XN-NF-82-20

SUPPLEMENT 3

ENC ECCS EVALUATION OF A CE 2×4 PWR USING THE EXEM/PWR ECCS MODEL

LARGE BREAK EXAMPLE PROBLEM

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1.0 INTRODUCTION AND SUMMARY

This document shows, by an example large break LOCA ECCS calculation, the system input model and example results that Exxon Nuclear Company (ENC) has obtained using the ENC EXEM/PWR ECCS Evaluation model for a Combustion Engineering (CE) 2x4 reactor operating at design power. Calculated results are demonstrated to meet the criteria specified by 10 CFR 50.46 and to be performed by an approved ECCS evaluation model in conformance to 10 CFR 50, Appendix K.

This document presents the results of a large break analyses for a Combustion Engineering (St. Lucie 1) reactor using the ENC EXEM/PWR ECCS model at a 2700 MWt power, 2250 psia pressurizer pressure, and 549^{o}F core inlet temperature with ENC 14x14 reload fuel. The postulated loss-of-coolant accident (LOCA) evaluated for the example calculation was the double-ended guillotine configuration for one pump discharge line using a discharge coefficient of 1.0.

The analysis involved calculations using the following ENC EXEM/PWR code versions[1,2,3,4] RELAP4-EM/ENC28FC for blowdown and hot channel analyses, REFLEX[3,4,8] for core reflood analyses, CONTEMPT LT/22 for containment backpressure analysis, and TOODEE2/APR82[4] for heatup analysis. FLECHT/ENC2 multipliers,[1] developed for PWR's with containment backpressure similar to calculations for this CE plant geometry, were used in these analyses.

Principal results of these analyses for the 1.0 DECLG break are contained in Tables 1.1 and 1.2. These results include a Peak Cladding Temperature (PCT) of 2154°F and a maximum local Zr/H_2O reaction of less than 6.5 percent at 395 seconds after the break. These analyses were performed at 2754 MWT which is 102 percent of rated power as indicated in Table 1.1. This analysis, if determined to be the limiting break, would support operation of the plant with a total Linear Heat Generation Rate (LHGR) of 15.0 kW/ft. Included in Table 1.2 are summaries of the transient times calculated for major events. Additional results of this analysis are presented in subsequent sections of the report.

Table 1.1 Analysis Results of Example Problem
(DECLG C_D = 1.0)

Analysis Results	DECLG (C_D=1.0)
Peak Clad Temperature, °F	2154
Peak Clad Temperature Location, ft from bottom	8.97
Local Zr/H_2O Reaction (max), % (@ 395 s)	6.44
Local Zr/H_2O Location, ft from bottom	8.97
Total H_2 Generation, % of Total Zr Reacted	<< 1.0
Hot Rod Burst Time, sec	53.52
Hot Rod Burst Location, ft from bottom	8.22
Peak Linear Heat Generation Rate, BOCREC, kW/ft	.752
Analysis Input	
License Core Power MWt	2700
Power Used for Analysis, MWt	2754
Peak Linear Power kW/ft	15.00*
Total Allowable Peaking Factor	2.42

* All power generated in fuel at 2700 MWt.

Table 1.2 Large Break Results Time Sequence of Events

Event	Time of Event (seconds) DECLG (C_D = 1.0)
Start	0.0
Initiate Break	0.05
Safety Injection Signal	0.83
Pressurizer Empties	8.8
Accumulator Injection, Broken Loop	10.5
Accumulator Injection, Single Intact Loop	16.6
Accumulator Injection, Double Intact Loop	16.6
End-of-Bypass	21.0
Safety Injection Flow, SIS	30.8
Start of Reflood	38.6
Accumulators Empty, Single Intact Loop	67.4
Accumulators Empty, Double Intact Loop	67.4
Peak Clad Temperature Reached	272.1

2.0 BLOWDOWN CALCULATION

2.1 MODEL DESCRIPTION

The input data for the example calculation was chosen to represent a Combustion Engineering design pressurized water reactor with a dry containment. Table 2.1 gives a general listing of some of the plant parameters used to develop the input for this model.

The system was modeled using 55 volumes, 70 junctions and 44 heat slabs (Figure 2.1). The model includes four accumulators (safety injection tanks), one pressurizer, and two vertical U-tube steam generators, with both primary and secondary sides of the steam generators modeled. The high and low pressure Safety Injection System (SIS) flows were modeled as fill junctions with typical flow rates given as a function of system back-pressure. The reactor core power is calculated by the RELAP4-EM solution of the space independent core kinetics equations with radioactive decay energy (ANS + 20%) and actinide contributions. Mass and energy release rates from the primary coolant system to the containment were used as input to the CONTEMPT LT/22 code for containment backpressure analysis. The pump performance curves were for a Byron-Jackson pump provided by the plant owner. The reactor core was modeled radially as an average core plus a single hot assembly, each with three axial nodes. Major hardware components were modeled using 40 heat conductors.

2.2 RESULTS

Results from the application of the RELAP4-EM program to the blowdown of the system are presented in Figures 2.2 through 2.6. The timing of various major blowdown events are listed in Table 1.2.

The results are typical of pressurized water reactor large break blowdown analyses. For large break analyses the system decompresses rapidly to the saturation point, and the pressure then continues to decrease smoothly to an ambient condition. After break initiation, the core inlet flow reverses, approaching a zero flow condition for several seconds before reversing again. The core flow approaches zero at the End-of-Bypass (EOBY).

Table 2.1 CE 2x4 PWR Data

Primary Heat Output, MWt	2700*
Primary Coolant Flow, lbm/hr	1.394×10^8
Primary Coolant Volume, ft^3	19,214**
Operating Pressure, psia	2250
Inlet Coolant Temperature, ^oF	549
Reactor Vessel Volume, ft^3	4402
Pressurizer Volume, Total, ft^3	1500
Pressurizer Volume, Liquid, ft^3	800
Accumulator Volume, Total, ft^3 (one of four)	2020
Accumulator Volume, Liquid, ft^3	1090
Accumulator Pressure, psia	230
Steam Generator Heat Transfer Area, ft^2 (one of two)	74,722
Steam Generator Secondary Flow, lbm/hr	5.899×10^6
Steam Generator Secondary Pressure, psia	885
Reactor Coolant Pump Head, ft	280
Reactor Coolant Pump Speed, rpm	886
Moment of Inertia, lbm-ft^2/rad	101,900
Cold Leg Pipe, I.D., in	30
Hot Leg Pipe, I.D., in	42
Pump Suction Pipe, I.D., in	30

* Primary Heat Output used in RELAP4-EM Model - 1.02 x 2700 = 2754 MWt.

**Includes total accumulator and pressurizer volume.

Table 2.1 (Continued)

Fuel Assembly Rod Diameter, in*	.440
Fuel Assembly Rod Pitch, in*	.580
Fuel Assembly Pitch, in*	8.180
Fueled (Core) Height, in*	136.7
Fuel Heat Transfer Area, ft^2	50,117
Fuel Total Flow Area, ft^2	53.19
Steam Generator Tube Plugging (Assumed Uniform)	5%

* ENC Fuel Parameters

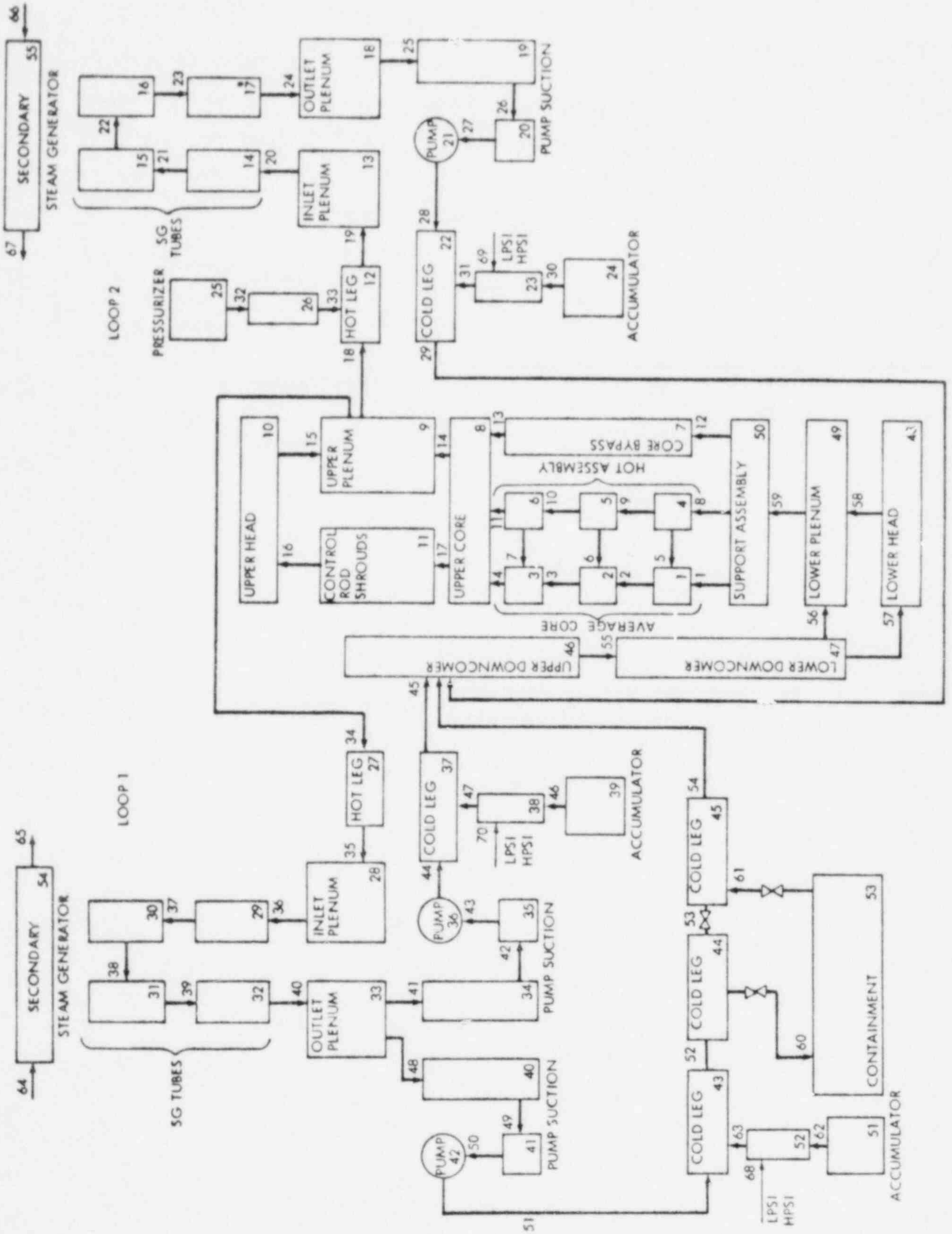


Figure 2.1 RELAP4-EM Blowdown System Nodalization for a CE 2x4 PWR

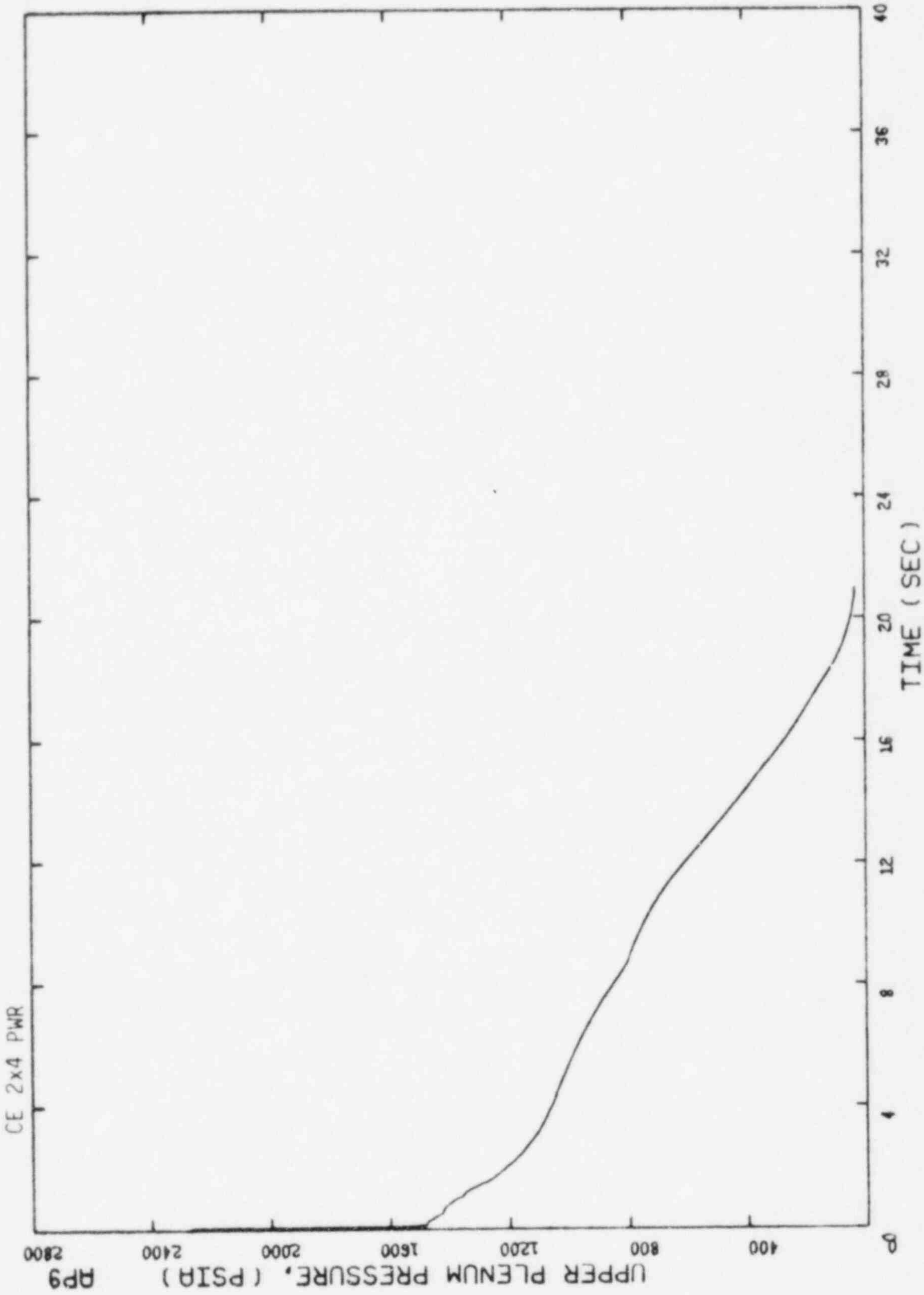


Figure 2.2 Upper Plenum Pressure, 1.0 DECLG

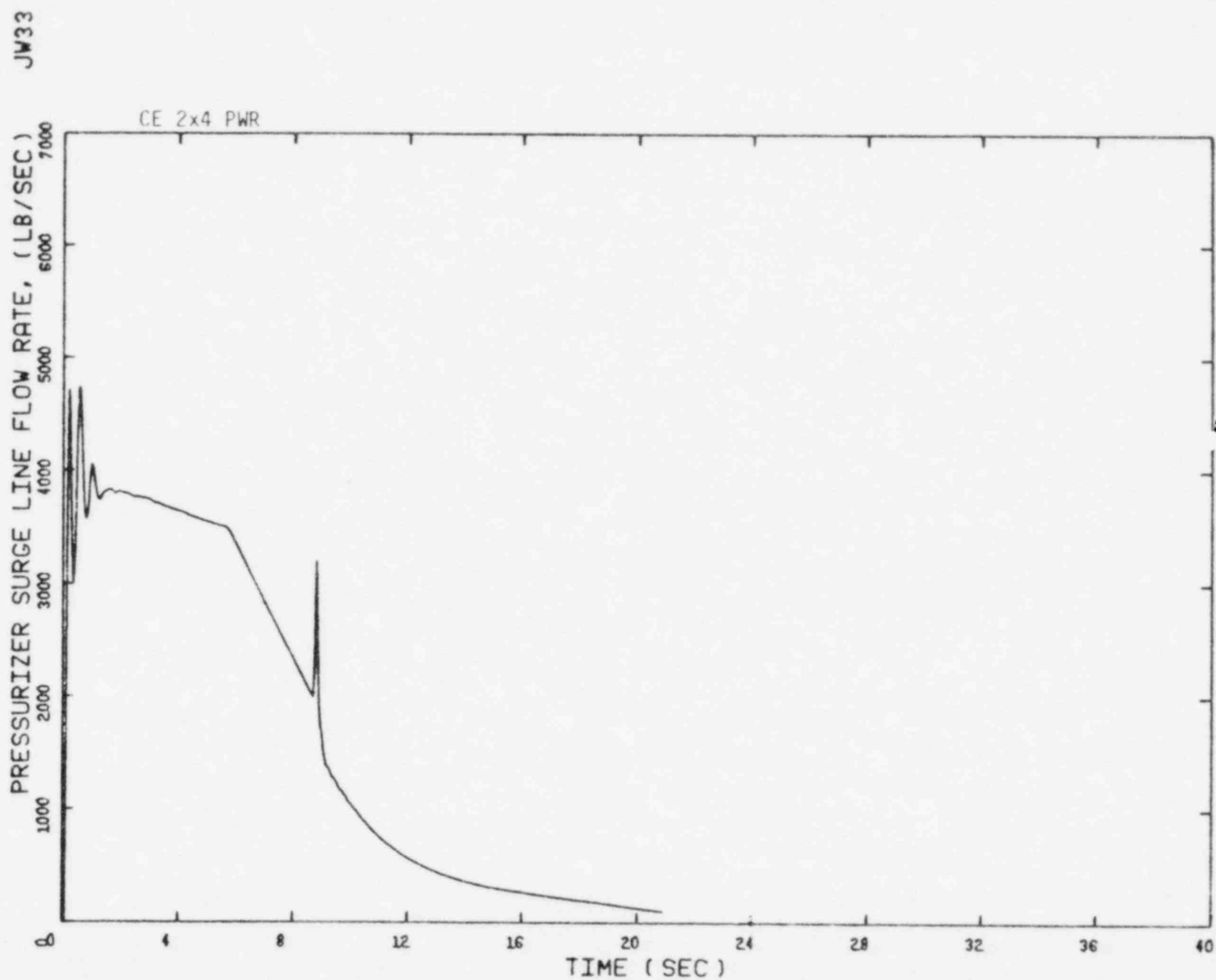


Figure 2.3 Pressurizer Surge Line Flow, 1.0 DECLG

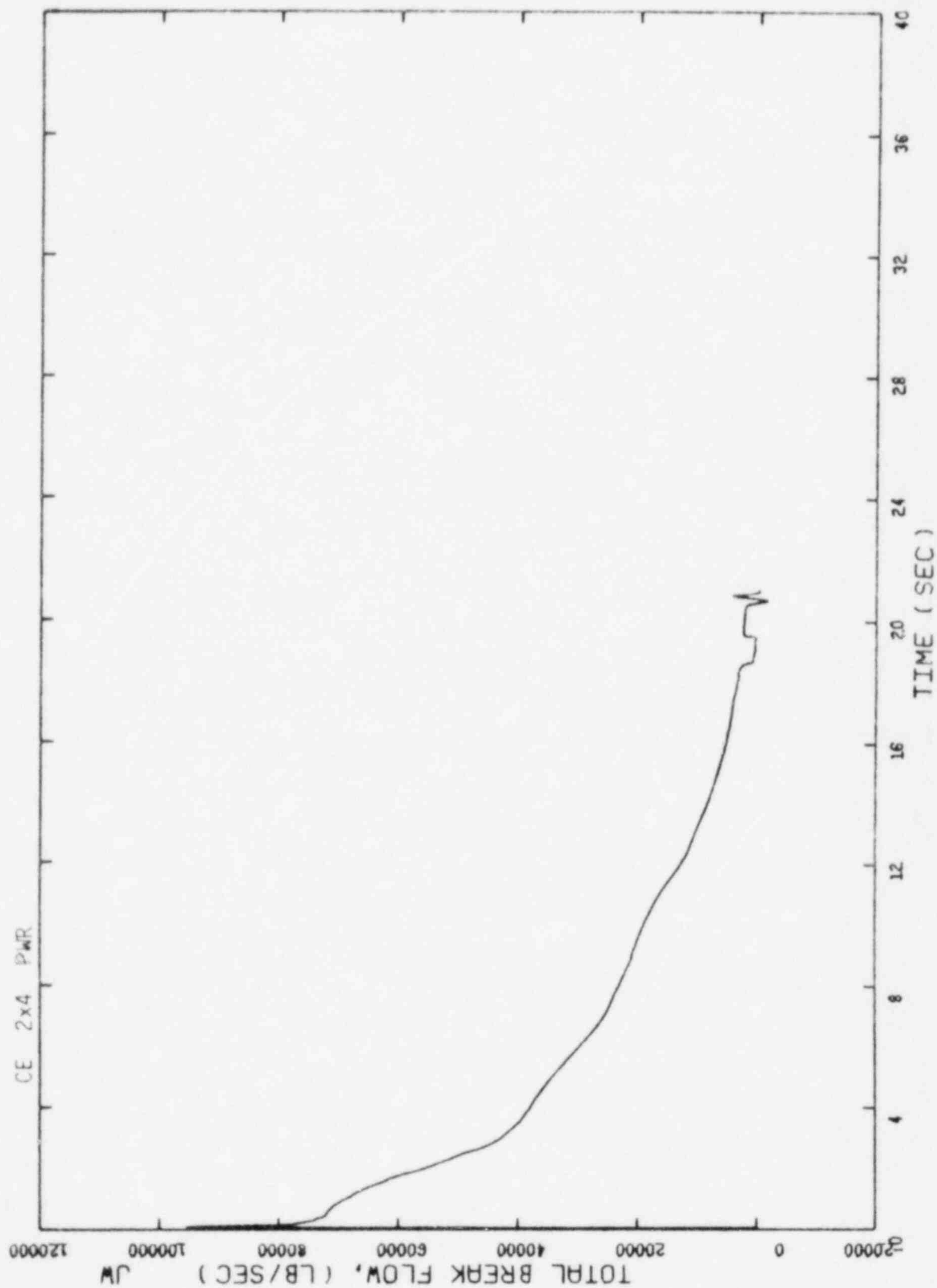


Figure 2.4 Total Break Flow, 1.0 DECLG

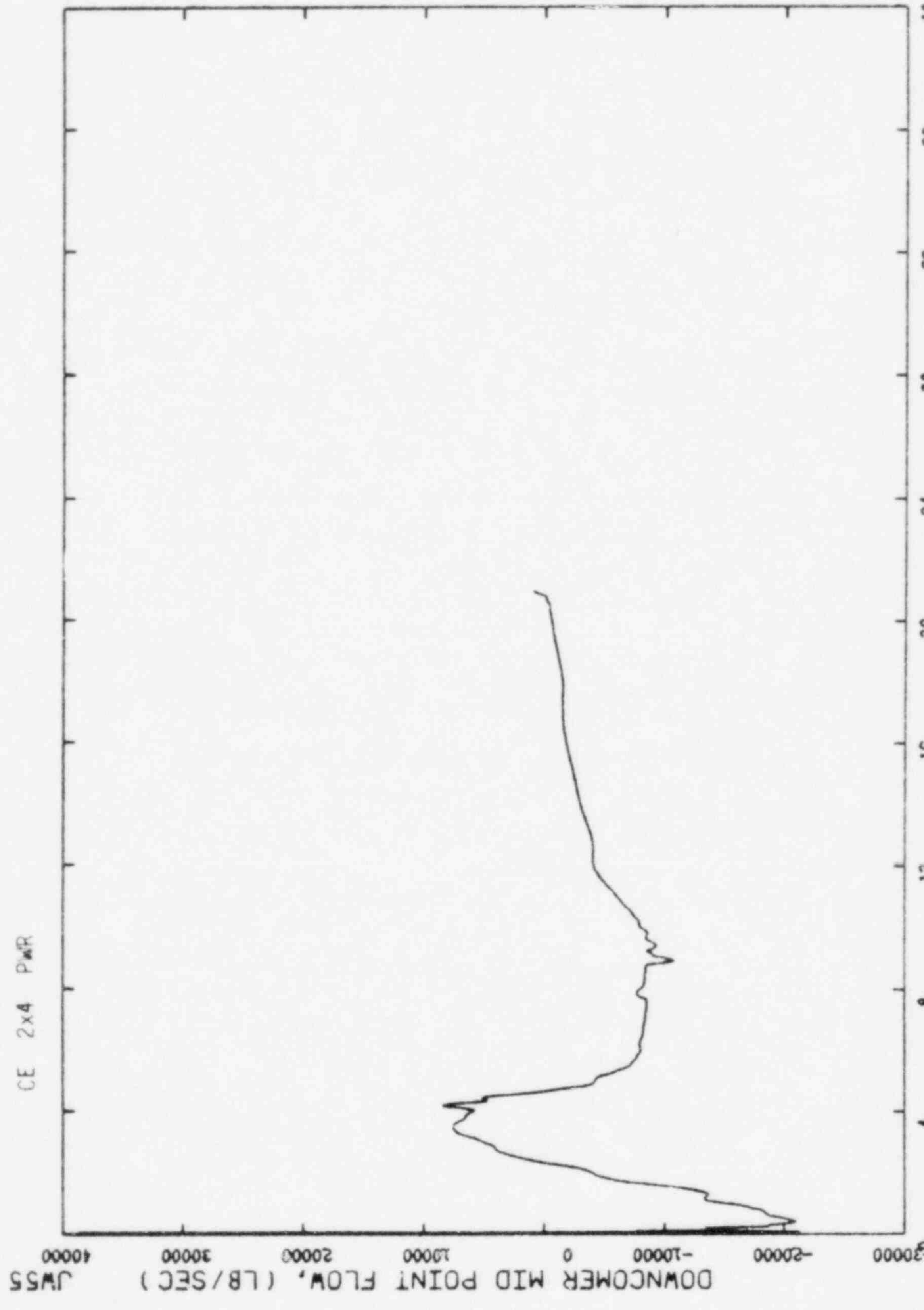


Figure 2.5 Downcomer Mid Point Flow, 1.0 DECLG

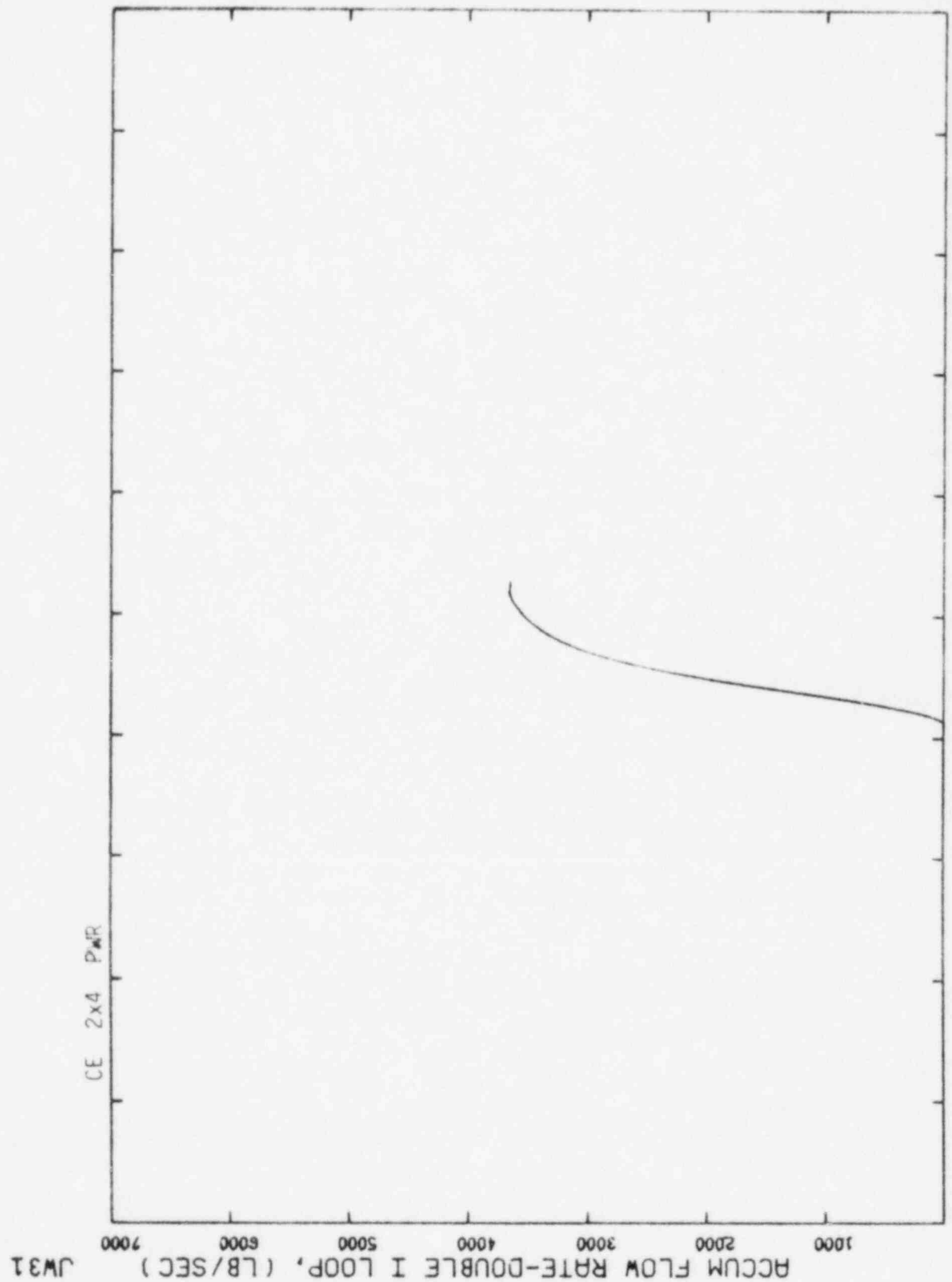


Figure 2.6 Single Intact Loop Safety Injection Tank Flow, 1.0 DECLG

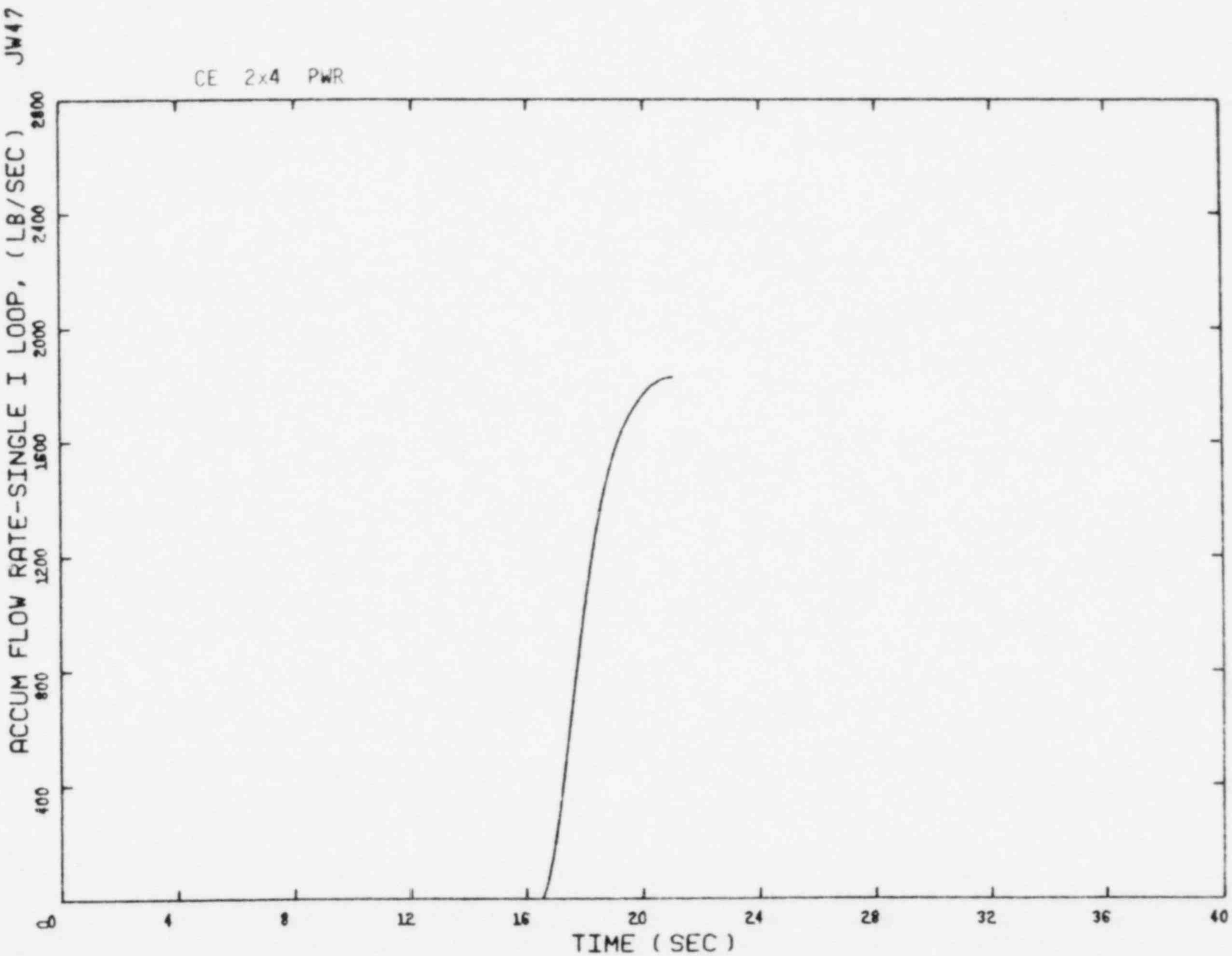


Figure 2.7 Double Intact Loop Safety Injection Tank Flow, 1.0 DECLG

3.0 HOT CHANNEL CALCULATION

3.1 MODEL DESCRIPTION

The RELAP4-EM/HOT CHANNEL model is used 1) to calculate the maximum power fuel rod heatup occurring during the blowdown phase, and 2) to establish the temperature profile and extent of the metal-water reaction at the EOBY for input into the fuel rod heatup code TOODEE2.

The hot channel model employed was nodalized to be compatible with both RELAP4-EM/BLOWDOWN and TOODEE2. The model contains eight volumes and eleven junctions as depicted in Figure 3.1. Volumes 1 and 8 (lower plenum and upper core) correspond to RELAP4-EM/BLOWDOWN, Volumes 50 and 8, respectively. RELAP4-EM/HOT CHANNEL uses the time dependent volume conditions from RELAP4-EM/BLOWDOWN for these volumes.

The model uses 31 heat slabs. Six of these represent the average core and hot assembly, and the remaining 25 heat slabs are allocated to the hot fuel rod. The hot fuel rod slabs are of varying height, with a concentration of 3-inch slabs around the point where the peak temperatures are expected, as shown in Figure 3.2. The heat slab nodalization of the hot fuel rod is identical to the nodalization used in TOODEE2.

A skewed axial power profile was chosen to represent the conditions for LOCA. From this profile the axial power profile input used in the blowdown and hot channel models was developed. This axial profile was applied to both average and hot fuel assemblies. Axial peaking was 1.38 and total peaking was 2.42.

3.2 RESULTS

Results for the node which ultimately becomes the PCT node during the LOCA transient are given in Table 3.1. The PCT clad node temperature history and depth of metal-water reaction are shown in Figures 3.3 and 3.4, respectively. Heat transfer coefficients are presented in Figure 3.5 and the volume average temperature for node 24 is shown in Figure 3.6. The core inlet and outlet flows for the average and hot channels are shown in Figures 3.7 through 3.10.

The PCT node in the hot channel analysis, which is node 24, corresponds to node 19 in the TOODEE2 analysis.

Table 3.1 RELAP4-EM/HOT CHANNEL Results for Node 24

Node 24 (Blowdown Conditions)	1.0 DECLG
Blowdown Peak Temperature, °F	1304
Elevation of Peak, Feet	8.97
Time of Blowdown Peak, Seconds	10.0
Clad Temperature at End-of-Bypass, °F	1192

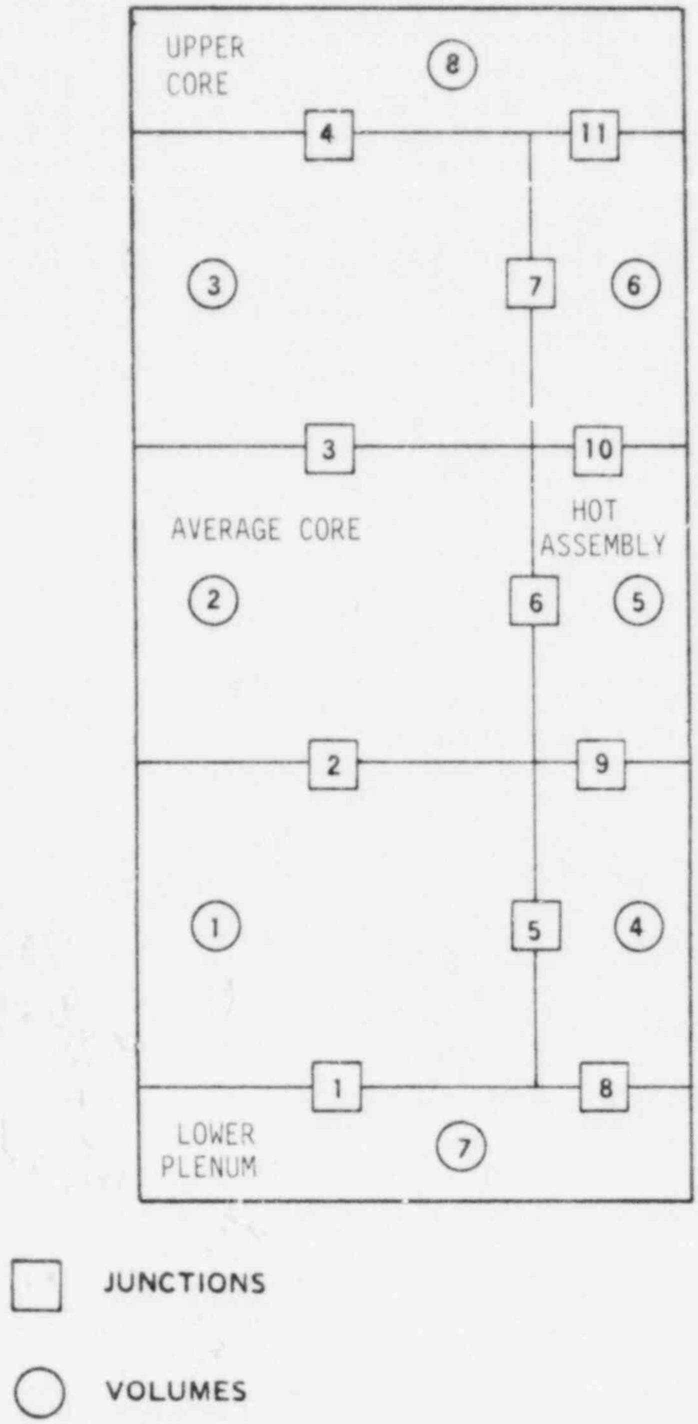


Figure 3.1 RELAP4-EM/Hot Channel Core Volumes and Junctions

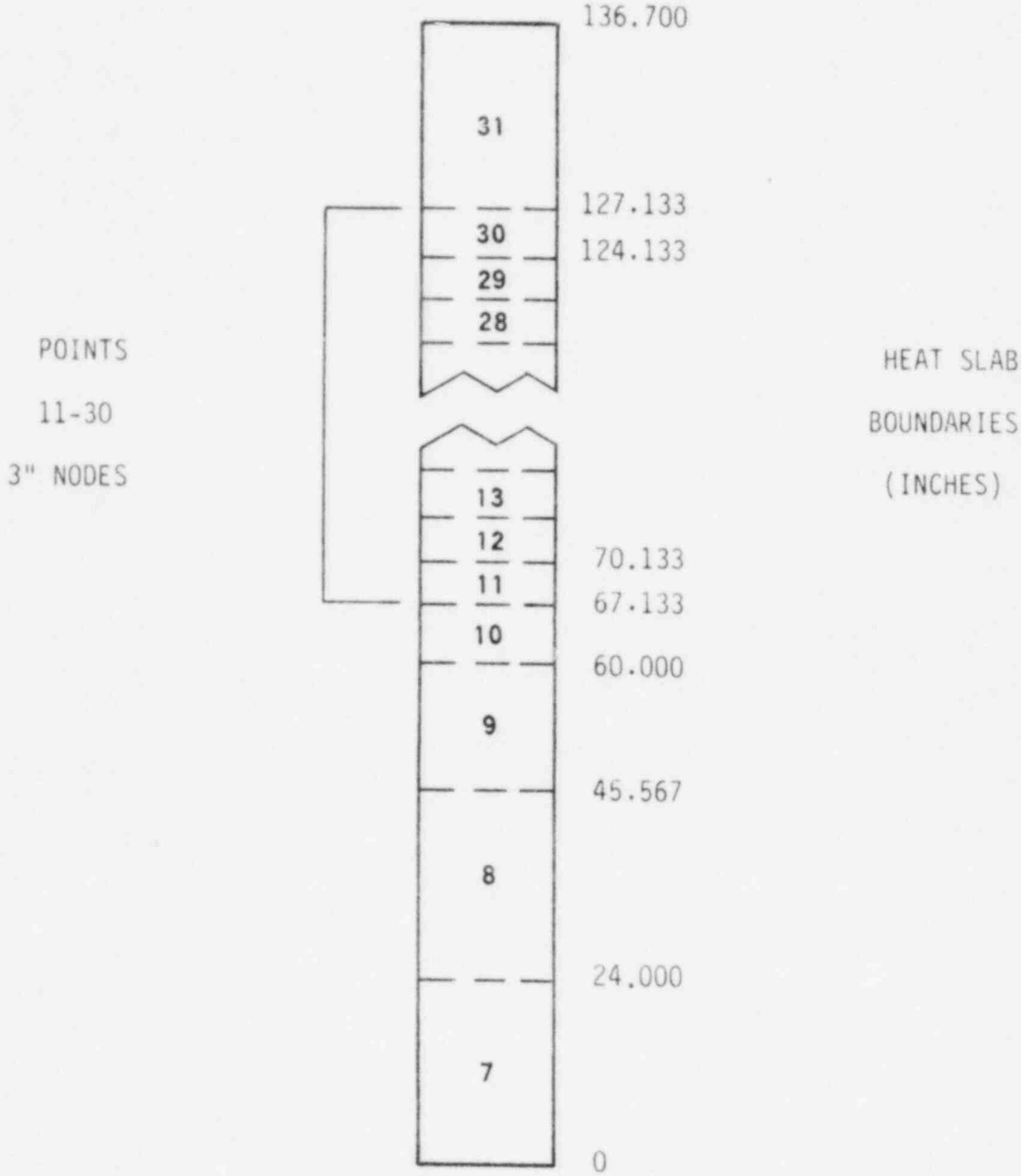


Figure 3.2 Hot Channel Hot Rod Heat Slab Nodalization

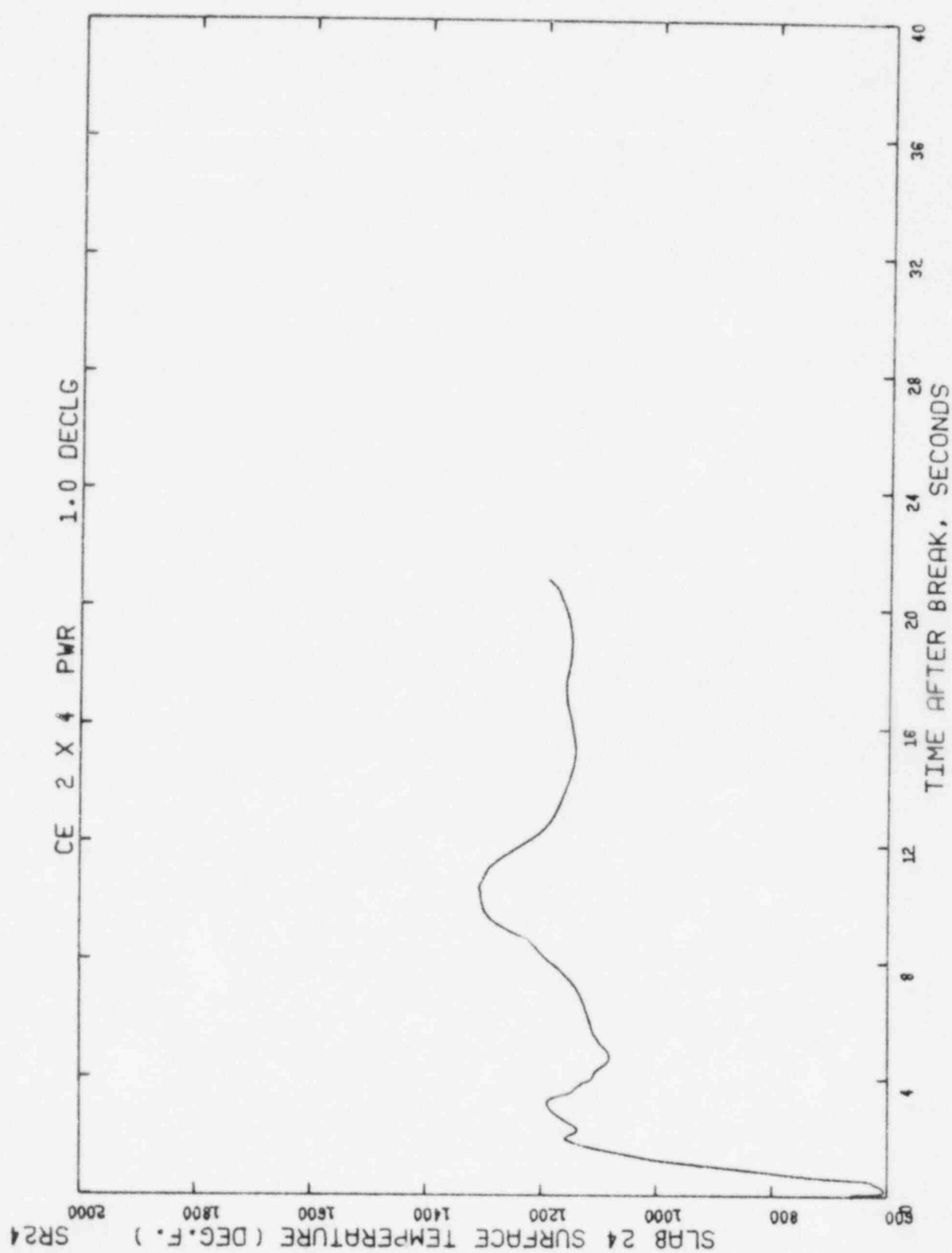


Figure 3.3 Cladding, Surface Temperature @ Node 24 During Blowdown, 1.0 DECLG

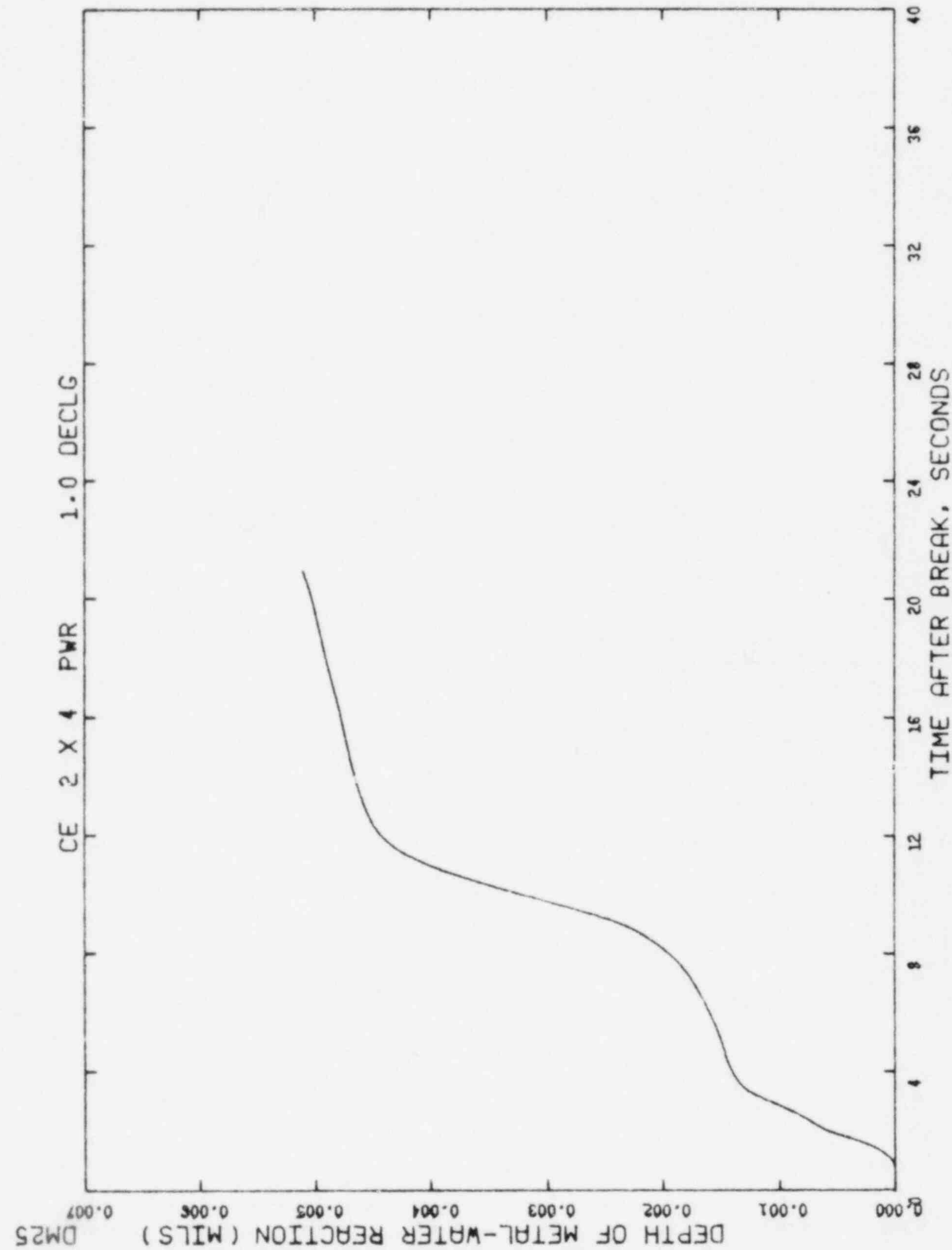


Figure 3.4 Depth of Metal-Water Reaction for Node 25 During Blowdown, 1.0 DECLG

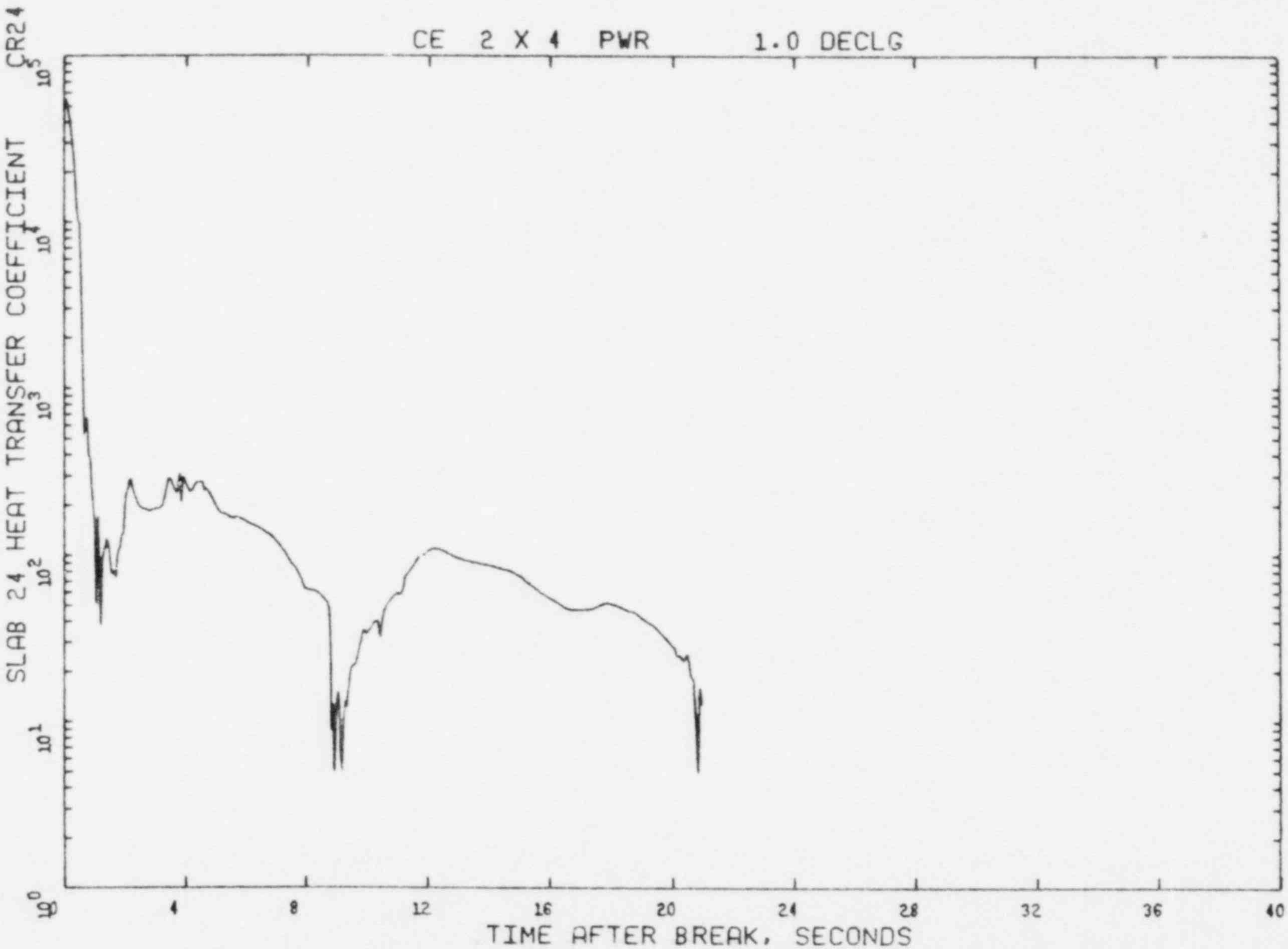


Figure 3.5 Heat Transfer Coefficient for Node 24 During Blowdown, 1.0 DECLG

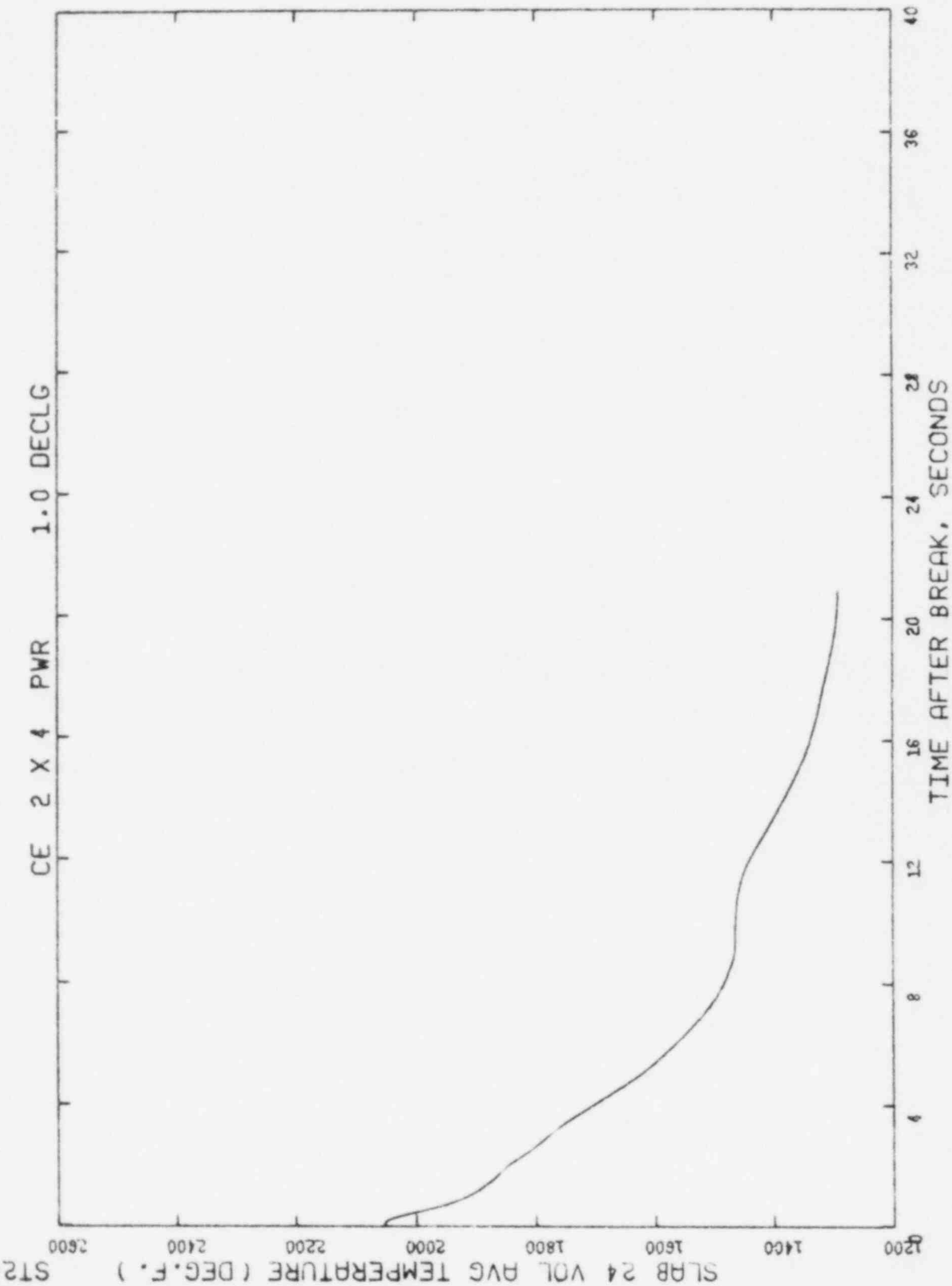


Figure 3.6 Volume Average Temperature @ Node 24 During Blowdown, 1.0 DECLG

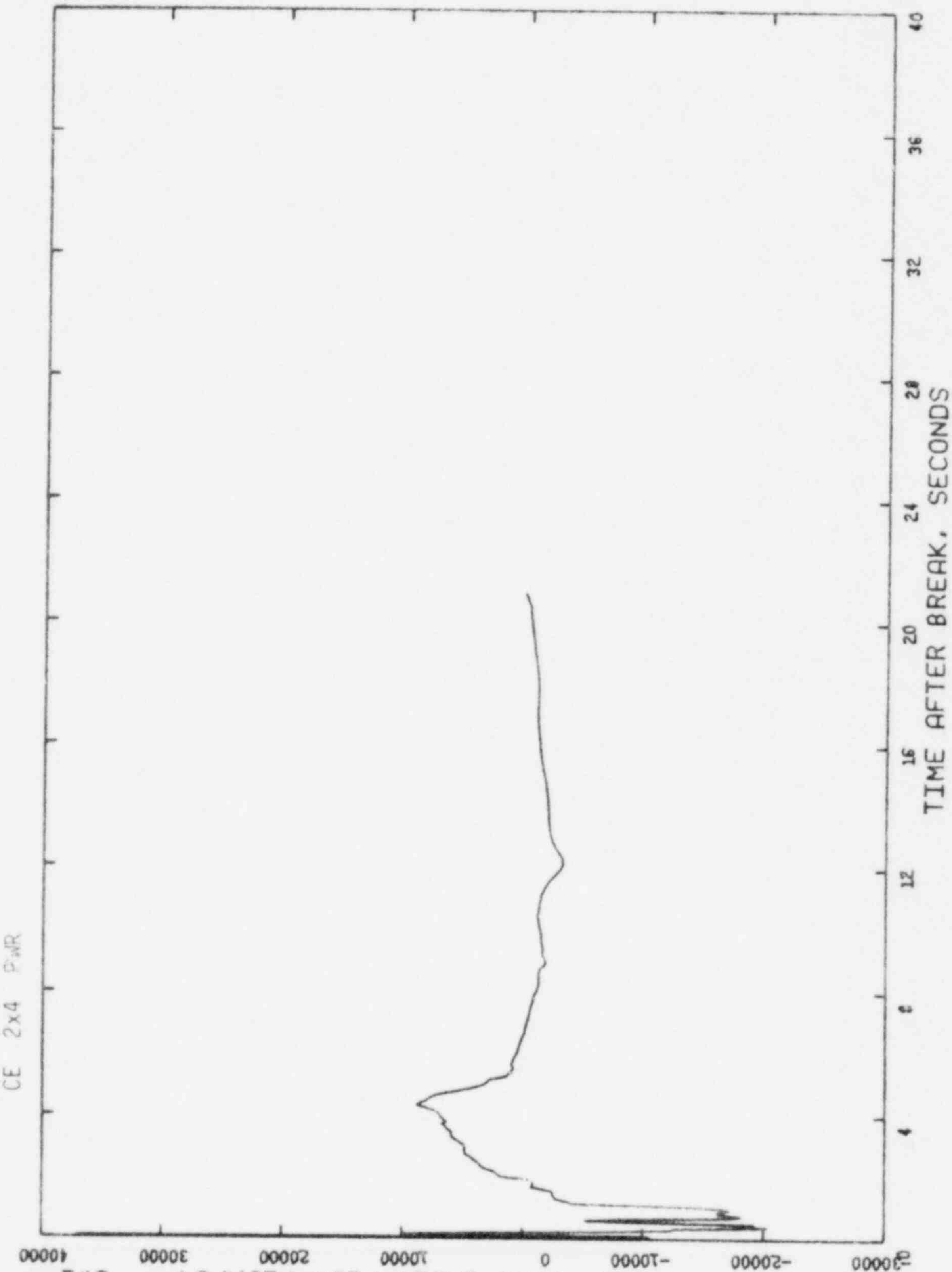


Figure 3.7 Average Core Inlet Flow, 1.0 DECLG

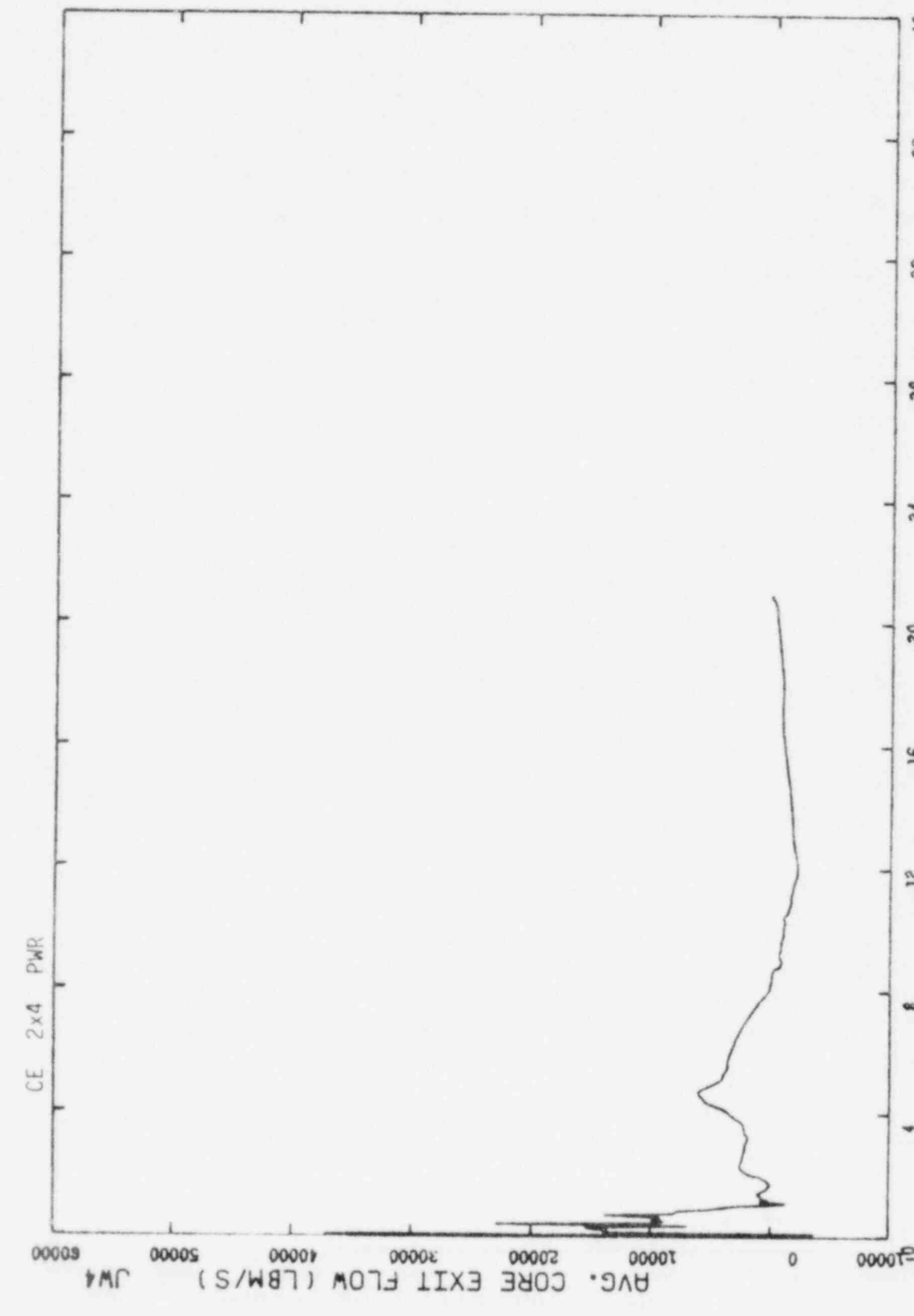


Figure 3.8 Average Core Exit Flow, 1.0 DECLG

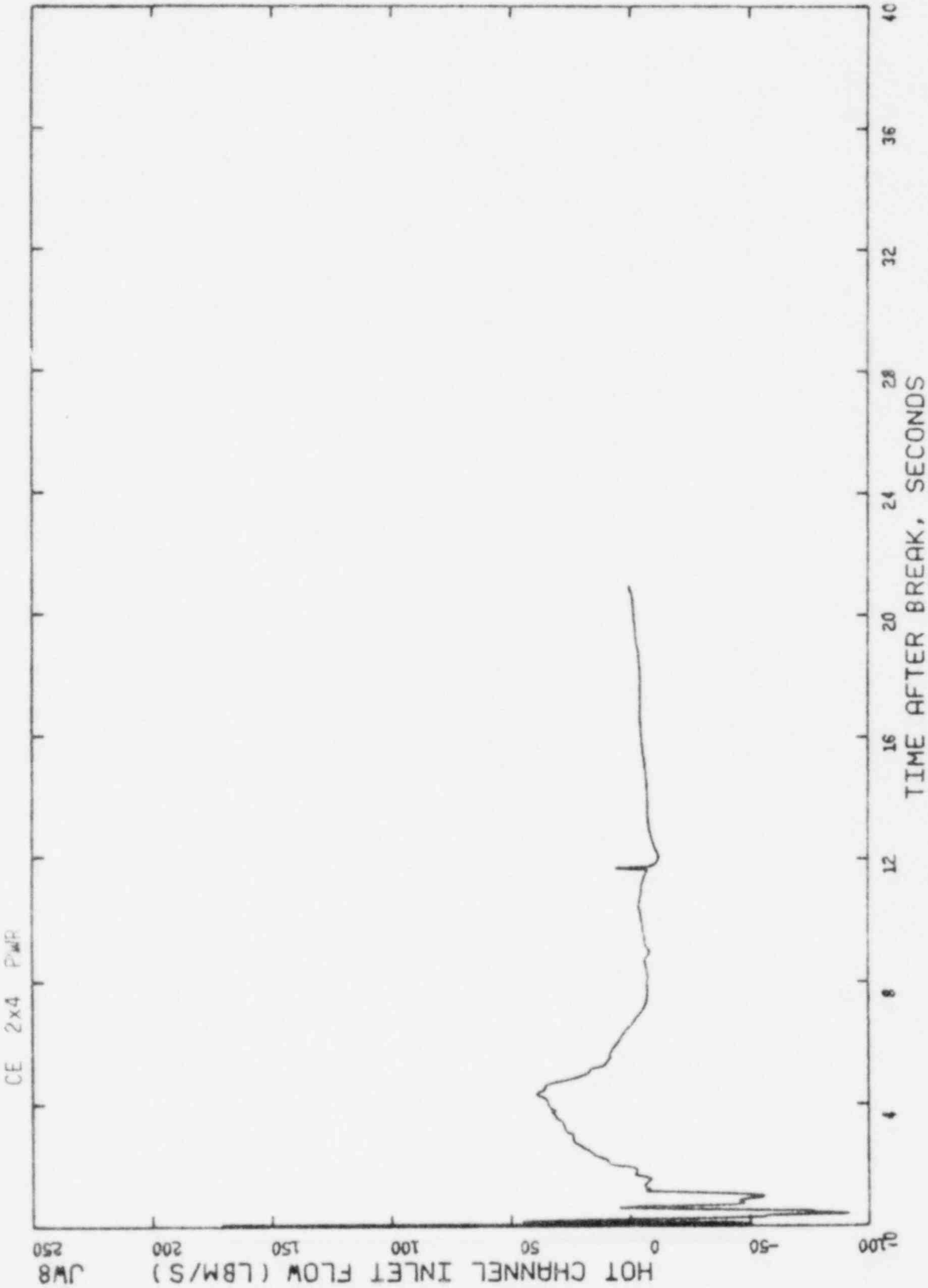


Figure 3.9 Hot Channel Inlet Flow, 1.0 DECLG

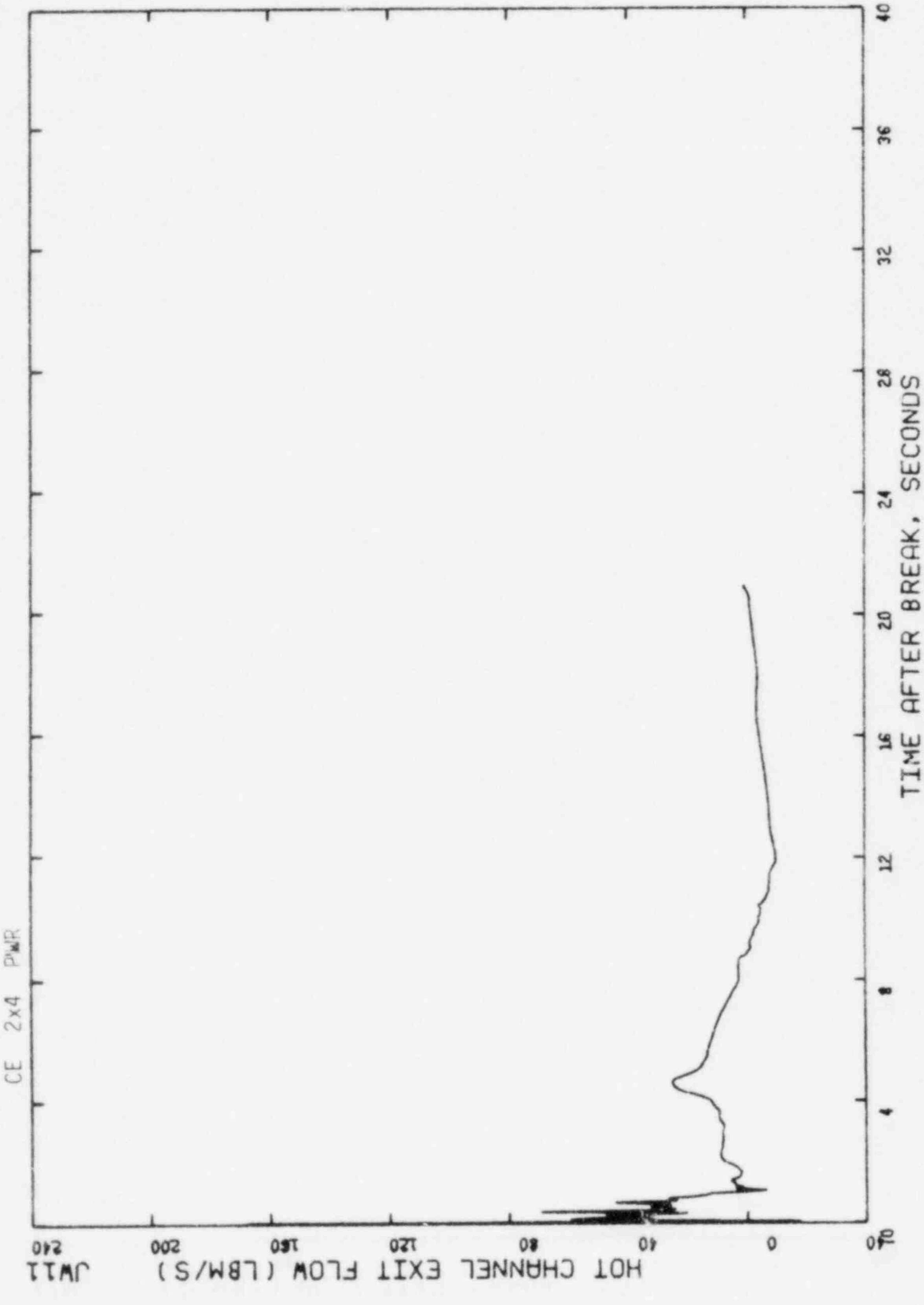


Figure 3.10 Hot Channel Exit Flow, 1.0 DECLG

4.0 REFILL CALCULATIONS

4.1 RELAP4 POWER

The power generated in the core during the refill and reflood portions of the transient is calculated using a one-volume RELAP4 model as described in XN-75-41, Appendix A, Section A6.0.[1] Input parameters include the shutdown reactivity from the RELAP4-EM blowdown calculation (voiding). The long term reactivity is input assuming the core becomes entirely voided. The fission product decay is expected to dominate the power calculation during the refill and reflood portions of the transient, the resulting power calculations include fission, decay energy (ANS + 20%) and actinide contributions.[4] The calculated power versus time for the example problem is shown in Figure 4.1.

4.2 RELAP4 REFILL

As described in XN-75-41, Supplements 5 and 6,[1] a five-volume, five-junction RELAP4 model was set up to determine the rate at which ECCS fluid is injected into the primary system intact recirculation lines during the refill and reflood portions of the transients. The model consists of three accumulators, accumulator lines, and cold leg volumes. High and low pressure safety injection systems are modeled as fill junctions to the cold leg in the RELAP4-EM BLOWDOWN model. Initial conditions in the five volumes are set at (EOBY) conditions. The pressure transients in the cold leg are input as time dependent conditions with the cold leg pressure equal to the containment backpressure. The ECCS fluid therefore flows against the containment backpressure. The flow rates calculated by five-volume RELAP4 program are input to the calculation to determine the time of beginning of reflood.

4.3 BOCREC CALCULATION

Following the EOBY as determined during the RELAP4-EM/BLOWDOWN calculation, downflow is calculated in the downcomer region of the reactor vessel. Emergency Core Cooling (ECC) water injected into the intact loops of the reactor will flow to the lower plenum under the influence of gravitational force. When the water level reaches the Bottom of the Core (BOCREC), the reflood portion of the transient can begin. ECCS flow rates are obtained from RELAP4 refill model.

The time to begin reflood is computed in accordance with ENC's generic PWR model as given in XN-75-41, Supplement 5, Revision 1.[1] The hot wall delay computation is based on results from the CREARE reports TN-188[10] and TN-202[11]. This hot wall delay is detailed in XN-76-27[2] which is the base document for the approved WREM-II model. Output from the BOCREC calculation defines the time to begin reflood and specifies the ECC injection rates to the lower plenum following beginning of reflood. This start of reflood is given by the BOCREC time plus the transport delay.

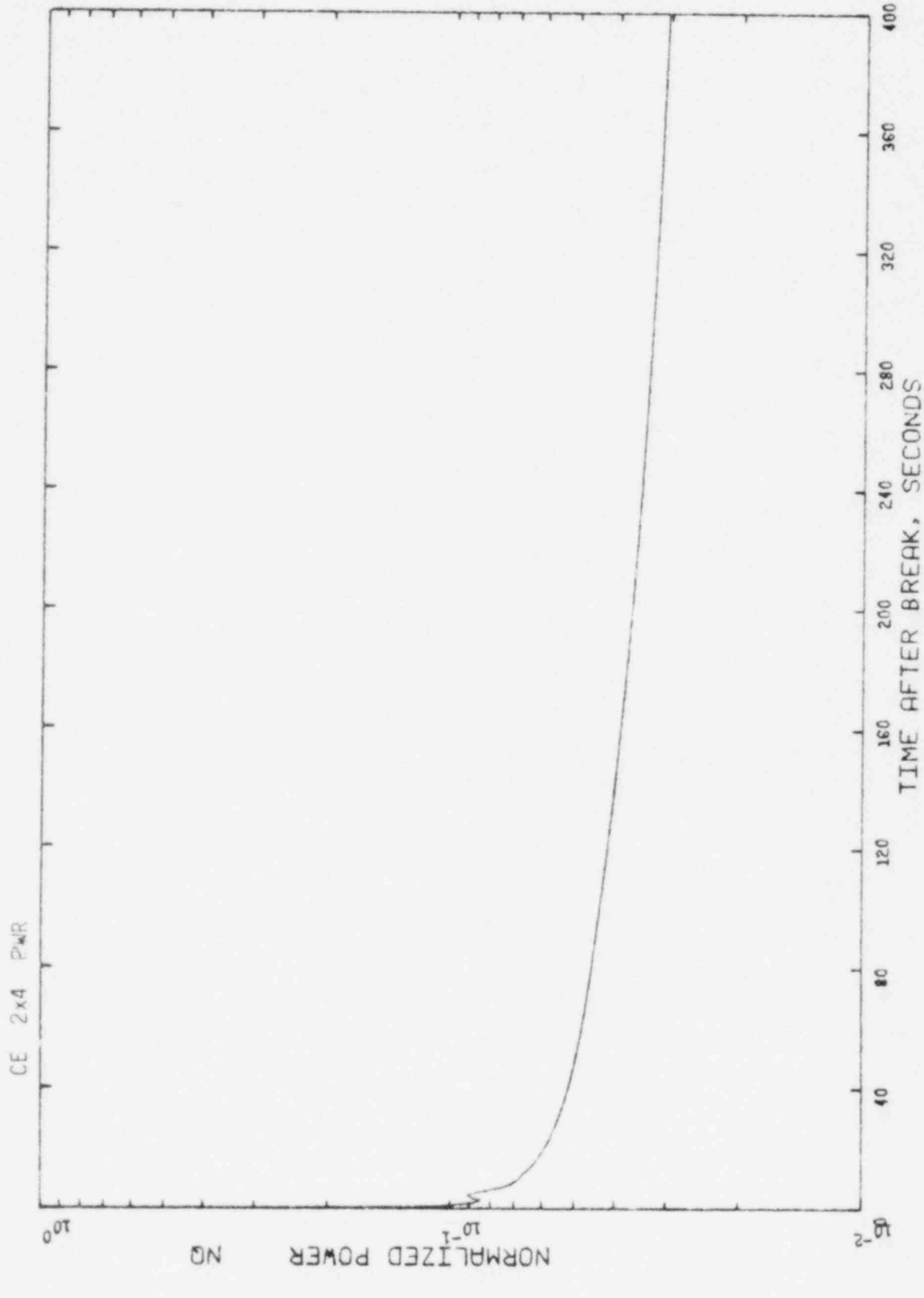


Figure 4.1 Normalized Power for Reflood, 1.0 DECLG

5.0 REFLOOD CALCULATION

The REFLEX[3,4,8] computer program was used to perform a reflooding analysis. This calculation considers refilling of the reactor vessel and the rate of reflooding of the reactor core. In the model, the primary system coolant pumps were assumed to have locked impellers, the ENC carryover fraction and core outlet enthalpy models[4] were used, and effects of compressed gas were conservatively ignored.

The reflood model is consistent with the plant data for the CE 2x4 plant and with the BLOWDOWN, HOT CHANNEL, and TOODEE2 models.

5.1 REFLEX MODEL DESCRIPTION

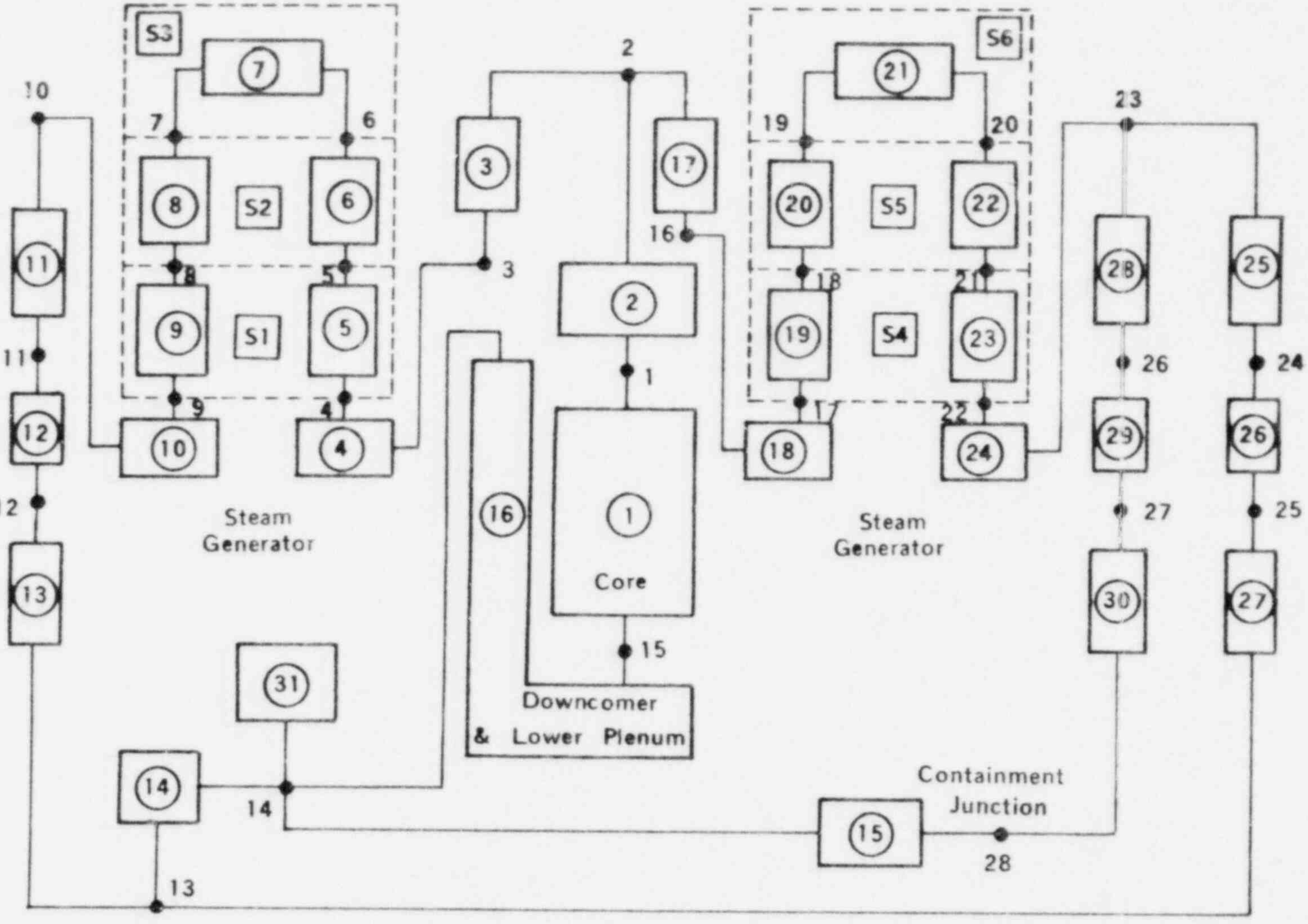
The REFLEX calculation used the 31 volume, 28 junction model for the guillotine break configuration shown in Figure 5.1. Geometrical data for the system were input to the model and are consistent with other portions of the EXEM/PWR analysis. The REFLEX calculation begins at BOCREC plus the free fall delay time which is 38.63 sec from the beginning of the LOCA analysis. The method of computing the start of reflood time is described in Revision 1 of Supplement 5, XN-75-41.[1] Injection pressure penalties of .4 and .15 psi, respectively, were input for 60^{o} injection angles.[1,3]

Decay power was input to the REFLEX calculation from the results given in Figure 4.1.

5.2 REFLOOD CALCULATION

The purpose of the reflood calculation is to supply the reflooding rate and fluid conditions for the TOODEE2 reflood cladding temperature calculation. The quantities obtained from REFLEX including reflood rates, core mixture level, downcomer mixture level, upper plenum pressure and core inlet flow rate are shown in Figures 5.2 through 5.6 for the 1.0 DECLG case.

Containment pressure during reflood was calculated using CONTEMPT-LT modified to conform to Branch Technical Positio Paper CSB 6-1.[12] Containment backpressure calculations are discussed in Section 7.0.



PRIMARY VOLUMES 1 to 31

JUNCTIONS 1 to 28

SECONDARY VOLUMES 1 to 6

Figure 5.1 Reflood Nodalization for a CE 2x4 PWR

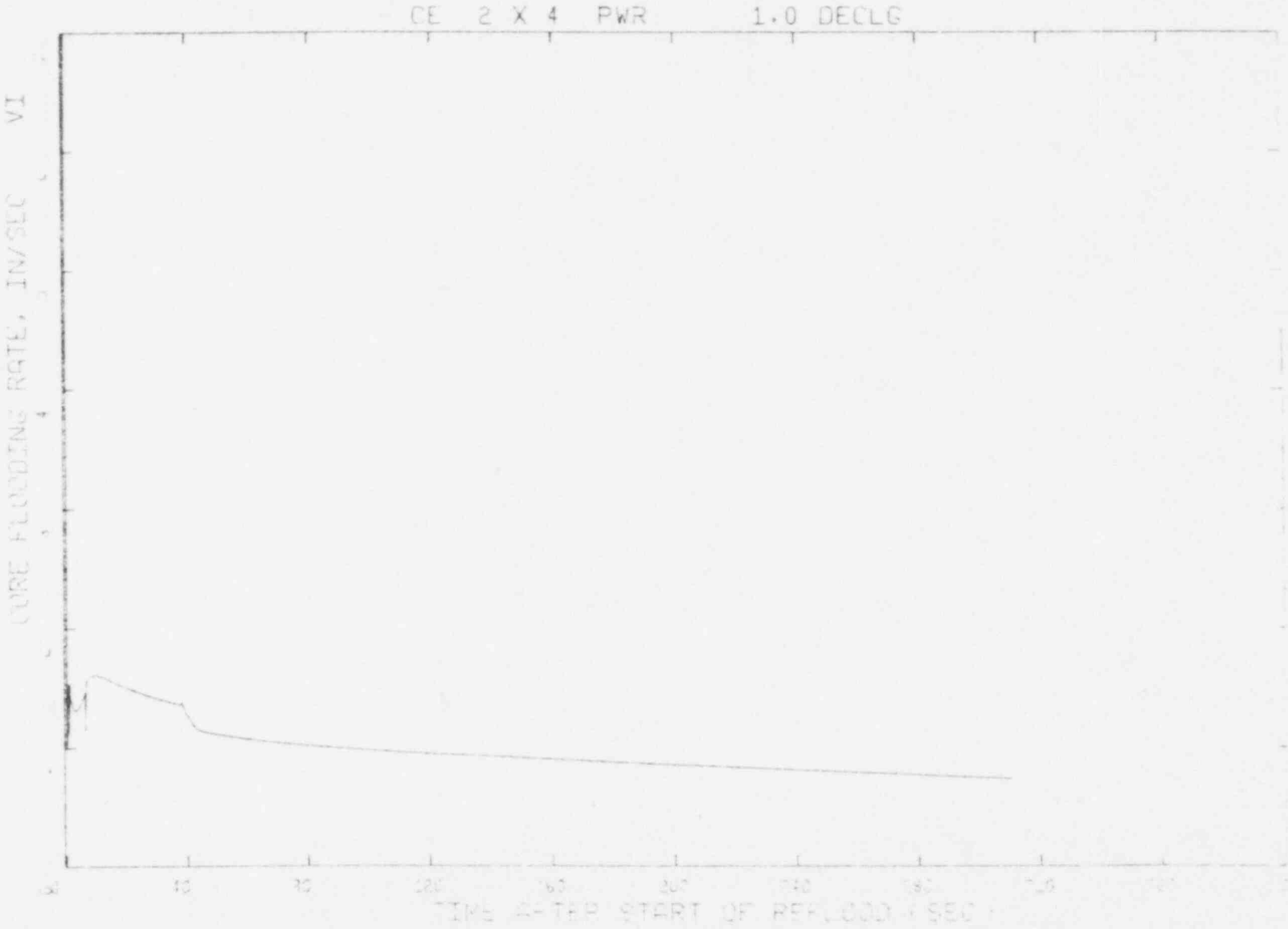


Figure 5.2 Core Flooding Rate, 1.0 DFCLG

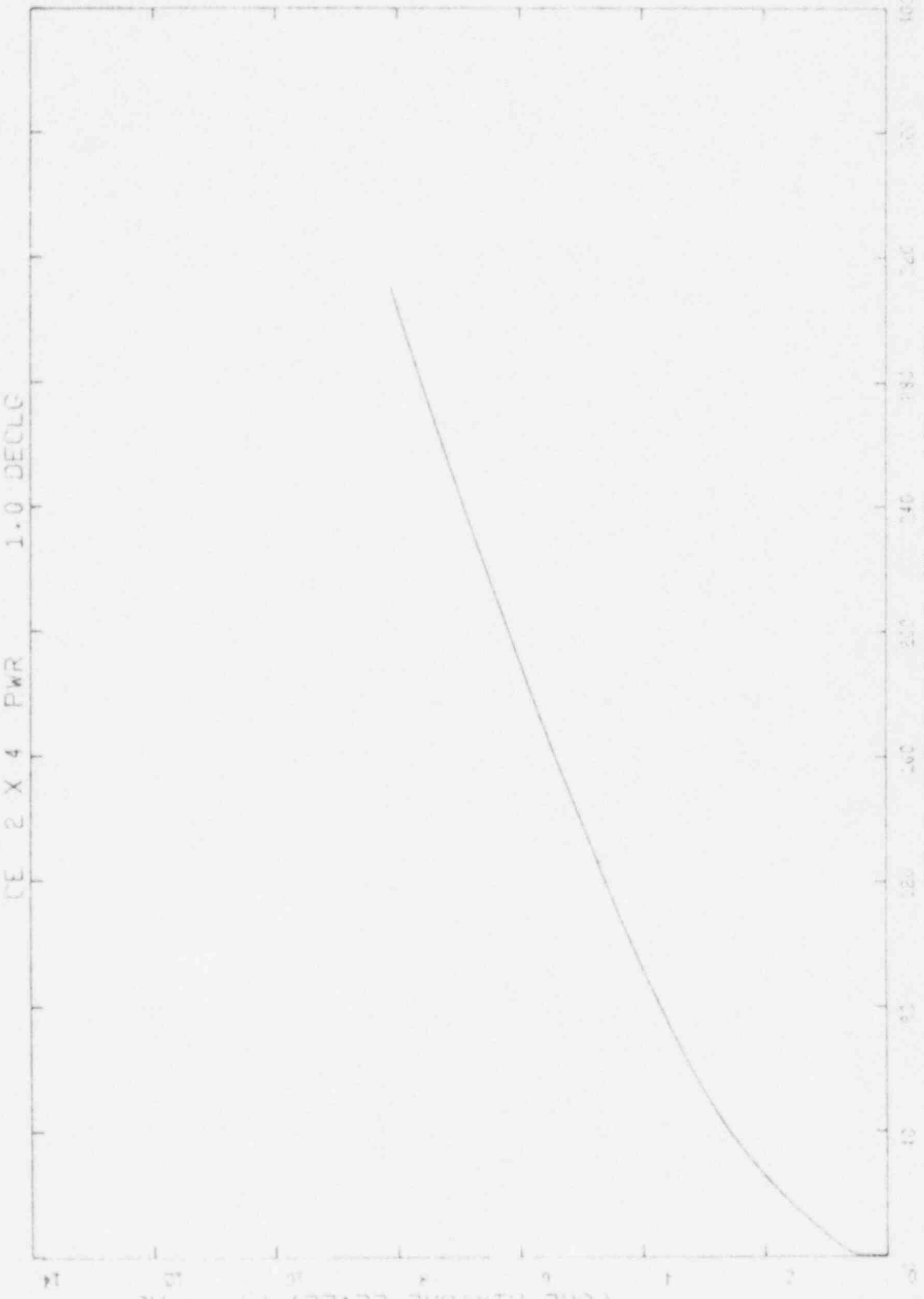


Figure 5.3 Core Mixture Level, 1.0 DECLG

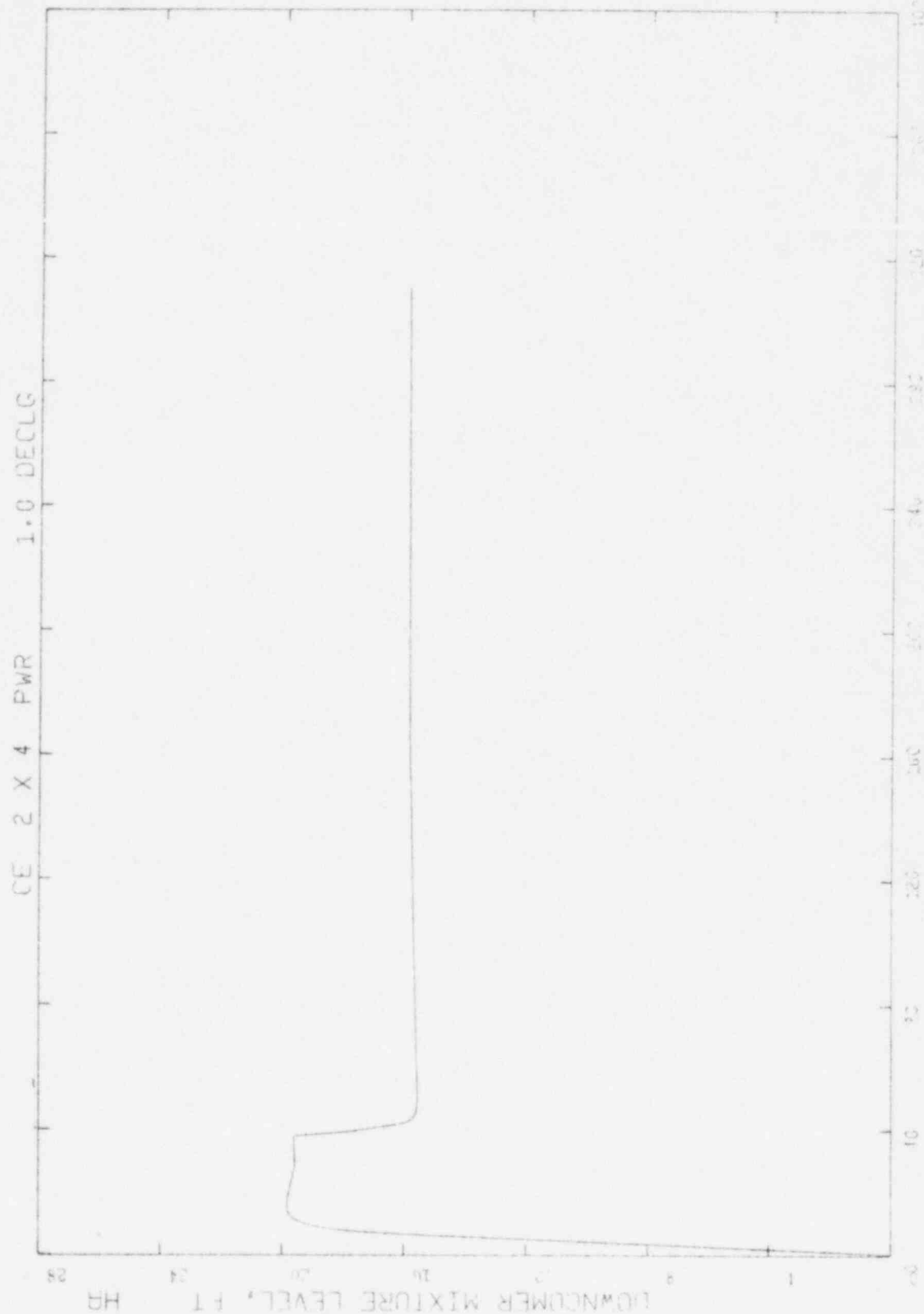


Figure 5.4 Downcomer Mixture Level, 1.0 DECLG

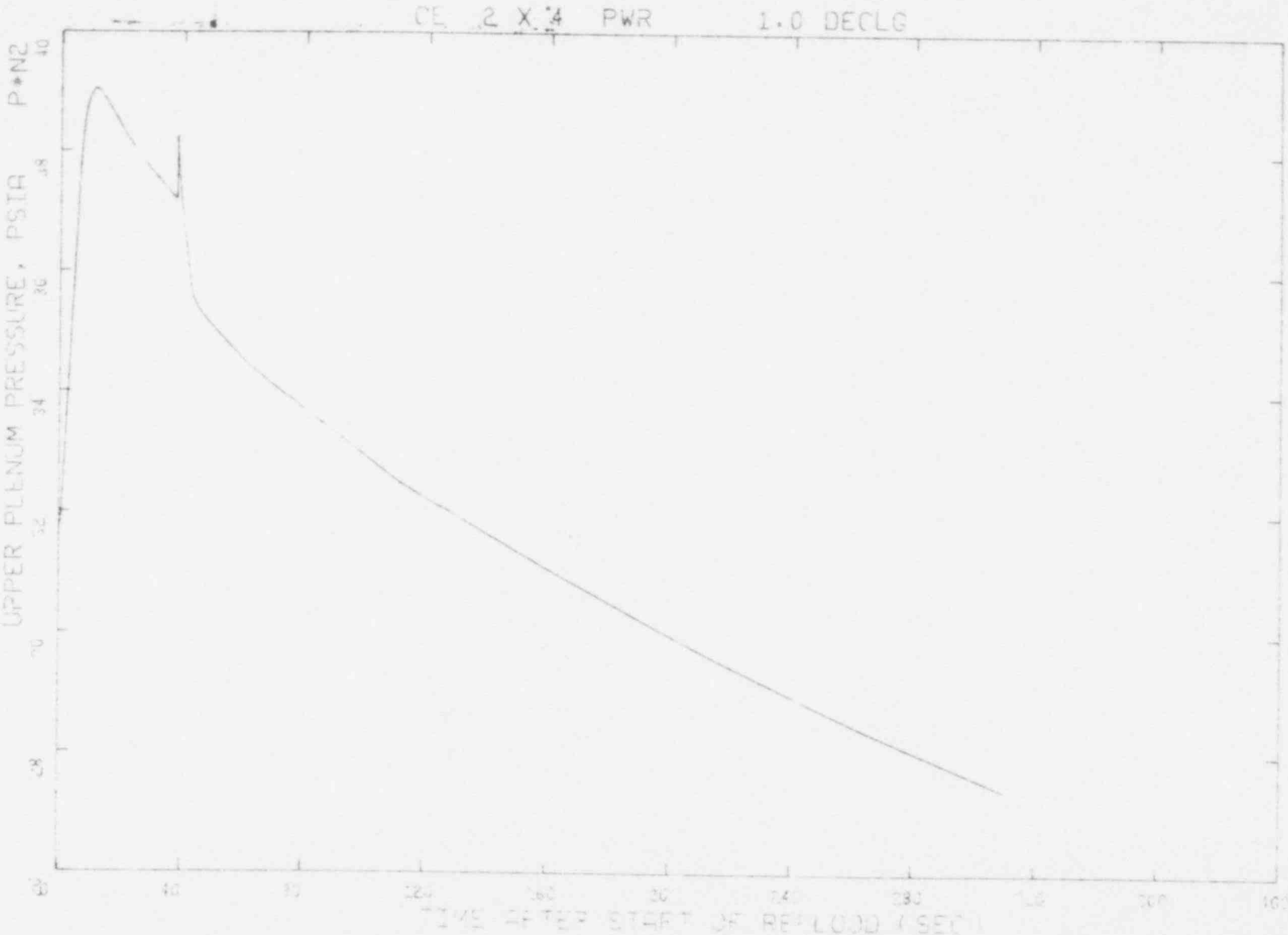


Figure 5.5 Upper Plenum Pressure, 1.0 DECLG

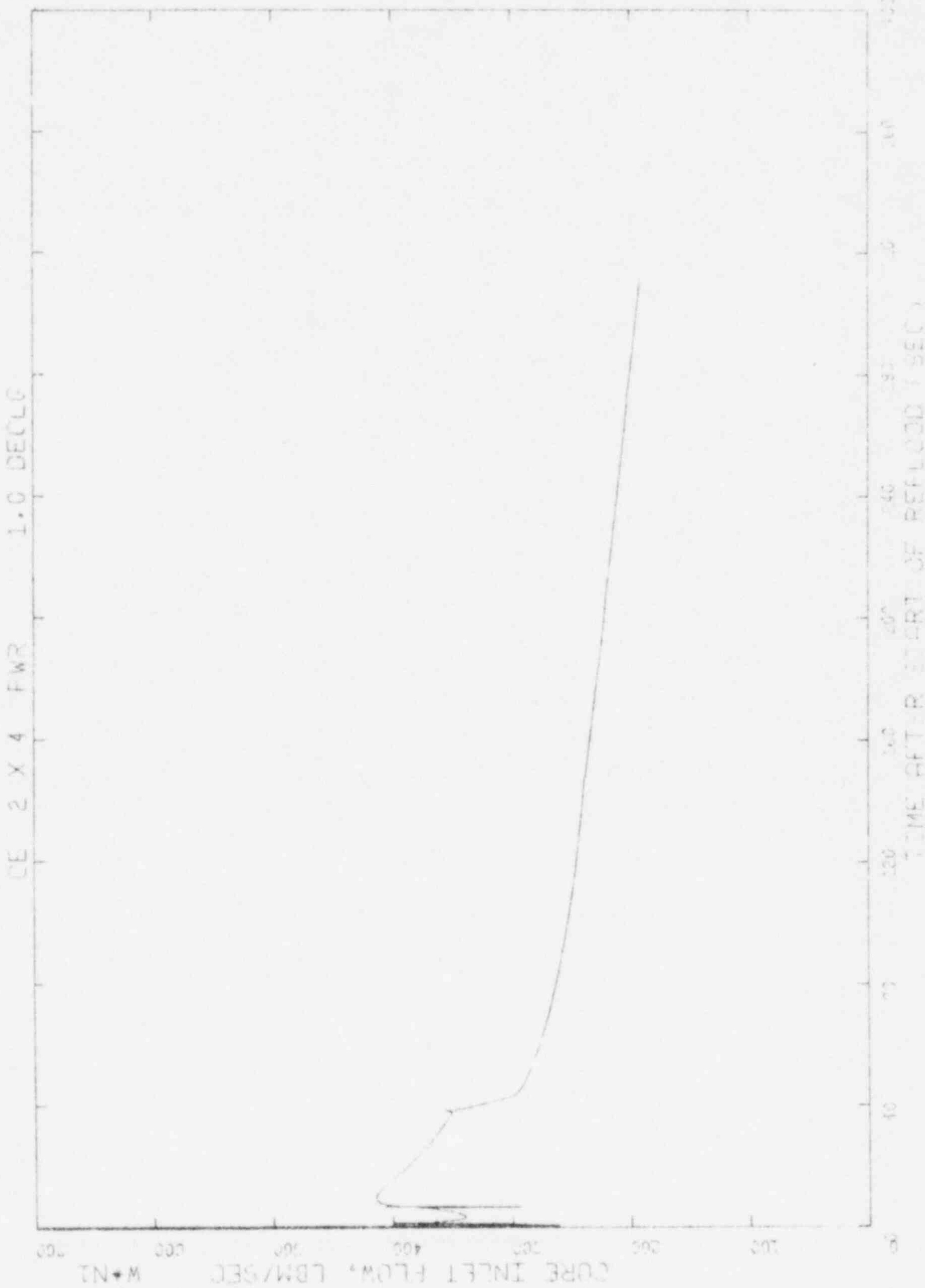


Figure 5.6 Core Inlet Flow, 1.0 DECLG

6.0 HEATUP CALCULATION

6.1 MODEL DESCRIPTION

The time dependent fuel rod thermal analysis program TOODEE2 is used to determine both the PCT and extent of metal-water reaction during the refill and reflood periods of a PWR LOCA. The hot fuel rod from the hot assembly is modeled with a total peaking factor of 2.42. The hot fuel rod is divided into 25 axial nodes as shown in Figure 6.1. As in the hot fuel rod nodalization used in the hot channel analysis, the nodes are of varying heights with the smaller nodes (3-inch) concentrated in the region of the expected maximum temperature. The fuel rod is divided into ten radial nodes, comprised of two cladding nodes, seven equally spaced fuel nodes, and one fuel/gap node. The radial nodalization is shown in Figure 6.2. The axial power distribution corresponds to that used in RELAP4-EM/HOT CHANNEL.

The code requires input from two sources, the initial fuel rod temperature distributions and depths of metal-water reaction from RELAP4-EM/HOT CHANNEL calculated values at the end-of-bypass. The time dependent fluid conditions (flooding rate, inlet enthalpy, etc.) are taken from REFLEX results. During the period from end-of-bypass to beginning of reflood, the ENC radiation model (Section 7.0 in Volume I, XN-75-41)[1] is used.

The heatup portion of the transient has been calculated by the method as reported in XN-75-41[1], XN-76-27[2], and XN-NF-82-20(P)[4] which includes the NRC swelling and rupture model and the EXEM/PWR steam cooling model. The results of the calculation with this model are shown in Figure 6.3.

The peak cladding temperature occurs at the 8.97 foot elevation. The temperature at this location turns around at 272.1 seconds and continues to decrease throughout the remainder of the transient.

6.2 RESULTS

Peak clad temperatures and corresponding times are presented in Tables 1.1 and 1.2. Also included in this table are clad rupture time, peak clad temperature, and peak linear heat generation rate at initiation of reflood.

The temperature history for the node of peak cladding temperature from the end-of-bypass through temperature turn-around is plotted in Figure 6.3.

The PCT Node in the TOODEE2 analysis, which is node 19, corresponds to node 24 in the hot channel analysis.

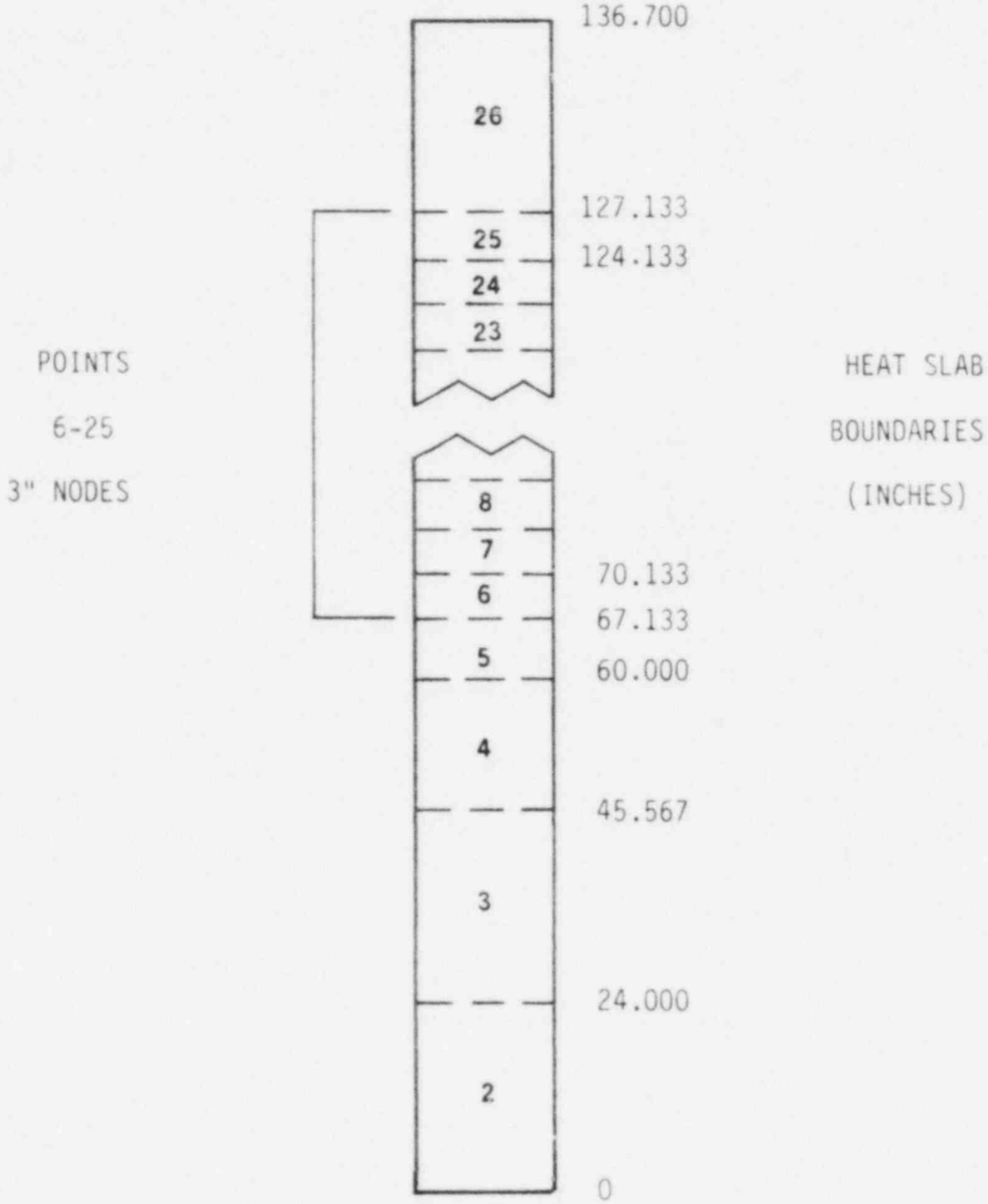
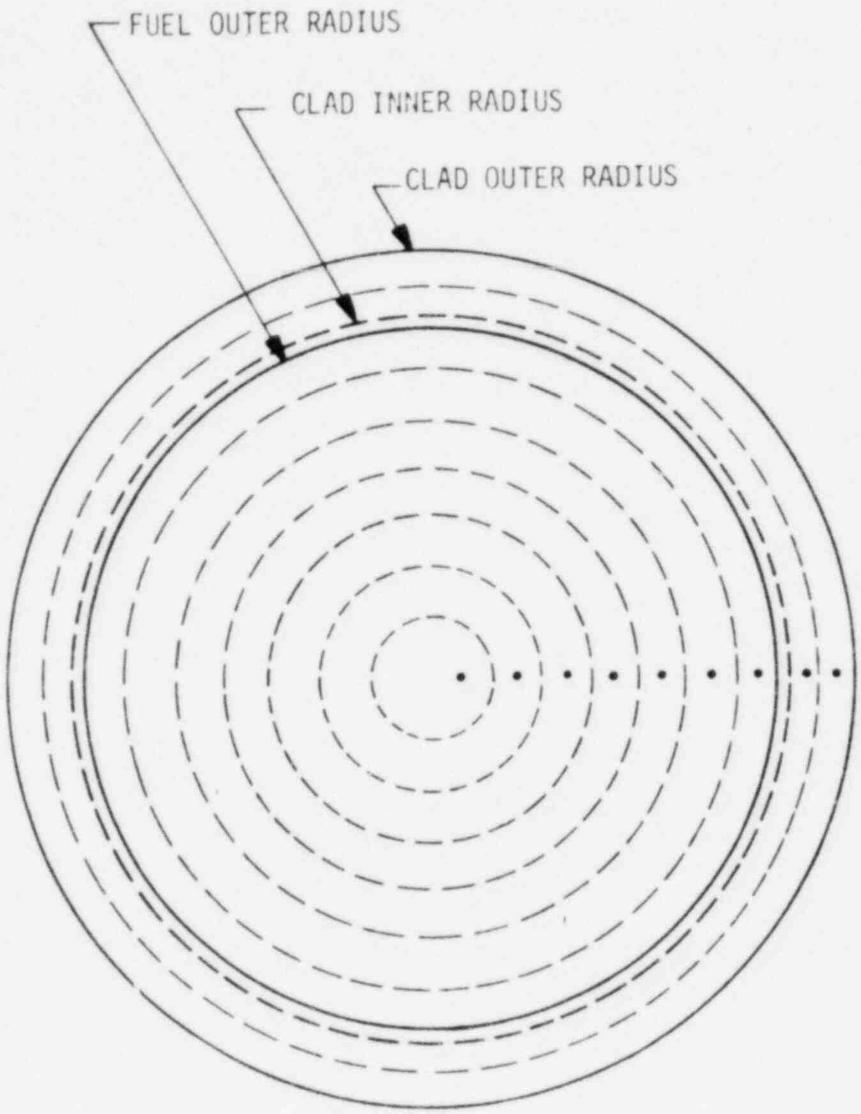


Figure 6.1 TOODEE2 Hot Rod Heat Slab Nodalization



10 GRID LINE LOCATIONS

11 POINT LOCATIONS

Figure 6.2 TOODEE2 Radial Point and Boundary Assignments for a CE 2x4 PWR Hot Channel Analysis

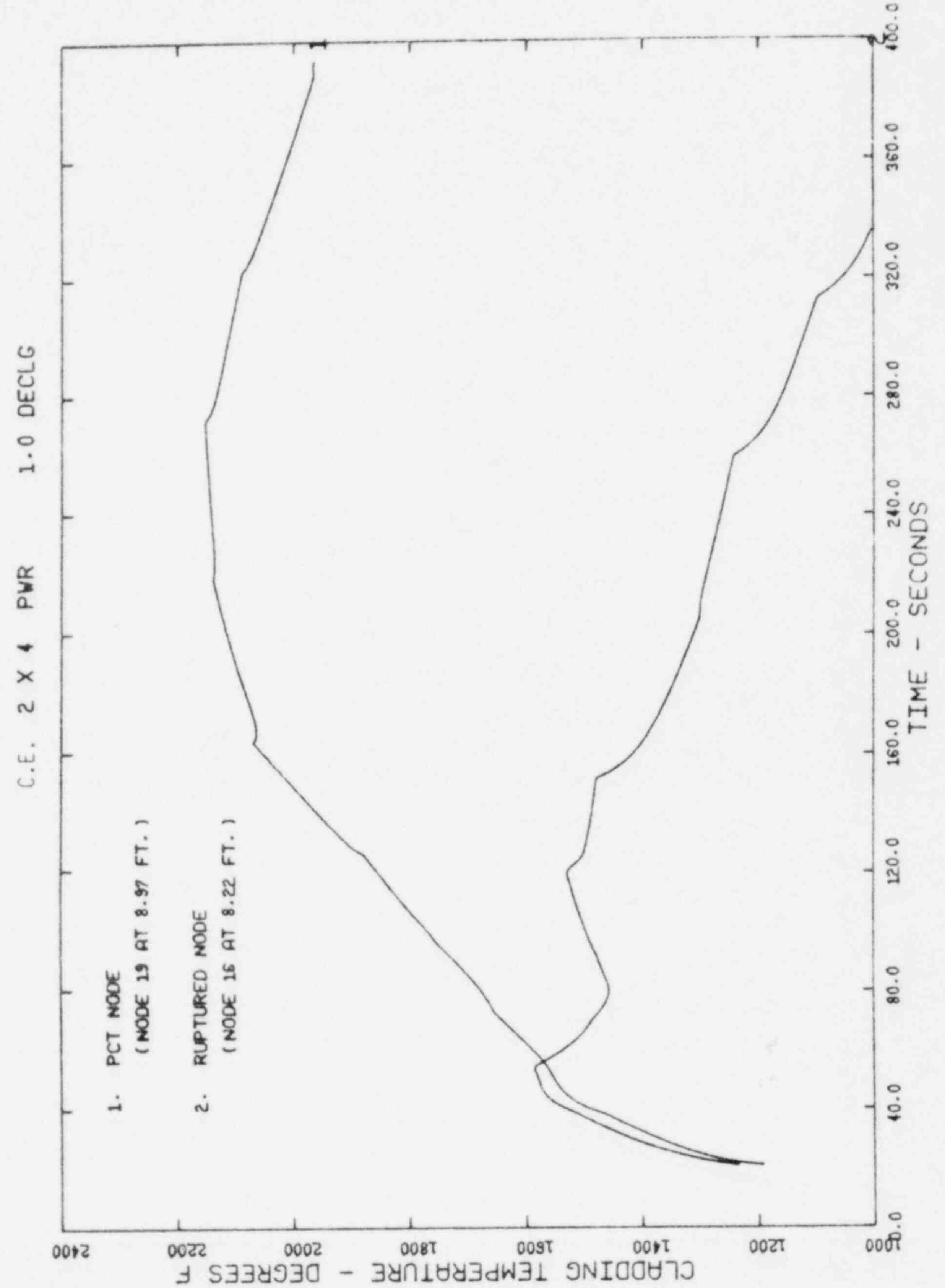


Figure 6.3 Cladding Temperature versus Time, 1.0 DECLG

7.0 CONTAINMENT BACKPRESSURE CALCULATION

The containment backpressure for the reflood period of the postulated LOCA was evaluated in accordance with the discussion presented in XN-75-41, Supplement 5, Section 4.6. A containment analysis was performed using the computer code CONTEMPT-LT, Version 22 modified as described in Supplement 5, Revision 1, of XN-75-41[1] and XN-NF-79-18[9].

The containment analysis considered the equivalent double-ended cold leg guillotine break using the mass and energy release from the RELAP4-EM blowdown analyses. Table 7.1 summarizes some of the pertinent input data such as containment volume, initial pressure and temperature, heat sink dimensions and properties, and capacity and initiation times for safety features.

The condensing heat transfer coefficient is modeled in accordance with Branch Technical Position CSB 6-1, "Minimum Containment Pressure Model for PWR ECCS Performance Evaluation."[12] Ten passive heat sinks were modeled.

The mass and energy from the blowdown analysis is input through the end-of-blowdown, then assumed zero until mass release resumes during the reflood period; the mass and energy from the reflood analysis is input through the remainder of the transient.

The predicted pressure history for the reflood period is shown in Figure 7.1.

Table 7.1 Dry Containment Data

Containment Physical and Thermal Parameters

Net Free Volume	$2.511 \times 10^6 ft^3$
Enclosure Building Temperature	38^oF
Initiation Time for:	
Spray Flow	30.0 sec
Fan Coolers	30.0 sec
Containment Initial Conditions:	
Temperature	90^oF
Pressure	14.6 psia
Relative Humidity	100%
Containment Spray Water:	
Temperature	55^oF
Flow Rate (Total, 2 pumps)	6750 gpm

Fan Air Cooler Capacity
(total 4 coolers)

Vapor Temperature (^oF)	Capacity (Btu/hr)
60	0.
120	5.00×10^6
180	1.06×10^8
220	1.67×10^8
264	3.00×10^8

Thermal Conductivity and Volumetric Heat Capacity

Materials	Thermal Conductivity (Btu/hr-ft-^oF)	Volumetric Heat Capacity (Btu/ft^3-^oF)
Steel	25.9	53.6
Structural Concrete	1.0	34.2
Stainless Steel	9.8	54.0
Galvanizing	64.0	40.6

Table 7.1 (Continued)

Containment Passive Heat Sinks

	DESCRIPTION	MATERIAL	THICKNESS	SURFACE AREA FT^2
1.	Containment Shell	steel	.1171 ft	86,700
2.	Miscellaneous Concrete	concrete	1.5 ft	87,751
3.	Floor Slab	concrete	20 ft	12,682
4.	Galvanized Steel	zinc steel	0.0059 ft 0.014 ft	130,000
5.	Carbon Steel	steel	0.031 ft	25,000
6.	Stainless Steel	steel	0.038 ft	22,300
7.	Miscellaneous Steel	steel	0.063 ft	40,000
8.	Miscellaneous Steel	steel	0.021 ft	41,700
9.	Miscellaneous Steel	steel	0.177 ft	7,000
10.	Imbedded Steel	steel concrete	0.071 ft 7.0 ft	18,000

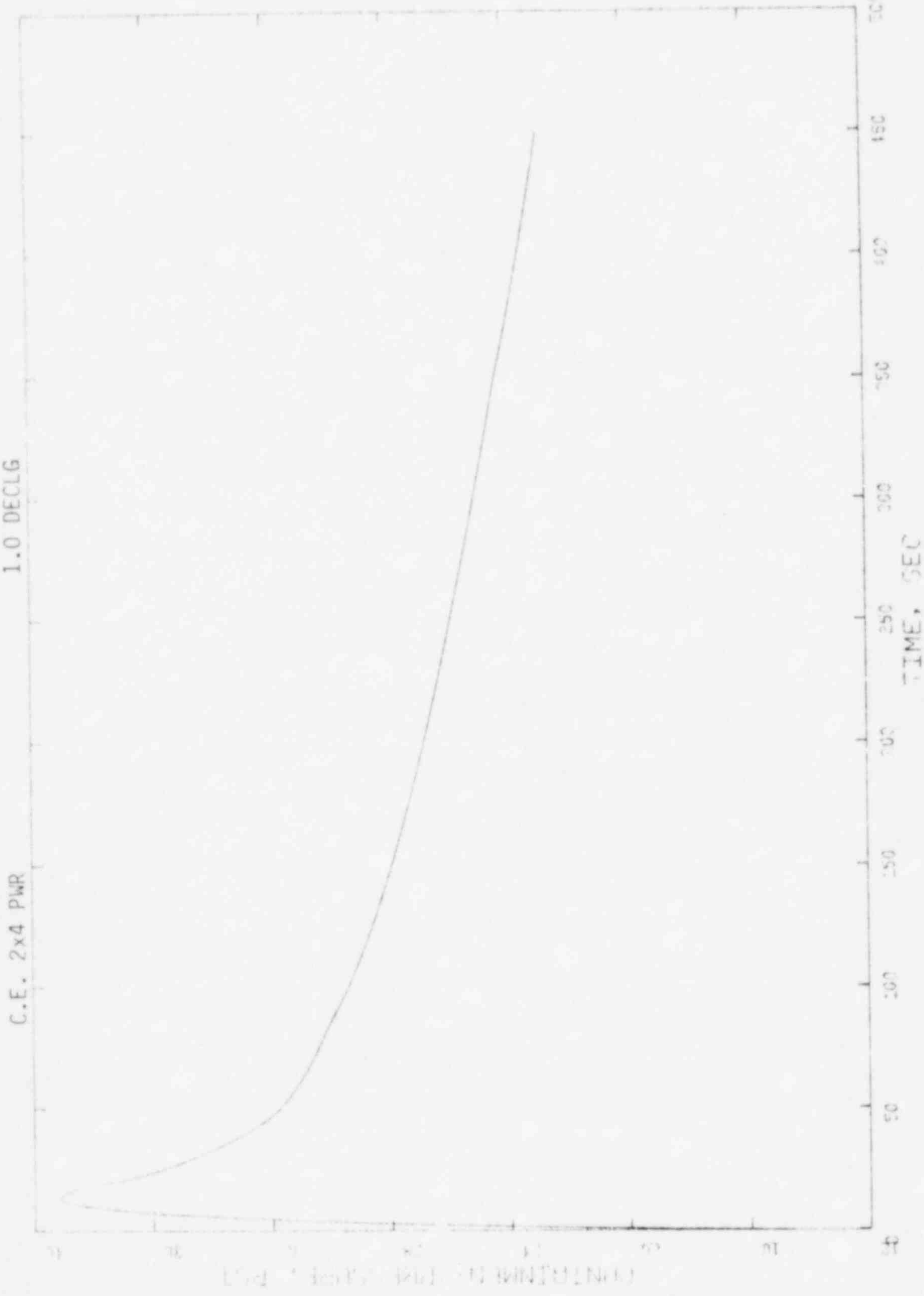


Figure 7.1 Containment Backpressure, 1.0 DECLG

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XN-NF-82-20
Supplement 3

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ENC ECCS EVALUATION OF A CE 2x4 PWR

USING THE EXEM/PWR ECCS MODEL

LARGE BREAK EXAMPLE PROBLEM

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