XN-NF-85-115(NP)
REVISION 2

D.C. COOK UNIT 1
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 D.C. Cook Unit 1 reactor operating with ENC fuel. The analysis was performed to determine the axial dependence of the linear heat generation rate (LHGR) limits for D.C. Cook Unit 1 (i.e., the K(Z) curve). The analyses assume a reactor operating power of 3315 MWt (3250 MWt plus 2% power uncertainty), and use of Exxon Nuclear Company's (ENC's) 15x15 fuel. The calculations were made for the double-ended cold leg split break with a discharge coefficient of 1.0 (1.0 DECLS), identified in previous analyses as the most limiting break.[1,2]

The LOCA analyses were performed for a full core of ENC fuel using the models outlined in Section 2.1. The maximum allowable linear heat generation rate (including the 1.02 factor for power uncertainty) is 14.3 kW/ft, corresponding to a maximum total power peaking factor of 2.04 ($F^T Q$), and nuclear enthalpy rise of 1.51 ($F^T_{\Delta H}$).

The present LOCA ECCS analyses were performed for Beginning-of-Cycle (BOC) fuel (2,000 MWd/MTM) and exposed fuel at End-of-Cycle (EOC) with a conservatively low peak rod average burnup of 9,000 MWd/MTM to maximize stored energy. A cosine axial power shape was used at the BOC exposure and a power shape representative of, or conservative with respect to, the anticipated power shapes at the EOC exposure was used. These power shapes are shown in Figure 1.1 and compared to the $F_Q(Z)$ limit. All of the ENC fuel currently in the D.C. Cook Unit 1 reactor is at exposures greater than 20,000 MWd/MTM.

An earlier sensitivity study[6] using the ENC evaluation models had shown that the peak clad temperature (PCT) increased when maximum LPSI flow was assumed. A similar sensitivity study was performed with the current power distributions and evaluation models to predict the PCT for both the maximum LPSI flow case and the case when one LPSI pump fails. The sensitivity study showed that the maximum PCT was reached when full LPSI flow was assumed. The results reported in this document are for the case with no failure of LPSI pumps.

The calculational basis and results of the present analyses are summarized in Table 1.1. For the BOC case, the maximum calculated PCT is 1853°F, and occurs at 72 seconds from the start of the transient

With the EOC exposure, the maximum calculated PCT is 1918°F, and occurs at 202 seconds from the start of the transient

In both cases, the total metal water reaction is less than one percent of the zircaloy in the core. The results of the analyses show that within the limits established, the D.C. Cook Unit 1 nuclear reactor satisfies the criteria specified by 10 CFR 50.46[16] for operation at the rated system power level. 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% 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 D.C. Cook Unit 1 LOCA-ECCS Analysis Results - K(Z)

Analysis Results	BOC 2000 MWD/MTM Peak Rod Average Exposure	EOC 9000 MWD/MTM Peak Rod Average Exposure
Peak Clad Temperature (PCT), °F	1853	1918
Time of PCT, sec.	71.9	202
Local Zr/H_2O Reaction (max.), %*	1.21	2.92
Total H_2 Generation, % of Total Zr Reacted	<1.0	<1.0
Hot Rod Burst Time, sec.	50.2	58.0

Calculational Basis		
License Core Power, MWt	3250	3250
Power Used for Analysis, MWt**	3315	3315
Peak Linear Power for Analysis, kW/ft**	14.3	13.7
Total Peaking Factor, F^T_Q	2.04	1.95
Enthalpy Rise, Nuclear, $F^N_{\Delta H}$	1.51	1.51

* Computer value at 400 seconds

** Including 1.02 factor for power uncertainties

Figure 1.1 Comparison of Power Distributions Analyzed to Limits

2.0 K(Z) LOCA ANALYSIS

This report provides the results of a LOCA/ECCS analysis performed for the D.C. Cook Unit 1 reactor operating with ENC 15x15 fuel. The purpose of this analysis was to define the axial dependence of the LOCA limit. The analytical techniques used are in compliance with Appendix K of 10 CFR 50, and are described in the ENC WREM models,[7] and the Emergency Core Cooling System Evaluation Model Updates: WREM-II,[8] WREM-IIA,[9] EXEM/PWR,[3] and the FCTF reflood correlations.[10,17]

A LOCA break spectrum analysis was performed for D.C. Cook Unit I, with results reported in XN-NF-76-51.[15] The limiting LOCA break was determined to be an equivalent double-ended split break of the cold leg (1.0 DECLS).

The analysis in this report is expected to be conservative with respect to ENC fuel at peak rod average exposures of up to 47,000 MWd/MTM. The peak clad temperatures are dependent upon the initial stored energy, which for the EXEM/PWR models increases from 0 to about 2000 MWd/MTM and then decreases with exposure. An analysis for a plant similar to D.C. Cook Unit 1 (D.C. Cook Unit 2, Reference 18) but with a 17x17 fuel geometry rather than a 15x15 fuel geometry demonstrates that over the exposure range of 0 to 47,000 MWd/MTM, the peak clad temperature occurs at the exposure point corresponding to the peak stored energy.

2.1 LOCA Analysis Model

The Exxon Nuclear Company EXEM/PWR ECCS evaluation model[3] was used to perform the analyses. This model consists of the following computer codes: RODEX2[4] code for initial rod stored energy and internal fuel rod gas inventory; RELAP4-EM[11] for the system blowdown and hot channel blowdown calculations; ICECON[12] for the computation of ice condenser containment backpressure; REFLEX[3,5,13] for computation of system reflood; and TOODEE2[3,5,14] 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 References 10 and 17.

The D.C. Cook Unit 1 nuclear reactor is a four-loop Westinghouse pressurized water reactor with an ice condenser containment. The reactor coolant system is nodalized into control volumes representing reasonably homogeneous regions, interconnected by flow-paths or "junctions." The system nodalization is as depicted in Figure 2.1. The pump performance characteristic curves are supplied by the NSSS vendor. The transient behavior was determined from the governing conservation equations for mass, energy, and momentum. Energy transport, flow rates, and heat transfer 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 analysis of the loss-of-coolant accident is performed at 102% of rated power. The fuel design parameters are shown in Table 2.2.

2.2 Results

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.

Table 2.3 presents the timing and sequence of events as determined for the split break with a discharge coefficient of 1.0. Comparison of the system results with the previous LOCA/ECCS analysis shows very slight change in the event times. Figures 2.4 through 2.10 present plotted results for system blowdown analysis. Unless otherwise noted on the figures, time zero corresponds to the time of break initiation. Figure 2.11 presents calculated containment backpressure time history. Figures 2.12 through 2.23 present results for the hot channel blowdown calculations. Figures 2.24 through 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 1.0 DECLS break at BOC is 1853°F (Figure 2.34). The maximum local metal-water reaction in this case is 1.21% after 400 seconds, and the total core metal-water reaction is less than 1%.

For ENC fuel at EOC, the PCT is 1918°F (Figure 2.35),

. The local metal-water reaction is 2.92%, with a total metal-water reaction of less than 1%.

An earlier sensitivity study[6] using the ENC evaluation models had shown that the peak clad temperature (PCT) increased when maximum LPSI flow was assumed. A similar sensitivity study was performed with the current power distributions and evaluation models to predict the PCT for both the maximum LPSI flow case and the case when one LPSI pump fails. The sensitivity study showed that the maximum PCT was reached when full LPSI flow was assumed. Only the more conservative results for the full LPSI flow case are reported. The results of the analyses show that within the limits established, the D.C. Cook Unit 1 nuclear reactor satisfies the criteria specified by 10 CFR 50.46[16] for operation at the rated system power level.

Table 2.1 Donald C. Cook Unit 1 System Data

Primary Heat Output, MWt	3250.*
Primary Coolant Flow, lbm/hr	135.6×10^6
Primary Coolant Volume, ft^3	11,890.
Operating Pressure, psia	2250.
Inlet Coolant Temperature ^oF	536.3
Reactor Vessel Volume, ft^3	4602.
Pressurizer Volume, Total, ft^3	1800.
Pressurizer Volume, Liquid, ft^3	1080.
Accumulator Volume, Total, ft^3 (each of four)	1350.
Accumulator Volume, Liquid, ft^3	929.
Accumulator Pressure, pisa	636.
Steam Generator Heat Transfer Area, ft^2	50,985.***
Steam Generator Secondary Flow, lbm/hr	3.53×10^6
Steam Generator Secondary Pressure, psia	758.
Reactor Coolant Pump Head, ft	227.
Reactor Coolant Pump Speed, rpm	1190.
Moment of Inertia, lbm-ft^2/rad	82,000.
Cold Leg Pipe, I.D., in	27.5
Hot Leg Pipe, I.D., in	29.0
Pump Suction Pipe, I.D., in	31.0
Fuel Assembly Rod Diameter, in	0.424**
Fuel Assembly Rod Pitch, in	0.563**
Fuel Assembly Pitch, in	8.466**
Active Core Height, in	144.0**
Fuel Heat Transfer Area, ft^2	52,200
Fuel Total Flow Area, ft^2	50.91

* Primary heat output used in RELAP4-EM Model = 1.02 x 3250 = 3315 MWt
** ENC fuel parameters.
*** Represents value corresponding to 1% steam generator tube plugging used in the analysis.

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	0.563

Table 2.3 D.C. Cook Unit 1 LOCA/ECCS Analysis Results, Event Times

Event	Time (sec)
Start	0.00
Break Initiation	.05
Safety Injection Signal	.65
Accumulator Injection, Broken Loop	2.0
Accumulator Injection, Intact Loop	15.5
End-of-Bypass	22.9
Safety Injection Flow	25.7
Accumulator Empties, Broken Loop	36.2
Start of Reflood	39.6
Accumulator Empties, Intact Loop	50.7
Peak Clad Temperature Reached	
BOC (Chopped cosine axial power peaking)	71.9
EOC (Upskewed axial power peaking)	202.0

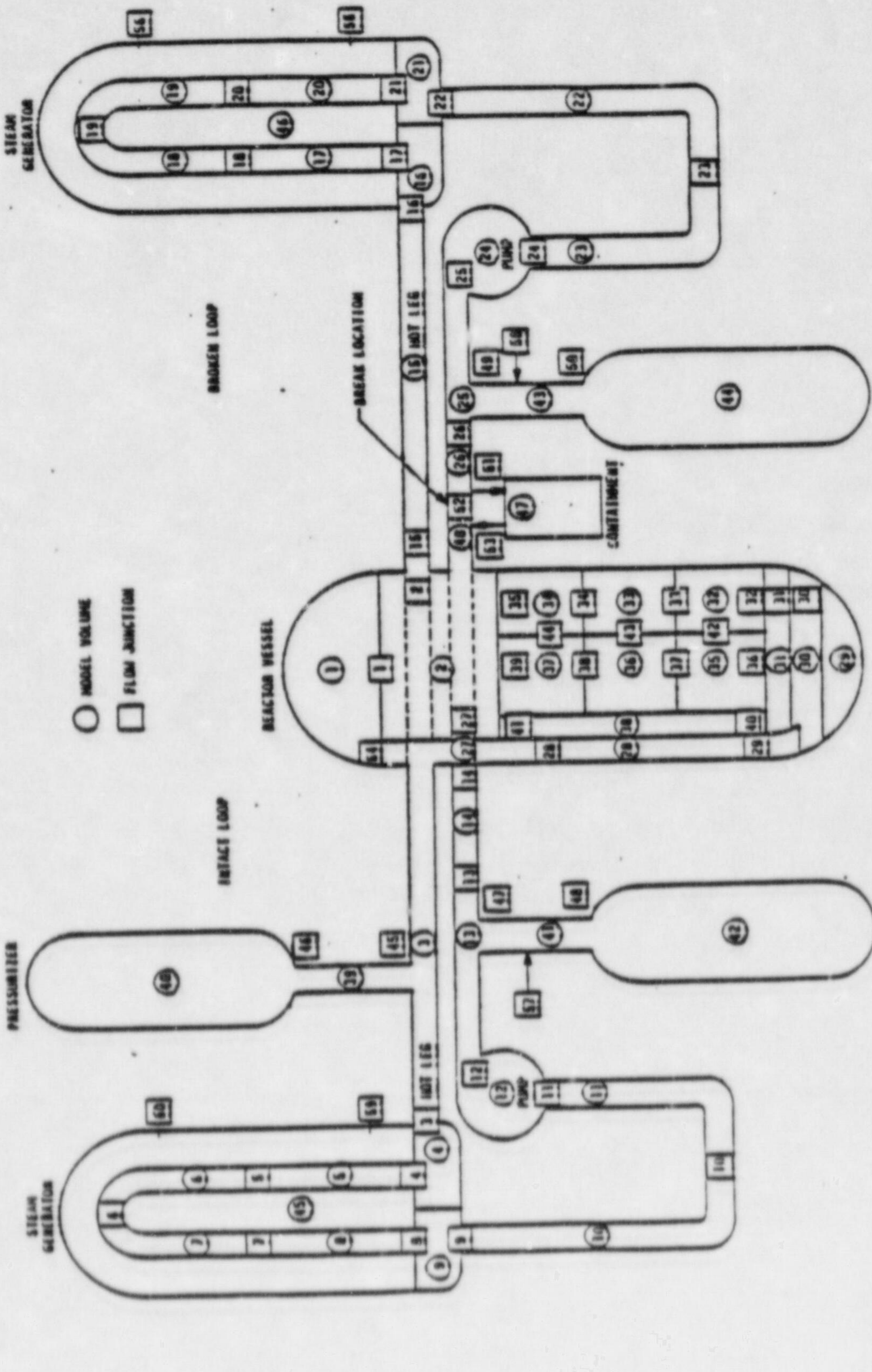

Figure 2.1 Blowdown System Nodalization for D. C. Cook Unit 1

Figure 2.2 Axial Peaking Factor versus Relative Height, 1.0 DEGS Break, BOC

Figure 2.1 Axial Peaking Factor versus Relative Height, 1.0 DECLS Break, EOC

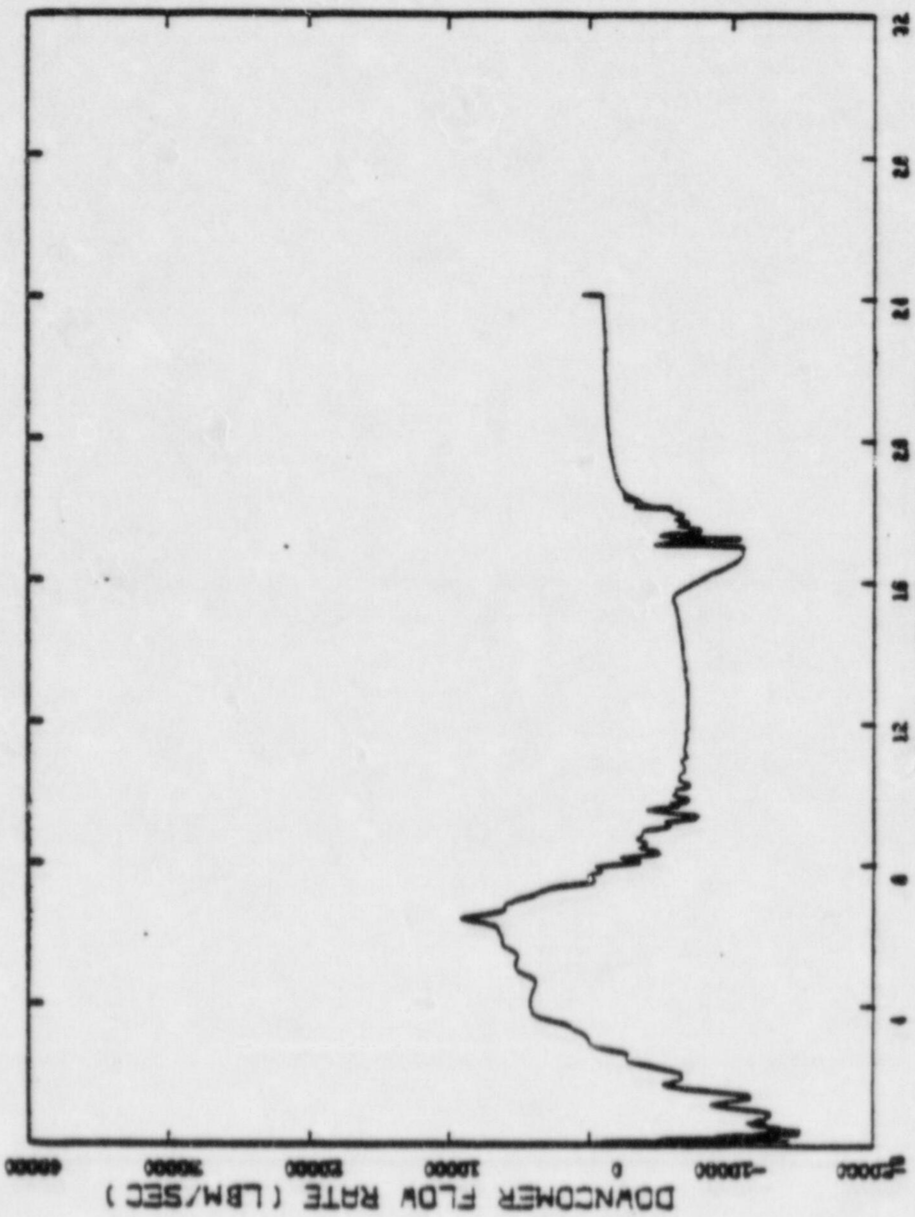

Figure 2.4 Downcomer Flow Rate, 1.0 DECLS Break

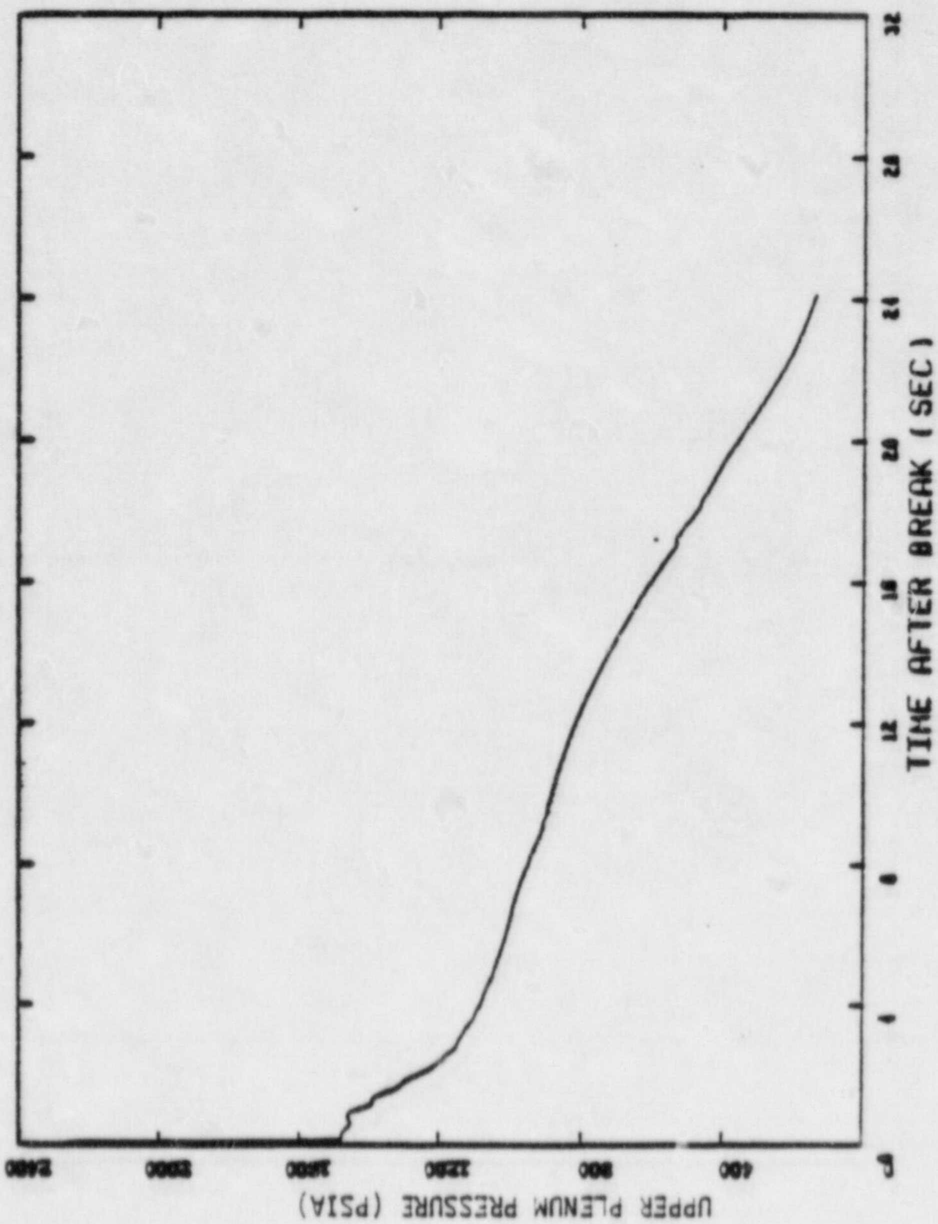

Figure 2.5 Upper Plenum Pressure, 1.0 DECLS Break

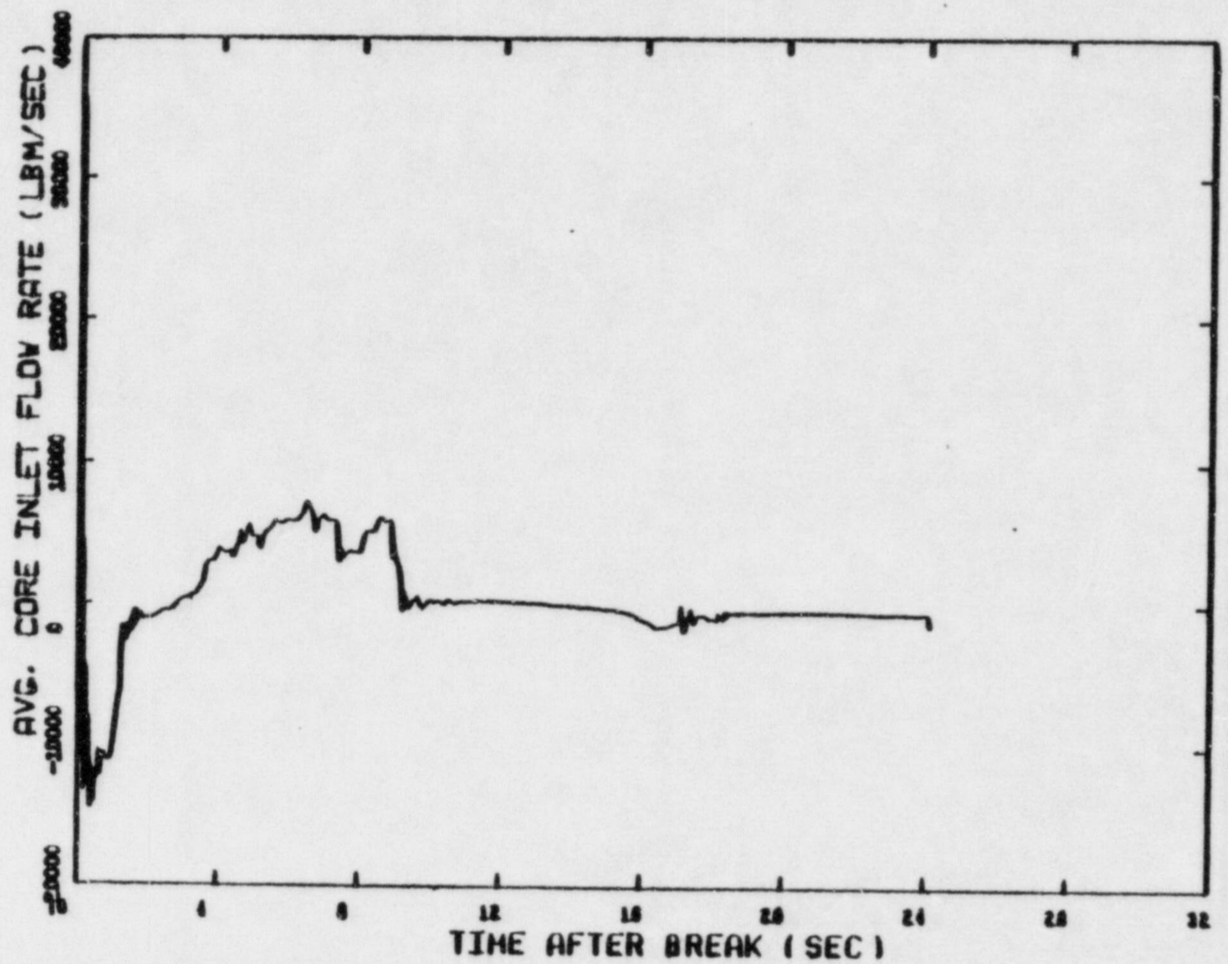

Figure 2.6 Average Core Inlet Flow, 1.0 DECLS Break

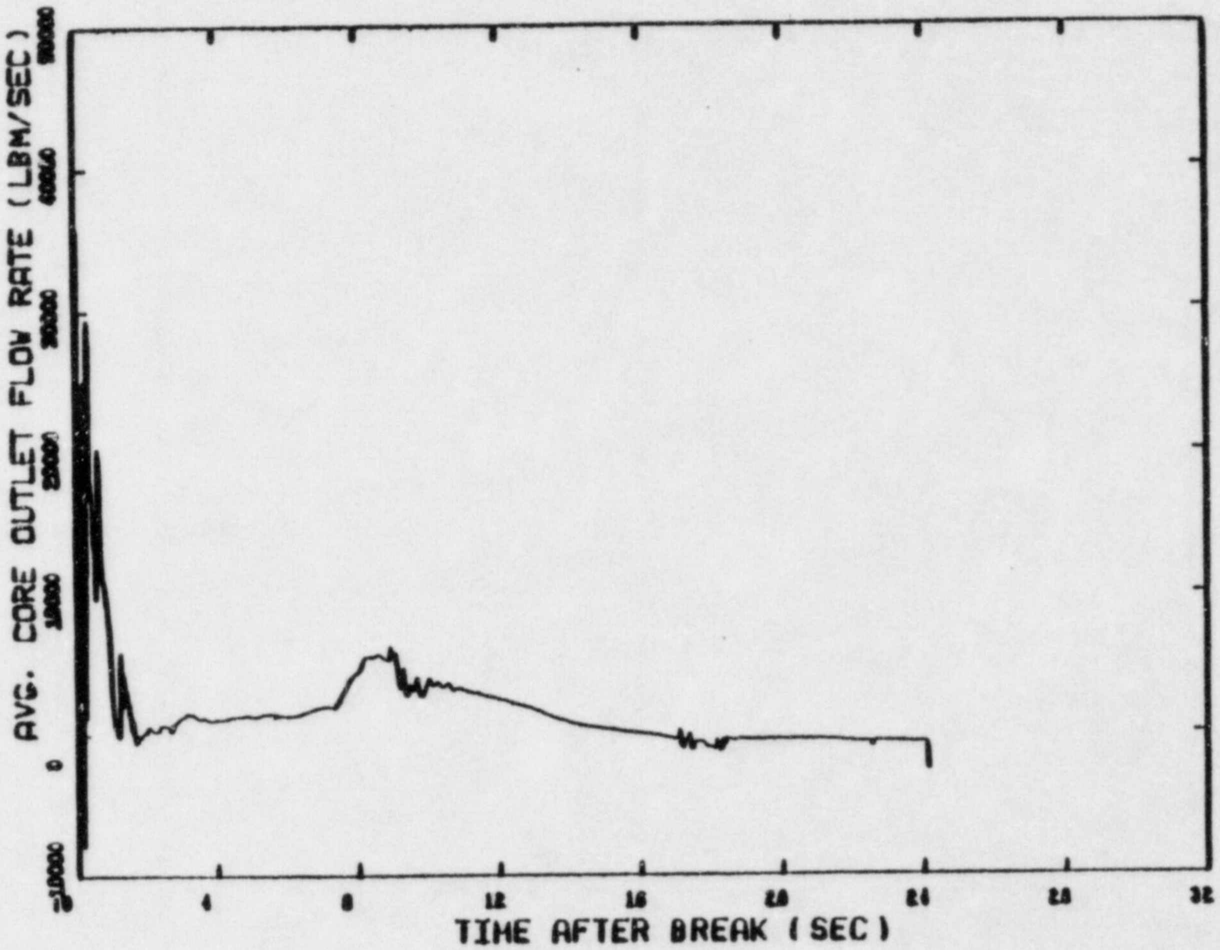

Figure 2.7 Average Core Outlet Flow, 1.0 DECLS Break

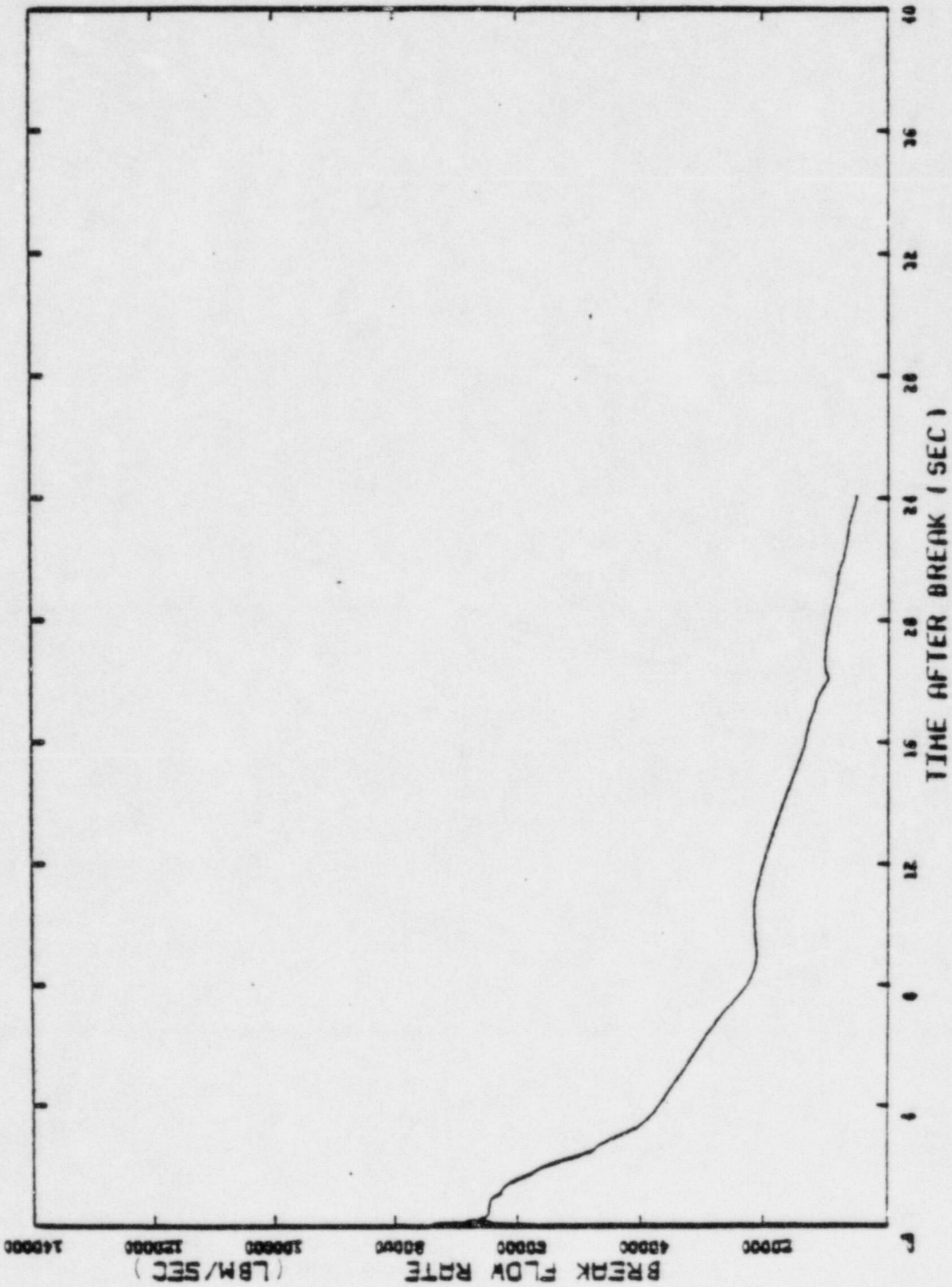

Figure 2.8 Total Break Flow, 1.0 DECLS Break

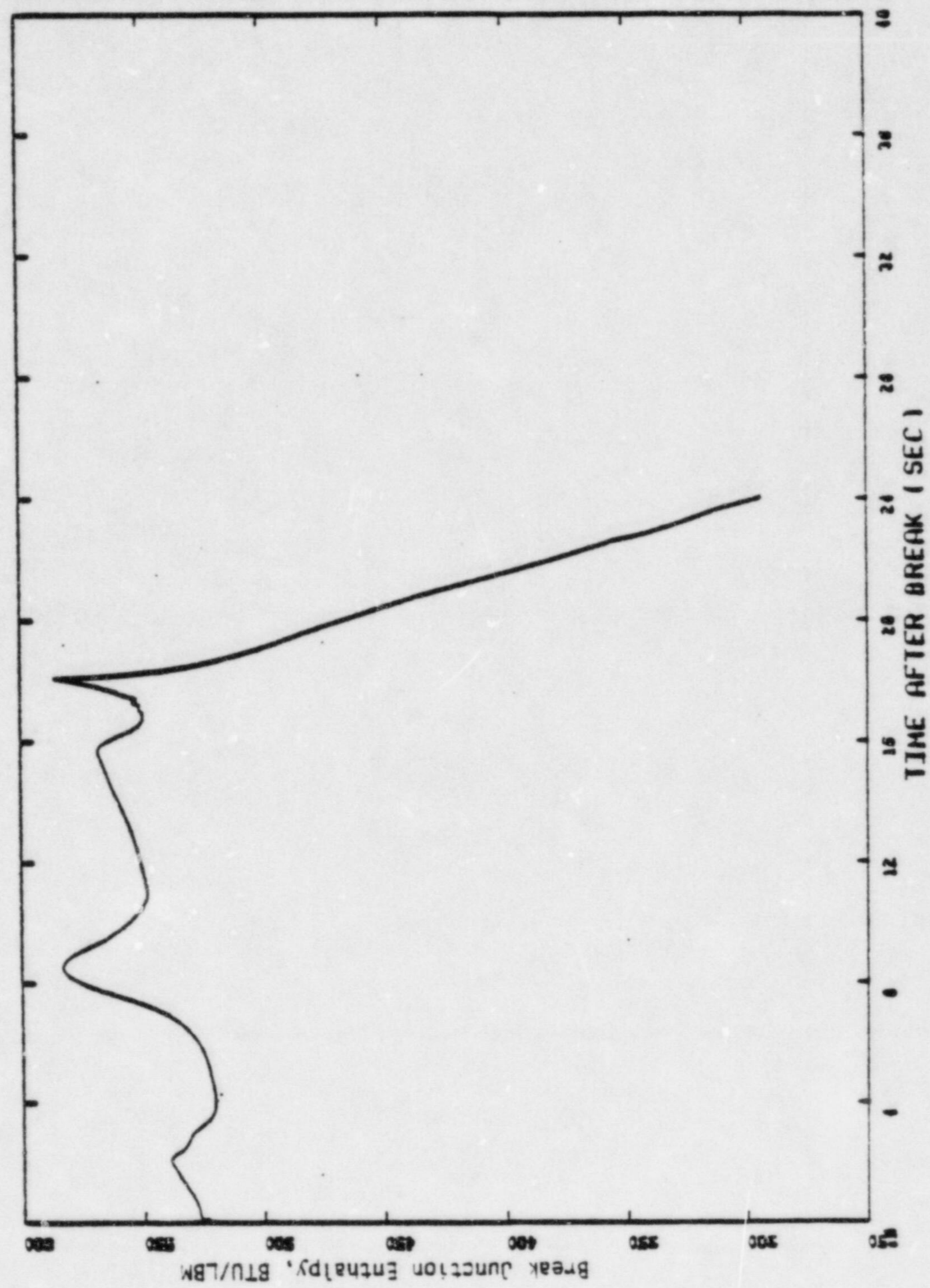

Figure 2.9 Break Junction Enthalpy, 1.0 DECLS

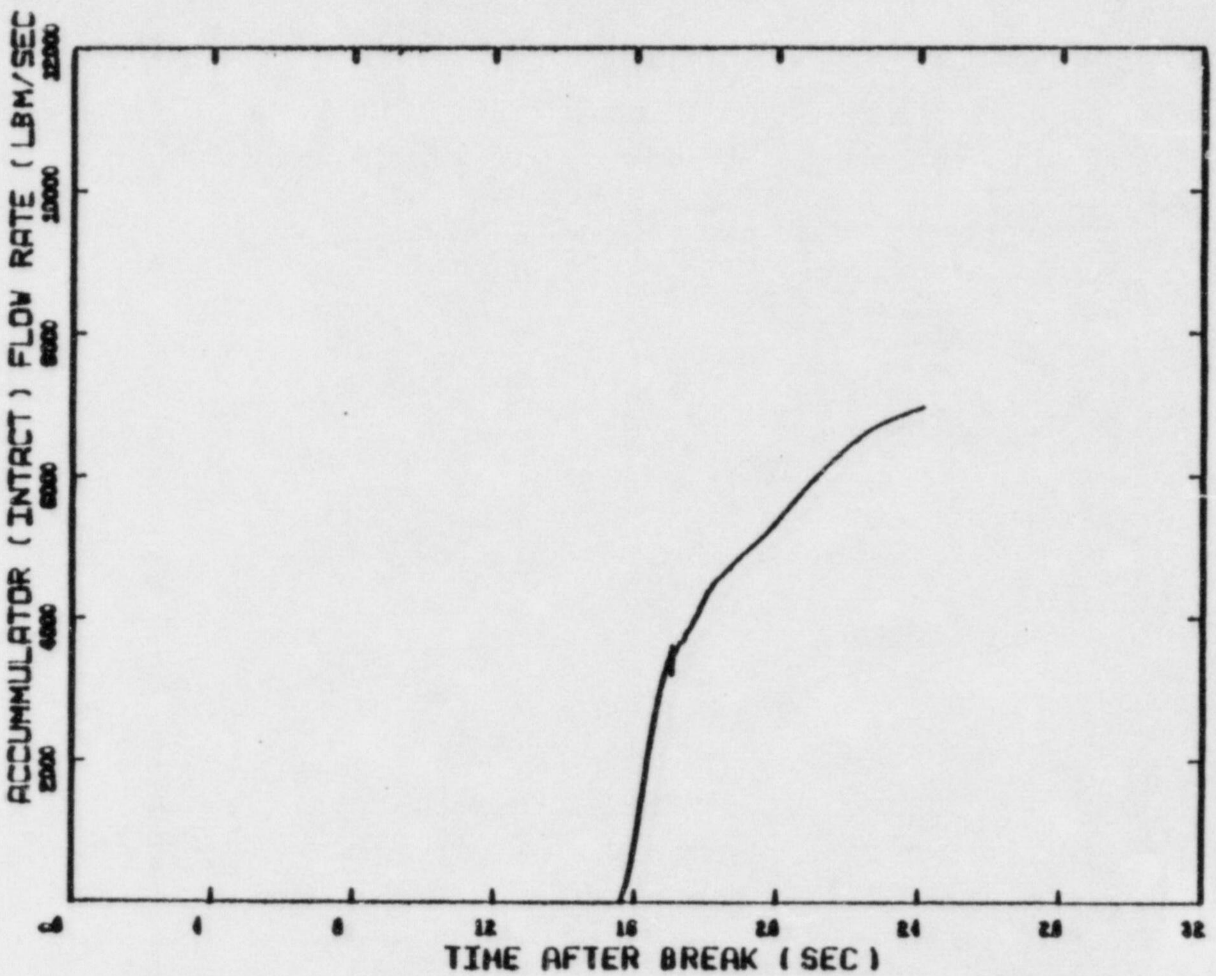

Figure 2.10 Flow From Intact Loop Accumulator, 1.0 DECLS Break

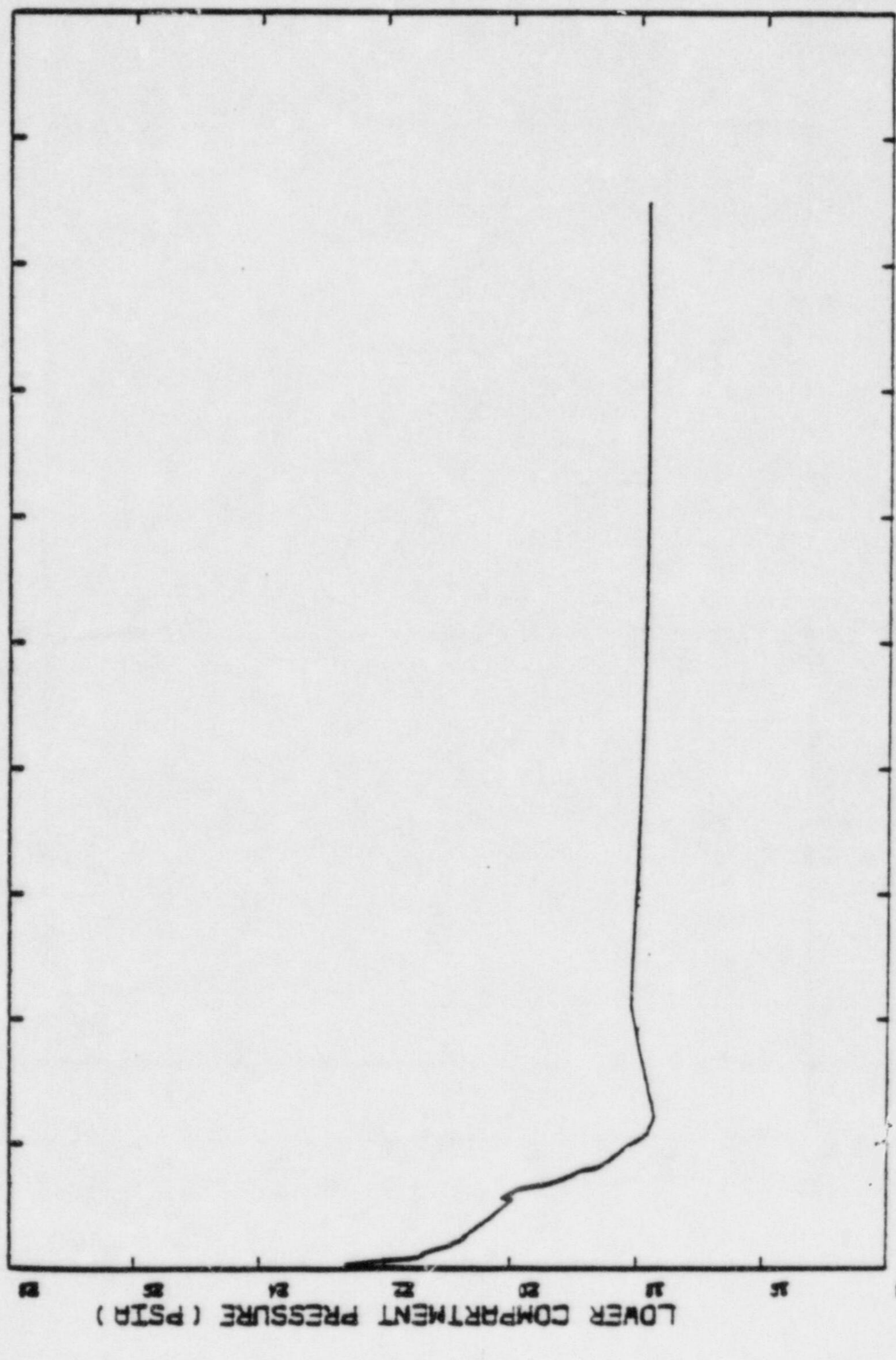

Figure 2.11 Containment Back-Pressure, 1.0 DECLS Break

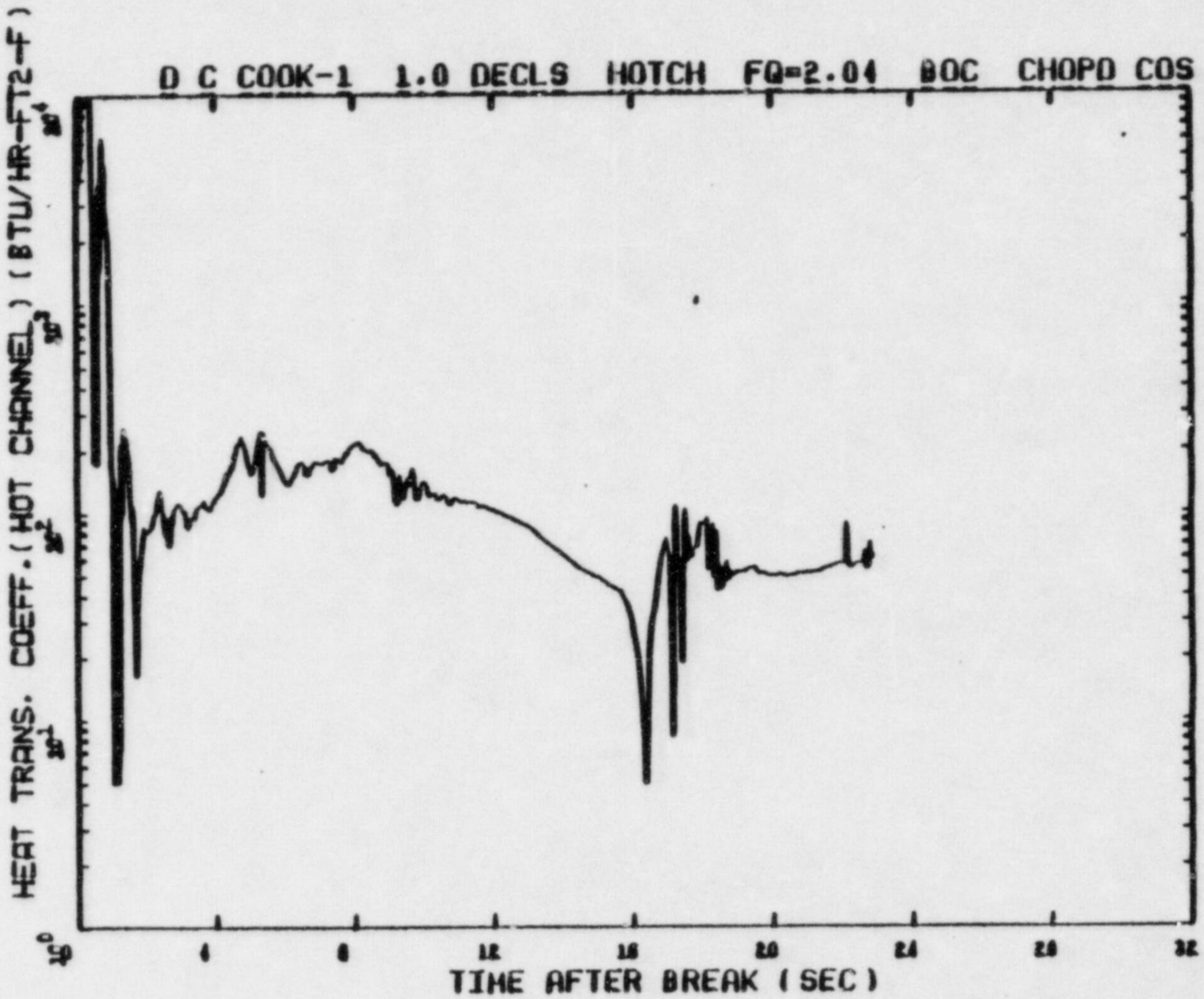

Figure 2.12 Hot Channel Heat Transfer Coefficient, 1.0 DECLS Break, BOC

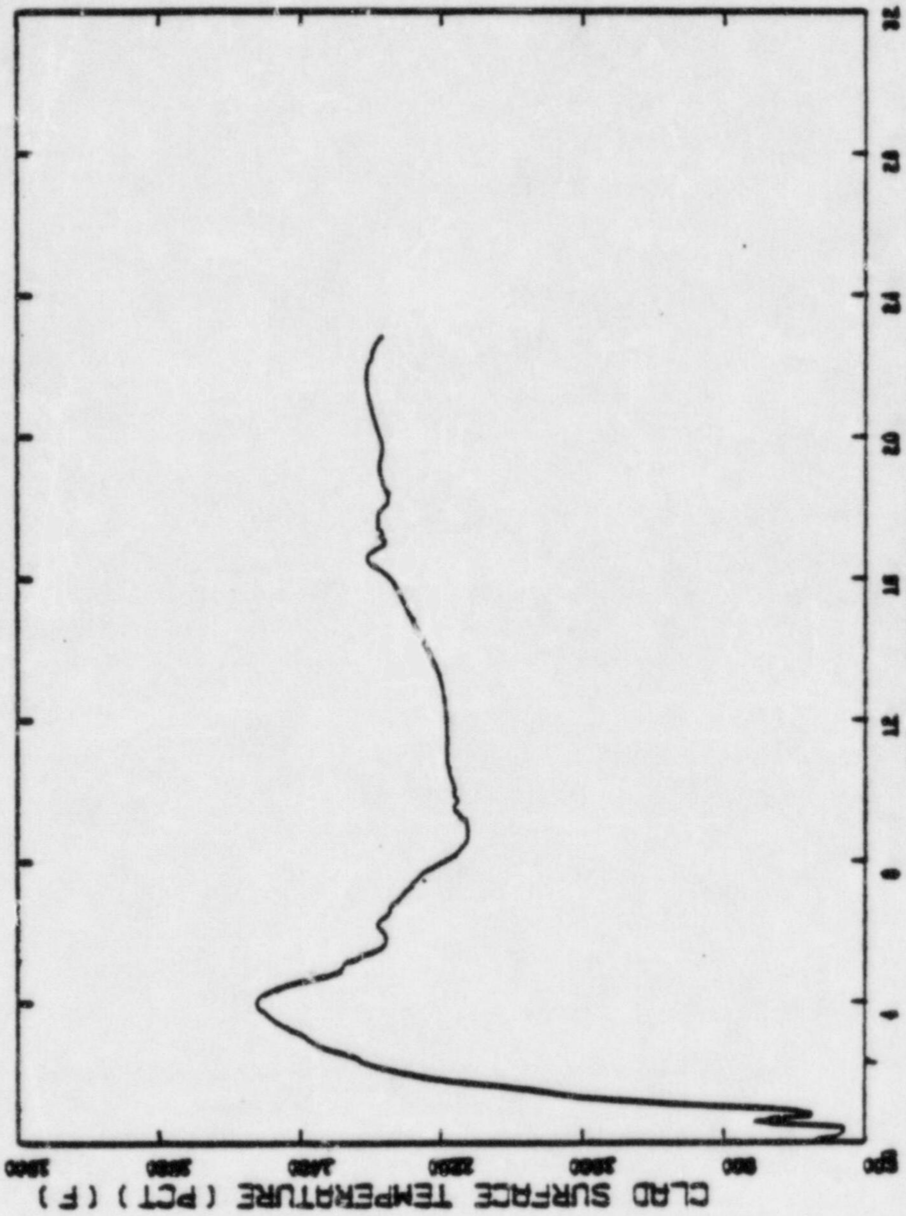

Figure 2.13 Clad Surface Temperature, 1.0 DECLS Break, BOC

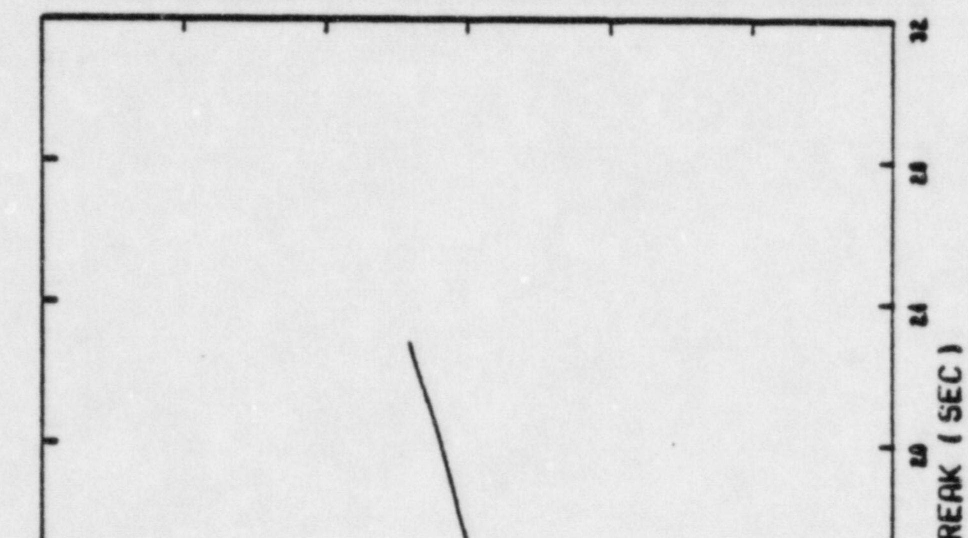

Figure 2.14 Depth of Metal-Water Reaction, 1.0 DECLS Break, BOC

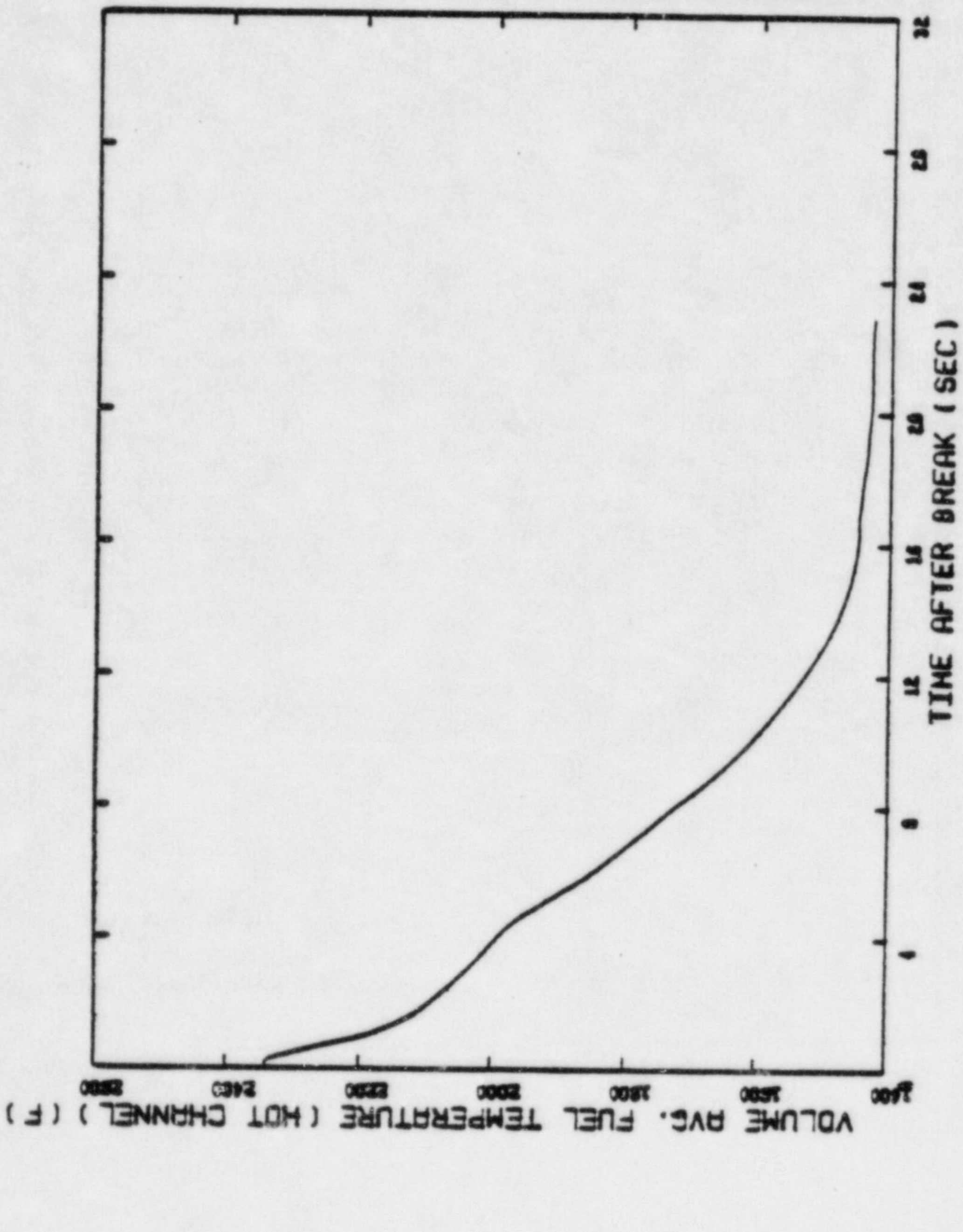

Figure 2.15 Hot Channel Average Fuel Temperature, 1.0 DECLS Break, BOC

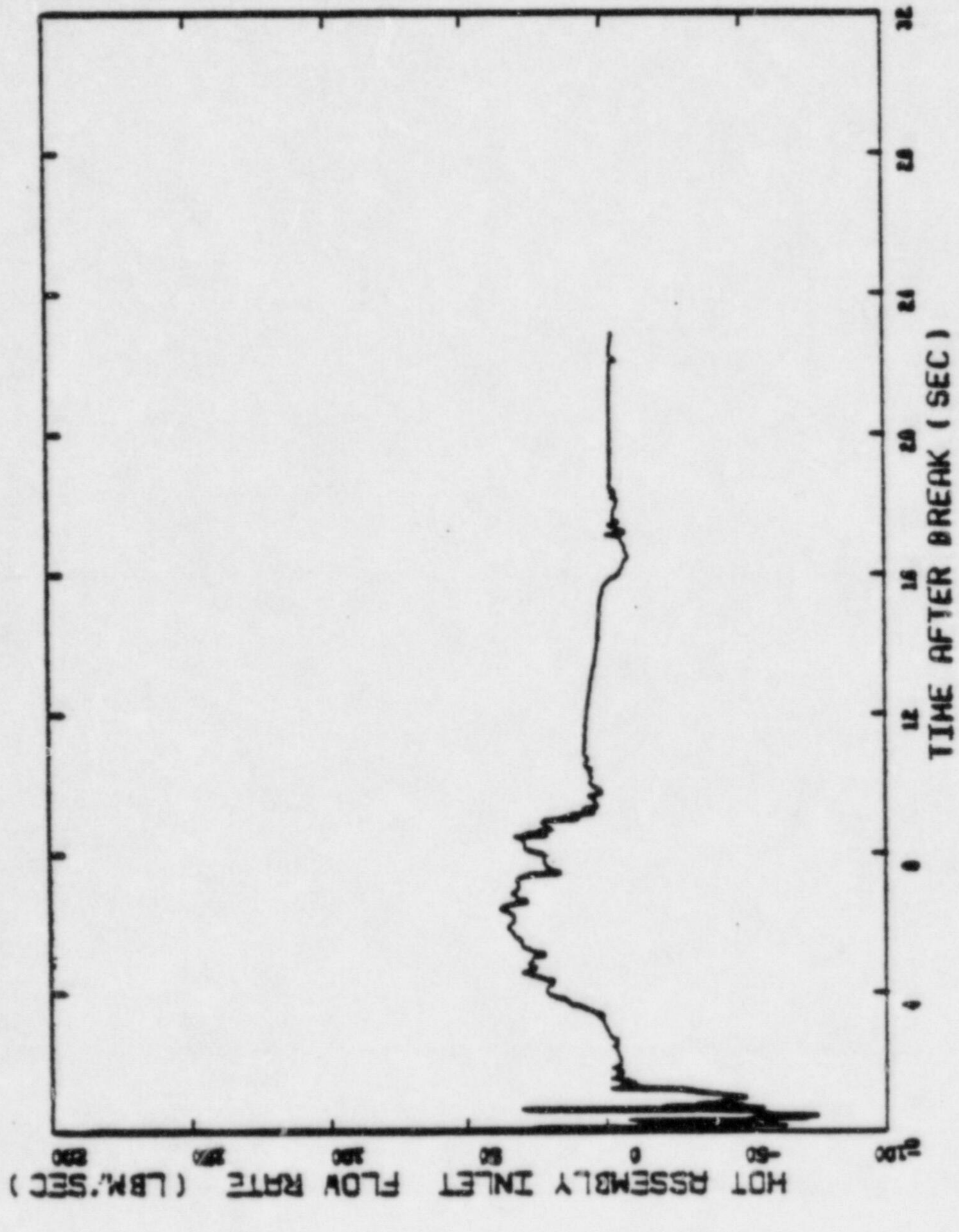

Figure 2.16 Hot Assembly Inlet Flow, 1.0 DECLS Break, BOC

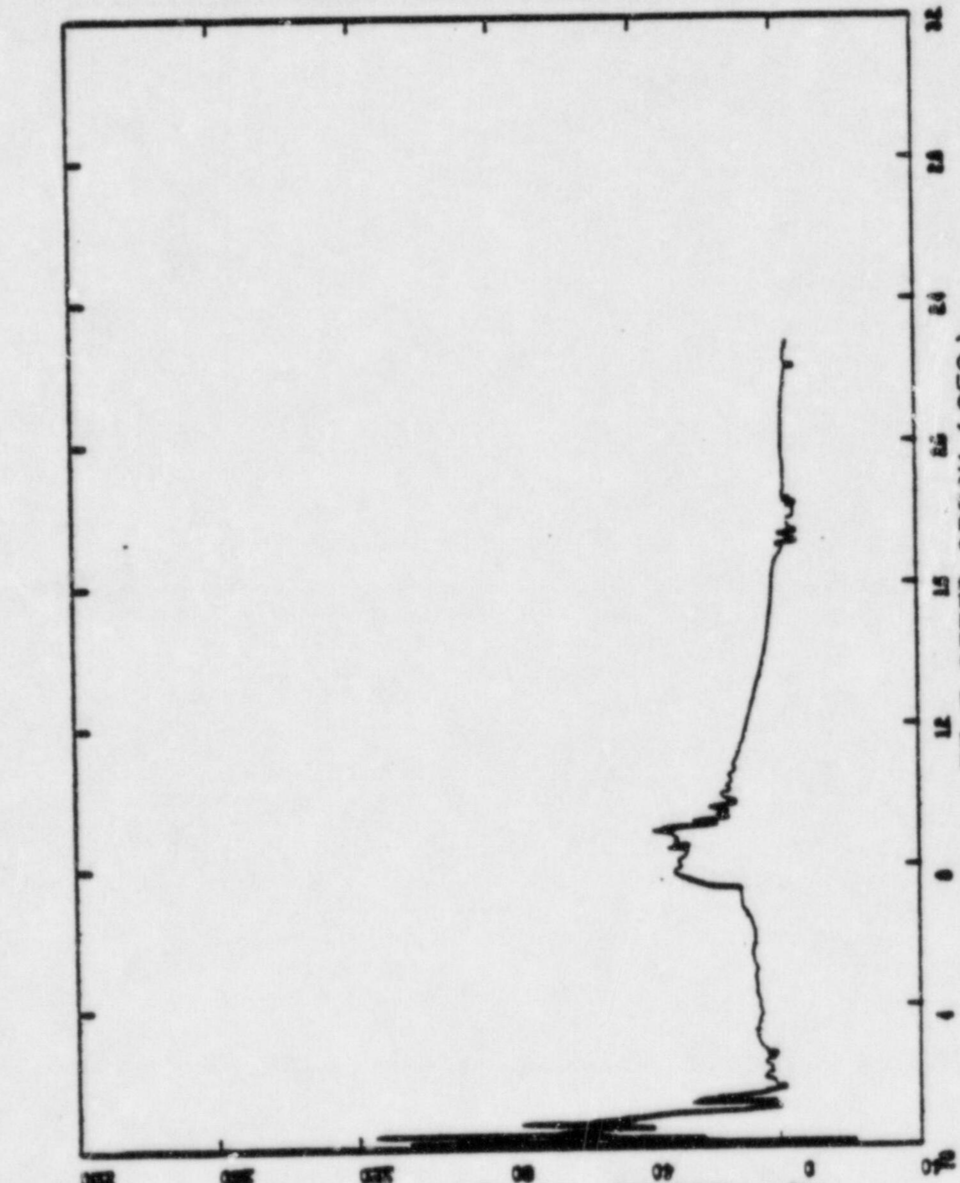

Figure 2.17 Hot Assembly Outlet Flow, 1.0 DECLS Break, BOC

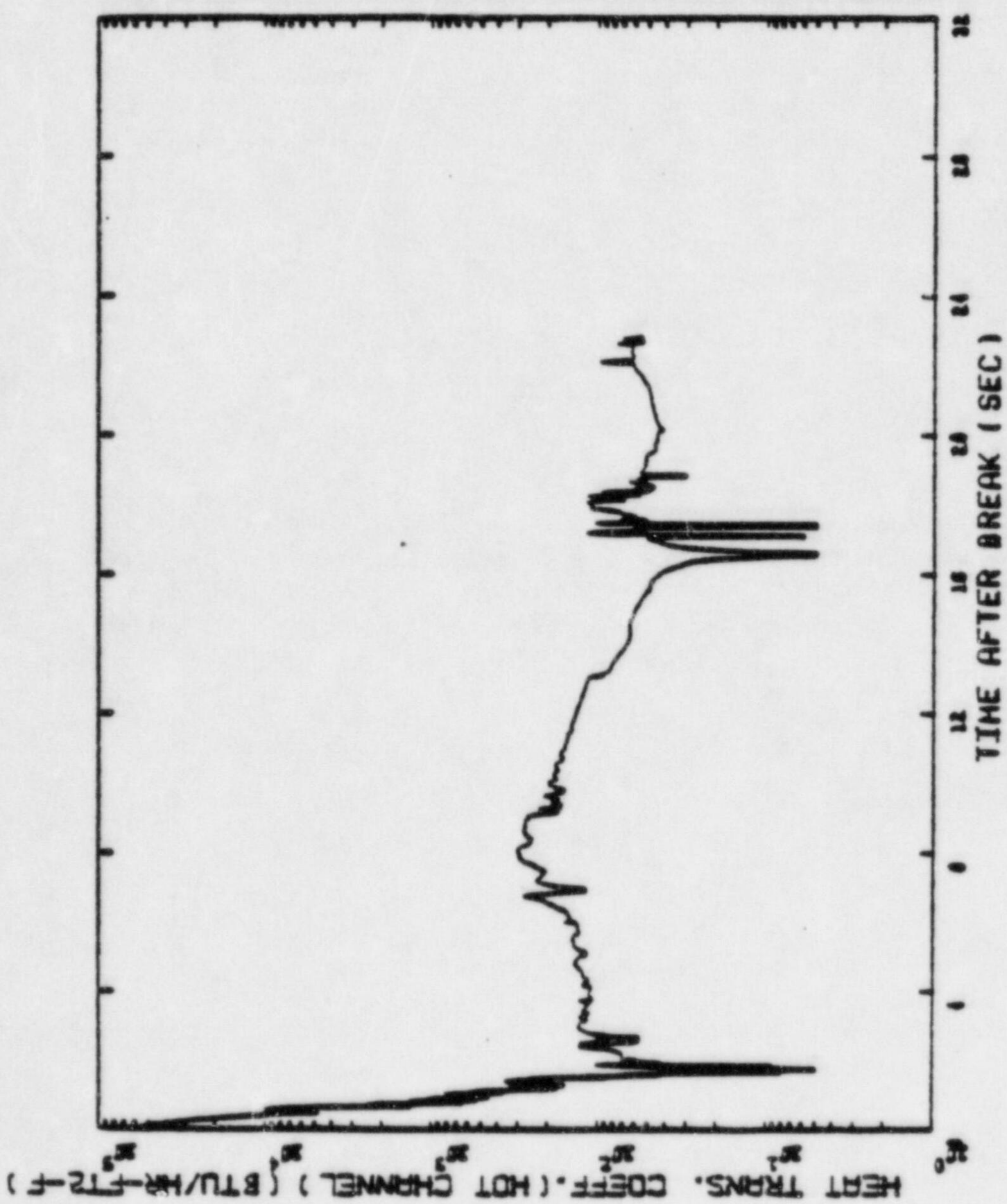

Figure 2.18 Hot Channel Heat Transfer Coefficient, 1.0 DECLS Break, EOC

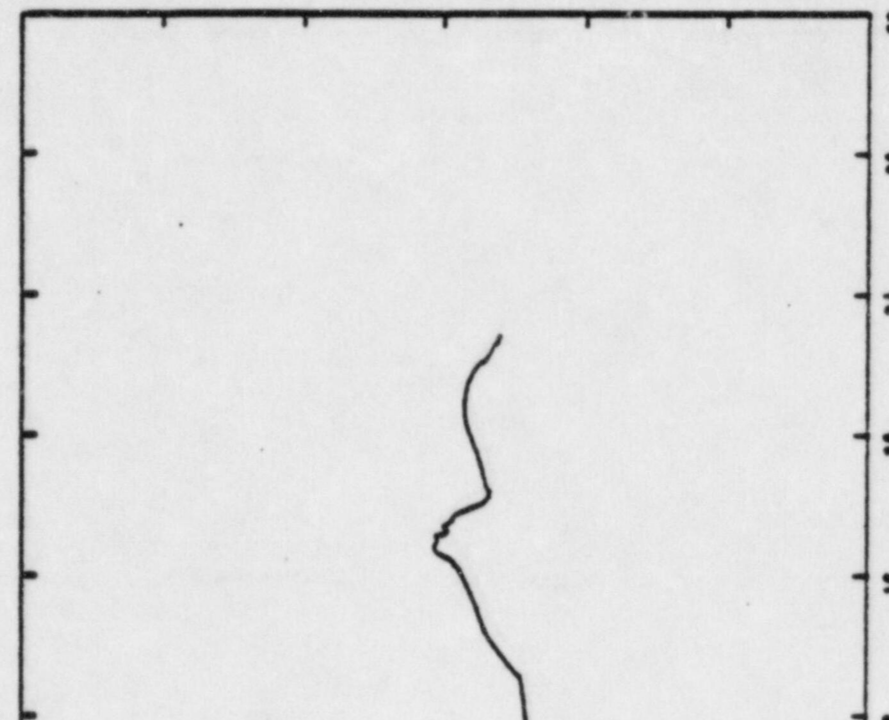

Figure 2.19 Clad Surface Temperature, 1.0 DECLS Break, EOC

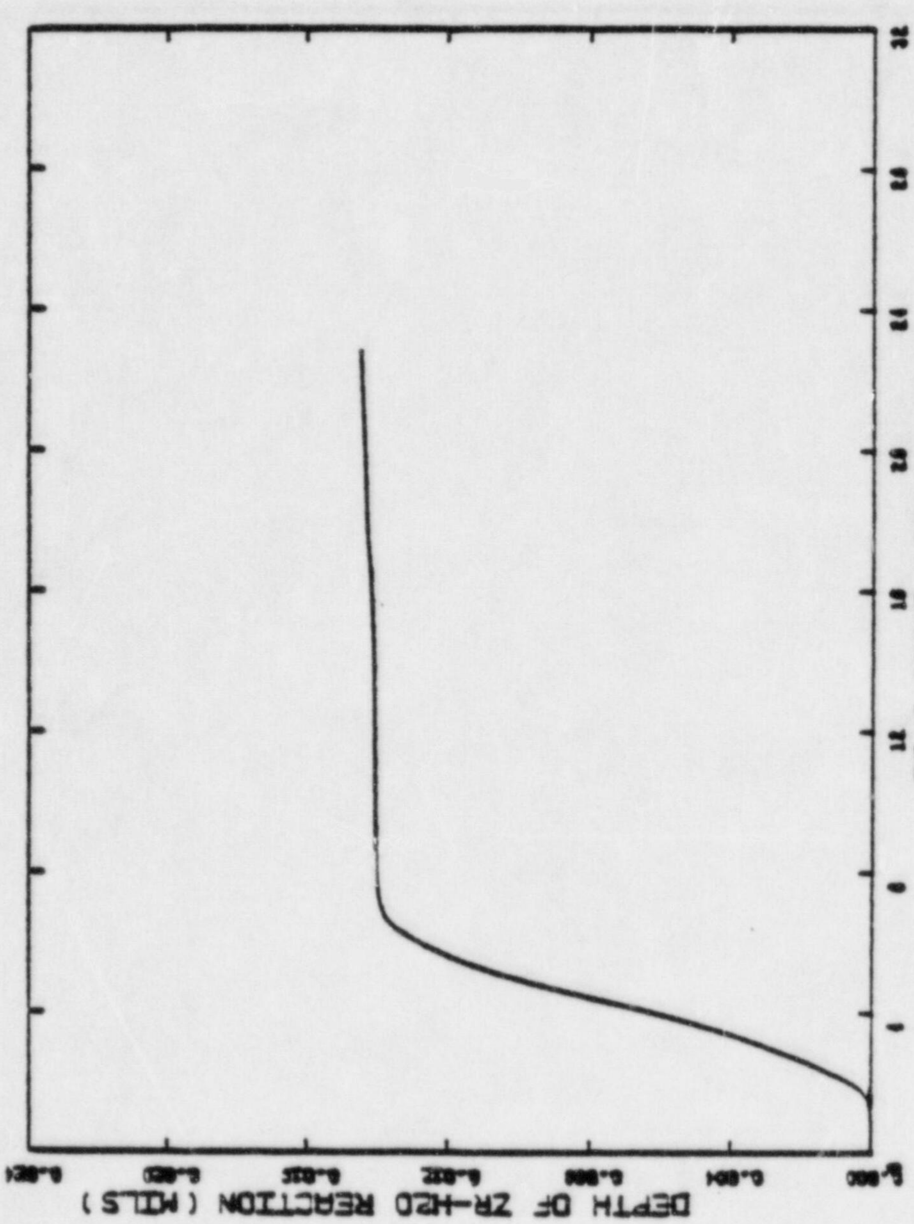

Figure 2.20 Depth of Metal-Water Reaction, 1.0 DECLS Break, EOC

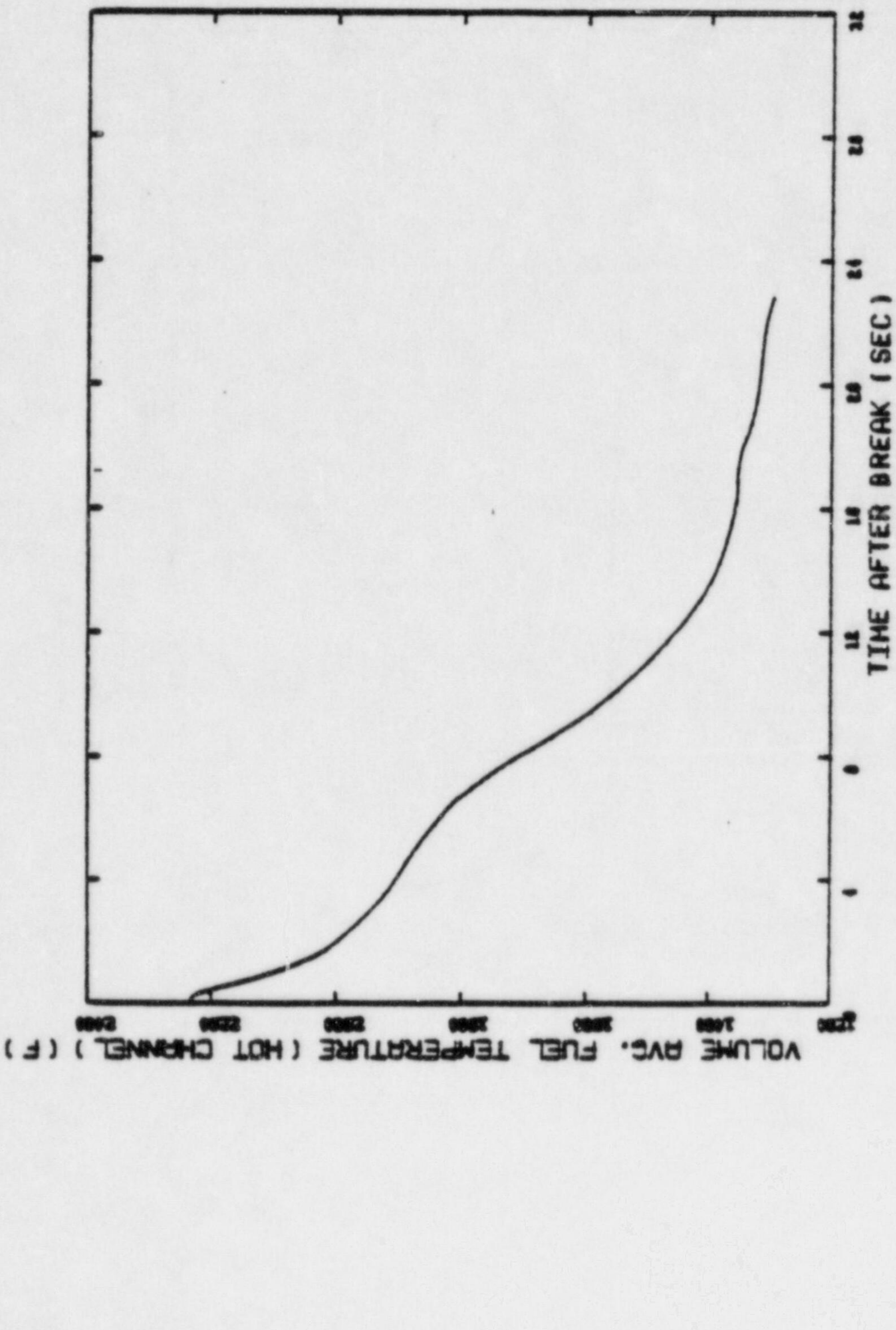

Figure 2.21 Hot Channel Average Fuel Temperature, 1.0 DECLS Break, EOC

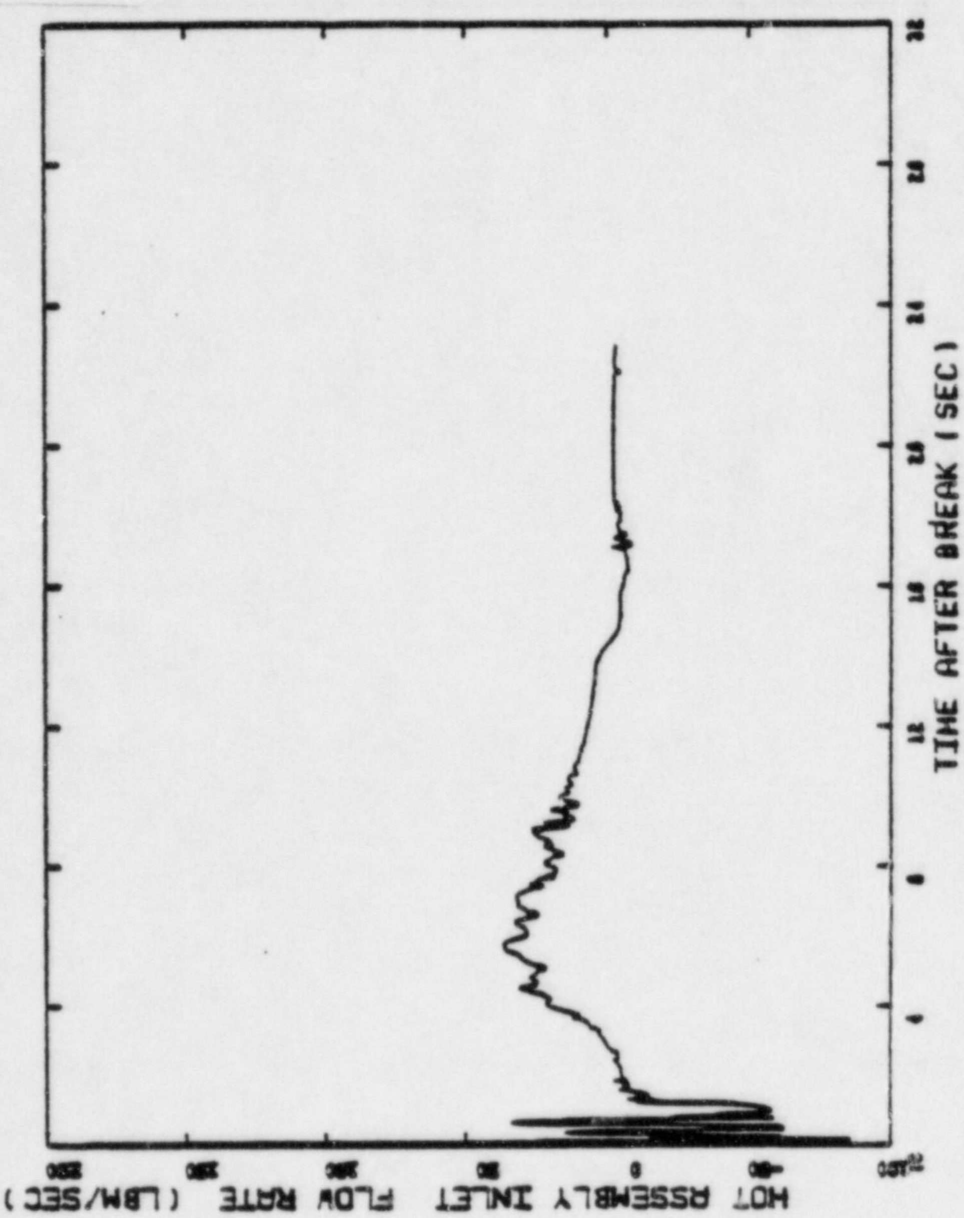

Figure 2.22 Hot Assembly Inlet Flow, 1.0 DECLS Break, EOC

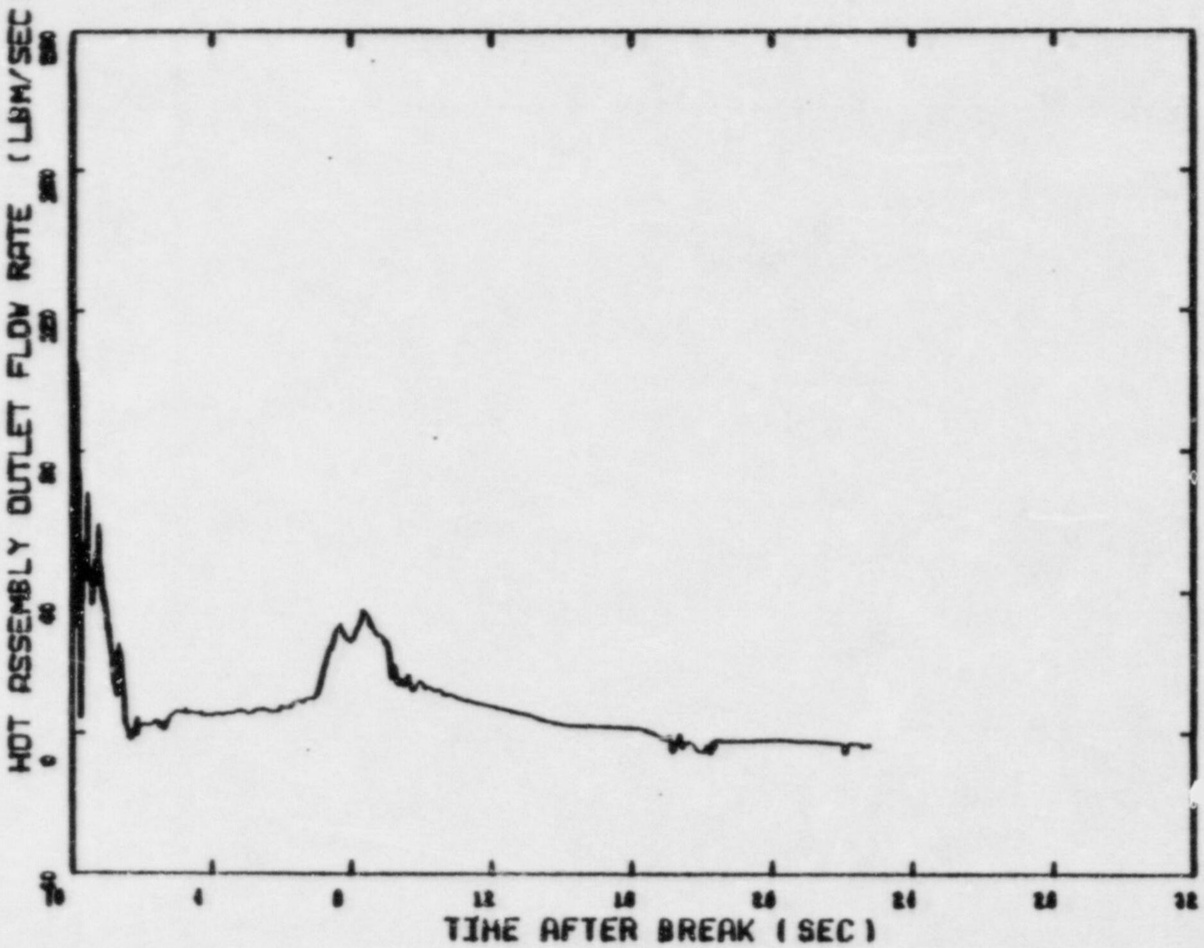

Figure 2.23 Hot Assembly Outlet Flow, 1.0 DECLS Break, EOC

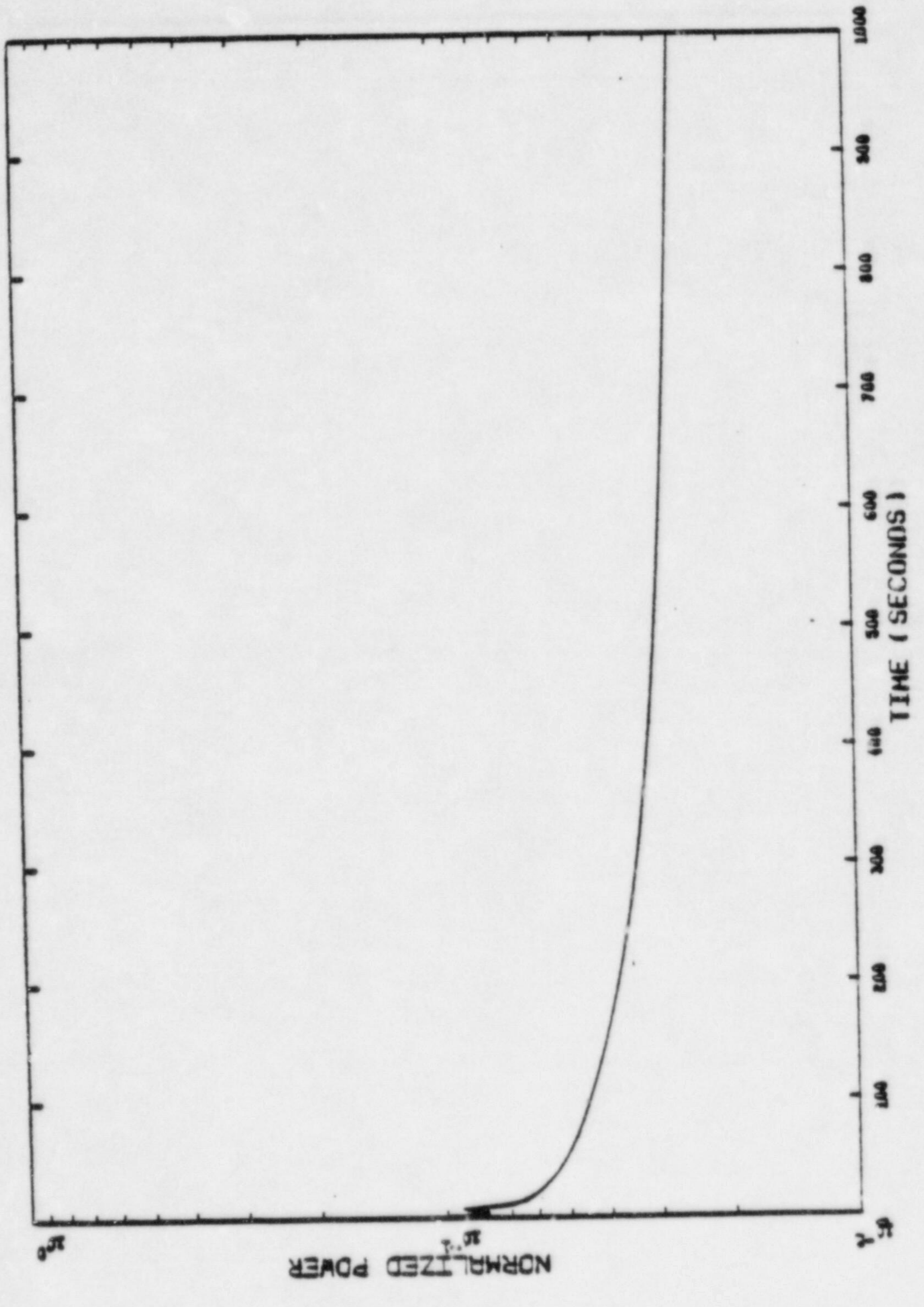

Figure 2.24 Normalized Power, 1.0 DECLS Break, BOC

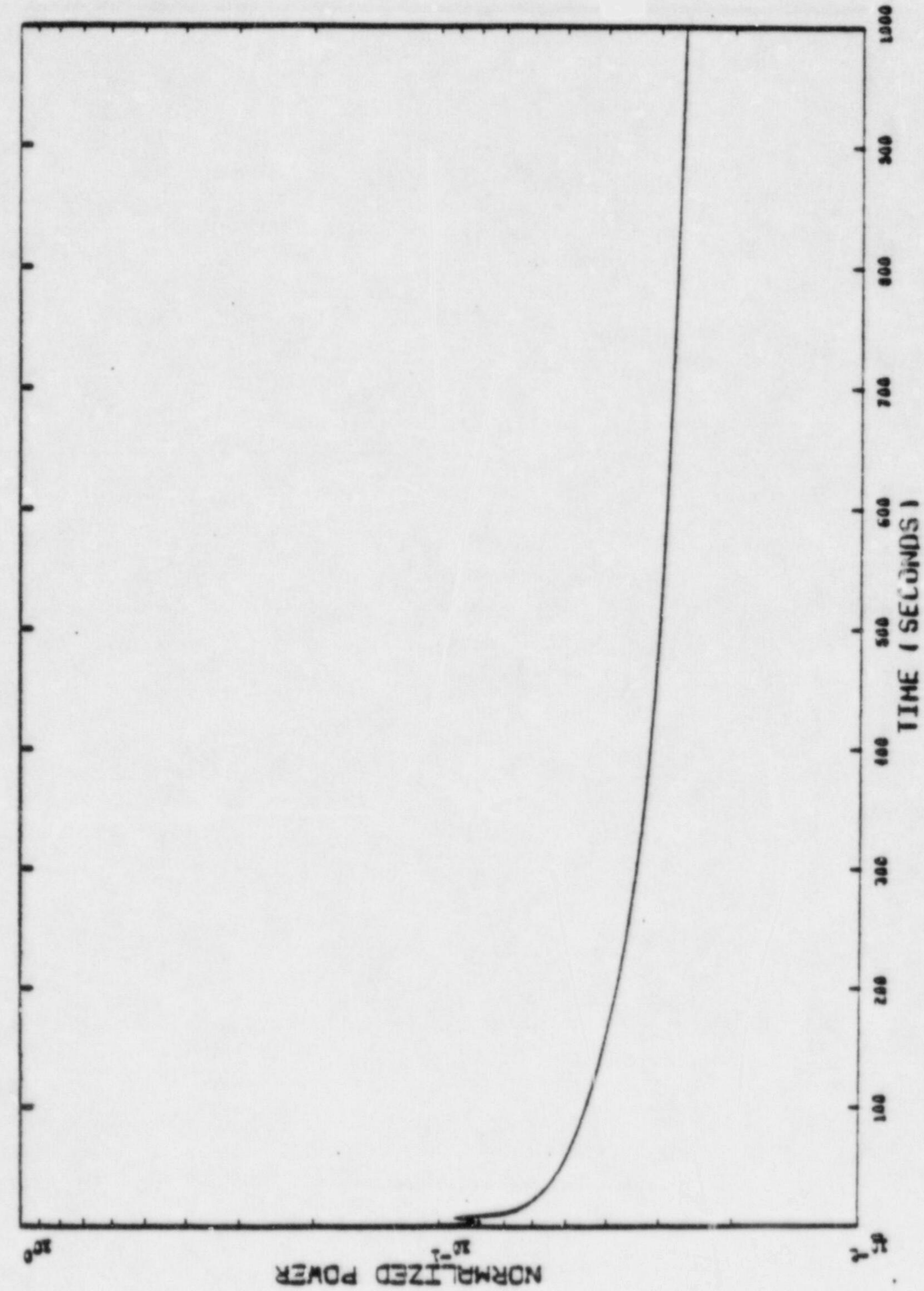

Figure 2.25 Normalized Power, 1.0 DECLS Break, EOC

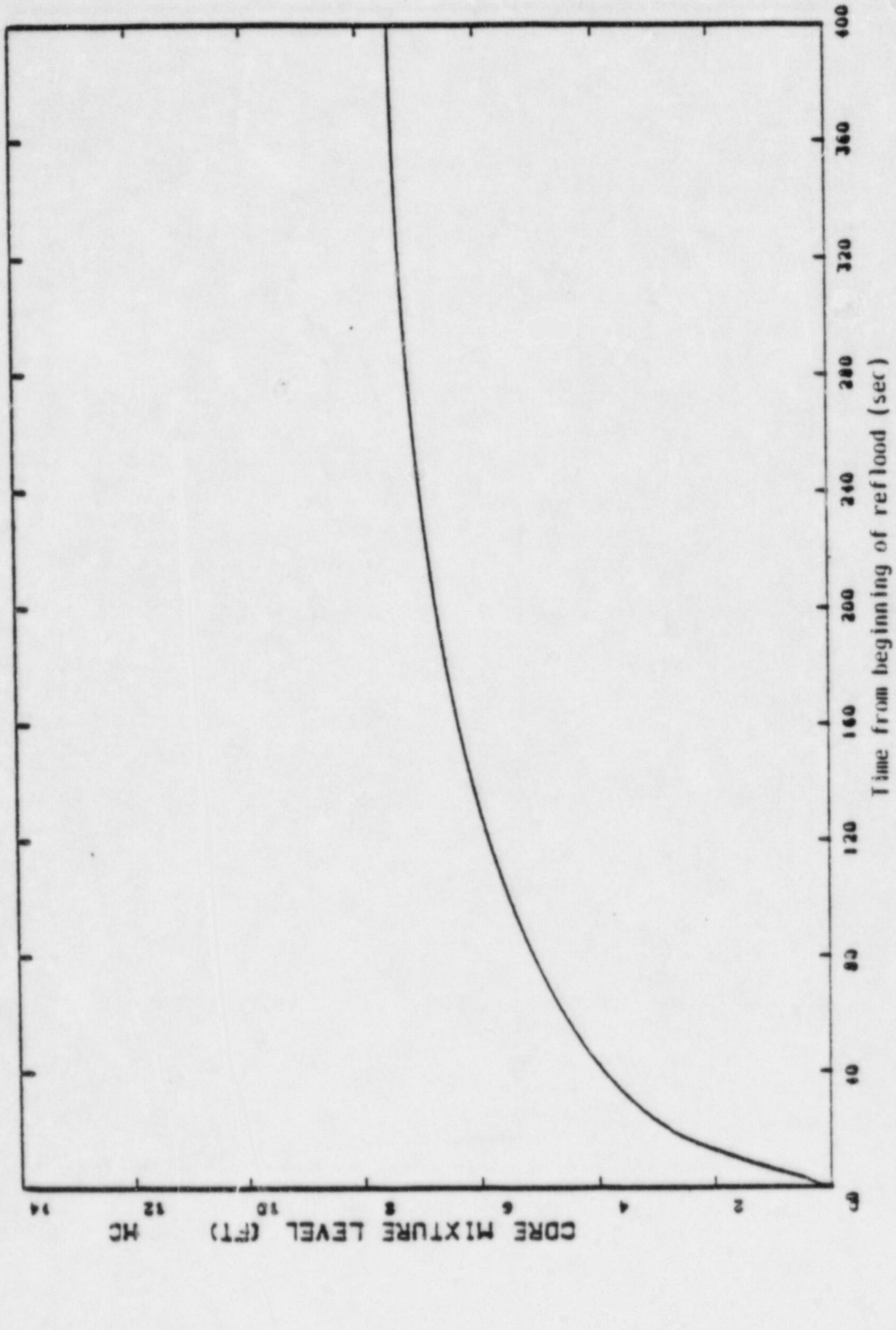

Figure 2.26 Reflood Core Mixture Level, 1.0 DECLS Break, BOC

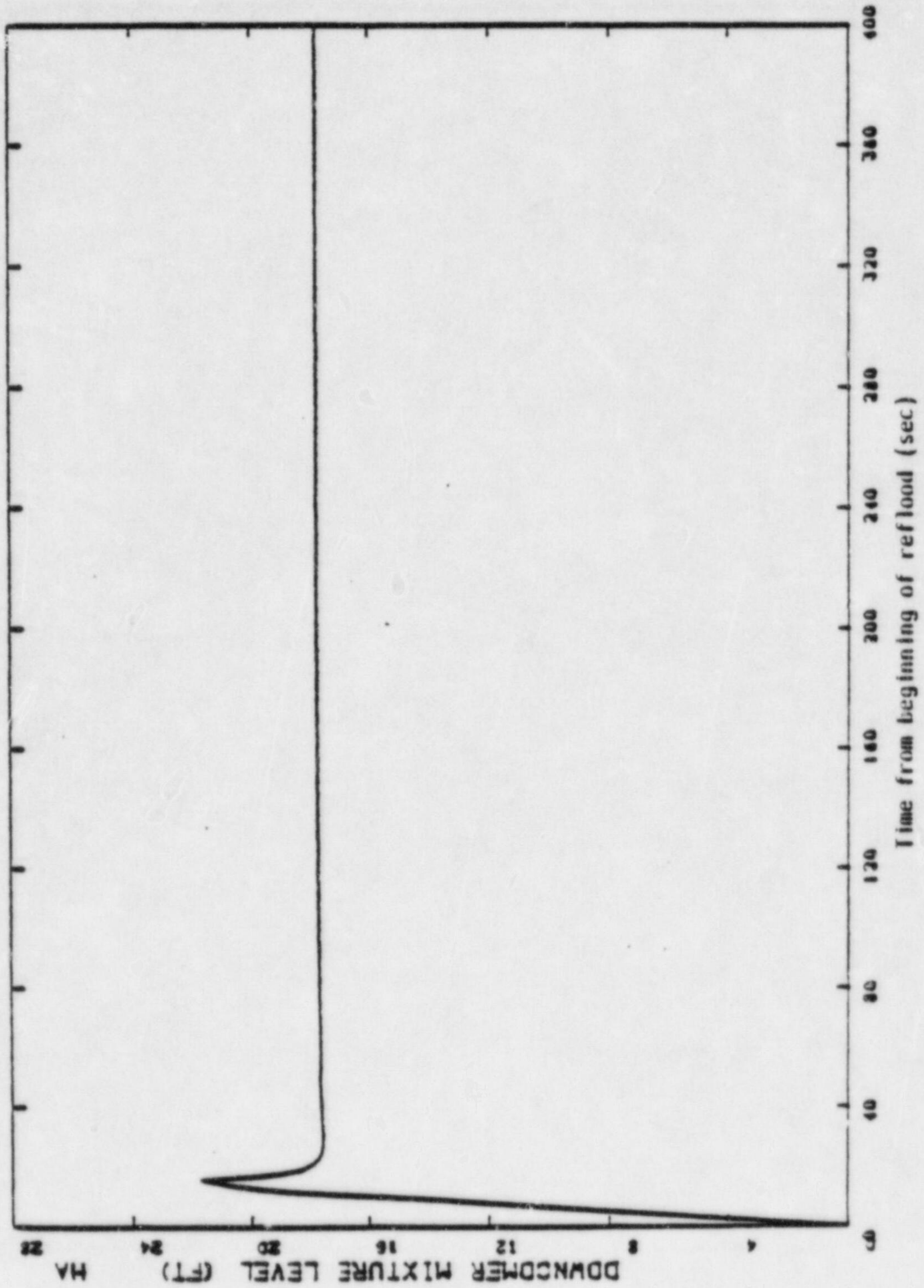

Figure 2.27 Reflood Downcomer Mixture Level, 1.0 DECLS Break, BOC

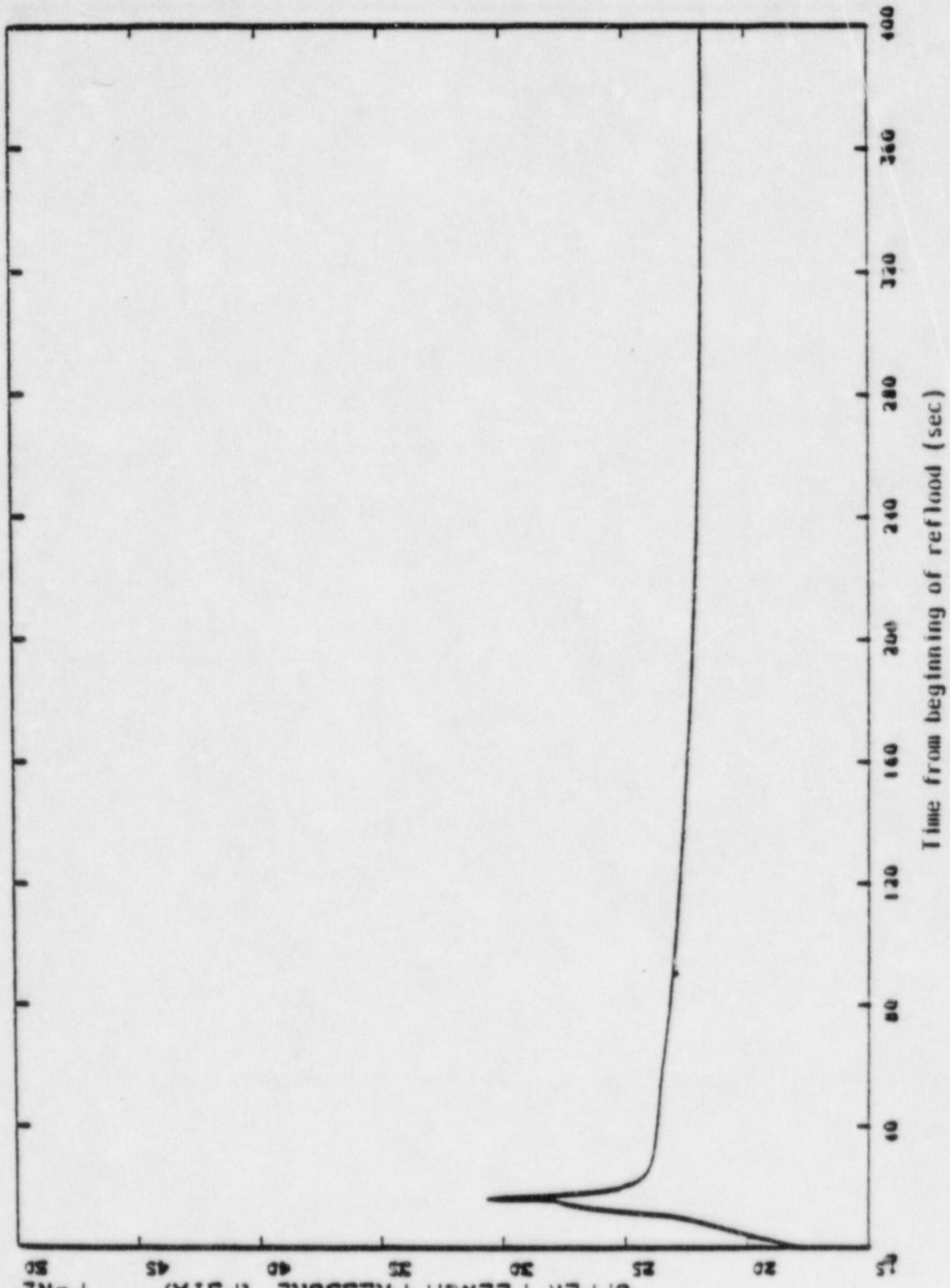

Figure 2.28 Reflood Upper Plenum Pressure, 1.0 DECLS Break, BOC

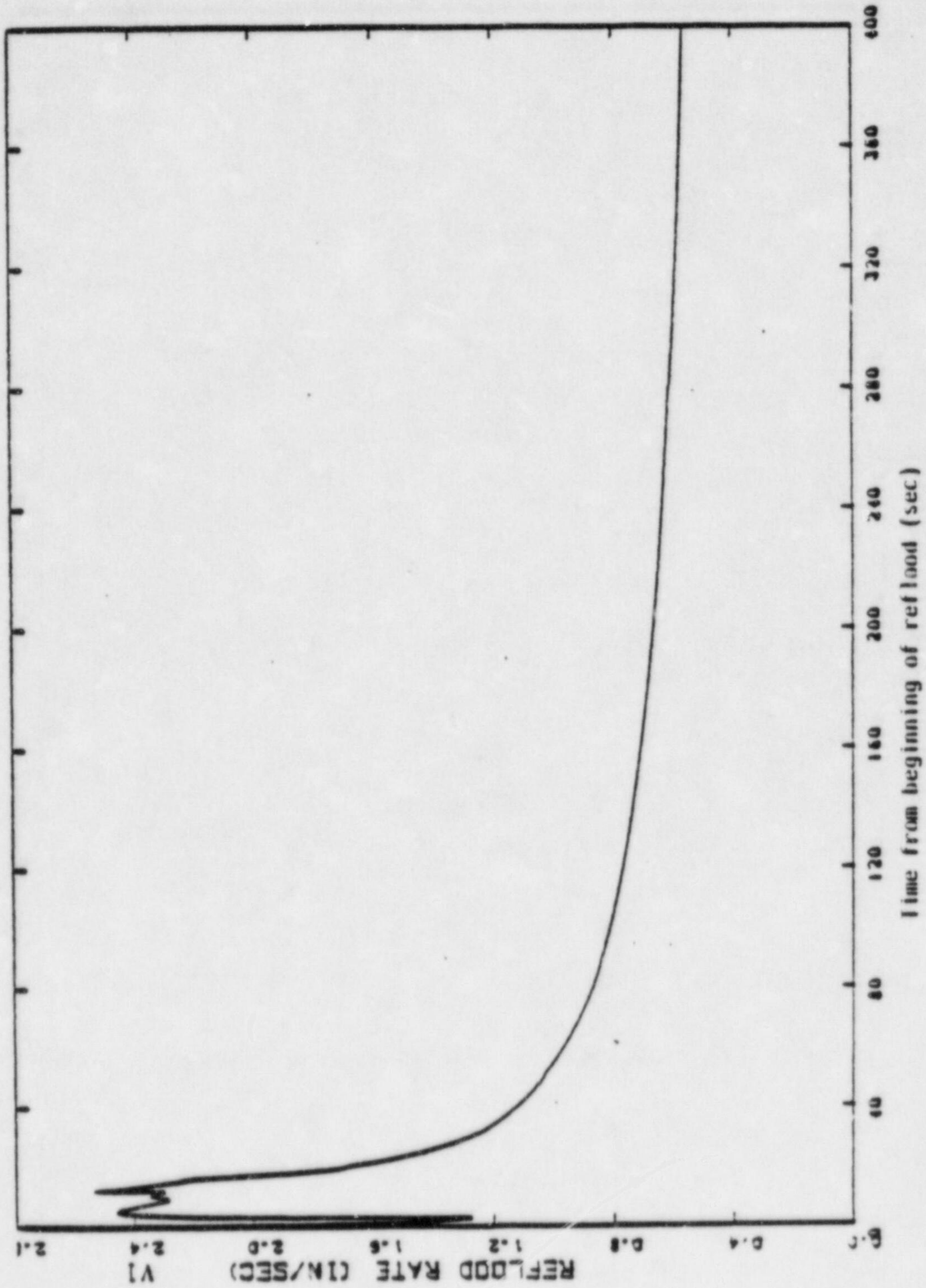

Figure 2.29 Core Flooding Rate, 1.0 DECLG Break, BOC

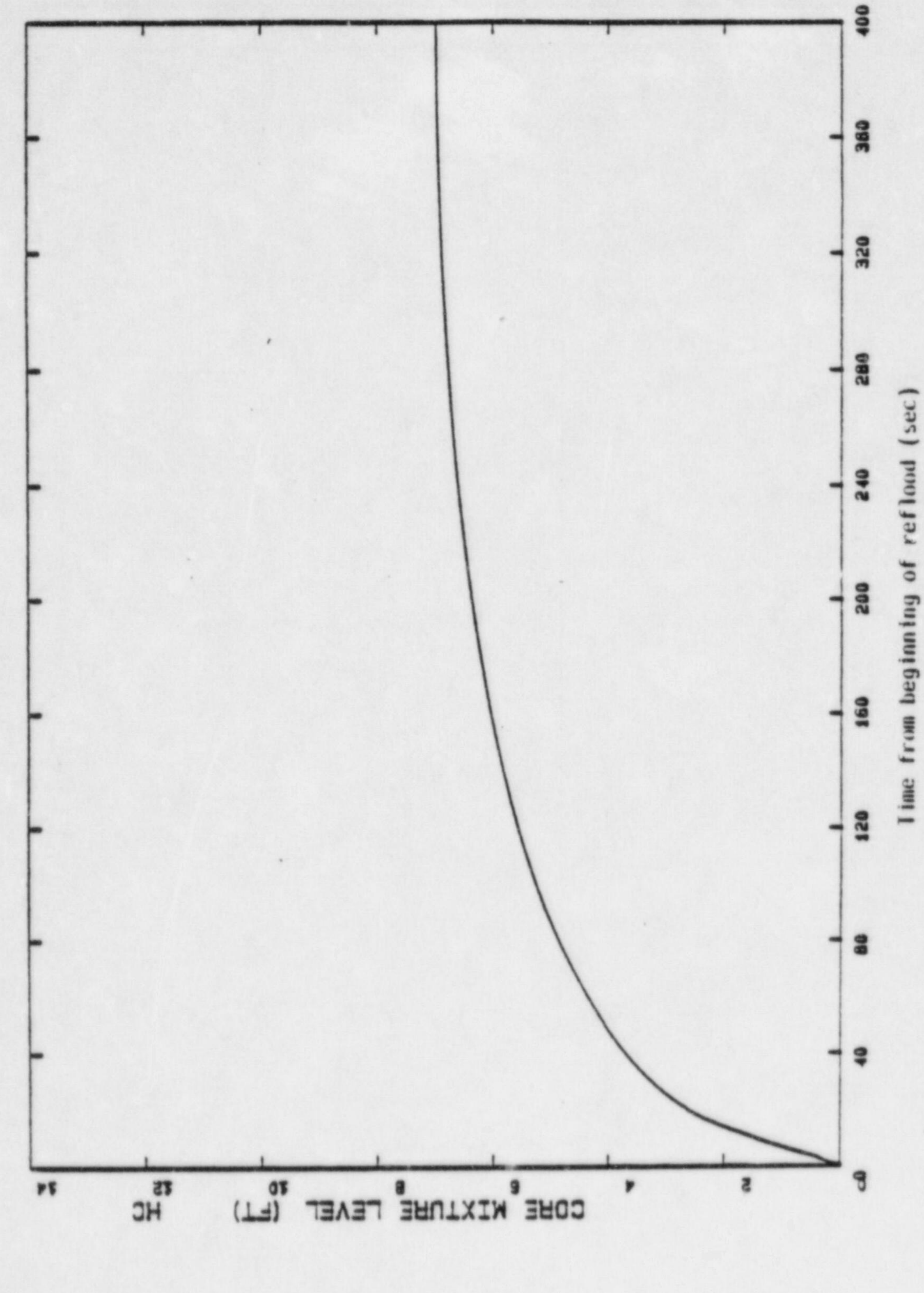

Figure 2.30 Reflood Core Mixture Level, 1.0 DECLS Break, EOC

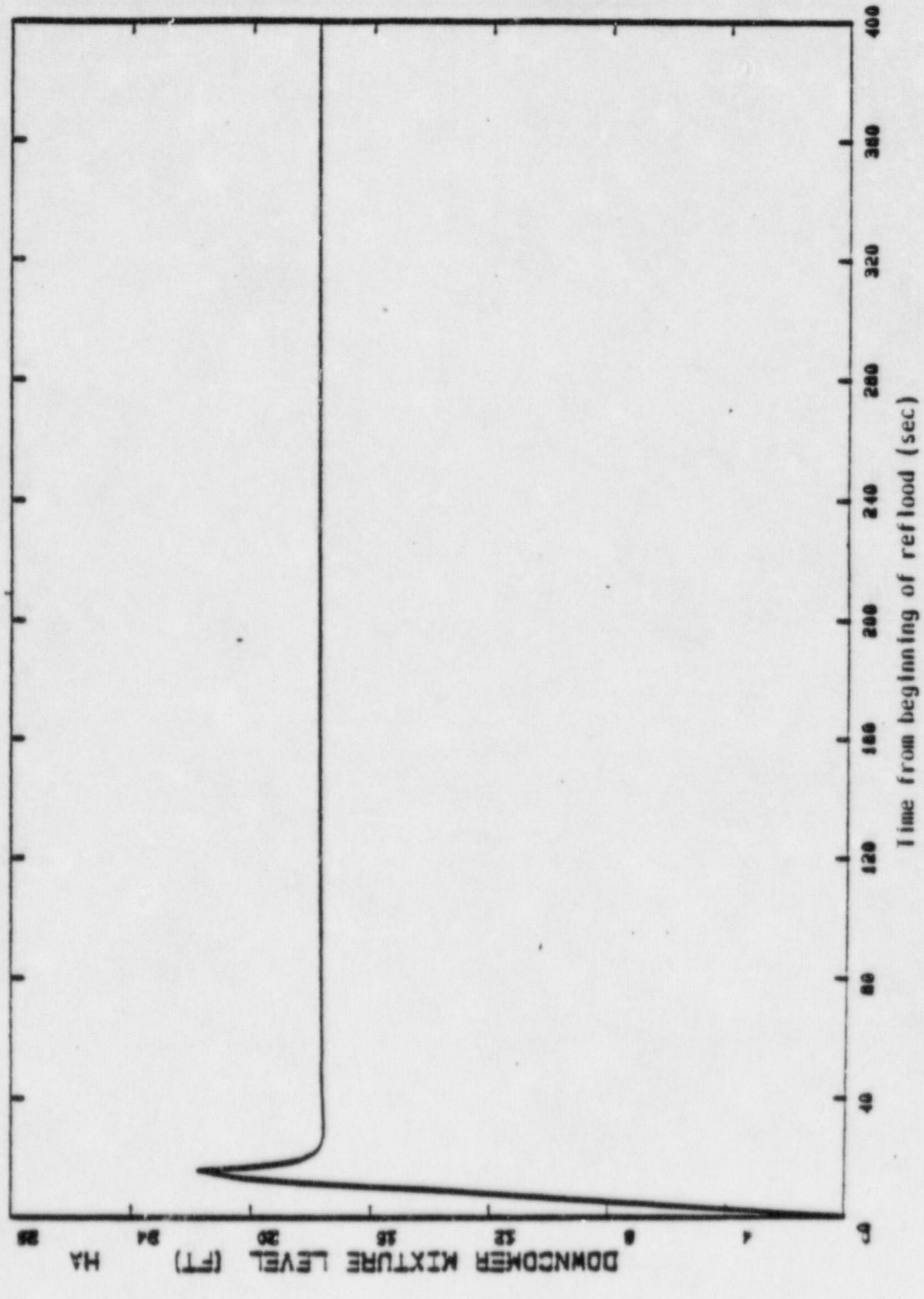

Figure 2.31 Reflood Downcomer Mixture Level, 1.0 DECLS Break, EOC

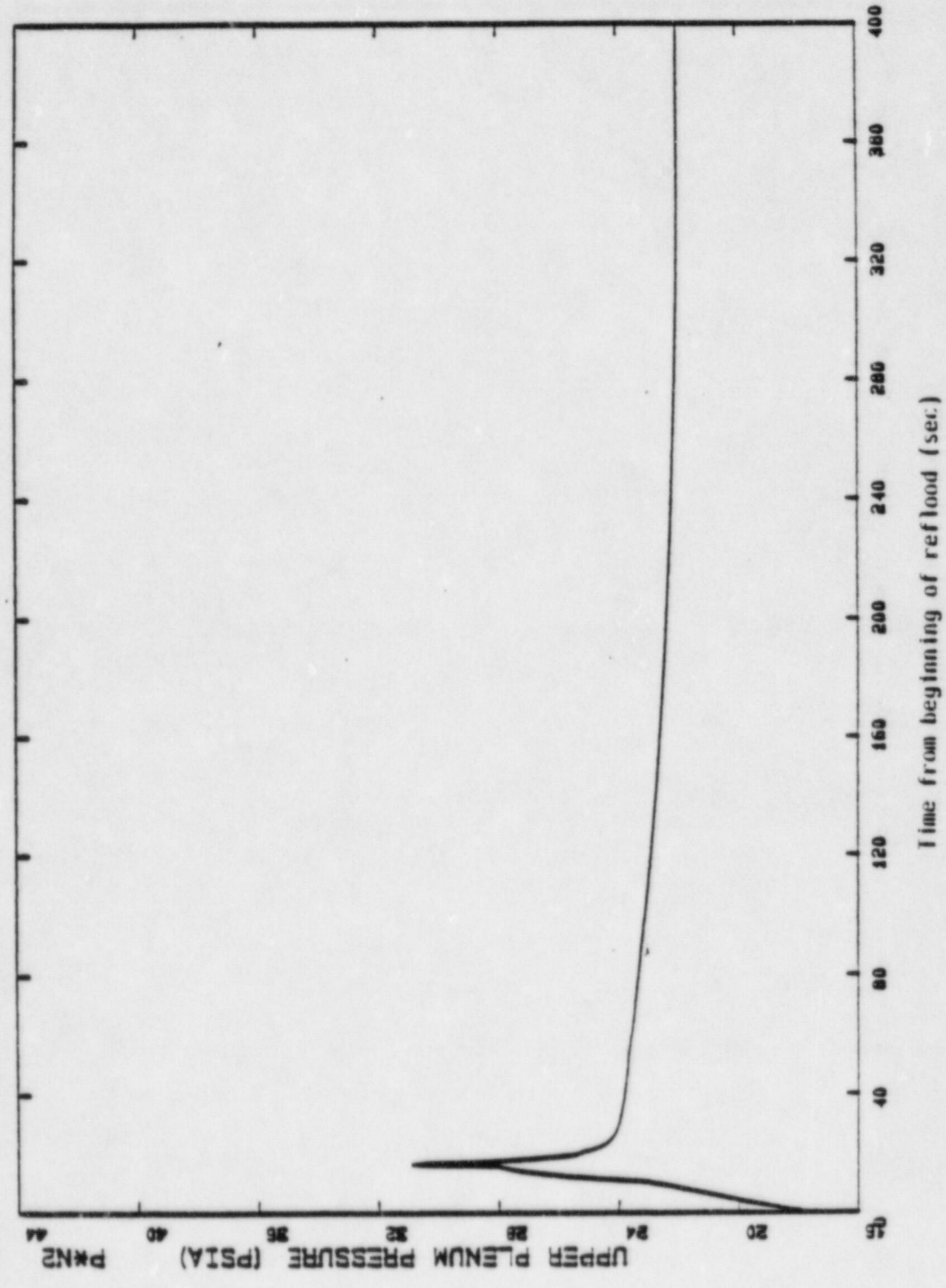

Figure 2.32 Reflood Upper Plenum Pressure, 1.0 DECLS Break, EOC

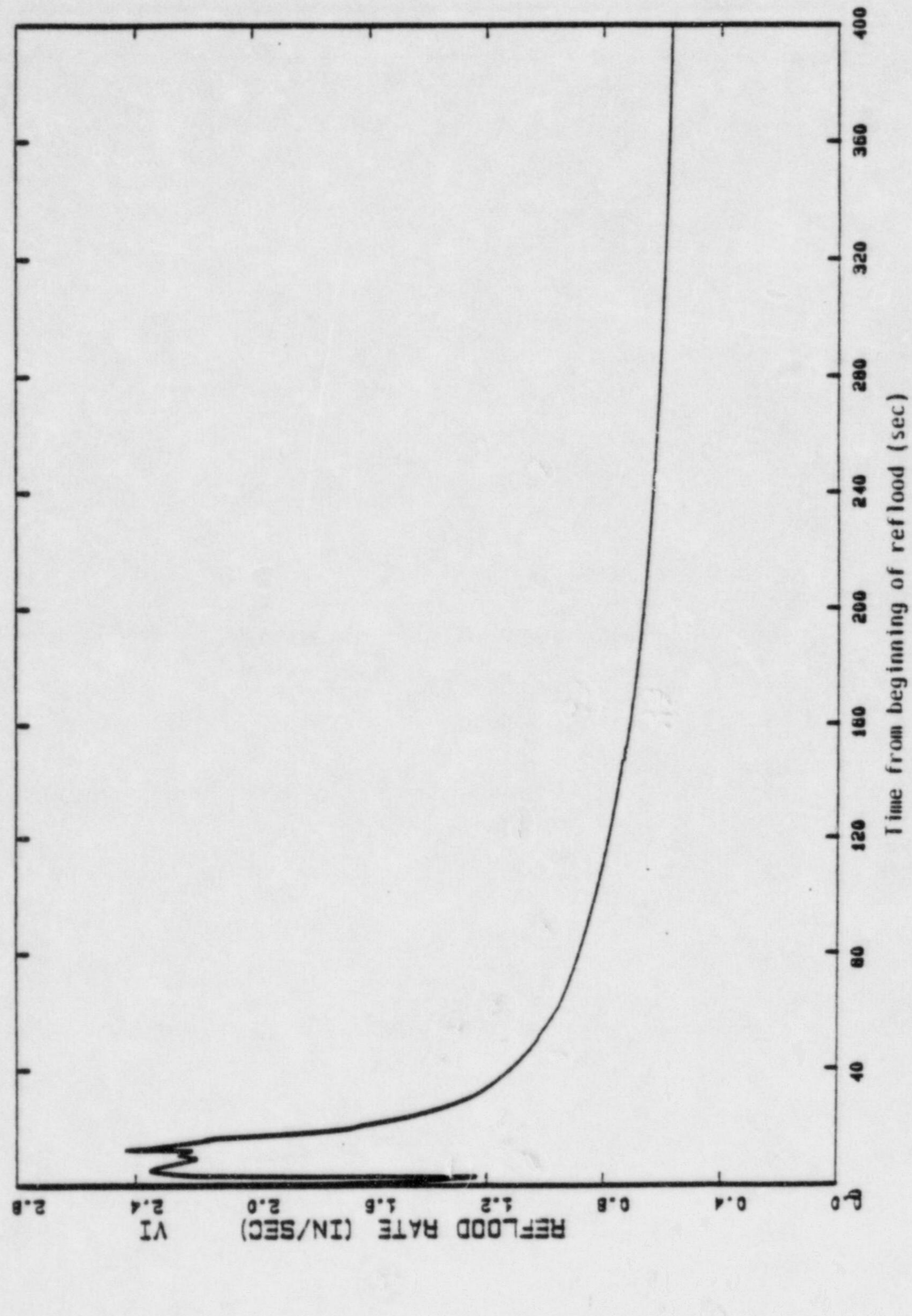

Figure 2.33 Core Flooding Rate, 1.0 DECLS Break, EOC

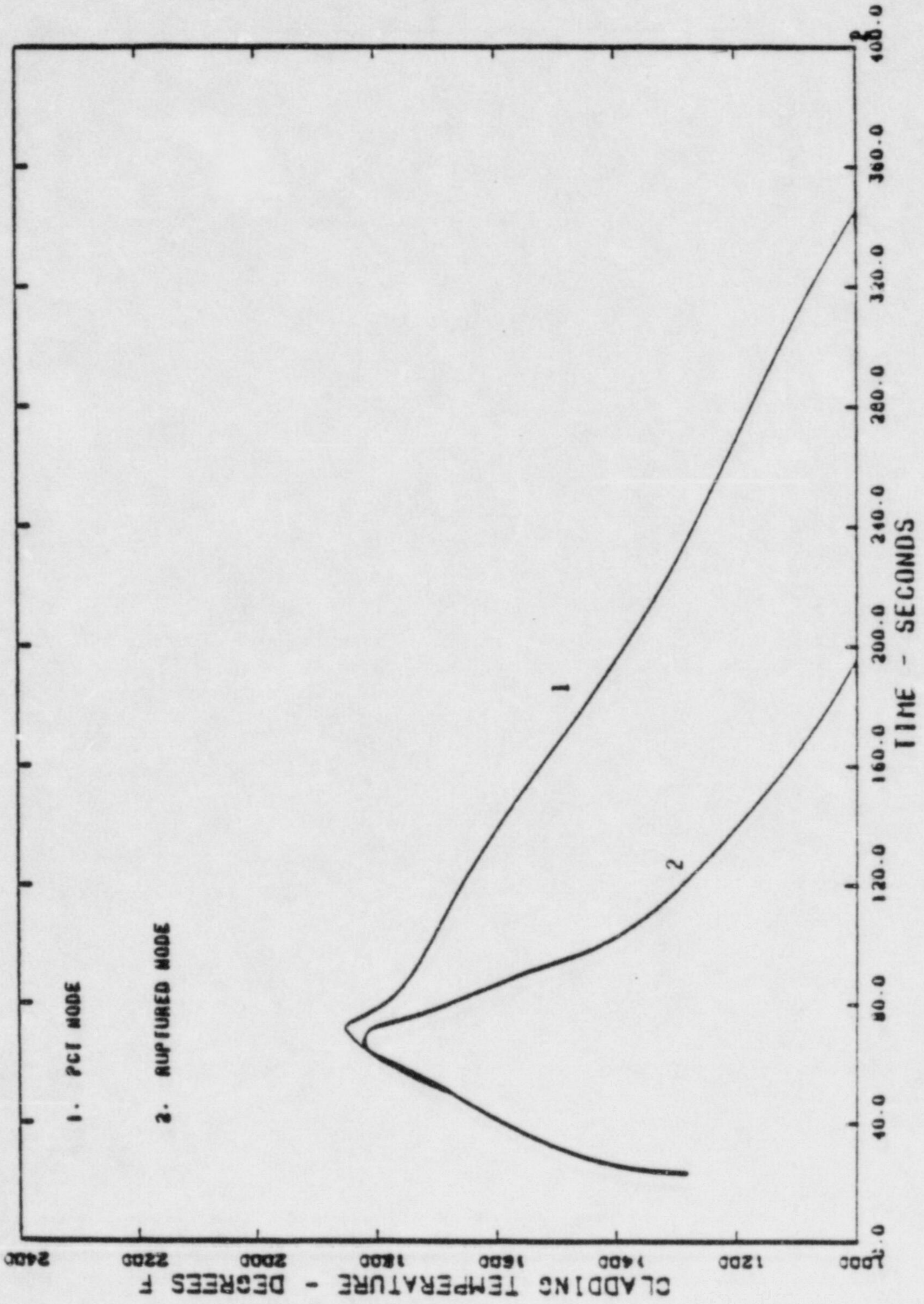

Figure 2.34 TOODEE2 Cladding Temperature vs Time, 1.0 DECLS Break, BOC

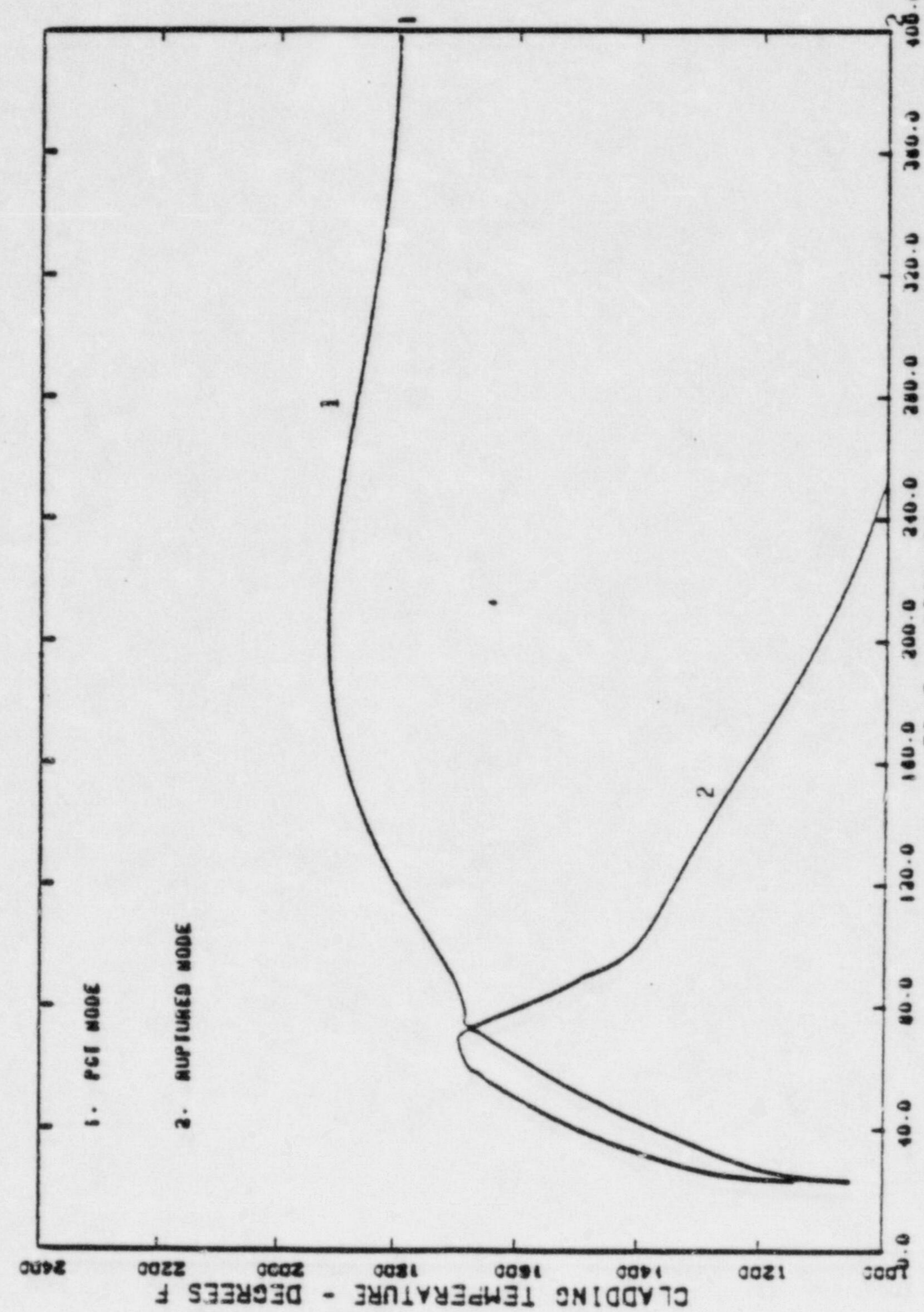

Figure 2.35 TOODEE2 Cladding Temperature vs Time, 1.0 DECLS Break, EOC

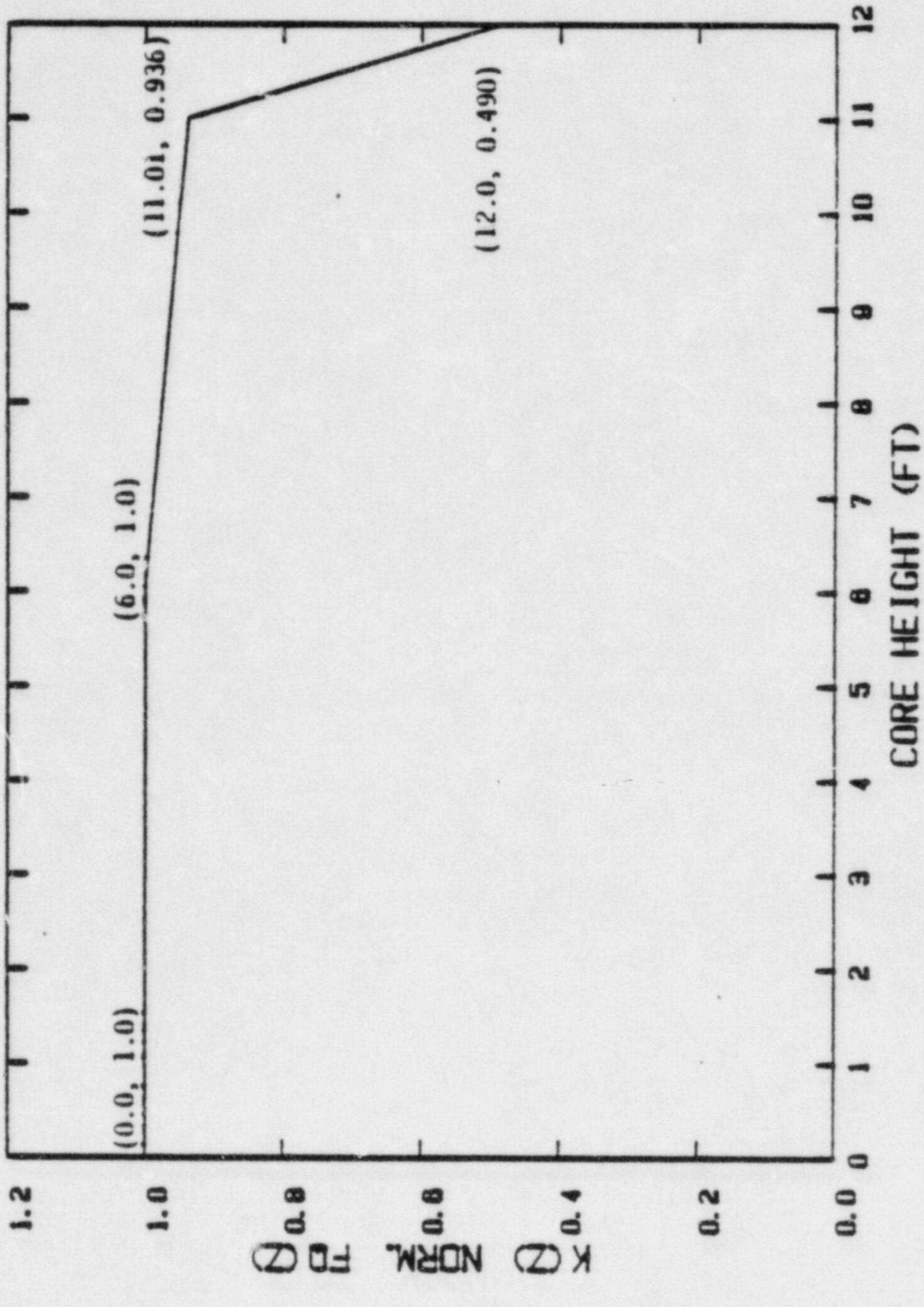

Figure 2.36 Hot Channel Factor Normalized Operating Envelope, Fq=2.04, K(Z) Function

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