and BRANCH) apply the basic hydrodynamic model to internal fluid regions. Another five components (SEPARATOR, PUMP, JETPMP, VALVE, and ACCUM) modify the basic hydrodynamic model to account for unique hydrodynamic phenomena within separators, centrifugal and jet pumps, valves, and accumulators. Finally, two components (TMDPVOL and TMDPJUN) allow the user to specify hydrodynamic boundary conditions for a system model.

The RELAP5YA code also contains models for simulating other transient processes pertinent to light-water reactors and thermal-hydraulic systems. These include the following:

a. Point reactor kinetics with decay heat, moderator density, Doppler, and SCRAM reactivity effects.

b. Thermal power sources and sinks.

c. Dynamic fuel rod behavior with swelling, rupture, and metal-water reaction.

d. Conduction heat transfer within solid materials.

e. Convective heat transfer between solid materials and the surrounding fluid.

f. Radiation heat transfer between participating solid material surfaces.

g. Generalized control systems and trip logic.

RELAP5YA Version 18V has been developed from the RELAP5 MOD1 Cycle 18 code that was originally developed by EG&G Idaho, Inc., under USNRC sponsorship, and publicly released. Substantial modifications have been made to RELAP5 MOD1 in order to:

a. Extend and improve upon the code simulation capabilities.

b. Provide options that conform to 10CFR50, Appendix K requirements.

c. Correct certain errors identified by YAEC and by EG&G Idaho, Inc., in their updates for Cycle 19 to Cycle 29.

The major modifications are identified in Table 1.3.1. Reference 1-2 provides a complete description of the RELAP5YA Computer Program. Its focus is primarily on modifications by YAEC to the original RELAP5 MOD1 Code. Reference 1-3 provides a user's manual for RELAP5YA. Reference 1-4 provides an extensive assessment of RELAP5YA calculations compared to many separate effect tests identified in Table 1.3.2, and integral tests identified in Table 1.3.3. This assessment establishes the viability of the RELAP5YA code to predict complex thermal-hydraulic phenomena encountered in LWR System analyses of LOCA events and other transients. References 1-5 through 1-9 contain additional information from YAEC's response to the 197 general RELAP5YA questions from the USNRC. Reference 1-10 contains YAEC's response to the 39 BWR-related questions about RELAP5YA.

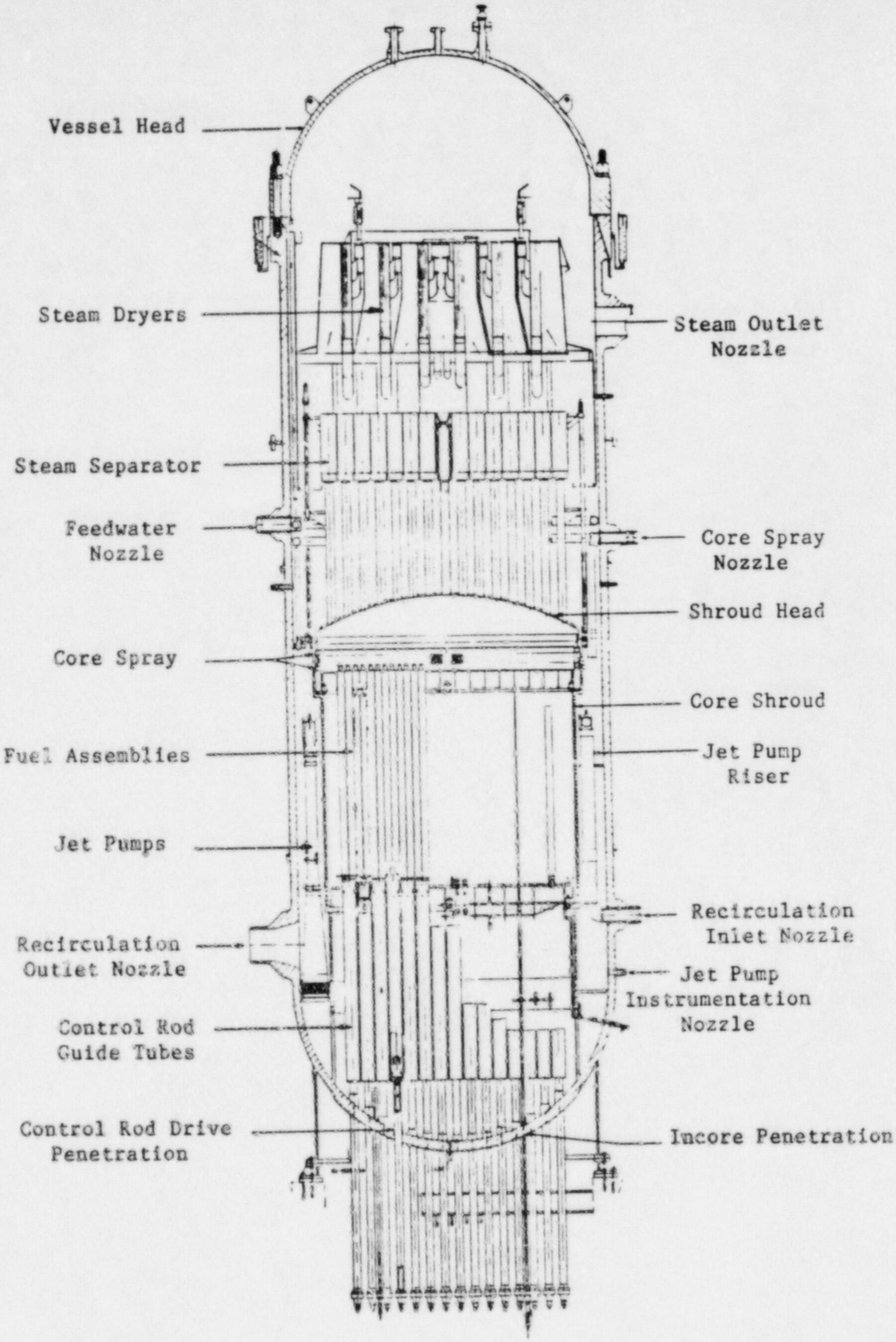

Figure 1.2-1: Vermont Yankee Reactor Vessel

TABLE 1.2.1

Vermont Yankee Operating Conditions

		Rated	Design
Core Power	(MWt)	1,593	1,664
Vessel Pressure	(psia)	1,020	1,035
Vessel Water Level	(inches)[a]	512	512
Feedwater Temperature	(°F)	372	376
Feedwater Flow	(MLBM/hr)[b]	6.40	6.72
Recirculation Loop Flow (each of two loops)	(MLBM/hr)	12.3	12.3
Control Rod Drive Flow	(MLBM/hr)	0.03	0.03
Core Flow	(MLBM/hr)	48.0	48.0
Main Steam Line Flow (four combined lines)	(MLBM/hr)	6.43	6.75

NOTES:

a. Inches above the top of the lower reactor vessel invert.

b. Million pounds mass per hour.

TABLE 1.3.1

RELAP5YA Model Development Tasks

	Analysis Requirement
A. Hydrodynamic Models	
1. Interphase Drag	BE, EM
2. Moody Two-Phase Critical Flow	EM
3. Jet Pump	BE, EM
B. Heat Transfer Models	
1. Forced Convective Boiling	BE, EM
2. Critical Heat Flux	BE, EM
3. Rewet and Quench	BE, EM
4. Multi-Surface Radiation	BE, EM
5. Heat Transfer Logic Options	EM
C. Fuel Behavior Models	
1. Internal Gas Pressure	BE, EM
2. Rod Deformation and Rupture	BE, EM
3. Transient Gap Conductance	BE, EM
4. Zircaloy-Water Reactions	EM

TABLE 1.3.2

Separate Effect Tests for RELAP5YA Model Assessment

Hydrodynamic Models		Assessment Cases
Interphase Drag	4	Frigg Loop Tests
	1	GE Level Swell Test
Two-Phase Critical Flow	7	Parametric Calculations
	1	Marviken Test
Jet Pump	233	1/6 Scale EG&G SS Tests
	2	1/6 Scale Blowdown Tests
		VY Jet Pump M-N Curve
Accumulator	1	Maine Yankee Test
	1	LOFT L3-1 Test
Heat Transfer Models		
Forced Convective Boiling	3	Bennett Tests
Critical Heat Flux	5	Columbia Tests
	4	GE Nine Rod Tests
	3	ORNL THTF Tests
Radiation	2	Analytical Solutions
	4	Parametric Calculations
EM Logic Options	9	Parametric Calculations
Fuel Behavior Models		
Metal-Water Reaction	1	Analytical Solution
All Models	1	TOODEE2-EM Run

TABLE 1.3.3

Integral Tests for RELAP5YA Code Assessment

		Reference
Thermal-Hydraulic Test Facility (ORNL-NRC)		
3	Steady-State Film Boiling Tests	1-4
1	Transient Film Boiling Test	1-4
1	Quasi Steady-State Boiloff Test	1-4
2	Reflood Tests	1-4
Two Loop Test Apparatus (GE-EPRI-NRC)		
	Large Break With ECCS, Test 6425/2	1-4, 1-10
	Large Break Without ECCS, Test 6426/1	1-4
	Small Break With Degraded ECCS, Test 6323/1	1-4, 1-10
	System Boiloff With Recovery, Test 6441/6	1-4
LOFT (EG&G-NRC)		
	Small Break With Pumps On, Test L3-6	1-4, 1-9
	Severe Core Transient With Pumps Tripped, Test L8-1	1-4
	Small Break With Pumps Off, Test L3-1	1-9
Semiscale Test Facility (EG&G-NRC)		
	Single-Phase, Two-Phase, and Reflux Modes of Natural Circulation, Test Series S-NC-2	1-9
Yankee Plant (YAEC)		
	Reactor Coolant Pump Trip Test	1-7

2.0 NUCLEAR STEAM SUPPLY SYSTEM MODEL

This section describes the RELAP5YA base input model for Vermont Yankee NSSS LOCA licensing analyses. This model contains a relatively detailed representation of the following:

a. Reactor vessel, internals, and core.

b. Each independent recirculation loop including the associated bank of ten jet pumps.

c. Feedwater lines from the check valves just outside the drywell wall to the reactor vessel.

d. Main steam lines and valves from the vessel to the turbine stop valves and bypass valves.

e. Emergency Core Cooling Systems.

f. Control systems and trip logic.

g. Core power.

The base input model is set up for a double-ended guillotine break in the discharge pipe of Recirculation Loop A just upstream of the header pipe. This case was selected because it is the current Design Basis Accident (DBA) for VYNPS (Section 6.5, Reference 1-1). Important accident assumptions include the following:

a. Coincident loss of normal auxiliary power.

b. Failure of LPCI-A injection due to the proximity of the break location to the injection pipe and valve.

c. Failure of the Recirculation Loop A discharge valve to close on demand due to the proximity of the break location to the valve.

d. Failure of the LPCI-B injection valve to open on demand (single failure criterion).

Other break sizes, locations, and single failure assumptions are modeled by making relatively minor changes to this input model. These changes will be identified and documented for each case.

The Vermont Yankee NSSS model summarized below results from a considerable amount of engineering insight, sound judgements, and experience gained over the past six years. This includes incorporation of the following:

a. Current information for the Vermont Yankee NSSS such as drawings, Technical Specifications, plant performance data, and guidance from supporting software.

b. Modeling techniques found successful for simulating the response of many separate effects and integral system tests identified in Tables 1.3.2 and 1.3.3.

c. Improvements to the model that have evolved from previous RELAP5YA analyses of the Vermont Yankee NSSS.

2.1 NSSS Volumes, Junctions, and Heat Structures

Figure 2.1-1 shows the Vermont Yankee NSSS nodalization diagram for the base input model. Table 2.1.1 identifies the corresponding regions or systems, and summarizes the number of volumes, junctions, and heat structures used in the Vermont Yankee NSSS model. Active volumes mean all volumes except Time-Dependent Volumes (TMDPVOLs). Likewise, active junctions mean all junctions except Time-Dependent Junctions (TMDPJUNs). Active heat structures mean those heat structures that model axial segments of fuel rods. Passive heat structures are those that model reactor vessel and pipe walls, and reactor vessel internal structures. Tables 2.1.2 through 2.1.5 summarize important input parameters for these volumes, junctions, valves and heat structures.

A brief explanation is provided for the component numbering system in the nodalization diagram to enhance easy recognition of components. Even digit numbers are generally used for all active volumes. Odd digit numbers are generally used for all active junctions and selected, where possible, to have values between the associated volume numbers. Heat structures generally retain the number corresponding to the fluid volume with which they interact. Blocks of numbers have been assigned for subregions, systems, and boundary conditions that are evident from Table 2.1.1. The numbering sequence generally traces the normal flow directions, beginning from the lower plenum.

2.2 Core Power

The total core power is determined by the point reactor kinetics model in RELAP5YA. Conservative input data are entered for this model in order to compute the fission power and decay heat per 10CFR50.46 Appendix K requirements. The model accounts for moderator void, Doppler, and SCRAM reactivity effects. Minimum plausible input values have been selected for the sample problems based upon a review of SIMULATE computer code (References 2-1 and 2-2) data for Vermont Yankee.

All core power is conservatively assumed to be generated in the fuel, i.e., none is deposited in moderator, cladding, or passive heat structures. This power is distributed according to the Nodal Power Factor (NPF) entered for each active heat structure (27) that represents a portion of UO_2 fuel. Each nodal power factor is the product of three terms:

$$NPF = F_B \times F_R \times F_Z$$

where:

F_B = Core region bundle fraction.

F_R = Core region radial power factor.

F_Z = Core region axial power factor.

SIMULATE computer code (References 2-1, 2-2, and 2-3) data for Vermont Yankee Cycles 9, 10, and 11 were reviewed to determine conservative values for each term in order to achieve bounding cycle-independent values. The following values were selected from this review:

Core Region	F_B	F_R	F_Z
Peripheral Low Power	0.315217	0.5851	1.40 Chopped Cosine
Central Average Power	0.673913	1.1860	1.40 Chopped Cosine
Central High Power	0.010870	1.5000	1.53 Chopped Cosine

This yields a maximum local peaking factor in the high power bundles of 2.295 (1.50 x 1.53). This value is 11.4% larger than the highest value found during the review. This peak occurs in axial Node 5 located between 72 and 90 inches above the bottom of the fuel zone. Finally, the power within each fuel node is distributed according to flux depression factors obtained from FROSSTEY computer code (Appendix A) results.

2.3 Trip Logic

The Vermont Yankee model uses a combination of 93 logical and variable trips to account for significant signals that will or might occur for a spectrum of LOCAs. Trip setpoints are generally obtained from the Vermont Yankee Technical Specifications if available. The trips account for delays built in to certain circuits and delays due to instrument and logic circuit response times. The trip functions and signals are summarized below.

a. Accident Initiation

- o Terminate normal operation.
- o Begin LOCA with loss of normal auxiliary power.

b. Reactor SCRAM

- o RPS MG set underfrequency time, OR
- o High drywell pressure time, OR
- o RPV low level (127 inches), OR

- o RPV high pressure (1,055 psig), OR
- o MSIV closure (<90% open).

c. Turbine Stop Valves (Junction 549) Closure

- o High drywell pressure time, OR
- o Reactor SCRAM plus 20 seconds.

d. Turbine Bypass Valves (Junction 571) Opening

- o Turbine stop valve closure plus 0.1 second.

e. MSIV (Junction 547) Closure

- o RPS MG set underfrequency time, OR
- o High main steam line flow (140%), OR
- o RPV low low level (82.5 inches).

f. Recirculation Pump Motor Trips

- o RPV high pressure (1,150 psig), OR
- o RPV low low level (82.5 inches) plus 10 seconds, OR
- o Recirculation loop MG set underfrequency time (17 seconds).

g. Safety/Relief and Safety Valves

	Open (psid)	Close (psid)
o S/RV1 (Junction 551)	1,080.0	1,047.6
o S/RV23 (Junction 553)	1,090.0	1.057.3
o S/RV4 (Junction 555)	1,100.0	1,067.0
o SV12 (Junction 557)	1,240.0	1,202.8

- o All S/RV junctions close if ADS opens.

h. Automatic Depressurization System (Junction 559) Actuation

- o High drywell pressure time, AND
- o Current RPV low low level (82.5 inches), AND
- o 120-second delay, AND
- o At least one low pressure ECCS pump running.

i. High Pressure Coolant Injection

- o Initiates on high drywell pressure time OR RPV low low level (82.5 inches).

- o Terminates on RPV high level (177 inches) OR low main steam line pressure (90 psia).

j. Low Pressure Core Spray

- o Pumps are at rated speed when emergency diesels are running (13 seconds) plus 15 second load and startup time AND high drywell pressure time OR RPV low low level (82.5 inches) occurs.

- o Injection valves are open when high drywell pressure time OR RPV low low level signal arrives AND RPV pressure permissive (315 psia) plus 8 seconds occurs.

k. Low Pressure Coolant Injection

- o Pumps are at rated speed when emergency diesels are running (13 seconds) plus 10 second load and startup time AND high drywell pressure time OR RPV low low level (82.5 inches) occurs.

- o Injection valves start to open when high dyrwell pressure time or RPV low low level AND RPV pressure permissive (315 psia) occurs.

- o Recirculation loop discharge valves start to close when LPCI initiation signal arrives AND RPV pressure permissive (315 psia) occurs.

1. Rewet and Quench Model Initiation Trip

   - o LPCS or LPCI is ready to inject.

2.4 Emergency Core Cooling Systems

2.4.1 High Pressure Coolant Injection (HPCI)

The HPCI system consists of one high pressure steam turbine assembly and a constant-flow pump assembly with associated piping, valves, controls, and instrumentation. This system is capable of delivering 4250 gpm over a broad range of vessel pressures (1,120 to 75 psid vessel to containment). The steam supply to the HPCI turbine is modeled with TMDPJUN 561. Values in Table 2.4.1 are used when the HPCI startup trip becomes true. The HPCI ECC flow is modeled using TMDPJUN 701. The flow versus time values for this table account for a 20.33-second startup time followed by a 5-second ramp to 587 lbm/sec (100^{o}F water) after the HPCI initiation signal occurs.

2.4.2 Automatic Depressurization System (ADS)

The ADS is modeled as a trip valve (Junction 559) using the combined nozzle flow areas of the four safety/relief valves. When the ADS opens, the corresponding SR/Vs (if open) are quickly ramped closed. A two-phase discharge coefficient of 0.848 is used for these valves in order to better approximate their rated conditions.

2.4.3 Low Pressure Core Spray (LPCS)

The two independent core spray systems are modeled as one combined system by TMDPJUN 721. A control variable (CV721) monitors the upper plenum to wetwell pressure difference (P206-P720). This parameter is used as the independent variable in the TMDPJUN table to determine the LPCS flow after the injection valve has opened. Table 2.4.2 contains the data for this component. These values have been conservatively selected from actual VYNPS pump data. Specifically, the lower of the two-pump performance curves was used and the flow rates were reduced by 3% to allow for the estimated measurement uncertainties.

2.4.4 Low Pressure Coolant Injection (LPCI)

Each independent LPCI System is modeled separately since they inject into different recirculation loops. These are modeled by TMDPJUNs 741 and 761. Each has an associated control variable that monitors the injection pipe to wetwell pressure difference:

CV741 = P742 - P740

CV761 = P762 - P760

Each CV parameter is then used as the independent variable for the corresponding TMDPJUN table. The two tables are identical. Values for TMDPJUN 741 are given in Table 2.4.3. The flows assume that two pumps are operating in each system and have been reduced by 150 gpm to allow for the estimated uncertainties.

2.5 Initial Conditions

The initialization of the NSSS model has been accomplished in several steps. First, an earlier version of the NSSS model was modified as follows:

a. Accident trips were set to false.

b. All passive heat structures were deleted to avoid long thermal time constants associated with their heatup.

c. The NSSS was filled with hot stagnant liquid to the desired vessel level with saturated steam above at approximately 988 psia. All fluid velocities were set to zero.

d. A pump speed versus time table was used to ramp the recirculation pumps from 0 to rated speed over 50 seconds and hold constant, thereafter.

e. A power versus time table was used to ramp the core power from zero at 10 seconds to full power at 50 seconds and hold constant, thereafter.

f. Perfect separation of the two-phase mixture exiting the steam separators was imposed.

g. The feedwater temperature was set at the desired value. The feedwater flow rate used control variables to be set at the main steam line flow rate plus an amount proportional to the desired minus actual vessel water level.

An "accelerated startup" transient was then run from 0 to 150 seconds. This allowed 100 seconds after rated pump speed and core power for the NSSS to stabilize. This provided a reasonable set of volume and junction initial conditions at full power operation. These were copied through files and added to a Vermont Yankee NSSS input deck as initial condition replacement cards.

A series of steady-state null transient runs were made with the Vermont Yankee NSSS model. The accident conditions were set to false and the recirculation pump speed was held constant. These runs allowed certain input parameters to be adjusted to achieve desired steady-state initial conditions. Also, the steady-state initialization flag for all heat structures is activated so they are initialized to operating temperatures. Slight adjustments were made to the fuel radius in each core region until the volume average fuel temperatures matched those calculated by the FROSSTEY code (see Appendix A) for the peak axial power location.

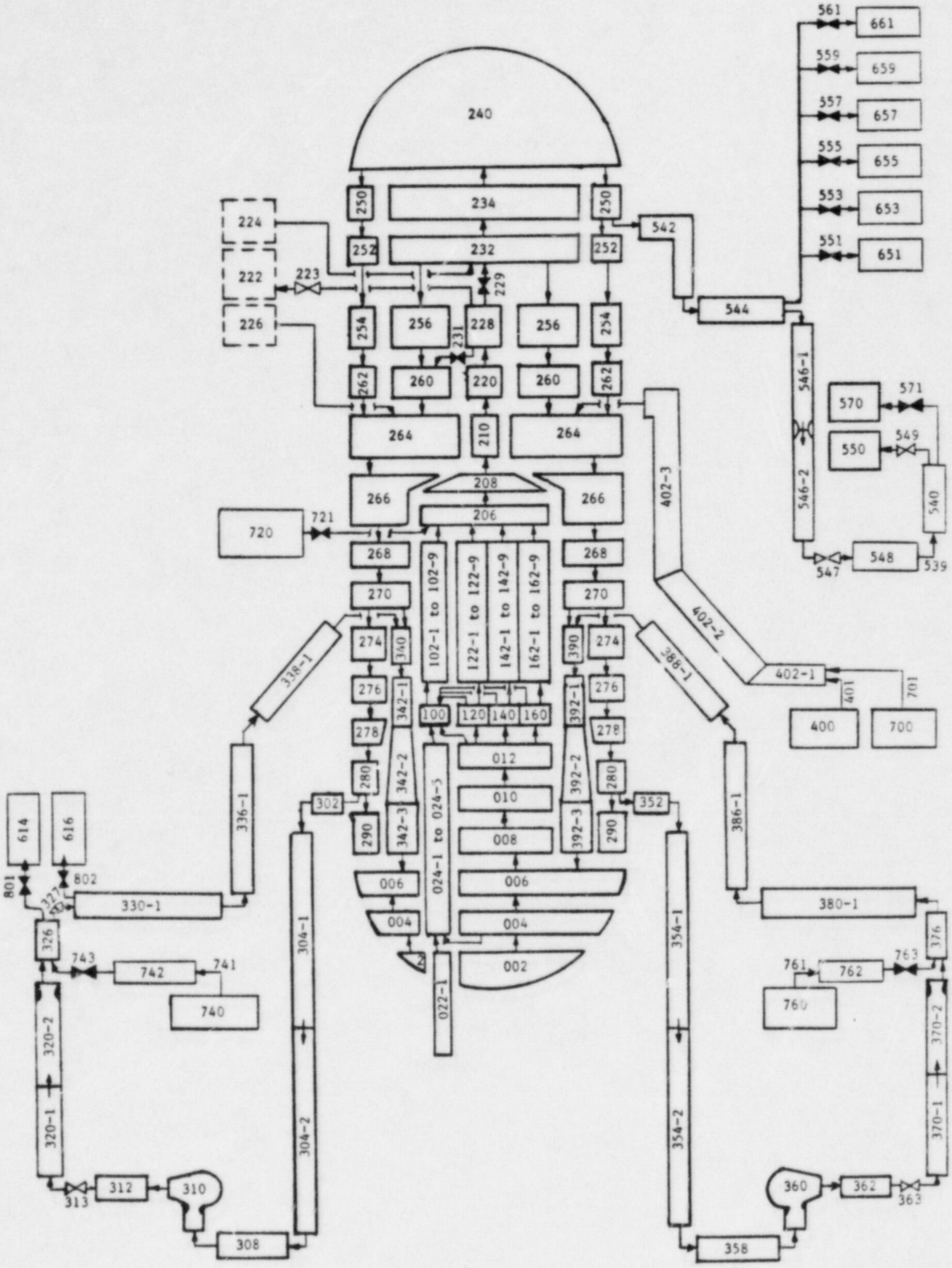

Figure 2.1-1: Vermont Yankee NSSS Nodalization Diagram

TABLE 2.1.1

Vermont Yankee NSSS Nodalization Summary

Region or System	Nodalization Diagram Numbers	Number of Volumes		Number of Junctions		Number of Heat Structures	
		Active	TMDPVOL	Active	TMDPJUN	Active	Passive
Reactor Pressure Vessel							
Lower Plenum	002 to 012	6	0	10	0	0	6
Control Rod Guide Tubes	022 to 024-5	6	0	6	0	0	6
Core Bypass	100 to 102-9	10	0	10	0	0	10
Core Fuel Assemblies							
116 Peripheral Low Power	120 to 122-9	10	0	11	0	9	10
248 Central Average Power	140 to 142-9	10	0	11	0	9	10
4 Central High Power	160 to 162-9	10	0	11	0	9	10
Upper Plenum	206 to 208	2	0	2	0	0	2
Standpipes and Separators	210 to 228	3	3	5	2	0	3
Intermediate Steam	232	1	0	2	0	0	0
Steam Dryer Assembly	234	1	0	1	0	0	1
Steam Dome	240	1	0	1	0	0	1
Downcomer	250 to 290	15	0	14	0	0	13
Other Systems							
Recirculation Loop A	302 to 338-1	12	0	12	0	0	12
Jet Pump Bank A	340 to 342-3	4	0	6	0	0	4
Recirculation Loop B	352 to 388-1	12	0	12	0	0	12
Jet Pump Bank B	390 to 392-3	4	0	6	0	0	4
Feedwater Lines	400 to 402-3	3	1	3	1	0	0
Main Steam Lines	540 to 550	6	1	7	0	0	5
Steam Relief and Supply	551 to 571	0	1	6	1	0	0
Containment	614 to 663	0	8	0	0	0	0
ECCS	700 to 763	2	4	2	4	0	0
DEG Break	801 to 802	0	0	2	0	0	0
TOTALS		118	18	140	8	27	109

TABLE 2.1.2

Summary of VY NSSS Fluid Volumes

Component Number	Type	Area (ft^2)	Length (ft)	Volume (ft^3)	Vert. Angle (degrees)	Elev. Change (ft)	Rough. (ft)	Hyd. Diam. (ft)	Flags
Lower Plenum Region									
002	SNGLVOL	(70.60)	3.5160	248.24	+90.0	+3.5160	1.5E-4	1.827	00
004	BRANCH	(119.89)	2.3180	277.90	+90.0	+2.3180	1.5E-4	1.389	00
006	BRANCH	(158.97)	2.2285	354.38	+90.0	+2.2285	1.5E-4	1.811	00
008	SNGLVOL	(81.42)	2.7726	225.77	+90.0	+2.7726	1.5E-4	1.049	00
010	SNGLVOL	(81.42)	2.7726	225.77	+90.0	+2.7726	1.5E-4	1.049	00
012	BRANCH	(75.42)	2.7725	209.13	+90.0	+2.7725	1.5E-4	0.635	00
Control Rod Guide Tube Region (89 Combined)									
022-1	PIPE	(10.27)	14.5830	149.77	+90.0	+14.5830	1.5E-4	0.2058	00
024-1	PIPE	(48.88)	2.3180	113.30	+90.0	+2.3180	1.5E-4	0.6070	00
024-2	PIPE	(48.88)	2.2285	108.95	+90.0	+2.2285	1.5E-4	0.6070	00
024-3	PIPE	(48.88)	2.7726	135.54	+90.0	+2.7726	1.5E-4	0.6070	00
024-4	PIPE	(48.88)	2.7726	135.54	+90.0	+2.7726	1.5E-4	0.6070	00
024-5	PIPE	(48.88)	2.7725	135.54	+90.0	+2.7725	1.5E-4	0.6070	00
Core Bypass Region									
100	BRANCH	(60.51)	0.9115	55.15	+90.0	+0.9115	1.5E-4	0.6380	00
102-1	PIPE	(67.07)	1.5000	100.61	+90.0	+1.5000	1.5E-4	0.2639	00
102-2	PIPE	(67.07)	1.5000	100.61	+90.0	+1.5000	1.5E-4	0.2639	00
102-3	PIPE	(67.07)	1.5000	100.61	+90.0	+1.5000	1.5E-4	0.2639	00
102-4	PIPE	(67.07)	1.5000	100.61	+90.0	+1.5000	1.5E-4	0.2639	00
102-5	PIPE	(67.07)	1.5000	100.61	+90.0	+1.5000	1.5E-4	0.2639	00
102-6	PIPE	(67.07)	1.5000	100.61	+90.0	+1.5000	1.5E-4	0.2639	00
102-7	PIPE	(67.07)	1.5000	100.61	+90.0	+1.5000	1.5E-4	0.2639	00
102-8	PIPE	(67.07)	1.5000	100.61	+90.0	+1.5000	1.5E-4	0.2639	00
102-9	PIPE	(63.32)	1.6234	102.80	+90.0	+1.6234	1.5E-4	0.1979	00

TABLE 2.1.2
(Continued)

Summary of VY NSSS Fluid Volumes

Component Number	Type	Area (ft²)	Length (ft)	Volume (ft³)	Vert. Angle (degrees)	Elev. Change (ft)	Rough. (ft)	Hyd. Diam. (ft)	Flags
Core Fuel Assembly Region									
Peripheral Low Power (116 Assemblies)									
120	BRANCH	(11.62)	0.9115	10.59	+90.0	+0.9115	1.5E-4	0.3570	00
122-1	PIPE	(12.75)	1.5000	19.12	+90.0	+1.5000	5.0E-6	0.04461	00
122-2	PIPE	(12.75)	1.5000	19.12	+90.0	+1.5000	5.0E-6	0.04461	00
122-3	PIPE	(12.75)	1.5000	19.12	+90.0	+1.5000	5.0E-6	0.04461	00
122-4	PIPE	(12.75)	1.5000	19.12	+90.0	+1.5000	5.0E-6	0.04461	00
122-5	PIPE	(12.75)	1.5000	19.12	+90.0	+1.5000	5.0E-6	0.04461	00
122-6	PIPE	(12.75)	1.5000	19.12	+90.0	+1.5000	5.0E-6	0.04461	00
122-7	PIPE	(12.75)	1.5000	19.12	+90.0	+1.5000	5.0E-6	0.04461	00
122-8	PIPE	(12.75)	1.5000	19.12	+90.0	+1.5000	5.0E-6	0.04461	00
122-9	PIPE	(13.42)	1.6234	21.78	+90.0	+1.6234	5.0E-6	0.04461	00
Central Average Power (248 Assemblies)									
140	BRANCH	(24.84)	0.9115	22.64	+90.0	+0.9115	1.5E-4	0.3570	00
142-1	PIPE	(27.26)	1.5000	40.88	+90.0	+1.5000	5.0E-6	0.04461	00
142-2	PIPE	(27.26)	1.5000	40.88	+90.0	+1.5000	5.0E-6	0.04461	00
142-3	PIPE	(27.26)	1.5000	40.88	+90.0	+1.5000	5.0E-6	0.04461	00
142-4	PIPE	(27.26)	1.5000	40.88	+90.0	+1.5000	5.0E-6	0.04461	00
142-5	PIPE	(27.26)	1.5000	40.88	+90.0	+1.5000	5.0E-6	0.04461	00
142-6	PIPE	(27.26)	1.5000	40.88	+90.0	+1.5000	5.0E-6	0.04461	00
142-7	PIPE	(27.26)	1.5000	40.88	+90.0	+1.5000	5.0E-6	0.04461	00
142-8	PIPE	(27.26)	1.5000	40.88	+90.0	+1.5000	5.0E-6	0.04461	00
142-9	PIPE	(28.68)	1.6234	46.56	+90.0	+1.6234	5.0E-6	0.04461	00

TABLE 2.1.2
(Continued)

Summary of VY NSSS Fluid Volumes

Component Number	Component Type	Area (ft^2)	Length (ft)	Volume (ft^3)	Vert. Angle (degrees)	Elev. Change (ft)	Rough. (ft)	Hyd. Diam. (ft)	Flags
Central High Power (4 Assemblies)									
160	BRANCH	(0.4007)	0.9115	0.3652	+90.0	+0.9115	1.5E-4	0.3570	00
162-1	PIPE	(0.4396)	1.5000	0.6594	+90.0	+1.5000	5.0E-6	0.04461	00
162-2	PIPE	(0.4396)	1.5000	0.6594	+90.0	+1.5000	5.0E-6	0.04461	00
162-3	PIPE	(0.4396)	1.5000	0.6594	+90.0	+1.5000	5.0E-6	0.04461	00
162-4	PIPE	(0.4396)	1.5000	0.6594	+90.0	+1.5000	5.0E-6	0.04461	00
162-5	PIPE	(0.4396)	1.5000	0.6594	+90.0	+1.5000	5.0E-6	0.04461	00
162-6	PIPE	(0.4396)	1.5000	0.6594	+90.0	+1.5000	5.0E-6	0.04461	00
162-7	PIPE	(0.4396)	1.5000	0.6594	+90.0	+1.5000	5.0E-6	0.04461	00
162-8	PIPE	(0.4396)	1.5000	0.6594	+90.0	+1.5000	5.0E-6	0.04461	00
162-9	PIPE	(0.4626)	1.6234	0.7510	+90.0	+1.6234	5.0E-6	0.04461	00
Upper Plenum Region									
206	BRANCH	(165.90)	1.8349	304.41	+90.0	+1.8349	1.5E-4	14.50	00
208	BRANCH	(151.58)	1.8542	281.06	+90.0	+1.8542	1.5E-4	11.54	00
Standpipe Region (129 Combined)									
210	SNGLVOL	(25.88)	4.2292	109.46	+90.0	+4.2292	1.5E-4	0.5054	00
Separator Region (129 Combined)									
220	BRANCH	(77.72)	3.6667	284.98	+90.0	+3.6667	1.5E-4	0.8758	00
222	TMDPVOL	(1.0E+4)	1.0E+2	1.0E+6	0.0	0.0	1.5E-4	0.0	10
224	TMDPVOL	(1.0E+4)	1.0E+2	1.0E+6	0.0	0.0	1.5E-4	0.0	10
226	TMDPVOL	(1.0E+4)	1.0E+2	1.0E+6	0.0	0.0	1.5E-4	0.0	10
228	BRANCH	(77.72)	3.6667	284.98	+90.0	+3.6667	1.5E-4	0.8758	00

TABLE 2.1.2
(Continued)

Summary of VY NSSS Fluid Volumes

Component Number	Component Type	Area (ft^2)	Length (ft)	Volume (ft^3)	Vert. Angle (degrees)	Elev. Change (ft)	Rough. (ft)	Hyd. Diam. (ft)	Flags
Intermediate Steam Region									
232	BRANCH	(209.14)	2.2917	479.28	+90.0	+2.2917	1.5E-4	9.970	00
Steam Dryer Region									
234	BRANCH	(188.44)	5.1666	973.58	+90.0	+5.1666	1.5E-4	0.5180	00
Steam Dome Region									
240	BRANCH	(229.21)	6.6528	1524.89	+90.0	+6.6528	1.5E-4	17.083	00
Downcomer Region									
250	BRANCH	(25.21)	5.1666	130.23	-90.0	-5.1666	1.5E-4	0.9084	00
252	BRANCH	(13.90)	2.2917	31.865	-90.0	-2.2917	1.5E-4	0.3711	00
254	BRANCH	(13.90)	3.6667	50.985	-90.0	-3.6667	1.5E-4	0.3711	00
256	BRANCH	(149.76)	3.6667	549.12	-90.0	-3.6667	1.5E-4	1.5540	00
260	BRANCH	(95.45)	3.6667	349.99	-90.0	-3.6667	1.5E-4	0.7400	00
262	BRANCH	(13.76)	3.6667	50.45	-90.0	-3.6667	1.5E-4	0.3673	00
264	BRANCH	(179.92)	4.2292	760.92	-90.0	-4.2292	1.5E-4	2.2760	00
266	BRANCH	(59.29)	3.6891	218.73	-90.0	-3.6891	1.5E-4	1.7020	00
268	SNGLVOL	(65.22)	2.9092	189.74	-90.0	-2.9092	1.5E-4	2.6350	00
270	BRANCH	(67.09)	2.7142	182.09	-90.0	-2.7142	1.5E-4	1.5900	00
274	SNGLVOL	(64.76)	3.7958	245.82	-90.0	-3.7958	1.5E-4	1.6160	00
276	SNGLVOL	(64.23)	3.6417	233.90	-90.0	-3.6417	1.5E-4	1.6030	00
278	SNGLVOL	(61.12)	3.8542	235.58	-90.0	-3.8542	1.5E-4	1.3430	00
280	BRANCH	(68.20)	2.5800	175.96	-90.0	-2.5800	1.5E-4	1.5820	00
290	SNGLVOL	(57.57)	3.3575	193.30	-90.0	-3.3575	1.5E-4	1.3200	00

TABLE 2.1.2
(Continued)

Summary of VY NSSS Fluid Volumes

Component Number	Component Type	Area (ft^2)	Length (ft)	Volume (ft^3)	Vert. Angle (degrees)	Elev. Change (ft)	Rough. (ft)	Hyd. Diam. (ft)	Flags
Recirculation Loop A (Broken Loop)									
302	BRANCH	(3.6395)	5.6123	20.426	0.0	0.0	1.5E-4	2.153	00
304-1	PIPE	(3.6395)	20.1276	73.254	-90.0	-19.0017	1.5E-4	2.153	00
304-2	PIPE	(3.6395)	20.1276	73.254	-90.0	-19.0017	1.5E-4	2.153	00
308	BRANCH	(3.6395)	9.9780	36.316	0.0	0.0	1.5E-4	2.153	00
310	PUMP	3.6395	(13.3411)	48.555	+90.0	+4.3333	1.5E-4	2.153	00
312	BRANCH	(3.6395)	9.2480	33.658	0.0	0.0	1.5E-4	2.153	00
320-1	PIPE	(3.6395)	8.6667	31.542	+90.0	+8.6667	1.5E-4	2.153	00
320-2	PIPE	(3.6395)	8.6667	31.542	+90.0	+8.6667	1.5E-4	2.153	00
326	BRANCH	(3.6395)	8.6666	31.542	+90.0	+8.6667	1.5E-4	2.153	00
330-1	PIPE	(4.2550)	17.8680	76.029	0.0	0.0	1.5E-4	2.328	00
336-1	PIPE	(3.5280)	11.7500	41.454	+90.0	+11.750	1.5E-4	0.9478	00
338-1	PIPE	(3.5280)	15.6888	55.350	+58.943	+9.792	1.5E-4	0.8774	00
Jet Pump Bank A (10 Combined)									
340	JETPMP	2.0462	4.4283	(9.0612)	-90.0	-4.4283	2.0E-6	0.5104	00
342-1	PIPE	(2.5411)	3.5717	9.0760	-90.0	-3.5717	3.62E-6	0.5688	00
342-2	PIPE	(7.3374)	4.6358	34.0147	-90.0	-4.6358	5.25E-6	0.7870	00
342-3	PIPE	(11.075)	4.5934	50.872	-90.0	-4.5934	5.25E-6	1.1875	00

TABLE 2.1.2
(Continued)

Summary of VY NSSS Fluid Volumes

Component Number	Component Type	Area (ft^2)	Length (ft)	Volume (ft^3)	Vert. Angle (degrees)	Elev. Change (ft)	Rough. (ft)	Hyd. Diam. (ft)	Flags
Recirculation Loop B									
352	BRANCH	(3.6395)	5.6123	20.426	0.0	0.0	1.5E-4	2.153	00
354-1	PIPE	(3.6395)	20.1276	73.254	-90.0	-19.0017	1.5E-4	2.153	00
354-2	PIPE	(3.6395)	20.1276	73.254	-90.0	-19.0017	1.5E-4	2.153	00
358	BRANCH	(3.6395)	9.9780	36.316	0.0	0.0	1.5E-4	2.153	00
360	PUMP	3.6395	(13.3411)	48.555	+90.0	+4.3333	1.5E-4	2.153	00
362	BRANCH	(3.6395)	9.2480	33.658	0.0	0.0	1.5E-4	2.153	00
370-1	PIPE	(3.6395)	8.6667	31.542	+90.0	+8.6667	1.5E-4	2.153	00
370-2	PIPE	(3.6395)	8.6667	31.542	+90.0	+8.6667	1.5E-4	2.153	00
376	BRANCH	(3.6395)	8.6666	31.542	+90.0	+8.6667	1.5E-4	2.153	00
380-1	PIPE	(4.2550)	17.8680	76.029	0.0	0.0	1.5E-4	2.328	00
386-1	PIPE	(3.5280)	11.7500	41.454	+90.0	+11.750	1.5E-4	0.9478	00
388-1	PIPE	(3.5280)	15.6888	55.350	+58.943	+9.792	1.5E-4	0.8774	00
Jet Pump Bank B (10 Combined)									
390	JETPMP	2.0462	4.4283	(9.0612)	-90.0	-4.4283	2.0E-6	0.5104	00
392-1	PIPE	(2.5411)	3.5717	9.0760	-90.0	-3.5717	3.62E-6	0.5688	00
392-2	PIPE	(7.3374)	4.6358	34.0147	-90.0	-4.6358	5.25E-6	0.7870	00
392-3	PIPE	(11.075)	4.5934	50.872	-90.0	-4.5934	5.25E-6	1.1875	00

TABLE 2.1.2
(Continued)

Summary of VY NSSS Fluid Volumes

Component Number	Component Type	Area (ft^2)	Length (ft)	Volume (ft^3)	Vert. Angle (degrees)	Elev. Change (ft)	Rough. (ft)	Hyd. Diam. (ft)	Flags
Feedwater Lines (2 + 4 Combined)									
400	TMDPVDL	(1.0E+5)	10.0	1.0E+6	+90.000	+10.0	1.5E-4	1000.0	11
402-1	PIPE	(2.0441)	49.429	101.036	+14.810	+12.635	1.5E-4	1.1407	00
402-2	PIPE	(2.0740)	34.466	71.483	0.000	0.0	1.5E-4	0.8125	00
402-3	PIPE	(2.0740)	44.005	91.267	+52.937	+35.115	1.5E-4	0.8125	00
Main Steam Lines (4 Combined), Turbine and Condenser									
542	SNGLVOL	5.6720	48.7517	(276.52)	-83.252	-43.5938	1.5E-4	1.3437	00
544	SNGLVOL	5.6720	25.4879	(144.57)	-12.600	-4.6563	1.5E-4	1.3437	00
546-1	PIPE	5.6720	22.9434	(130.14)	-25.463	-7.4011	1.5E-4	1.3437	00
546-2	PIPE	5.6720	22.9434	(130.14)	-25.463	-7.4011	1.5E-4	1.3437	00
548	PIPE	5.6720	216.9808	(1230.72)	+1.606	+6.0800	1.5E-4	1.3437	00
540	SNGLVOL	5.6720	25.00	(141.80)	0.0	0.0000	1.5E-4	1.3437	00
550	TMDPVOL	(1.0E+5)	10.00	(1.0E+6)	+90.0	+10.0000	1.5E-4	1.0E+3	11
570	TMDPVOL	(1.0E+5)	10.00	(1.0E+6)	+90.0	+10.0000	1.5E-4	1.0E+3	11
Primary Containment (Drywell and Wetwell) Steam Sinks									
614	TMDPVOL	(1.0E+5)	10.0	1.0E+6	+90.0	+10.0	1.5E-4	1.0E+3	11
616	TMDPVOL	(1.0E+5)	10.0	1.0E+6	+90.0	+10.0	1.5E-4	1.0E+3	11
651	TMDPVOL	(1.0E+5)	10.0	1.0E+6	+90.0	+10.0	1.5E-4	1.0E+3	11
653	TMDPVOL	(1.0E+5)	10.0	1.0E+6	+90.0	+10.0	1.5E-4	1.0E+3	11
655	TMDPVOL	(1.0E+5)	10.0	1.0E+6	+90.0	+10.0	1.5E-4	1.0E+3	11
657	TMDPVOL	(1.0E+5)	10.0	1.0E+6	+90.0	+10.0	1.5E-4	1.0E+3	11
659	TMDPVOL	(1.0E+5)	10.0	1.0E+6	+90.0	+10.0	1.5E-4	1.0E+3	11
661	TMDPVOL	(1.0E+5)	10.0	1.0E+6	+90.0	+10.0	1.5E-4	1.0E+3	11
*663	TMDPVOL	(1.0E+5)	10.0	1.0E+6	+90.0	+10.0	1.5E-4	1.0E+3	11

* Deactivated.

TABLE 2.1.2
(Continued)

Summary of VY NSSS Fluid Volumes

Component Number	Component Type	Area (ft^2)	Length (ft)	Volume (ft^3)	Vert. Angle (degrees)	Elev. Change (ft)	Rough. (ft)	Hyd. Diam. (ft)	Flags
Reactor Core Isolation Cooling (RCIC), Deactivated									
*710	TMDPVOL	(1.0E+5)	10.0	1.0E+6	+90.0	+10.0	1.5E-4	1.0E+3	11
Emergency Core Cooling Systems (ECCS)									
High Pressure Coolant Injection (HPCI)									
700	TMDPVOL	(1.0E+5)	10.0	1.0E+6	+90.0	+10.0	1.5E-4	1.0E+3	11
Low Pressure Core Spray (LPCS)									
720	TMDPVOL	(1.0E+5)	10.0	1.0E+6	+90.0	+10.0	1.5E-4	1.0E+3	11
Low Pressure Coolant Injection - A Loop (LPCI-A)									
740	TMDPVOL	(1.0E+5)	10.0	1.0E+6	+90.0	+10.0	1.5E-4	1.0E+3	11
742	SNGLVOL	2.5360	25.0	(63.40)	0.0	0.0	1.5E-4	1.7968	00
Low Pressure Coolant Injection - B Loop (LPCI-B)									
760	TMDPVOL	(1.0E+5)	10.0	1.0E+6	+90.0	+10.0	1.5E-4	1.0E+3	11
762	SNGLVOL	2.5360	25.0	(63.40)	0.0	0.0	1.5E-4	1.7968	00

TABLE 2.1.3

Summary of VY NSSS Junctions

Component Number	Component Type	Connections From Vol.	Connections To Vol.	Area (ft^2)	Loss Coefficient Forward	Loss Coefficient Reverse	Discharge Coefficient Subcooled	Discharge Coefficient 2-Phase	Flags
Lower Plenum Region									
003	SNGLJUN	00201	00400	(70.60)	0.169	0.184	1.0	1.0	00000
004-1	BRANCH	00400	02400	2.127E-3	1.500	1.500	1.0	1.0	00020
004-2	BRANCH	00401	00600	(119.89)	0.060	0.111	1.0	1.0	00000
007	SNGLJUN	00601	00800	(81.42)	0.221	0.238	1.0	1.0	00000
009	SNGLJUN	00801	01000	(81.42)	0.000	0.000	1.0	1.0	00000
011	SNGLJUN	01001	01200	(75.42)	0.022	0.005	1.0	1.0	00000
031	SNGLJUN	01201	10000	0.1877	1.492	1.494	1.0	1.0	00020
032	SNGLJUN	01201	12000	2.1195	2.312	2.798	1.0	1.0	00000
034	SNGLJUN	01201	14000	6.6786	2.203	2.865	1.0	1.0	00000
036	SNGLJUN	01201	16000	0.10772	2.203	2.865	1.0	1.0	00000
Control Rod Guide Tube Region (89 Combined)									
023	SNGLJUN	02201	02400	(10.27)	0.624	0.316	1.0	1.0	00000
024-1	PIPE	02401	02402	(48.88)	0.000	0.000	1.0	1.0	00000
024-2	PIPE	02402	02403	(48.88)	0.000	0.000	1.0	1.0	00000
024-3	PIPE	02403	02404	(48.88)	0.000	0.000	1.0	1.0	00000
024-4	PIPE	02404	02405	(48.88)	0.000	0.000	1.0	1.0	00000
037	SNGLJUN	02405	10000	2.000	1.414	1.403	1.0	1.0	00000
Core Bypass Region									
100-1	BRANCH	10001	10200	60.15	0.011	0.035	1.0	1.0	00000
102-1	PIPE	10201	10202	(67.07)	0.000	0.000	1.0	1.0	00000
102-2	PIPE	10202	10203	(67.07)	0.000	0.000	1.0	1.0	00000
102-3	PIPE	10203	10204	(67.07)	0.000	0.000	1.0	1.0	00000
102-4	PIPE	10204	10205	(67.07)	0.000	0.000	1.0	1.0	00000
102-5	PIPE	10205	10206	(67.07)	0.000	0.000	1.0	1.0	00000
102-6	PIPE	10206	10207	(67.07)	0.000	0.000	1.0	1.0	00000
102-7	PIPE	10207	10208	(67.07)	0.000	0.000	1.0	1.0	00000
102-8	PIPE	10208	10209	(67.07)	0.000	0.000	1.0	1.0	00000
109	SNGLJUN	10209	20600	41.47	0.490	0.401	1.0	1.0	00000

TABLE 2.1.3
(Continued)

Summary of VY NSSS Junctions

Component Number	Component Type	Connections From Vol.	Connections To Vol.	Area (ft^2)	Loss Coefficient Forward	Loss Coefficient Reverse	Discharge Coefficient Subcooled	Discharge Coefficient 2-Phase	Flags
Core Fuel Assembly Region									
Peripheral Low Power (116 Assemblies)									
120-1	BRANCH	12001	10001	0.3714	5.415	5.415	1.0	1.0	00020
120-2	BRANCH	12001	12200	8.0230	0.437	0.543	1.0	1.0	00000
122-1	PIPE	12201	12202	(12.748)	1.085	1.085	1.0	1.0	00000
122-2	PIPE	12202	12203	(12.748)	1.085	1.085	1.0	1.0	00000
122-3	PIPE	12203	12204	(12.748)	1.085	1.085	1.0	1.0	00000
122-4	PIPE	12204	12205	(12.748)	1.085	1.085	1.0	1.0	00000
122-5	PIPE	12205	12206	(12.748)	1.085	1.085	1.0	1.0	00000
122-6	PIPE	12206	12207	(12.748)	1.085	1.085	1.0	1.0	00000
122-7	PIPE	12207	12208	(12.748)	1.085	1.085	1.0	1.0	00000
122-8	PIPE	12208	12209	(12.748)	1.085	1.085	1.0	1.0	00000
129	SNGLJUN	12209	20600	10.058	0.909	0.909	1.0	1.0	00000
Central Average Power (248 Assemblies)									
140-1	BRANCH	14001	10001	0.7940	4.322	4.322	1.0	1.0	00020
140-2	BRANCH	14001	14200	17.1520	0.437	0.543	1.0	1.0	00000
142-1	PIPE	14201	14202	(27.255)	1.085	1.085	1.0	1.0	00000
142-2	PIPE	14202	14203	(27.255)	1.085	1.085	1.0	1.0	00000
142-3	PIPE	14203	14204	(27.255)	1.085	1.085	1.0	1.0	00000
142-4	PIPE	14204	14205	(27.255)	1.085	1.085	1.0	1.0	00000
142-5	PIPE	14205	14206	(27.255)	1.085	1.085	1.0	1.0	00000
142-6	PIPE	14206	14207	(27.255)	1.085	1.085	1.0	1.0	00000
142-7	PIPE	14207	14208	(27.255)	1.085	1.085	1.0	1.0	00000
142-8	PIPE	14208	14209	(27.255)	1.085	1.085	1.0	1.0	00000
149	SNGLJUN	14209	20600	21.504	0.909	0.909	1.0	1.0	00000

TABLE 2.1.3
(Continued)

Summary of VY NSSS Junctions

Component Number	Component Type	Connections From Vol.	Connections To Vol.	Area (ft^2)	Loss Coefficient Forward	Loss Coefficient Reverse	Discharge Coefficient Subcooled	Discharge Coefficient 2-Phase	Flags
Central High Power (4 Assemblies)									
160-1	BRANCH	16001	10001	0.01281	4.247	4.247	1.0	1.0	00020
160-2	BRANCH	16001	16200	0.2766	0.437	0.543	1.0	1.0	00000
162-1	PIPE	16201	16202	(0.4396)	1.085	1.085	1.0	1.0	00000
162-2	PIPE	16202	16203	(0.4396)	1.085	1.085	1.0	1.0	00000
162-3	PIPE	16203	16204	(0.4396)	1.085	1.085	1.0	1.0	00000
162-4	PIPE	16204	16205	(0.4396)	1.085	1.085	1.0	1.0	00000
162-5	PIPE	16205	16206	(0.4396)	1.085	1.085	1.0	1.0	00000
162-6	PIPE	16206	16207	(0.4396)	1.085	1.085	1.0	1.0	00000
162-7	PIPE	16207	16208	(0.4396)	1.085	1.085	1.0	1.0	00000
162-8	PIPE	16208	16209	(0.4396)	1.085	1.085	1.0	1.0	00000
169	SNGLJUN	16209	20600	0.3468	0.909	0.909	1.0	1.0	00000
Upper Plenum Region									
206-1	BRANCH	20601	20800	(151.58)	0.043	0.007	1.0	1.0	00000
208-1	BRANCH	20801	21000	25.881	0.415	0.688	1.0	1.0	00000
Standpipe and Separator Regions (129 Combined)									
220-1	BRANCH	21001	22000	25.8809	1.216	1.216	1.0	1.0	00000
220-2	BRANCH	22001	22800	77.7200	0.000	0.000	1.0	1.0	00000
223	TRPVALVE	22801	22200	31.1143	1.9137	1.4091	1.0	1.0	00000
225	TMDPJUN	22400	23200	31.1143	NA	NA	NA	NA	NA
227	TMDPJUN	22600	26400	58.0618	NA	NA	NA	NA	NA
229	TRPVALVE	22801	23200	31.1143	1.9137	1.4091	1.0	1.0	00000
231	TRPVALVE	22800	26000	58.0618	1.6263	1.6263	1.0	1.0	00000

TABLE 2.1.3
(Continued)

Summary of VY NSSS Junctions

Component Number	Component Type	Connections From Vol.	Connections To Vol.	Area (ft²)	Loss Coefficient Forward	Loss Coefficient Reverse	Discharge Coefficient Subcooled	Discharge Coefficient 2-Phase	Flags
Intermediate Steam Region									
232-1	BRANCH	23201	23400	108.19	1.196	1.1877	1.0	1.0	00000
232-2	BRANCH	23200	25600	149.76	0.123	0.0810	1.0	1.0	00000
Steam Dryer Region									
234-1	BRANCH	23401	24000	37.33	0.9851	0.7264	1.0	1.0	00000
Steam Dome Region									
240-1	BRANCH	24000	25000	(25.21)	0.345	0.792	1.0	1.0	00000
Downcomer Region									
250-1	BRANCH	25001	25200	(13.90)	0.184	0.201	1.0	1.0	00000
252-1	BRANCH	25201	25400	(13.76)	0.000	0.000	1.0	1.0	00000
254-1	BRANCH	25401	26200	(13.76)	0.004	0.001	1.0	1.0	00000
256-1	BRANCH	25601	26000	(95.45)	0.151	0.132	1.0	1.0	00000
260-1	BRANCH	26001	26400	(95.45)	0.2204	0.2347	1.0	1.0	00000
262-1	BRANCH	26201	26400	(13.76)	0.8529	0.4618	1.0	1.0	00000
264-1	BRANCH	26401	26600	(59.29)	0.265	0.450	1.0	1.0	00000
266-1	BRANCH	26601	26800	(59.29)	0.008	0.027	1.0	1.0	00000
270-1	BRANCH	26801	27000	(65.22)	0.001	0.004	1.0	1.0	00000
270-2	BRANCH	27001	27400	(64.76)	0.005	0.001	1.0	1.0	00000
275	SNGLJUN	27401	27600	(64.23)	0.000	0.000	1.0	1.0	00000
277	SNGLJUN	27601	27800	(61.12)	0.010	0.002	1.0	1.0	00000
280-1	BRANCH	27801	28000	(61.12)	0.011	0.036	1.0	1.0	00000
280-2	BRANCH	28001	29000	(57.57)	0.0782	0.0244	1.0	1.0	00000

TABLE 2.1.3
(Continued)

Summary of VY NSSS Junctions

Component Number	Component Type	Connections From Vol.	Connections To Vol.	Area (ft^2)	Loss Coefficient Forward	Loss Coefficient Reverse	Discharge Coefficient Subcooled	Discharge Coefficient 2-Phase	Flags
Recirculation Loop A (Broken Loop)									
302-1	BRANCH	28001	30200	(3.6395)	0.159	0.664	1.0	1.0	00000
302-2	BRANCH	30201	30400	(3.6395)	0.168	0.168	1.0	1.0	00000
304-1	PIPE	30401	30402	(3.6395)	0.000	0.000	1.0	1.0	00000
305	SNGLJUN	30402	30800	2.670	0.264	0.264	1.0	1.0	00000
310-1	PUMP INLET	30801	(31000)	1.8045	0.240	0.240	1.0	1.0	00000
310-2	PUMP OUTLET	(31001)	31200	(3.6395)	0.000	0.000	1.0	1.0	00000
313	MTRVALVE	31201	32000	2.047	0.264	0.264	1.0	1.0	00100
320-1	PIPE	32001	32002	(3.6395)	0.000	0.000	1.0	1.0	00000
326-1	BRANCH	32002	32600	1.6669	0.124	0.124	1.0	1.0	00000
327	TRPVALVE	32601	33000	3.6395	0.696	1.288	1.0	1.0	00000
335	SNGLJUN	33001	33600	(3.528)	0.810	0.855	1.0	1.0	00000
337	SNGLJUN	33601	33800	(3.528)	0.833	0.730	1.0	1.0	00000
Jet Pump Bank A (10 Combined)									
340-1	JETPMP-DR	33801	34000	0.5304	(a)	(b)	1.0	1.0	00000
340-2	JETPMP-SU	27001	34000	2.4006	(a)	(b)	1.0	1.0	00000
340-3	JETPMP-TH	34001	34200	2.0462	(a)	(b)	1.0	1.0	00000
(a) FDK1 to FDK7:		0.04129	0.1174	0.8733	0.1268	0.6400	0.8998	0.0	
(b) RDK1 to RDK7:		0.90000	0.2441	1.0000	0.4695	1.0000	0.0	0.0	
342-1	PIPE	34201	34202	4.1539	0.1501	0.1065	1.0	1.0	00000
342-2	PIPE	34202	34203	11.0753	0.0335	0.0305	1.0	1.0	00000
343	SNGLJUN	34203	00601	11.0753	4.8000	0.3653	1.0	1.0	00000

TABLE 2.1.3
(Continued)

Summary of VY NSSS Junctions

Component		Connections		Area	Loss Coefficient		Discharge Coefficient		Flags
Number	Type	From Vol.	To Vol.	(ft^2)	Forward	Reverse	Subcooled	2-Phase	
Recirculation Loop B (Intact Loop)									
352-1	BRANCH	28001	35200	(3.6395)	0.159	0.664	1.0	1.0	00000
352-2	BRANCH	35201	35400	(3.6395)	0.168	0.168	1.0	1.0	00000
354-1	PIPE	35401	35402	(3.6395)	0.000	0.000	1.0	1.0	00000
355	SNGLJUN	35402	35800	2.670	0.264	0.264	1.0	1.0	00000
360-1	PUMP INLET	35801	36000	1.8045	0.240	0.240	1.0	1.0	00000
360-2	PUMP OUTLET	36001	36200	(3.6395)	0.000	0.000	1.0	1.0	00000
363	MTRVALVE	36201	37000	2.047	0.264	0.264	1.0	1.0	00100
370-1	PIPE	37001	37002	(3.6395)	0.000	0.000	1.0	1.0	00000
376-1	BRANCH	37002	37600	1.6669	0.124	0.124	1.0	1.0	00000
377	TRPVALVE	37601	38000	3.6395	0.696	1.288	1.0	1.0	00000
385	SNGLJUN	38001	38600	(3.528)	0.810	0.855	1.0	1.0	00000
387	SNGLJUN	38601	38800	(3.528)	0.833	0.730	1.0	1.0	00000
Jet Pump Bank B (10 Combined)									
390-1	JETPMP-DR	38801	39000	0.5304	(a)	(b)	1.0	1.0	00000
390-2	JETPMP-SU	27001	39000	2.4006	(a)	(b)	1.0	1.0	00000
390-3	JETPMP-TH	39001	39200	2.0462	(a)	(b)	1.0	1.0	00000
(a) FDK1 to FDK7:		0.04129	0.1174	0.8733	0.1268	0.6400	0.8998	0.0	
(b) RDK1 to RDK7:		0.90000	0.2441	1.0000	0.4695	1.0000	0.0	0.0	
392-1	PIPE	39201	39202	4.1539	0.1501	0.1065	1.0	1.0	00000
392-2	PIPE	39202	39203	11.0753	0.0335	0.0305	1.0	1.0	00000
393	SNGLJUN	39203	00601	11.0753	4.8000	0.3653	1.0	1.0	00000
Feedwater Lines (2 and 4 Combined)									
401	TMDPJUN	40000	40200	2.044	NA	NA	NA	NA	NA
402-1	PIPE	40201	40202	2.044	0.666	0.730	1.0	1.0	00000
402-2	PIPE	40202	40203	2.074	0.308	0.308	1.0	1.0	00000
403	SNGLJUN	40203	26400	2.074	1.453	0.970	1.0	1.0	00000

TABLE 2.1.3
(Continued)

Summary of VY NSSS Junctions

Component		Connections		Area	Loss Coefficient		Discharge Coefficient		Flags
Number	Type	From Vol.	To Vol.	(ft^2)	Forward	Reverse	Subcooled	2-Phase	
Main Steam Lines (4 Combined)									
541	SNGLJUN	25001	54200	5.672	0.2944	1.0944	1.0	1.0	00000
543	SNGLJUN	54201	54400	(5.672)	0.3109	0.3109	1.0	1.0	00000
545	SNGLJUN	54401	54600	(5.672)	0.1623	0.1623	1.0	1.0	00000
546-1	PIPE	54601	54602	1.665	0.1708	0.4488	1.0	1.0	00000
547	MTRVALVE	54602	54800	5.672	1.5436	1.5436	1.0	1.0	00100
539	SNGLJUN	54801	54000	5.672	0.0000	0.0000	1.0	1.0	00000
549	MTRVALVE	54001	55000	5.672	0.6187	0.6187	1.0	1.0	00100
Steam Relief and Supply									
551	MTRVALVE	54401	65100	0.09945	0.0	0.0	1.0	0.848	00100
553	MTRVALVE	54401	65300	0.19890	0.0	0.0	1.0	0.848	00100
555	MTRVALVE	54401	65500	0.09945	0.0	0.0	1.0	0.848	00100
557	MTRVALVE	55401	65700	0.20360	0.0	0.0	1.0	0.848	00100
559	TRPVALVE	54401	65900	0.39780	0.0	0.0	1.0	0.848	00100
561	TMDPJUN	54401	66100	0.49870	NA	NA	NA	NA	NA
* 563	TMDPJUN	54401	66300	0.49870	NA	NA	NA	NA	NA
571	MTRVALVE	54001	57000	1.01000	0.0	0.0	1.0	1.000	00100
Reactor Core Isolation Cooling (RCIC), Deactivated									
* 711	TMDPJUN	71000	40200	0.7610	NA	NA	NA	NA	NA

* Deactivated.

TABLE 2.1.3
(Continued)

Summary of VY NSSS Junctions

Component		Connections		Area	Loss Coefficient		Discharge Coefficient		Flags
Number	Type	From Vol.	To Vol.	(ft^2)	Forward	Reverse	Subcooled	2-Phase	
				Emergency Core Cooling Systems (ECCS)					
High Pressure Coolant Injection (HPCI)									
701	TMDPJUN	70100	40200	0.7610	NA	NA	NA	NA	NA
Low Pressure Core Spray (LPCS), (2 Combined)									
721	TMDPJUN	72000	20600	31.76	NA	NA	NA	NA	NA
Low Pressure Coolant Injection - A Loop (LPCI-A)									
741	TMDPJUN	74000	74200	2.536	NA	NA	NA	NA	NA
743	MTRVALVE	74201	32600	2.536	0.0	0.0	1.0	1.0	00100
Low Pressure Coolant Injection - B Loop (LPCI-B)									
761	TMDPJUN	76000	76200	2.536	NA	NA	NA	NA	NA
763	MTRVALVE	76201	37600	2.536	0.0	0.0	1.0	1.0	00100
Pipe Breaks									
801	TRPVALVE	32601	61400	3.6395	0.0	0.0	1.0	1.0	10100
802	TRPVALVE	33000	61600	3.6395	0.0	0.0	1.0	1.0	10100

TABLE 2.1.4

Summary of VY NSSS Model Valves

Valve Number	Valve Type	Initial Position	Trips Open	Trips Close	Stroke Time (sec)	Description
Steam Separator Region						
223	Trip	Opened	501		0.0	Steady-State Separator Exit
229	Trip	Closed	502		0.0	Transient Separator Top Path
231	Trip	Closed	502		0.0	Transient Separator Skirt Path
Recirculation Loops						
313	Motor	Opened	501	647*	33.0	Recirculation Loop A Discharge Valve
327	Trip	Opened	501		0.0	DEG Pipe Severance
801	Trip	Closed	502		0.0	Upstream Pipe Break
802	Trip	Closed	502		0.0	Downstream Pipe Break
363	Motor	Opened	501	647	33.0	Recirculation Loop B Discharge Valve
Main Steam Lines						
547	Motor	Opened	501	531	10.0	4 Main Steam Isolation Valves
549	Motor	Opened	501	517	0.1	4 Turbine Stop Valves
Steam Relief						
551	Motor	Closed	660	661	0.03	1 Safety/Relief Valve
553	Motor	Closed	662	663	0.03	2 Safety/Relief Valves
555	Motor	Closed	664	665	0.03	1 Safety/Relief Valve
557	Motor	Closed	566	567	0.20	2 Safety Valves
559	Trip	Closed	655		0.0	Auto Depressurization System
571	Motor	Closed	518	503	0.60	10 Turbine Bypass Valves
ECCS						
743	Motor	Closed	547*	503	24.0	LPCI-A Injection Valve
763	Motor	Closed	547**	503	24.0	LPCI-B Injection Valve

* Deactivated for DEG discharge pipe breaks.

** Single failure for large recirculation pipe breaks.

TABLE 2.1.5

Summary of VY NSSS Heat Structures

Component Number	Geom. Type	Mesh Points	Material		Coordinates (ft)		Boundary Volumes		SS-CHF Flag
			Type	Volume (ft^3)	Left	Right	Left	Right	
Lower Plenum Region									
0021	SPH.SEG.	2	C-Steel	105.643	8.5417	9.0486	002	0	15
0041	CYL	2	C-Steel	77.966	6.1775	6.6800	004	0	15
0061	CYL	2	C-Steel	74.993	7.1140	7.6165	006	0	15
0081	CYL	2	S-Steel	16.306	6.6563	6.7954	008	0	15
0101	CYL	2	S-Steel	16.297	6.6563	6.7953	010	0	15
0121	CYL	2	S-Steel	46.882	6.6563	7.0491	012	0	15
Control Rod Guide Tube Region (89 Combined)									
0221	CYL	2	S-Steel	173.770	0.21230	0.29610	022-1	0	15
0241-1	CYL	2	S-Steel	17.368	0.43345	0.46335	024-1	004	15
0241-2	CYL	2	S-Steel	16.704	0.43345	0.46335	024-2	006	15
0241-3	CYL	2	S-Steel	20.773	0.43345	0.46335	024-3	008	15
0241-4	CYL	2	S-Steel	20.773	0.43345	0.46333	024-4	010	15
0242	CYL	2	S-Steel	28.703	0.43345	0.47420	024-5	012	15
Core Bypass Region (Shroud, 89 Control Rods, 30 Instrument Tubes)									
1001	CYL	2	S-Steel	8.020	6.8125	7.0151	100	0	15
1021-1	CYL	2	S-Steel	13.060	6.8125	7.0130	102-1	0	15
1021-2	CYL	2	S-Steel	13.060	6.8125	7.0130	102-2	0	15
1021-3	CYL	2	S-Steel	13.060	6.8125	7.0130	102-3	0	15
1021-4	CYL	2	S-Steel	13.060	6.8125	7.0130	102-4	0	15
1021-5	CYL	2	S-Steel	13.060	6.8125	7.0130	102-5	0	15
1021-6	CYL	2	S-Steel	13.060	6.8125	7.0130	102-6	0	15
1021-7	CYL	2	S-Steel	13.060	6.8125	7.0130	102-7	0	15
1021-8	CYL	2	S-Steel	13.060	6.8125	7.0130	102-8	0	15
1021-9	CYL	2	S-Steel	31.312	6.8125	7.0130	102-9	0	15

TABLE 2.1.5
(Continued)

Summary of VY NSSS Heat Structures

Component Number	Geom. Type	Mesh Points	Material Type	Material Volume (ft^3)	Coordinates (ft) Left	Coordinates (ft) Right	Boundary Volumes Left	Boundary Volumes Right	SS-CHF Flag
Core Fuel Assembly Regions									
Peripheral Low Power Fuel Rods (116 Bundles x 62 Rods Each = 7,192 Fuel Rods)									
1221-1	CYL	7	(Note a)	13.7135	0.0	0.02011539	0	12201	15
1221-2	CYL	7	(Note a)	13.7135	0.0	0.02011539	0	12202	15
1221-3	CYL	7	(Note a)	13.7135	0.0	0.02011539	0	12203	15
1221-4	CYL	7	(Note a)	13.7135	0.0	0.02011539	0	12204	15
1221-5	CYL	7	(Note a)	13.7135	0.0	0.02011539	0	12205	15
1221-6	CYL	7	(Note a)	13.7135	0.0	0.02011539	0	12206	15
1221-7	CYL	7	(Note a)	13.7135	0.0	0.02011539	0	12207	15
1221-8	CYL	7	(Note a)	13.7135	0.0	0.02011539	0	12208	15
1221-9	CYL	7	(Note a)	4.5712	0.0	0.02011539	0	12209	15

Note a: 4 Intervals UO_2, 1 Interval Fission Gas, 1 Interval Zircaloy Cladding

Component Number	Geom. Type	Mesh Points	Material Type	Material Volume (ft^3)	Coordinates (ft) Left	Coordinates (ft) Right	Boundary Volumes Left	Boundary Volumes Right	SS-CHF Flag
Peripheral Low Power Hardware (116 Assemblies)									
1201	CYL	2	S-Steel	7.506	0.17855	0.23340	120	100	15
1222-1	CYL	2	Zircaloy	2.130	0.28888	0.29555	122-1	102-1	15
1222-2	CYL	2	Zircaloy	2.130	0.28888	0.29555	122-2	102-2	15
1222-3	CYL	2	Zircaloy	2.130	0.28888	0.29555	122-3	102-3	15
1222-4	CYL	2	Zircaloy	2.130	0.28888	0.29555	122-4	102-4	15
1222-5	CYL	2	Zircaloy	2.130	0.28888	0.29555	122-5	102-5	15
1222-6	CYL	2	Zircaloy	2.130	0.28888	0.29555	122-6	102-6	15
1222-7	CYL	2	Zircaloy	2.130	0.28888	0.29555	122-7	102-7	15
1222-8	CYL	2	Zircaloy	2.130	0.28888	0.29555	122-8	102-8	15
1223	CYL	2	S-Steel	8.360	1.05644	1.06311	122-9	102-9	15

TABLE 2.1.5
(Continued)

Summary of VY NSSS Heat Structures

Component Number	Geom. Type	Mesh Points	Material Type	Material Volume (ft^3)	Coordinates (ft) Left	Coordinates (ft) Right	Boundary Volumes Left	Boundary Volumes Right	SS-CHF Flag
Central Average Power Fuel Rods (248 Bundles x 62 Rods Each = 15,376 Fuel Rods)									
1421-1	CYL	7	(Note a)	29.3176	0.0	0.02011510	0	14201	15
1421-2	CYL	7	(Note a)	29.3176	0.0	0.02011510	0	14202	15
1421-3	CYL	7	(Note a)	29.3176	0.0	0.02011510	0	14203	15
1421-4	CYL	7	(Note a)	29.3176	0.0	0.02011510	0	14204	15
1421-5	CYL	7	(Note a)	29.3176	0.0	0.02011510	0	14205	15
1421-6	CYL	7	(Note a)	29.3176	0.0	0.02011510	0	14206	15
1421-7	CYL	7	(Note a)	29.3176	0.0	0.02011510	0	14207	15
1421-8	CYL	7	(Note a)	29.3176	0.0	0.02011510	0	14208	15
1421-9	CYL	7	(Note a)	9.7725	0.0	0.02011510	0	14209	15
Central Average Power Hardware (248 Assemblies)									
1401	CYL	2	S-Steel	16.048	0.17855	0.23340	140	100	15
1422-1	CYL	2	Zircaloy	4.655	0.28888	0.29555	142-1	102-1	15
1422-2	CYL	2	Zircaloy	4.655	0.28888	0.29555	142-2	102-2	15
1422-3	CYL	2	Zircaloy	4.655	0.28888	0.29555	142-3	102-3	15
1422-4	CYL	2	Zircaloy	4.655	0.28888	0.29555	142-4	102-4	15
1422-5	CYL	2	Zircaloy	4.655	0.28888	0.29555	142-5	102-5	15
1422-6	CYL	2	Zircaloy	4.655	0.28888	0.29555	142-6	102-6	15
1422-7	CYL	2	Zircaloy	4.655	0.28888	0.29555	142-7	102-7	15
1422-8	CYL	2	Zircaloy	4.655	0.28888	0.29555	142-8	102-8	15
1423	CYL	2	S-Steel	17.984	1.05644	1.06311	142-9	102-9	15

Note a: 4 Intervals UO_2, 1 Interval Fission Gas, 1 Interval Zircaloy Cladding

TABLE 2.1.5
(Continued)

Summary of VY NSSS Heat Structures

Component Number	Geom. Type	Mesh Points	Material Type	Material Volume (ft^3)	Coordinates (ft) Left	Coordinates (ft) Right	Boundary Volumes Left	Boundary Volumes Right	SS-CHF Flag
Central High Power Fuel Rods (4 Bundles x 62 Rods Each = 248 Fuel Rods)									
1621-1	CYL	7	(Note a)	0.4721	0.0	0.02009934	0	16201	15
1621-2	CYL	7	(Note a)	0.4721	0.0	0.02009934	0	16202	15
1621-3	CYL	7	(Note a)	0.4721	0.0	0.02009934	0	16203	15
1621-4	CYL	7	(Note a)	0.4721	0.0	0.02009934	0	16204	15
1621-5	CYL	7	(Note a)	0.4721	0.0	0.02009934	0	16205	15
1621-6	CYL	7	(Note a)	0.4721	0.0	0.02009934	0	16206	15
1621-7	CYL	7	(Note a)	0.4721	0.0	0.02009934	0	16207	15
1621-8	CYL	7	(Note a)	0.4721	0.0	0.02009934	0	16208	15
1621-9	CYL	7	(Note a)	0.1574	0.0	0.02009934	0	16209	15
Note a: 4 Intervals UO_2, 1 Interval Fission Gas, 1 Interval Zircaloy Cladding									
Central High Power Hardware (4 Assemblies)									
1601	CYL	2	S-Steel	0.25900	0.17855	0.23340	160	100	15
1622-1	CYL	2	Zircaloy	0.07344	0.28888	0.29555	162-1	102-1	15
1622-2	CYL	2	Zircaloy	0.07344	0.28888	0.29555	162-2	102-2	15
1622-3	CYL	2	Zircaloy	0.07344	0.28888	0.29555	162-3	102-3	15
1622-4	CYL	2	Zircaloy	0.07344	0.28888	0.29555	162-4	102-4	15
1622-5	CYL	2	Zircaloy	0.07344	0.28888	0.29555	162-5	102-5	15
1622-6	CYL	2	Zircaloy	0.07344	0.28888	0.29555	162-6	102-6	15
1622-7	CYL	2	Zircaloy	0.07344	0.28888	0.29555	162-7	102-7	15
1622-8	CYL	2	Zircaloy	0.07344	0.28888	0.29555	162-8	102-8	15
1623	CYL	2	S-Steel	0.28848	1.05644	1.06311	162-9	102-9	15
Upper Plenum Region									
2061	CYL	2	S-Steel	12.778	7.2500	7.4013	206	0	15
2081	CYL	2	S-Steel	26.560	7.2500	7.5579	208	0	15

TABLE 2.1.5
(Continued)

Summary of VY NSSS Heat Structures

Component Number	Geom. Type	Mesh Points	Material		Coordinates (ft)		Boundary Volumes		SS-CHF Flag
			Type	Volume (ft^3)	Left	Right	Left	Right	
Standpipe and Separator Regions (129 Combined)									
2561	CYL	2	S-Steel	49.455	0.3270	0.3700	0	256	15
2601	CYL	2	S-Steel	49.455	0.5013	0.5313	0	260	15
2642	CYL	2	S-Steel	39.390	0.2147	0.2761	0	264	15
Steam Dryer Region									
2341	CYL	2	S-Steel	78.930	0.2590	0.2774	234	0	15
Steam Dome Region									
2401	SPH.SEG.	2	C-Steel	270.758	8.5417	9.0441	240	0	15
Downcomer Region									
2501	CYL	2	C-Steel	143.425	8.5417	9.0441	250	0	15
2521	CYL	2	C-Steel	72.586	8.5417	9.1128	252	0	15
2541	CYL	2	C-Steel	105.796	8.5417	9.0633	254	0	15
2621	CYL	2	C-Steel	104.706	8.5417	9.0581	262	0	15
2641	CYL	2	C-Steel	117.400	8.5417	9.0441	264	0	15
2661	CYL	2	C-Steel	102.407	8.5417	9.0441	266	0	15
2681	CYL	2	C-Steel	80.758	8.5417	9.0441	268	0	15
2701	CYL	2	C-Steel	80.787	8.5417	9.0793	270	0	15
2741	CYL	2	C-Steel	112.981	8.5417	9.0793	274	0	15
2761	CYL	2	C-Steel	108.392	8.5417	9.0793	276	0	15
2781	CYL	2	C-Steel	114.721	8.5417	9.0793	278	0	15
2801	CYL	2	C-Steel	76.800	8.5417	9.0793	280	0	15
2901	CYL	2	C-Steel	99.943	8.5417	9.0793	290	0	15

TABLE 2.1.5
(Continued)

Summary of VY NSSS Heat Structures

Component Number	Geom. Type	Mesh Points	Material Type	Material Volume (ft^3)	Coordinates (ft) Left	Coordinates (ft) Right	Boundary Volumes Left	Boundary Volumes Right	SS-CHF Flag
Recirculation Loop A (Broken Loop)									
3021	CYL	2	S-Steel	3.872	1.0778	1.1753	302	0	15
3041-1	CYL	2	S-Steel	13.888	1.0778	1.1753	304-1	0	15
3041-2	CYL	2	S-Steel	13.888	1.0778	1.1753	304-2	0	15
3081	CYL	2	S-Steel	6.885	1.0778	1.1753	308	0	15
3101	CYL	2	S-Steel	25.332	1.0763	1.3278	310	0	15
3121	CYL	2	S-Steel	6.753	1.0778	1.1807	312	0	15
3201-1	CYL	2	S-Steel	6.328	1.0778	1.1807	320-1	0	15
3201-2	CYL	2	S-Steel	6.328	1.0778	1.1807	320-2	0	15
3261	CYL	2	S-Steel	6.328	1.0778	1.1807	326	0	15
3301	CYL	2	S-Steel	13.435	0.8303	0.9637	330	0	15
3361	CYL	2	S-Steel	12.826	0.4740	0.7156	336	0	15
3381	CYL	2	S-Steel	3.969	0.4175	0.5531	338	0	15
Jet Pump Bank A (10 Combined)									
3401	CYL	2	S-Steel	1.539	0.25521	0.27604	340	274	15
3421	CYL	2	S-Steel	1.378	0.28440	0.30523	342-1	276	15
3422	CYL	2	S-Steel	2.995	0.48238	0.50411	342-2	278	15
3423	CYL	2	S-Steel	5.112	0.59375	0.62287	342-3	290	15
Recirculation Loop B (Intact Loop)									
3521	CYL	2	S-Steel	3.872	1.0778	1.1753	352	0	15
3541-1	CYL	2	S-Steel	13.888	1.0778	1.1753	354-1	0	15
3541-2	CYL	2	S-Steel	13.888	1.0778	1.1753	354-2	0	15
3581	CYL	2	S-Steel	6.885	1.0778	1.1753	358	0	15
3601	CYL	2	S-Steel	25.332	1.0763	1.3278	360	0	15
3621	CYL	2	S-Steel	6.753	1.0778	1.1807	362	0	15
3701-1	CYL	2	S-Steel	6.328	1.0778	1.1807	370-1	0	15
3701-2	CYL	2	S-Steel	6.328	1.0778	1.1807	370-2	0	15
3761	CYL	2	S-Steel	6.328	1.0778	1.1807	376	0	15
3801	CYL	2	S-Steel	13.435	0.8303	0.9637	380	0	15
3861	CYL	2	S-Steel	12.826	0.4740	0.7156	386	0	15
3881	CYL	2	S-Steel	3.969	0.4175	0.5531	388	0	15

TABLE 2.1.5
(Continued)

Summary of VY NSSS Heat Structures

Component Number	Geom. Type	Mesh Points	Material		Coordinates (ft)		Boundary Volumes		SS-CHF Flag
			Type	Volume (ft^3)	Left	Right	Left	Right	
Jet Pump Bank B (10 Combined)									
3901	CYL	2	S-Steel	1.539	0.25521	0.27604	390	274	15
3921	CYL	2	S-Steel	1.378	0.28440	0.30523	392-1	276	15
3922	CYL	2	S-Steel	2.995	0.48238	0.50411	392-2	280	15
3923	CYL	2	S-Steel	5.112	0.59375	0.62287	392-3	290	15
Main Steam Lines (4 Combined)									
5421	CYL	2	S-Steel	68.088	0.6718	0.7500	542	0	15
5441	CYL	2	S-Steel	35.597	0.6718	0.7500	544	0	15
5461-1	CYL	2	S-Steel	32.043	0.6718	0.7500	546-1	0	15
5461-2	CYL	2	S-Steel	32.043	0.6718	0.7500	546-2	0	15
5481	CYL	2	S-Steel	303.041	0.6718	0.7500	548	0	15

TABLE 2.4.1

HPCI Steam Turbine Flow Rates

Steam Line Pressure (psia)	Vapor Flow Rate (lbm/sec)
90	0.0
90	18.4
165	19.6
450	24.7
550	27.1
650	29.9
750	33.2
850	37.2
1,100	47.2
1,135	48.1
1,135	0.0

TABLE 2.4.2

LPCS Injection Velocities and Flow Rates

CV721 (psid)	Liquid Velocity (ft/sec)	Volumetric Flow (gpm)
-10.01	0.0000	0
-10.00	0.6174	8,800
46.58	0.5612	8,000
100.13	0.4910	7,000
120.00	0.4608	6,570
145.97	0.4210	6,000
184.11	0.3508	5,000
216.66	0.2806	4,000
239.39	0.2104	3,000
256.53	0.1404	2,000
265.97	0.0702	1,000
274.05	0.0000	0

TABLE 2.4.3

LPCI Injection Velocities and Flow Rates

CV741 (psid)	Liquid Velocity (ft/sec)	Volumetric Flow (gpm)
-10.01	0.000	0
-10.00	12.188	13,873
69.98	10.543	12,000
134.50	8.785	10,000
185.18	7.028	8,000
224.12	5.271	6,000
251.34	3.514	4,000
266.82	1.757	2,000
279.03	0.000	0

3.0 HOT CHANNEL MODEL

3.1 Objective and Description of the Model

The Vermont Yankee Hot Channel (VY HC) model is a subset of the Vermont Yankee Nuclear Steam Supply System (VY NSSS) model. The Vermont Yankee HC model utilizes appropriate hydraulic boundary conditions at the inlet and outlet of the high power bundle region from a Vermont Yankee NSSS calculation with the same accident assumptions.

The objective of the Vermont Yankee HC model is to allow greater detail in the investigation of the impact of fuel exposure (Burnup Study) on the outcome of postulated Loss-of-Coolant Accidents (LOCA). These advantages result from the comparatively low computational time associated with the Vermont Yankee HC model. This time is approximately one-third of the Vermont Yankee NSSS computational time for large breaks. The increase in detail comes in the form of higher numbers of burnup points that can be investigated using a combination of both the Vermont Yankee NSSS and Vermont Yankee HC models than would be feasible to investigate with the Vermont Yankee NSSS model alone.

Figure 3.1-1 shows the heat structures (stippled) and fluid volumes (clear) represented in the Vermont Yankee HC model.

The hydrodynamic characteristics of the hot channel are obtained from two parallel channels: one representing one-eighth of the hot assembly, the other representing the associated bypass region. The bypass region is modeled so that the heat transfer across the channel wall can be taken into account. The outlets to both the bypass and the hot assembly region are represented by time-dependent volumes and junctions as shown in Figure 3.1-1. These two volumes (TV207 and TV206) are represented by only one volume (V206) in the Vermont Yankee NSSS model. The Vermont Yankee HC model requires two volumes because of a code constraint. The constraint requires that a time-dependent volume can be connected to no more than one junction. Therefore, the boundary conditions fed into TV206 and TV207 are identical.

The Vermont Yankee HC model represents one-eighth of the hot assembly and its corresponding fraction of the bypass region. Thus, the Vermont Yankee HC model represents the ten rods (six full-size and four half-size rods) shown in Figure 3.1-2(a). However, the Vermont Yankee HC model does not use ten heat structure geometries, since this would require excessive computation time. Instead, Rods 1 to 9 of Figure 3.1-2(a) are lumped into an average rod and Rod 10 (half-size rod) is kept as the hot rod. The arrangement is shown in Figure 3.1-2(b). Hence, the Vermont Yankee HC model embodies three heat structure geometries: (A) channel (box) wall, (B) average rod, and (C) hot rod. This compromise allows radiation heat transfer (to be used in a conservative manner) while retaining sufficient radial power detail to ensure that the hottest rod is accounted for.

As in the Vermont Yankee NSSS model, the corresponding heat structure geometries in the Vermont Yankee HC model have nine axial nodes each as shown in Figure 3.1-1. The numbering scheme is similar to that used in the Vermont Yankee NSSS model which has been given in Tables 2.1.1 to 2.1.5. The only exceptions are the heat structures and hydrodynamic components shown in Table 3.1.1.

The input parameters for the Vermont Yankee HC model are obtained (with the exception of the radiation heat transfer input) from the Vermont Yankee NSSS input deck in the manner specified below:

a. The hot assembly volume flow areas are divided by 32 since Vermont Yankee NSSS represents four assemblies while Vermont Yankee HC represents one-eighth of one assembly. The bypass flow areas are divided by 368 (assemblies in the core) and then by eight to account for the symmetry.

b. The length, hydraulic diameter, and roughnesses are set at the same value in the Vermont Yankee HC as in the Vermont Yankee NSSS.

c. The junction flow areas are divided by 32 and 2944 as described in (a) above.

d. The junction loss coefficients are unchanged.

e. THe Vermont Yankee HC nodal power factors for the average Rod B (Figure 3.1-2(b)) are obtained from the Vermont Yankee NSSS high power region rod divided by 62 (rods per assembly), then divided by 4 (assemblies in high power region), then multiplied by 7.5 (rods represented by average Rod (B)).

f. Similarly, the Vermont Yankee HC nodal power factors for the hot Rod C (Figure 3.1-2(b)) are the Vermont Yankee NSSS value for the high power region divided by 62, then by 4, then by 2 (the hot rod is half-size, Figure 3.1-2(b)).

The radiation view factors are obtained in a two-step process: (1) The view factors for the actual physical rod layout shown in Figure 3.1-2(a) are obtained, and then (2) these view factors are "collapsed" into the geometry implemented in the Vermont Yankee HC model which is shown in Figure 3.1-2(b). In Step One, the planar view factors, i.e., the various F_{ij}, where i=1 to 11 and j=1 to 11, where 11 represents the channel wall (Figure 3.1-2(a)), are computed for a given elevation utilizing the PWR Licensing Code HUXY (Reference 3.1) and the methodology described in that report. View factors between different elevations are set to zero for the sake of simplicity. By neglecting interplanar radiation, the heat removal from the hottest heat structure is slightly less than if such mechanism had been considered.

In Step Two, the radiation view factors previously computed for Heat Structures 1 to 11, Figure 3.1-2(a), are used to obtain the view factors for Heat Structures (A), (B), and (C), shown in Figure 3.1-2(b). This three heat structure arrangement has been chosen because it is the minimum number of heat structures which allows for some radiation heat transfer without having the hot rod radiate directly to the channel wall. The method used to collapse the view factors is a direct application of continuity and reciprocity relations. In the equations that follow, the letter "F" stands for the view factor and "A" for the radiation heat transfer area. The subscripts, as in F_{ij}, are either the letters A, B, C, or numbers 1 to 11, as in Figures 3.1-2(b) and (a), respectively.

The key relations for the three heat structure model are therefore:

1. $A_A F_{AB} = A_B F_{BA}$
2. $A_A F_{AC} = A_C F_{CA}$ } Reciprocity
3. $A_B F_{BC} = A_C F_{CB}$

4. $F_{AA} + F_{AB} + F_{AC} = 1.0$
5. $F_{BA} + F_{BB} + F_{BC} = 1.0$ } Continuity
6. $F_{CA} + F_{CB} + F_{CC} = 1.0$

Similarly, for the 11-heat structure model:

7. $F_{1010} + F_{1011} + \sum_{j=1}^{9} F_{10j} = 1.0$

8. $F_{1110} + \sum_{j=1}^{9} F_{11j} + F_{1111} = 1.0$

Now F_{1010}, F_{1011}, F_{1110}, and F_{1111} are known from Step One (HUXY).

By a simple comparison of Figures 3.1-2(a) and (b), it is evident that:

$F_{AA} = F_{1111}$

$F_{CA} = F_{1011}$

$F_{AC} = F_{1110}$

$F_{CC} = F_{1010}$

F_{CB} and F_{AB} are obtained by comparing Equations (6) and (7) and Equations (4) and (8), respectively.

Finally, Equations (1) and (2) are used to obtain F_{BA} and F_{BC}.

3.2 Boundary Conditions and Validation

The hydrodynamic boundary conditions used in the Vermont Yankee HC calculation are the inlet phasic velocities and outlet pressures as indicated by the use of time-dependent junctions (TJ) and time-dependent volumes (TV) in Figure 3.1-1. Furthermore, for the purpose of property donoring, the pressure, internal energy, and quality are specified at the bottom and top of the solution domain (Volumes 100, 160, 206, and 207 shown in Figure 3.1-1). These boundary conditions are read off tape from a previous Vermont Yankee NSSS calculation and utilized in the Vermont Yankee HC calculation.

In order to verify the methodology and the implementation of the Vermont Yankee HC model, the three Vermont Yankee NSSS calculations have been performed with the Vermont Yankee HC model, as described in this section. In all cases, excellent agreement was observed between Vermont Yankee HC and Vermont Yankee NSSS results, for clad temperatures, qualities and heat transfer coefficients for the high power region. This is shown in Figures 4.1-15 to 4.1-26, 4.2-15 to 4.2-26, and 5.0-17 to 5.0-27.

A comparison of Vermont Yankee HC hot and average clad temperatures in Figures 4.1-21 to 22, 4.2-21 to 22, and 5.0-23 to 24 showed a very small calculated impact of radiation heat transfer on rod temperatures. Both hot and average rods utilized the same nodal power factors (those of the NSSS high power region rod) in these calculations. The only difference was in the radiation view factors. The hot rods "saw" only the average rods, while the average rods "saw" both the hot rod and the channel wall. The Vermont Yankee HC hot rod temperatures matched the corresponding Vermont Yankee NSSS rod temperatures, and the average Vermont Yankee HC rods were slightly cooler, although the difference is insignificant. This was expected since Vermont Yankee NSSS rods did not account for radiation heat transfer, while the Vermont Yankee HC hot rod minimized it by radiating only to the average rod and not to the channel wall.

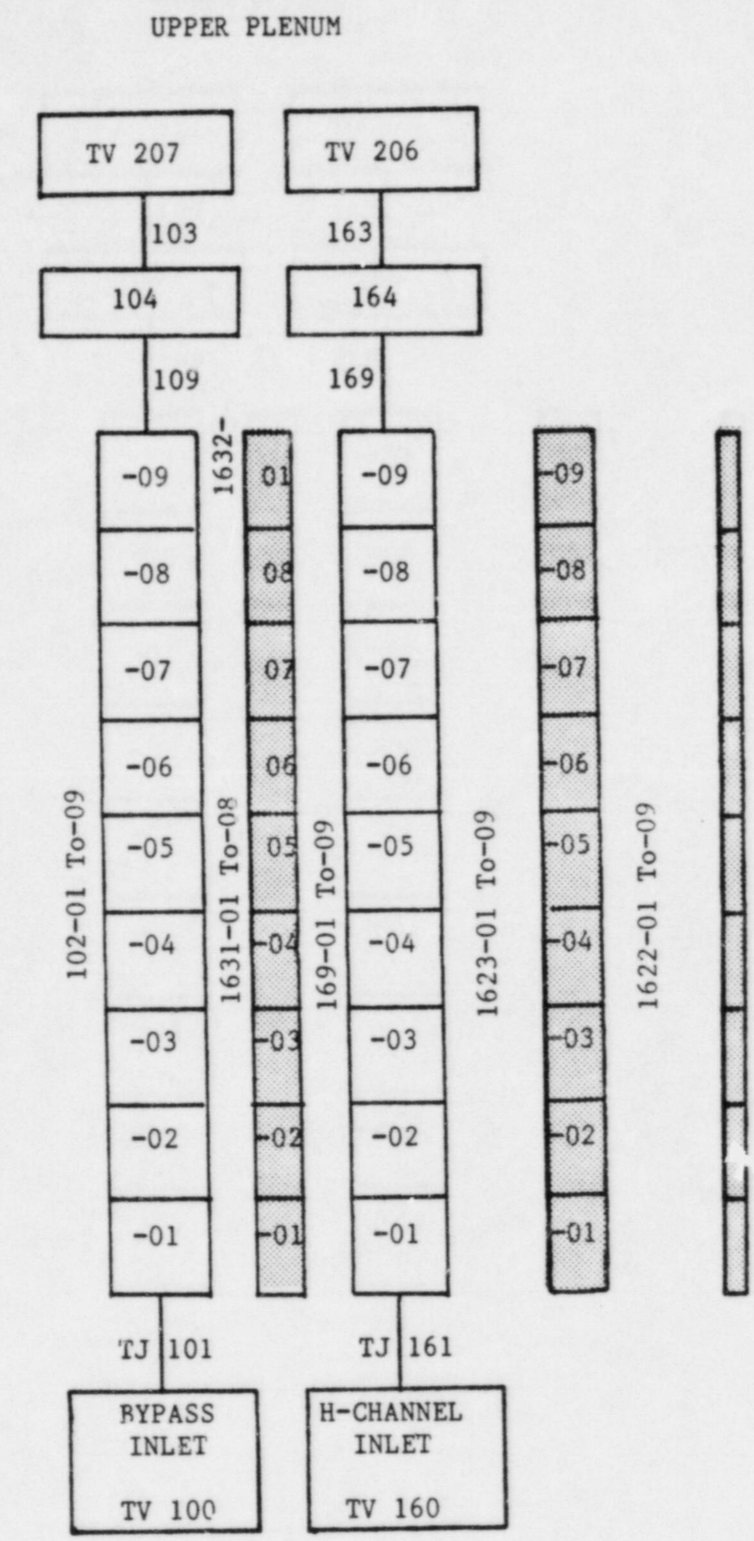

Figure 3.1-1: VY HC Axial Nodalization

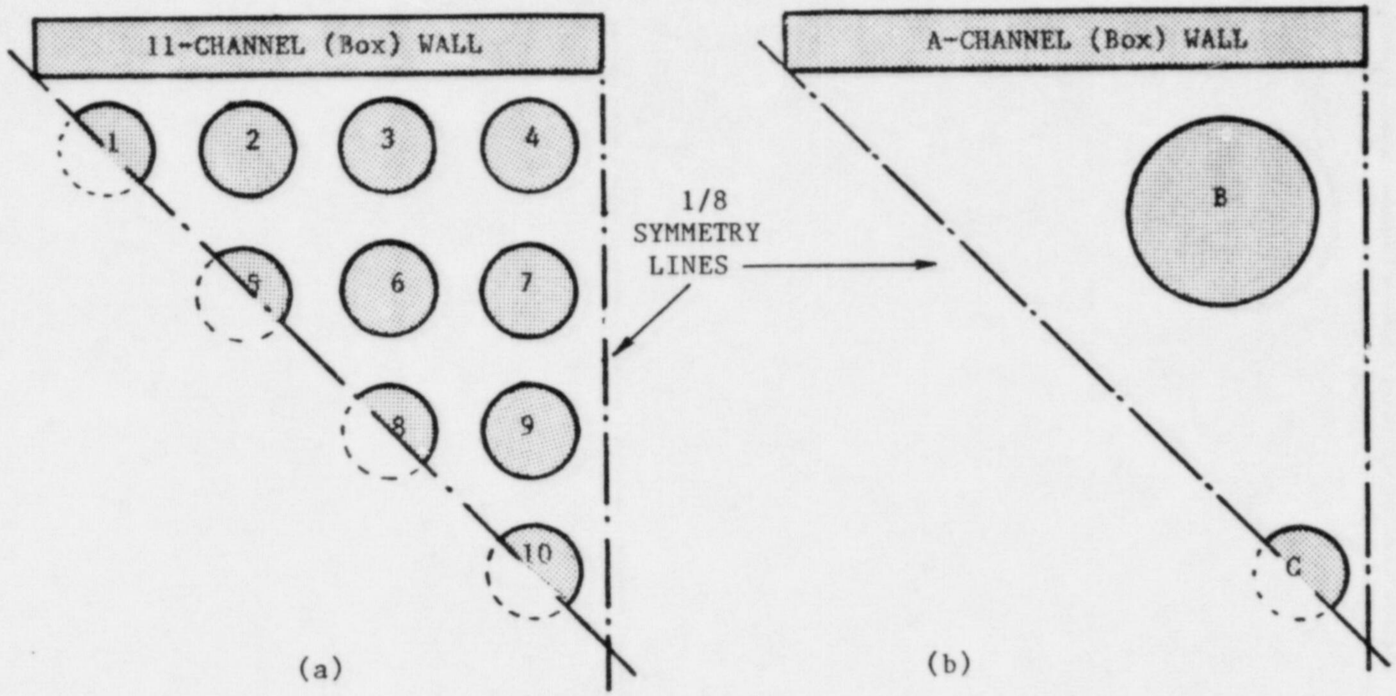

Figure 3.1-2: VY Rod Lay Out: (a) Number and Location of the Rods Represented, and (b) As Modeled

TABLE 3.1.1

Differences Between VY NSSS and VY HC Numbering Scheme for Heat Structures and Hydrodynamic Components

Region Description	(a) Heat Structure Number in VY NSSS	VY HC
Channel Wall		
- Elevation 01-08	1622 (001-008)	1631 (001-008)
- Elevation 09	1623 (001)	1632 (001)
Average Rod in Hot Assembly	1621 (001-009)	1621 (001-009)
Hot Rod in Hot Assembly	------------	1622 (001-009)

Region Description	(b) Hydrodynamic Component Number in VY NSSS	VY HC
Bottom of Bypass	100010000	101000000
Bottom of Hot Assembly	160020000	161000000
Upper Plenum		
- Above Bypass	206010000	104000000 207000000
- Above Hot Assembly	206010000	164000000 206010000

4.0 SAMPLE PROBLEMS 1 AND 2: LARGE RECIRCULATION LOOP BREAKS

This section presents licensing analysis results for a Double-Ended Guillotine (DEG) break in the discharge pipe of one recirculation loop. The accident assumptions are summarized in Table 4.0.1. The method used complies with 10CFR50.46 and Appendix K thereto. The major assumptions are that a DEG break occurs at time 4.0E-6 seconds with a coincident loss of normal auxiliary power. LPCI injection into the broken A loop is lost due to the proximity of the break location. LPCI injection into the B loop is lost due to the assumed failure of the LPCI-B injection valve to open on demand (Single Failure Criterion). Thus, HPCI and two LPCS Systems are available to mitigate the consequences of this accident.

Two cases are presented. Section 4.1 describes Base Case EA wherein decreasing power from the motor-generator sets that are coasting down is provided to the recirculation pump motors until pump trip signals arrive. Section 4.2 describes Sensitivity Case EB wherein the power to each recirculation pump motor terminates at the accident initiation time due to an additional assumed failure in each electrical system.

TABLE 4.0.1

Summary of Vermont Yankee Large Break Accident Assumptions

1. DEG recirculation discharge break ($2*3.624\ ft^2$) occurs at 4.0 E-6 seconds.

2. Loss of auxiliary power occurs at 4.0 E-6 seconds.

3. Reactor scrams after a 0.5-second delay from first RPS signal. Scram Curve 67B-EOC is used.

4. Feedwater coasts down to 0.0 lbm/sec at 5.0 seconds.

5. MSIVs close 10.0 seconds after isolation signal plus 0.5 second delay. Recirculation Loop A discharge valve fails open due to proximity of break location.

6. Recirculation pumps in A and B loops coast down with decreasing power from loss of MG sets.

7. ADS may actuate if appropriate signals exist. Thereafter, ADS cycles open/close at 12 psid between steam line and drywell anytime ADS criteria are currently met.

8. HPCI injects upon demand, and terminates on high RPV level or low steam line pressure (<90 psia).

9. No credit for RCIC operation.

10. Two LPCS Systems inject on demand.

11. LPCI-A pipe severs due to proximity of break location.

12. LPCI-B injection valve fails to open upon demand (single failure).

13. Drywell pressure and temperature are assumed constant at 16.4 psia and 212°F for fluid sink conditions. High drywell pressure is calculated to occur at 0.04 seconds for this case by containment model.

14. Wetwell pressure and temperature are assumed constant at 14.7 psia and 165°F for fluid source and sink conditions.

15. EM point reactor kinetics initially at 1664 MWth.

16. EM core heat transfer with XMNB = 0.5.

17. Passive heat structures are included.

18. Moody two-phase critical flow model is used at each break location.

19. 1971 ANS Decay Heat Standard plus 20%.

4.1 Sample Problem 1: Large Break Case EA

Table 4.1.1 summarizes the timing of significant events for this accident case. This table provides an aid to review the following figures that contain results. Figures 4.1-1 through 4.1-12 present Vermont Yankee NSSS results for the system response. Figures 4.1-13 through 4.1-20 present Vermont Yankee NSSS results for the core response. Figures 4.1-21 through 4.1-26 present Vermont Yankee hot channel results that show this model replicates the high power bundle results obtained from the Vermont Yankee NSSS model. A description of these results follows.

Figures 4.1-1 and 4.1-2 show the reactor power and net reactivity following the accident. The reactor power begins to decrease due to negative reactivity from core voiding. Reactor scram occurs on a high drywell pressure signal at 0.55 seconds, and the control rods are fully inserted by 4.22 seconds. Beyond this time, core power follows the Appendix K decay heat values (1.2 times 1971 ANS Decay Heat Standard).

Figure 4.1-3 shows the early feedwater and main steam line flow histories. The loss of auxiliary power to the condensate and feedwater pumps causes the feedwater flow to coastdown in 5.0 seconds. The steam line flow initially drops due to decreases in the feedwater flow, core power, and steam dome pressure. However, the high drywell pressure signal, sensed on the LPCS instruments, causes a generator and turbine trip followed by opening of the turbine bypass valves at 1.16 seconds. The MSIVs begin to close on an RPS MG set underfrequency condition at 3.52 seconds and are fully closed by 13.52 seconds (the slowest achievable closure rate). This terminates all main steam line flow to the turbine bypass valves.

Figure 4.1-4 shows the narrow-range water level measured with respect to the top of the enriched fuel (351.5 inches above the RPV invert). The level generally declines and reaches the low-low level (82.5 inches) setpoint at 13.3 seconds. Three short-term rises occur. The first level swell occurs shortly after the turbine bypass valves open at 1.16 seconds. The second level swell starts at the onset of lower plenum flashing at about

5.0 seconds. The third mild swell between 9 and 13 seconds occurs as the vessel fluid redistributes when the MSIVs are reaching full closure. The narrow-range level remains off-scale low thereafter.

Figure 4.1-5 shows the early upstream (Junction 801) and downstream (Junction 802) break flow rates. These flows rapidly accelerate to two-phase critical flow (Moody model) in less than 0.1 second. Rapid depressurization, flashing, and upstream internal choking limit the initial peak flow rates. The downstream peak flow rate is larger than the upstream peak since it is fed by a larger area (Junction 335, 3.528 ft^2 versus Junction 326, 1.667 ft^2). The peak flow rates quickly decrease as their respective upstream volumes rapidly void (95% at 0.6 second). The downstream break subsequently decreases to a lower flow rate when the broken loop jet pump drive nozzles (Junction 340-1, 0.53 ft^2) choke. Figure 4.1-6 shows the long-term break flow histories. These continue to decline to low values as the vessel pressure declines. Beyond 206 seconds, occasional oscillations occur in the downstream break flow rate when the system has reached lower pressures. This anomalous behavior was caused by the Moody model occasionally dropping the break volume pressure below the containment backpressure and an improper specification of the containment conditions (16.4 psia, 212.0^{o}F). Thus, the break flow would occasionally reverse and draw subcooled water rather than steam from the containment TMDPVOL. This will be eliminated in the future by specifying saturated steam in the TMDPVOL. However, this anomaly had no significant impact since the core was well cooled beyond 190 seconds.

Figure 4.1-7 shows the steam dome pressure history throughout this accident. The initially rapid depressurization is temporarily arrested at 13.5 seconds when the MSIVs close. The vessel subsequently depressurizes to 315 psia (low pressure permissive for ECC injection valves to open) at 59.6 seconds, and to 90 psia (HPCI shutoff) at 95.2 seconds. The vessel pressure is 33.0 psia and decreasing very slowly at 300 seconds.

Figure 4.1-8 shows the ECCS flow rates. The HPCI System begins injecting coolant at 20.4 seconds, and terminates due to low turbine pressure at 95.2 seconds. The two low pressure core spray systems commence injecting coolant at 68.2 seconds about 8 seconds after the low pressure permissive signal occurs to open the injection valve. The occasional zero flow spikes appear to result from very short pressure spikes, calculated in the upper plenum pressure, that temporarily halt LPCS flow. However, these pressure spikes are less than a 0.2-second duration since they do not appear in the plot file.

Figure 4.1-9 shows the net flow rate into the NSSS. Large negative values prior to 0.6 second have been suppressed to enhance the ordinate scale for this accident. Note that the net inflow becomes positive shortly after LPCS injection begins at 68.2 seconds. The oscillations after 206 seconds are caused by the anomalous break flow rate. Figure 4.1-10 shows the fluid mass within the NSSS. The minimum value occurs shortly after LPCS injection begins at 68.2 seconds. The anomalous break flow rates beyond 206 seconds have an insignificant impact on the NSSS fluid inventory. The curve shows that by 300 seconds the primary system has regained 142,769 lbm from the minimum inventory of 90,213 lbm.

Figures 4.1-11 and 4.1-12 show the fluid mass histories for the upper plenum, bypass, lower plenum, and Control Rod Guide Tube (CRGT) regions that surround the core. Flashing in the lower plenum and CRGT regions at five seconds expels fluid through the broken loop jet pumps and core. This expulsion through the core causes a temporary increase in the upper plenum mass until 13.2 seconds. The liquid subsequently drains back through the bypass and core to the lower vessel regions. LPCS injection into the upper plenum begins at 68.2 seconds. The emergency coolant preferentially drains through the bypass and peripheral low power regions against updrafting vapor. The drainage behavior is quite similar to results from the CCFL/Refill System Effects Tests conducted in the large 30 degree sector Lynn Facility (Section 2.3.3, Reference 4-1). By 97.5 seconds, sufficient hydrostatic head has developed in the bypass region to increase the drainage rate to the lower plenum and CRGT regions. Beyond 126 seconds, the bypass and upper plenum regions refill in an oscillatory manner, i.e., cycles of liquid accumulation and drainage, due to the interaction of relatively cold ECC with hot steam. Likewise, the lower plenum and CRGT regions begin refilling beyond 96 seconds.

Figures 4.1-13 and 4.1-14 show the fluid mass histories for the three core fuel assembly regions. The early peaks between 4 and 37 seconds are due to fluid flashing in the lower core and vessel regions, and drainage from the upper plenum (through the upper tie plates) and bypass region (through the drilled holes in the fuel supports). These fluid masses drain to the lower plenum until after LPCS injection begins at 68.2 seconds. Subsequently, the peripheral low power region refills more readily than the central average and high power regions. All three regions have regained significant fluid inventories by 180 seconds.

Figures 4.1-15 and 4.1-16 show the outer clad surface temperatures and static qualities at four elevations in the high power assemblies. The four high power assemblies remain well cooled during the first 13 seconds due to positive core flow induced by rundown of the intact loop recirculation pump and lower plenum fluid flashing. CHF occurs at 13.1 seconds and a rapid heatup occurs as the bundles dry out. The early heatup is temporarily arrested between 22 and 37 seconds as a two-phase mixture flows back into these assemblies from the bypass region. The conservative heat transfer assumptions per Appendix K did not allow the rods to quench as might be expected from TLTA Test 6424 Run 1 (Pages K-78 through K-88, Reference 4-2). Subsequently, these assemblies dry out and heat up to a maximum of 1065.2^{o}F (1066.6^{o}F inner peak clad temperature) at the 81-inch elevation at 82.6 seconds. Liquid enters from the bypass region through the drilled holes in the fuel support piece to arrest the second heatup. Thereafter, these assemblies gradually cool down and are essentially quenched by 190 seconds. The last elevation to quench is located at 89 inches above the bottom of the fuel.

Figures 4.1-17 and 4.1-18 show the corresponding heat transfer coefficients for the high power assemblies. These figures show the transition to low post-CHF heat transfer at 13 seconds down to values as low as 0.0028 Btu/sec ft^{2} ^{o}F (10 Btu/hr ft^{2} ^{o}F) at 82 seconds and generally rising values thereafter. These post-CHF heat transfer values form a lower bound on those determined from TLTA Test 6423 Run 3 (Peak Power, Low Rate/High Temperature ECC) given in Figure 3-86 of Reference 4-3.

Figures 4.1-19 and 4.1-20 show outer clad surface temperature and heat transfer coefficients calculated for each core region at the 81-inch elevation. The low power assemblies encounter CHF later at 38 seconds compared to the central assemblies that reach CHF at 13 seconds. Otherwise, the temperatures are similar and reflect the relative power in each type of assembly.

Figures 4.1-21 through 4.1-26 show results from the corresponding Vermont Yankee hot channel model for this accident case. These results show that the Vermont Yankee HC model replicates the Vermont Yankee NSSS results for the high power assemblies as discussed in Section 3.2.

TABLE 4.1.1

Sequence of Events for Large Break Case EA

	Event	Time (seconds)
1.	Break opens	4.0E-6
2.	Loss of normal auxiliary power	4.0E-6
3.	High drywell pressure (p >2.5 psig)	0.048
4.	Turbine stop valve starts to close (and is completely closed in 0.1 second)	0.45
5.	Reactor scram on high drywell pressure	0.55
6.	Initiate turbine bypass valve opening	0.56
7.	Turbine bypass valve completely open	1.16
8.	Low level signal (127 inches) occurs	2.96
9.	RPS MG set underfrequency (57 Hz) condition occurs	3.01
10.	MSIVs begin to close on RPS underfrequency	3.52
11.	Control rods are fully inserted	4.22
12.	Feedwater flow coasts down to zero	5.0
13.	Lower plenum flashing begins	5.0
14.	Earliest nodal critical heat flux	13.10
15.	Low low level signal (82.5 inches) occurs	13.38
16.	MSIVs are completely closed	13.52
17.	Recirculation pumps trip on underfrequency due to loss of auxiliary power	17.00
18.	HPCI injection begins	20.40
19.	Recirculation Loop B (intact) discharge valve begins to close	59.62
20.	LPCS injection begins	68.20

TABLE 4.1.1
(Continued)

Sequence of Events for Large Break Case EA

	Event	Time (seconds)
21.	Minimum Primary System inventory (90,213 lb) occurs	74.60
22.	Peak clad temperature occurs (inner 1066.6°F, outer 1065.8°F)	82.60
23.	Recirculation Loop B discharge valve closed	92.61
24.	HPCI flow terminated on low pressure signal	95.20
25.	Core, including high power bundle, is well cooled	190.00

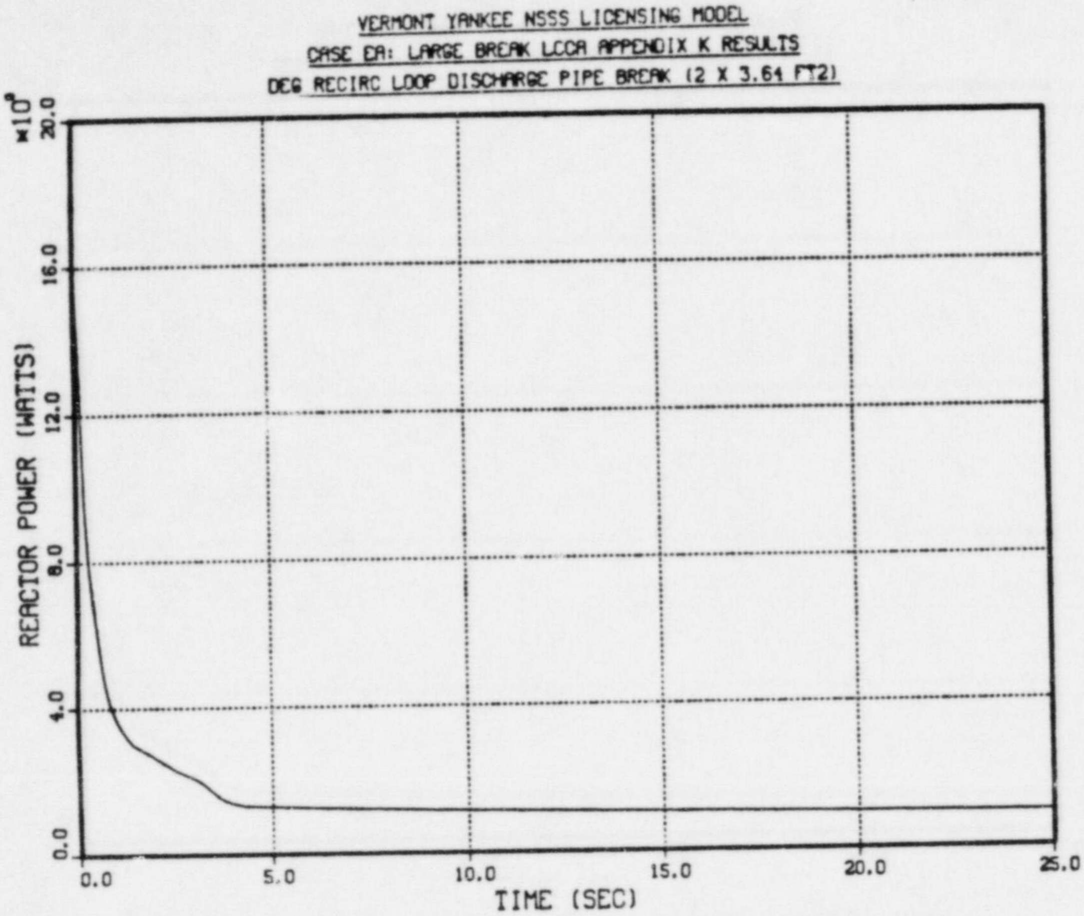

Figure 4.1-1: Reactor Power History (LBLOCA-EA)

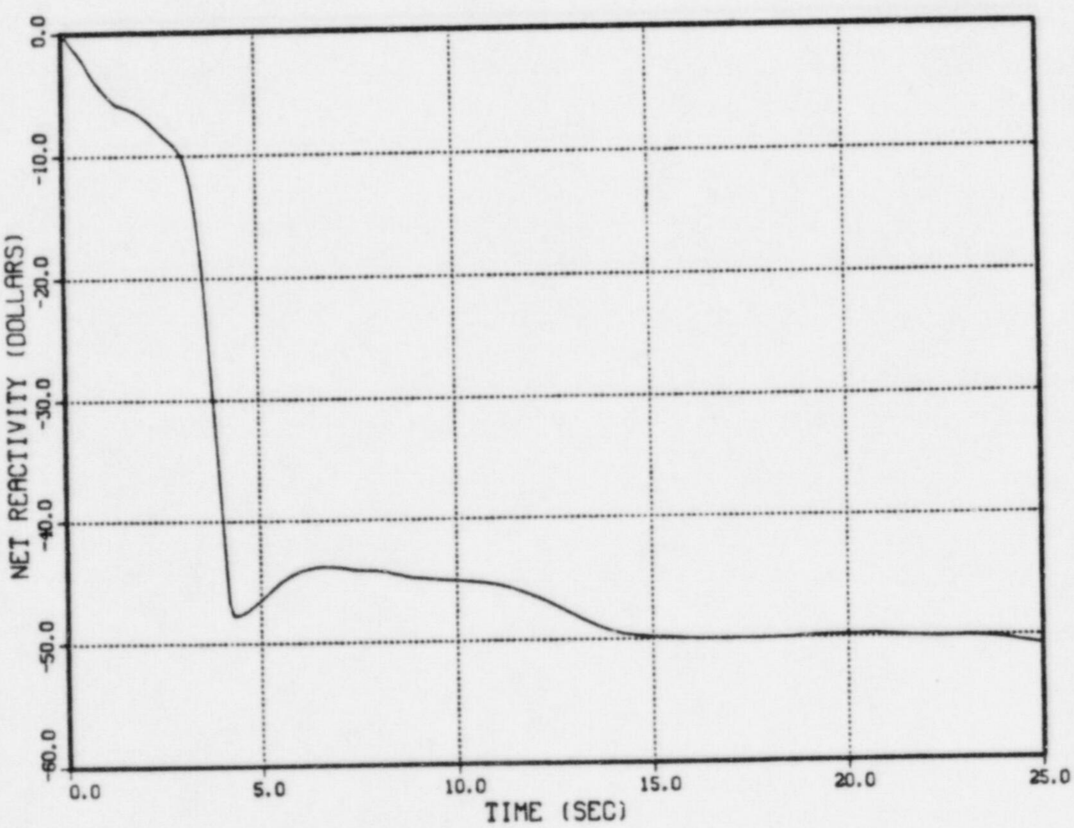

Figure 4.1-2: Net Reactivity (LBLOCA-EA)

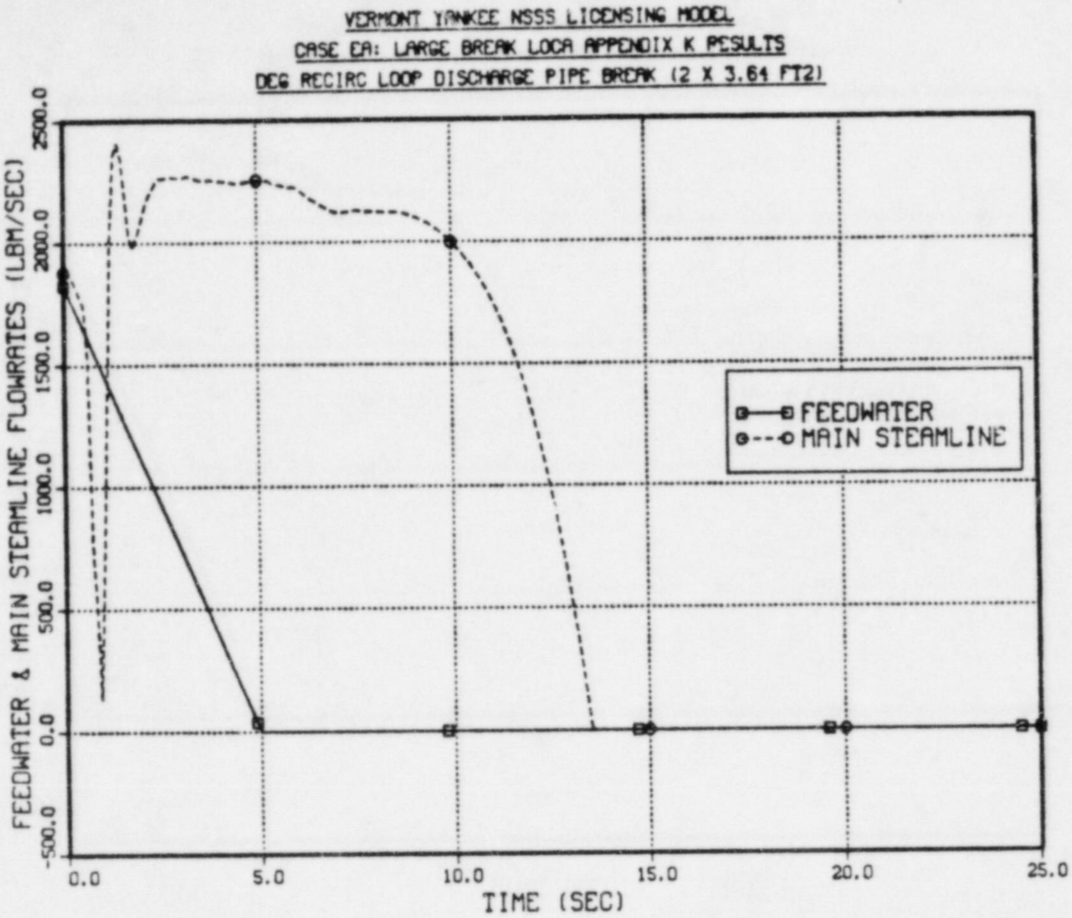

Figure 4.1-3: Feed and Main Steam Flows (LBLOCA-EA)

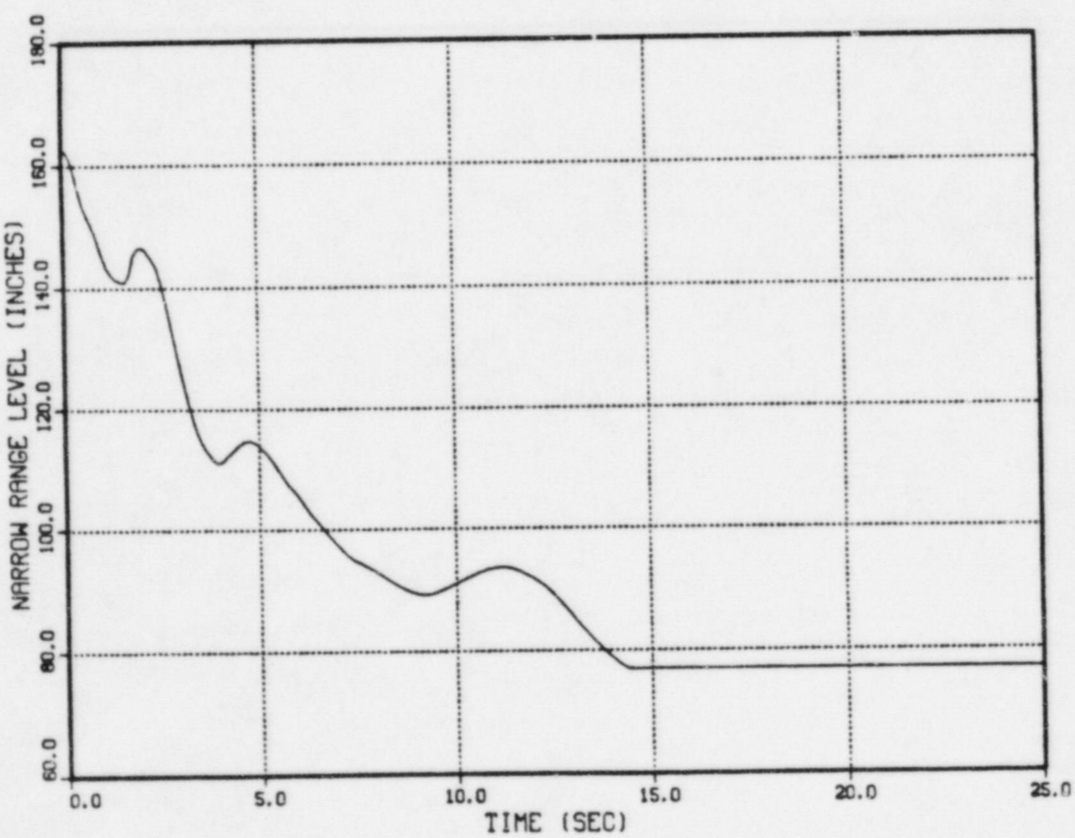

Figure 4.1-4: Vessel Water Level (LBLOCA-EA)

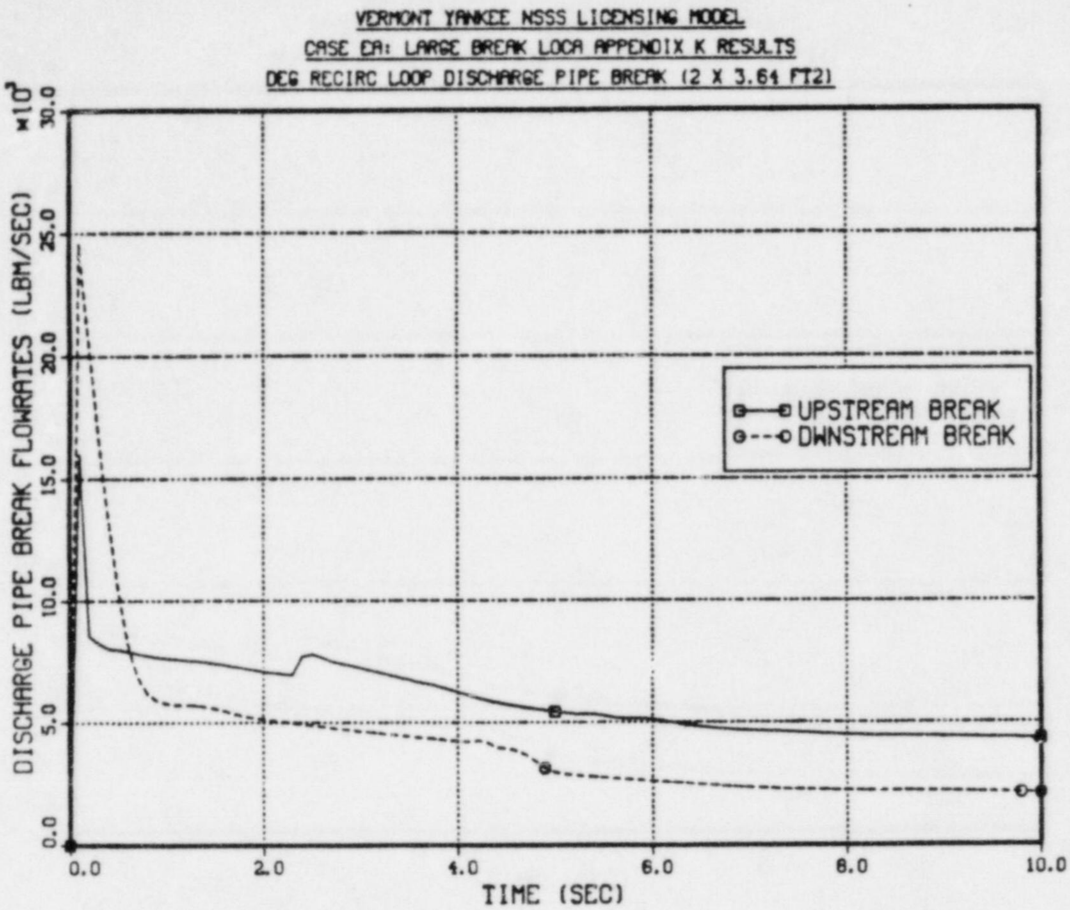

Figure 4.1-5: Early Break Flowrates (LBLOCA-EA)

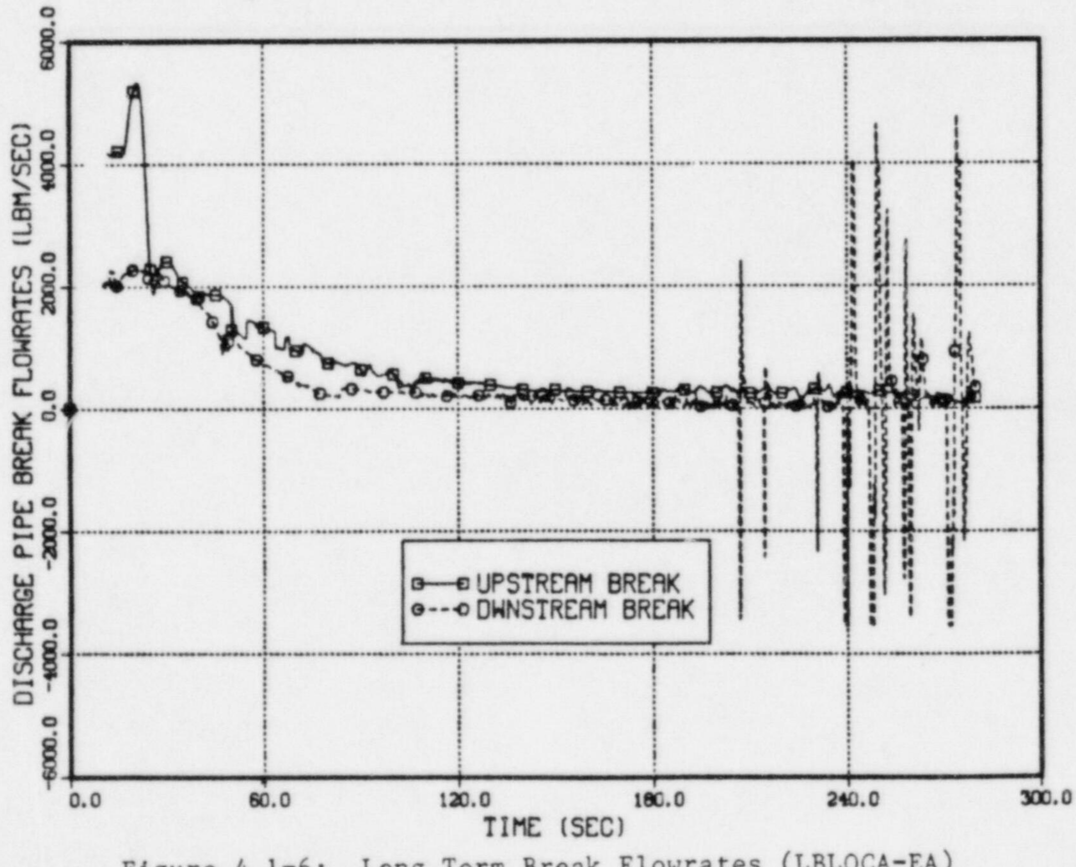

Figure 4.1-6: Long Term Break Flowrates (LBLOCA-EA)

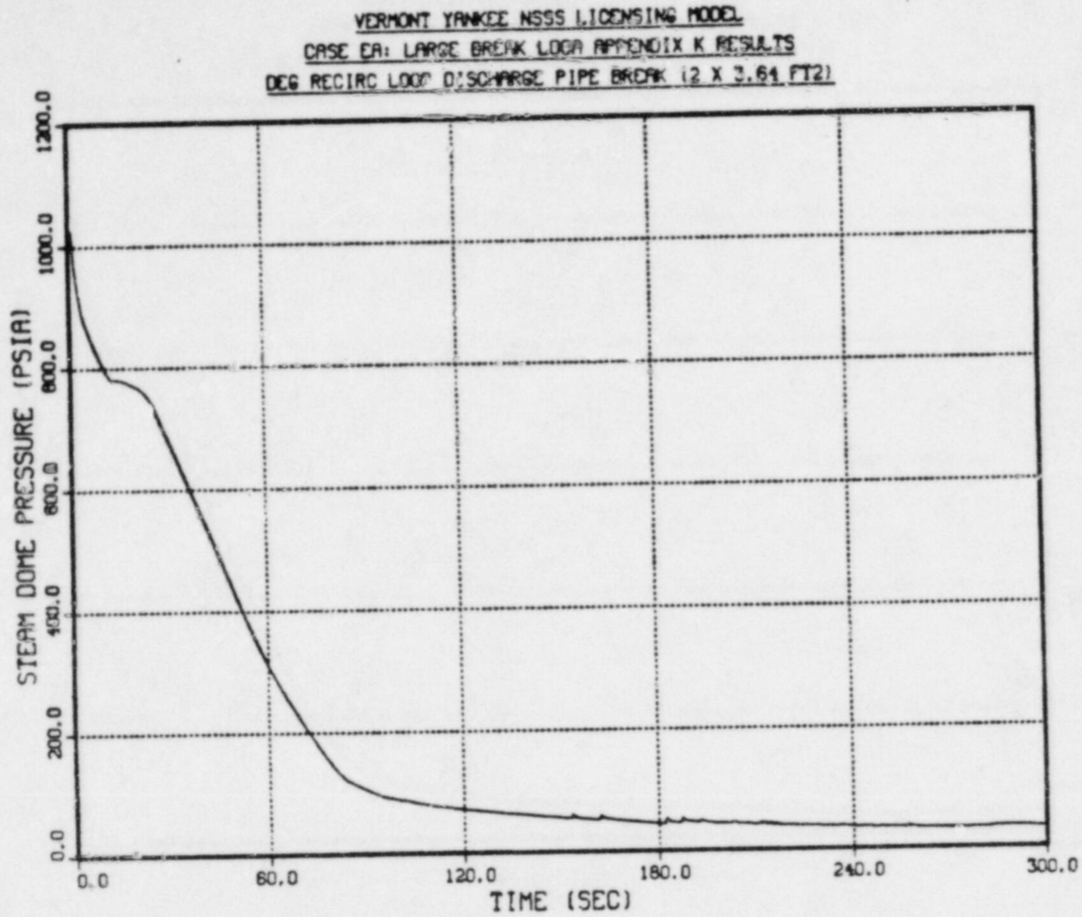

Figure 4.1-7: Vessel Pressure History (LBLOCA-EA)

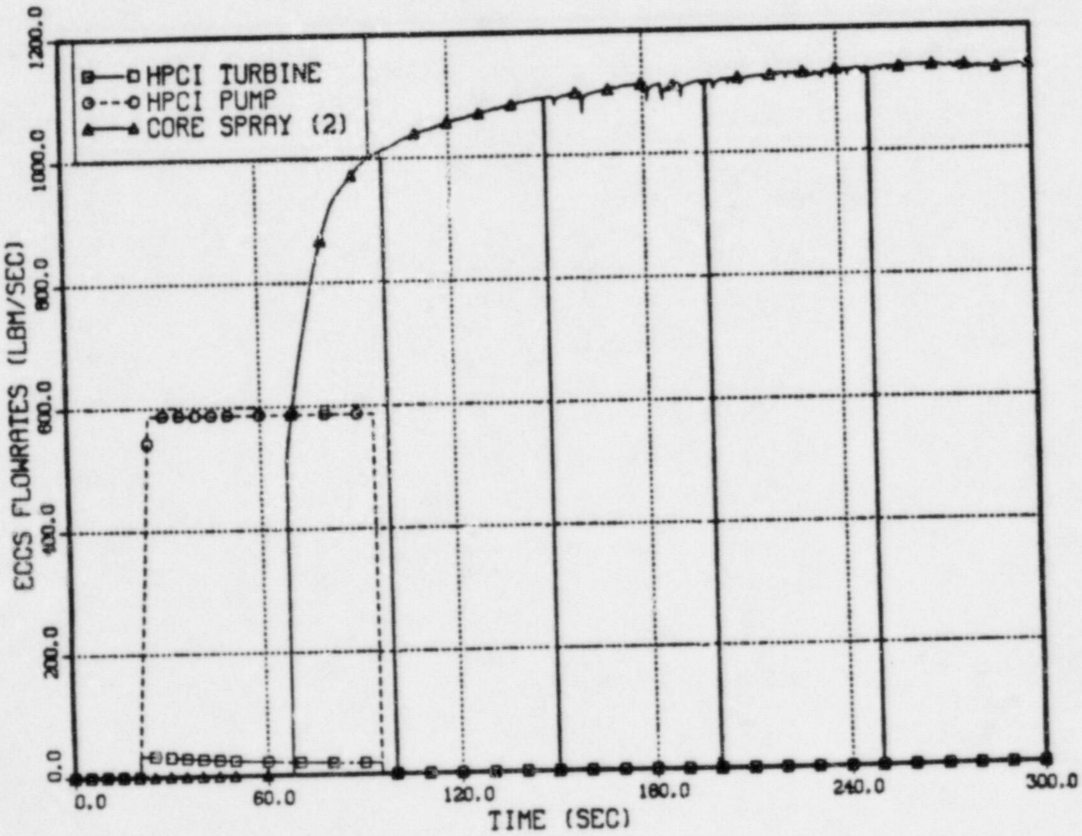

Figure 4.1-8: ECCS Flowrates (LBLOCA-EA)

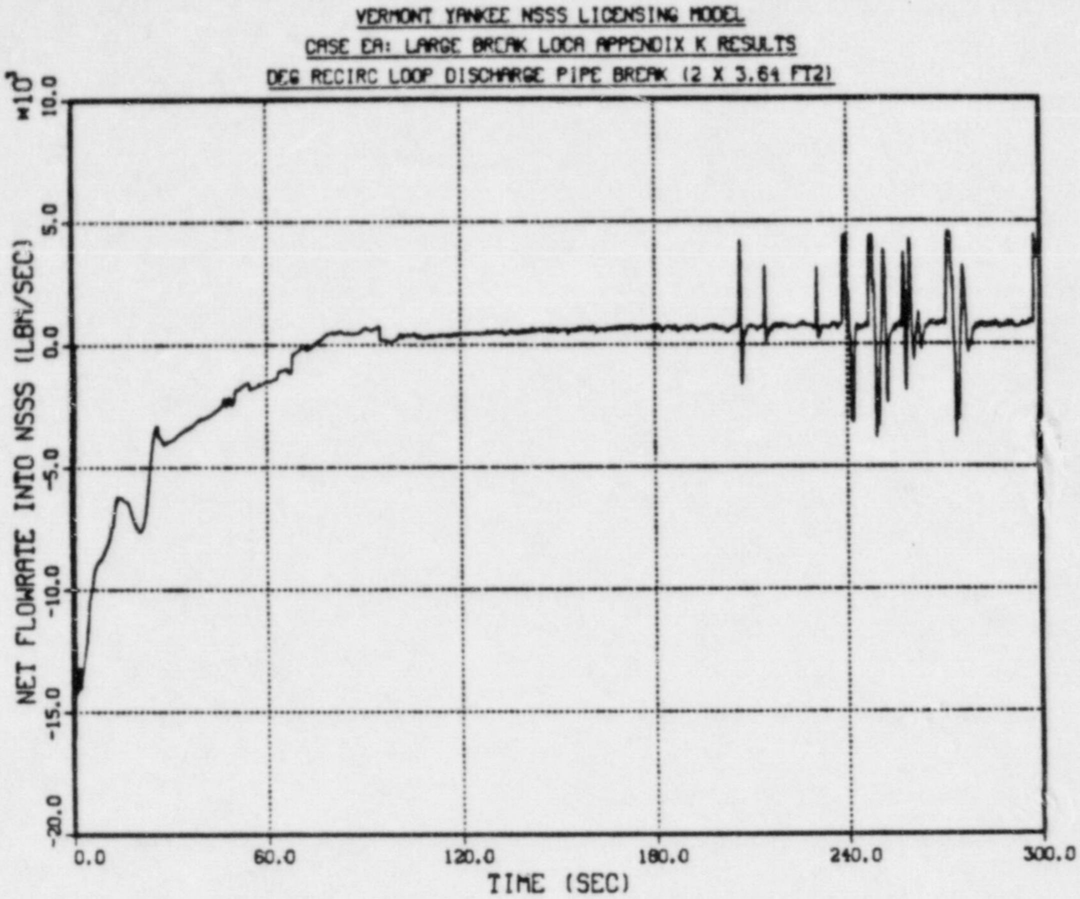

Figure 4.1-9: Net Flowrate into NSSS (LBLOCA-EA)

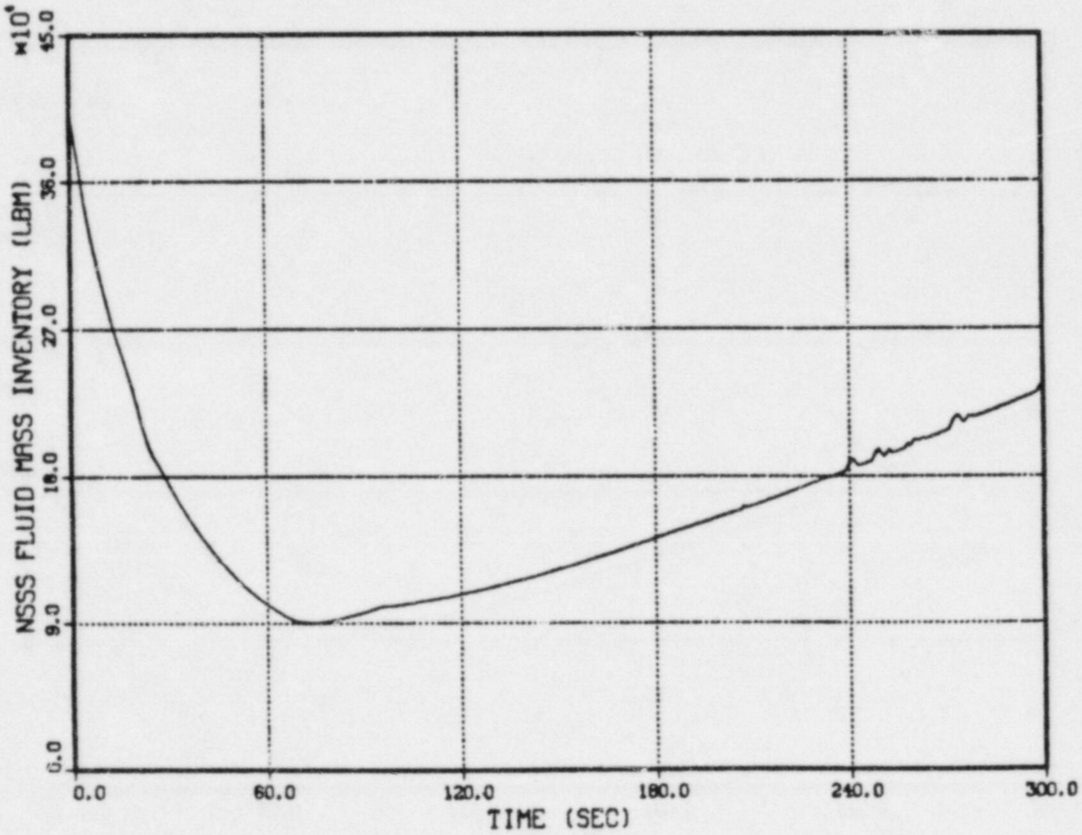

Figure 4.1-10: NSSS Fluid Mass Inventory (LBLOCA-EA)

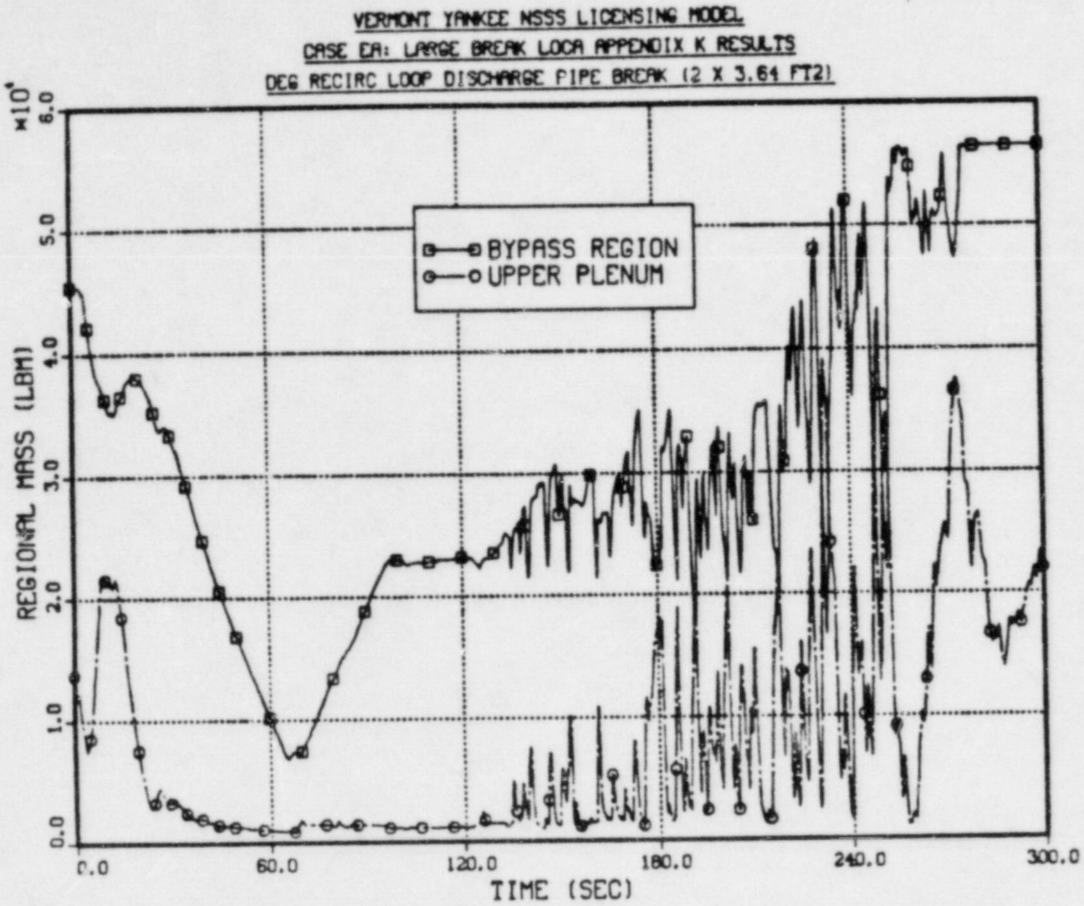

Figure 4.1-11: Bypass and Upper Plenum Fluid Mass (LBLOCA-EA)

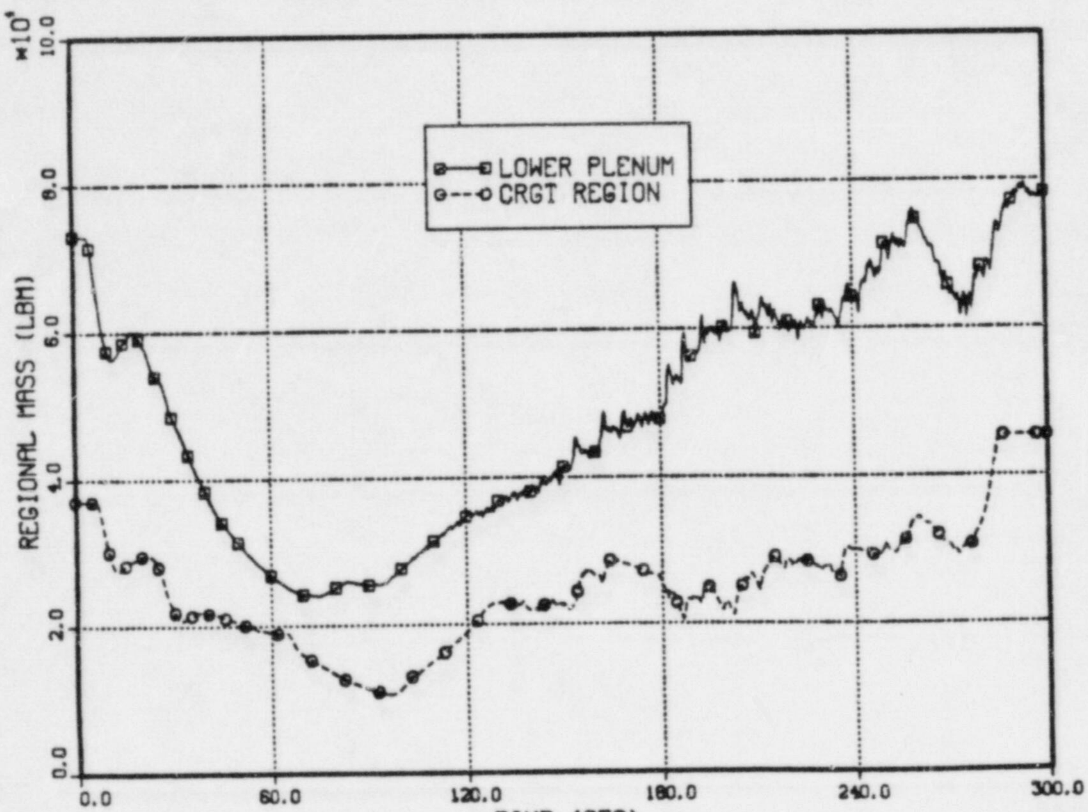

Figure 4.1-12: CRGT and Lower Plenum Fluid Mass (LBLOCA-EA)

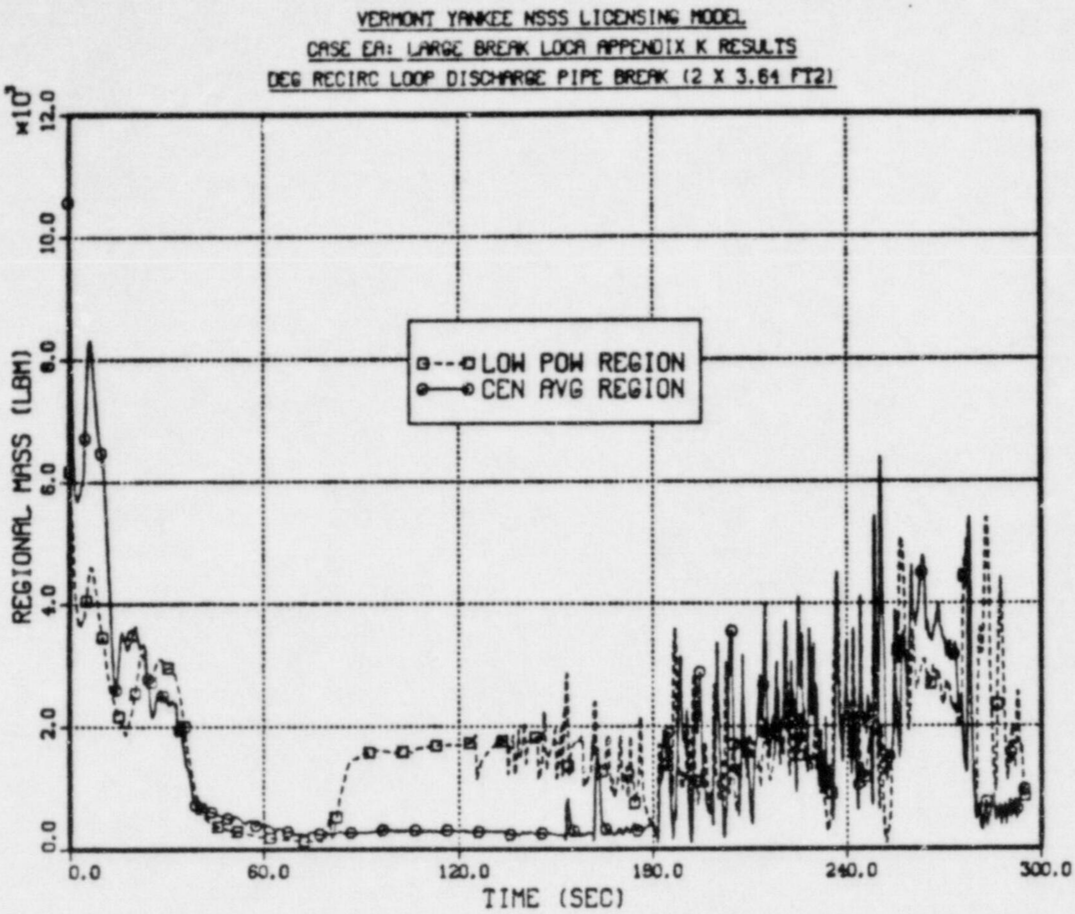

Figure 4.1-13: Outer and Central Core Fluid Mass (LBLOCA-EA)

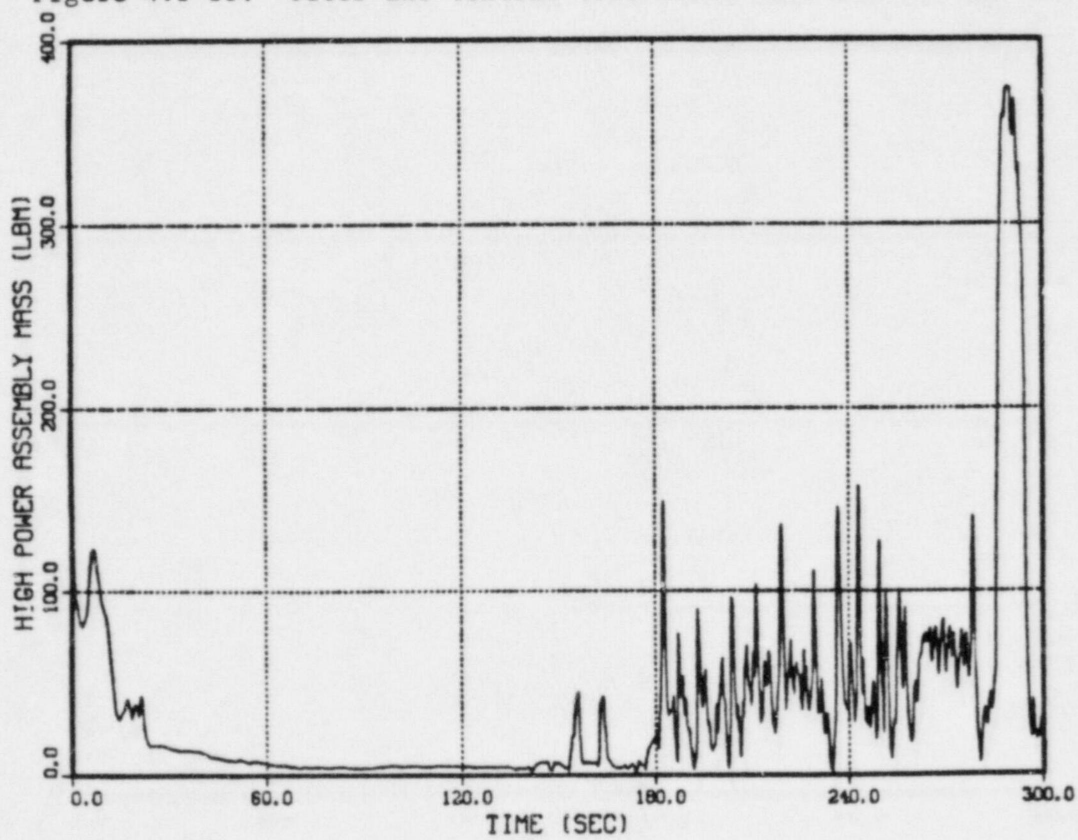

Figure 4.1-14: High Power Assembly Fluid Mass (LBLOCA-EA)

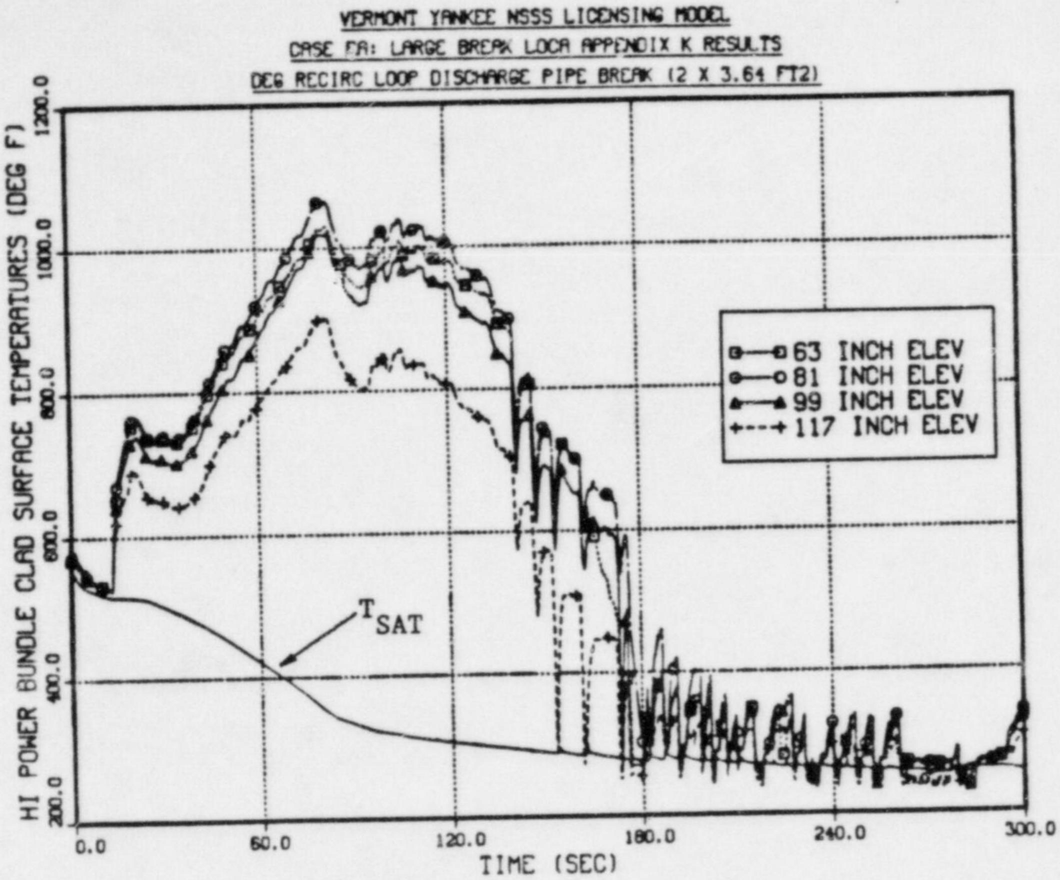

Figure 4.1-15: High Power Bundle Clad Temperatures (LBLOCA-EA)

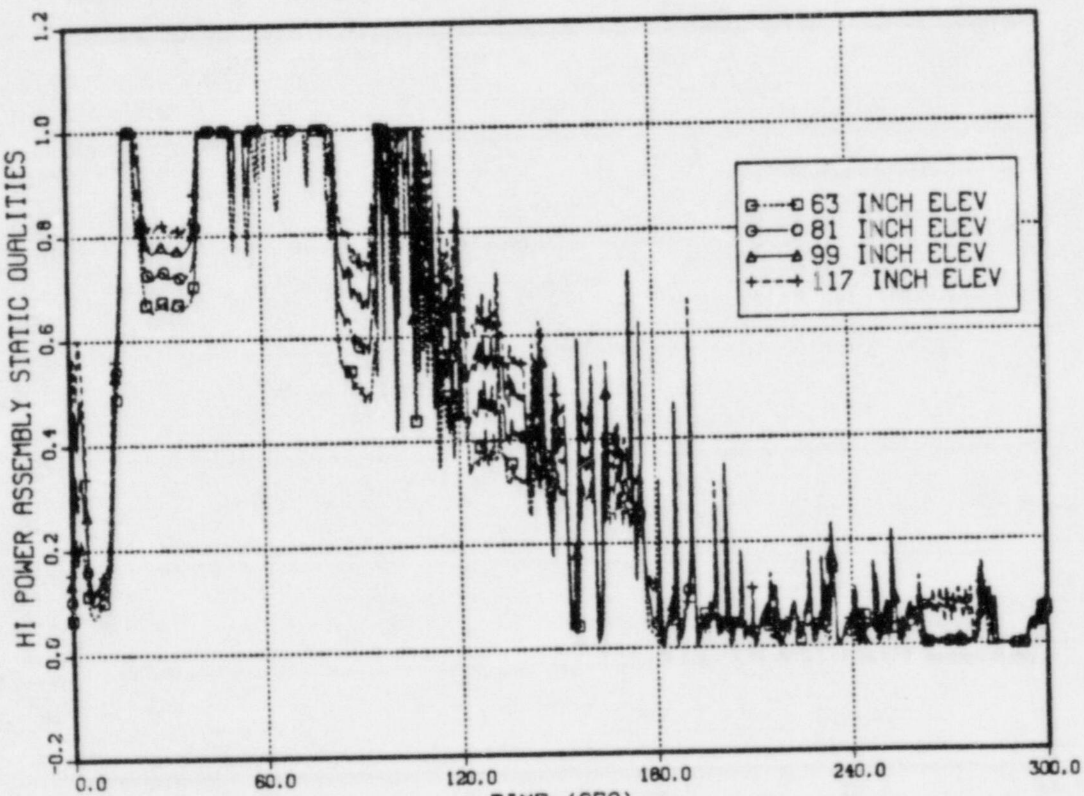

Figure 4.1-16: High Power Bundle Qualities (LBLOCA-EA)

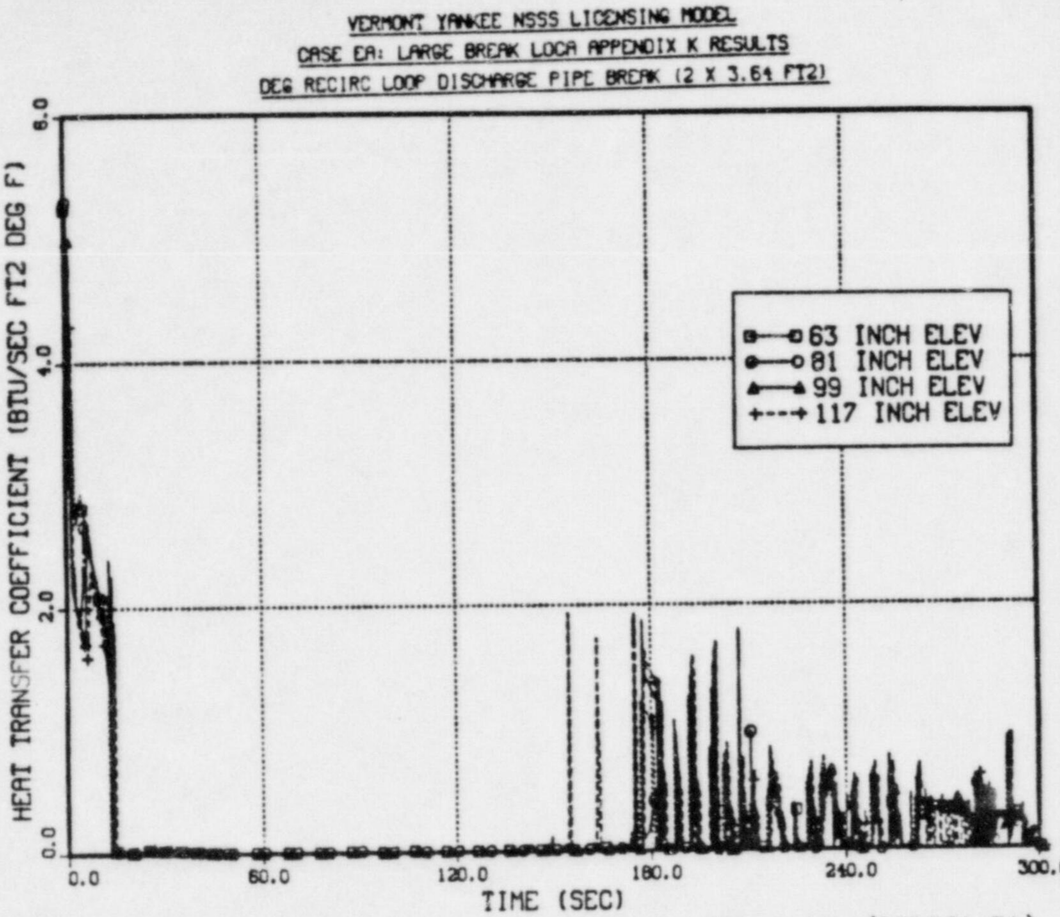

Figure 4.1-17: Long Term Heat Transfer Coefficients (LBLOCA-EA)

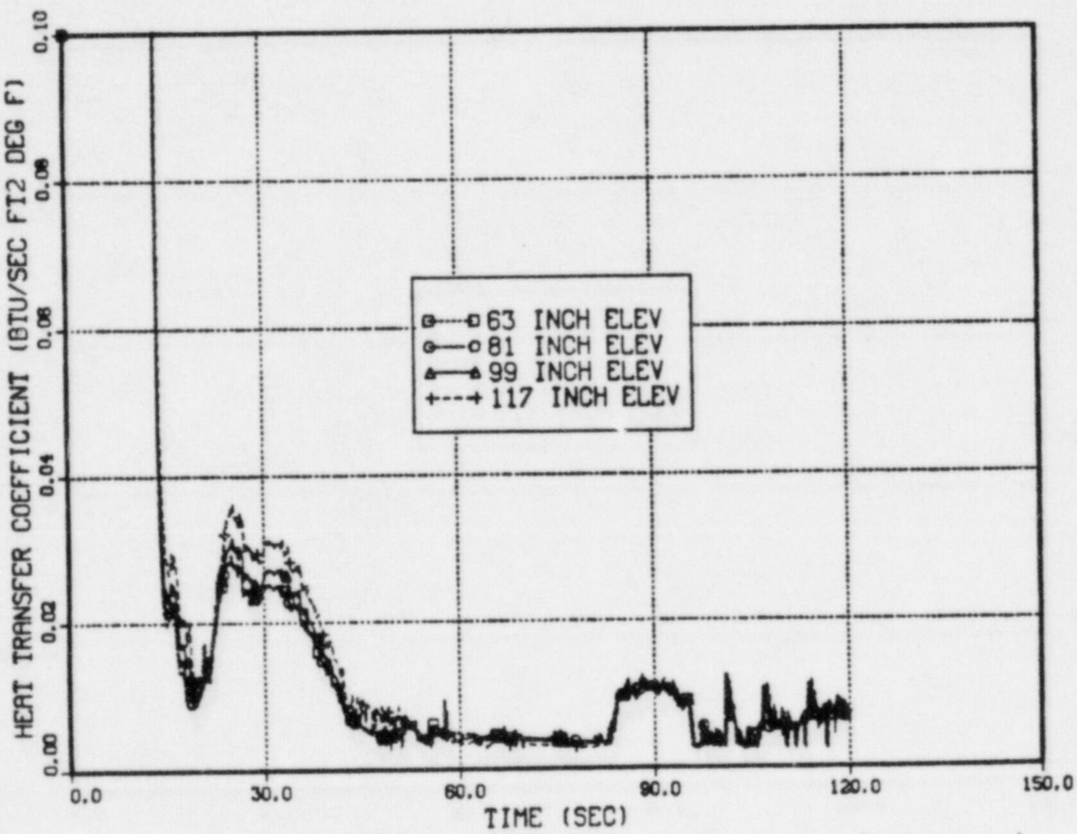

Figure 4.1-18: Degraded Heat Transfer Coefficients (LBLOCA-EA)

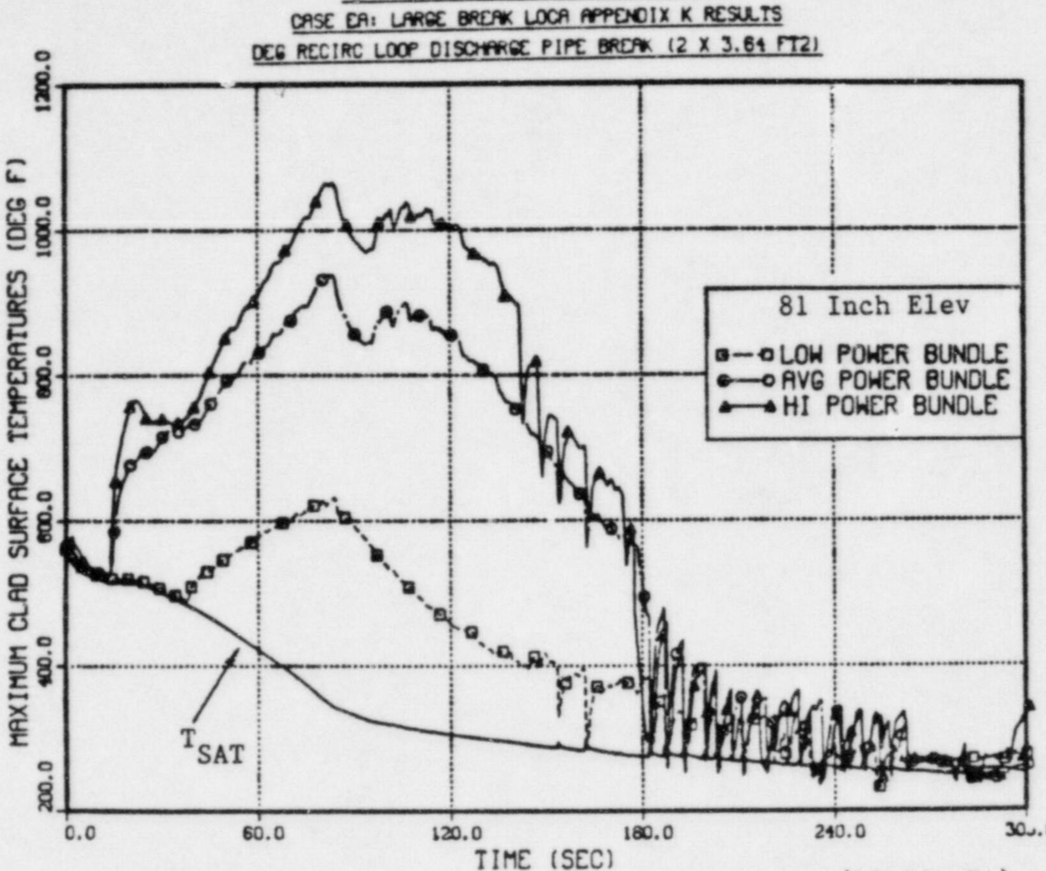

Figure 4.1-19: Maximum Bundle Clad Temperatures (LBLOCA-EA)

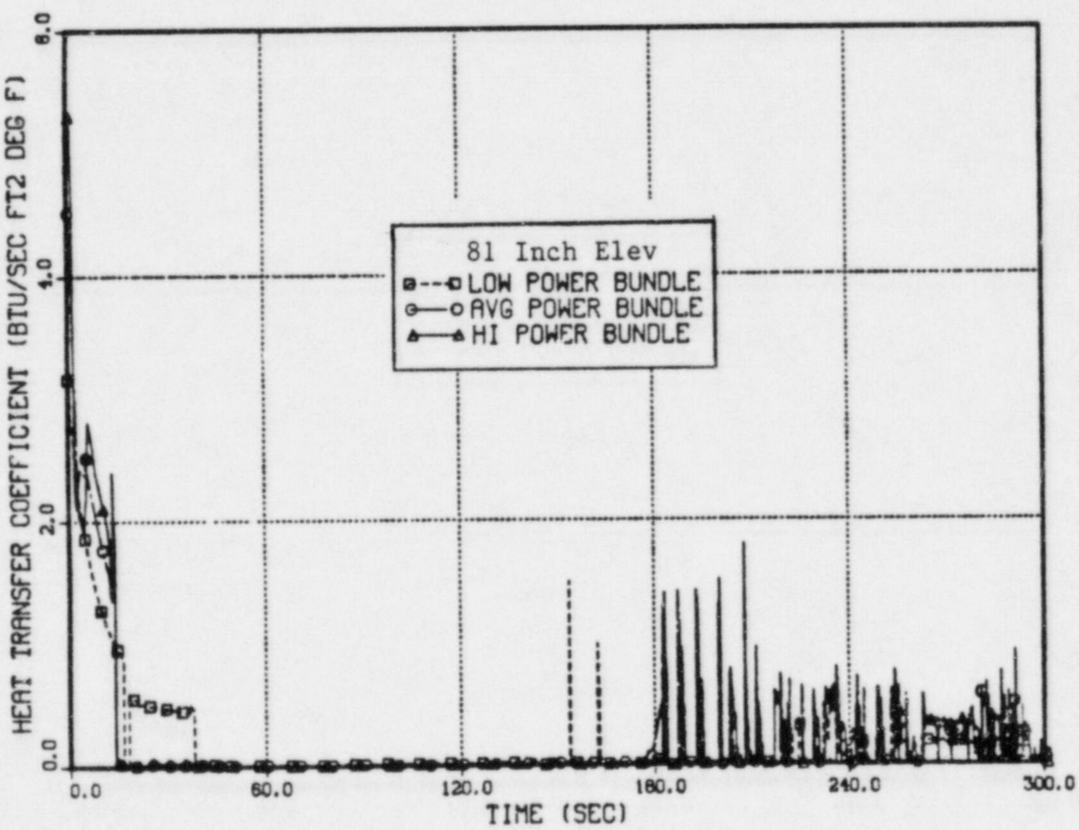

Figure 4.1-20: Bundle Heat Transfer Coefficients (LBLOCA-EA)

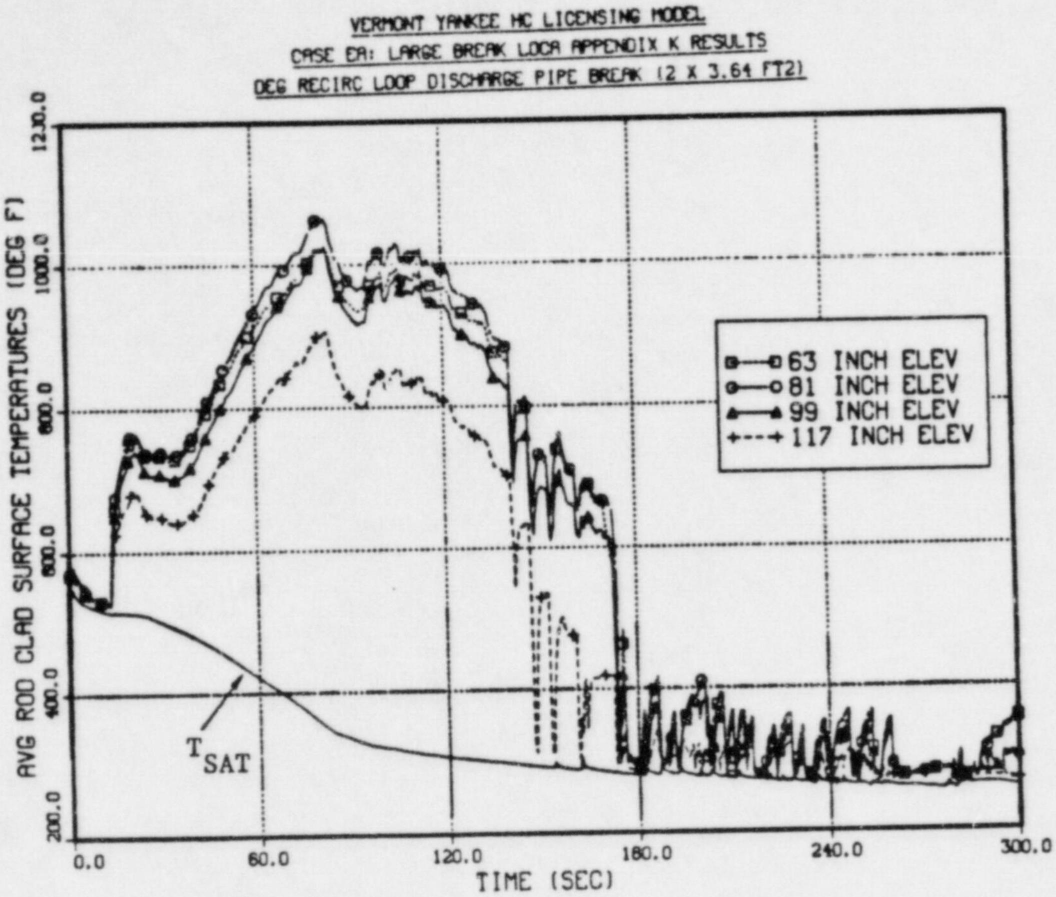

Figure 4.1-21: VY-HC Avg Rod Clad Temperatures (LBLOCA-EA)

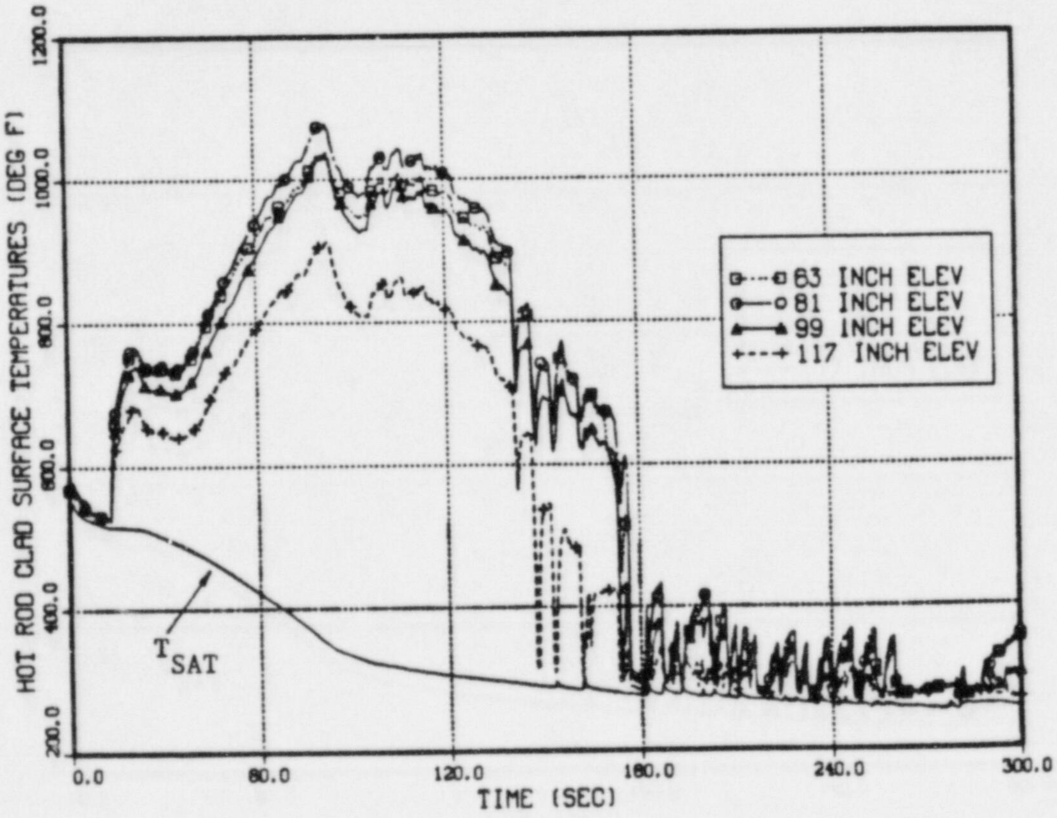

Figure 4.1-22: VY-HC Hot Rod Clad Temperatures (LBLOCA-EA)

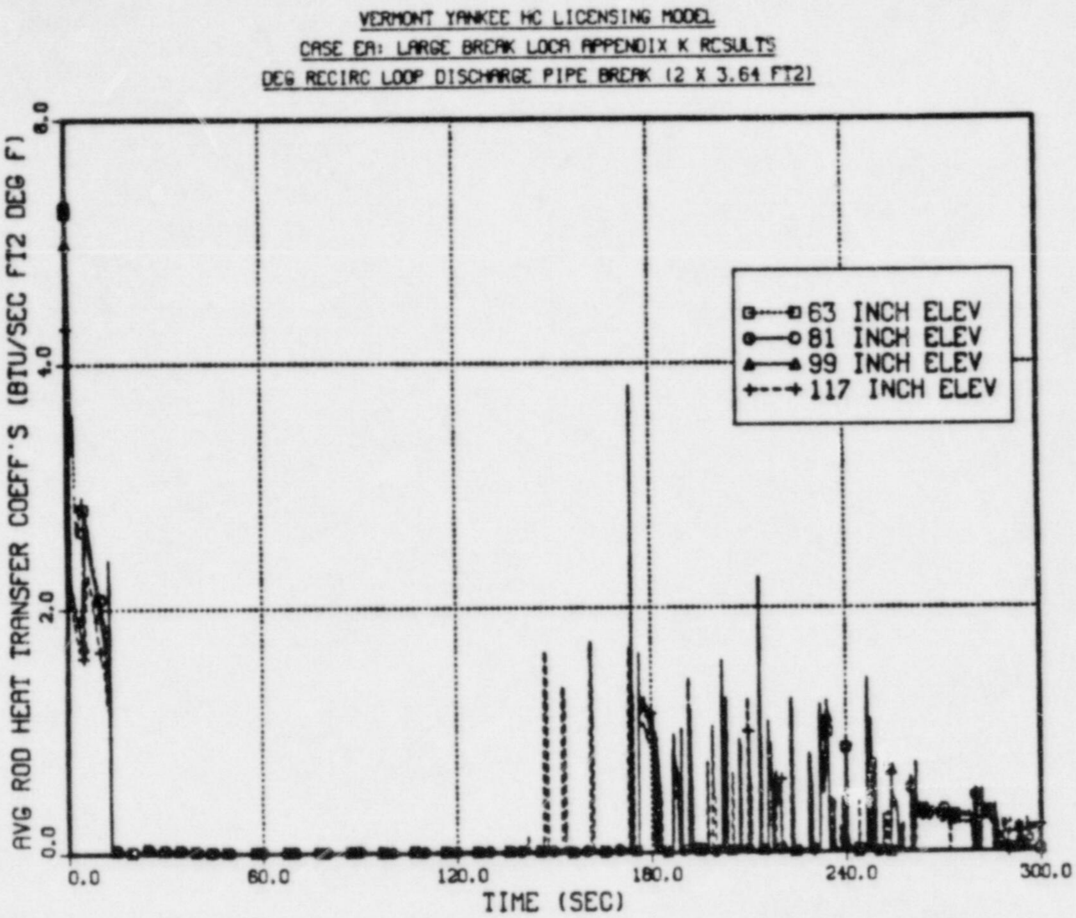

Figure 4.1-23: VY-HC Avg. Rod Heat Transfer Coefs (LBLOCA-EA)

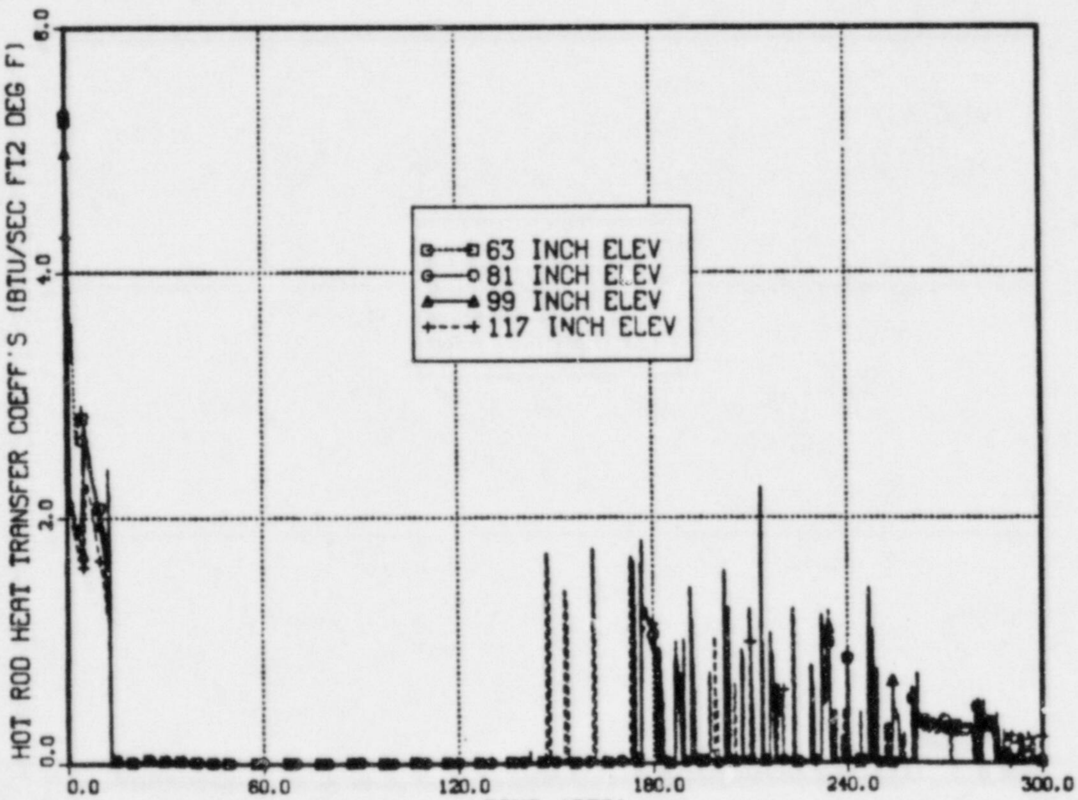

Figure 4.1-24: VY-HC Hot Rod Heat Transfer Coefs (LBLOCA-EA)

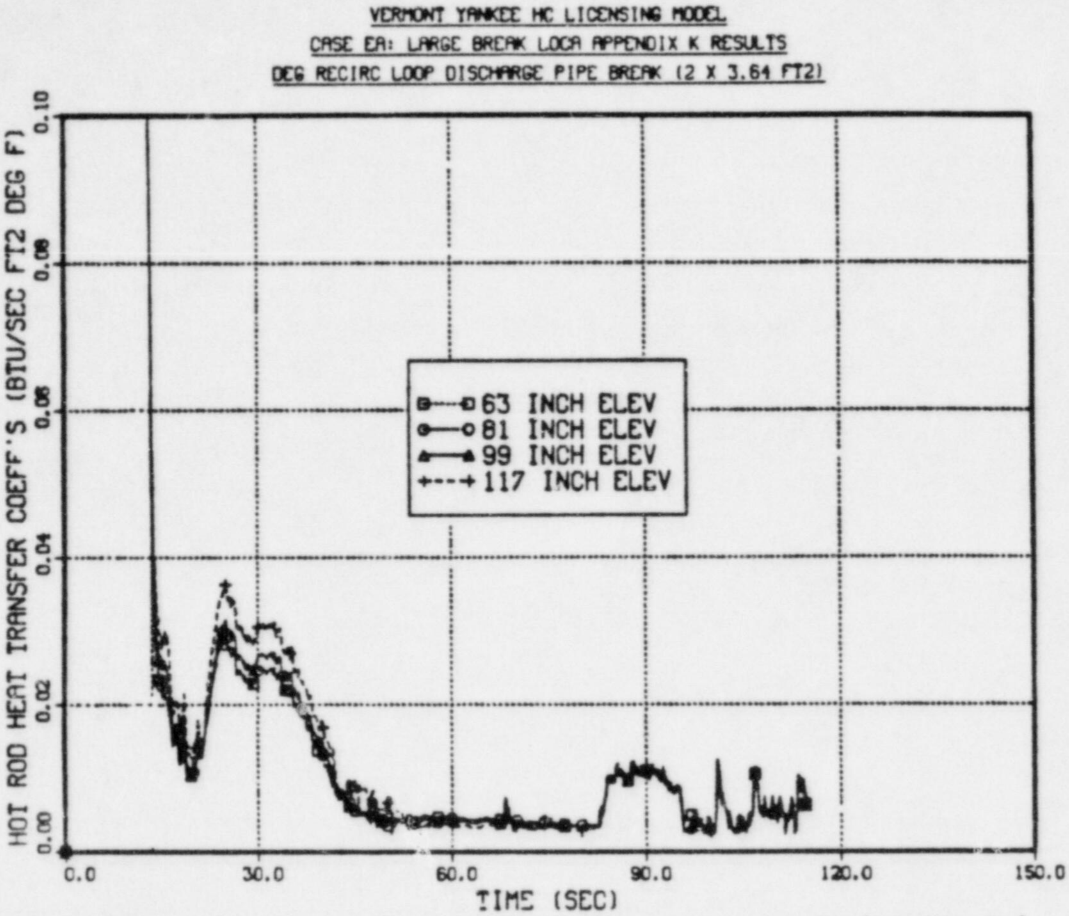

Figure 4.1-25: VY-HC Degraded Heat Transfer Coefs (LBLOCA-EA)

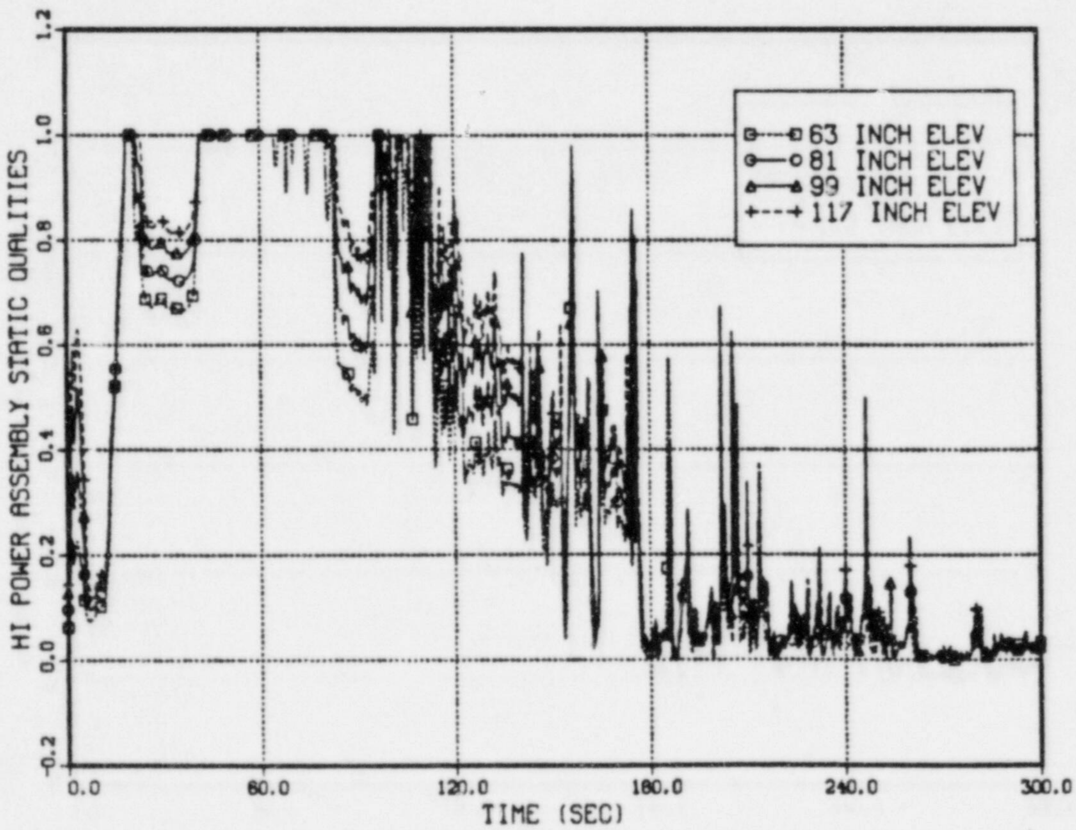

Figure 4.1-26: VY-HC High Power Bundle Qualities (LBLOCA-EA)

4.2 Sample Problem 2: Large Break Case EB

Sensitivity Case EB is identical to Base Case EA except for two changes. For this case, we have assumed that electrical power to each recirculation loop pump motor terminates at the accident initiation time. This assumes that an additional failure has occurred in the Electrical-Mechanical System associated with each Recirculation Pump System. Certain high-grade components in these systems are not classified as safety-related nor environmentally-qualified at the present time. A preliminary engineering review indicates that these components are either qualifiable, similar to existing qualified equipment, or not likely to be adversely affected during the early stages of a LOCA prior to the arrival of pump trip signals (Reference 4-4). Thus, we believe their failure is highly unlikely. However, given their current classification, Case EB examines whether earlier freewheeling pump conditions in the intact and broken loops would substantially alter the core flow coastdown induced by the intact loop recirculation pump and/or the flow rates out the broken recirculation loop. The results for Case EB show very minor changes compared to Case EA. These are discussed below.

Table 4.2.1 summarizes the timing of significant events for Case EB. A comparison of these event times to those for Case EA shows the following differences:

a. The low low level signal and mid-core CHF occurred about 1 second earlier for Case EB.

b. LPCS injection and recirculation Loop B discharge valve closure occur about 3 seconds earlier due to a slightly faster depressurization of the vessel.

c. Minimum vessel inventory occurs 4.6 seconds earlier and is 927 lbm lower.

d. Maximum clad outer surface temperature occurs 4.6 seconds earlier and is 3.2°F lower. The peak clad temperature on the inner surface is 0.8°F lower (1,065.8°F, Case EB, 1,066.6°F, Case EA).

e. HPCI termination and core quenching occur 4 seconds earlier due to the slightly faster vessel depressurization.

Figures 4.2-1 through 4.2-12 present Vermont Yankee NSSS results for the system response. Figures 4.2-13 through 4.2-20 present Vermont Yankee NSSS results for the core response. Figures 4.2-21 through 4.2-26 present Vermont Yankee hot channel results that show this model replicates the high power bundle results obtained from the Vermont Yankee NSSS model. Since the results in these figures are very similar to those for Case EA, only differences will be described. Finally, Figure 4.2-27 presents a comparison of the maximum clad outer surface temperature histories for Cases EA and EB.

A comparison of the break flow rates in Figures 4.1-5 and 4.1-6 to those in Figures 4.2-5 and 4.2-6, and a review of the output data for each case shows the following:

(a) The downstream break flow rates are virtually identical. After 206 seconds, the occasional spikes occur at different times, but the mean flowrates are nearly the same.

(b) The upstream break flow rates are virtually identical during the first 0.6 seconds.

(c) The break flowrates for Case EB become approximately 25% larger than for Case EA between 0.6 and 17 seconds (recirculation pump trip time for Case EA). During this period, Recirculation Pump A began to overspeed for Case EB whereas the declining electrical power caused a rundown for Case EA. The overspeed causes less hydraulic resistance and flashing through the pump than the rundown does. Thus, the quality in the discharge pipe at the choking locations (venturi and upstream pipe break) was lower for Case EB, resulting in higher break flow rates.

(d) After 17.0 seconds, Recirculation Pump A begins to overspeed. After 21 seconds, the upstream break flow rates are essentially the same for both cases.

A comparison of Figures 4.1-7 to 4.2-7 shows that Case EB has a slightly faster depressurization rate than Case EA. This accounts for several of the earlier event times discussed before. At 120 seconds, the two pressure histories merge and remain essentially the same thereafter.

A comparison of Figures 4.1-14 to 4.2-14 shows similar behavior for the high power bundle mass history except during the period from 91 to 132 seconds when more two-phase fluid entered the bundle for Case EB. This occurs after the peak cladding temperature has been reached in both cases and appears to result from a shift of that the hottest temperature about 18 inches upward for Case EB. This apparently allows fluid to enter the bundle more readily through the drilled holes in the fuel support piece at the bottom.

A comparison of Figures 4.1-15 and 4.1-16 to Figures 4.2-15 and 4.1-16 shows generally similar behavior for the two cases, but the following differences are noted:

a. Case EA suppresses CHF at all elevations until 13.1 seconds. Case EB allowed the upper elevations (99 and 117 inches) to reach CHF at 2.[illegible] seconds and the mid-elevations (63 and 81 inches) to reach CHF at 12.3 seconds due to less mass in the high power bundle early in time.

b. The subsequent bundle heatup for Case EA shows the 81-inch elevation has the highest PCT whereas the 63 and 99-inch elevations are slightly lower. For Case EB, the 99-inch elevation has the highest PCT and essentially the same value as the 81-inch value for Case EA. Now, the 63-inch and 81-inch elevations are cooler than for Case EA.

c. It appears that the lower temperatures at the mid-core elevations allow the more pronounced two-phase fluid insurge in Case EB between 91 and 132 seconds as seen in Figures 4.1-16 and 4.2-16.

The high power bundle cools down more readily in Case EB than in Case EA as seen in Figure 4.2-15. The major edit data for both cases show that Node 5 (72 to 90 inches above BOHL) is the last node to quench in the high power bundle. Figure 4.2-27 shows a comparison of the peak node (5) temperature for Case EA and the peak node (6) temperature for Case EB.

TABLE 4.2.1

Sequence of Events for Large Break Case EB

Event	Time (seconds)
1. Break opens	4.0E-6
2. Loss of auxiliary power and power to the recirculation pump motors	4.0E-6
3. High drywell pressure (p >2.5 psig)	0.048
4. Turbine stop valve starts to close (and is completely closed in 0.1 second)	0.45
5. Reactor scrams on high drywell pressure	0.55
6. Initiate turbine bypass valve opening	0.56
7. Turbine bypass valve completely open	1.16
8. Low level signal (127 inches) occurs	3.04
9. RPS MG set underfrequency (57 Hz) condition occurs	3.01
10. MSIVs begin to close on RPS underfrequency	3.52
11. Control rods are fully inserted	4.22
12. Feedwater flow coasts down to zero	5.00
13. Lower plenum flashing begins	5.00
14. Midcore critical heat flux occurs	12.30
15. Low low level signal (82.5 inches) occurs	12.30
16. MSIVs are completely closed	13.52
17. HPCI injection begins	20.40
18. Recirculation Loop B (intact) discharge valve begins to close	56.50
19. LPCS injection begins	65.00
20. Minimum Primary System inventory (89,286 lb) occurs	70.00
21. Peak clad temperature occurs (inner 1,065.8^{o}F; outer 1,062.0^{o}F)	78.00

TABLE 4.2.1
(Continued)

Sequence of Events for Large Break Case EB

	Event	Time (seconds)
22.	Recirculation Loop B discharge valve closed	89.50
23.	HPCI flow terminated on low pressure signal	91.20
24.	Core, including high power bundle, is well cooled	194.00

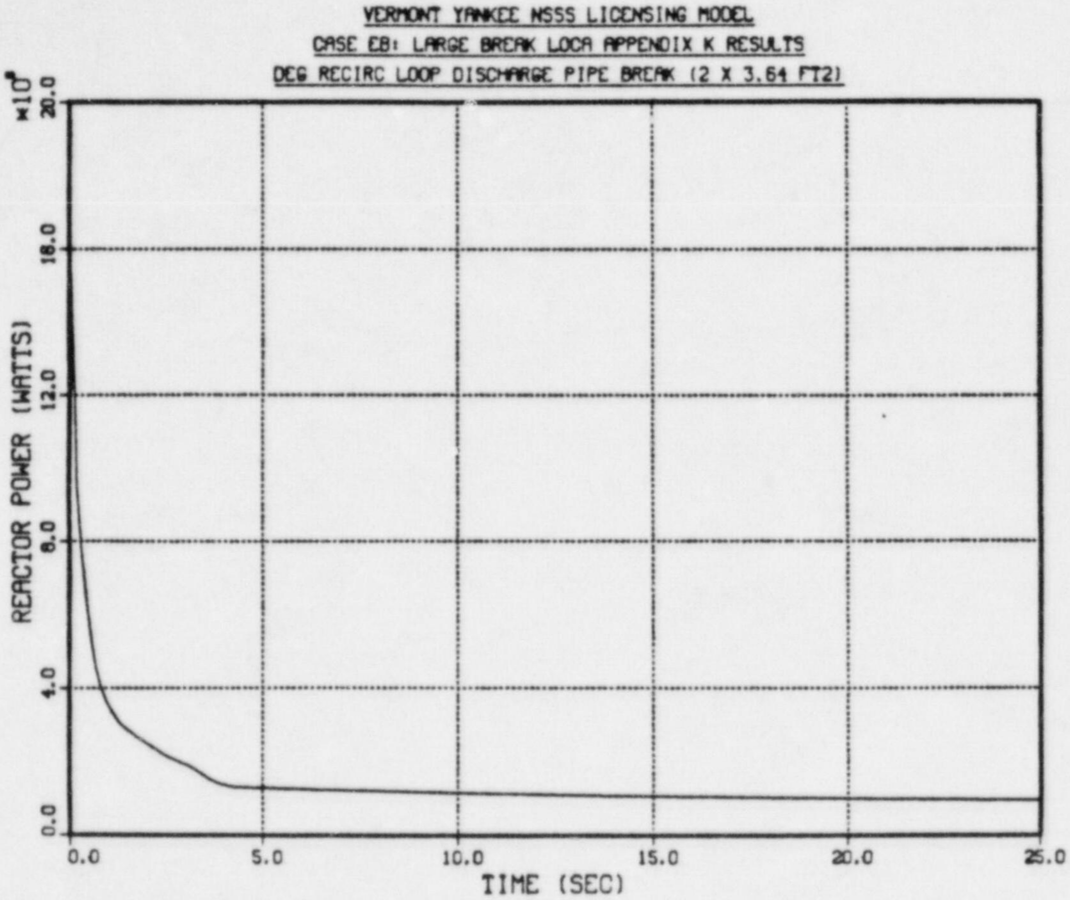

Figure 4.2-1: Reactor Power History (LBLOCA-EB)

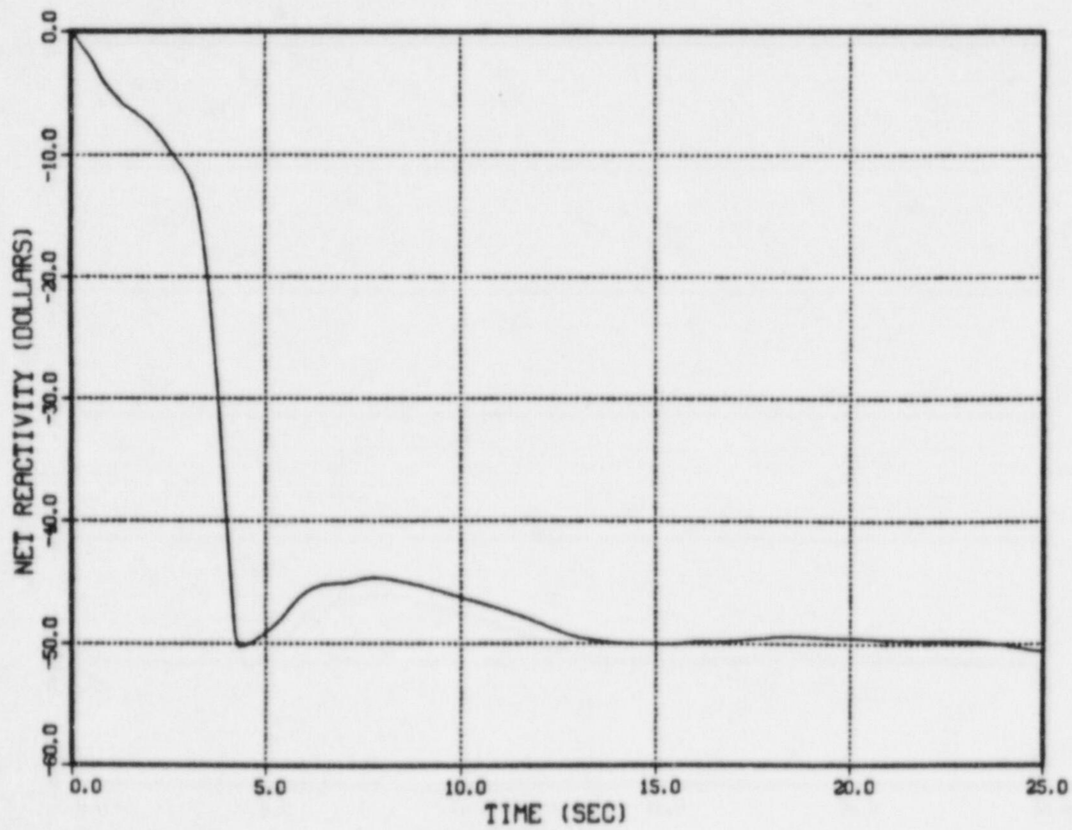

Figure 4.2-2: Net Reactivity (LBLOCA-EB)

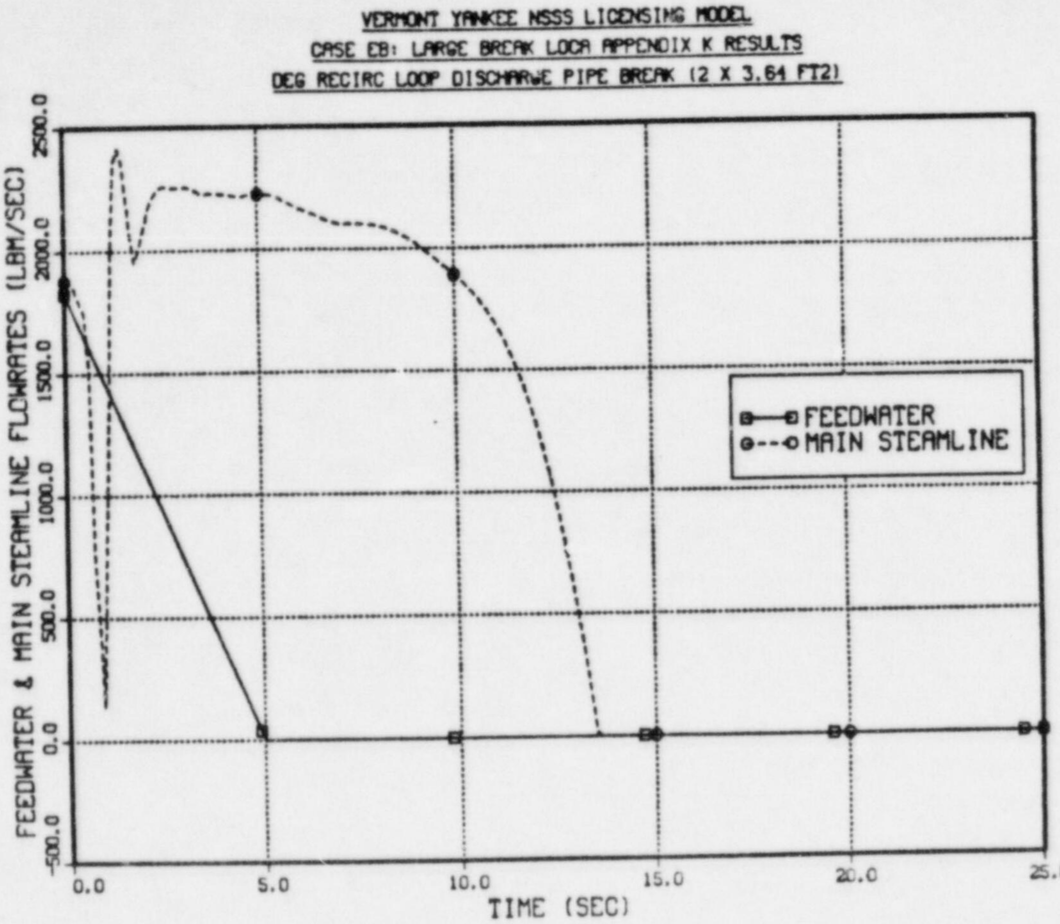

Figure 4.2-3: Feed and Main Steam Flows (LBLOCA-EB)

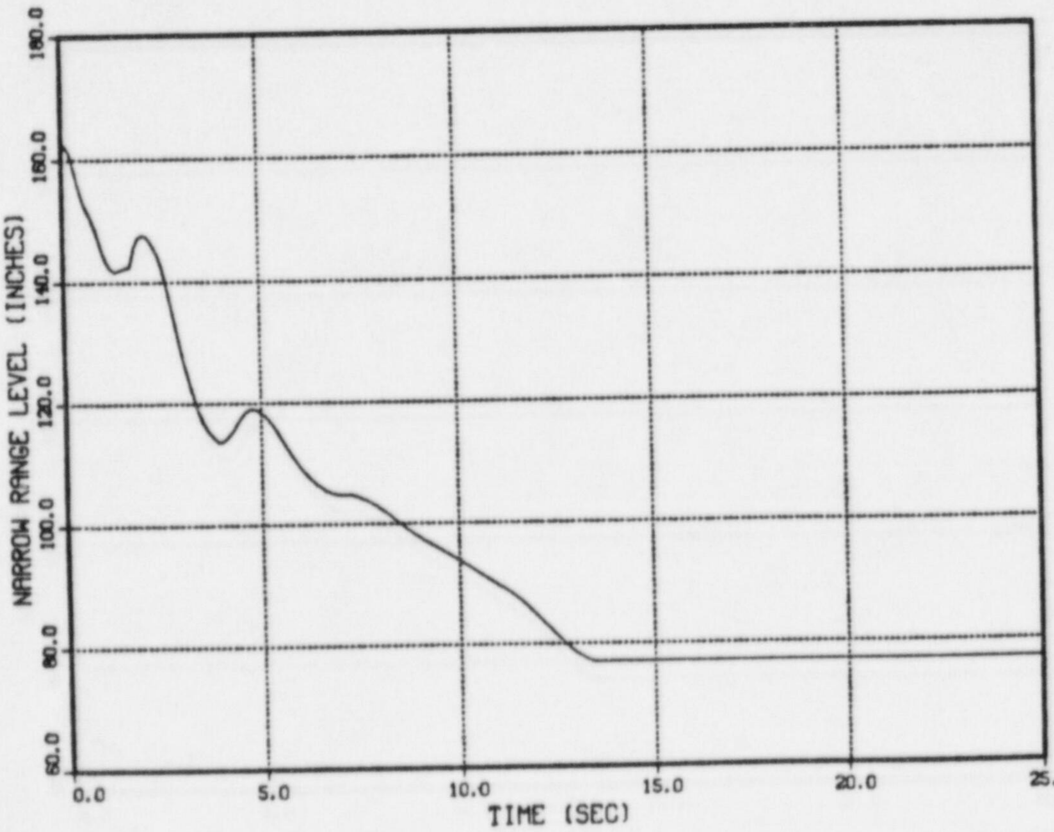

Figure 4.2-4: Vessel Water Level (LBLOCA-EB)

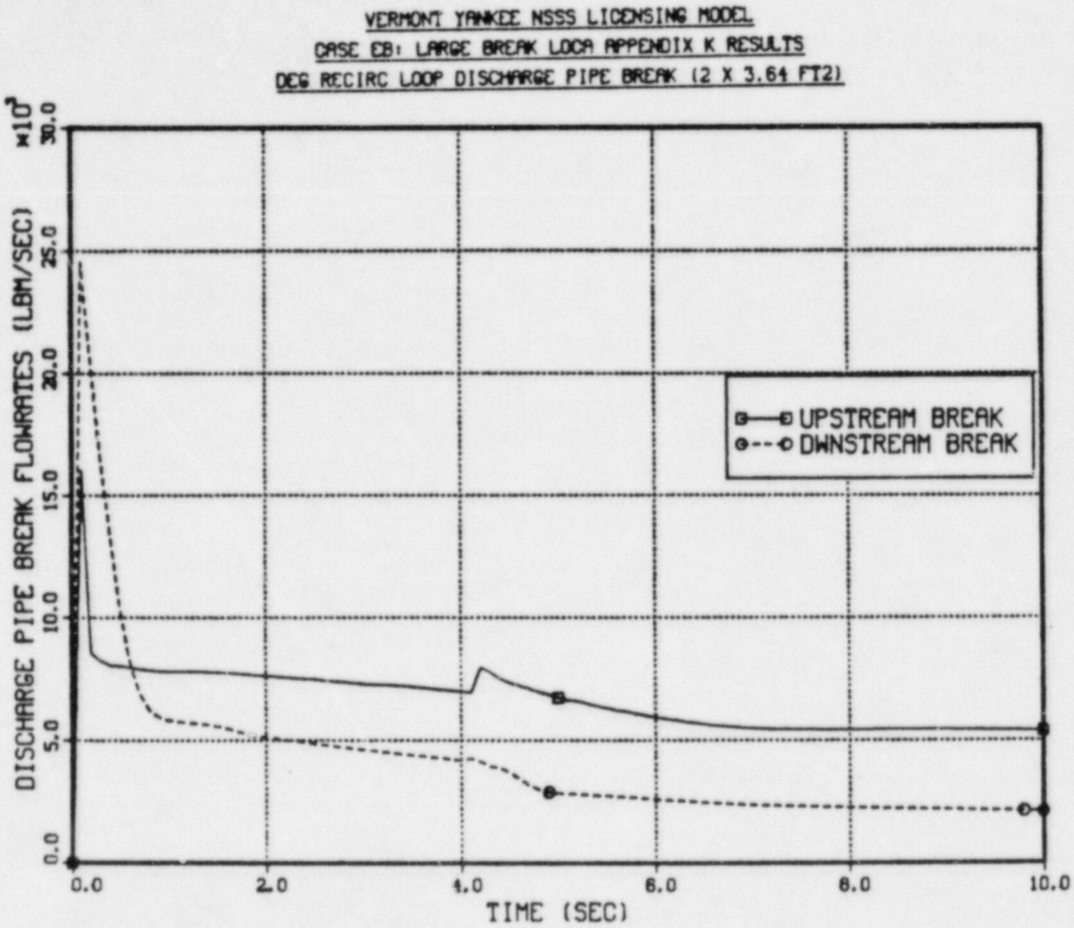

Figure 4.2-5: Early Break Flowrates (LBLOCA-EB)

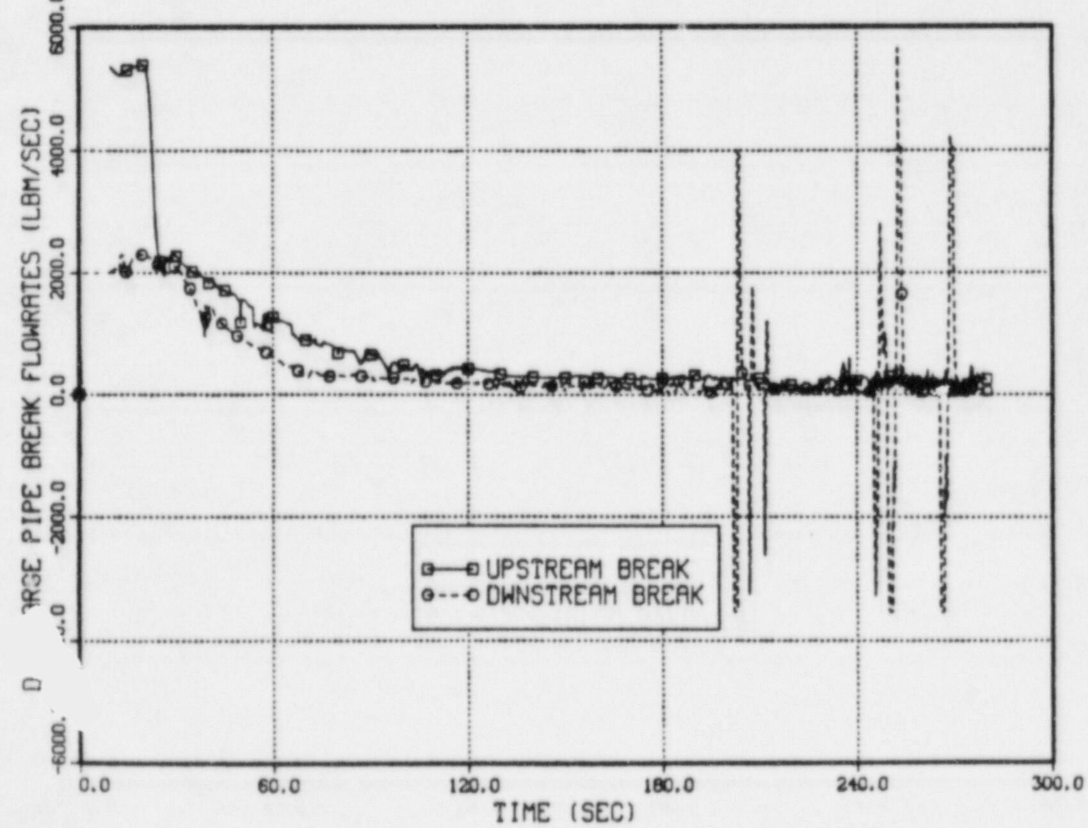

Figure 4.2-6: Long Term Break Flowrates (LBLOCA-EB)

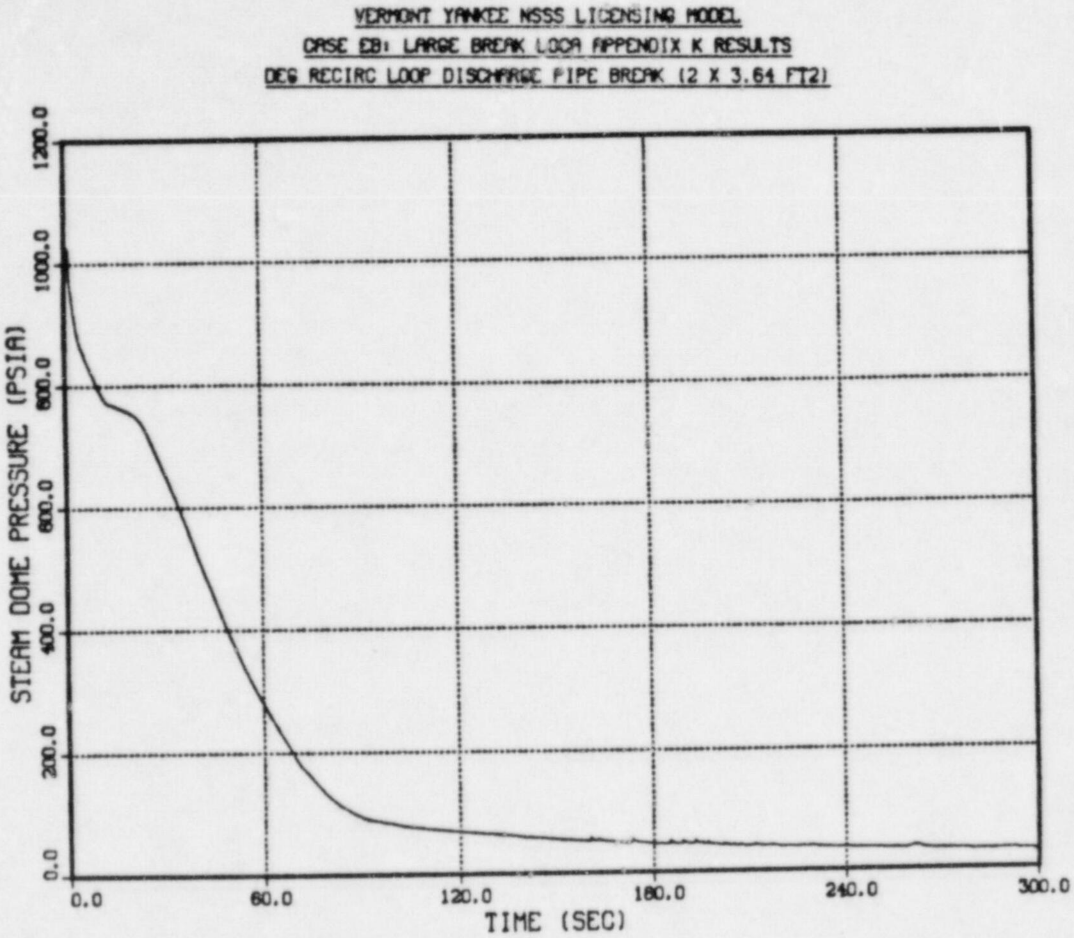

Figure 4.2-7: Vessel Pressure History (LBLOCA-EB)

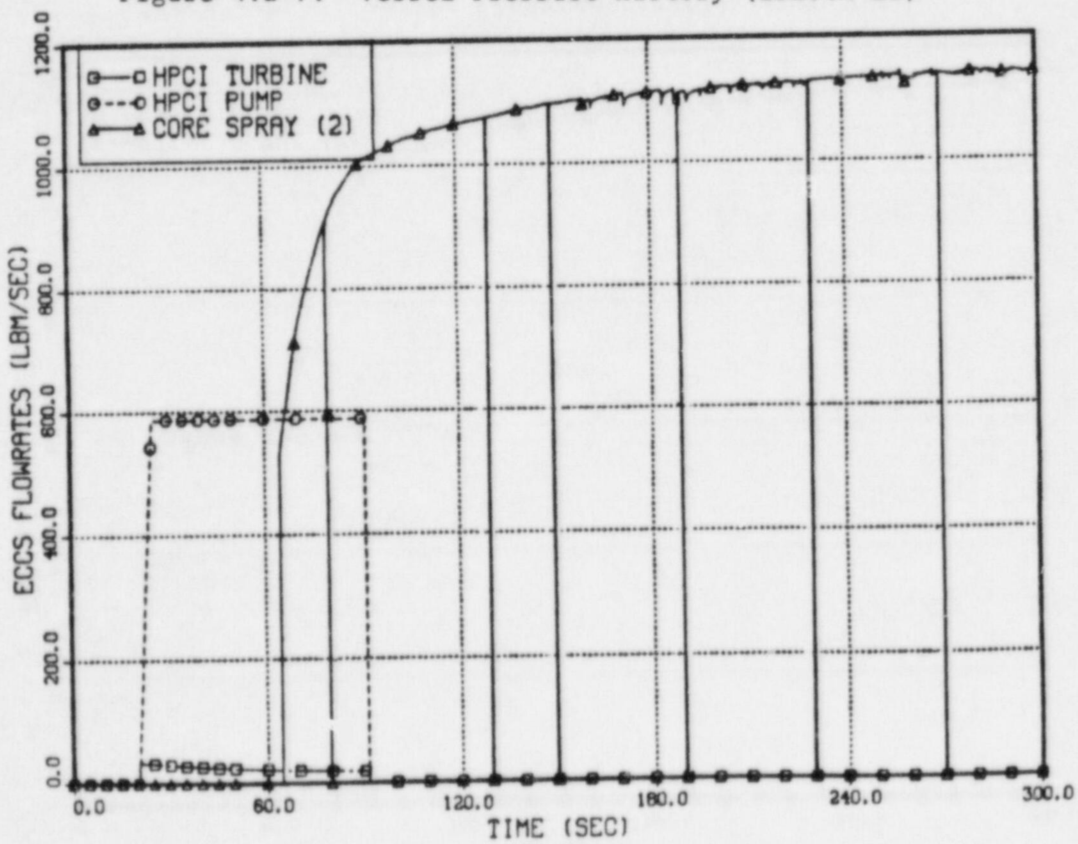

Figure 4.2-8: ECCS Flowrates (LBLOCA-EB)

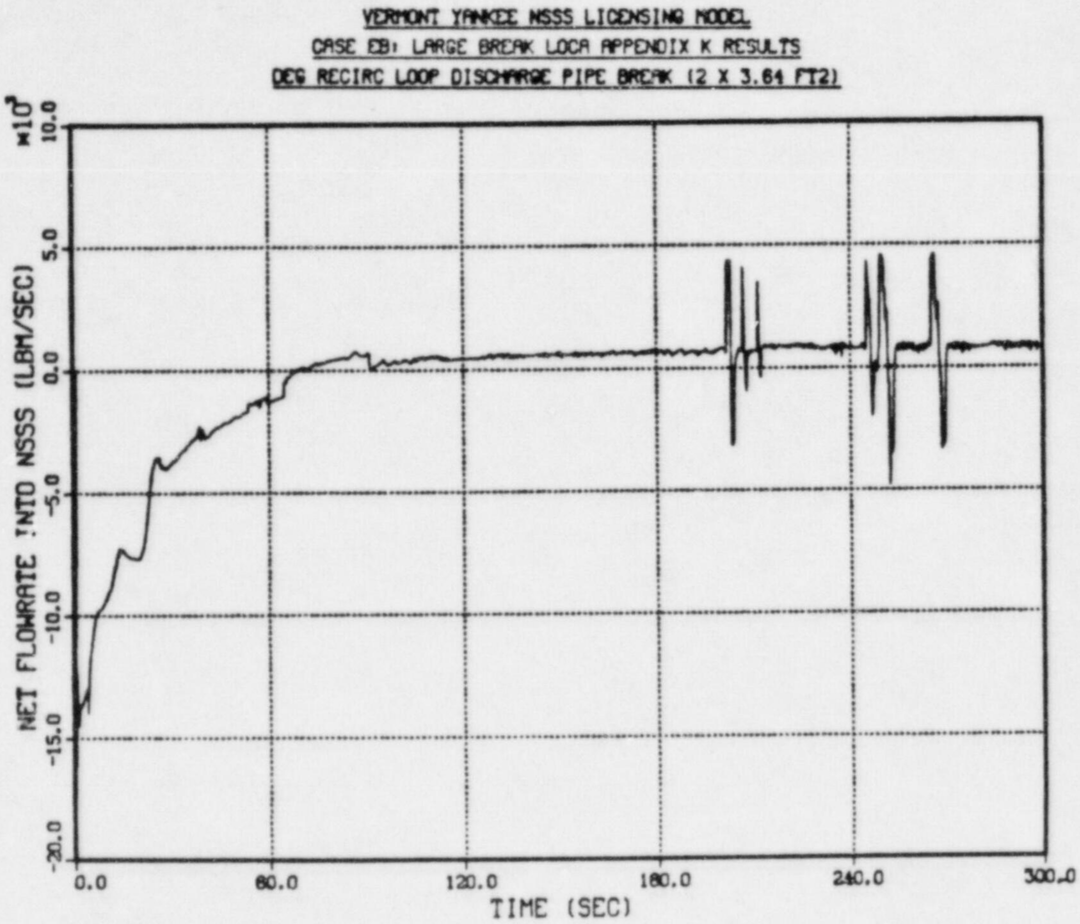

Figure 4.2-9: Net Flowrate into NSSS (LBLOCA-EB)

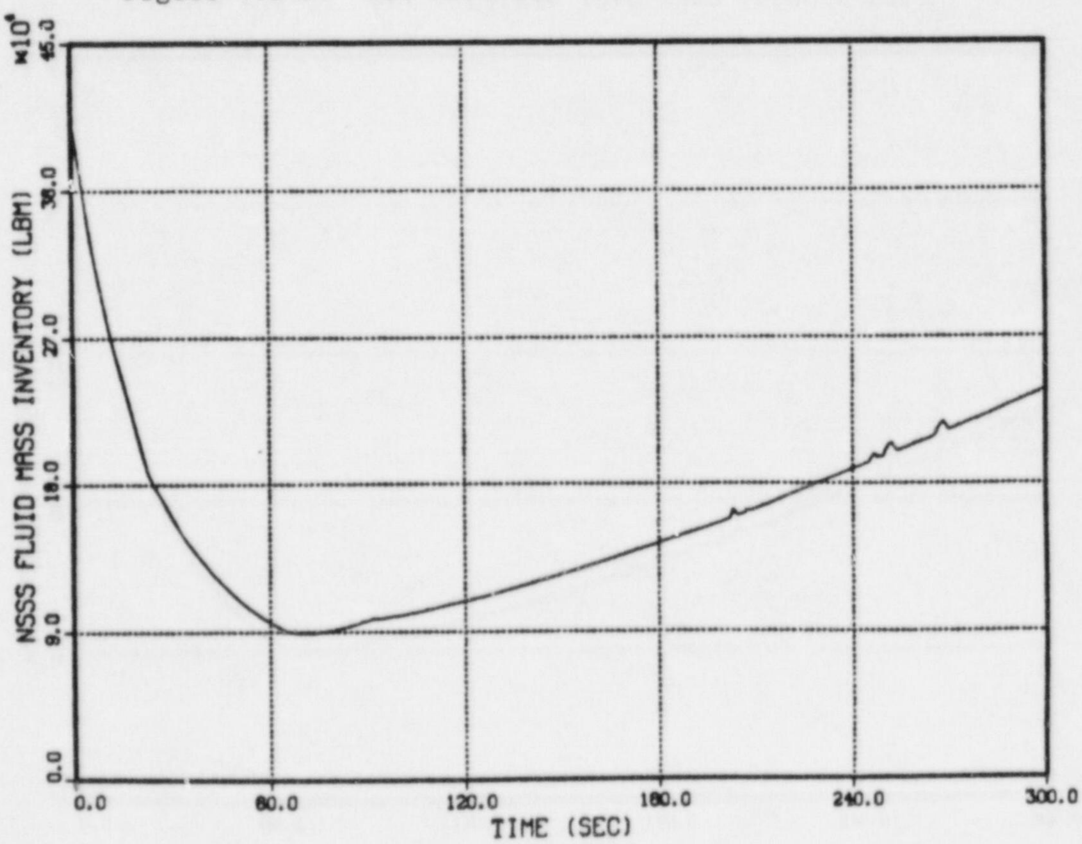

Figure 4.2-10: NSSS Fluid Mass Inventory (LBLOCA-EB)

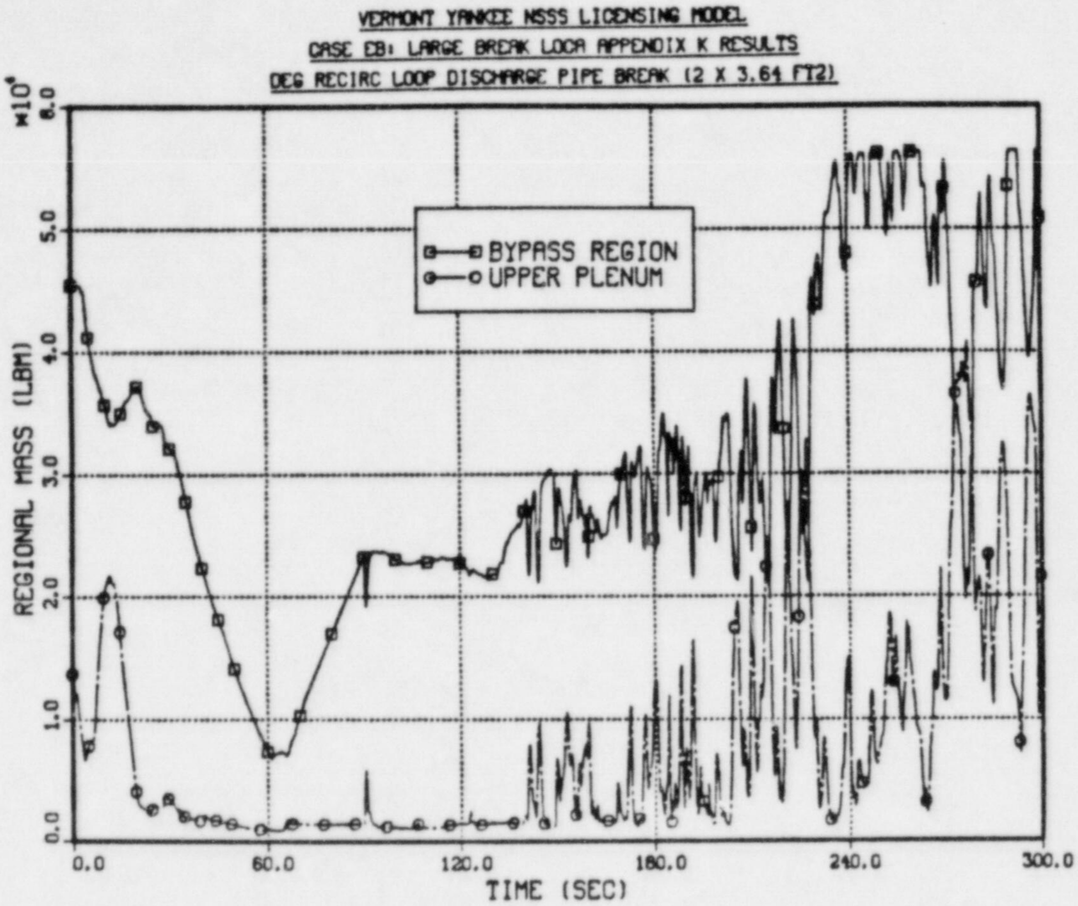

Figure 4.2-11: Bypass and Upper Plenum Fluid Mass (LBLOCA-EB)

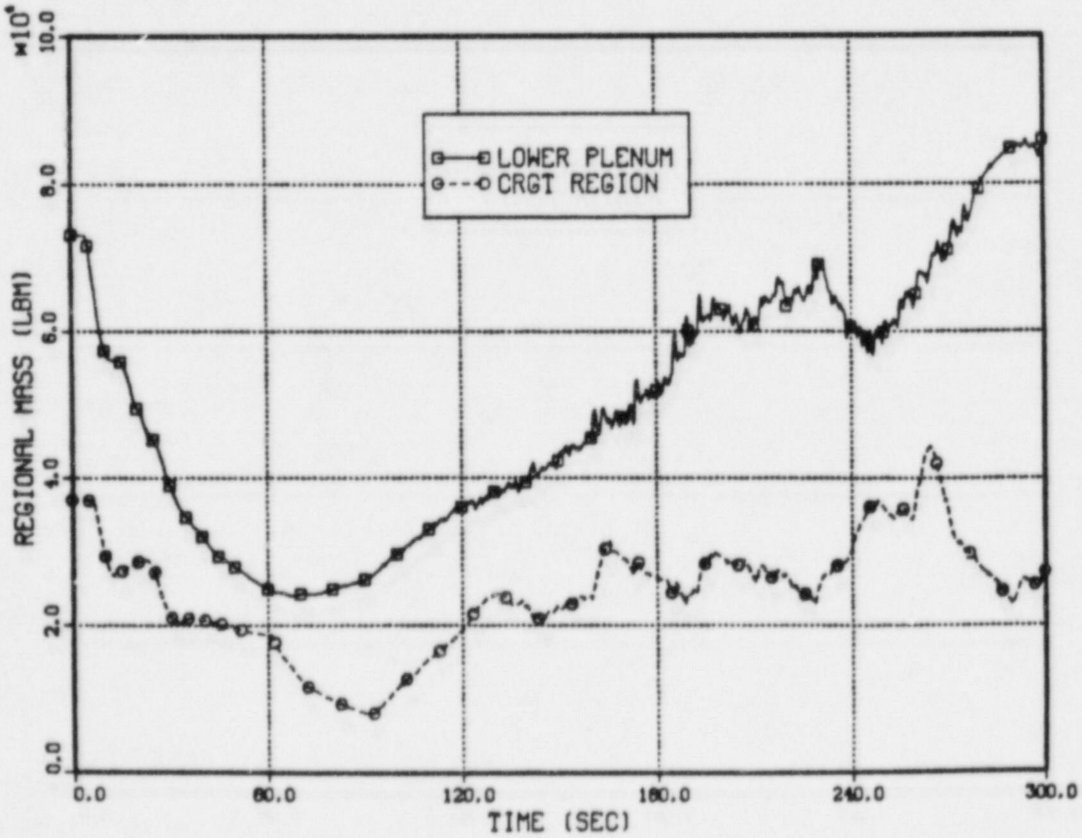

Figure 4.2-12: CRGT and Lower Plenum Fluid Mass (LBLOCA-EB)

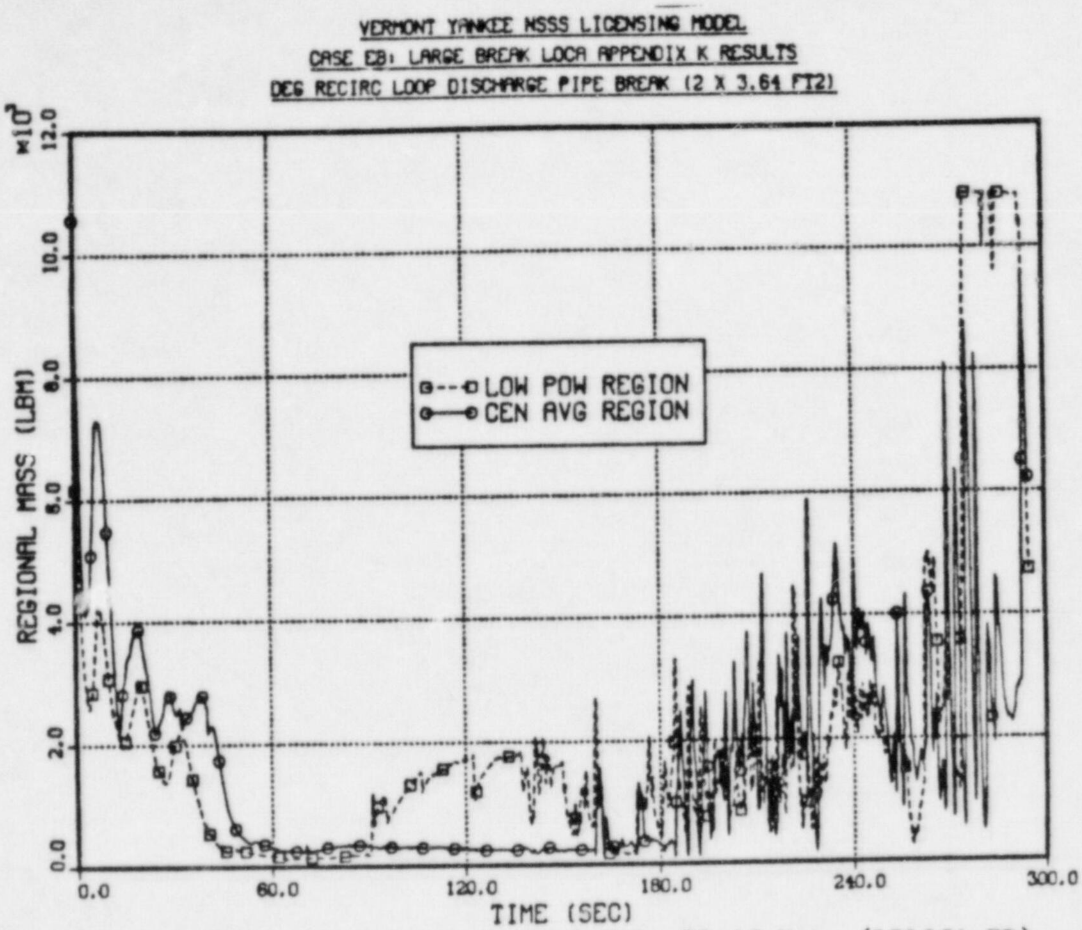

Figure 4.2-13: Outer and Central Core Fluid Mass (LBLOCA-EB)

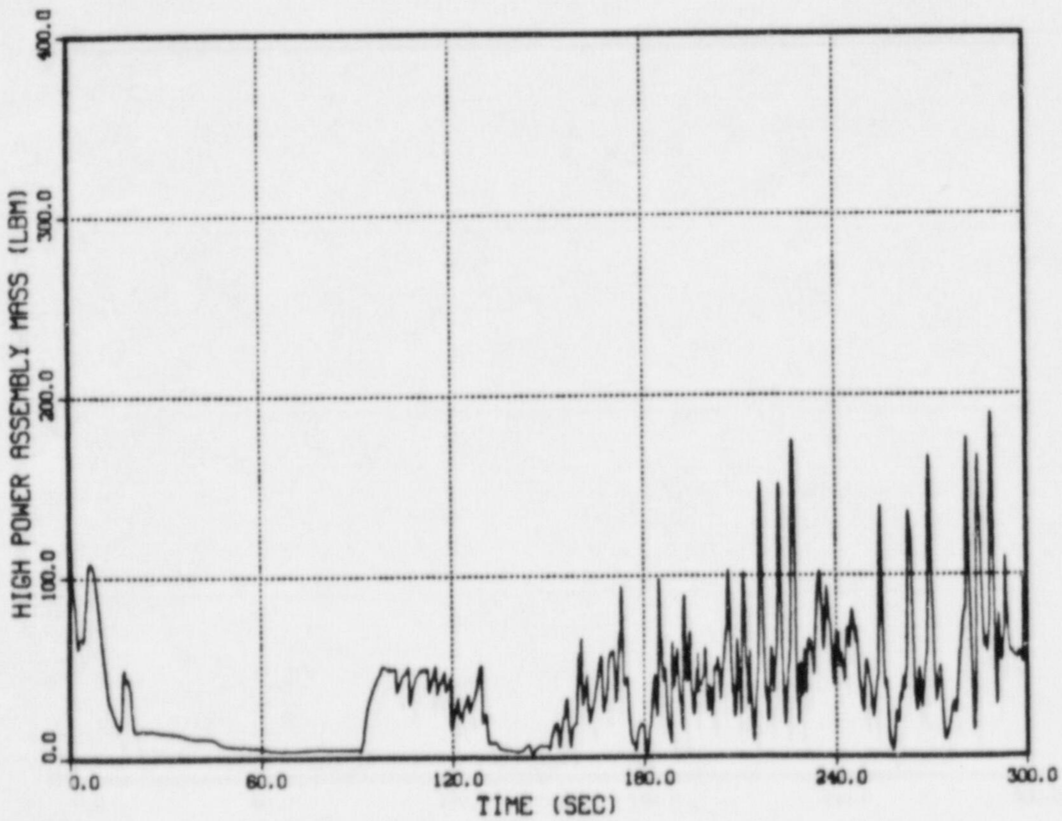

Figure 4.2-14: High Power Assembly Fluid Mass (LBLOCA-EB)

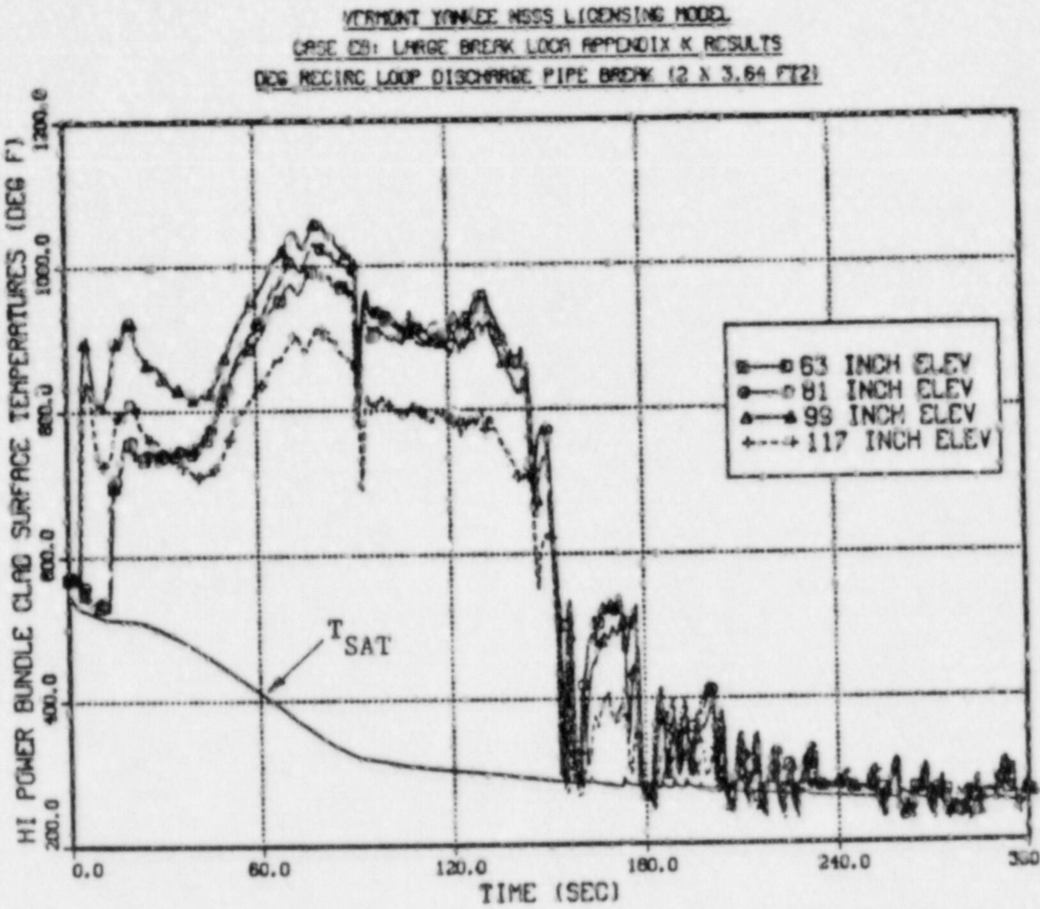

Figure 4.2-15: High Power Bundle Clad Temperatures (LBLOCA-EB)

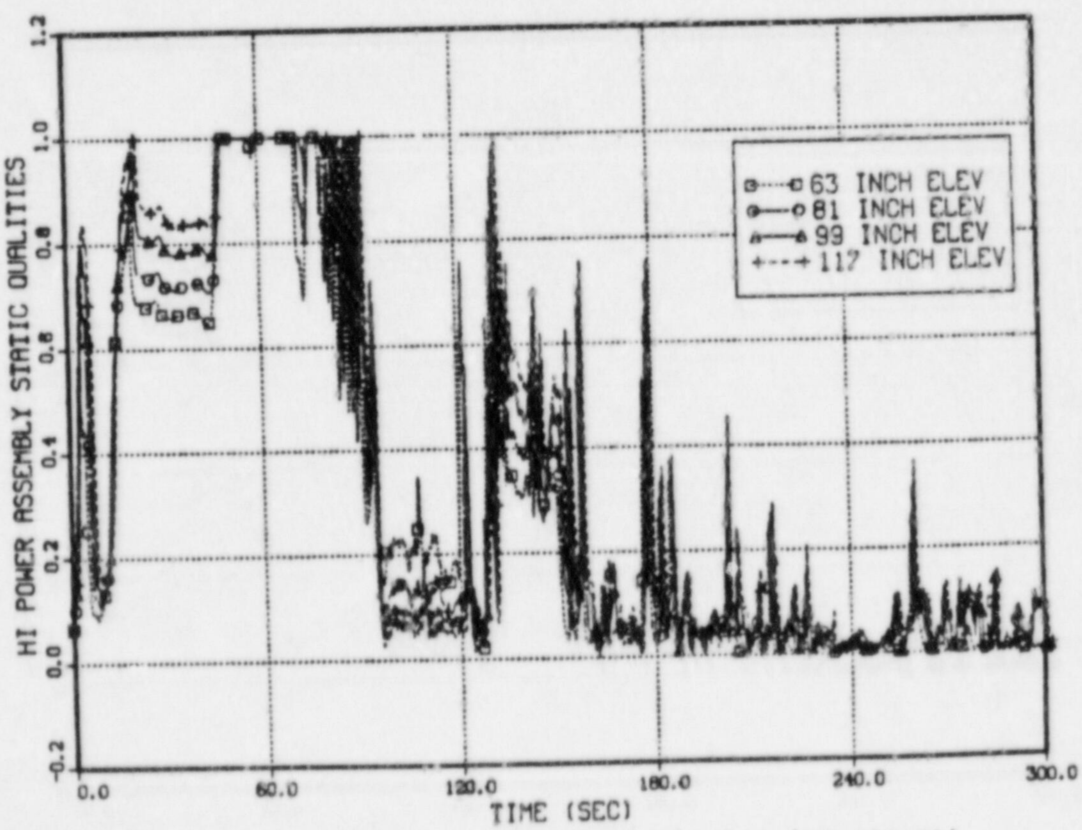

Figure 4.2-16: High Power Bundle Qualities (LBLOCA-EB)

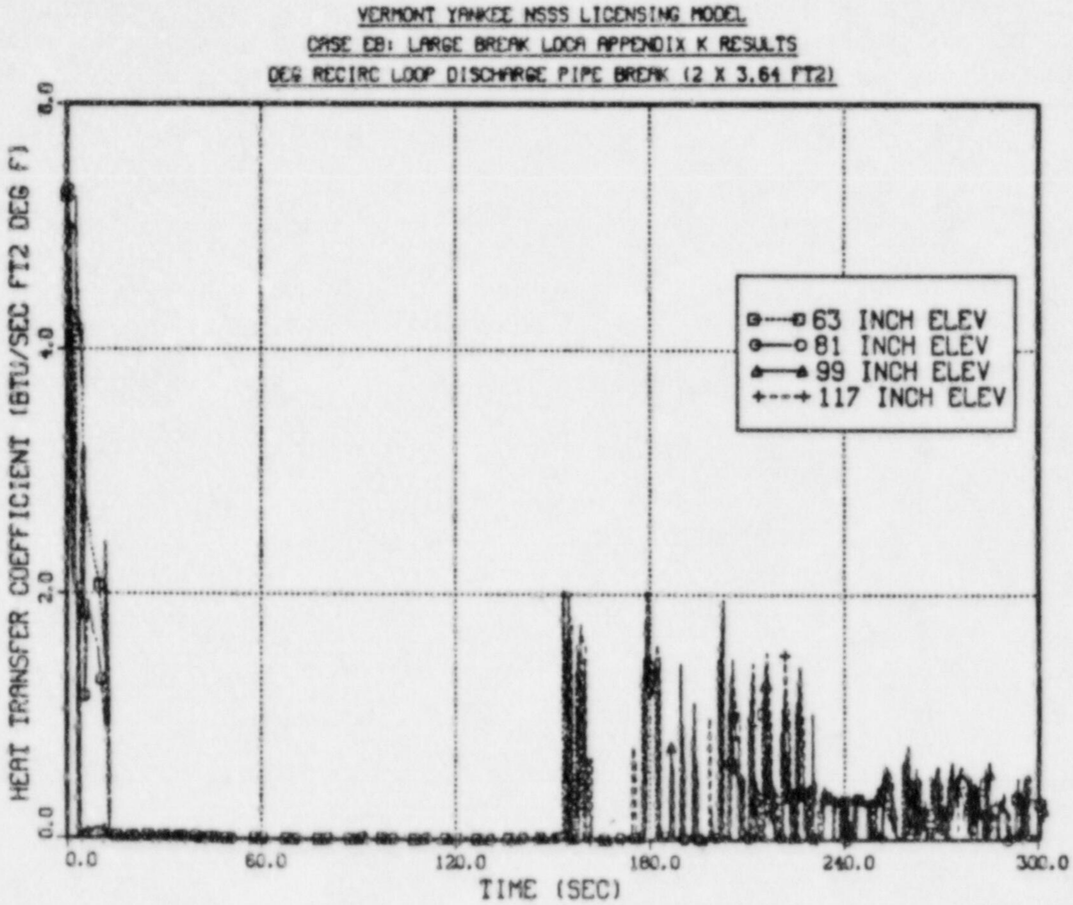

Figure 4.2-17: Long Term Heat Transfer Coefficients (LBLOCA-EB)

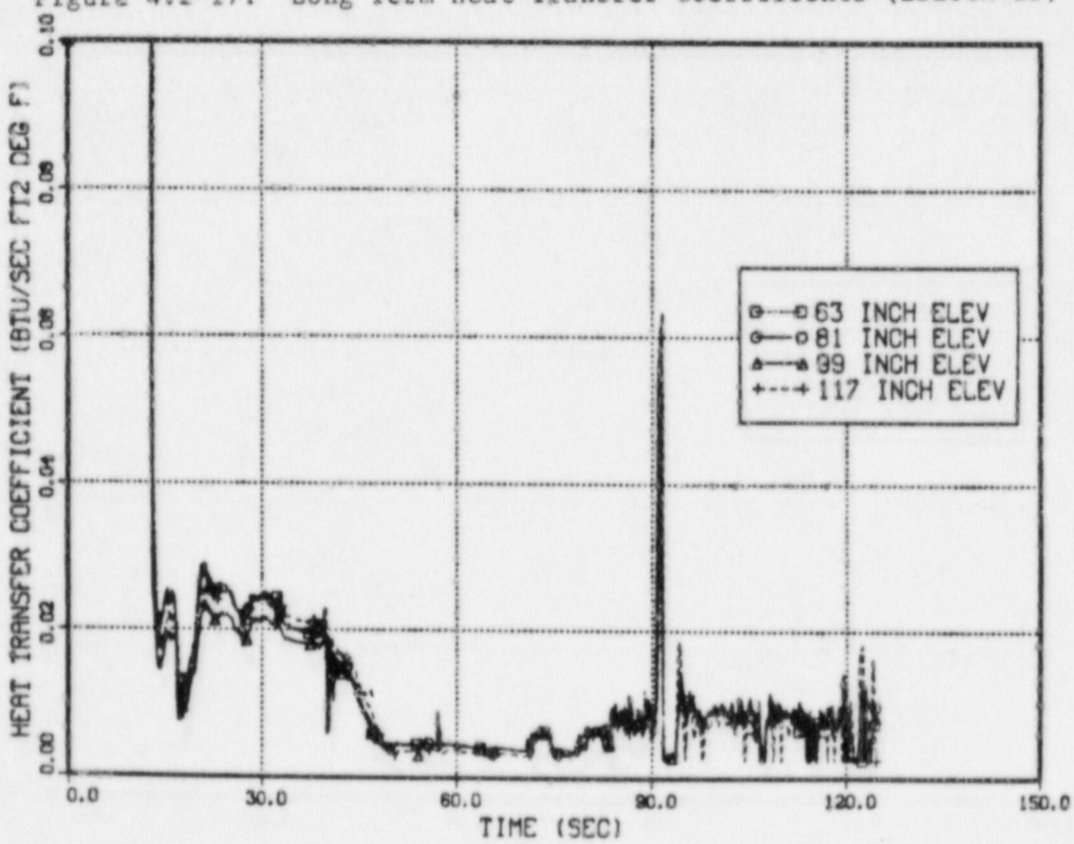

Figure 4.2-18: Degraded Heat Transfer Coefficients (LBLOCA-EB)

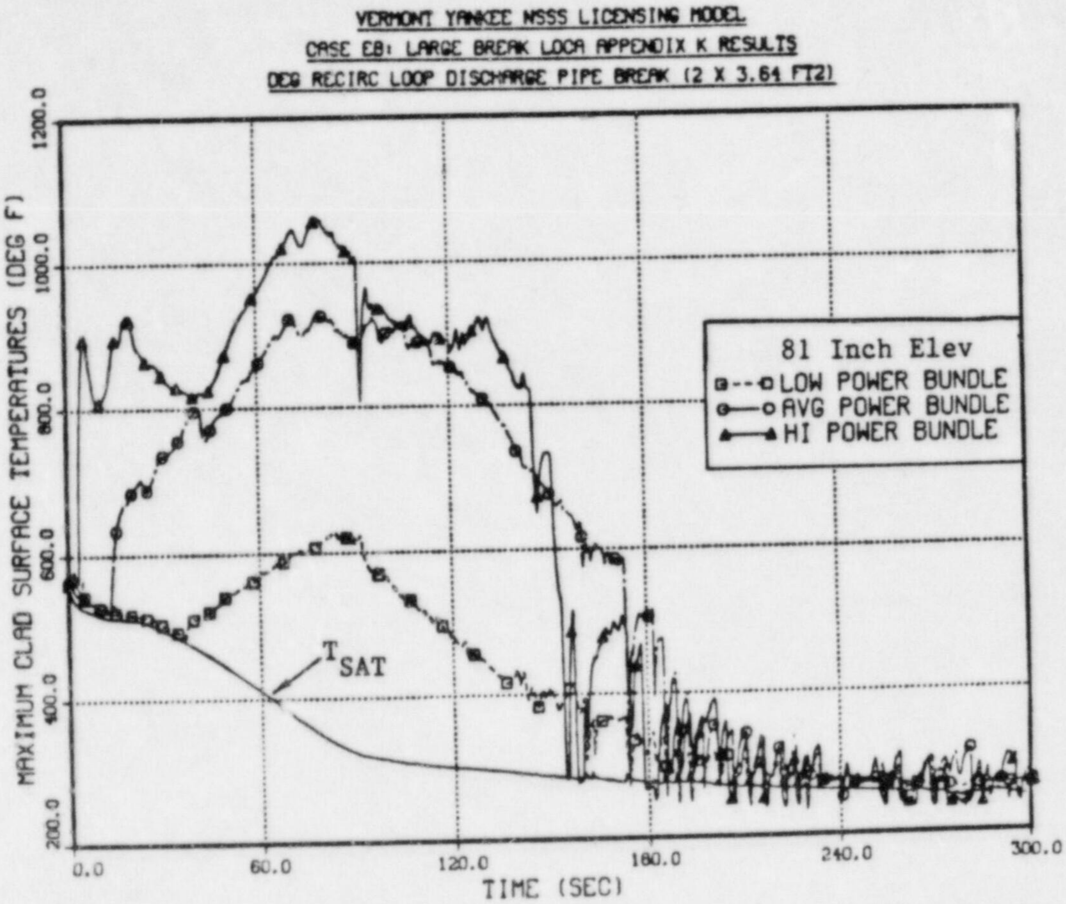

Figure 4.2-19: Maximum Bundle Clad Temperatures (LBLOCA-EB)

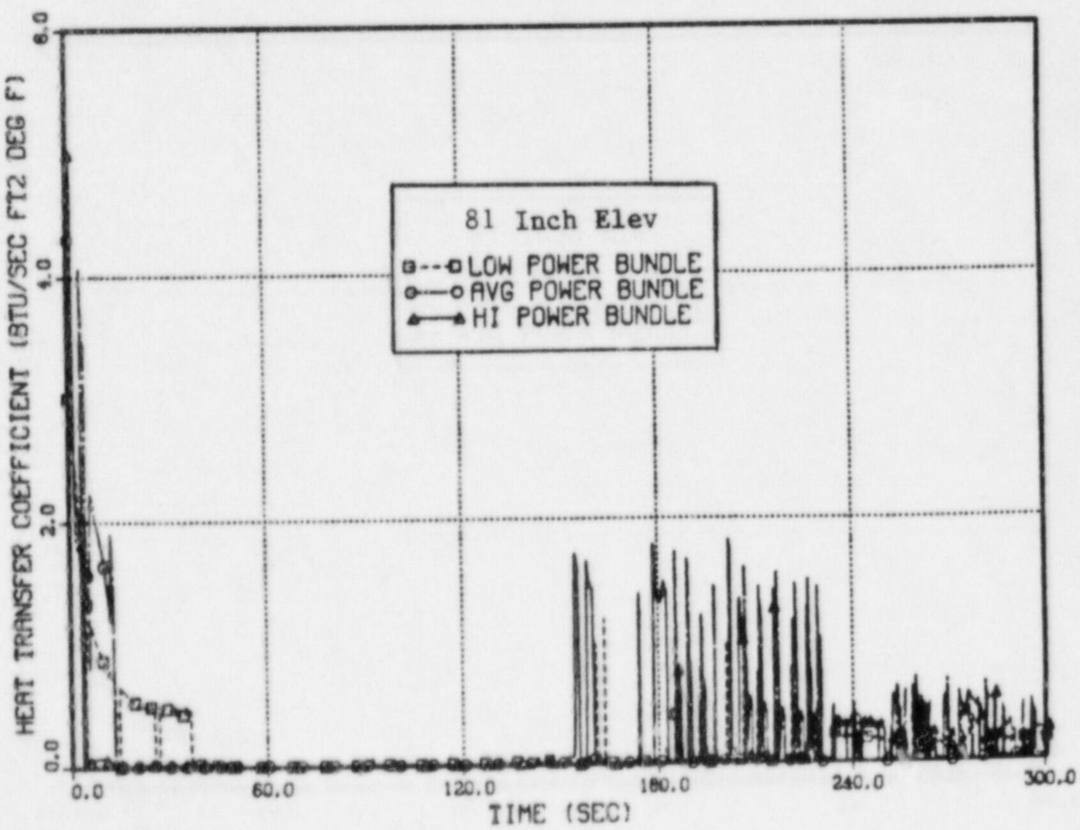

Figure 4.2-20: Bundle Heat Transfer Coefficients (LBLOCA-EB)

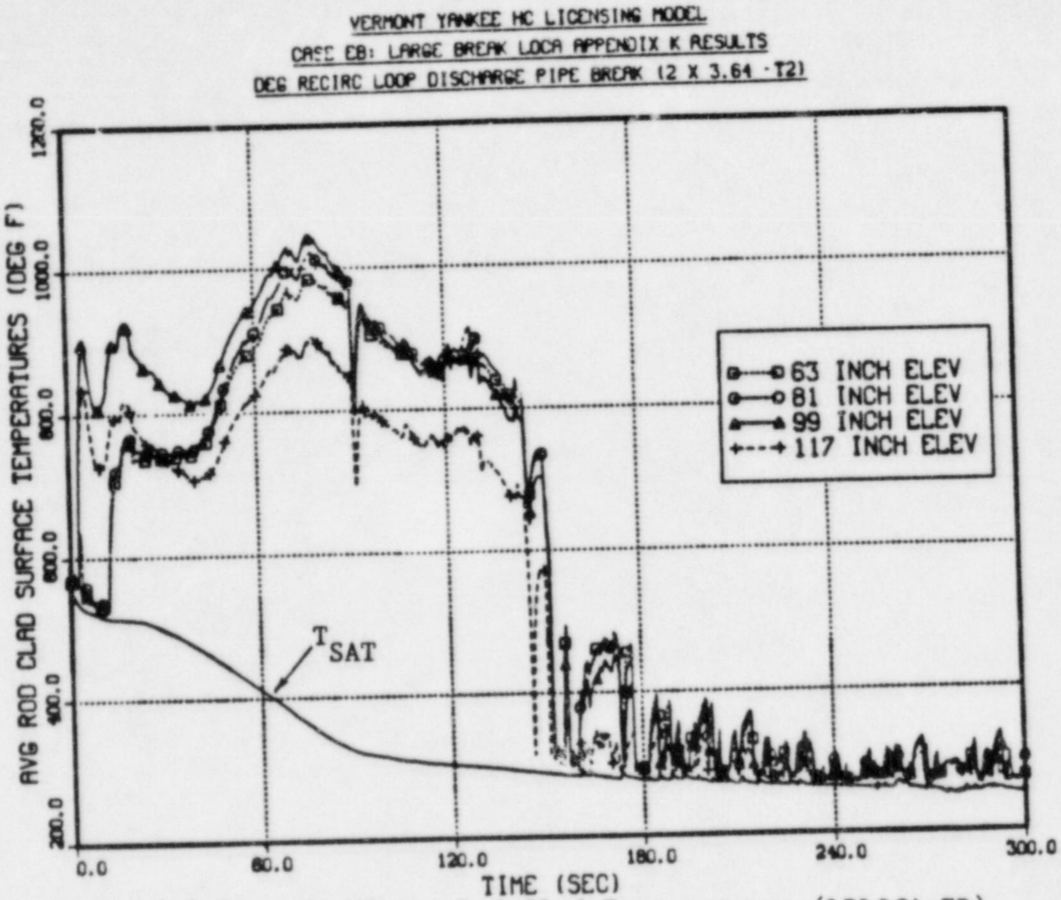

Figure 4.2-21: VY-HC Avg Rod Clad Temperatures (LBLOCA-EB)

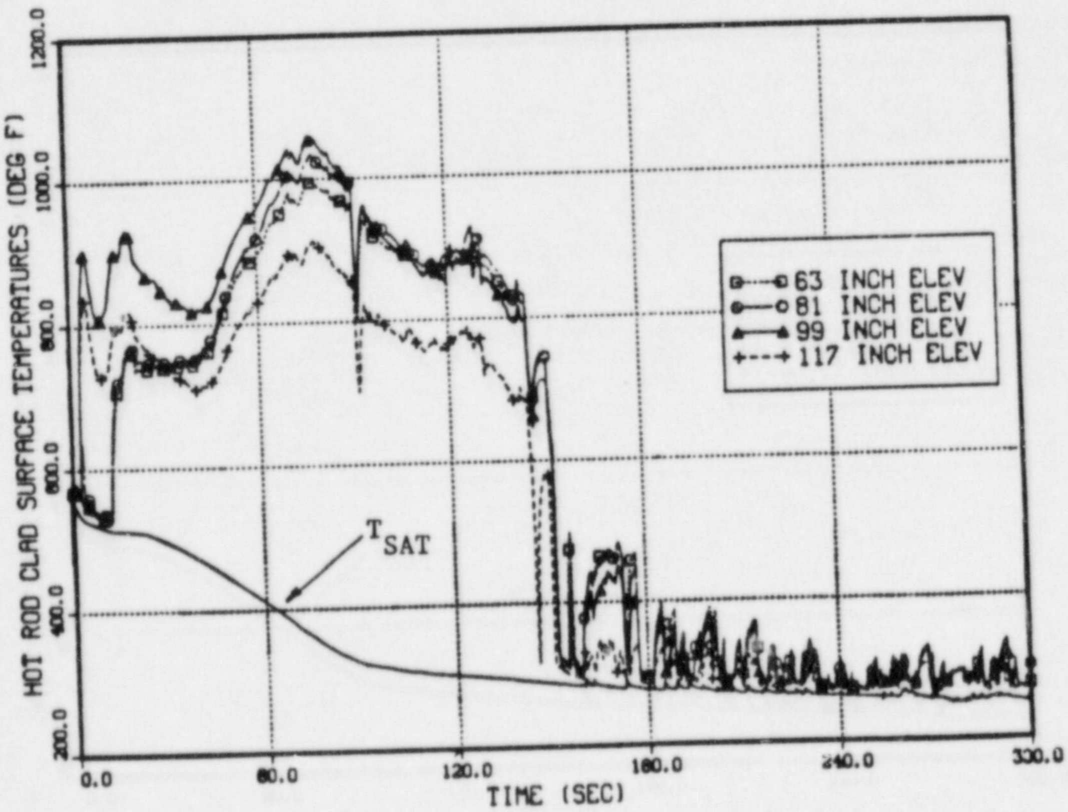

Figure 4.2-22: VY-HC Hot Rod Clad Temperatures (LBLOCA-EB)

VERMONT YANKEE HC LICENSING MODEL
CASE EB: LARGE BREAK LOCA APPENDIX K RESULTS
DEG RECIRC LOOP DISCHARGE PIPE BREAK (2 X 3.64 - T2)

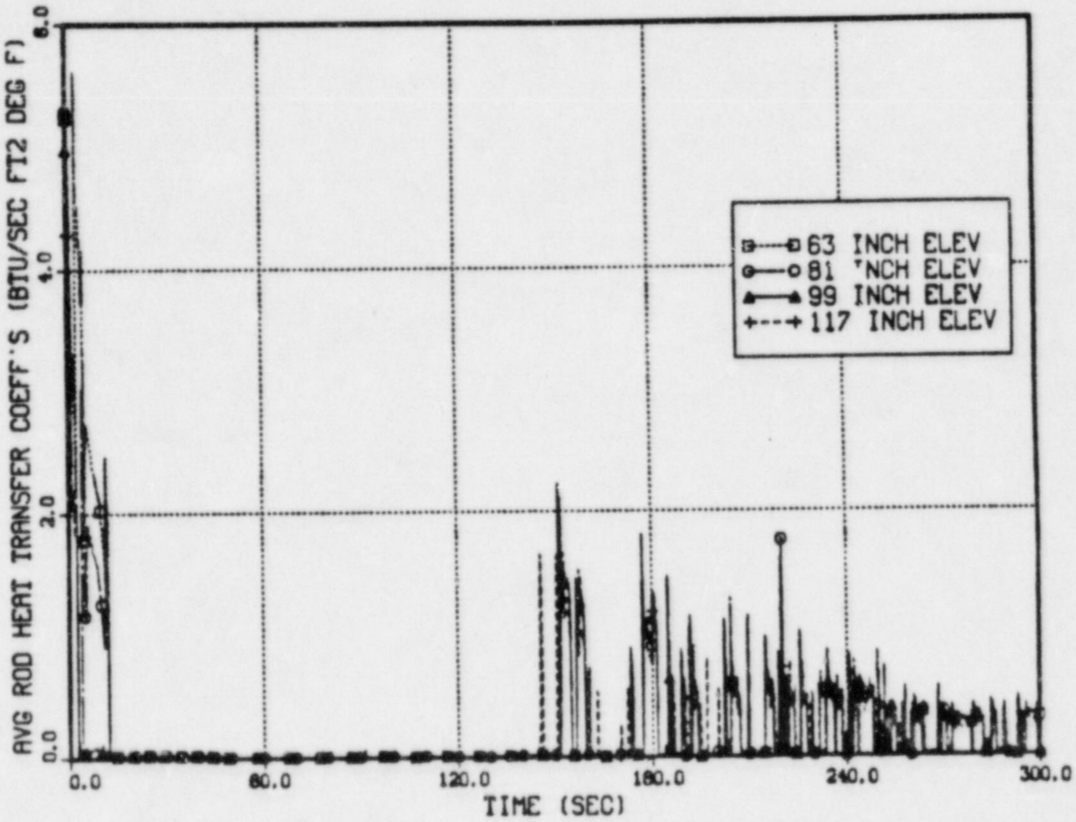

Figure 4.2-23: VY-HC Avg. Rod Heat Transfer Coefs (LBLOCA-EB)

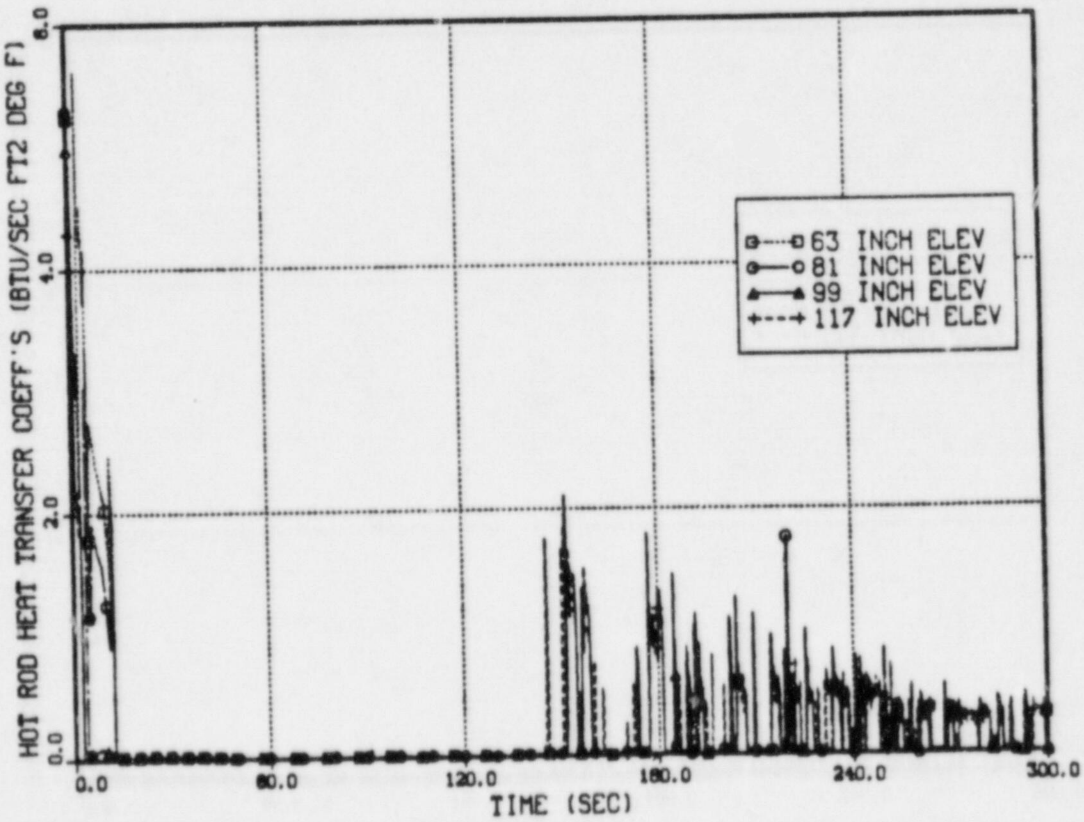

Figure 4.2-24: VY-HC Hot Rod Heat Transfer Coefs (LBLOCA-EB)

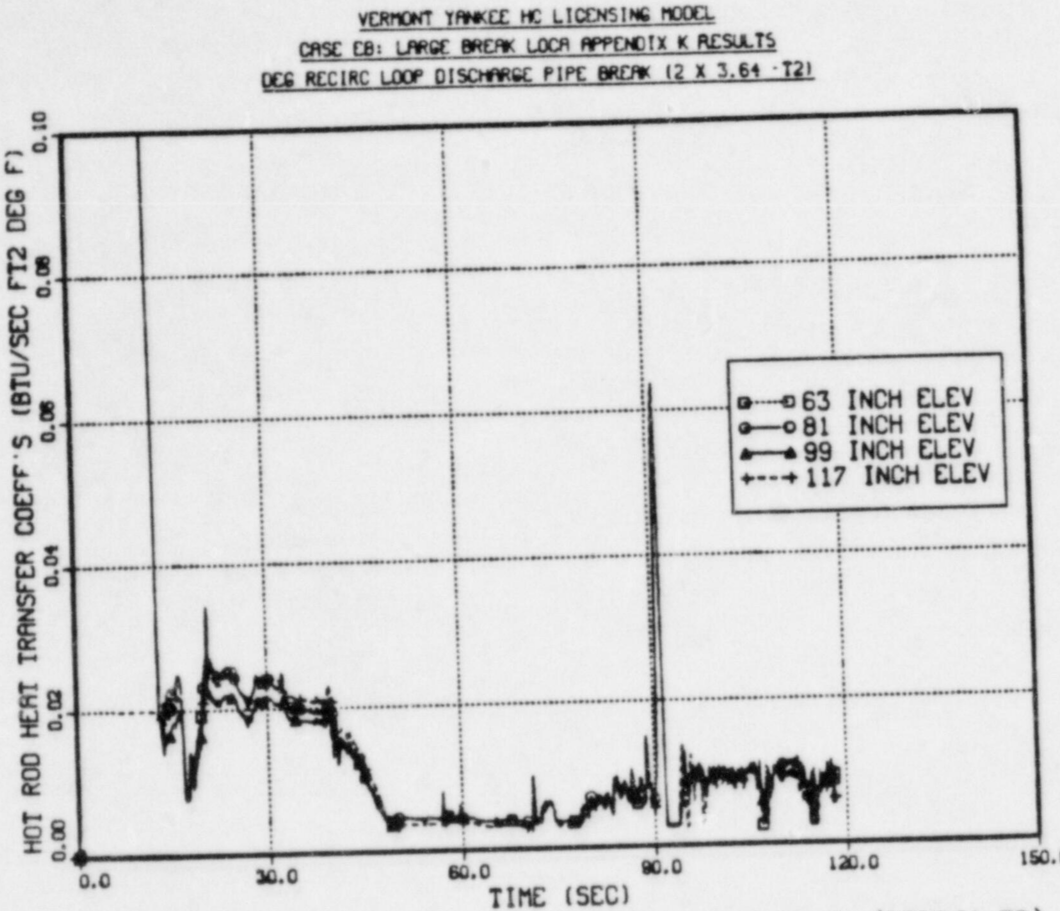

Figure 4.2-25: VY-HC Degraded Heat Transfer Coefs (LBLOCA-EB)

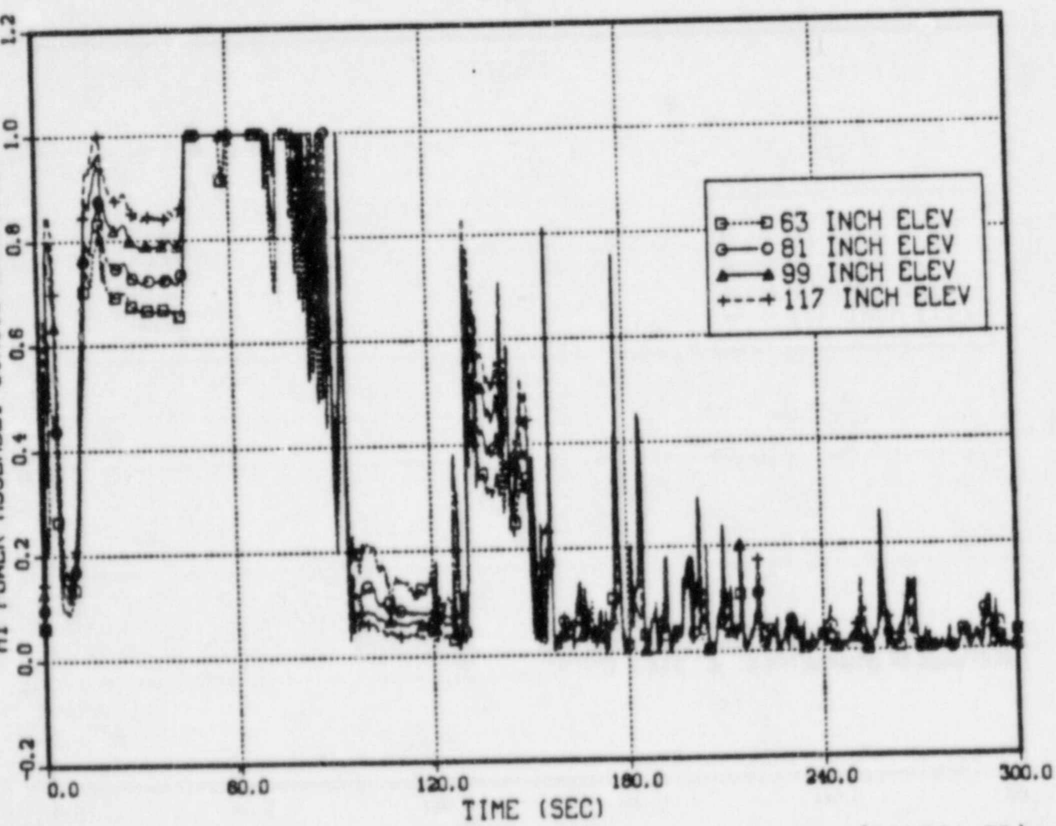

Figure 4.2-26: VY-HC High Power Bundle Qualities (LBLOCA-EB)

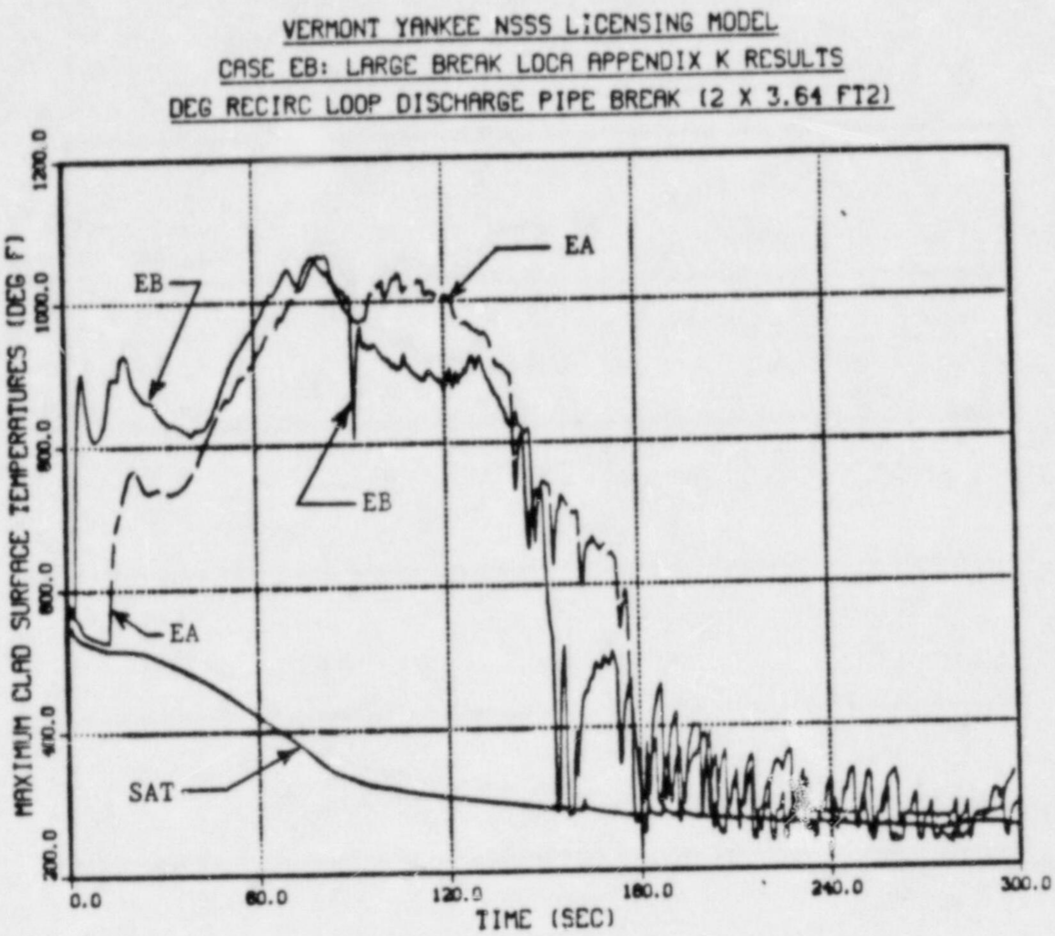

Figure 4.2-27: Peak Clad Temperatures for Cases EA & EB

5.0 SAMPLE PROBLEM 3: SMALL RECIRCULATION LOOP BREAK

This section presents licensing analysis results for a small (approximately three-inch diameter) break in the discharge pipe of one recirculation loop. The method used complies with 10CFR50.46 and Appendix K thereto. The accident assumptions are summarized in Table 5.0.1. As in the previous sample problems, the break occurs at 4.0E-6 seconds with a coincident loss of normal auxiliary power. HPCI is postulated to fail in compliance with the single failure criterion. Furthermore, RCIC is also postulated to fail. Therefore, the ECCSs available to mitigate the accident are: (a) two LPCS Systems, and (b) two LPCI Systems.

Table 5.0.2 summarizes the timing of significant events for this accident case. Figures 5.0-1 through 5.0-14 present the Vermont Yankee NSSS results for the system response. Figures 5.0-15 through 5.0-22 present the Vermont Yankee NSSS results for the reactor core response. Figures 5.0-23 through 5.0-27 present the Vermont Yankee HC (hot channel) results. The Vermont Yankee HC results are presented in order to demonstrate the implementation of the methodology described in Section 3.0.

Figures 5.0-1 and 5.0-2 show the reactor power and net reactivity. In the first second, the power drops sharply due to about -33 cents reactivity caused by voidance. Then, voidance is temporarily arrested causing the power to stabilize and briefly increase from 0.5 to 3.0 seconds. Finally, RPS underfrequency generates a scram signal at 3.0 seconds. At 3.56 seconds, control rod insertion is initiated. This quickly overpowers the short lived reactivity increase. At 7.23 seconds, the rods are fully inserted, and the chain reaction is ended. Beyond this time, the reactor power follows the Appendix K decay heat values.

Figure 5.0-3 shows the early feedwater and main steam line flow rates. The loss of auxiliary power to the condensate and feedwater pumps causes the feedwater flow to coast down in 5.0 seconds. The steam line flow drops in the first three seconds due to the decrease in power and feedwater flow. At 3.56 seconds, the Main Steam Isolation Valves (MSIVs) begin to close and are fully closed 10 seconds later. The main steam line flow ramps to zero accordingly.

The turbine stop and bypass valve signals at 18.9 and 19.05 seconds, respectively, are inconsequential. This is because they occur after the steam flow has been cut off by the MSIVs.

Figure 5.0-4 shows the narrow-range water level measured with respect to the top of the enriched fuel. The level generally declines and reaches the low level setpoint at 6.4 seconds.

The low low level signal (15.5 seconds) combines with the high drywell pressure signal (18.4 seconds) to initiate the countdown for the actuation of the Automatic Depressurization System (ADS). In the meantime, following MSIV closure and prior to ADS actuation, Safety Relief Valve 1 (SRV1) is cycled 6 times to maintain the pressure between its lower (1047 psid) and upper (1080 psid) setpoints. The valve cycling and the corresponding pressure behavior are shown in Figures 5.0-6 and 5.0-5, respectively. Finally, following the normal delay (120.4 seconds), the ADS operates as designed. This causes SRVs 1 through 4 to open completely at 138.4 seconds. Their combined discharge is also shown in Figure 5.0-6. The attendant sharp depressurization is clearly visible in Figure 5.0-5.

Figure 5.0-7 shows the break flow. Prior to ADS actuation at 138.4 seconds, the flow is usually choked and fairly constant at around 500 lb/sec. During this period, the break is discharging liquid water, as evidenced in the break void fraction plot of Figure 5.0-8. Following ADS actuation up to 230 seconds, the break flow declines sharply due to voidance (Figure 5.0-8). Between 170 and 230 seconds, the break flow is oscillatory. Given the void pattern of Figure 5.0-8, the mean values for the break flow between 200 and 230 seconds are felt to be too high. This behavior is currently believed attributable to the explicit implementation of Moody's break flow model. This belief is based on the observation of successive reductions in mean break flow over this period (200 to 230 seconds), as successively smaller time steps were used in the calculations. While the issue deserves attention from a best estimate standpoint, it is not felt to be significant from the evaluation model perspective. This is because a break spectrum is required for licensing and because there is evidence to support the conclusion that the higher break flow gives conservative results.

Figures 5.0-9 and 5.0-10 show the timing and injection flow rates of the two combined LPCS Systems and both LPCI Systems. The brief shutoff periods have been previously explained in connection with the large break (Section 4.1).

Figure 5.0-11 shows the net flow into the system, which remains negative until a few seconds after the injection of LPCI is initiated.

Figure 5.0-12 presents the NSSS mass inventory. The key points are: (a) the rapid mass depletion due to the ADS actuation at 138.4 seconds, and (b) the minimum inventory and turnaround due to ECC injection at the time of zero net inflow (Figure 5.0-11), and finally, (c) the recovery of inventory to the pre-ADS actuation level at 300 seconds.

Figures 5.0-13 and 5.0-14 show regional mass histories. The bypass region mass decreases slowly prior to 100 seconds and then begins to deplete more rapidly. This region begins to refill simultaneously with the initiation of LPCI injection. The upper plenum mass increases in the first 30 seconds. This results from the core void collapse due to the reactor scram. The hydrostatic head imbalance and inertia drive fluid from the downcomer through the core into the upper plenum. The MSIV closure then leads to an inventory rise. Eventually, the upper plenum mass reaches a maximum (30 seconds) and begins to decrease following the system trend. At 140 seconds, the initiation of the ADS causes a brief surge in upper plenum inventory due to flashing inside the core shroud. The brief surge is followed by a sharp decline. This region's inventory remains very low until it recovers a few seconds after LPCS injection begins. The lower plenum and the control rod guide tube region mass histories are shown in Figure 5.0-14. Both regional inventories are nearly insensitive to the break flow itself. A significant depletion is seen only during ADS actuation. Finally, the lower plenum responds to ECC injection with a small delay and begins to refill at 240 seconds.

Figures 5.0-15 and 5.0-16 present local inventories within the reactor core itself. In all three regions, viz., central average, low power, and high power, there is an early inventory surge which is due to void collapsing and inflow from the downcomer, as previously described in connection with the upper plenum. In all three regions, the inventory remains high until the ADS is actuated, This causes rapid depletion in all three regions. Eventually, the low power region begins to refill sooner than the central average and high power regions. By 280 seconds, all regions have regained their initial inventories.

Figures 5.0-17 and 5.0-18 present the outer clad surface temperatures and the qualities in the high power assembly at four elevations. In spite of the failure of HPCI, the outer clad remains well cooled prior to ADS actuation. Following this event, the quality in the hot assembly rises sharply, causing all elevations to experience Critical Heat Flux (CHF) at 157.0 seconds. At about 170 seconds, the rods are cooled by the fluid surge and lower vessel voiding caused by ADS actuation (Figure 5.0-16). This cooldown, however, is not sustained and a new heatup begins. The maximum temperatures occur shortly after the ECC injection begins. Shortly after that, the temperatures drop sharply to the saturation temperature also shown in Figure 5.0-17.

The heat transfer coefficients for the four elevations are shown in Figure 5.0-19. The values are seen to drop sharply at 157 seconds which coincides with the onset of CHF. The cooldown and final quench are evidenced by two periods of high values. The intervening period is characterized by low values (approximately 20 Btu/hr ft^2 ^oF) similar to those calculated for the large breaks.

Figures 5.0-20, 5.0-21, and 5.0-22 compare the outer clad surface temperatures, qualities, and heat transfer coefficients for the three regions, viz., low power peripheral, central average, and high power for the 81-inch elevation. The behavior in the other two regions is consistent with the previous description for the high power assembly.

Finally, the hot channel results are presented in Figures 5.0-23 to 5.0-27. These results replicate the corresponding Vermont Yankee NSSS results as discussed in Section 3.2.

TABLE 5.0.1

Summary of the Vermont Yankee Small Break Accident Assumptions

1. Small recirculation discharge break (0.05 ft^2) at 4.0E-6 seconds.

2. Loss of auxiliary power occurs at 4.0E-6 seconds.

3. Reactor scrams after 0.5-second delay from first RPS signal. Scram curve 67B-EOC is used.

4. Feedwater coasts down to 0.0 lbm/sec at 5.0 seconds.

5. MSIVs close in 10.0 seconds after isolation signal plus 0.5-second delay.

6. Recirculation pumps in A and B loops coast down with decreasing power from loss of MG sets.

7. ADS may actuate if appropriate signals exist. Thereafter, ADS cycles open/close at 12 psid between steam line and drywell any time ADS criteria are currently met.

8. HPCI steam turbine admission valve fails to open on demand. Thus, HPCI fails to inject. (This is the single failure.)

9. No credit for RCIC operation.

10. Two LPCS Systems inject on demand.

11. LPCI-A injection valve opens upon demand.

12. LPCI-B injection valve opens upon demand.

13. Drywell pressure and quality are assumed constant at 16.4 psia and 1.0°F for fluid sink conditions. High drywell pressure is conservatively estimated to occur at 18.4 seconds for this case by a containment calculation.

14. Wetwell pressure and temperature are assumed constant at 14.7 psia and 165°F for fluid source and sink conditions.

15. EM point reactor kinetics initially at 1,664 MWth.

16. EM core heat transfer.

17. Passive heat structures are included.

18. Moody two-phase critical flow model used at the break location.

19. 1971 ANS Decay Heat Standard plus 20%.

TABLE 5.0.2

Sequence of Events for Small Break Case EY

	Event	Time (sec)
1.	Break opens.	4.0E-6
2.	Loss of auxiliary power.	4.0E-6
3.	Control rod insertion initiated 0.5 second beyond estimated RPS underfrequency reactor trip signal.	3.56
4.	MSIVs begin to close.	3.56
5.	Feedwater flow coasts down to zero.	5.0
6.	MSIVs completely closed.	13.56
7.	Low-low level signal.	15.6
8.	Recirculation pump motors trip on low frequency at their MG sets.	17.0
9.	High drywell pressure.	18.45
10.	Turbine stop valve begins to close.	18.9
11.	Turbine bypass valve begins to open.	19.05
12.	Turbine bypass valve completely open.	19.65
13.	ADS valves open.	138.4
14.	Earliest nodal CHF.	157.0
15.	LPCS injection begins.	206.07
16.	Recirculation loop discharge valves begin to close.	206.07
17.	Minimum primary system inventory (99,483 lb) occurs.	214.40
18.	Peak clad temperature occurs (inner 742.3^{o}F; outer 740.5^{o}F).	221.90
19.	LPCI begins to inject.	230.47
20.	Average core and high power regions are well cooled.	251.0

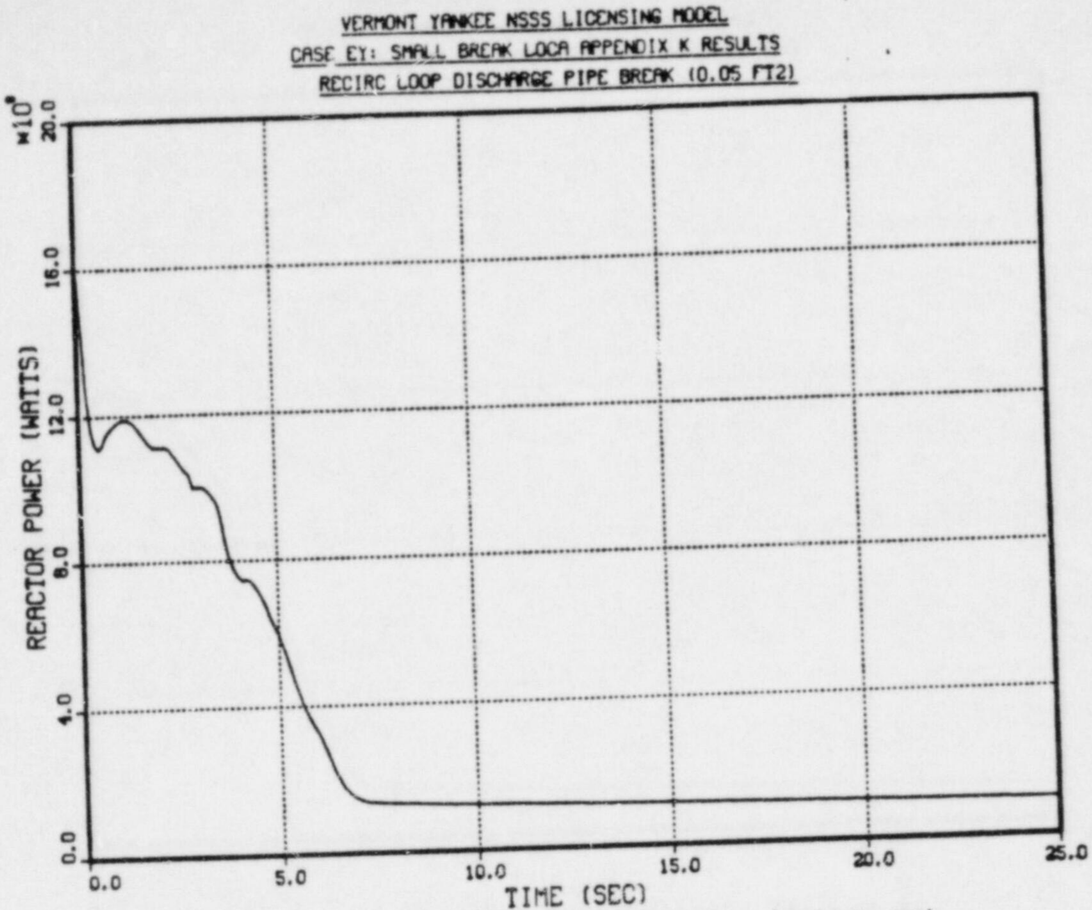

Figure 5.0-1: Reactor Power History (SBLOCA-EY)

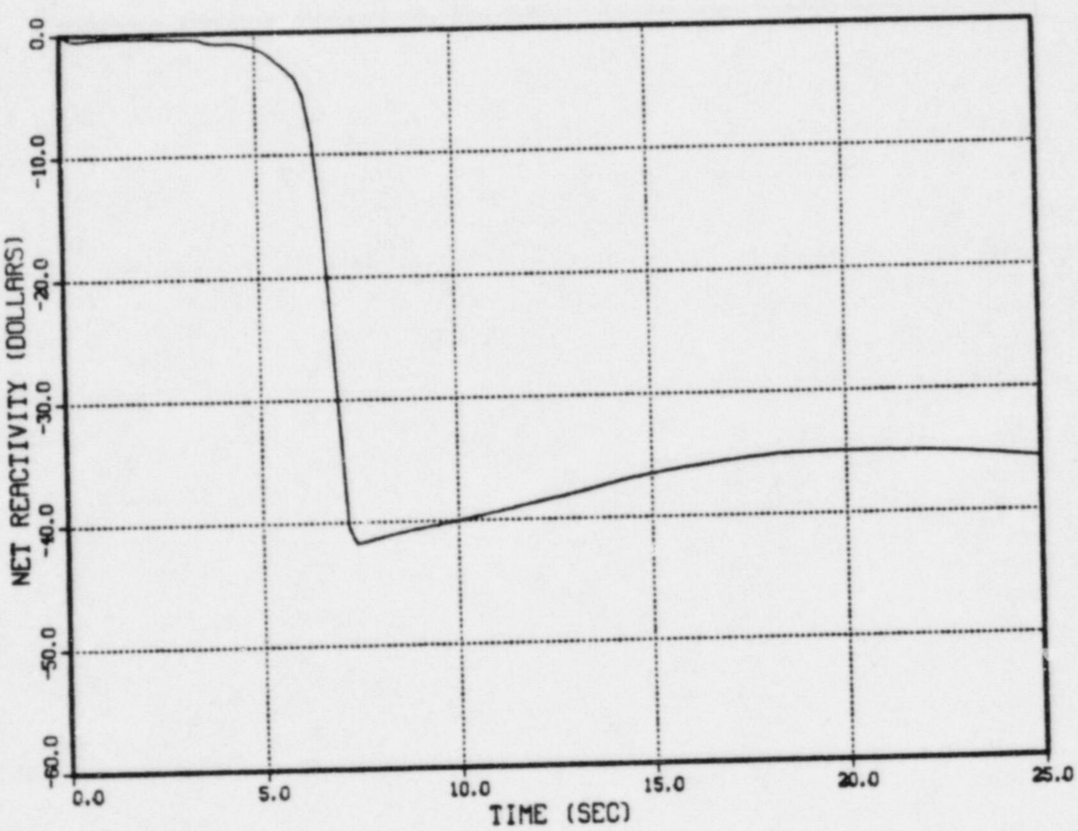

Figure 5.0-2: Net Reactivity (SBLOCA-EY)

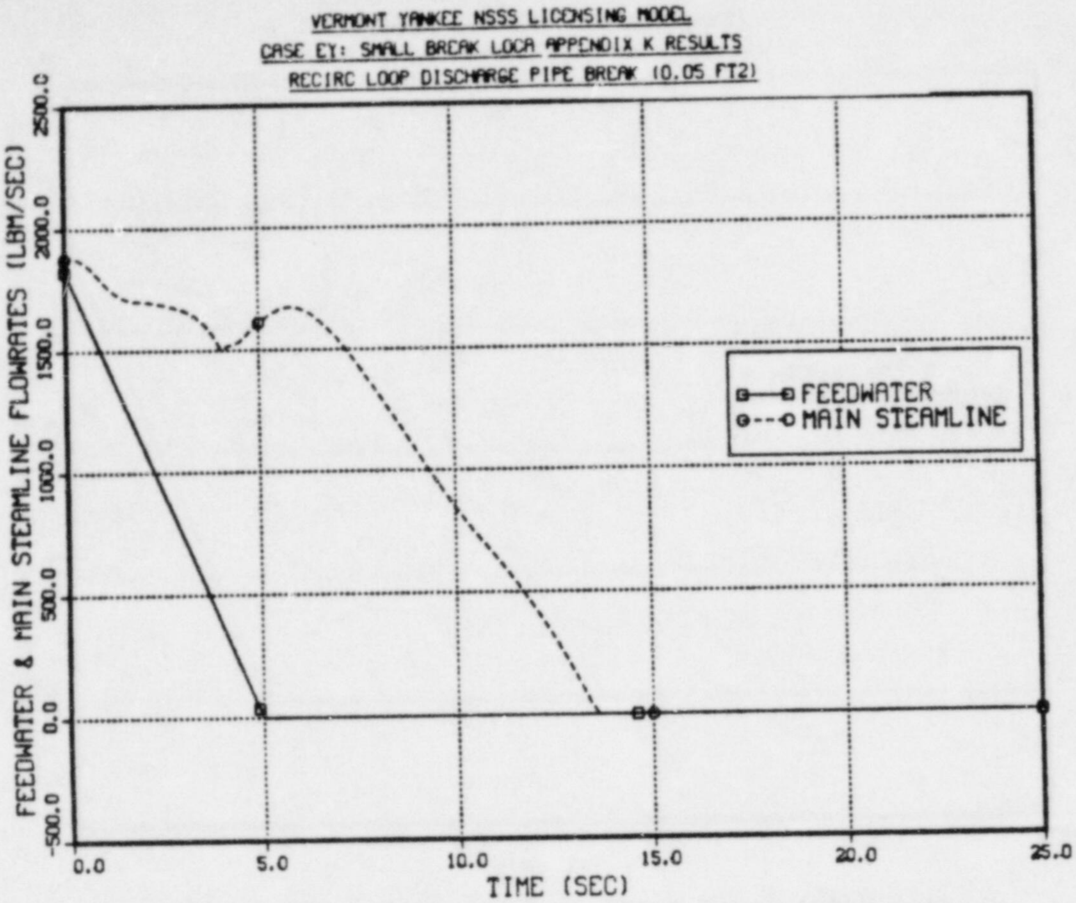

Figure 5.0-3: Feed and Main Steam Flows (SBLOCA-EY)

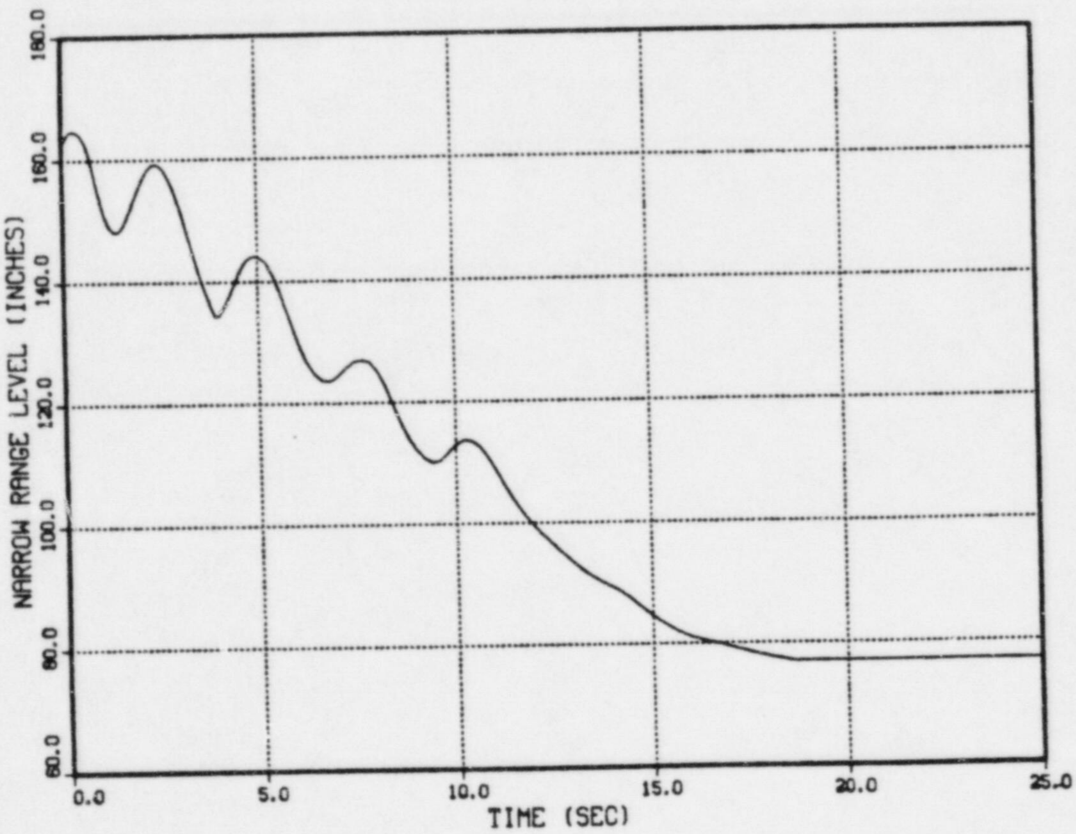

Figure 5.0-4: Vessel Water Level (SBLOCA-EY)

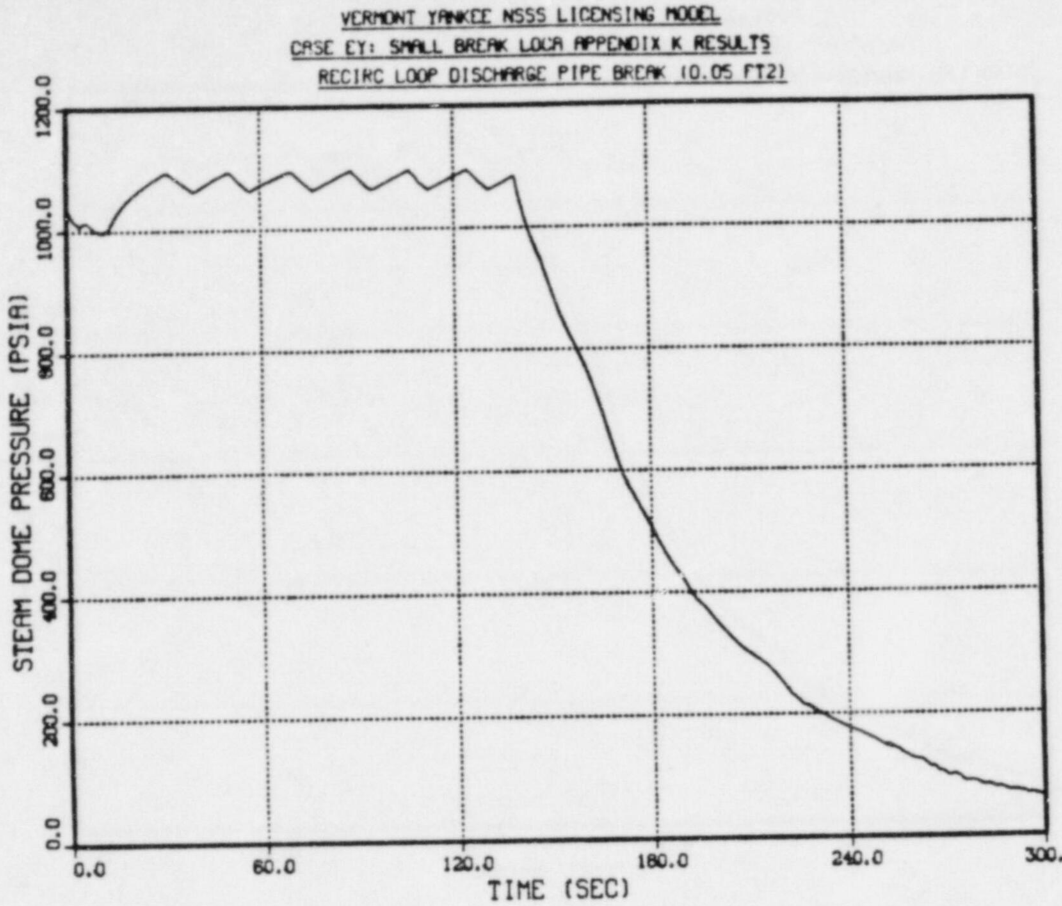

Figure 5.0-5: Vessel Pressure History (SBLOCA-EY)

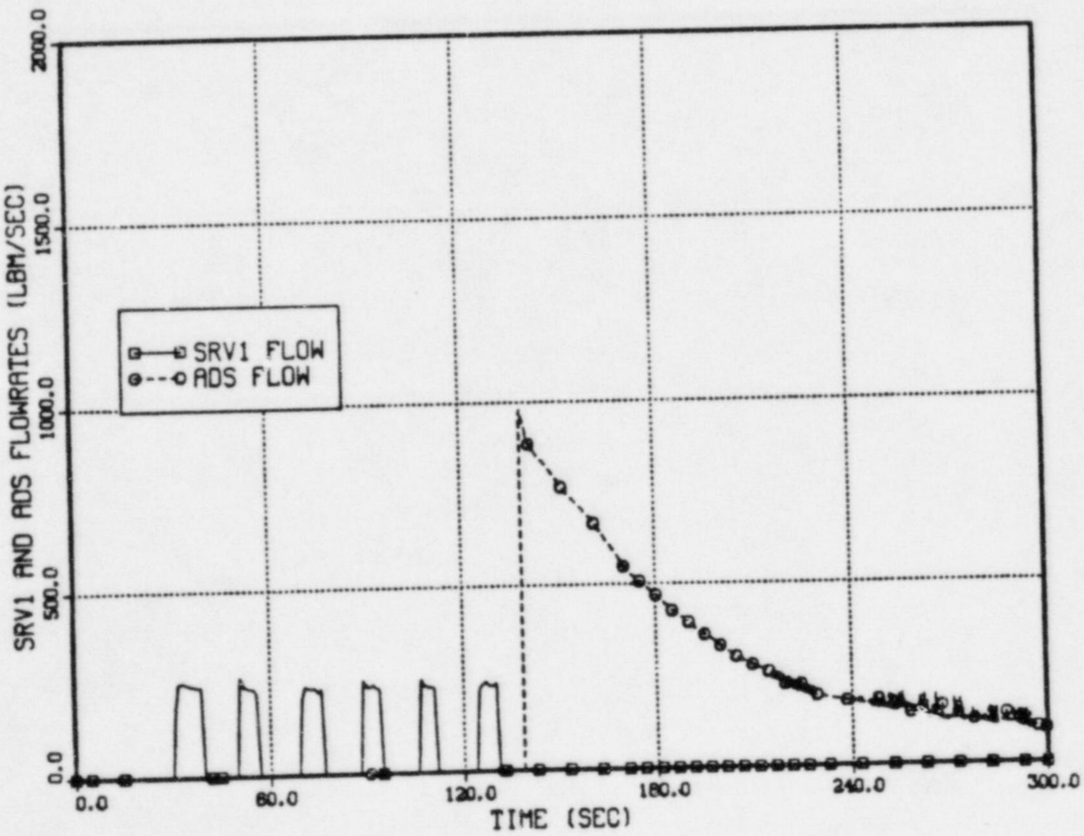

Figure 5.0-6: S/RV and ADS Flowrates (SBLOCA-EY)

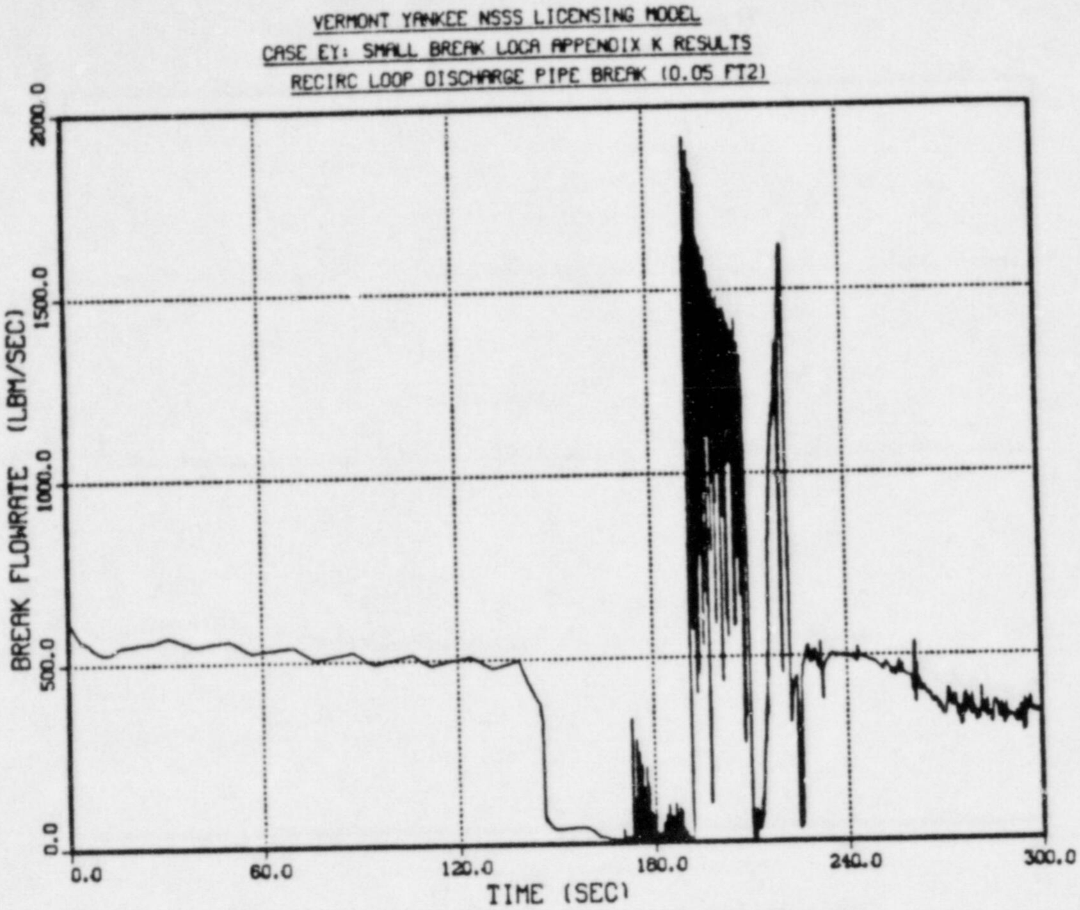

Figure 5.0-7: Break Flowrate (SBLOCA-EY)

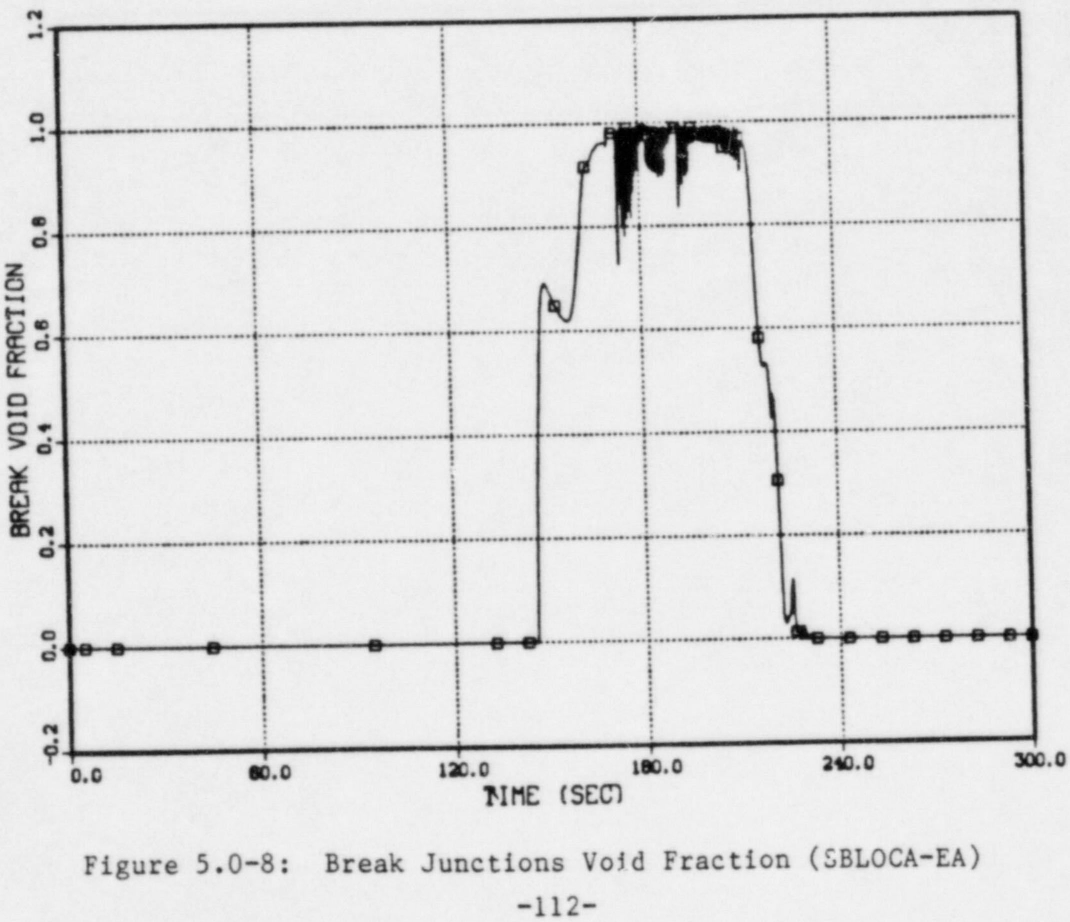

Figure 5.0-8: Break Junctions Void Fraction (SBLOCA-EA)

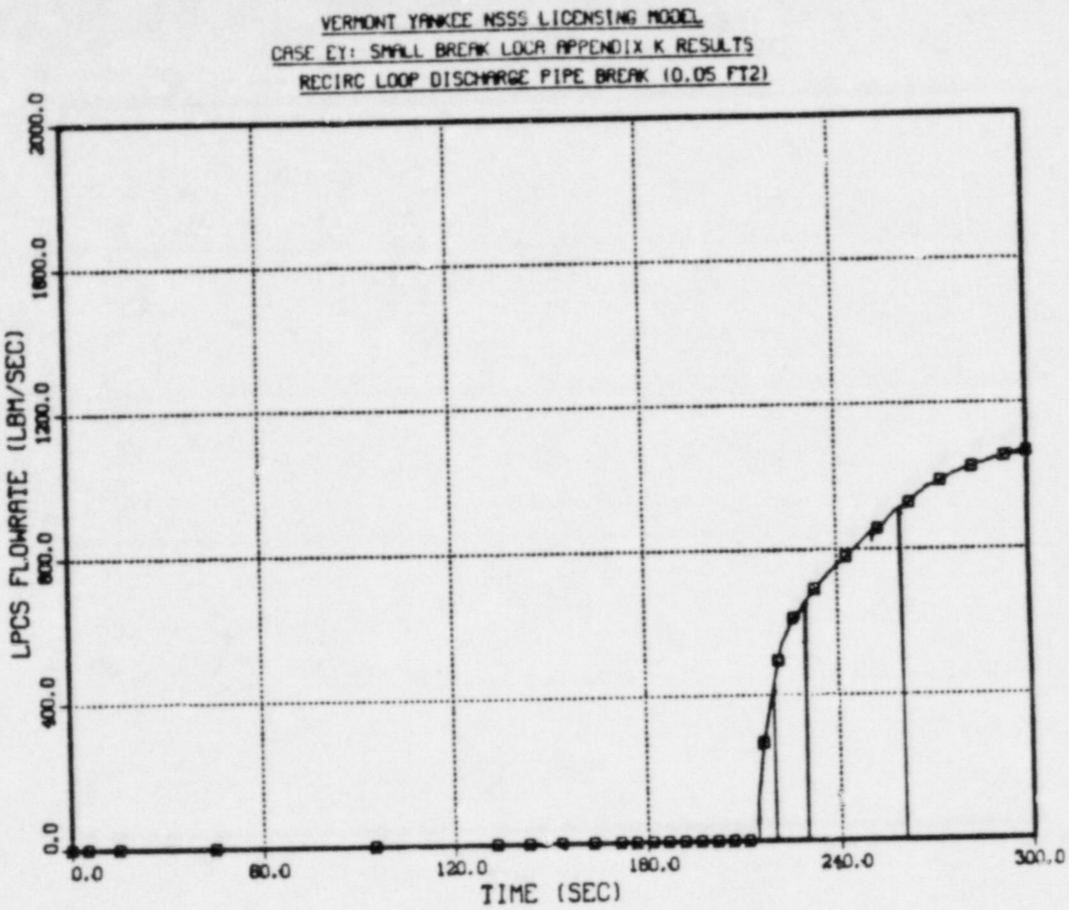

Figure 5.0-9: LPCS Flowrate (SBLOCA-EY)

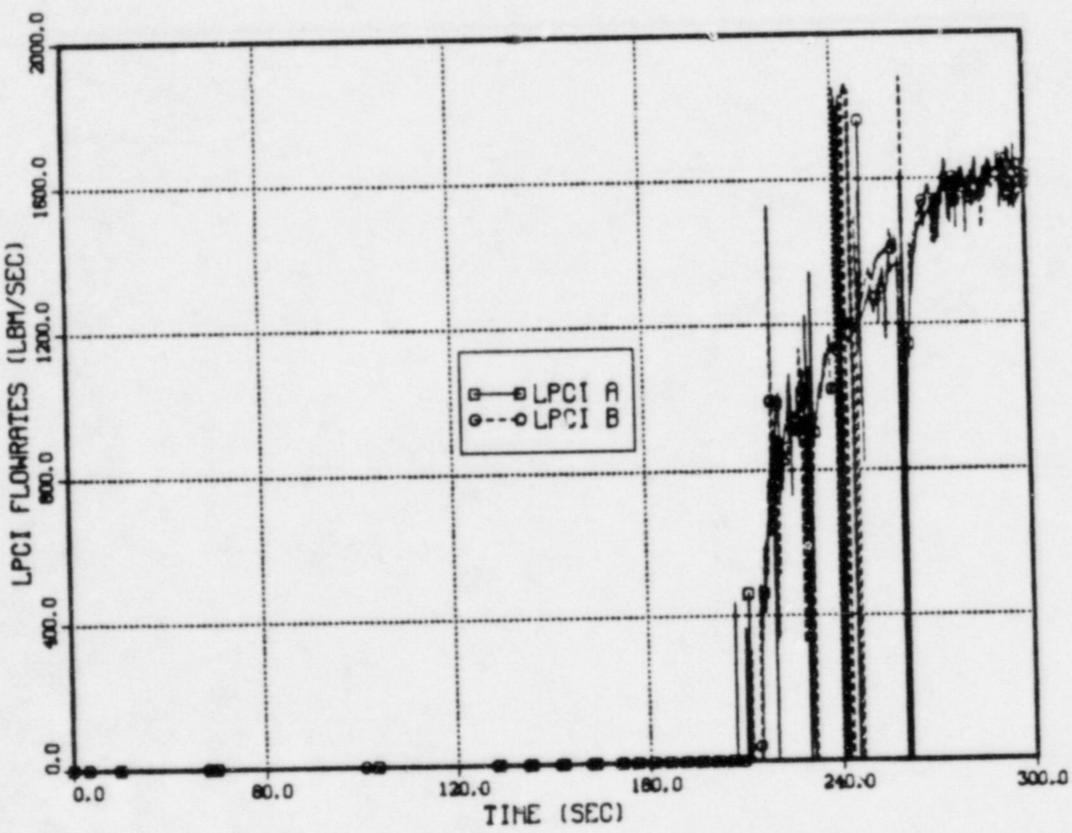

Figure 5.0-10: LPCI A and B Flowrates (SBLOCA-EY)

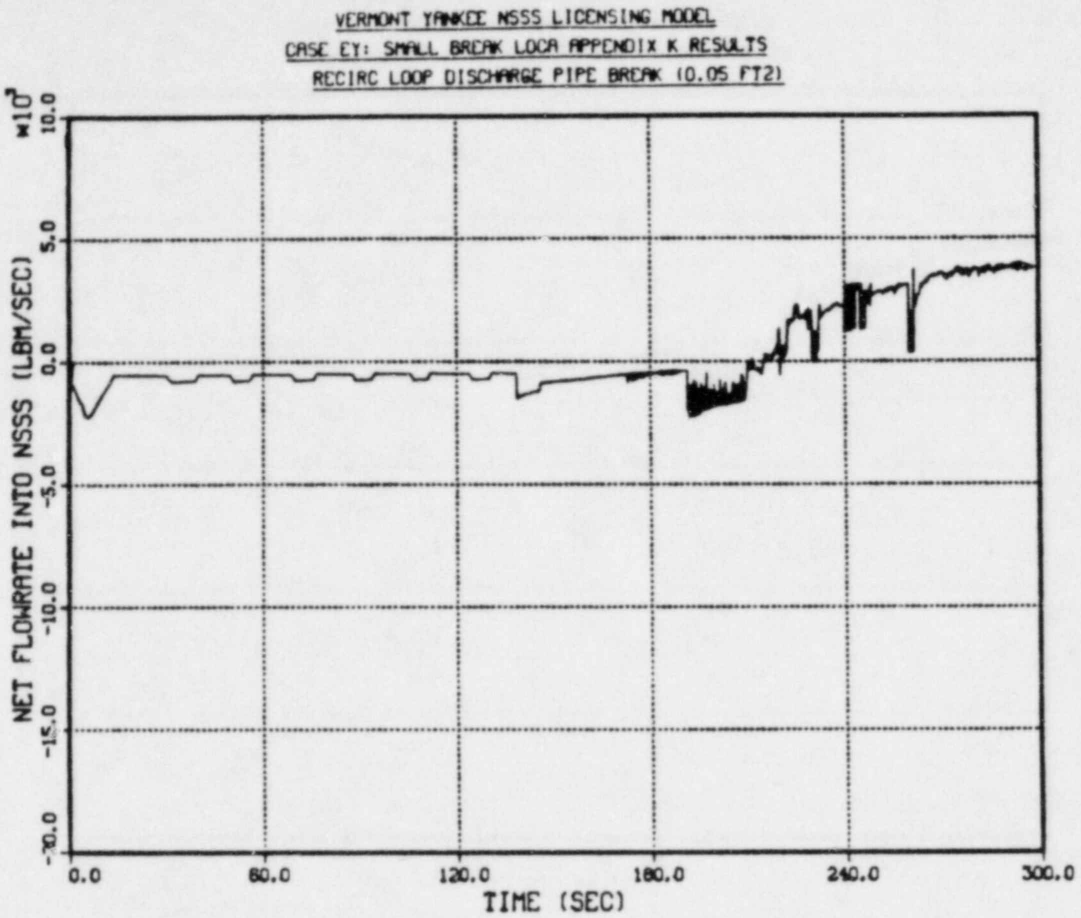

Figure 5.0-11: Net Flowrate into NSSS (SBLOCA-EY)

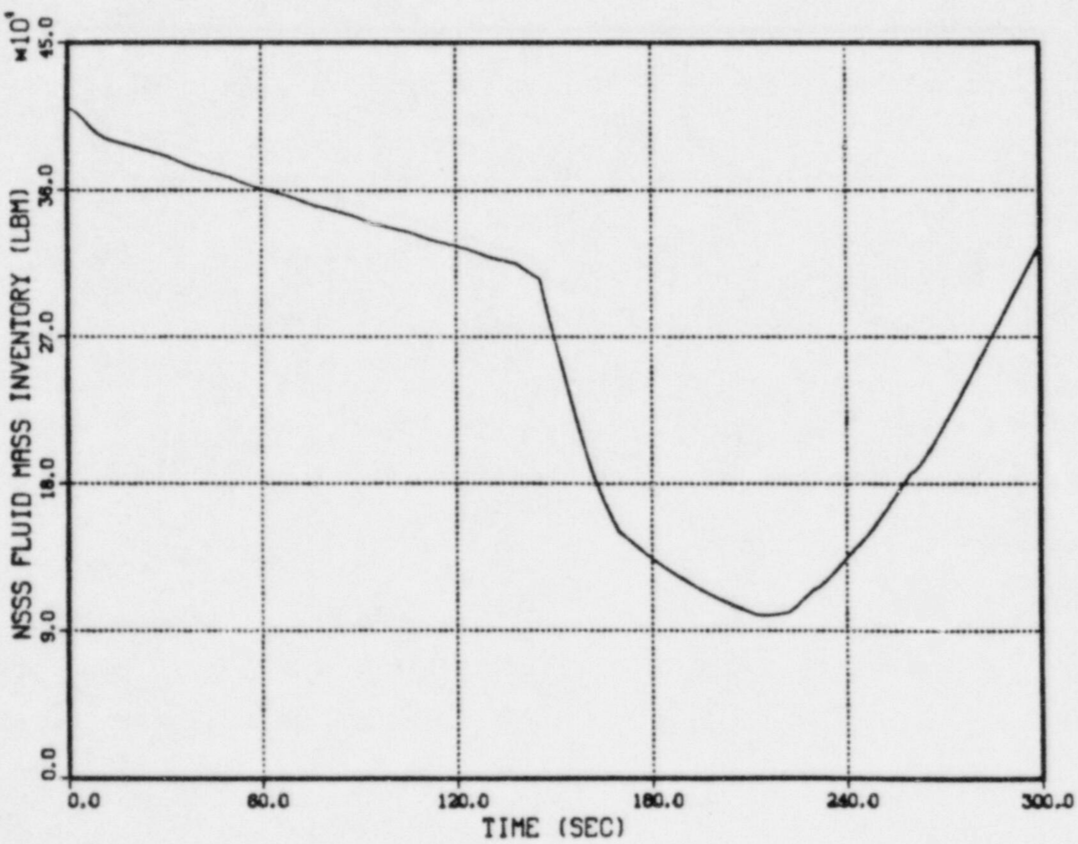

Figure 5.0-12: NSSS Fluid Mass Inventory (SBLOCA-EY)

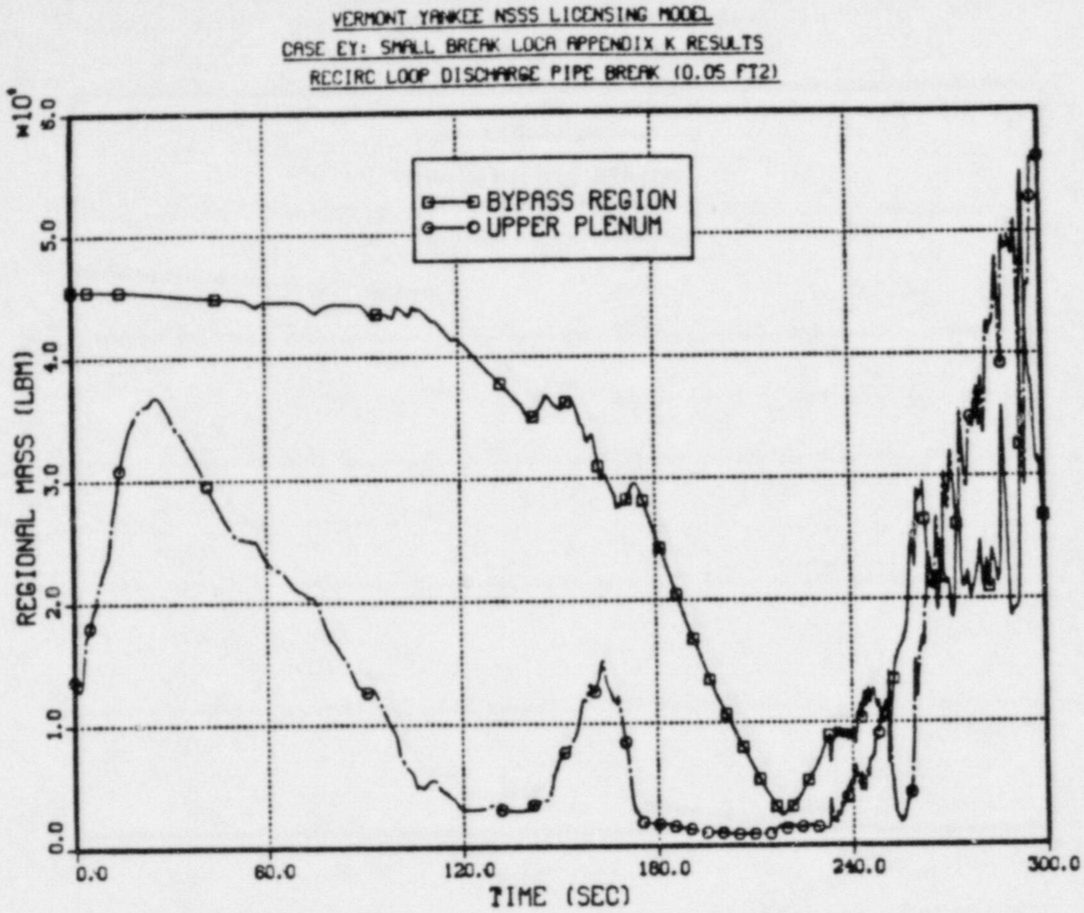

Figure 5.0-13: Bypass and Upper Plenum Fluid Mass (SBLOCA-EY)

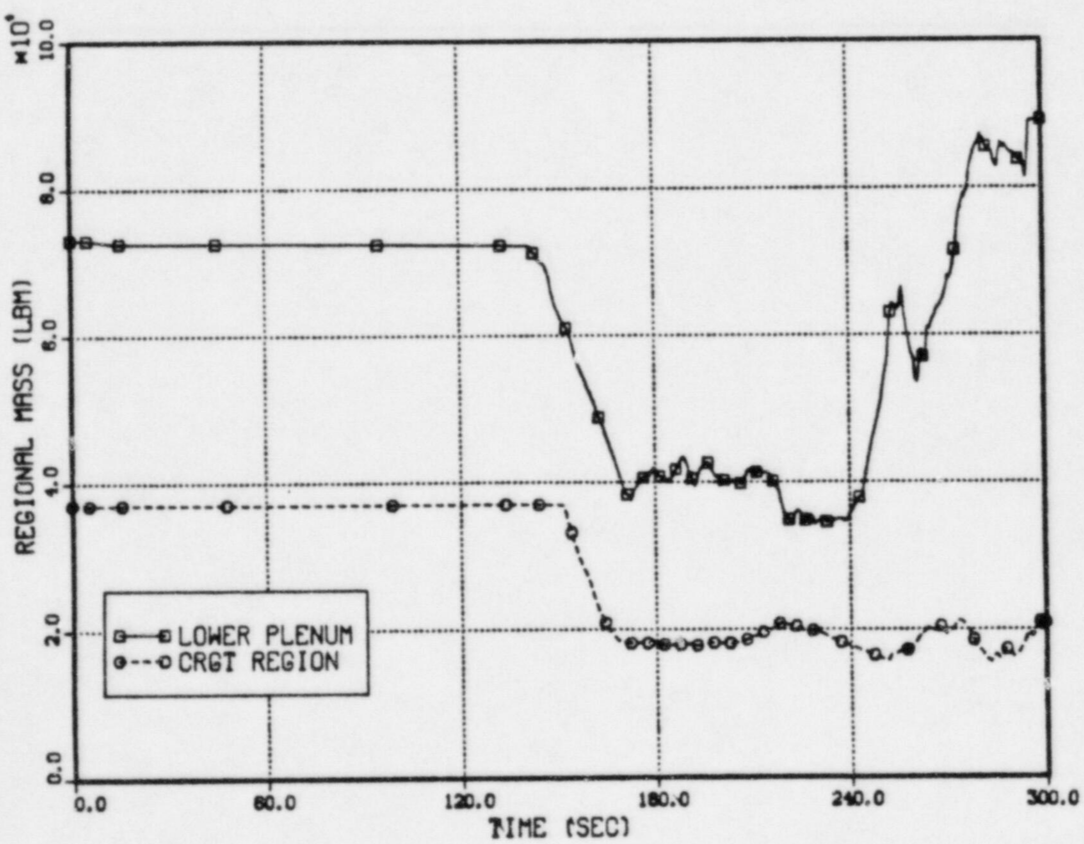

Figure 5.0-14: CRGT and Lower Plenum Fluid Mass (SBLOCA-EY)

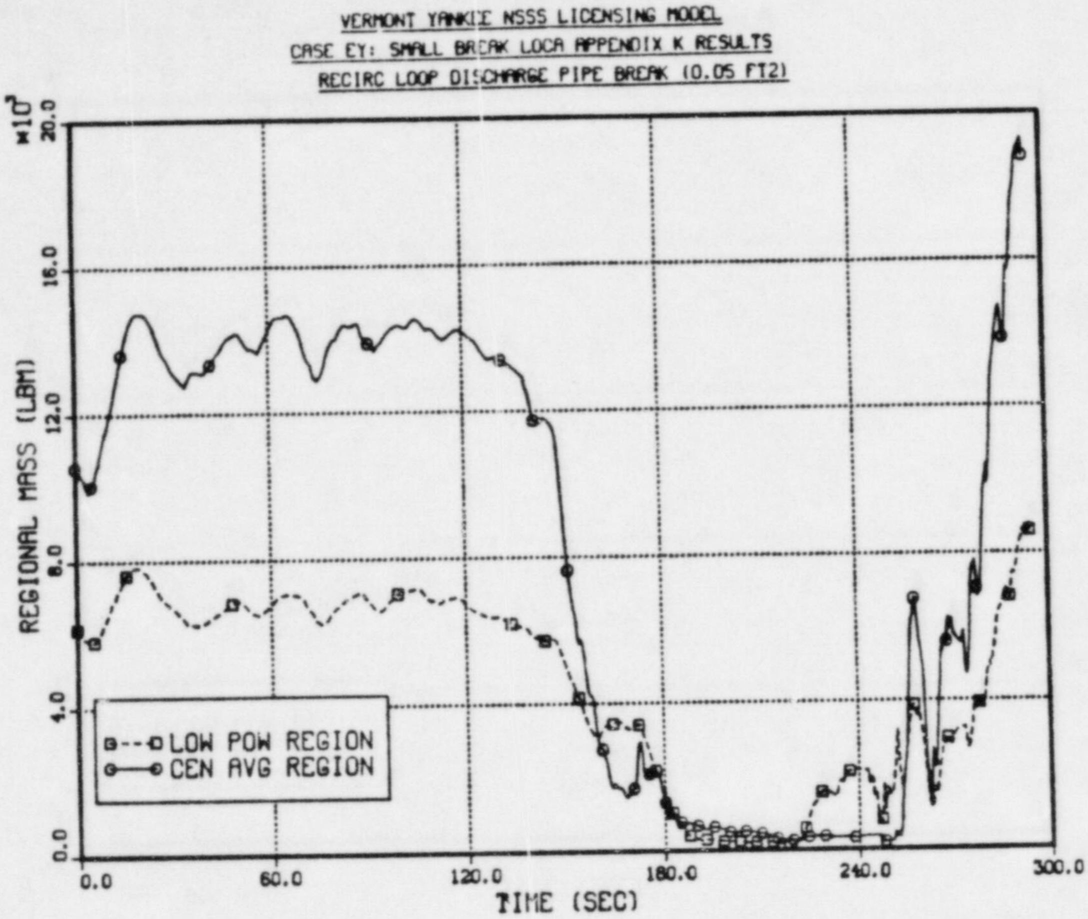

Figure 5.0-15: Outer and Central Core Fluid Mass (SBLOCA-EY)

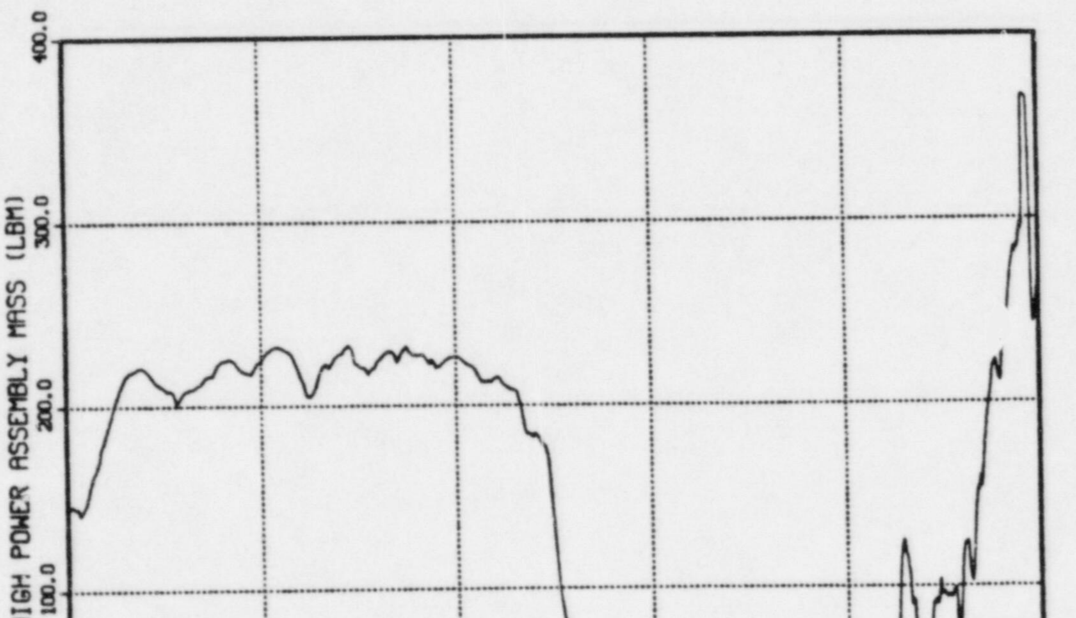

Figure 5.0-16: High Power Assembly Fluid Mass (SBLOCA-EY)

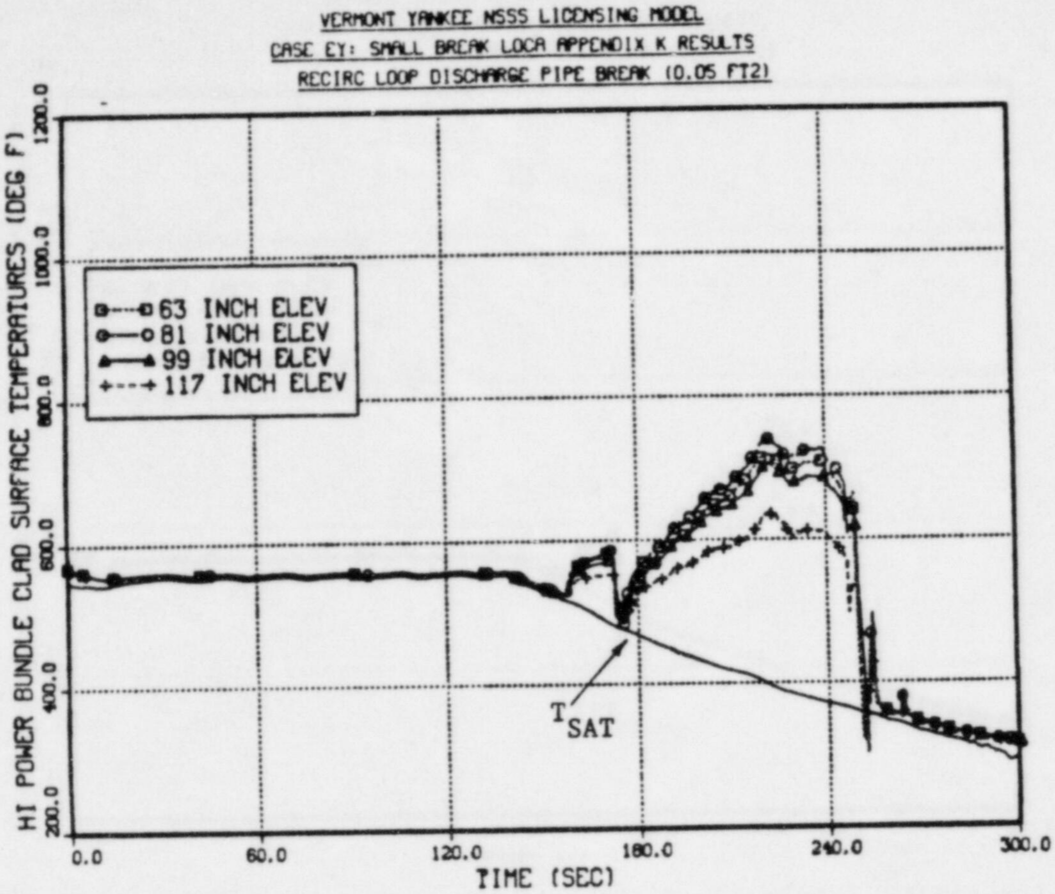

Figure 5.0-17: High Power Bundle Clad Temperatures (SBLOCA-EY)

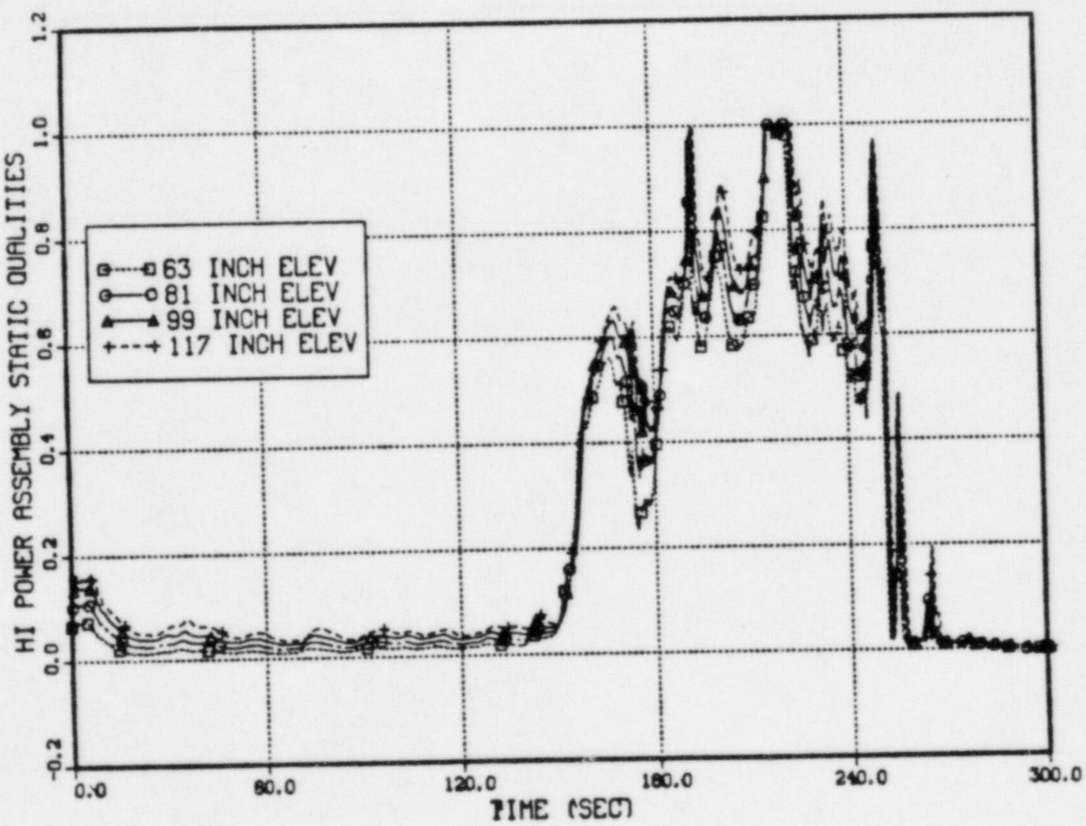

Figure 5.0-18: High Power Bundle Qualities (SBLOCA-EY)

VERMONT YANKEE NSSS LICENSING MODEL
CASE EY: SMALL BREAK LOCA APPENDIX K RESULTS
RECIRC LOOP DISCHARGE PIPE BREAK (0.05 FT2)

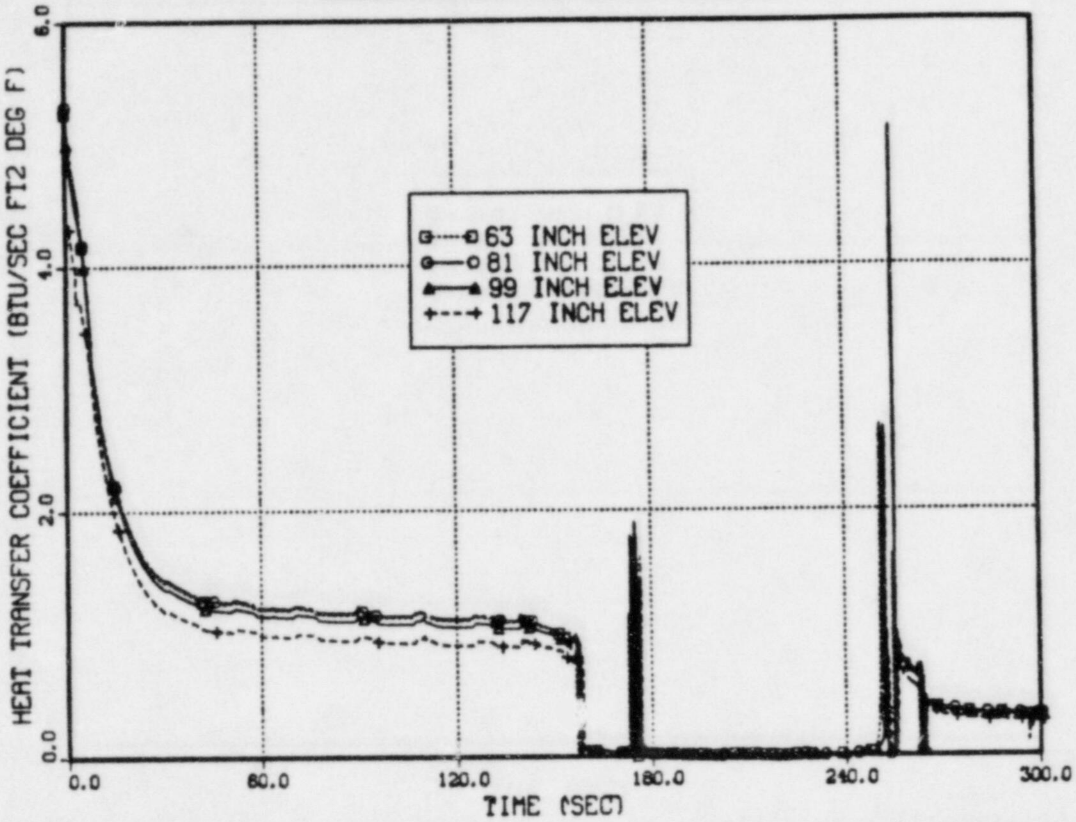

Figure 5.0-19: Long Term Heat Transfer Coefficients (SBLOCA-EY)

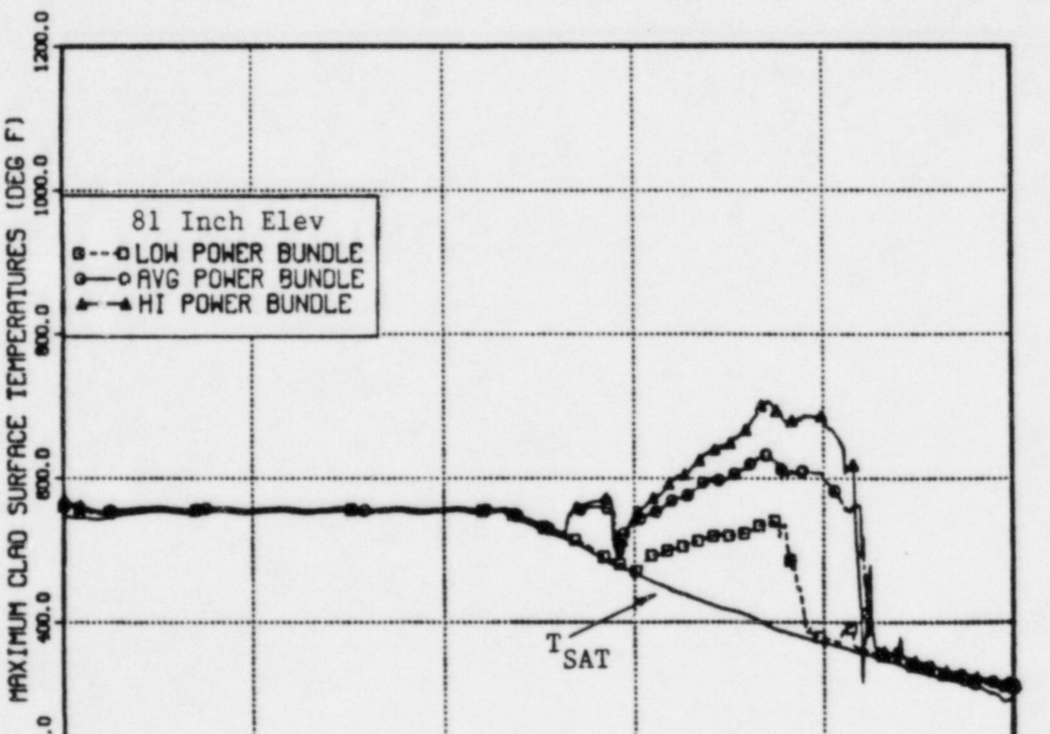

Figure 5.0-20: Maximum Bundle Clad Temperatures (SBLOCA-EY)

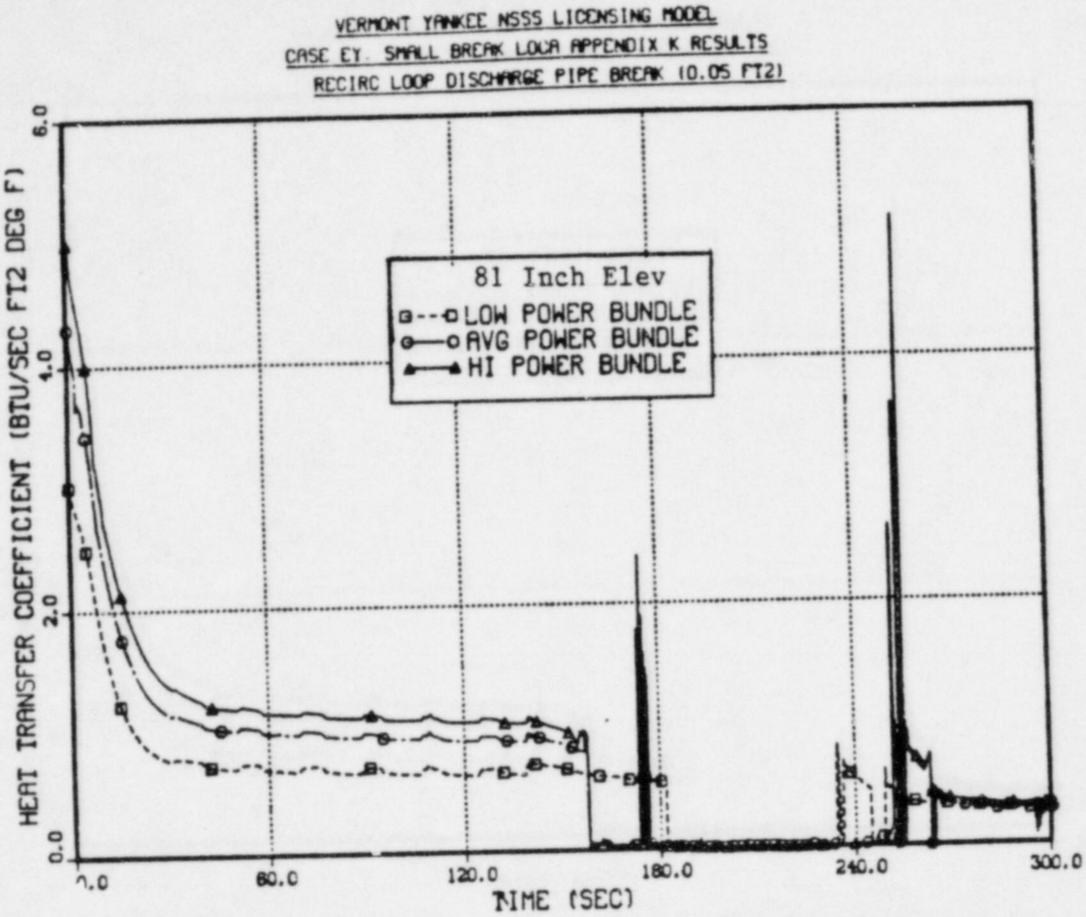

Figure 5.0-21: Bundle Heat Transfer Coefficients (SBLOCA-EY)

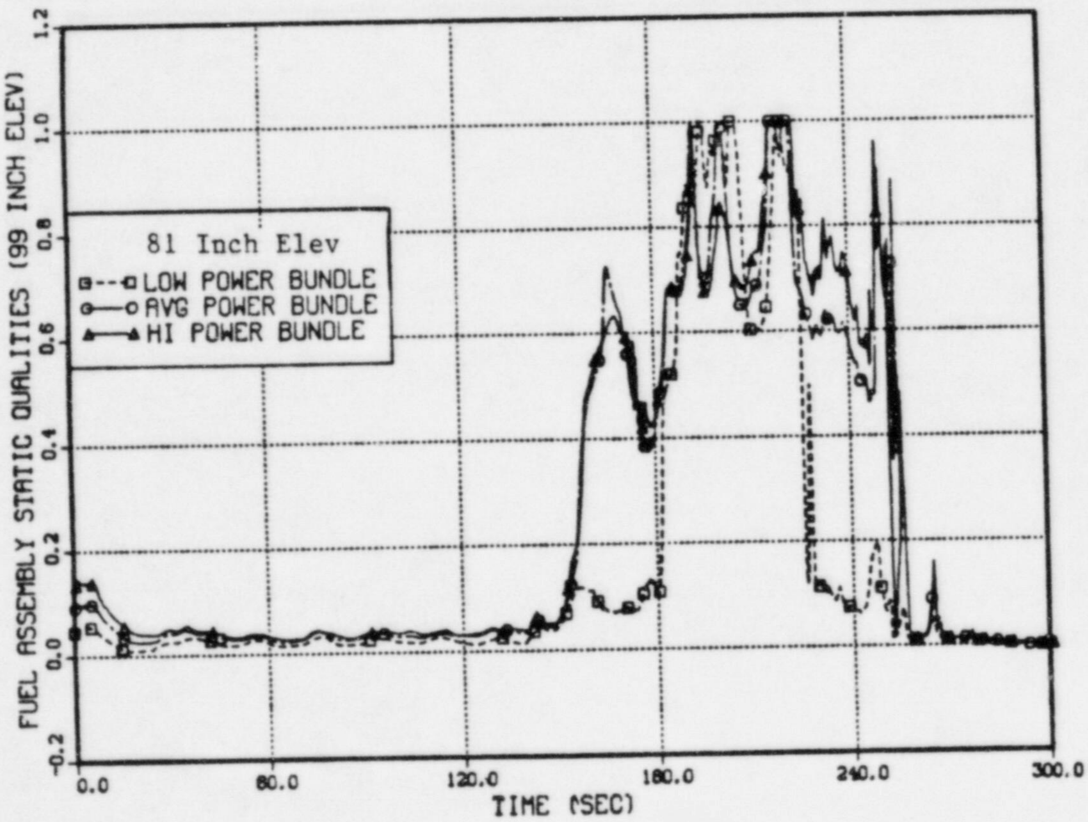

Figure 5.0-22: Bundle Static Qualities (SBLOCA-EY)

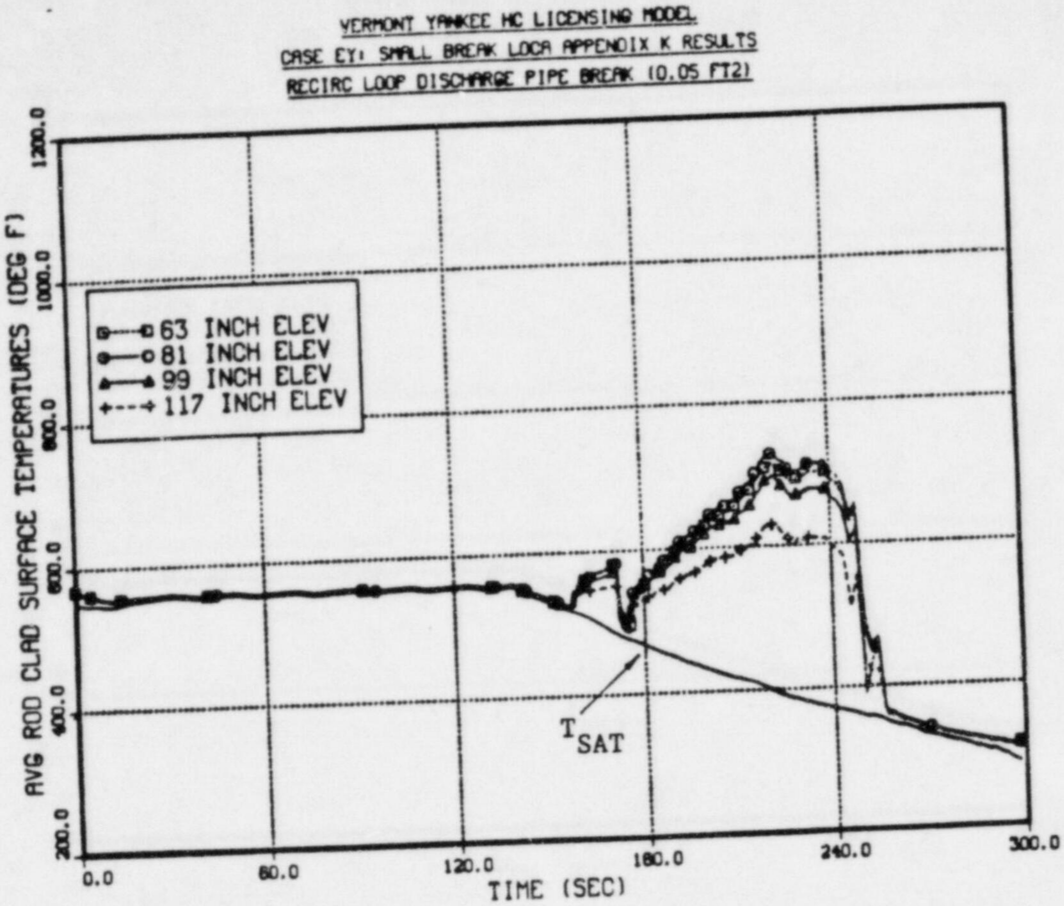

Figure 5.0-23: VY HC Avg Rod Clad Temperatures (SBLOCA-EY)

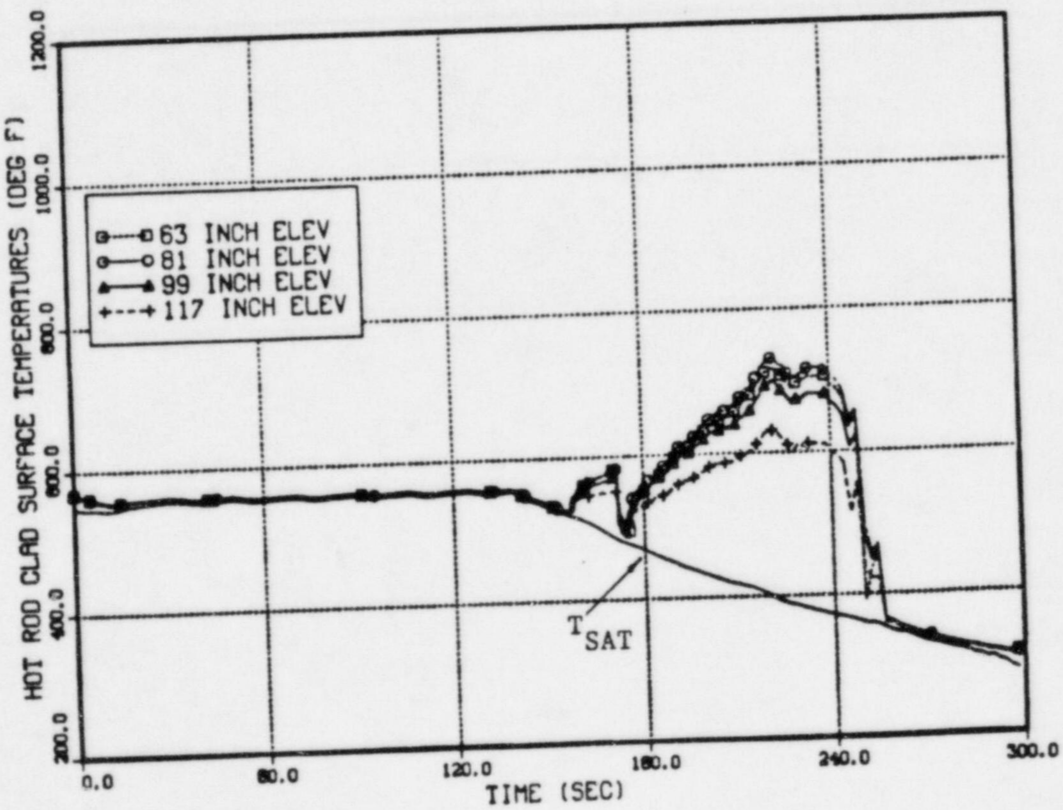

Figure 5.0-24: VY HC Hot Rod Clad Temperatures (SBLOCA-EY)

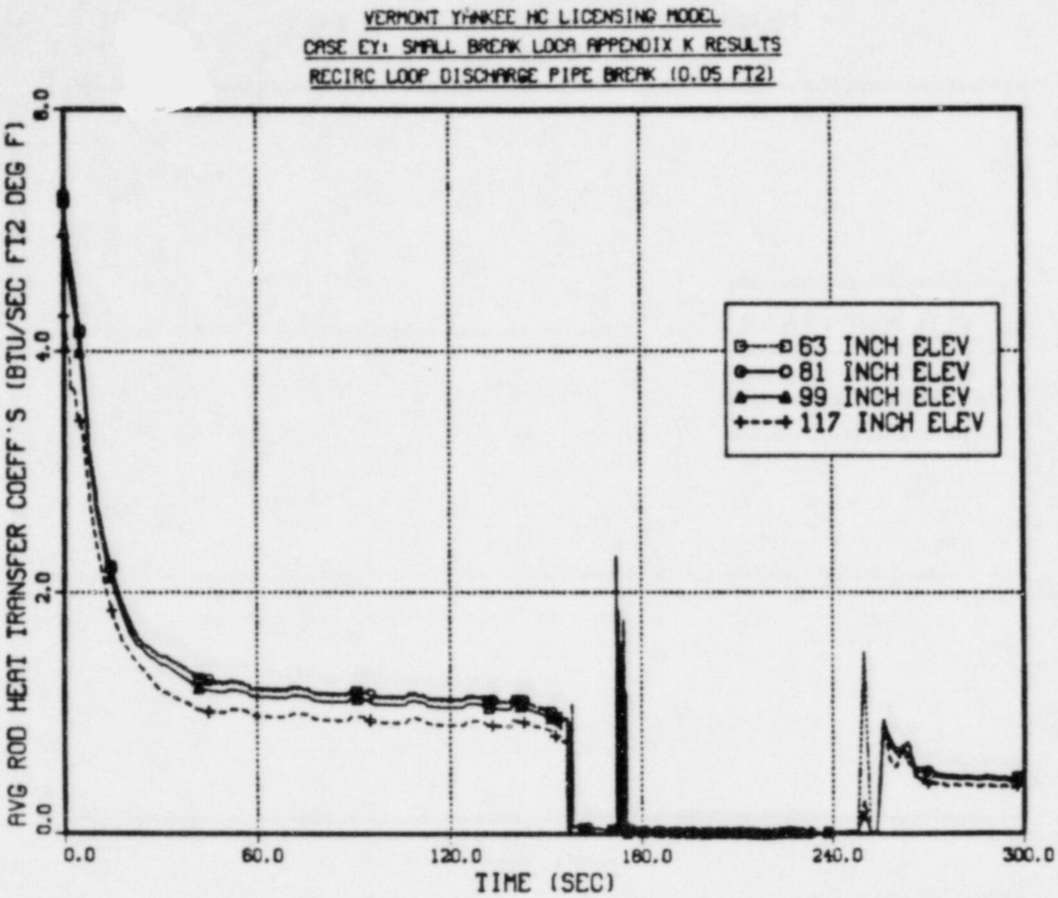

Figure 5.0-25: VY HC Avg Rod Heat Transfer Coefs (SBLOCA-EY)

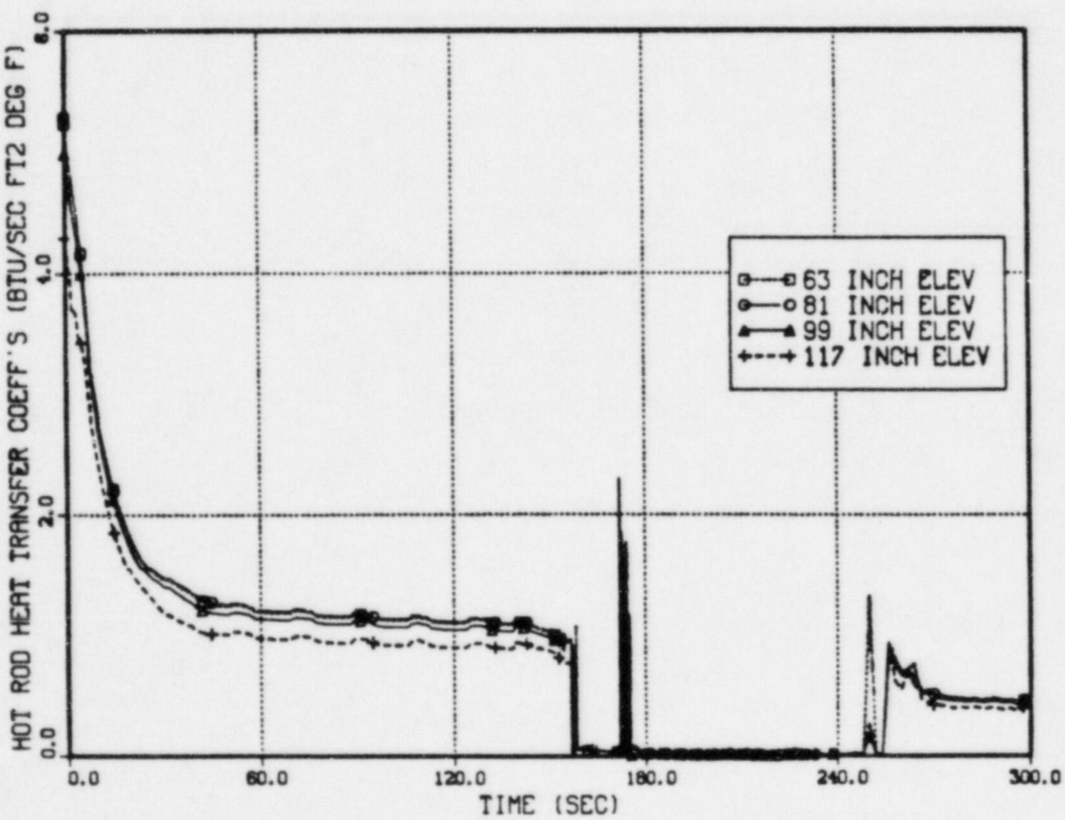

Figure 5.0-26: VY HC Hot Rod Heat Transfer Coefs (SBLOCA-EY)

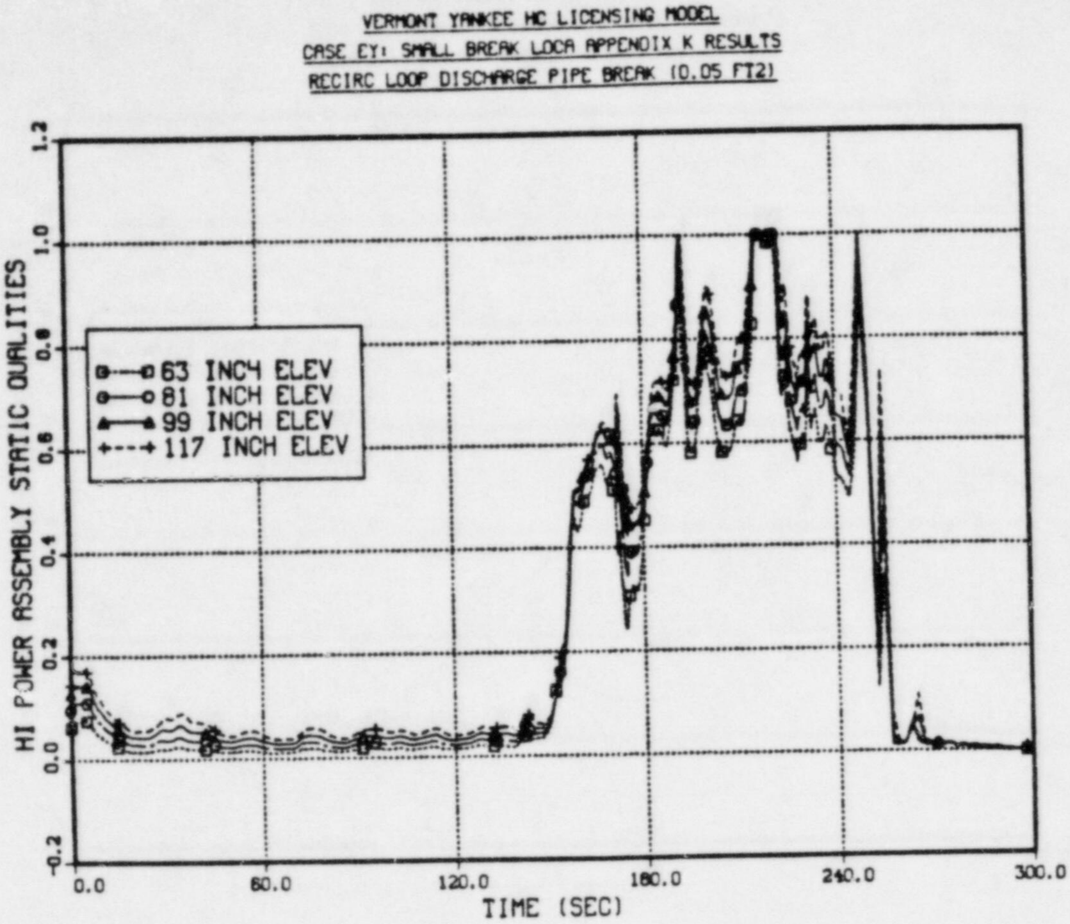

Figure 5.0-27: VY HC High Power Bundle Qualities (SBLOCA-EY)

6.0 CONCLUSIONS

The Vermont Yankee BWR loss-of-coolant accident licensing analysis method has been described. This method is based upon the RELAP5YA and FROSSTEY computer codes. Each code has been extensively assessed against experimental data, analytical solutions, and sensitivity studies summarized in Tables 1.3.2 and 1.3.3 and Reference A-2. This assessment has shown that these codes will yield conservative and reliable predictions for both large and small break LOCAs when applied in a conservative manner.

The method uses two Vermont Yankee base input models: Vermont Yankee NSSS and Vermont Yankee HC. Conservative initial fuel rod conditions for these models are derived from FROSSTEY calculations. Each base input model uses licensing assumptions and computational options within the RELAP5YA code that comply with 10CFR50.46 and Appendix K requirements. Additional conservative assumptions, including certain items listed in Tables 4.0.1 and 5.0.1, are incorporated in the input data for the two base models.

Three LOCA sample problems have been presented to demonstrate the application of this method for the Vermont Yankee Nuclear Power Station. These include two large break cases and one small break case. For each case, the calculated results show the following:

a. The calculated peak clad temperature for the two large break and the small break cases are below the 2,200^{o}F peak clad temperature limit specified in 10CFR50.46(b)(1).

b. The total cladding oxidation at the peak location is below the 17% limit specified in 10CFR50.46(b)(2).

c. The hydrogen generated in the core by cladding oxidation during these accidents is less than the 1% limit specified in 10CFR50.46(b)(3).

d. The calculations show that the core retained a coolable geometry for each case analyzed. The fuel rod models for the three core regions show minor dimensional changes but no clad ruptures are calculated. Thus, the coolable geometry criterion in 10CFR50.46(b)(4) is satisfied for these three cases.

e. Each calculation shows that the available ECCS successfully initiated and the core was well cooled in less than 300 seconds. Therefore, the long-term core cooling criterion in 10CFR50.46(b)(5) is satisfied for these cases.

Together, the RELAP5YA computer code, FROSSTEY computer code and the two Vermont Yankee base input models will be used to obtain LOCA ECCS results for Vermont Yankee that comply with 10CFR50.46 criteria and Appendix K requirements.

7.0 REFERENCES

1-1. Final Safety Analysis Report: Vermont Yankee Nuclear Power Station, Vermont Yankee Nuclear Power Corporation, Brattleboro, Vermont, as amended.

1-2. Fernandez, R. T., R. K. Sundaram, J. Ghaus, A. Husain, J. N. Loomis, L. Schor, R. C. Harvey, and R. Habert, RELAP5YA - A Computer Program for Light-Water Reactor System Thermal-Hydraulic Analysis, Volume I: Code Description, Yankee Atomic Electric Company Report YAEC-1300P (October 1982). (Proprietary)

1-3. Fernandez, R. T., R. K. Sundaram, J. Ghaus, A. Husain, J. N. Loomis, L. Schor, R. C. Harvey, and R. Habert, RELAP5YA - A Computer Program for Light-Water Reactor System Thermal-Hydraulic Analysis, Volume II: Users Manual, Yankee Atomic Electric Company Report YAEC-1300P (October 1982). (Proprietary)

1-4. Fernandez, R. T., R. K. Sundaram, J. Ghaus, A. Husain, J. N. Loomis, L. Schor, R. C. Harvey, and R. Habert, RELAP5YA - A Computer Program for Light-Water Reactor System Thermal-Hydraulic Analysis, Volume III: Code Assessment, Yankee Atomic Electric Company Report YAEC-1300P (October 1982). (Proprietary)

1-5. YAEC Letter to USNRC, "Response to the NRC Questions on RELAP5YA," FYR 85-22, FVY 85-18 (March 1, 1985).

1-6. YAEC Letter to USNRC, "Response to the NRC Questions on RELAP5YA," FYR 85-48 (April 30, 1985).

1-7. YAEC Letter to USNRC, "Response to the NRC Questions on RELAP5YA," FYR 85-72 (July 1, 1985).

1-8. YAEC Letter to USNRC, "Response to the NRC Questions on RELAP5YA," FYR 85-87 (August 15, 1985).

1-9. YAEC Letter to USNRC, "Response to NRC Questions on the RELAP5YA Computer Program," FYR 85-121 (November 1, 1985).

1-10 YAEC Letter to USNRC, "Response to Additional NRC Questions on the RELAP5YA Computer Code," FVY 85-122, FYR 85-139 (December 31, 1985).

2-1 VerPlanck, D. M., Methods for the Analysis of Boiling Water Reactors Steady-State Core Physics, YAEC-1238, March 1981.

2-2 VerPlanck, D. M., SIMULATE-2: A Nodal Core Analysis Program for Light-Water Reactors, YAEC-1392P, June 1984.

2-3 Letter, D. B. Vassallo, NRC, to J. B. Sinclair, "Methods Reports Acceptance," NVY 82-157, September 15, 1982.

3-1 Steves, L. H., et al., HUXY: A Generalized Multi-Rod Heatup Code With 10CFR50, Appendix K Heatup Option User's Manual, Exxon Nuclear Company, Inc., XN-CC-33(A), Revision 1, November 14, 1975.

4-1. Meyers, L. L., BWR Refill-Reflood Program: Final Report, EPRI NP-3093, GEAP-30157, NUREG/CR-3223, General Electric Company, San Jose, CA (April 1984).

4-2. Lee, L. S., G. L. Sozzi, S. A. Allison, BWR Large Break Simulation Tests: BWR Blowdown/Emergency Core Cooling Program, Volume 2, EPRI NP-1783, GEAP-24962-2, NUREG/CR-2229, General Electric Company, San Jose, CA (July 1982).

4-3. Lee, L. S., G. L. Sozzi, S. A. Allison, BWR Large Break Simulation Tests: BWR Blowdown/Emergency Core Cooling Program, Volume I, EPRI NP-1783, GEAP-24962-1, NUREG/CR-2229, General Electric Company, San Jose, CA (April 1982).

APPENDIX A: FUEL ROD INITIAL CONDITIONS FROM FROSSTEY

A.1 FROSSTEY DESCRIPTION

RELAP5YA requires the user to supply information concerning the initial conditions of the fuel contained within the NSSS model. The information is extracted from the FROSSTEY (Fuel Rod Steady-State Thermal Effects) code (References A-1 and A-2) developed by Yankee Atomic Electric Company. The FROSSTEY code has undergone extensive benchmarking against both commercial and test reactor fuel rods irradiated under a wide variety of conditions. FROSSTEY has proved capable of predicting the response of these rods in a manner consistent with its intended use (i.e., commercial rods operating at low to high burnups at moderate power levels). THe FROSSTEY code has been reviewed by the NRC's core performance branch and a SER on the code's use in non-LOCA applications at low to moderate exposures has been issued. YAEC is submitting an updated version of the code with the intention of gaining approval for use at high fuel burnup and for LOCA applications.

The FROSSTEY code is specifically designed to provide fuel rod temperature distributions, fuel-to-clad gap conductances, fuel rod dimensional changes, fission gas release and gap inventories, internal pressure, and stored energy predictions as a function of the fuel rod operating history. The RELAP5YA code requires a number, but not all, of these parameters to be specified as input.

The general component models which comprise the FROSSTEY code are listed in Table A.1. The code models the fuel rod as a number of axial segments and a plenum region which are in communication with each other. The power history of the fuel rod is represented by a series of constant power steps. A file management structure within the code allows the user to store appropriate variables to allow a problem restart at a particular time step in subsequent computer runs.

A.2 SYSTEM CALCULATION DATA

The Vermont Yankee NSSS core was divided into three radial zones for analysis purposes in the FROSSTEY fuel performance calculations. These radial zones correspond to the three regions defined in the RELAP5YA NSSS model. The low power peripheral region contains 116 fuel bundles with the highest exposures, but relatively low power. The average power central region contains 248 fuel bundles with lower exposures but with a higher power. The high power central region represents the four highest power bundles within the core.

The response of the regions is defined to be the response of a single fuel rod operating with the region's average parameters. All fuel was modeled as P8X8R bundles containing 62 fuel rods at 2.89 w/o U-235 within a UO_2 matrix. The active fuel length was represented as 25 axial slices each 6 inches in length. The FROSSTEY model employed the recommended set of options.

The power history of the three regions is based on Cycle 10 which is fairly representative of Vermont Yankee's present operation. The power level chosen for the central average region is representative of the power level at the exposure intervals (end-of-cycle) for those bundles. The high power central region power is conservatively set at a peaking factor of 1.50. The 1.50 peaking factor bounds all assembly radial peaking factors seen to date at Vermont Yankee. The average power central region has a peaking factor of 1.186. The peripheral region's peaking factor is 0.5851 and is defined as the remainder of the core total power. The exposure of each region is defined by the upper and lower bound of the batch average exposures within the regions.

The fuel rod response, predicted by the FROSSTEY code, was based on a long-term exposure with a Haling axial power shape, and is restarted for a short-term exposure step with a highly peaked chopped cosine axial power shape. During the long-term exposure, the reactor was assumed to be operating at 1593 MWth (100% NBR), and during the short-term was assumed to be at 1664 MWth (104.5% NBR). The switch to the higher power is designed to encompass the Appendix K power uncertainty (1.02%) without incurring the permanent effects on certain physical processes which are history-dependent.

A.3 HOT CHANNEL CALCULATION DATA

The hot channel calculations are performed in a manner that provides assurance that the bundle power history bounds all fuel bundles in the core. The response is predicted in a manner similar to the method used to define the NSSS region's responses. The response is based on a long-term exposure employing bounding power and a Haling axial shape followed by a short-term exposure at a target power level employing a highly peaked shape. The target power level is defined to be high enough to bound all allowable peak location powers.

The switch to the short-term power level is accomplished by raising the power to correspond with operation at 1664 MWth and a change to a higher peaked axial shape. The switch occurs at the time corresponding to the exposure point where the LOCA limit is to be evaluated. The hot rod and the average bundle peak power location are both placed on the target power level.

A.4 REFERENCES

A-1 Schultz, S. P. and K. E. St.John, Method for the Analysis of Oxide Fuel Rod Steady-State Thermal Effects (FROSSTEY) Code/Model Description Manual, YAEC-1249P, April 1981.

A-2 Schultz, S. P. and K. E. St.John, Method for the Analysis of Oxide Fuel Rod Steady-State Thermal Effects (FROSSTEY) Code Qualification and Application, YAEC-1265P, June 1981.

A-3 Letter, D. B. Vassallo (USNRC) to R. W. Capstick (VYNPC), "Approval of Use of Fuel Performance Code FROSSTEY," September 27, 1985.

TABLE A.1

FROSSTEY Component Models

Closed Coolant Channel Heat Balance

Coolant-to-Cladding Heat Transfer

Clad Crudding

Clad Corrosion

Clad Creepdown

Clad Elastic Deflection

Clad Axial Growth

Thermal Dimensional Changes

Thermal Flux Depression

Fuel Densification

Fuel Relocation/Cracking

Fuel Fission Product Swelling (History-Dependent)

Fission Gas Production and Release (History-Dependent)

Indigenous (Sorbed) Gas Release and Reaction

Pellet Dish Effects

Grain Growth and Thermal Restructuring

Fuel Melting Dimensional Changes

Fuel Cladding Gap Conductance (Component Analysis)

Rod Internal Pressure

Fuel Heat Capacity and Stored Energy