XN-NF-85-98

KEWAUNEE LIMITING BREAK K (Z)
LOCA/ECCS ANALYSIS

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1.0 INTRODUCTION AND SUMMARY

This document presents analytical results for a postulated large break loss-of-coolant accident (LOCA) for the Kewaunee reactor operating with ENC fuel. The analysis was performed to determine the axially dependent linear heat generation rate (LHGR) limits for Kewaunee (i.e., the K(Z) curve). The analyses assume a reactor operating power of 1683 MWt (1650 MWt plus 2% power uncertainty), and use of Exxon Nuclear Company's (ENC's) fuel. The calculations were made for the double-ended cold leg guillotine break with a discharge coefficient of 0.4 (0.4 DECLG), identified in the previous analyses as the most limiting break[1,2,3,4].

The LOCA analyses were performed for a full core of ENC fuel using the EXEM/PWR ECCS evaluation model[5], with the RODEX2 computer model for evaluating the rod stored energy and fission gas release[6]. The EXEM/PWR ECCS evaluation model includes the NRC fuel swelling and flow blockage model, NUREG-0630[7]. The analyses are applicable to a five percent (5%) average steam generator (SG) tube plugging. The maximum allowable linear heat generation rate (including the 1.02 factor for power uncertainty) is 14.76 kW/ft, corresponding to a maximum total power peaking factor of 2.28 (F^T_Q), and nuclear enthalpy rise of 1.55 ($F^T_{\Delta H}$)[4].

The present LOCA ECCS analyses were performed for Beginning-of-Cycle (BOC) fuel and exposed fuel at End-of-Cycle (EOC) with a conservatively low peak average rod burnup of 10,000 MWD/MTM to maximize peak stored energy. Power shapes representative of, or conservative with respect to, the most top peaked shapes anticipated at the exposure analyzed were used. These power shapes are shown in Figure 1.1 and compared to the $F_Q(Z)$ limit. LOCA analyses using cosine-shaped axial power profile peakings were not performed, since calculations with the cosine power shape had been previously performed[4] and had been used as the basis for setting the maximum total peaking at 2.28.

The calculational basis and results of the present analysis are summarized in Table 1.1. The maximum calculated PCT is equal to 1887°F, and occurs at 59 seconds from the start of the transient at a location 7.63 feet from the bottom of the active core, with a total metal-water reaction less than one percent. The 1887°F PCT result includes a 72°F temperature correction to allow for the use of NRC interim upper plenum injection model[8] as modified by Westinghouse[9]. The results of the analyses show that within the limits established, the Kewaunee nuclear reactor satisfies the criteria specified by 10 CFR 50.46[10] for operation at the rated system power level and with the steam generator tube plugging up to 5%.

For breaks up to and including the double-ended severance of a reactor cold leg coolant pipe, the Emergency Core Cooling System for the Kewaunee unit will meet the Acceptance Criteria as presented in 10 CFR 50.46, with the 2.28 F^T_Q and 1.55 $F^T_{\Delta H}$ limits. The criteria are as follows:

(1) The calculated peak fuel element clad temperature does not exceed the 2200°F limit.

(2) The amount of fuel element cladding that reacts chemically with water or steam does not exceed 1 percent of the total amount of zircaloy in the reactor.

(3) The cladding temperature transient is terminated at a time when the core geometry is still amenable to cooling. The hot fuel rod cladding oxidation limits of 17% are not exceeded during or after quenching.

(4) The core temperature is reduced and decay heat is removed for an extended period of time, as required by the long-lived radioactivity remaining in the core.

Table 1.1 Kewaunee LOCA-ECCS Analysis Results - K(Z)

Analysis Results	BOC	EOC 10000 MWD/MTM Peak Average Rod Exposure
Peak Clad Temperature (PCT), ^{o}F***	1887	1816
ΔPCT for UPI, ^{o}F	-72	-70
Time of PCT, sec.	59	150
Peak Clad Temperature Location, ft.	7.63	10.88
Local Zr/H_2O Reaction (max.), %*	2.6	2.5
Local Zr/H_2O Location, ft. from bottom	7.63	10.88
Total H_2 Generation, % of Total Zr Reacted	<1.0	<1.0
Hot Rod Burst Time, sec.	42	44.7
Hot Rod Burst Location, ft.	7.63	10.125
Peak Power Location, ft.	7.63	10.25
Calculational Basis		
License Core Power, MWt	1650	1650
Power Used for Analysis, MWt**	1683	1683
Peak Linear Power for Analysis, kW/ft**	14.4	14.0
Total Peaking Factor, F^T_Q	2.23	2.16
Enthalpy Rise, Nuclear, $F^T_{\Delta H}$	1.79	1.55
Steam Generator Tube Plugging (%)	5.00	5.00

* Computer value at 380 seconds

** Including 1.02 factor for power uncertainties

*** Includes ΔPCT for UPI

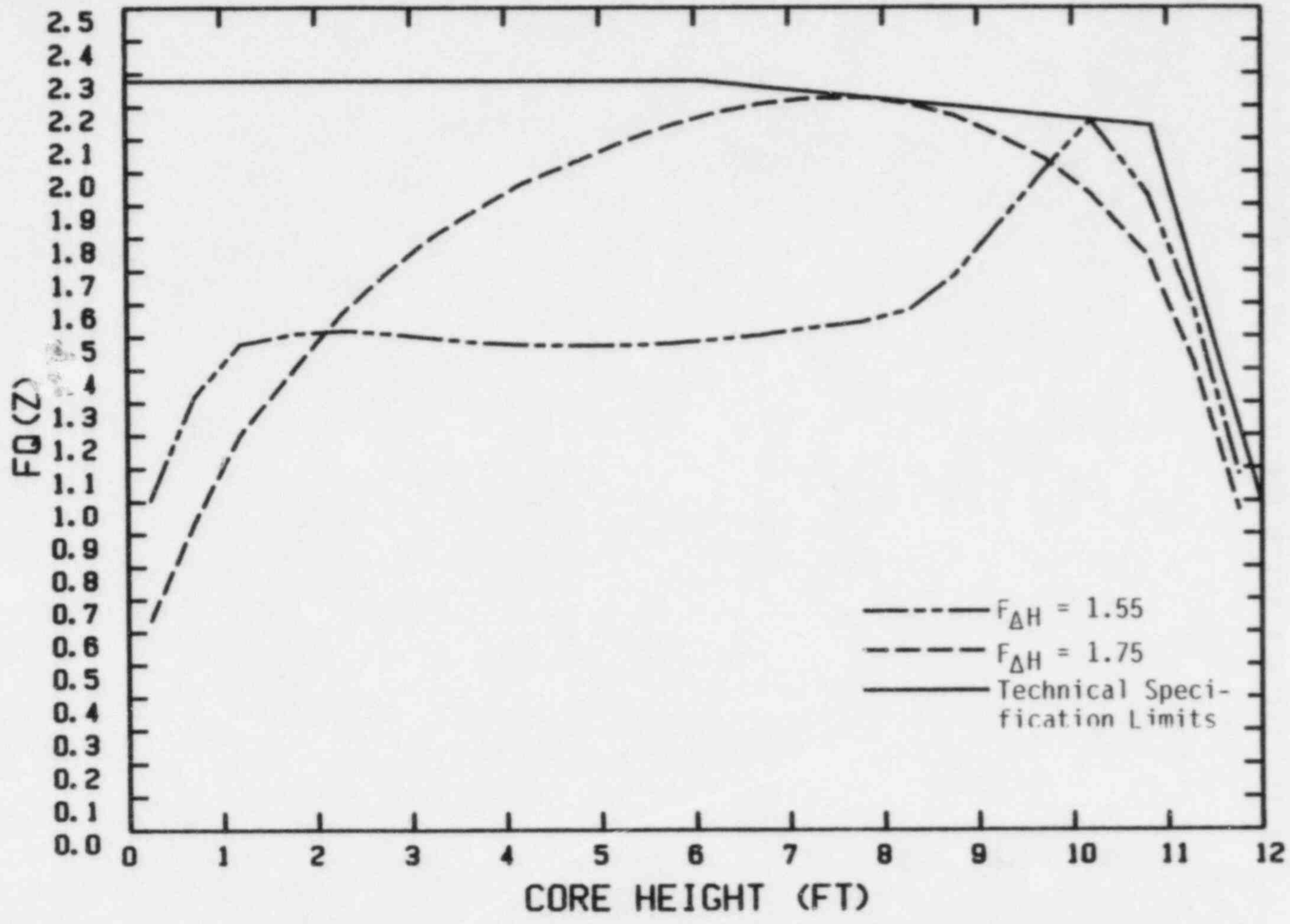


Figure 1.1 Comparison of Power Distributions Analyzed to Limits

2.0 LIMITING BREAK LOCA ANALYSIS

This report provides the results of a LOCA-ECCS analysis performed for Kewaunee with total steam generator tube plugging up to 5%. The analytical techniques used are in compliance with Appendix K of 10 CFR 50, and are described in the ENC WREM models[11], and the Emergency Core Cooling System Evaluation Model Updates: WREM-II[12], WREM-IIA[13] and EXEM/PWR[5,18].

A LOCA break spectrum analysis was performed for a similar Westinghouse two-loop plant, with results reported in XN-NF-78-46[1]. The limiting LOCA break was determined to be a large double-ended guillotine break of the cold leg, with a discharge coefficient of 0.4 (0.4 DECLG).

2.1 LOCA Analysis Model

The Exxon Nuclear Company EXEM/PWR ECCS evaluation model[5] was used to perform the analyses. This model consists of the following computer codes: RODEX2[6] code for initial rod stored energy and internal fuel rod gas inventory; RELAP4-EM[14] for the system blowdown and hot channel blowdown calculations; CONTEMPT-LT/22 as modified in CSB 6-1[15] for computation of containment backpressure; REFLEX[5,7,16] for computation of system reflood; and TOODEE2[5,7,17] for the calculation of final fuel rod heatup. The quench and heat transfer coefficient models used in the reflood portion of the transient are based on the Fuel Cooling Test Facility (FCTF) test data and are reported in reference 18. The NRC upper plenum injection (UPI) interim model, developed by the NRC Staff[8] and modified by Westinghouse[9], was utilized.

The Kewaunee nuclear reactor is a two-loop Westinghouse pressurized water reactor with an upper plenum injection and dry containment. The reactor coolant system is nodalized into control volumes representing reasonably homogeneous regions, interconnected by flow-paths or "junctions" as described in XN-NF-77-25(A)[15]. The system nodalization is as depicted in Figure 2.1.

The pump performance characteristic curves are supplied by the NSSS vendor. Five percent of the steam generator tubes are assumed to be plugged in each generator. The transient behavior was determined from the governing conservation equations for mass, energy, and momentum. Energy transport, flow rates, and heat transfers are determined from appropriate correlations. System input parameters are given in Table 2.1.

The reactor core is modeled with heat generation rates determined from reactor kinetics equations with reactivity feedback and with decay heating as required by Appendix K of 10 CFR 50. The LOCA/ECCS analysis presented in this report supports the current K(Z) function developed by the NSSS vendor for the portion of the function defined by the large break LOCA. Where small break LOCA is limiting, the K(Z) curve is defined such that the Linear Heat Generation Rates (LHGRs) determined by the NSSS vendor analysis are unchanged. The K(Z) function is shown in Figure 2.36. The analysis of the loss-of-coolant accident is performed at 102 percent of rated power. The fuel design parameters are shown in Table 2.2.

LOCA/ECCS calculations were performed at BOC and EOC conditions to bound the power distributions anticipated to occur. Two power shapes representative of the most top peaked anticipated at BOC and EOC conditions were chosen from a study of a number of different reactors and cycles. The BOC axial power distribution (Figure 2.2) was analyzed in conjunction with a conservative value for $F_{\Delta H}$ in excess of the Technical Specification limit. This was done in order to be able to analyze with a peak F_Q at the desired Technical Specification limit. The EOC axial power distribution (Figure 2.3) was conservatively increased in value in the top portion of the core and decreased at the bottom portion of the core in order to be analyzed with a peak F_Q at the Technical Specification limit and with an $F_{\Delta H}$ value equal to the Technical Specification limit. The EOC case was analyzed with a conservatively low rod burnup. The use of a low rod burnup results in a higher stored energy than would be anticipated to occur in conjunction with the axial power shape utilized. LOCA analyses using cosine-shaped axial power peakings were not performed since analyses with these shapes were previously reported. These power shapes are shown in Figure 1.1 and compared to the $F_Q(Z)$ limit.

2.2 Results

Table 2.3 presents the timing and sequence of events as determined for the large guillotine break with a discharge coefficient of 0.4. Comparison of these results with the previous LOCA-ECCS analysis for ENC fuel shows very slight change in the event times. Figures 2.4 through 2.10 present plotted results for system blowdown analysis[4]. Unless otherwise noted on the figures, time zero corresponds to the time of break initiation. Figure 2.11 presents calculated containment backpressure time history[4]. Figures 2.12 through 2.23 present results for the hot channel blowdown calculations. Figures 2.24 and 2.25 show the normalized power calculation results. The reflood calculation results are shown in Figures 2.26 through 2.33.

The maximum peak cladding temperature (PCT) calculated for the 0.4 DECLG break at BOC is 1887°F (Figure 2.34). This value includes a 72°F temperature reduction associated with the use of the NRC interim upper plenum injection (UPI) model as modified by Westinghouse. The maximum local metal-water reaction in this case is 2.6% after 380 seconds, and the total core metal-water reaction is less than 1%. The PCT location is at an elevation of 7.63 feet from the bottom of active core. For ENC fuel at EOC, the PCT is 1816°F (Figure 2.35) including -70°F for UPI effect, occurring at 10.88 feet elevation relative to the bottom of the active core. The local metal-water reaction is 2.5%, with a total metal-water reaction of less than 1%. The peak cladding temperatures shown in Figures 2.34 and 2.35 do not include the UPI corrections.

Table 2.1 Kewaunee System Data

Primary Heat Output, MWt	1650*
Primary Coolant Flow, lbm/hr	6.82×10^7
Operating Pressure, psia	2,250
Inlet Coolant Temperature, ^oF	534
Reactor Vessel Volume, ft^3	2406
Pressurizer Volume, Total, ft^3	1000
Pressurizer Volume, Liquid, ft^3	600
Accumulator Volume, Total, ft^3 (each of two)	2000
Accumulator Volume, Liquid, ft^3	1250
Accumulator Trip Point Pressure, psia	714.7
Steam Generator Secondary Heat Transfer Area, ft^2	48,925**
Steam Generator Secondary Flow, lbm/hr	3.56×10^6
Steam Generator Secondary Pressure, psia	750
Reactor Coolant Pump Head, ft (Design)	277
Reactor Coolant Pump Speed, rpm (Design)	1190
Moment of Inertia, lbm-ft^2/rad	80,000
Cold Leg Pipe, I.D., in	27.5
Hot Leg Pipe, I.D., in	29
Pump Suction Pipe, I.D., in	31

* Primary Heat Output used in RELAP4-EM Model = 1.02 x 1650 = 1683 MWt.
** Includes 5% SG tube plugging.

Table 2.2 Fuel Design Parameters

Cladding, O.D., in.	0.424
Cladding, I.D., in.	0.364
Cladding Thickness, in.	0.030
Pellet O.D., in.	0.3565
Diametral Gap, in.	0.0075
Pellet Density, % TD	94.0
Active Fuel Length, in.	144.0
Rod Pitch, in.	0.556

Table 2.3 Kewaunee LOCA-ECCS Analysis Results, Event Times

Event	Time (sec.)
Start	0.00
Break Initiation	.05
Safety Injection Signal	.65
Accumulator Injection, Broken Loop	4.8
Accumulator Injection, Intact Loop	8.8
End-of-Bypass	22.7
Safety Injection Flow	25.7
Start of Reflood	36.9
Accumulator Empties, Intact Loop	43.1
Peak Clad Temperature Reached -	
BOC	59.0
EOC	150.0

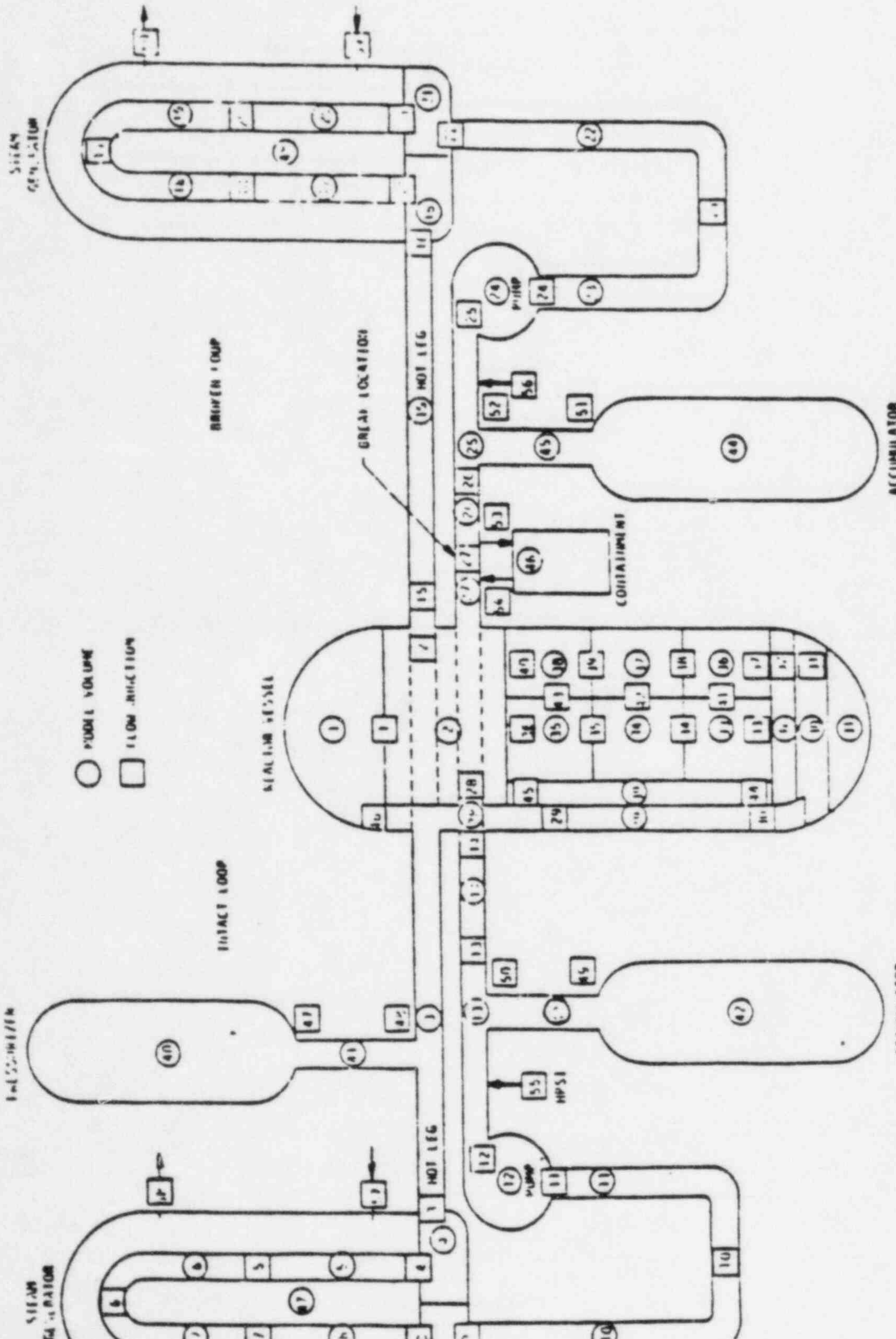


Figure 2.1 RELAP4/EM Blowdown System Nodalization for Kewaunee

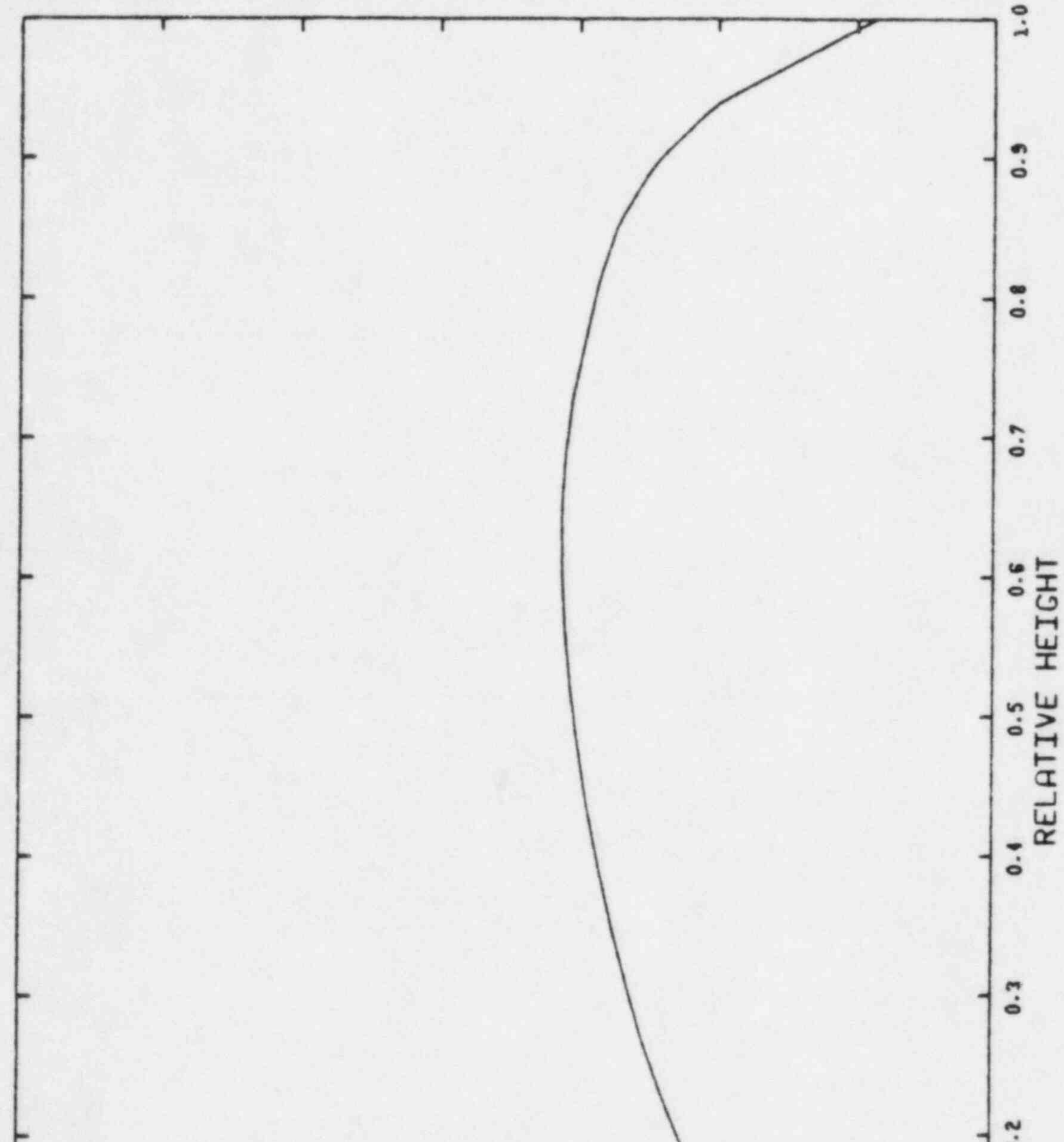


Figure 2.2 Axial Peaking Factor vs. Relative Height, 0.4 DECLG Break, BOC

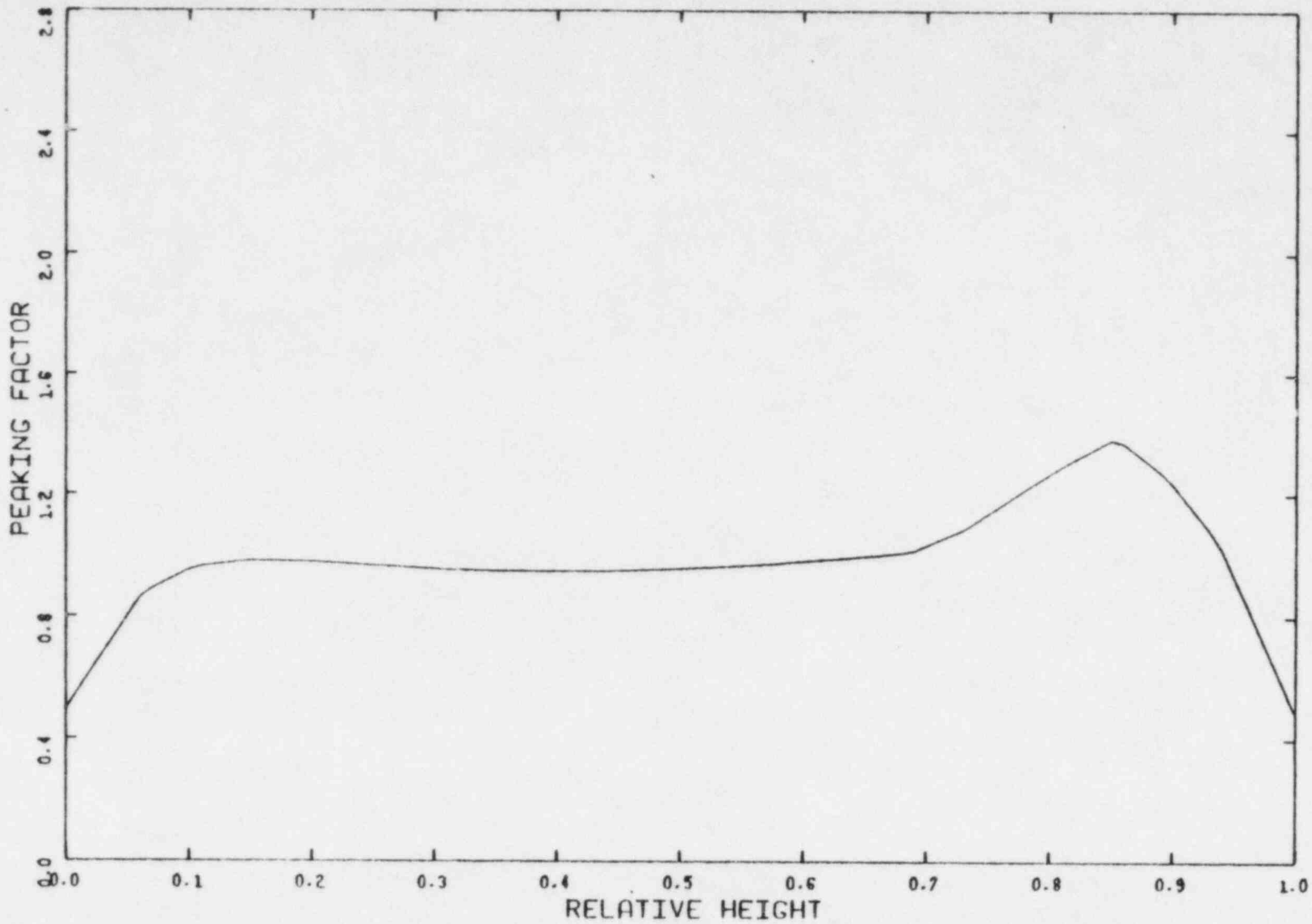


Figure 2.3 Axial Peaking Factor vs. Relative Height,
0.4 DECLG Break, EOC

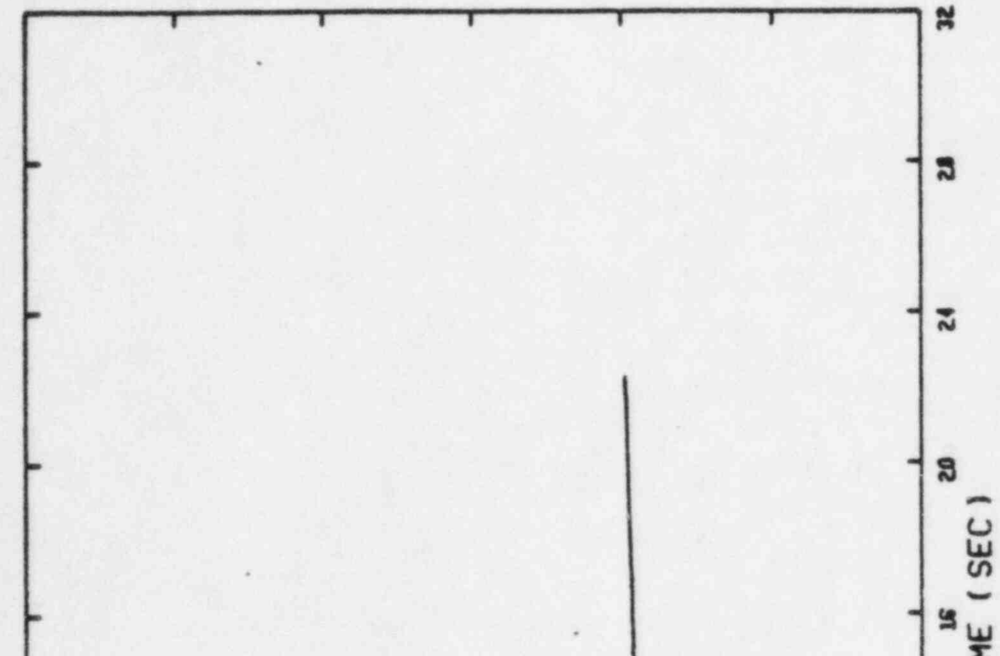


Figure 2.4 Downcomer Flow Rate, 0.4 DECLG Break

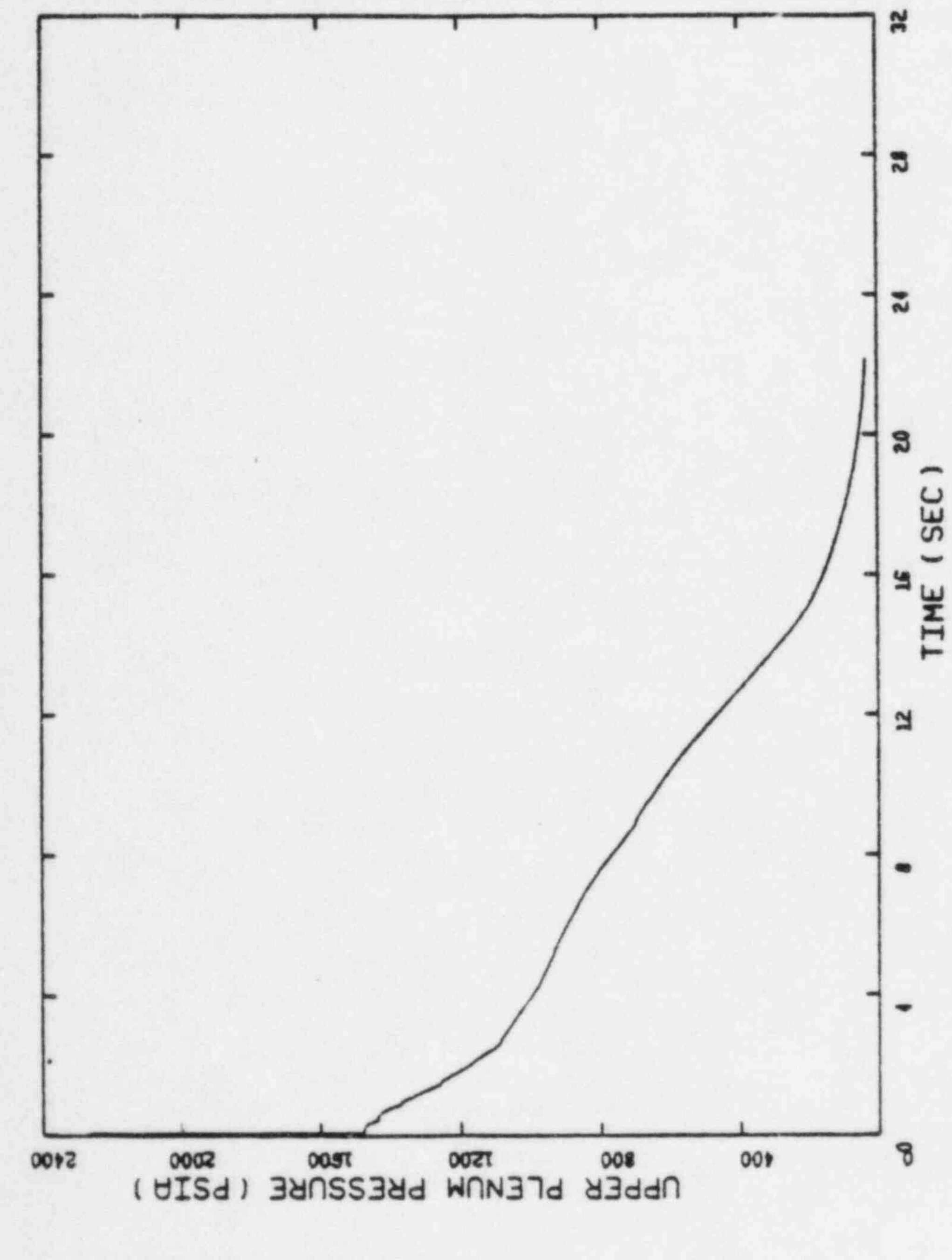


Figure 2.5 Upper Plenum Pressure, 0.4 DECLG Break

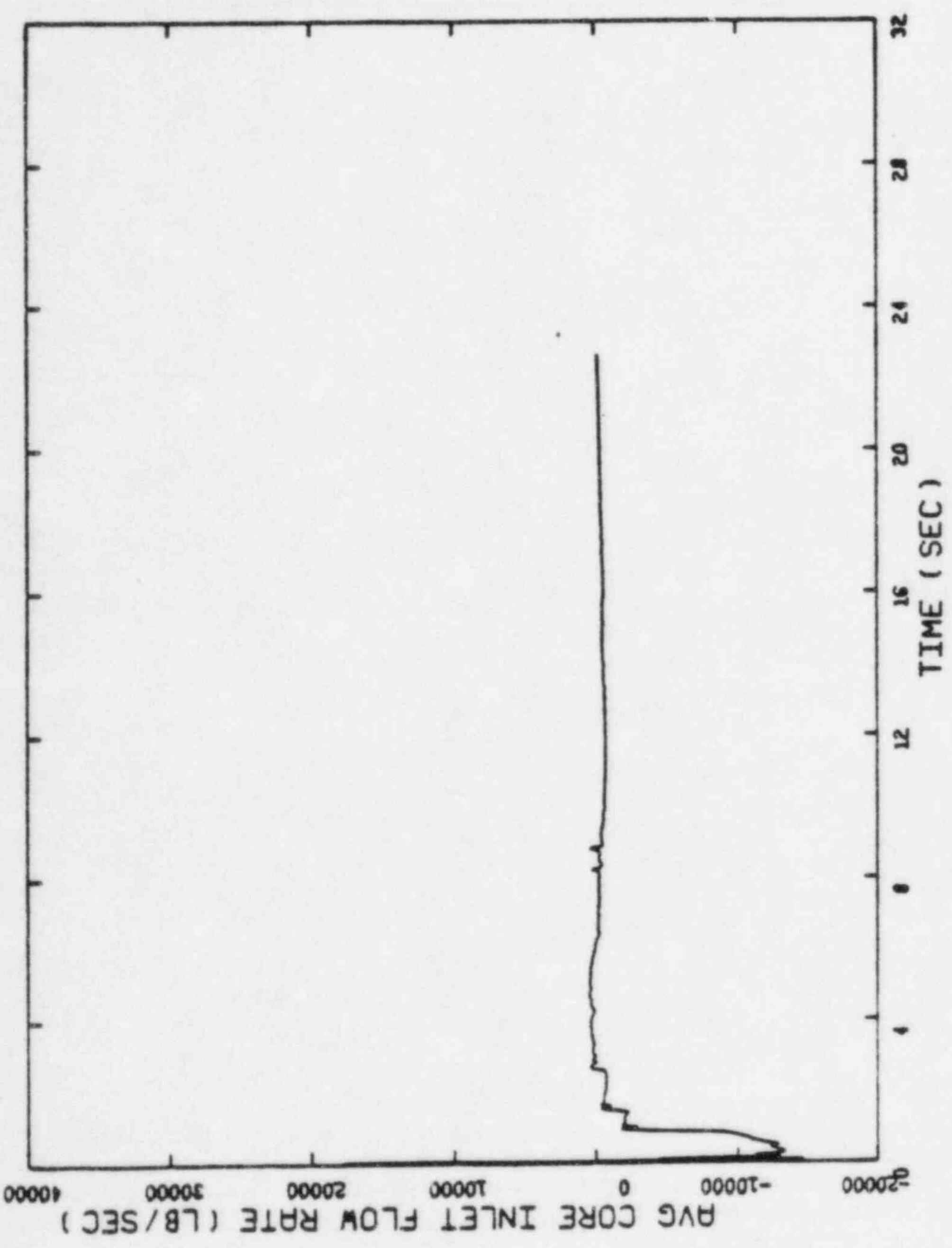


Figure 2.6 Average Core Inlet Flow, 0.4 DECLG Break

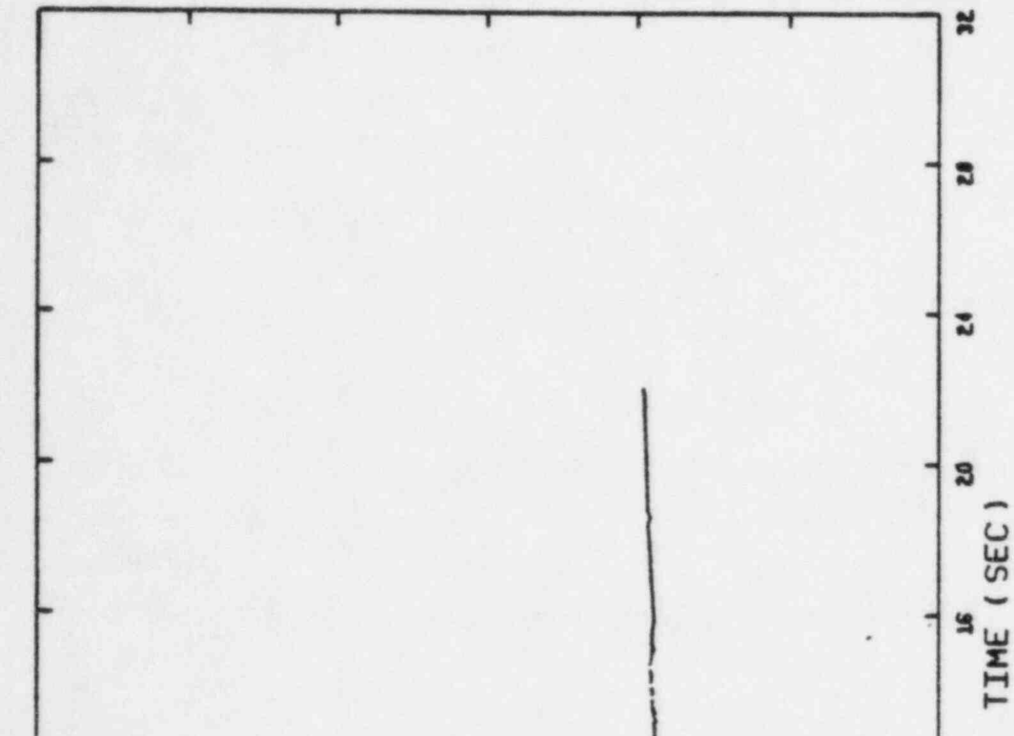


Figure 2.7 Average Core Outlet Flow, 0.4 DECLG Break

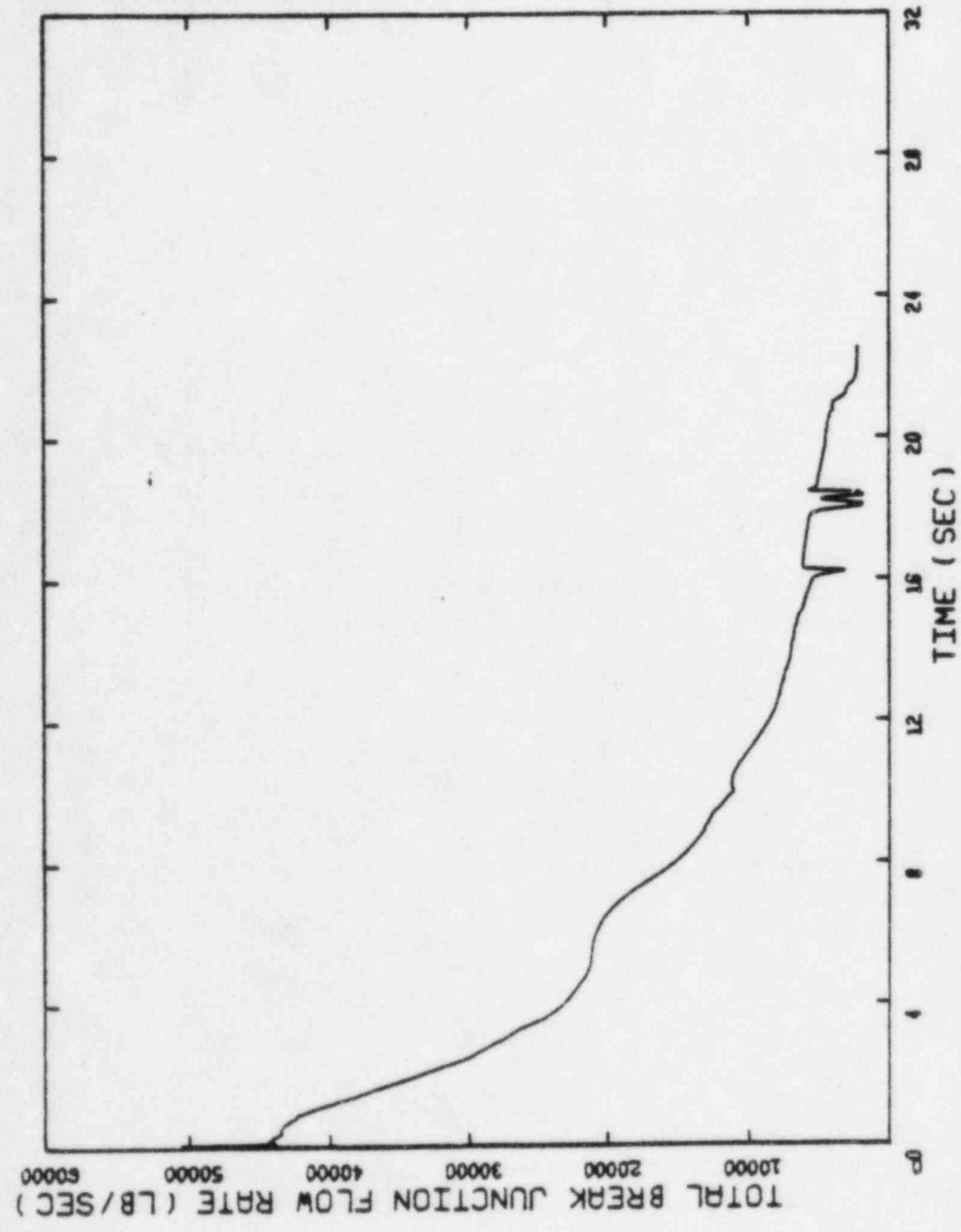


Figure 2.8 Total Break Flow, 0.4 DECLG Break

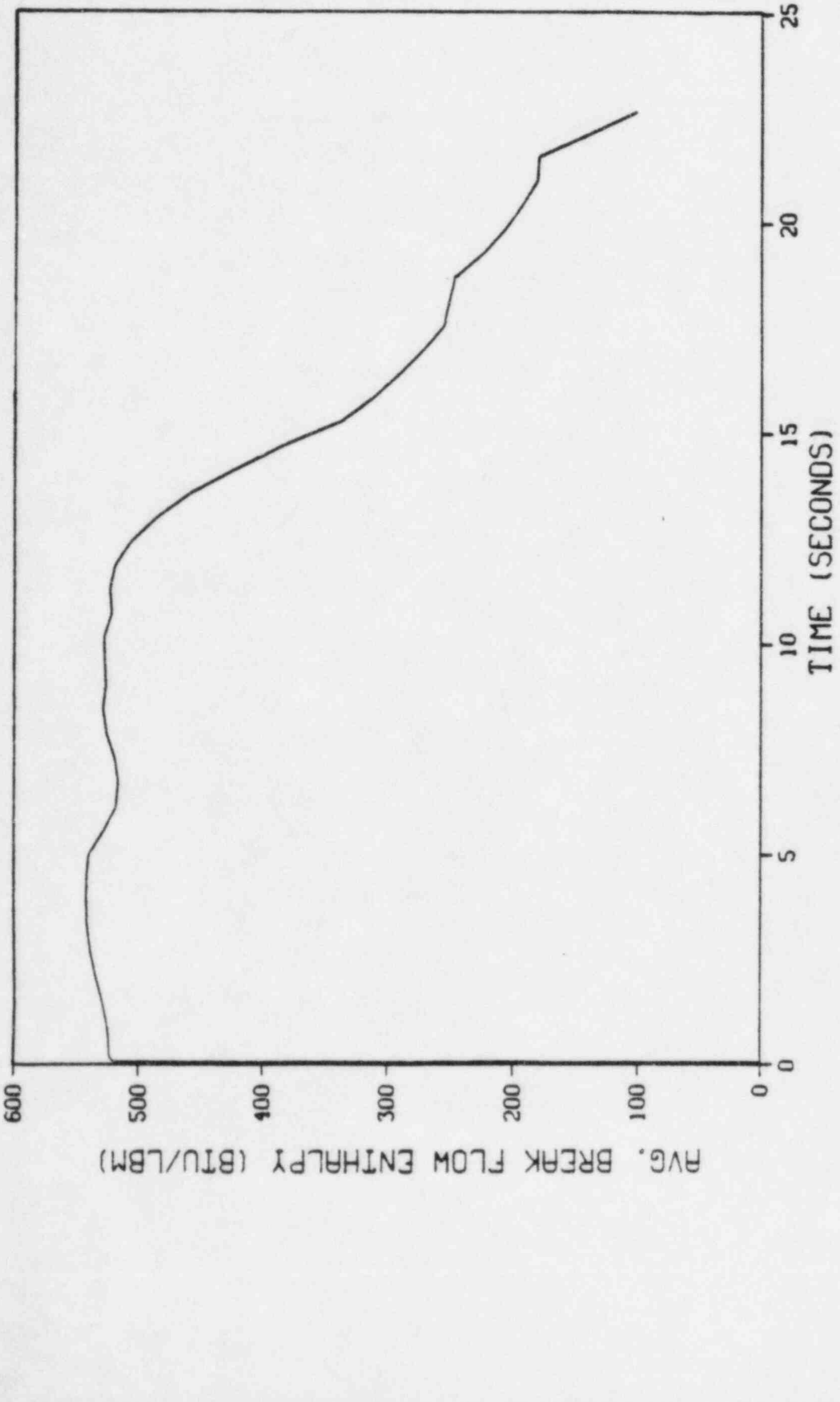


Figure 2.9 Average Break Flow Enthalpy, 0.4 DECLG

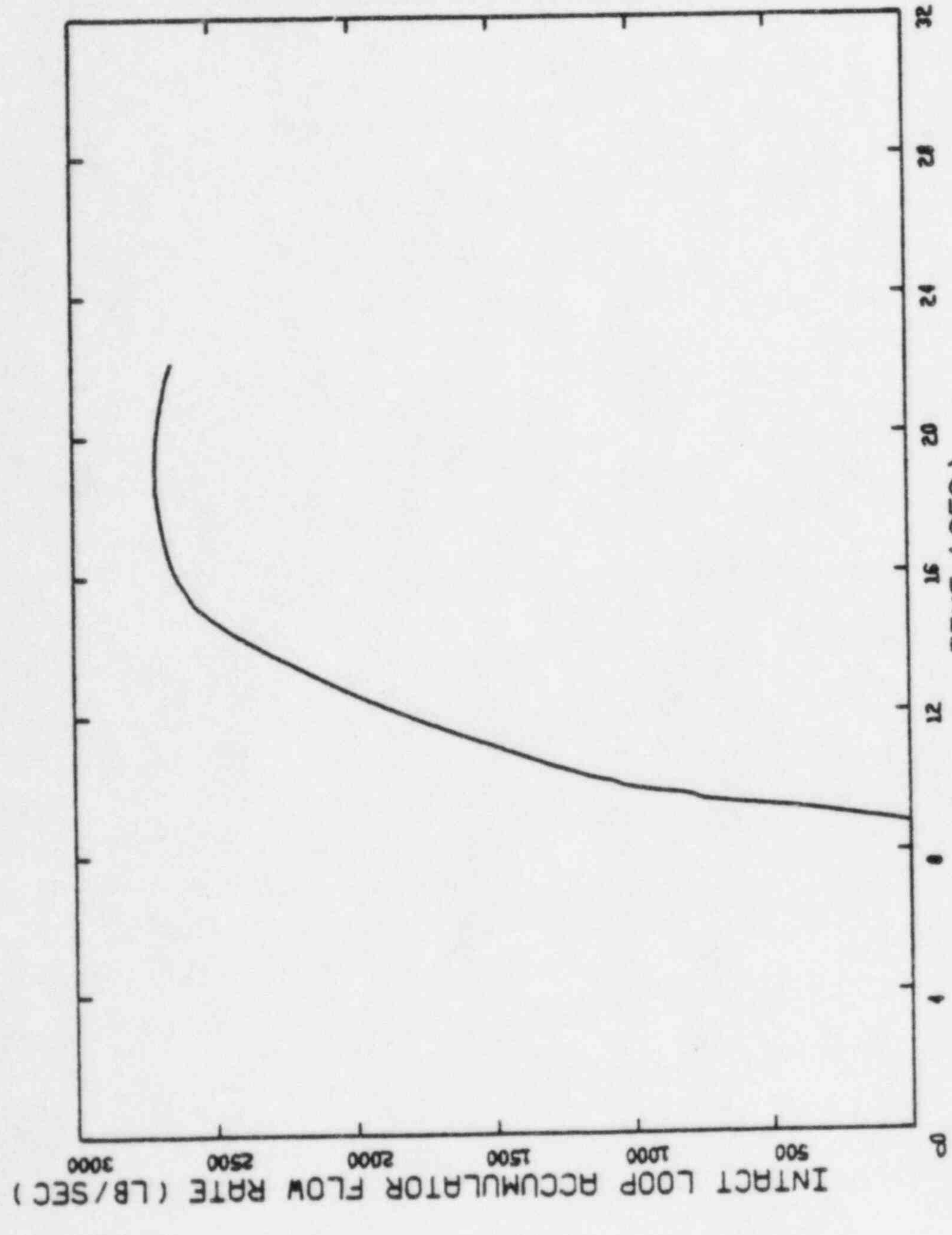


Figure 2.10 Flow From Intact Loop Accumulator,
0.4 DECLG Break

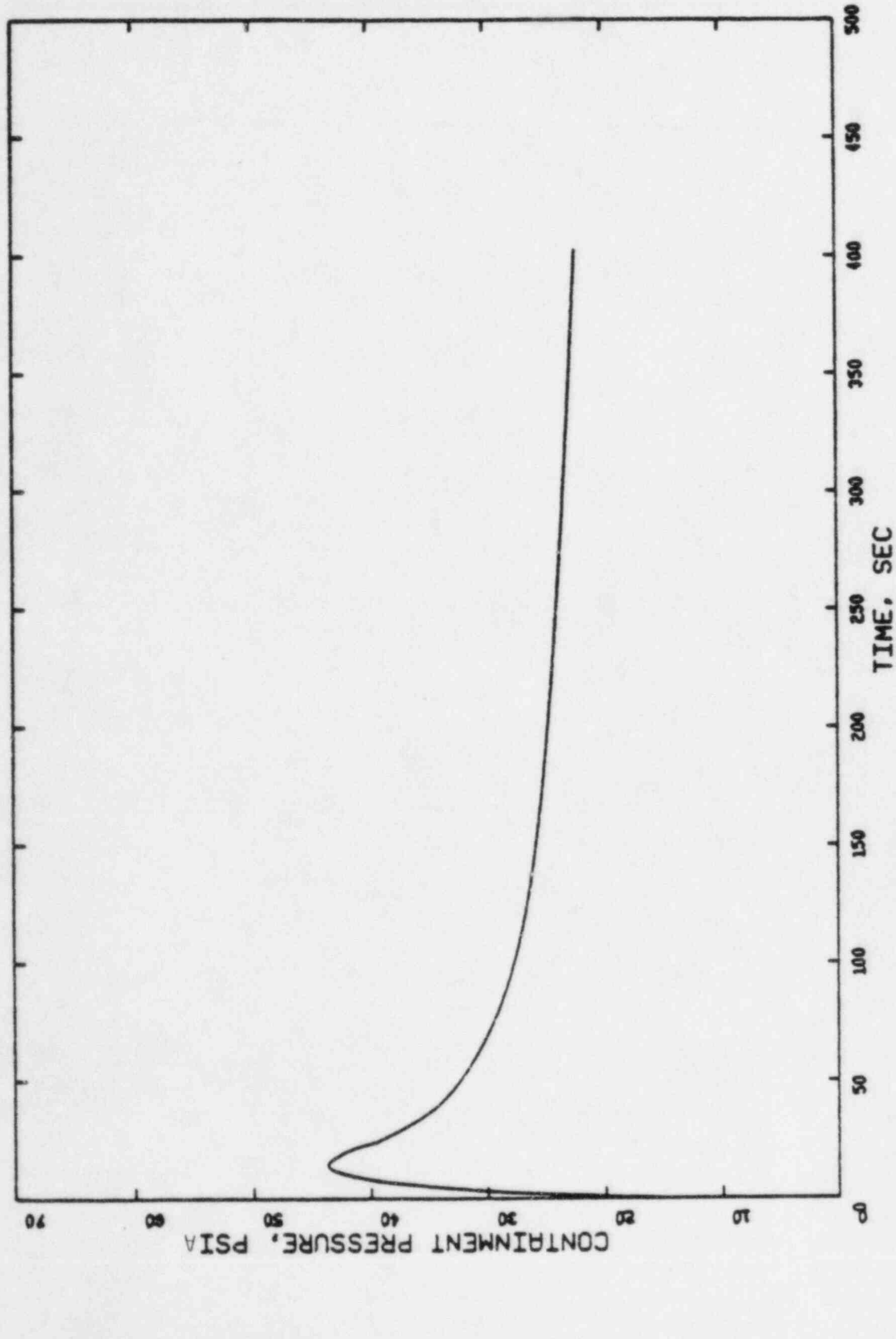


Figure 2.11 Containment Back Pressure, 0.4 DECLG Break

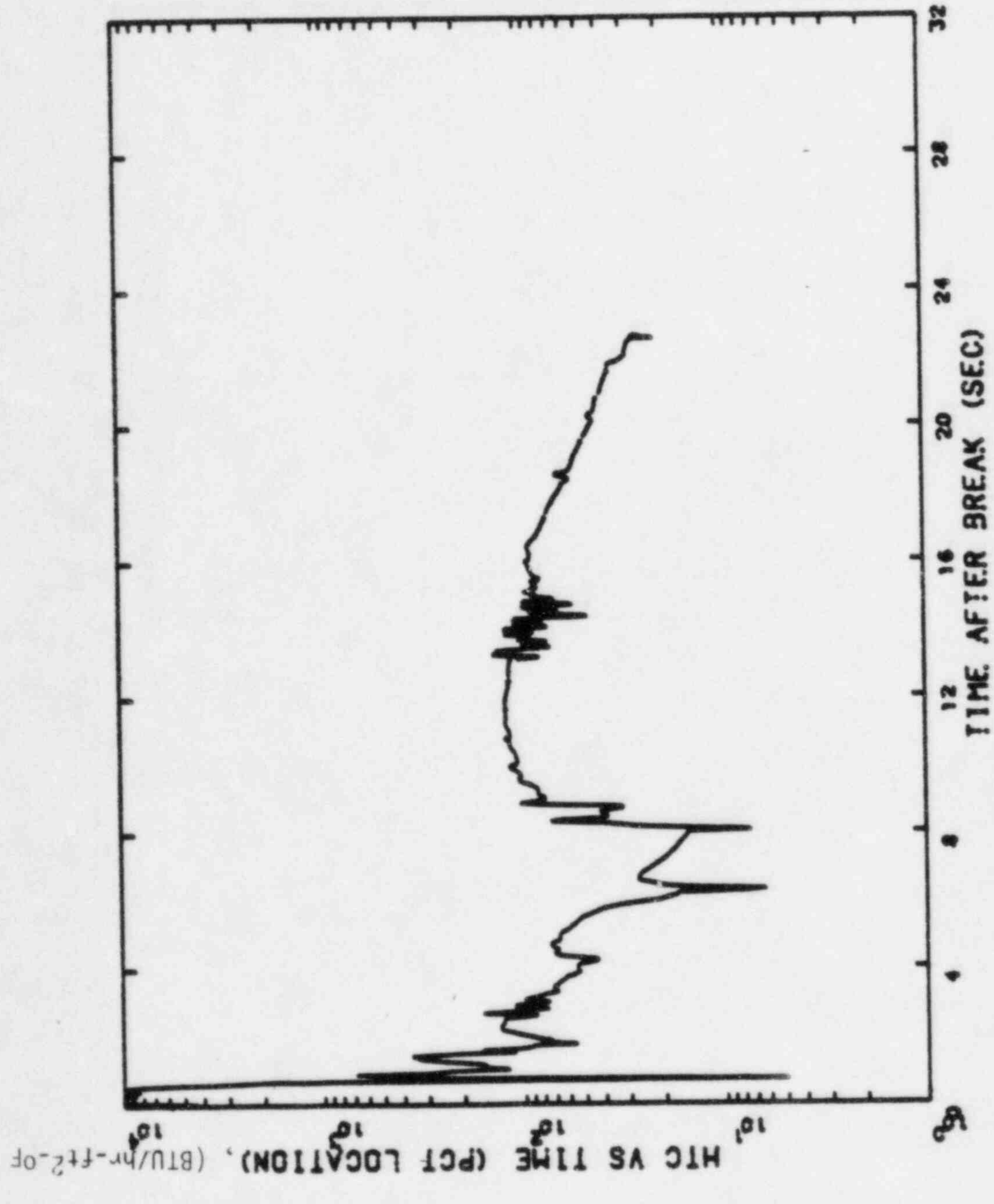


Figure 2.12 Hot Channel Heat Transfer Coefficients, 0.4 DECLG Break, BOC

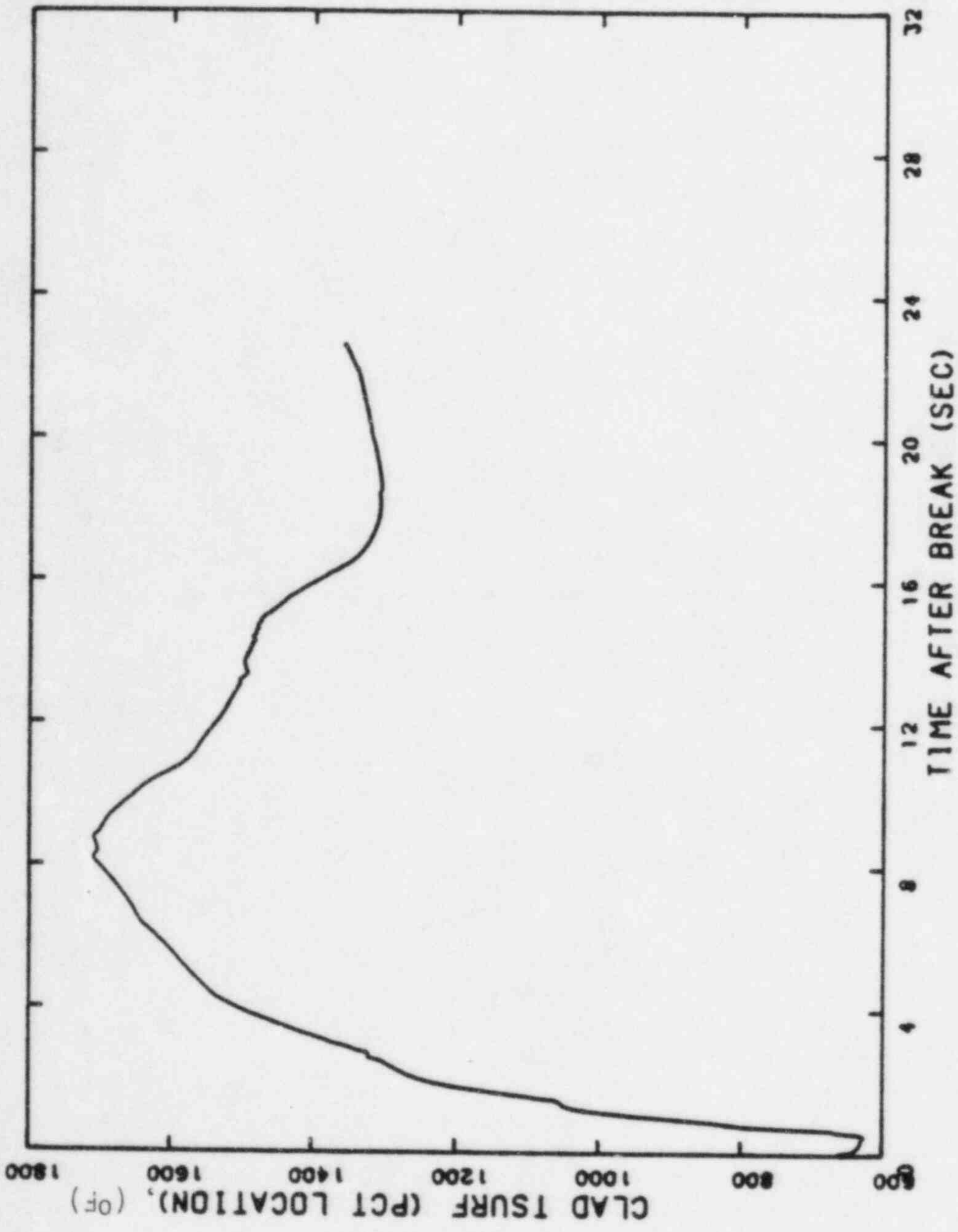


Figure 2.13 Clad Surface Temperature, 0.4 DECLG Break, BOC

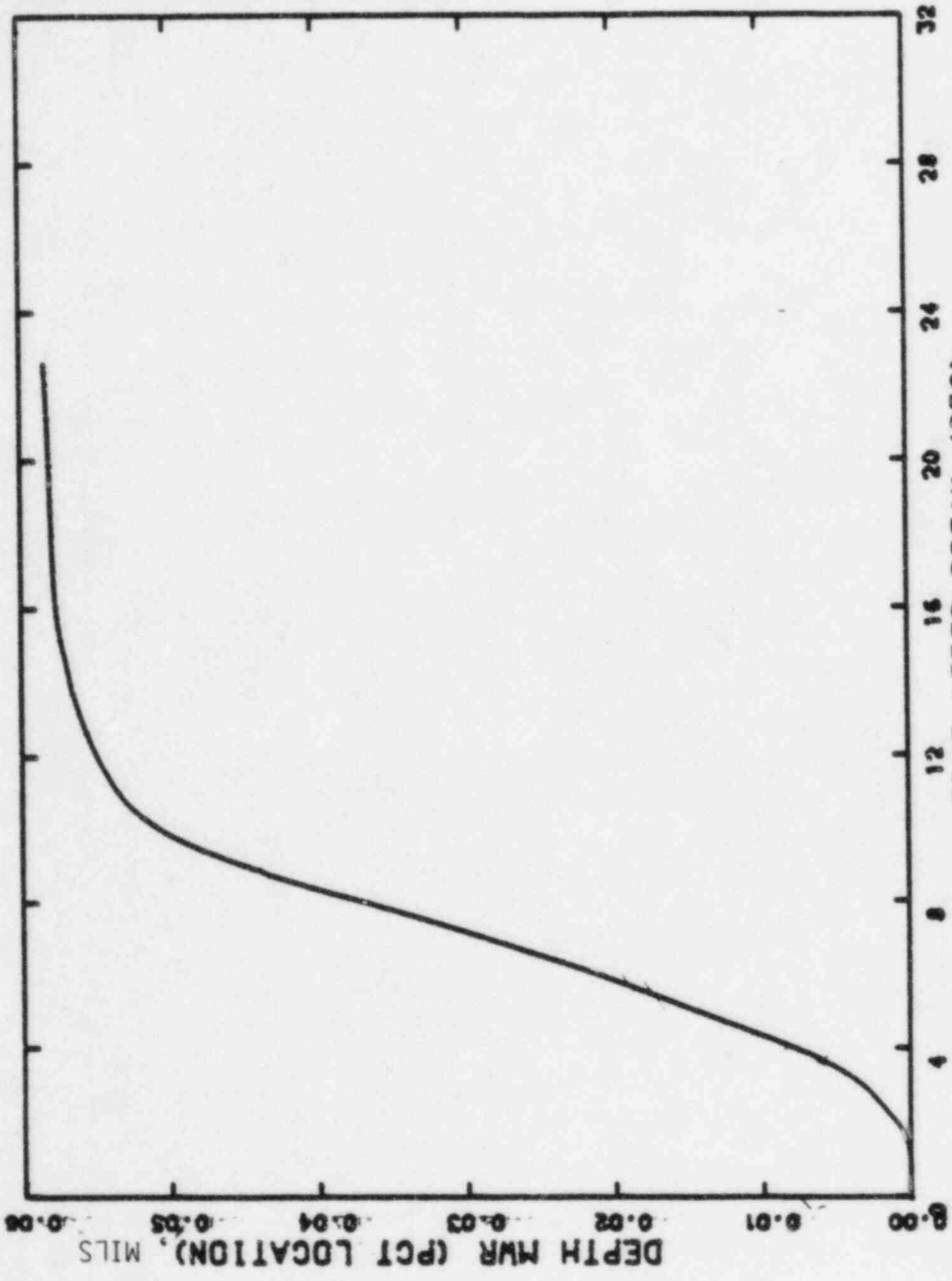


Figure 2.14 Depth of Metal-Water Reaction, 0.4 DECLG Break, BOC

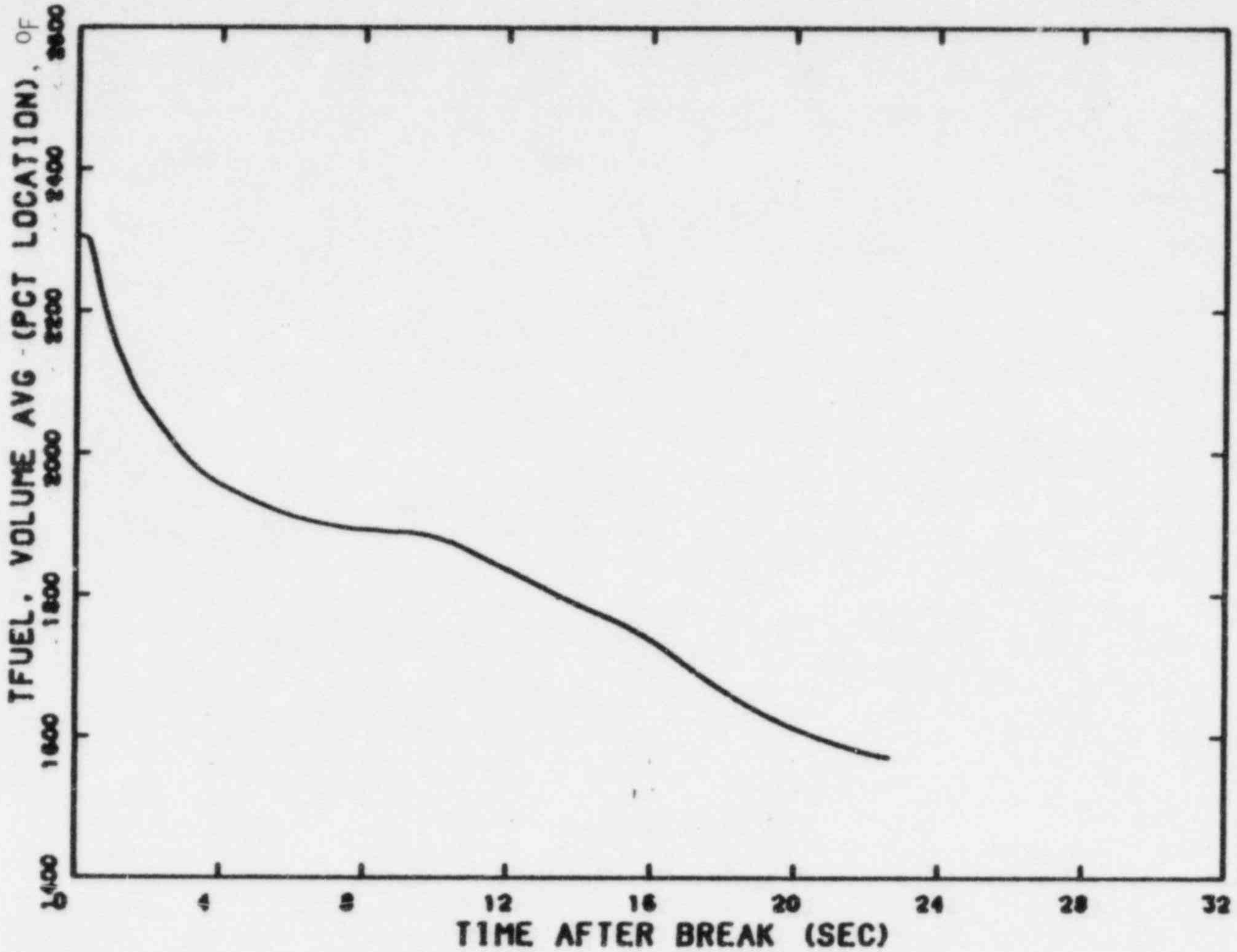


Figure 2.15 Hot Channel Average Fuel Temperature, 0.4 DECLG Break, BOC

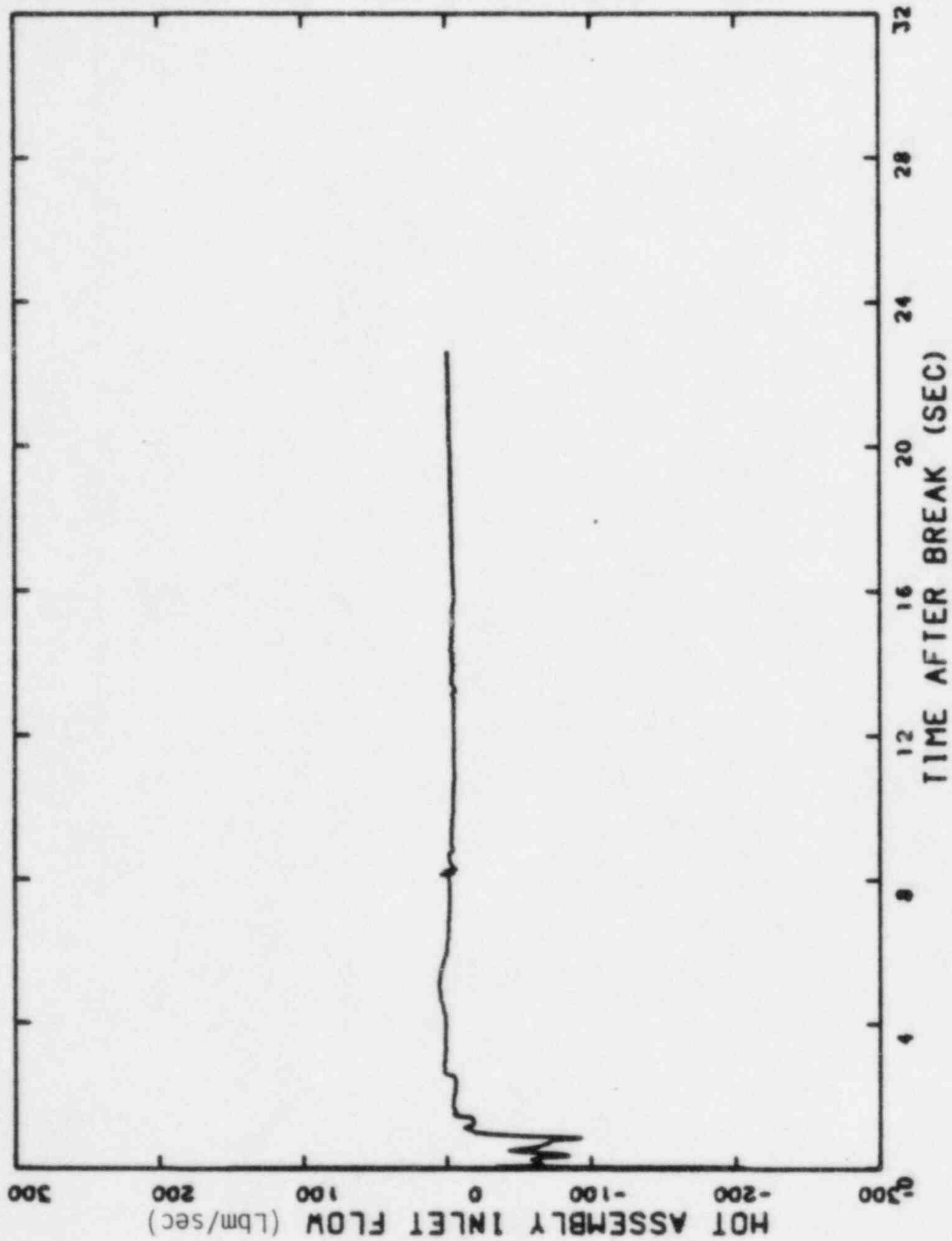


Figure 2.16 Hot Assembly Inlet Flow, 0.4 DECLG Break, BOC

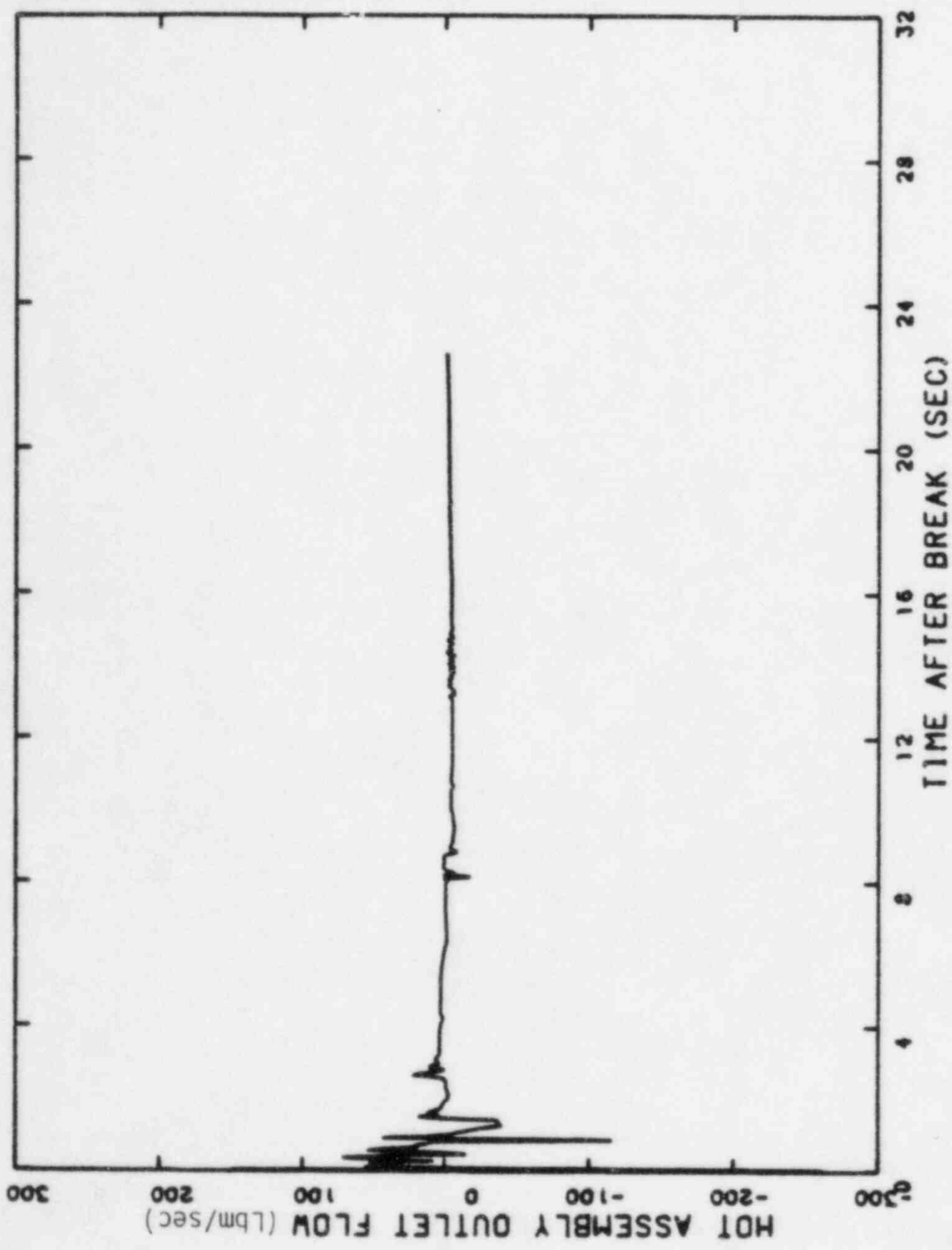


Figure 2.17 Hot Assembly Outlet Flow, 0.4 DECLG Break, BOC

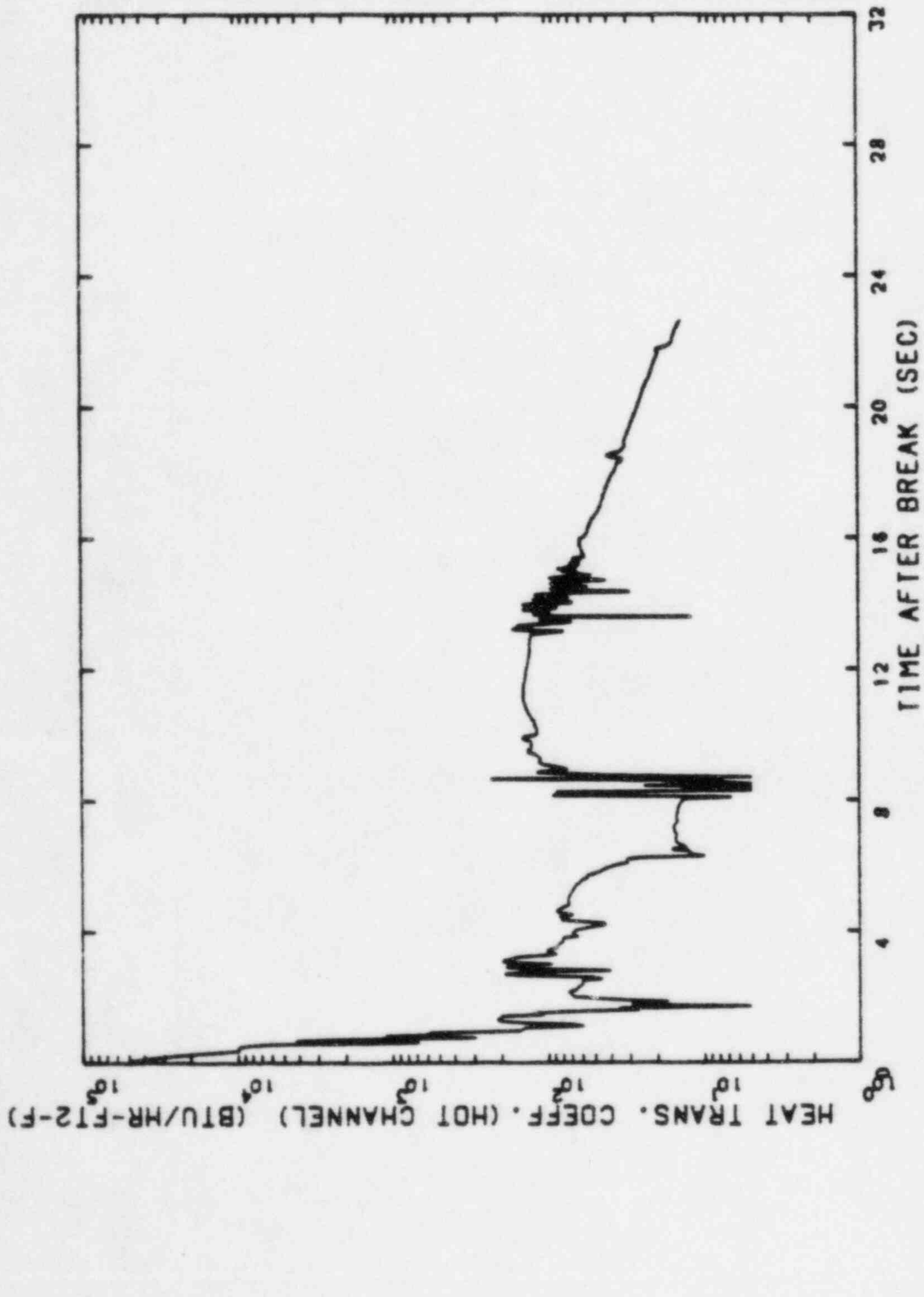


Figure 2.18 Hot Channel Heat Transfer Coefficient, 0.4 DECLG Break, EOC

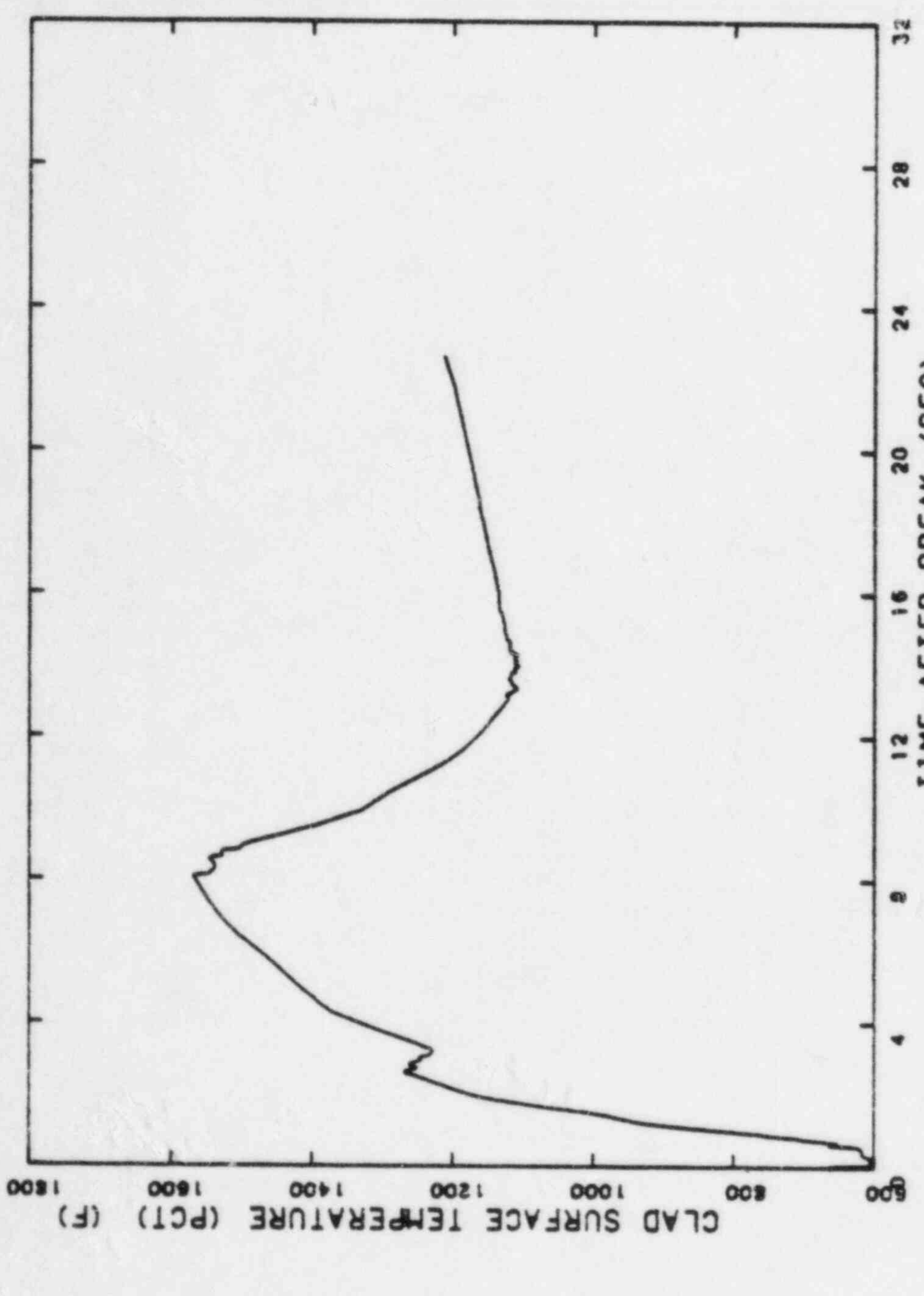


Figure 2.19 Clad Surface Temperature, 0.4 DECLG Break, EOC

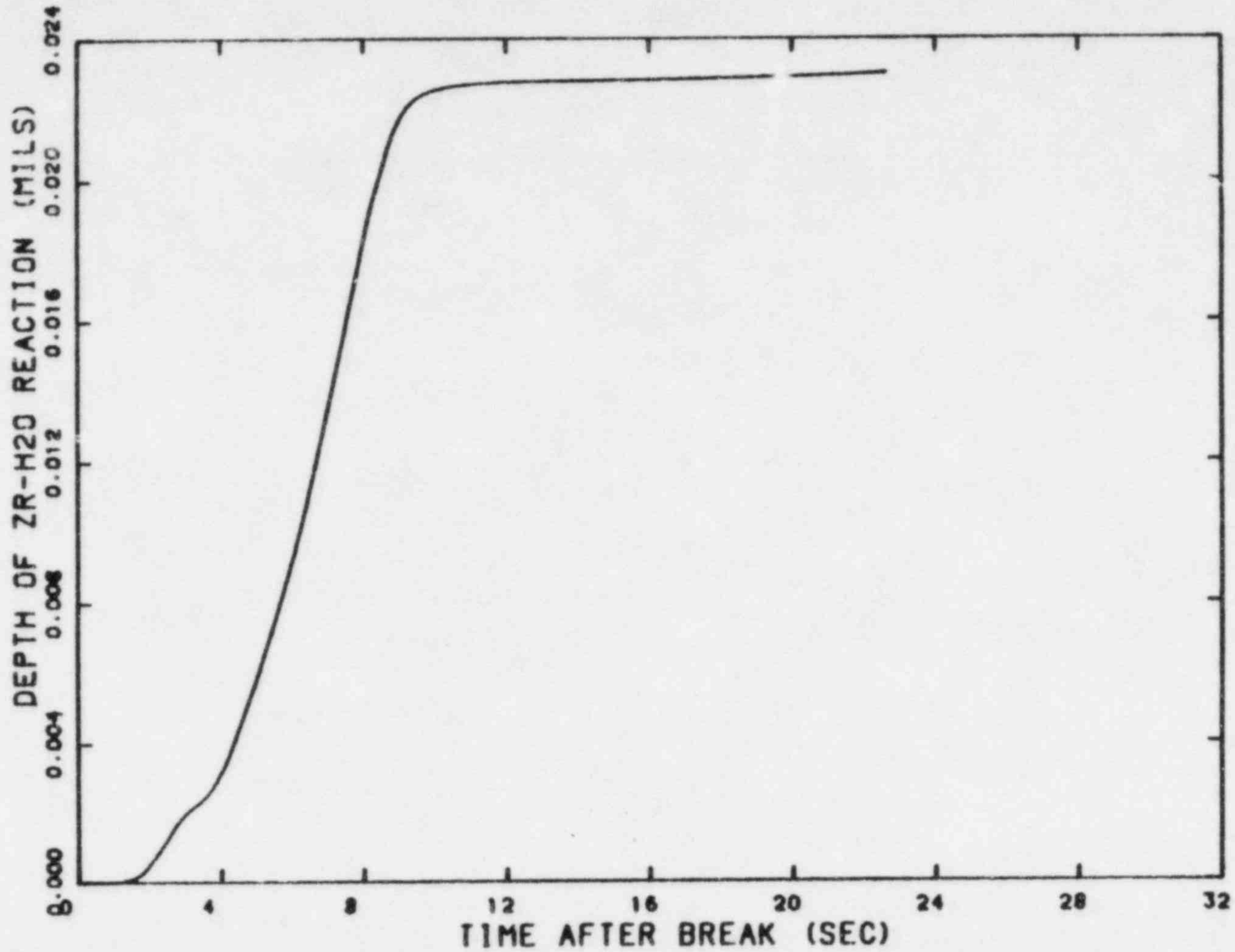


Figure 2.20 Depth of Metal-Water Reaction, 0.4 DECLG Break, EOC

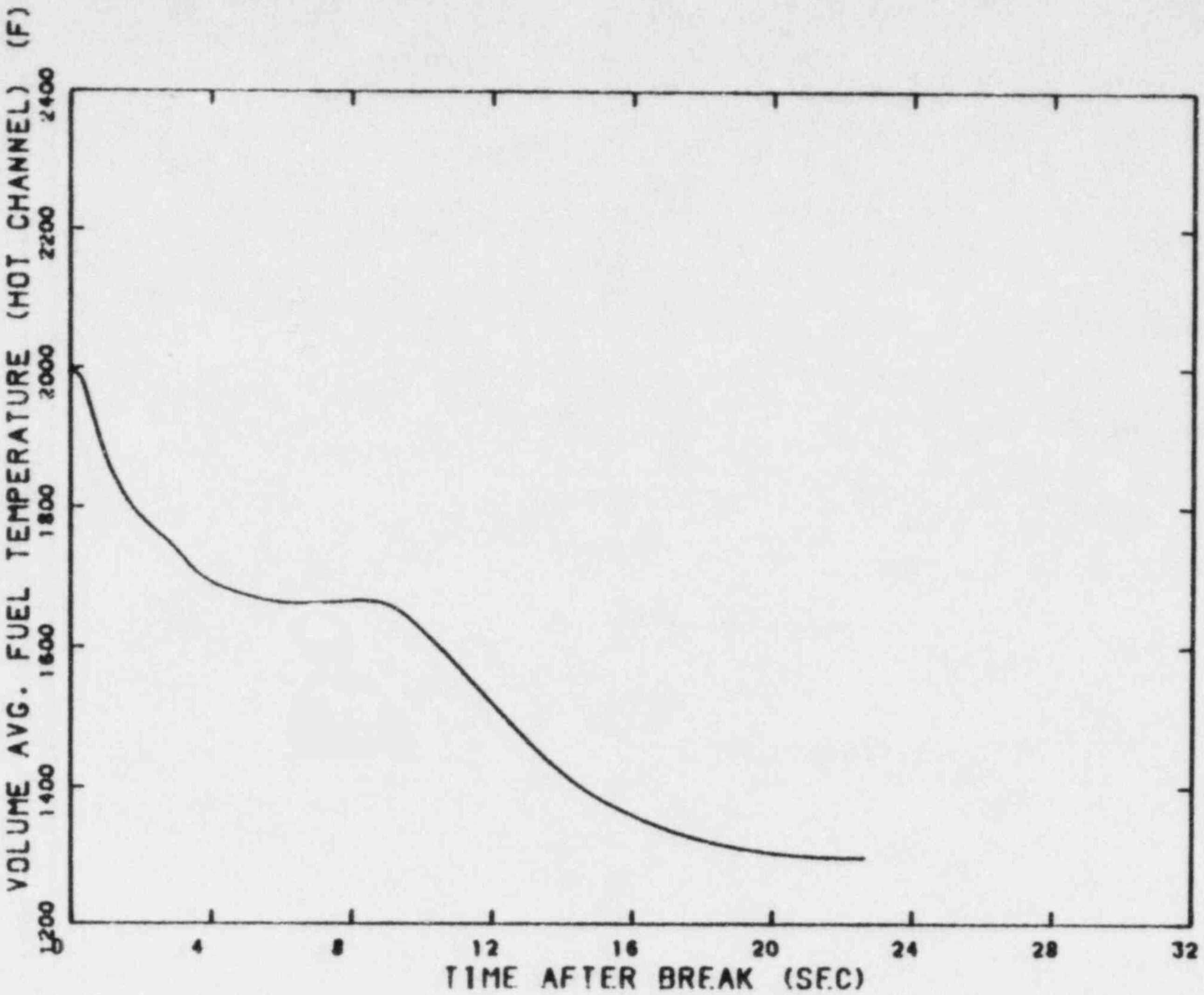


Figure 2.21 Hot Channel Average Fuel Temperature,
0.4 DECLG Break, EOC

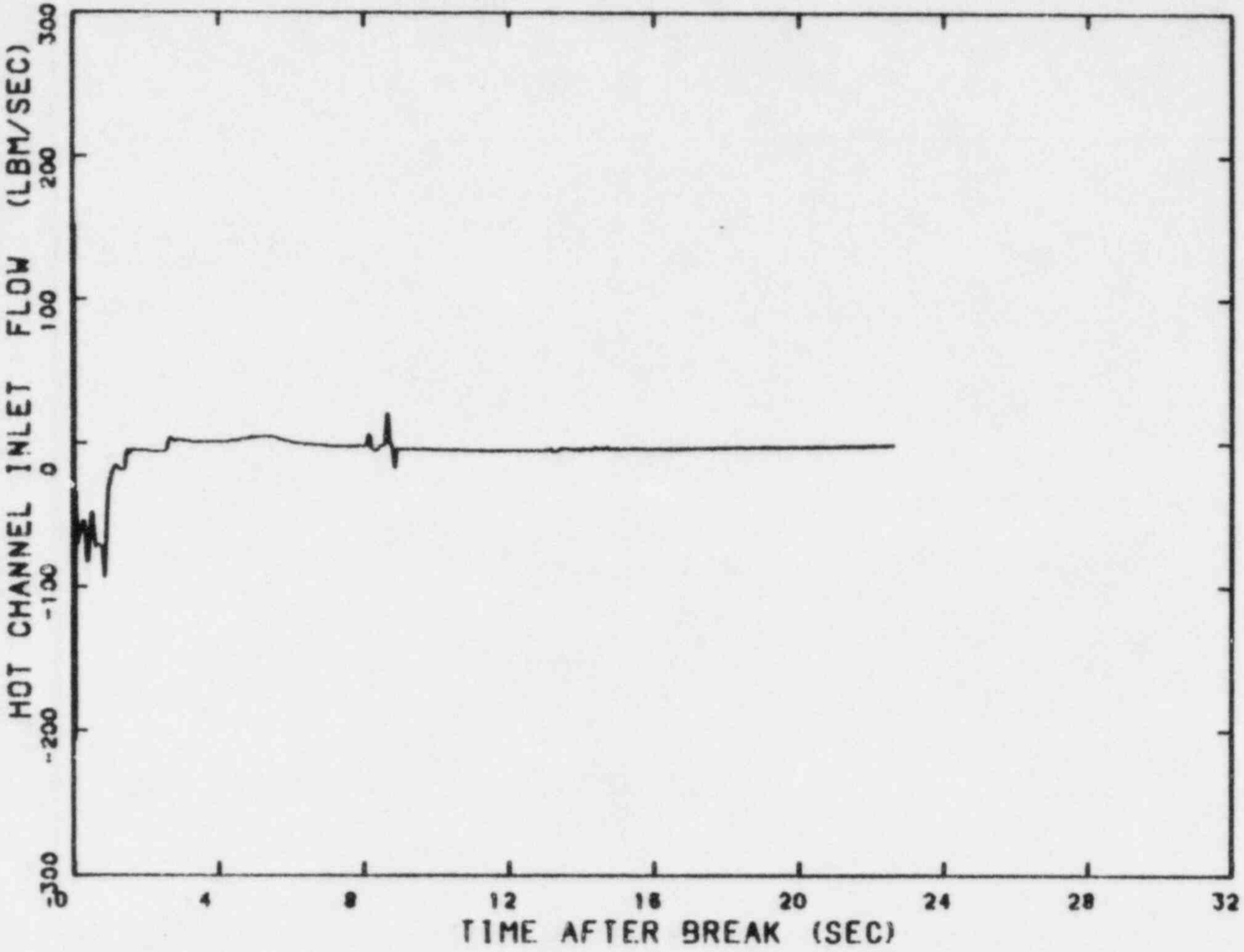


Figure 2.22 Hot Assembly Inlet Flow,
0.4 DECLG Break, EOC

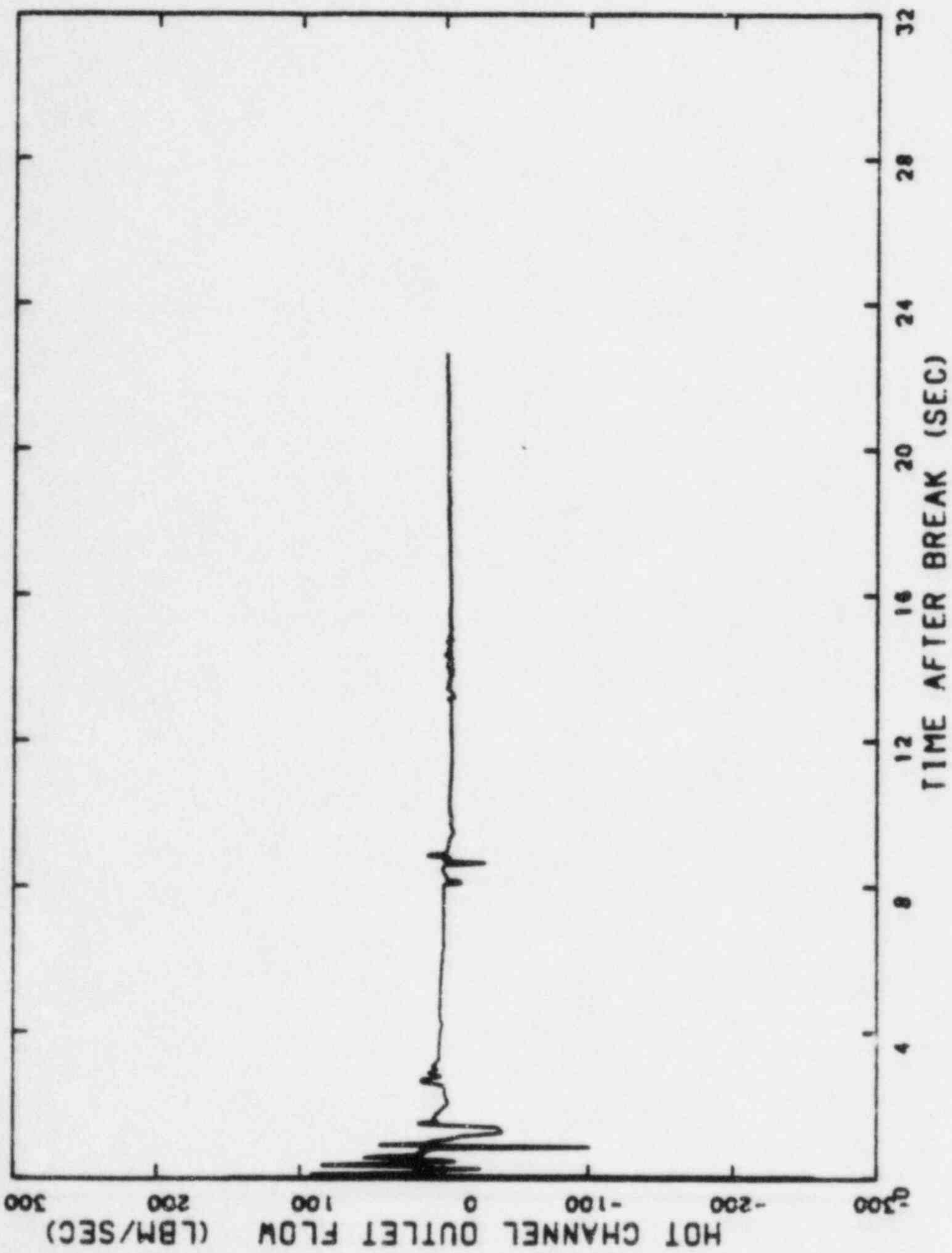


Figure 2.23 Hot Assembly Outlet Flow, 0.4 DECLG Break, EOC

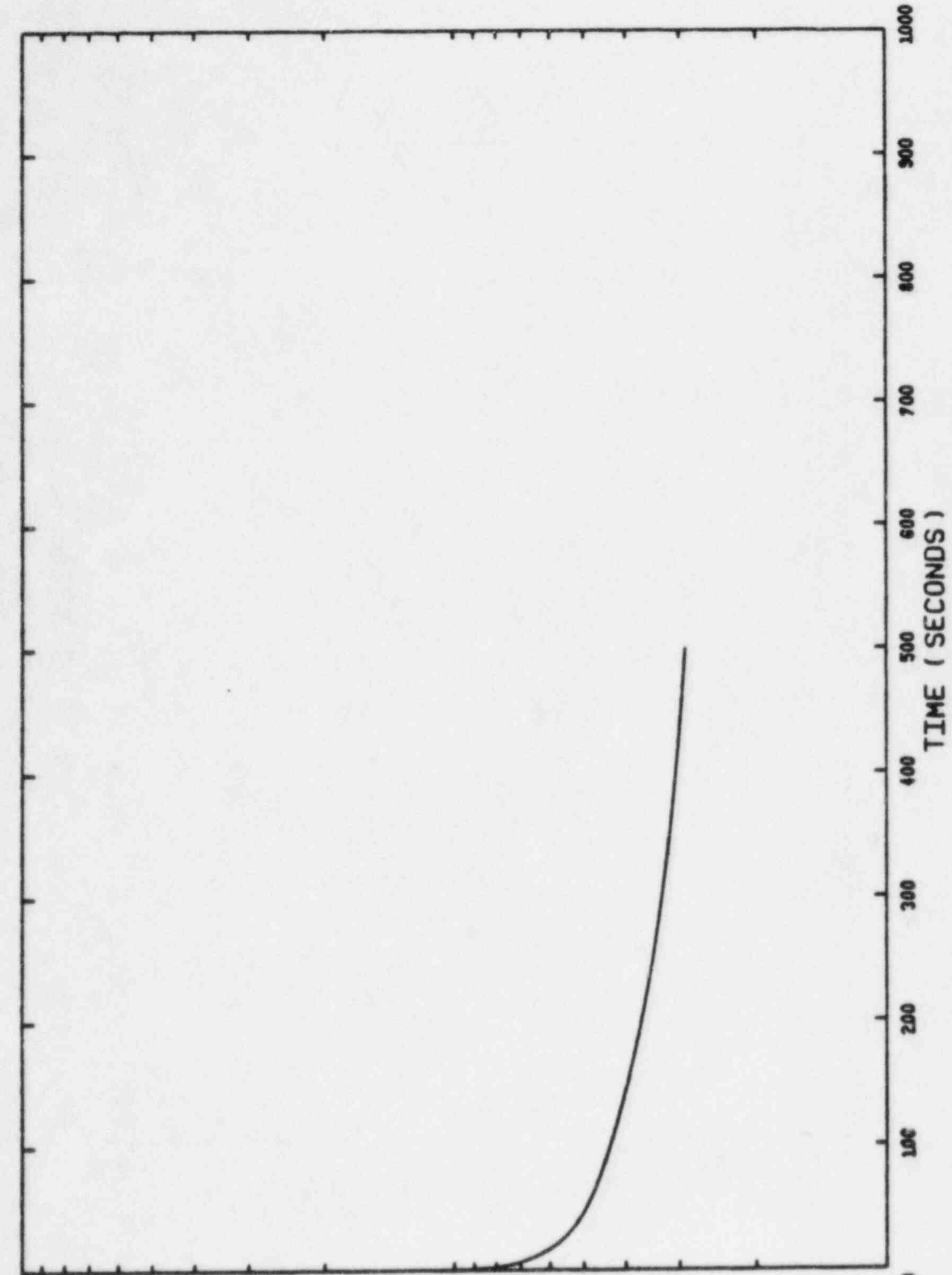


Figure 2.24 Normalized Power, 0.4 DECLG Break, BOC

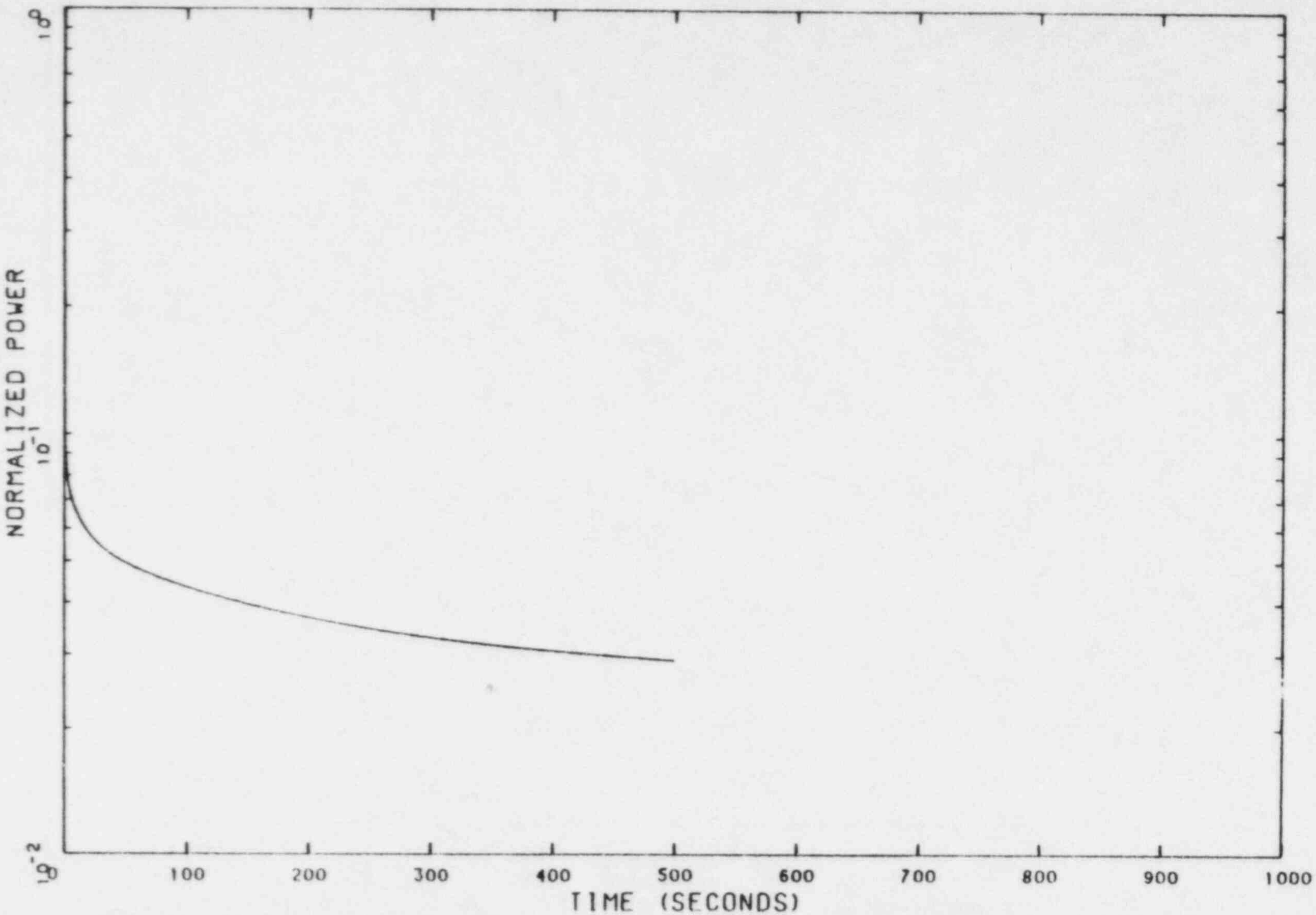


Figure 2.25 Normalized Power,
0.4 DECLG Break, EOC

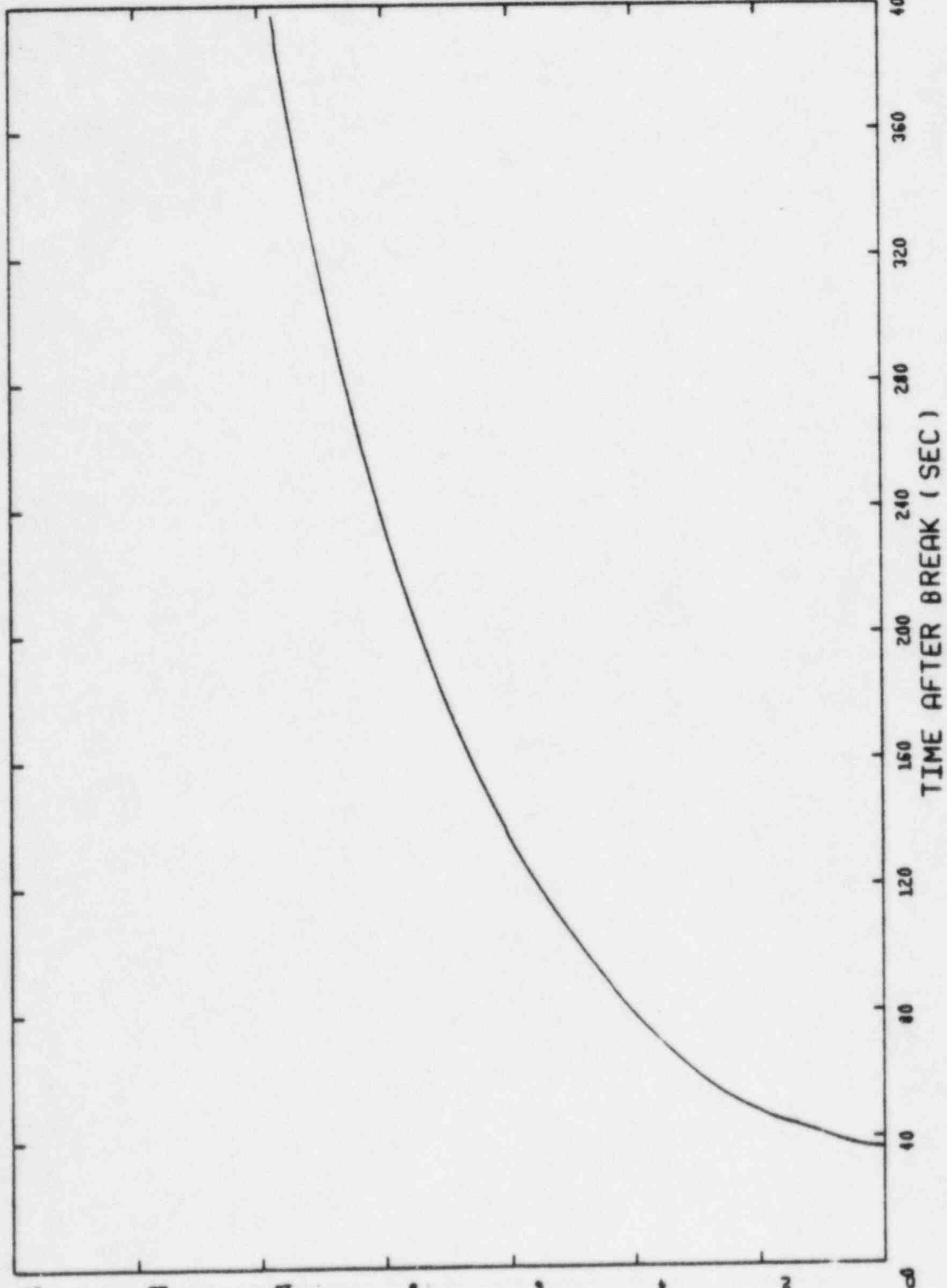


Figure 2.26 Reflood Core Mixture Level, 0.4 DECLG Break, BOC

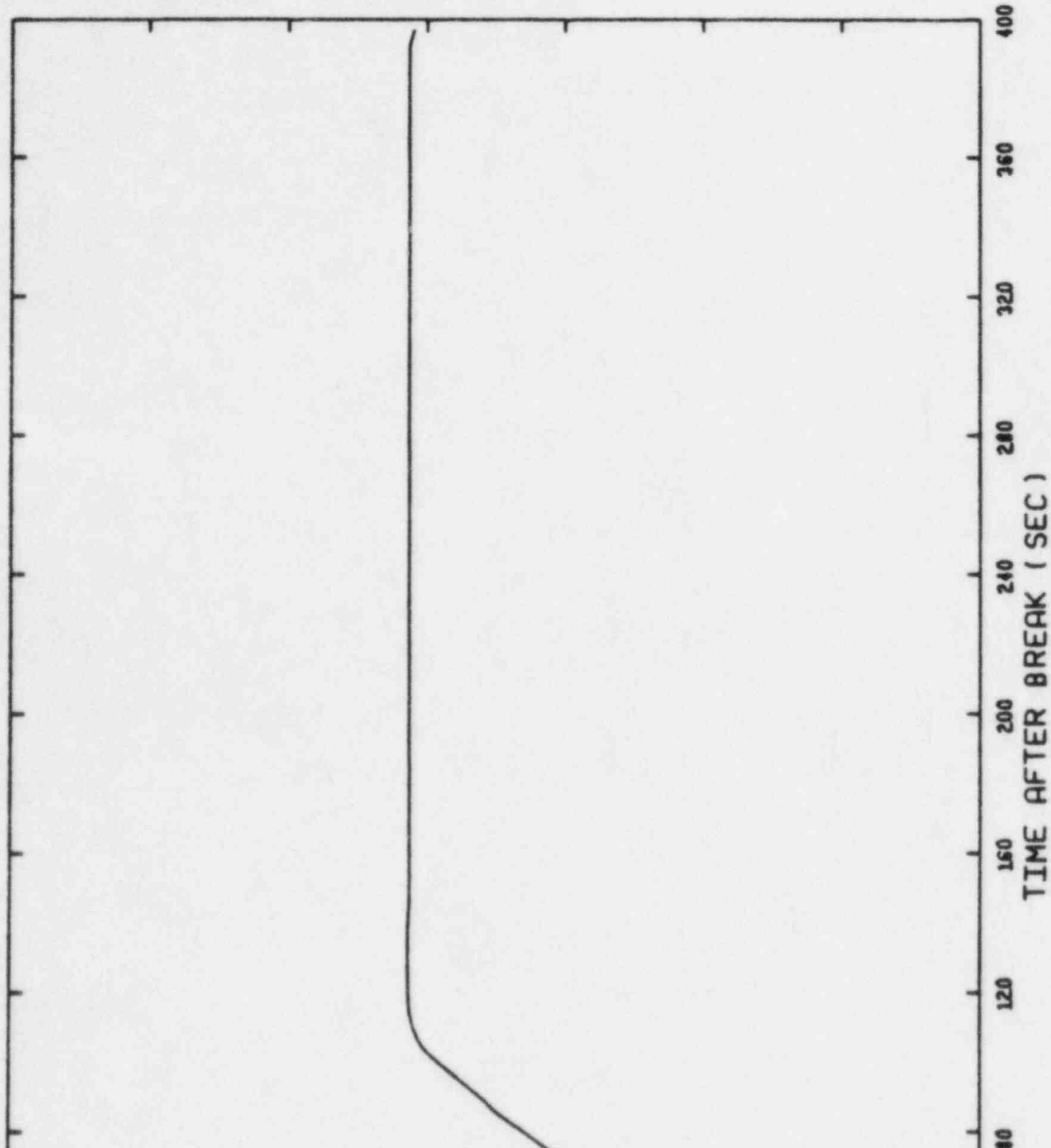


Figure 2.27 Reflood Downcomer Mixture Level, 0.4 DECLG Break, BOC

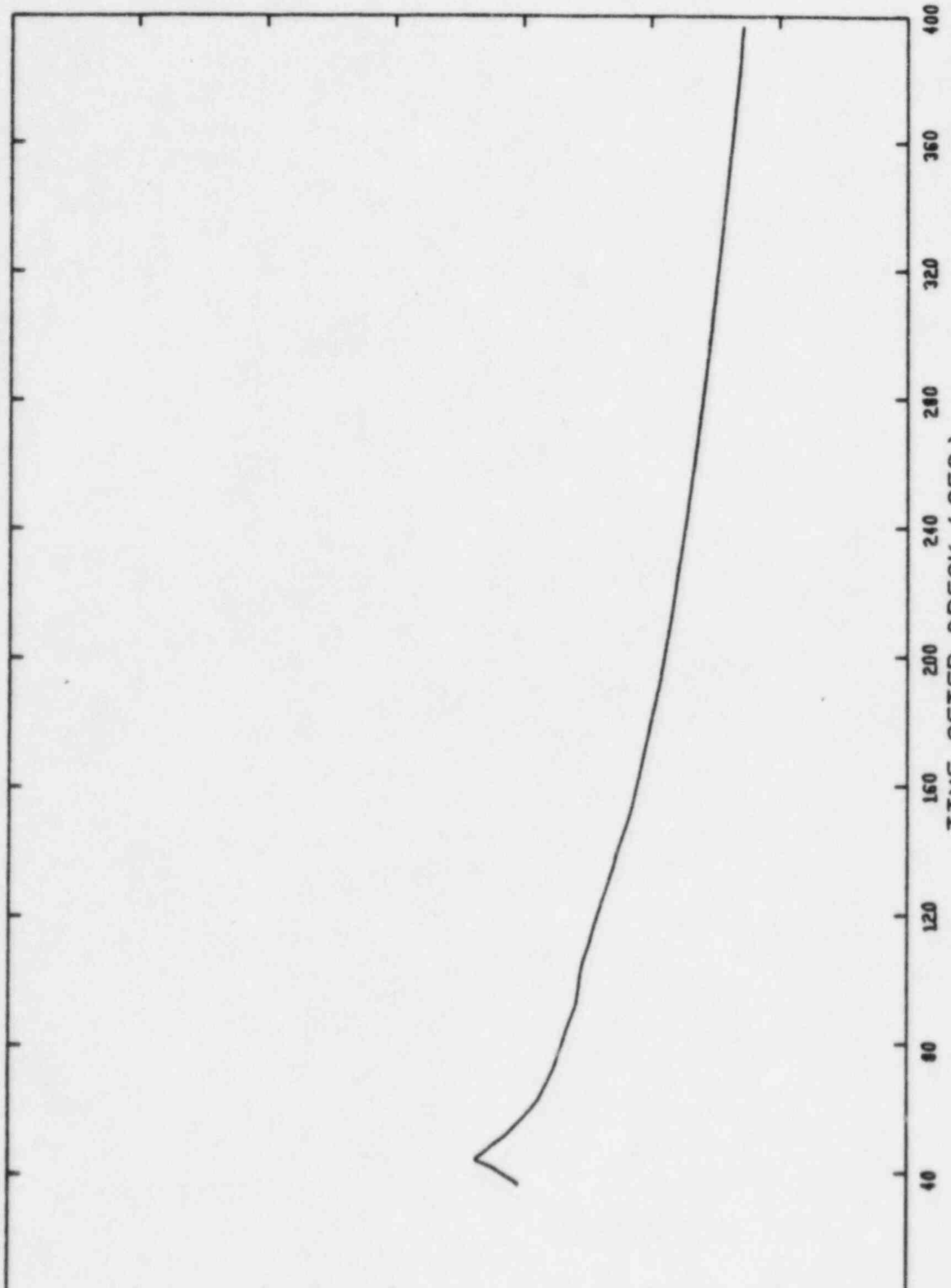


Figure 2.28 Reflood Upper Plenum Pressure, 0.4 DECLG Break, BOC

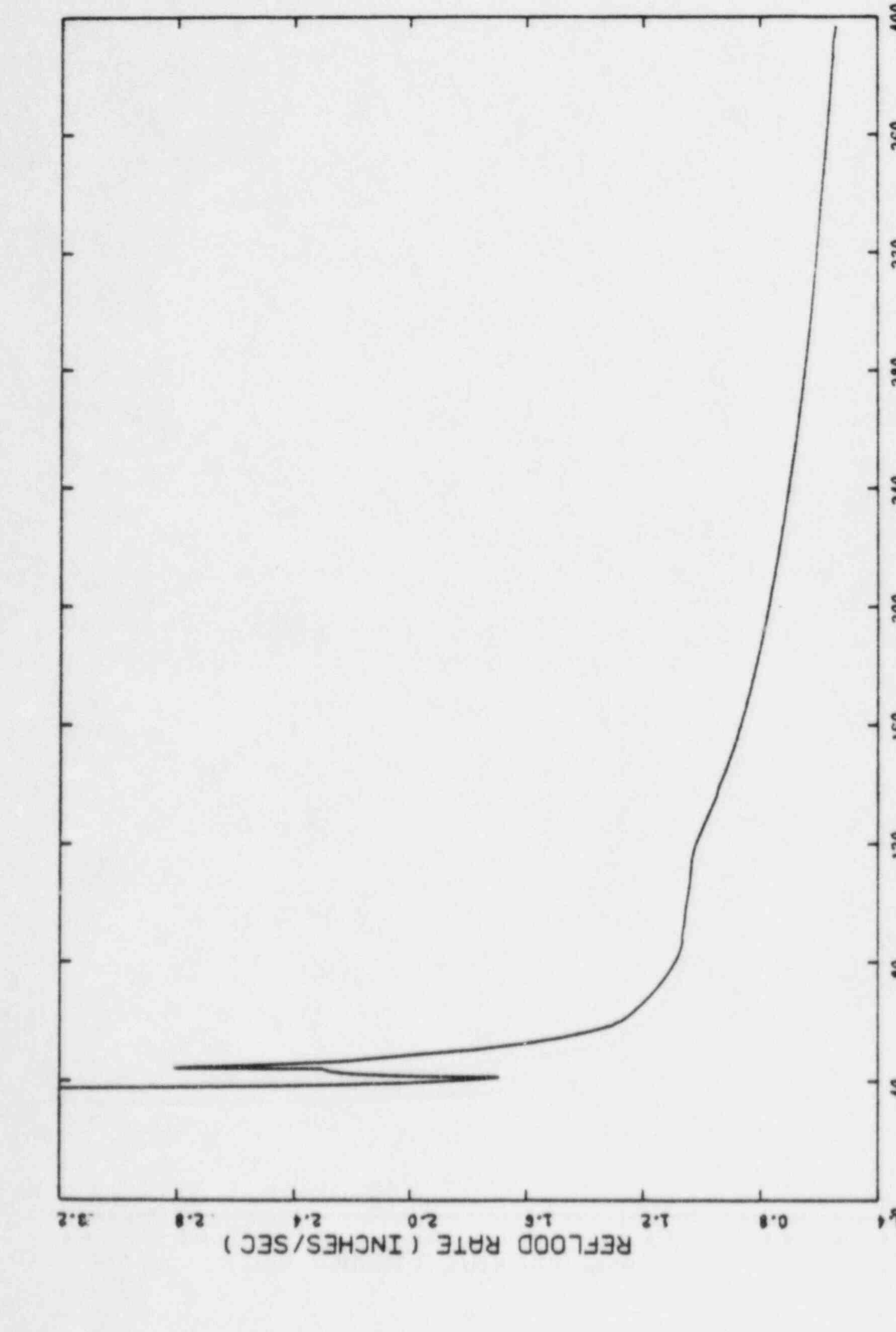


Figure 2.29 Core Flooding Rate, 0.4 DECLG Break, BOC

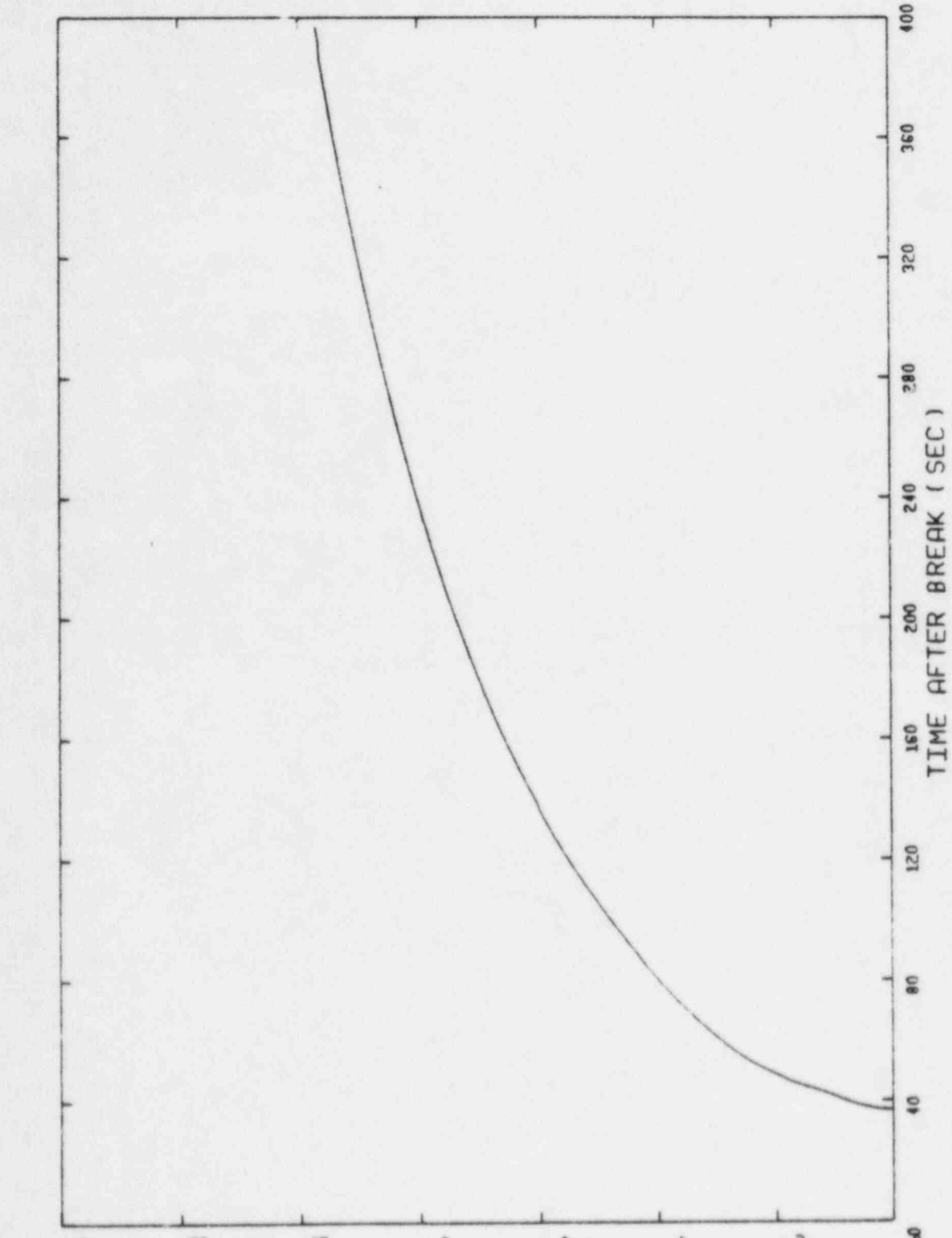


Figure 2.30 Reflood Core Mixture Level, 0.4 DECLG Break, EOC

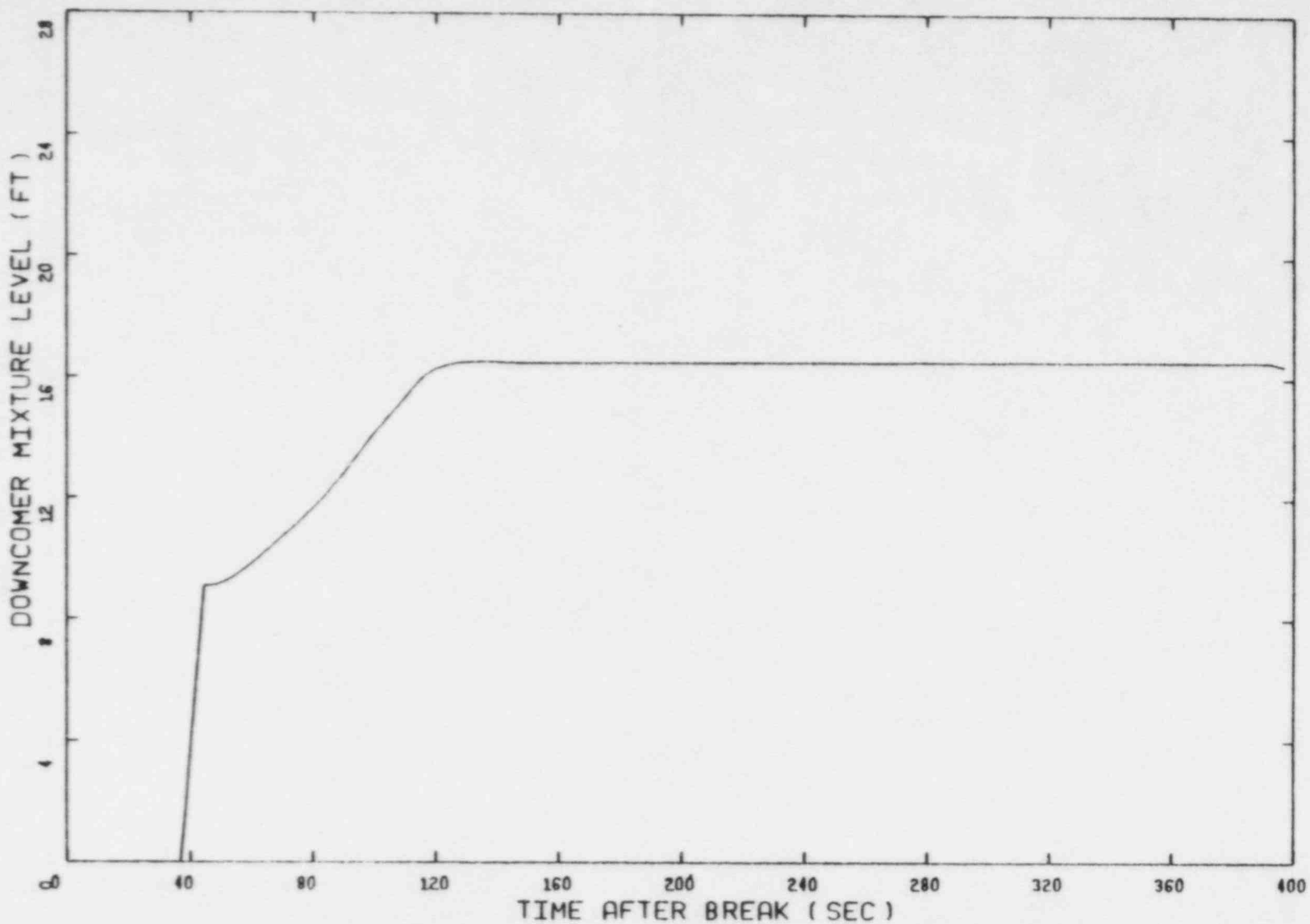
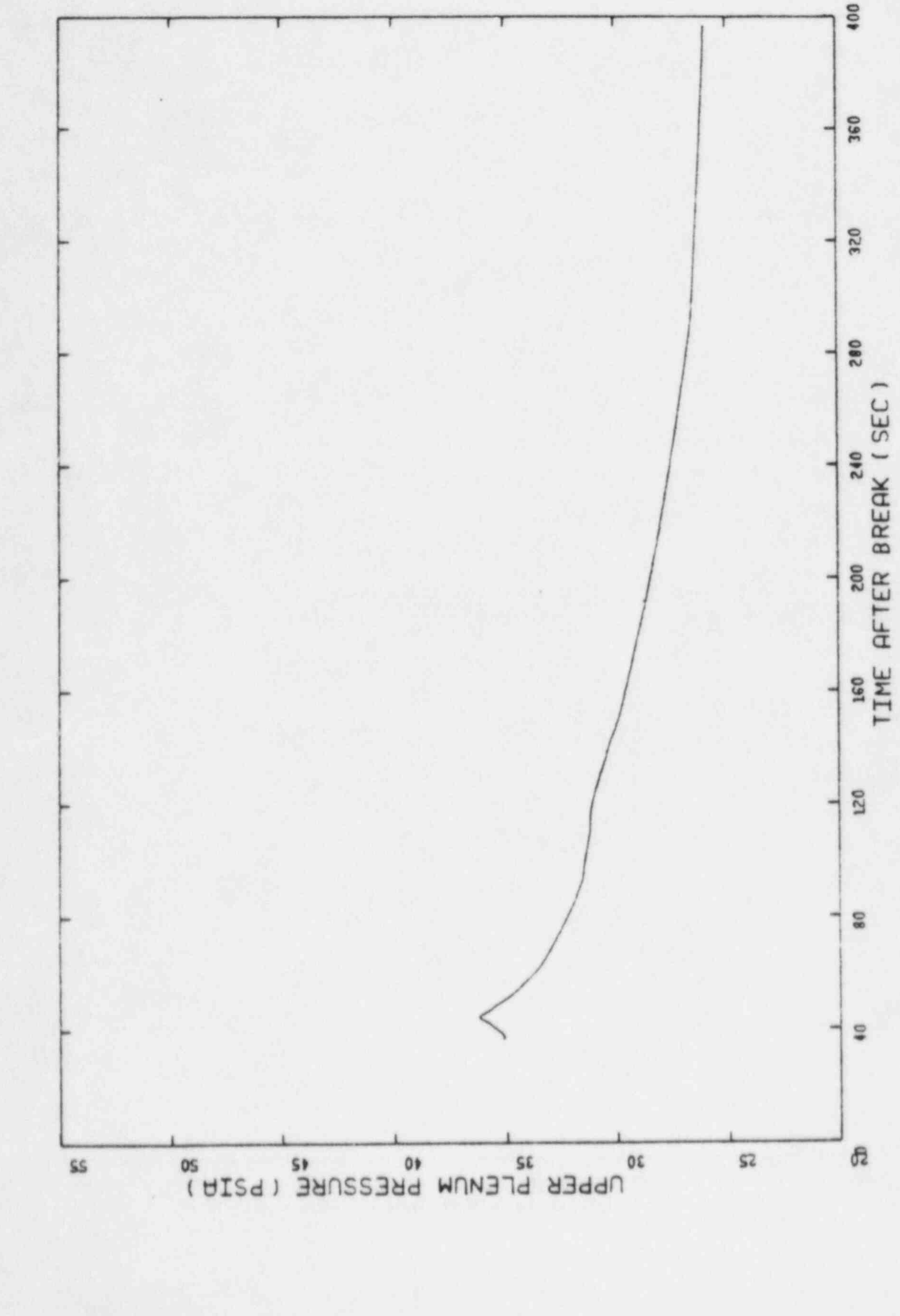


Figure 2.31 Reflood Downcomer Mixture Level, 0.4 DECLG Break, EOC



F gure 2.32 Reflood Upper Plenum Pressure,
0.4 DECLG Break, EOC

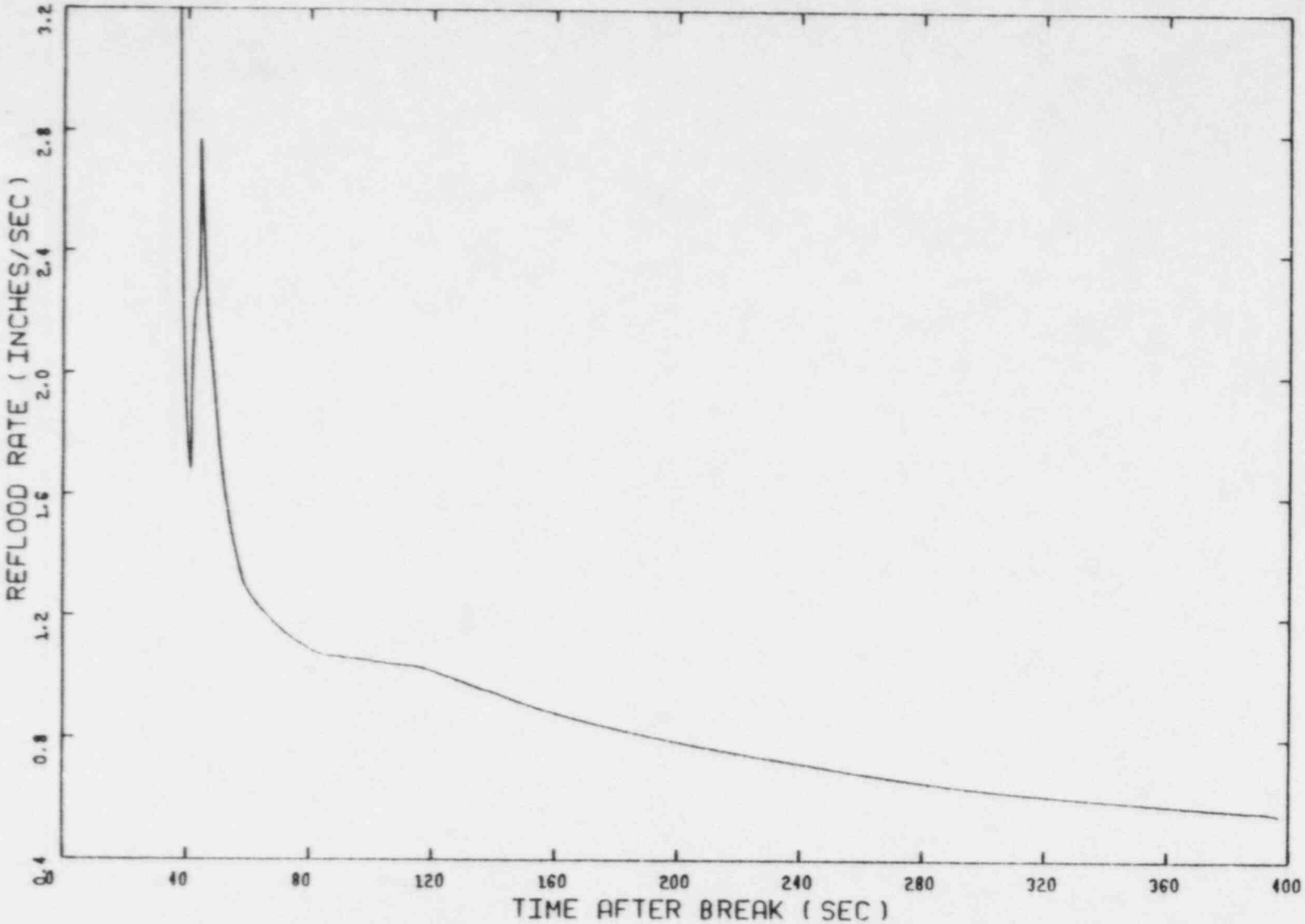


Figure 2.33 Core Flooding Rate, 0.4 DECLG Break, EOC

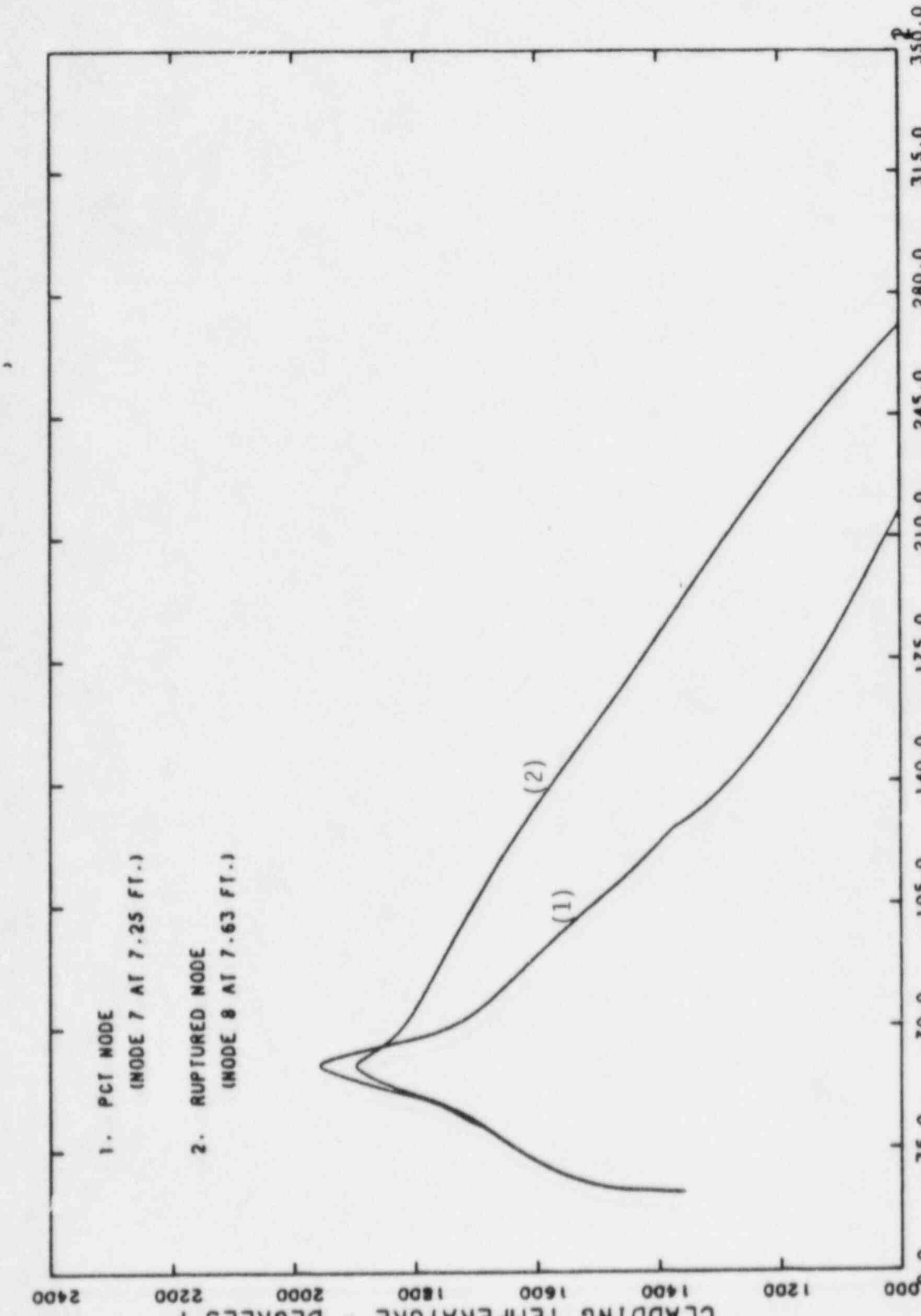


Figure 2.34 TOODEE2 Cladding Temperature vs. Time,
0.4 DECLG Break, BOC

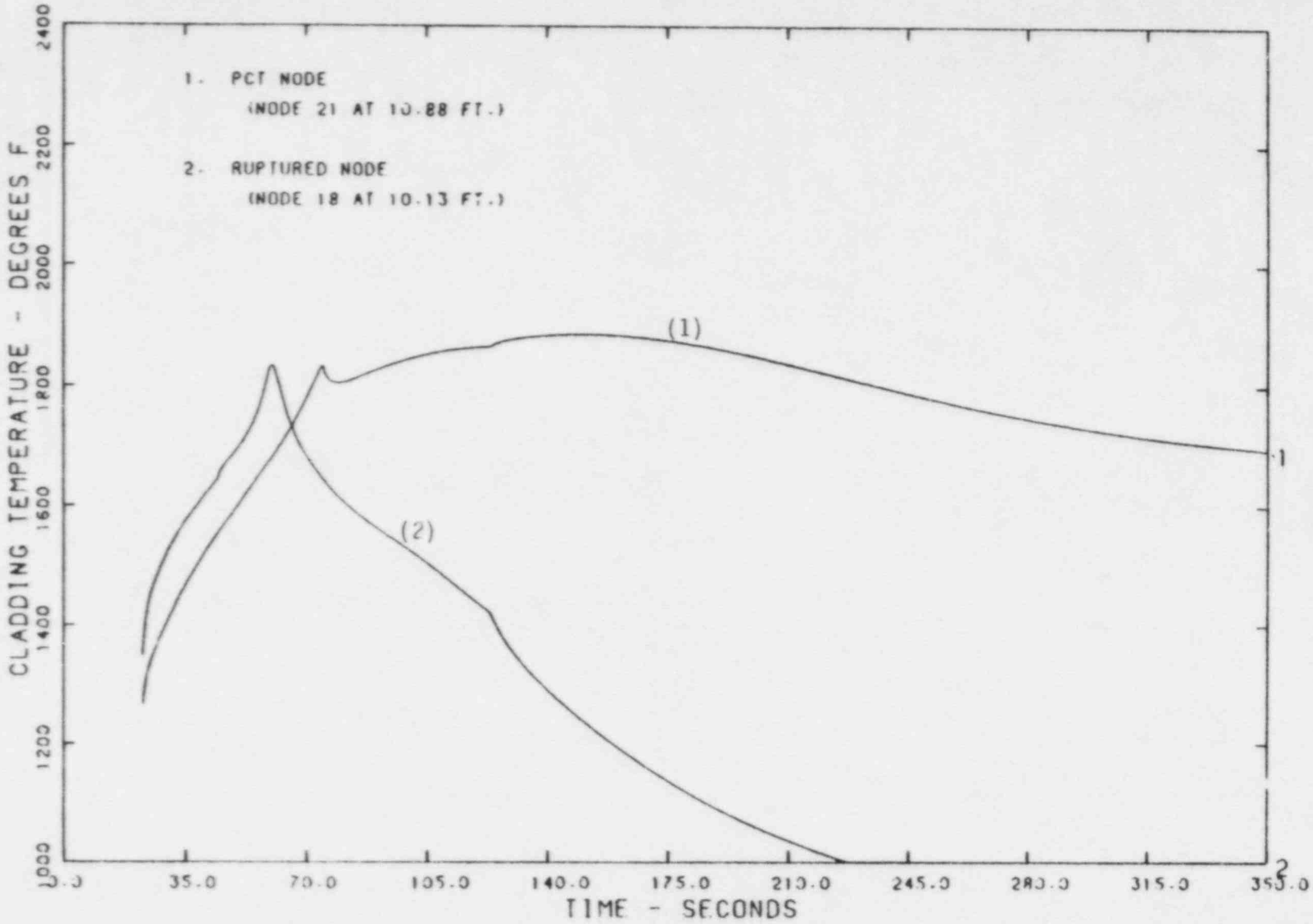


Figure 2.35 TOODEE2 Cladding Temperature vs. Time,
0.4 DECLG Break, EOC

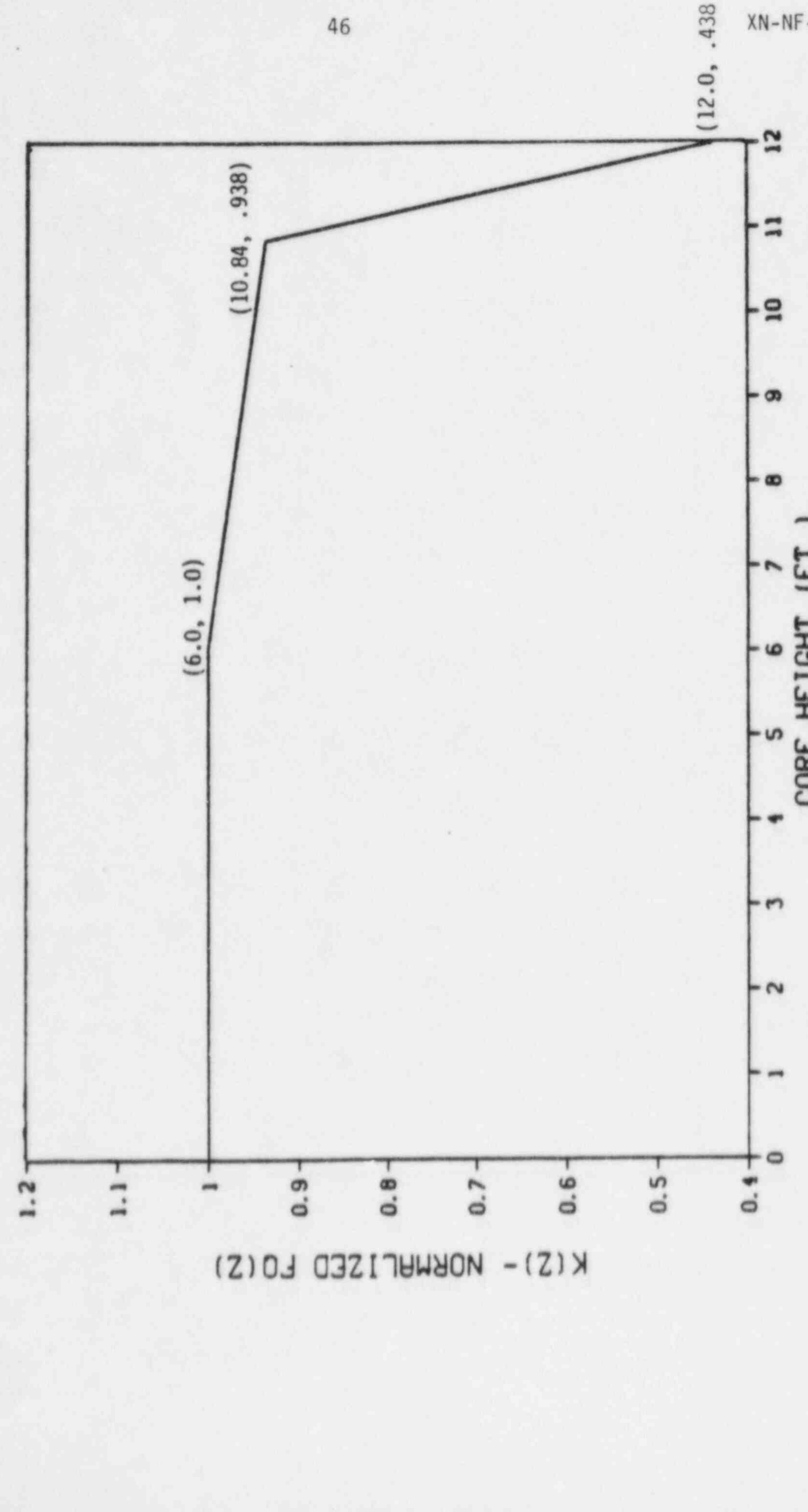


Figure 2.36 Hot Channel Factor Normalized Operating Envelope, F_Q = 2.28, K(Z) Function

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KEWAUNEE LIMITING BREAK K(Z)

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