XN-NF-84-21 (NP)
REVISION 1

DONALD C. COOK UNIT 2 CYCLE 5
5% STEAM GENERATOR TUBE PLUGGING
LIMITING BREAK LOCA/ECCS ANALYSIS

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1.0 INTRODUCTION

Large break LOCA/ECCS analyses were performed in 1982[1,2] to support operation of the D.C. Cook Unit 2 reactor at 3425 MWt with ENC fuel. Reference 1 presented analytical results for a spectrum of postulated large break LOCAs. The limiting break was identified as the 1.0 DECLG break. Reference 2 presented results for the previously identified limiting break using the EXEM/PWR[3] ECCS models, except GAPEX was used as the fuel performance model in place of RODEX2. The RODEX2 code was not approved by the NRC for use in ECCS analyses in 1982. The analysis therefore used the GAPEX[4] code which was approved by the NRC to calculate fuel properties at the initialization of the LOCA calculation. The Reference 2 report documented the results of calculations with one and two LPSI pumps operating. At equivalent core peaking limits, higher peak cladding temperatures (PCTs) were calculated in the LOCA analysis when two LPSI pumps were assumed operating. The Reference 2 analysis with two LPSI pumps operating was performed for Cycle 4 operation of D.C. Cook Unit 2.

This report documents the results of a LOCA/ECCS analysis to support operation of the D.C. Cook Unit 2 reactor for Cycle 5 at a thermal power rating of 3425 MWt, with up to 5% of the steam generator tubes plugged, with two LPSI pumps operating, and for ENC fuel exposed up to a peak rod average burnup of 47 MWD/kg. The calculations were performed using the EXEM/PWR LOCA/ECCS models, including fuel properties calculated at the start of the LOCA transient with ENC's generically approved RODEX2 code.[5]

2.0 SUMMARY

LOCA/ECCS calculations were performed to determine core peaking limits which permit operation of the D.C. Cook Unit 2 reactor within guidelines specified by 10 CFR 50.46 and Appendix K.[6] The calculations assumed operation:

1) At a thermal power of 3425 MWt;
2) With 5% average steam generator tube plugging; and
3) With the Cycle 5 core configuration (85% ENC fuel).

The calculations were performed for the previously identified limiting break, the 1.0 DECLG break, with full ECCS flow.

The results of the analysis are summarized in Table 2.1. The analysis supports operation of the D.C. Cook Unit 2 reactor for Cycle 5 at a total peak limit (F_Q^T) of 2.04 and a corresponding $F_{\Delta H}^T$ limit of 1.415.

Table 2.1 D.C. Cook Unit 2 LOCA/ECCS Analysis Summary

Results for the Cycle 5 Core Configuration (85% ENC Fuel)

Peak Rod Average Burnup (MWD/kg)	2.0	10.0	47.0
F_Q^T	2.04	2.04	2.04
$F_{\Delta H}^T$	1.415	1.415	1.415
Peak Cladding Temperature (^oF)	2198	2190	2096
Maximum Local $Zr-H_2O$ Reaction (%)	7.4	7.3	5.7
Total $Zr-H_2O$ Reaction	< 1.0	< 1.0	< 1.0

3.0 LIMITING BREAK LOCA ANALYSIS

This report supplements previous LOCA/ECCS analyses performed and documented for D.C. Cook Unit 2. A spectrum of LOCA breaks was performed and reported in XN-NF-82-35.(1) The limiting LOCA break was determined to be the large double-ended guillotine break of the cold leg or reactor vessel inlet pipe with a discharge coefficient of 1.0 (1.0 DECLG). Reference 2 established that for D.C. Cook Unit 2 it is more limiting in the LOCA analysis to assume no failure of a LPSI pump. The analysis performed and reported herein considers:

1) That 5% of the steam generator tubes are plugged;
2) That 85% of the Cycle 5 core is composed of ENC fuel;
3) That both LPSI pumps are operational; and
4) That ENC fuel may be exposed to a peak average burnup of 47 MWD/kg.

3.1 LOCA ANALYSIS MODEL

The Exxon Nuclear Company EXEM/PWR-ECCS evaluation model was used to perform the analyses required. This model(3) consists of the following computer codes: RODEX2(5) code for initial stored energy; RELAP4-EM(7) for the system blowdown and hot channel blowdown calculations; ICECON(8) for the computation of the ice condenser containment backpressure; REFLEX(3,9) for computation of system reflood; and TOODEE2(3,10,11) for the calculation of final fuel rod heatup.

The Donald C. Cook Unit 2 nuclear power plant is a 4-loop Westinghouse pressurized water reactor with ice condenser containment. The reactor coolant system is nodalized into control volumes representing reasonably homogeneous regions, interconnected by flow-paths or "junctions".

reasonably homogeneous regions, interconnected by flow-paths or "junctions". The system nodalization is depicted in Figure 3.1. The unbroken loops were assumed symmetrical and modeled as one intact loop with appropriately scaled input. Pump performance curves characteristic of a Westinghouse series 93A pump were used in the analysis. The transient behavior was determined from the governing conservation equations for mass, energy, and momentum. Energy transport, flow rates, and heat transfer were determined from appropriate correlations.

The Cycle 4 LOCA analysis(2) assumed that 1% of the steam generator tubes were plugged. In the current analysis, the plant was modeled assuming asymmetric steam generator tube plugging: 3.33% of the tubes plugged in the intact loops, and 10.0% of the tubes plugged in the broken loop. The larger plugging in the broken loop results in higher PCTs. The primary coolant flow at full power was reduced by 1.1% from the current measured flow at the plant to account for the assumed average 5% steam generator plugging. Additionally, the core model assumed that the core is 85% ENC fuel, whereas the previous analysis assumed the Cycle 4 core configuration. ENC fuel has a smaller rod diameter than the Westinghouse fuel it replaces. To offset the impact of increased flow area on the LOCA analysis results, the core power was reduced from 3425 MWt to 3411 MWt. System input parameters are given in Table 3.1.

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. Chopped cosine axial power profiles are assumed with the maximum axial peaking factor used in the analysis given in Table 3.2. The analysis of the loss-of-coolant accident is performed at 102 percent of rated power. The core power and other parameters used in the analyses are given in Table 3.1.

3.2 RESULTS

Table 3.3 presents the timing and sequence of events as determined for the large break guillotine configuration with a discharge coefficient of 1.0 for full ECCS operation. Table 3.4 presents the results of the exposure analysis for Cycle 5 composed of 85% ENC fuel.

Results of the analyses are given in Figures 3.2 to 3.43. Figures 3.2 to 3.10 provide plots of key system blowdown parameters versus times. Figures 3.11 to 3.28 provide plots of key core responses during the blowdown period. Figures 3.29 to 3.32 provide the ECCS flows in the broken and intact loop during the refill period. Figure 3.33 presents the containment pressure during the LOCA. Figures 3.34 to 3.36 present the normalized power during the LOCA for the three exposure cases analyzed. Figures 3.37 to 3.40 provide results from the reflood portion of the transient for the case in which 85% of the core is ENC fuel. Finally, Figures 3.41 to 3.43 provide the response of the fuel during the refill and reflood periods of the LOCA transient for the fuel burnup cases investigated.

Table 3.1 Donald C. Cook Unit 2 System Input Parameters

Thermal Power, MWt*	3425
Core, MWt	3411
Pump, MWt	14
Primary Coolant Flow, Mlbm/hr	143.1
Primary Coolant Volume, ft^3	11,768
Operating Pressure, psia	2250
Inlet Coolant Temperature, ^oF	542
Reactor Vessel Volume, ft^3	4945
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 (each of four)	950
Accumulator Pressure, psia	636
Steam Generator Heat Transfer Area, ft^2 - SG1, SG2, SG3, SG4	11,588, 3(12,446)
Steam Generator Secondary Flow, lbm/hr - SG1, SG2, SG3, SG4	3.505×10^6, $3(3.764 \times 10^6)$
Steam Generator Secondary Pressure, psia	799
Reactor Coolant Pump Head, ft	277
Reactor Coolant Pump Speed, rpm	1189
Moment of Inertia, $lbm\text{-}ft^2$	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.	0.360
Fuel Assembly Rod Pitch, in.	0.496
Fuel Assembly Pitch, in.	8.466
Fueled (Core) Height, in.	144.0
Fuel Heat Transfer Area, ft^2**	57,327
Fuel Total Flow Area, Bare Rod, ft^2**	53.703
Refueling Water Storage Tank Temperature, ^oF	80
Accumulator Water Temperature, ^oF	120

*Primary Heat Output used in RELAP4-EM Model = $1.02 \times 3425 = 3493.5$ MWt

**ENC Fuel Parameters.

Table 3.2 1.0 DECLG Break Analysis Parameters

Peak Rod Average Burnup (MWD/kg)	2.0	10.0	47.0
Total Core Power (MWt)*	3411	3411	3411
Total Peaking (F_Q^T)	2.04	2.04	2.04
Fraction Energy Deposited in Fuel			
• Fully Moderated Core	0.974	0.974	0.974
• Voided Core	0.954	0.954	0.954
Cycle 5 (85% ENC Fuel)			
Peaking			
• Axial x Engineering	1.442	1.442	1.442
• Enthalpy Rise ($F_{\Delta H}^T$)	1.415	1.415	1.415

*2% power uncertainty is added to this value in the LOCA analysis.

Table 3.3 D. C. Cook Unit 2 1.0 DECLG Break Event Times

Event	Time (sec.)
Start	0.00
Break Initiation	0.05
Safety Injection Signal	0.65
Accumulator Injection	
Broken Loop	3.2
Intact Loop	15.5
End of Bypass	24.31
Safety Pump Injection	25.65
Start of Reflood	40.48
Accumulator Empty	
Broken Loop	44.2
Intact Loop	52.9

Table 3.4 1.0 DECLG Break Fuel Response Results for Cycle 5

Peak Rod Average Burnup (MWD/kg)	2.0	10.0	47.0
Initial Peak Fuel Average Temperature (^{O}F)	2151	2060	1629
Hot Rod Burst			
• Time (sec)	60.9	61.7	67.9
• Elevation (ft)	6.50	6.50	7.00
• Channel Blockage Fraction	.24	.27	.47
Peak Clad Temperature			
• Time (sec)	227	227	241
• Elevation (ft)	8.63	8.63	8.88
• Temperature (^{O}F)	2198	2190	2096
Zr-Steam Reaction			
• Local Maximum Elevation (ft)	8.63	8.63	8.88
• Local Maximum (%)*	7.4	7.3	5.7
• Core Maximum	<1.0	<1.0	<1.0

*Values 400 sec into LOCA transient.

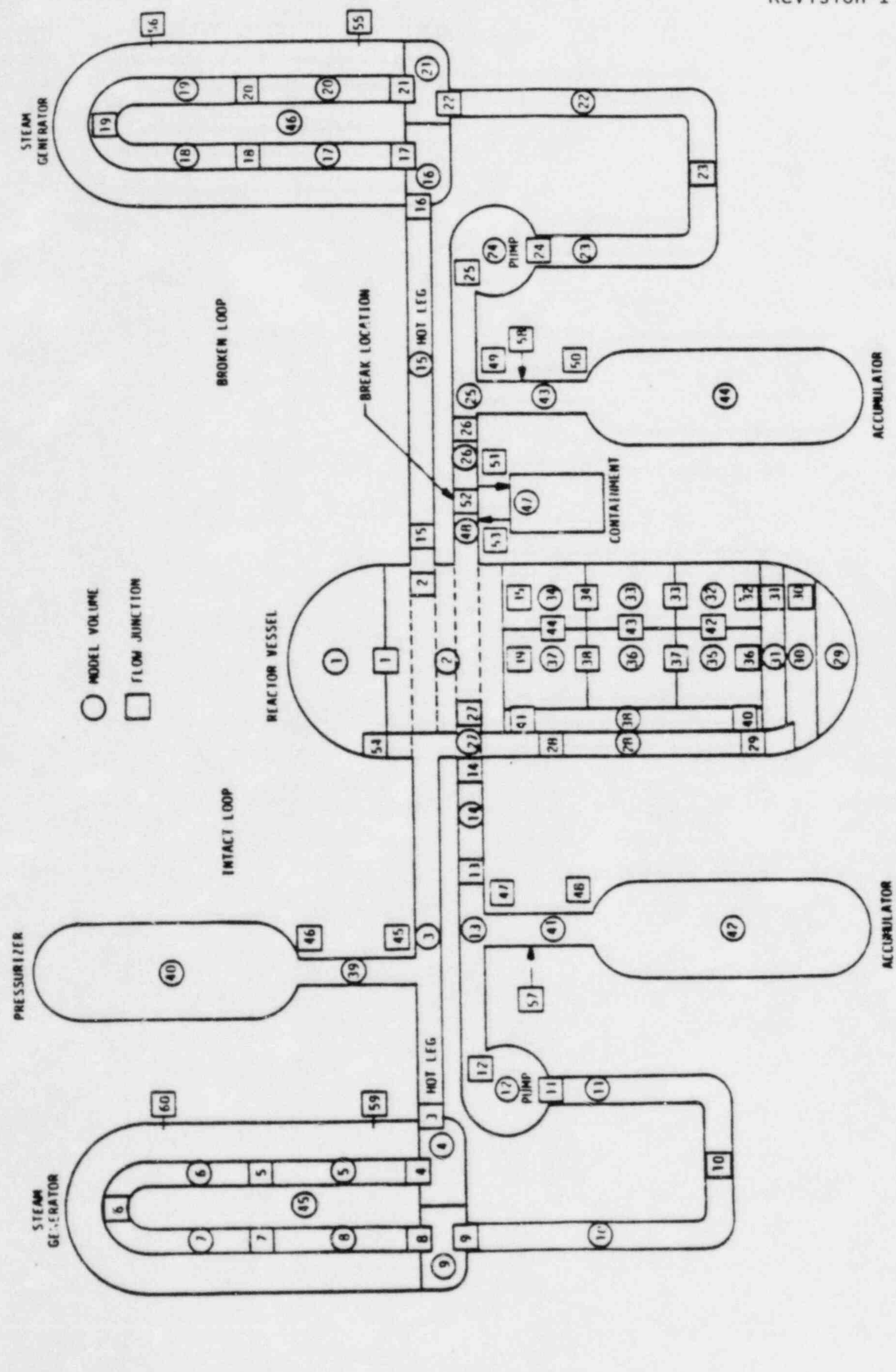

Figure 3.1 RELAP4/EM Blowdown System Nodalization for D.C. Cook Unit 2

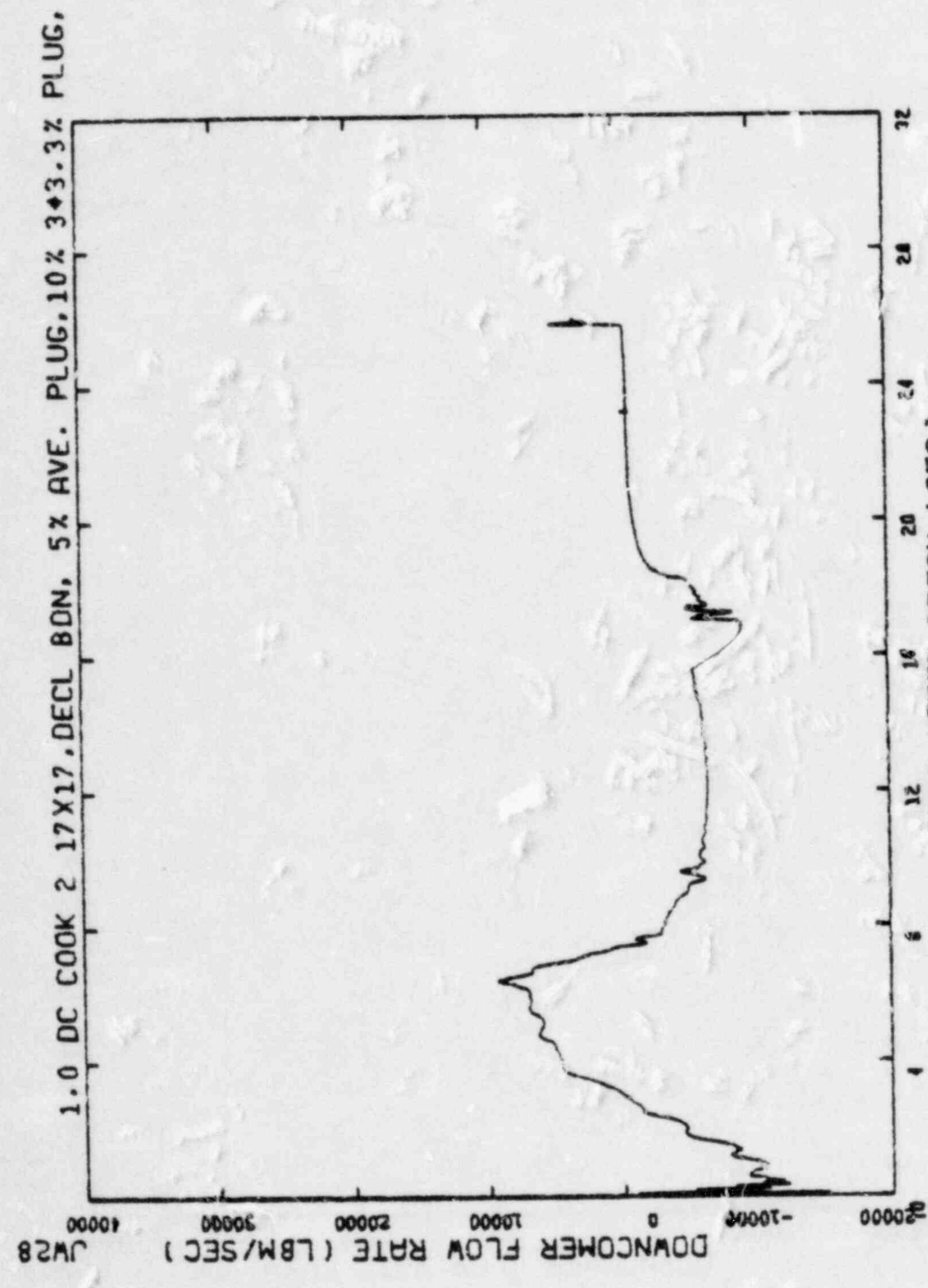

Figure 3.2 Downcomer Flow Rate During Blowdown Period, 1.0 DECLG Break

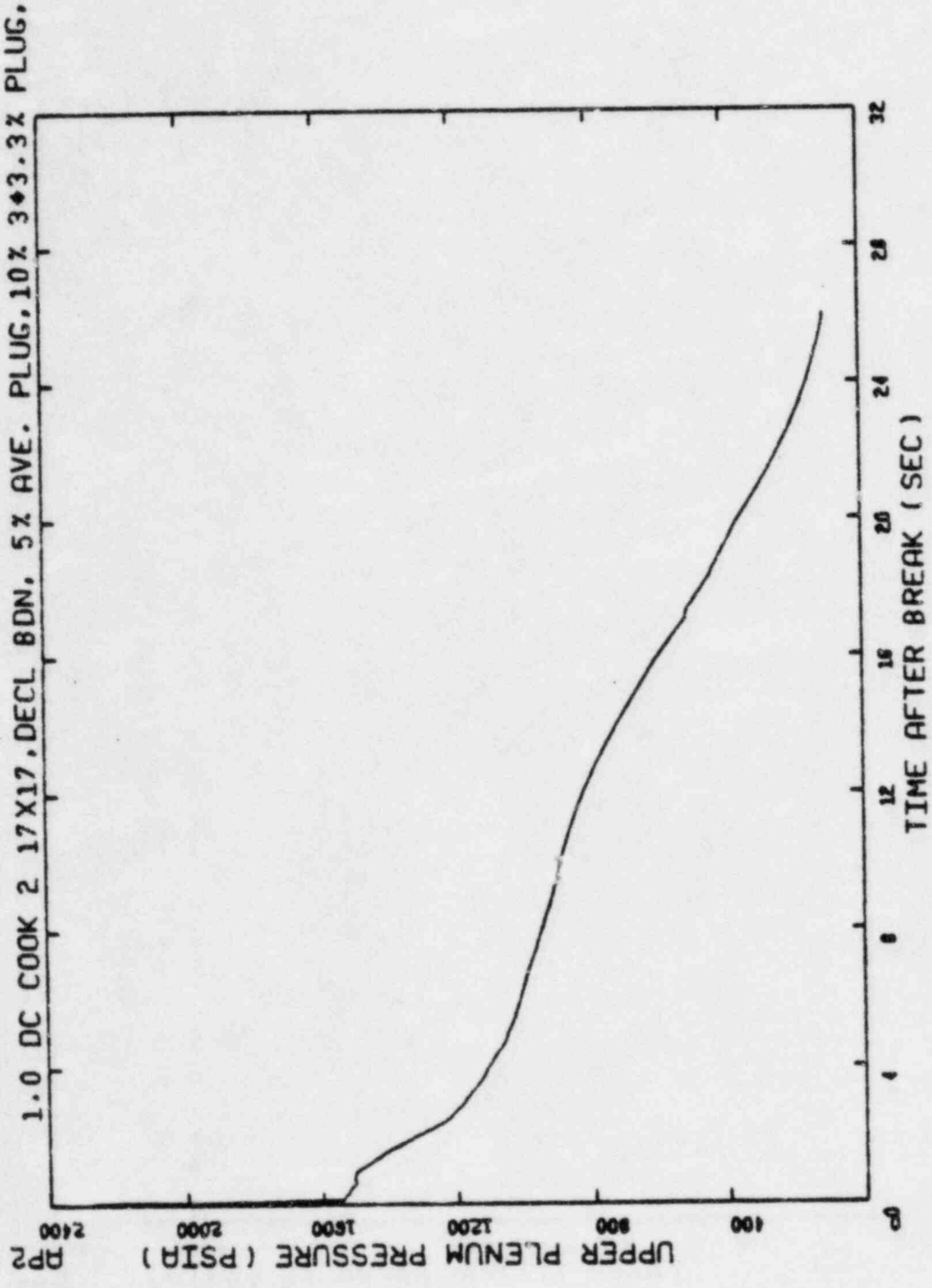

Figure 3.3 Upper Plenum Pressure During Blowdown Period, 1.0 DECLG Break

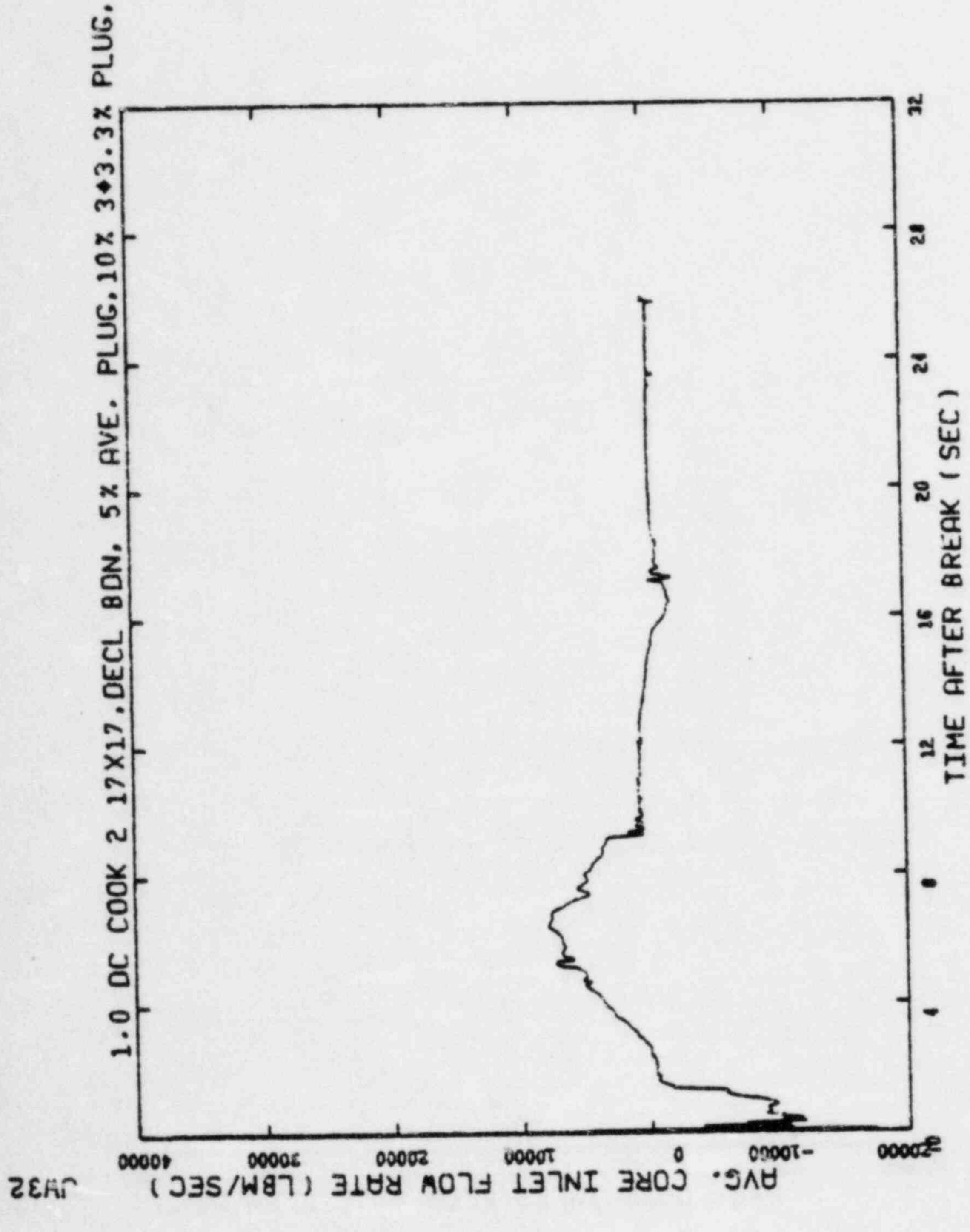

Figure 3.4 Average Core Inlet Flow during Blowdown Period, 1.0 DECLG Break

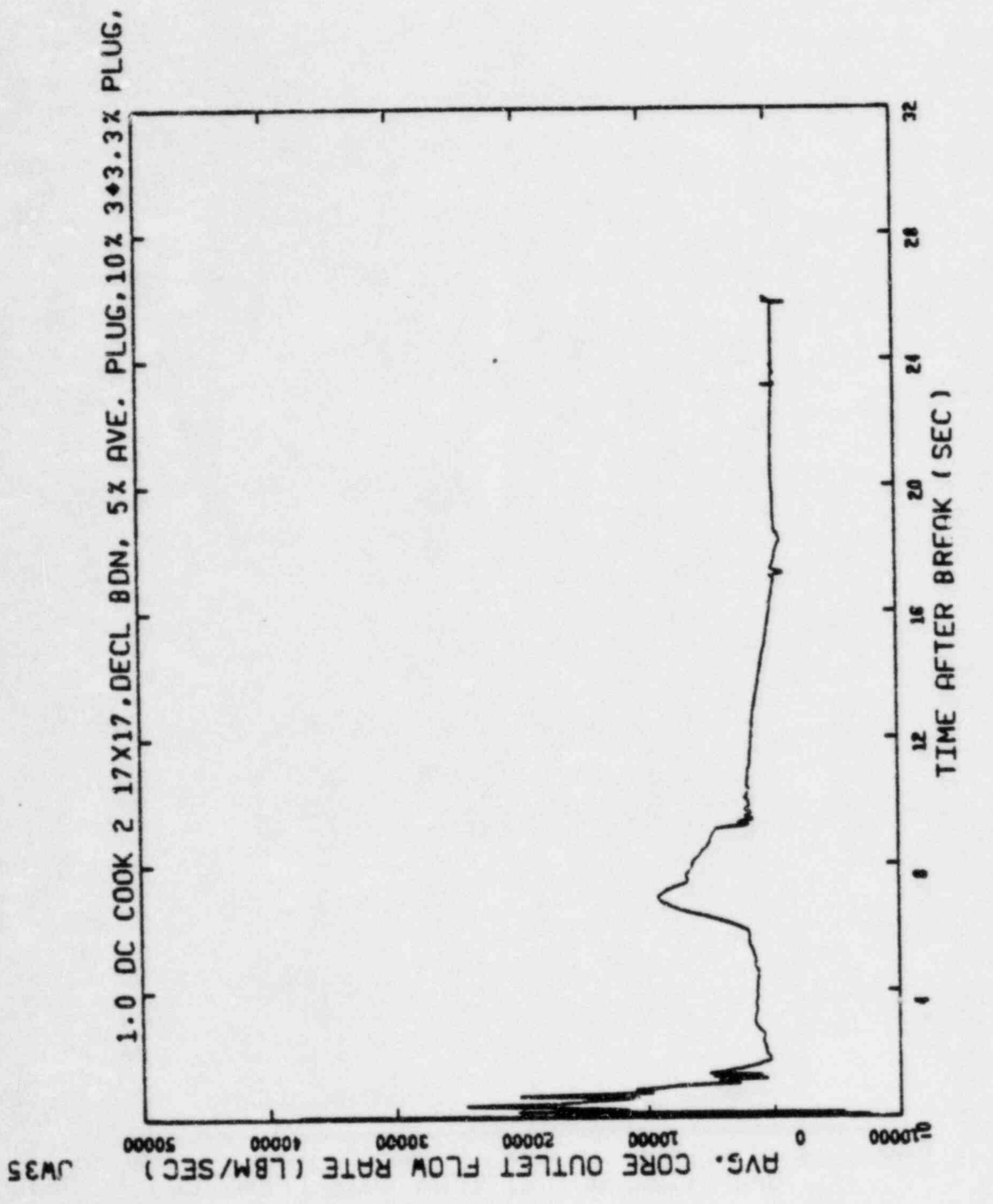

Figure 3.5 Average Core Outlet Flow during Blowdown Period, 1.0 DECLG Break

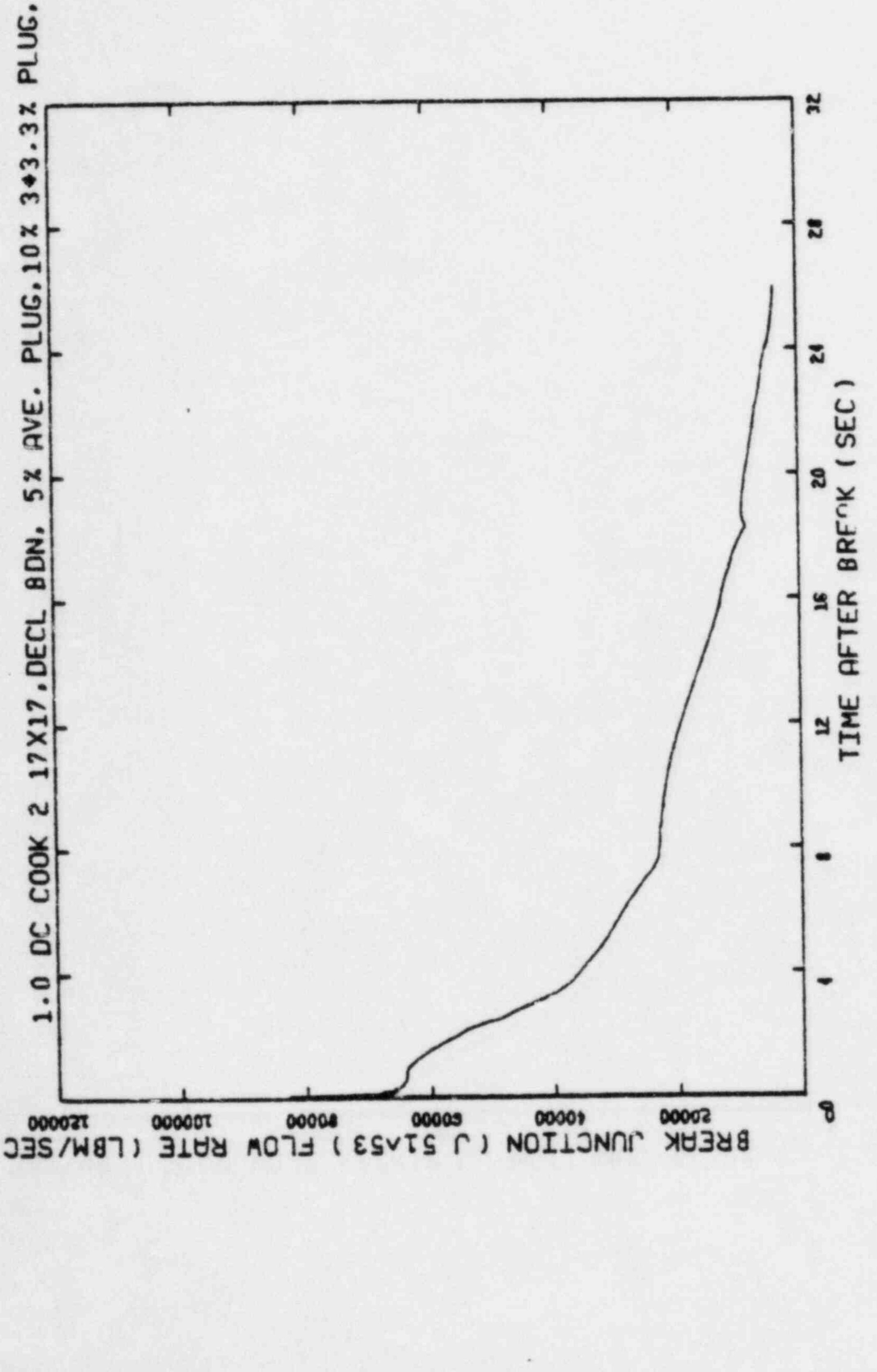

Figure 3.6 Total Break Flow during Blowdown Period, 1.0 DECLG Break

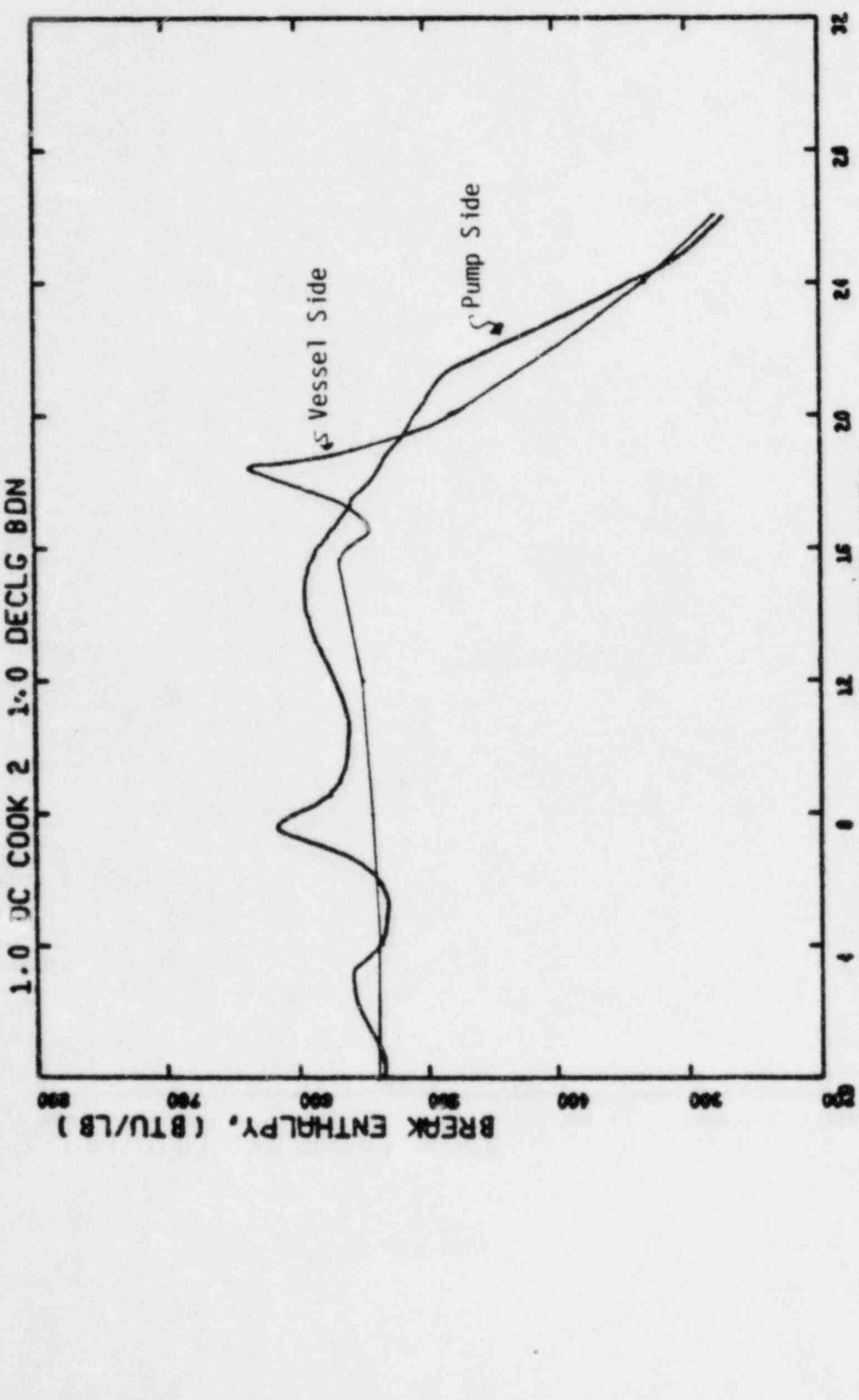

Figure 3.7 Break Flow Enthalpy During Blowdown, 1.0 DECLG Break

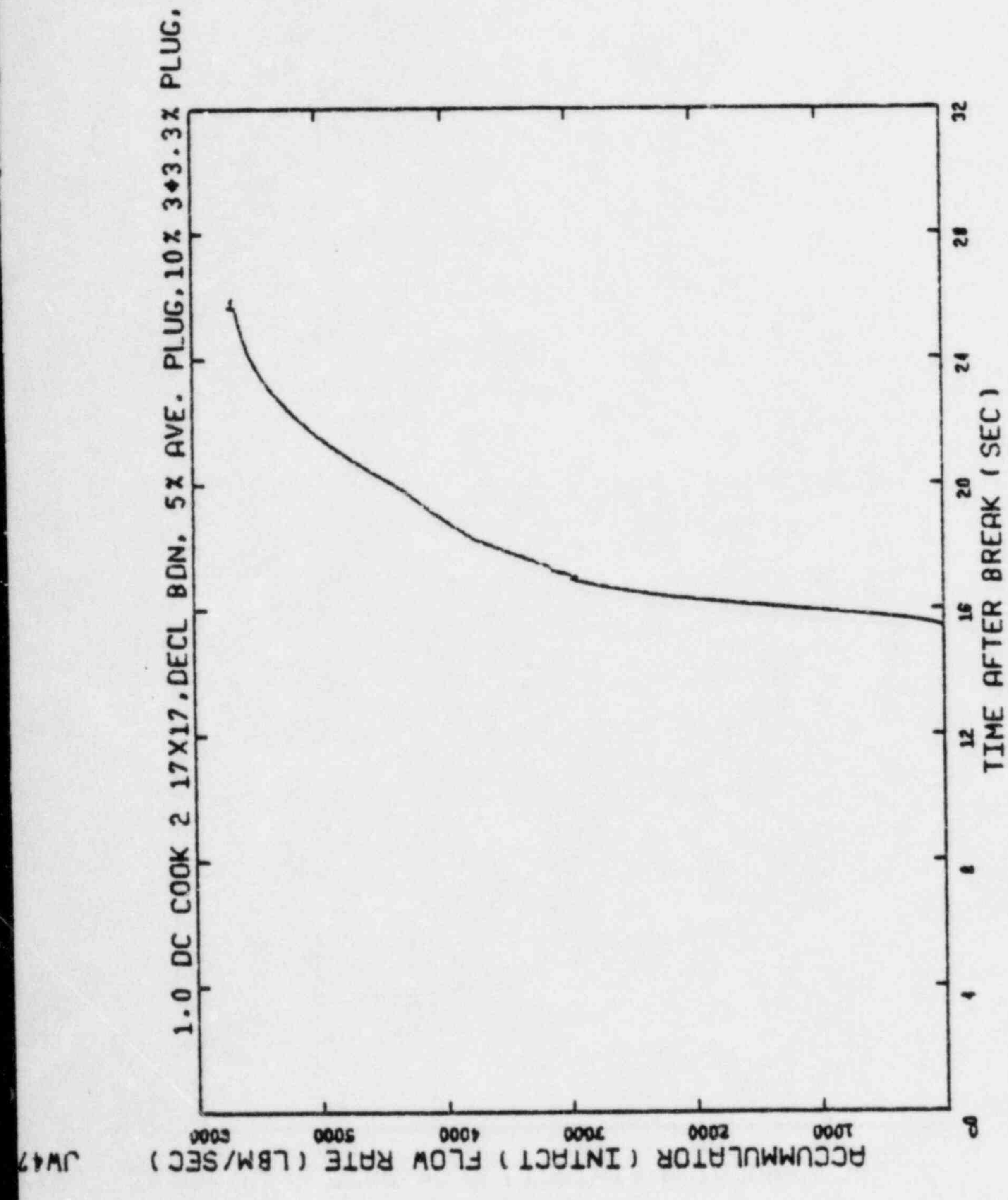

Figure 3.8 Flow from Intact Loop Accumulator during Blowdown Period, 1.0 DECLG Break

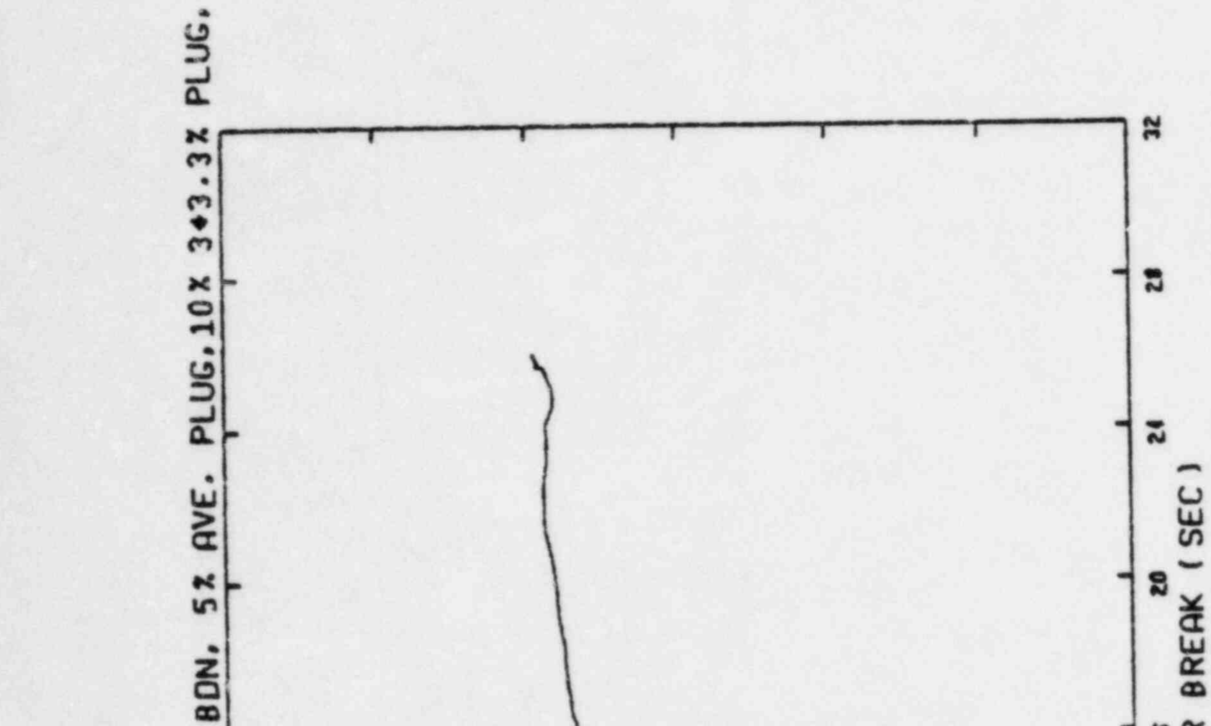

Figure 3.9 Flow from Broken Loop Accumulator during Blowdown Period, 1.0 DECLG Break

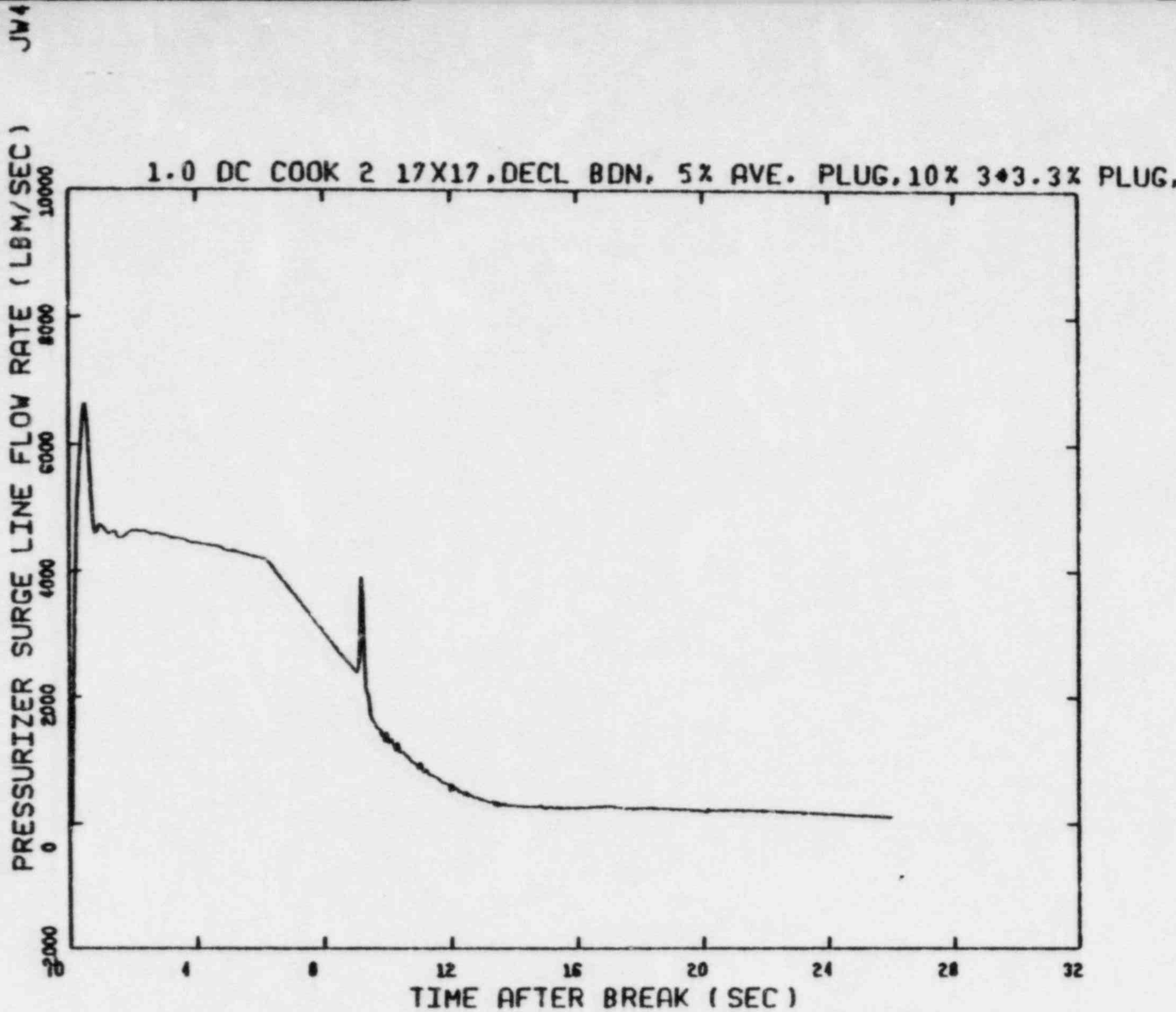

Figure 3.10 Pressurizer Surge Line Flow during Blowdown Period, 1.0 DECLG Break

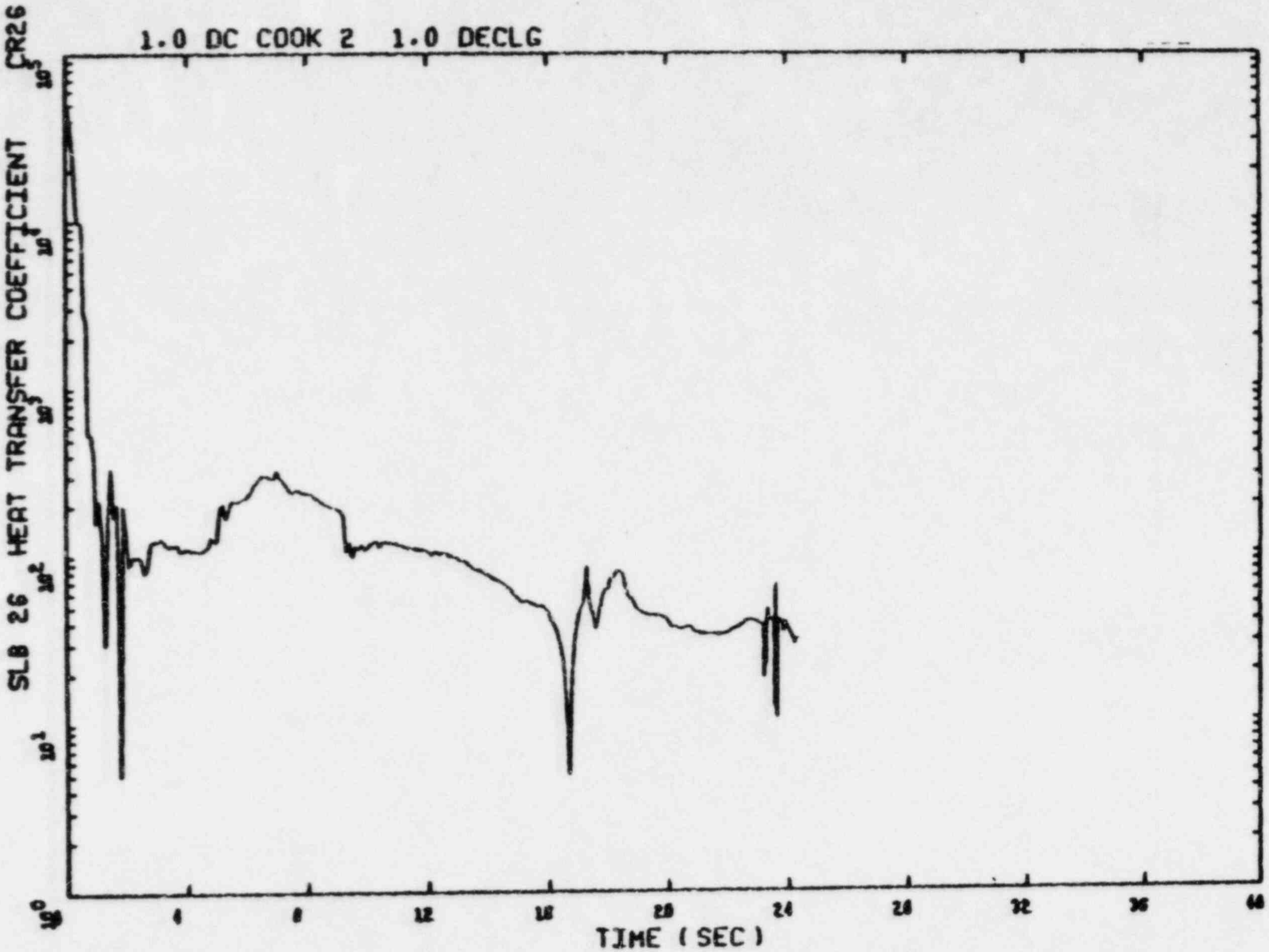

Figure 3.11 Heat Transfer Coefficient during Blowdown Period at PCT Node, 1.0 DECLG Break, 2.0 MWD/kg Case

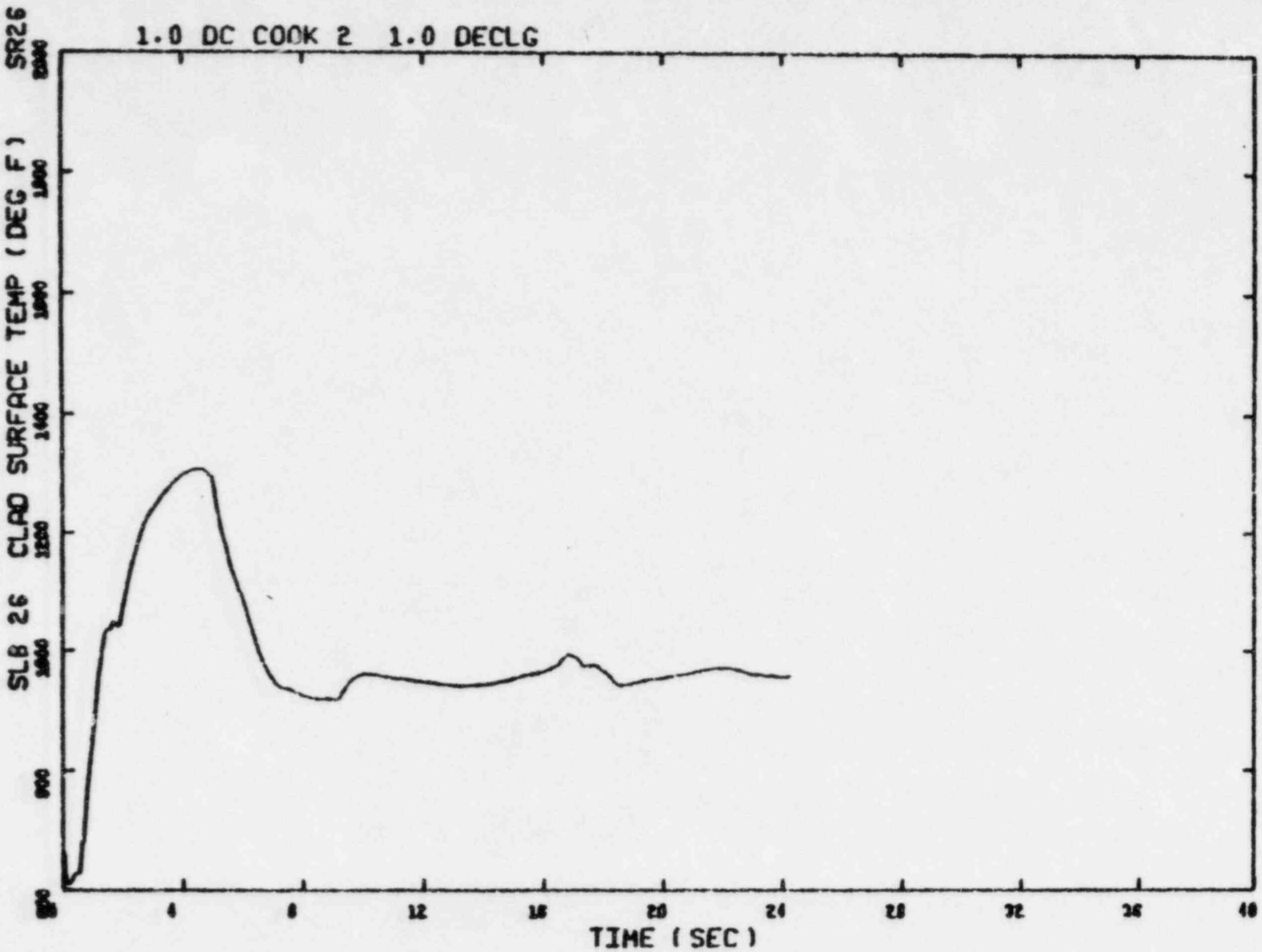

Figure 3.12 Clad Surface Temperature during Blowdown Period at PCT Node, 1.0 DECLG Break, 2.0 MWD/kg Case

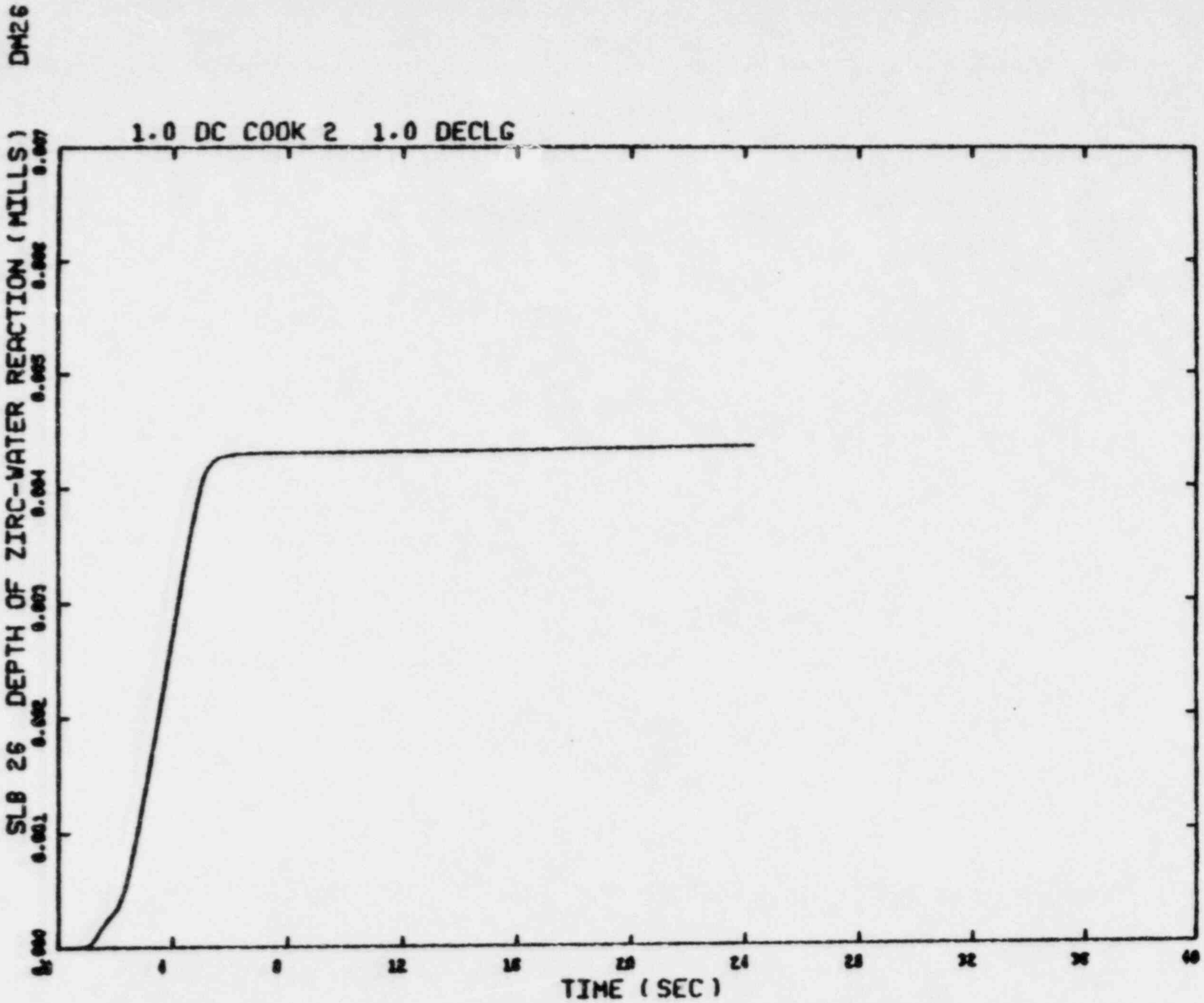

Figure 3.13 Depth of Metal-Water Reaction during Blowdown Period at PCT Node, 1.0 DECLG Break, 2.0 MWD/kg Case

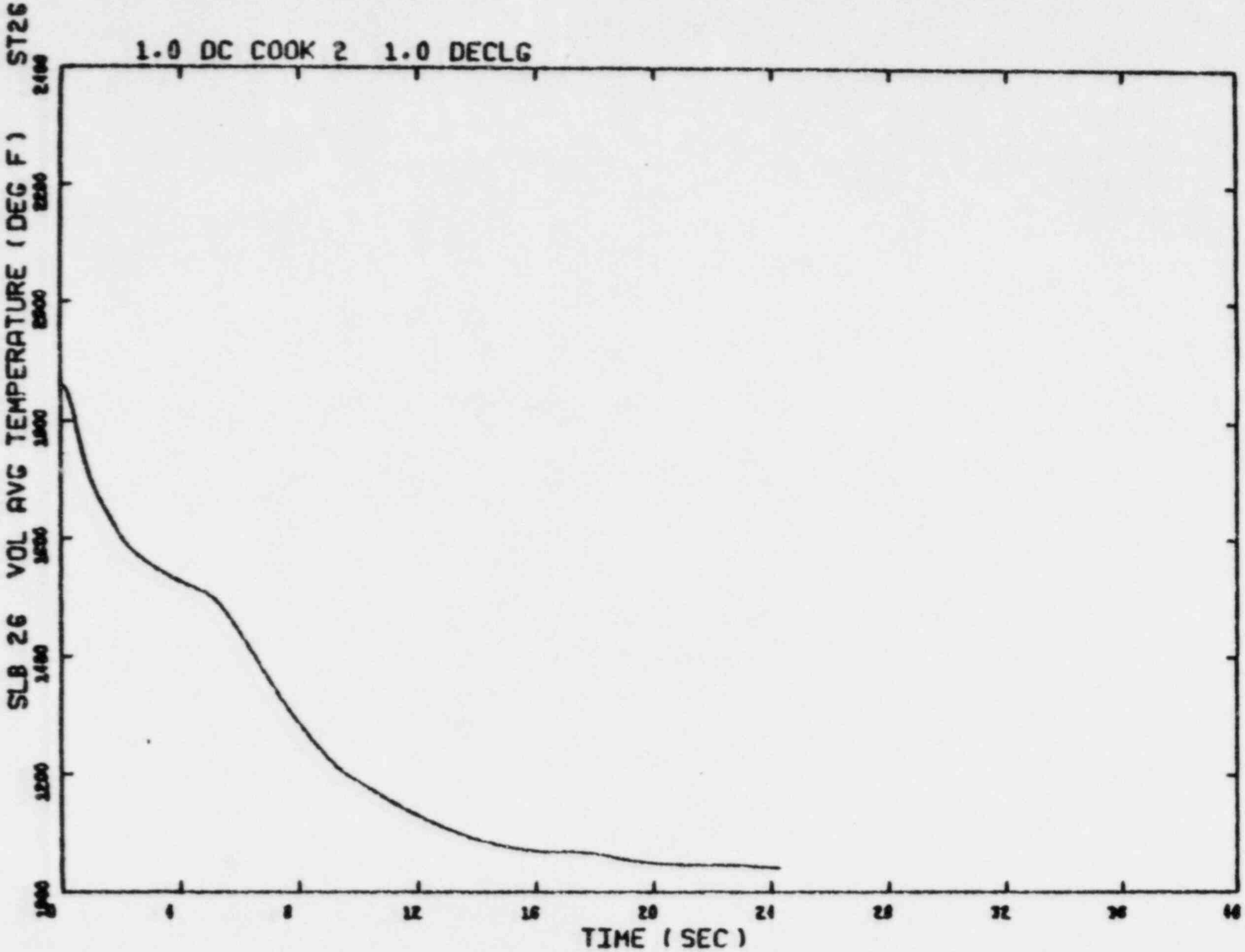

Figure 3.14 Average Fuel Temperature during Blowdown Period at PCT Location, 1.0 DECLG Break, 2.0 MWD/kg Case

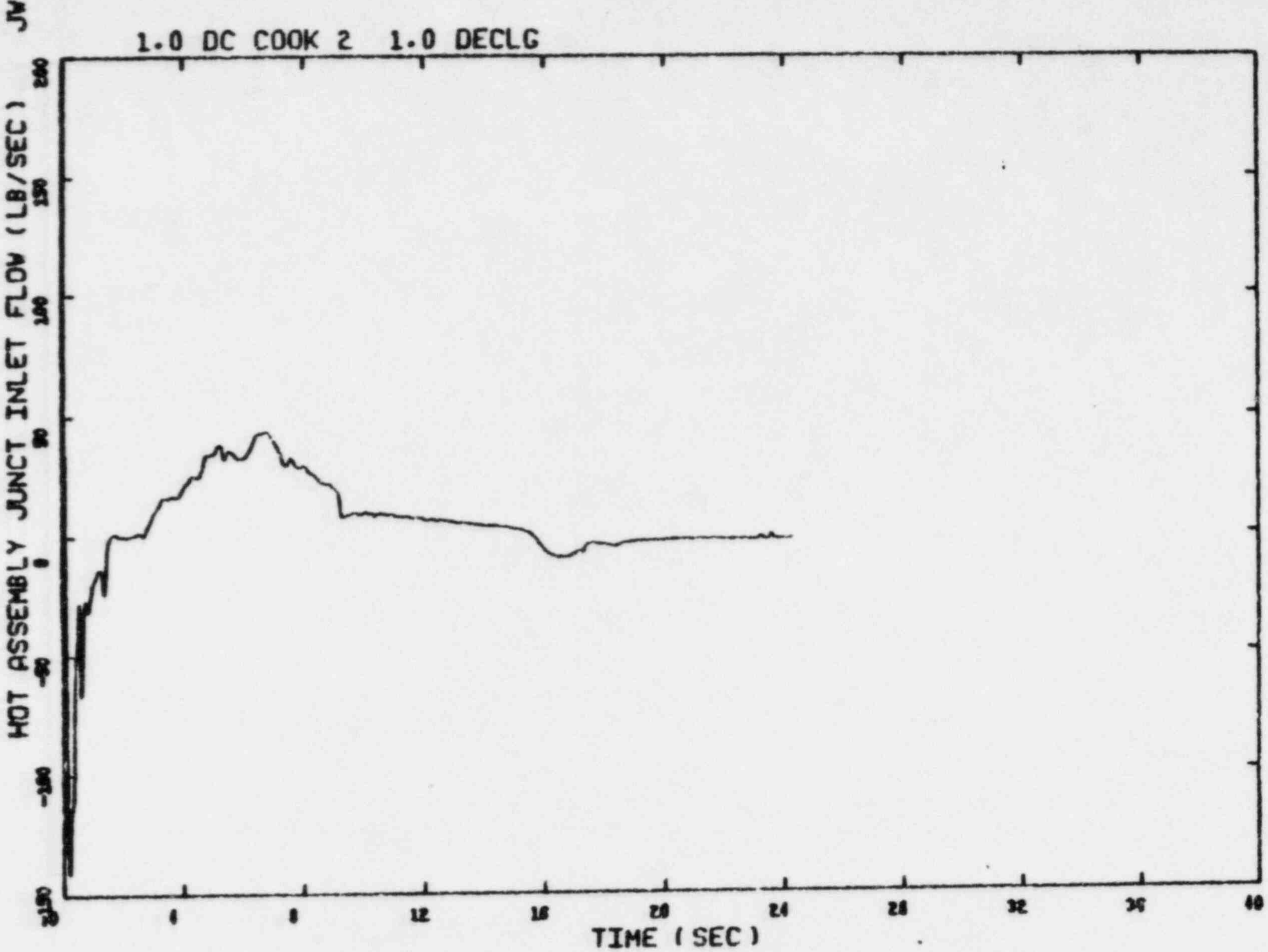

Figure 3.15 Hot Assembly Inlet Flow during Blowdown Period, 1.0 DECLG Break, 2.0 MWD/kg Case

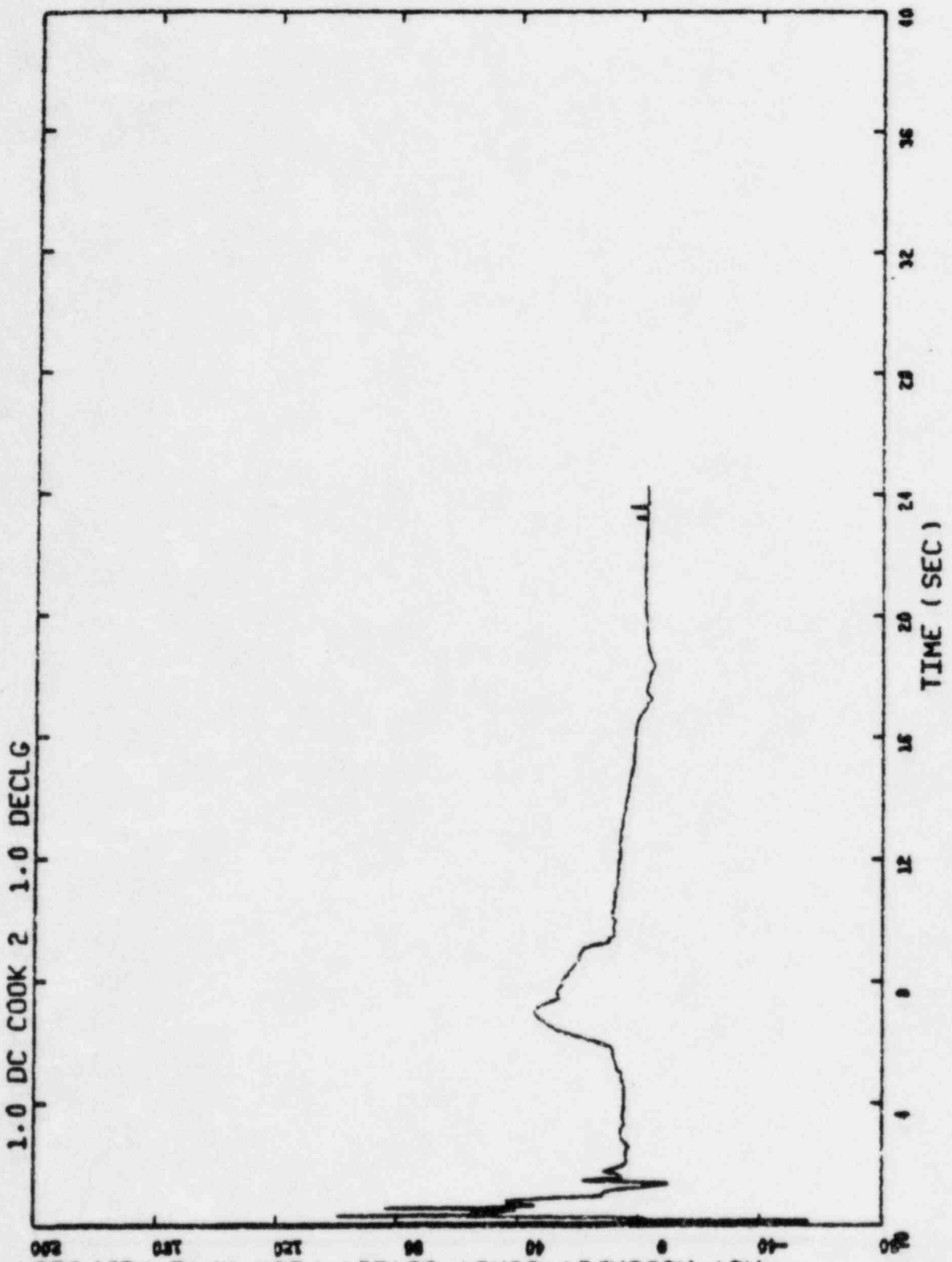

Figure 3.16 Hot Assembly Outlet Flow during Blowdown Period, 1.0 DECLG Break, 2.0 MWD/kg Case

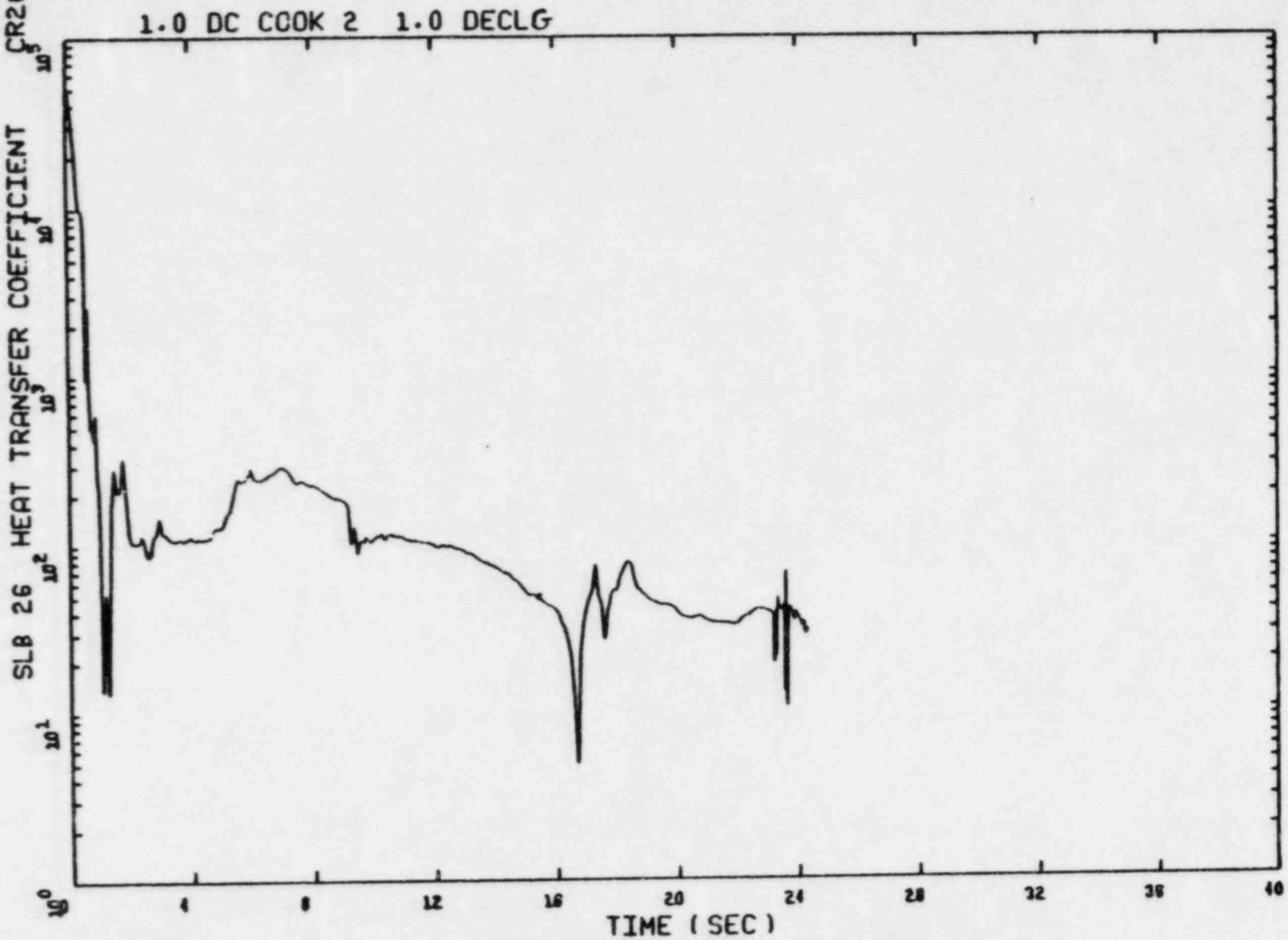

Figure 3.17 Heat Transfer Coefficient during Blowdown Period at PCT Node, 1.0 DECLG Break, 10.0 MWD/kg Case

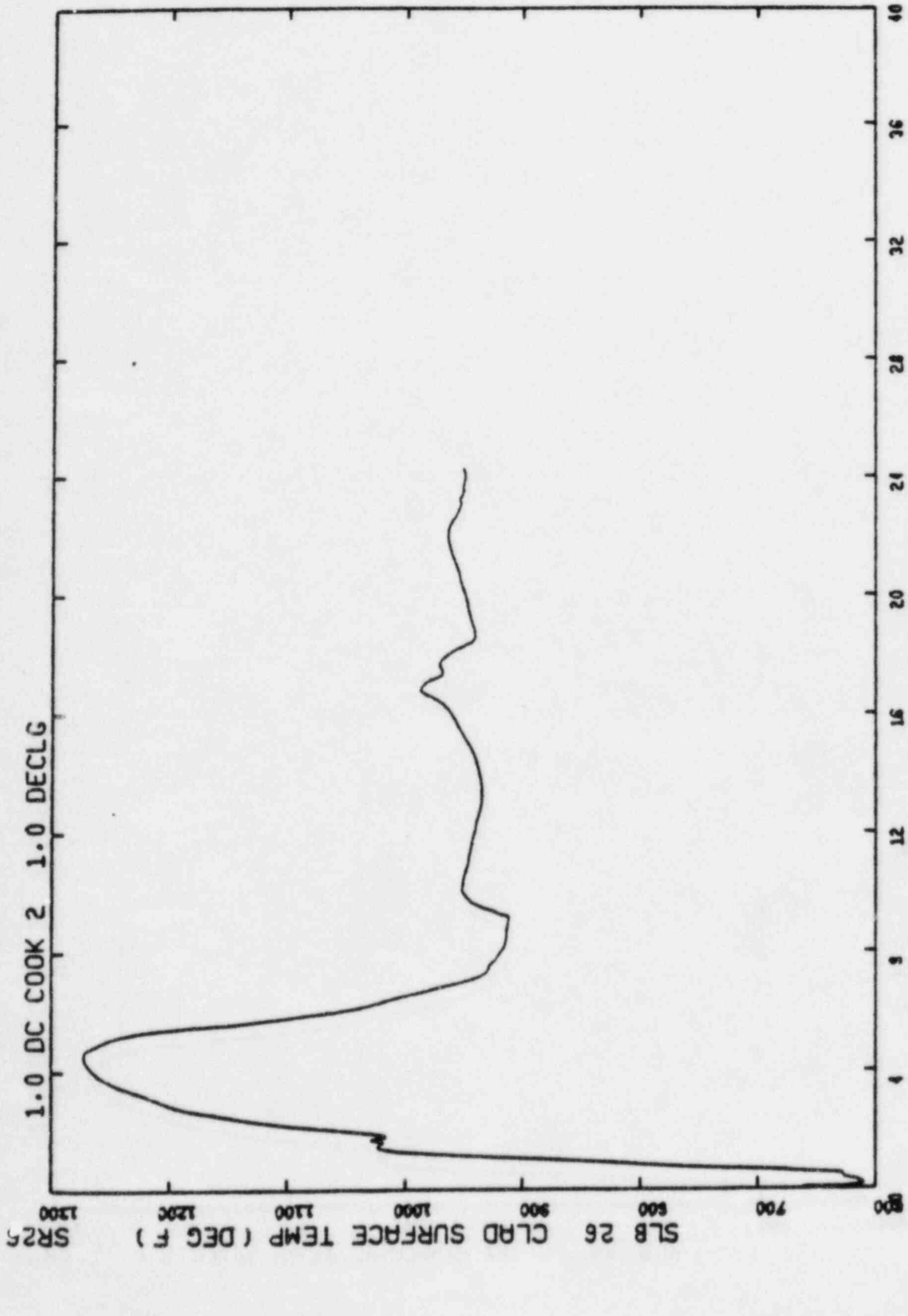

Figure 3.18 Clad Surface Temperature during Blowdown Period at PCT Node, 1.0 DECLG Break, 10.0 MWD/kg Case

Figure 3.19 Depth of Metal-Water Reaction during Blowdown Period at PCT Node, 1.0 DECLG Break, 10.0 MWD/kg Case

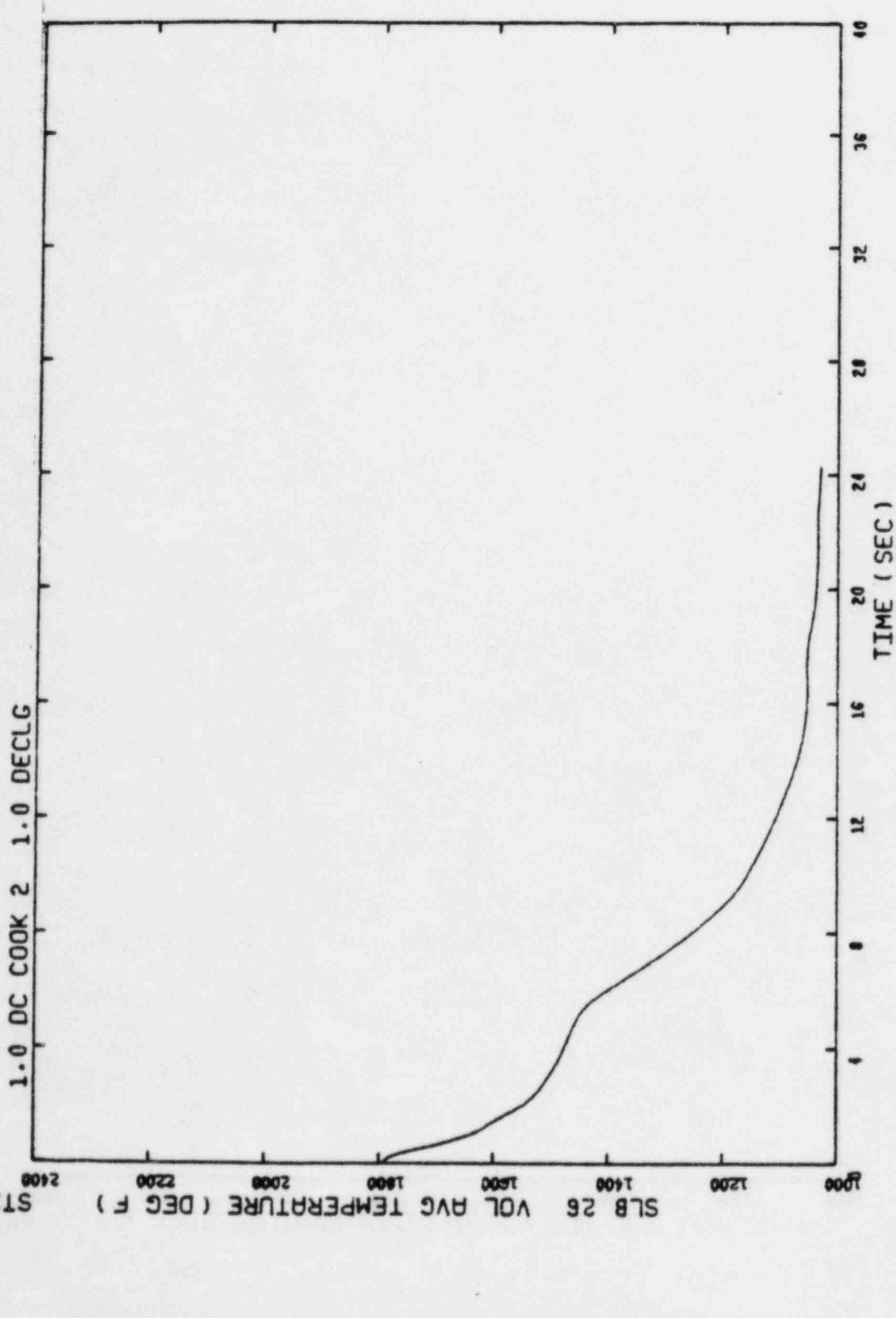

Figure 3.20 Average Fuel Temperature during Blowdown Period at PCT Location, 1.0 DECLG Break, 10.0 MWD/kg Case

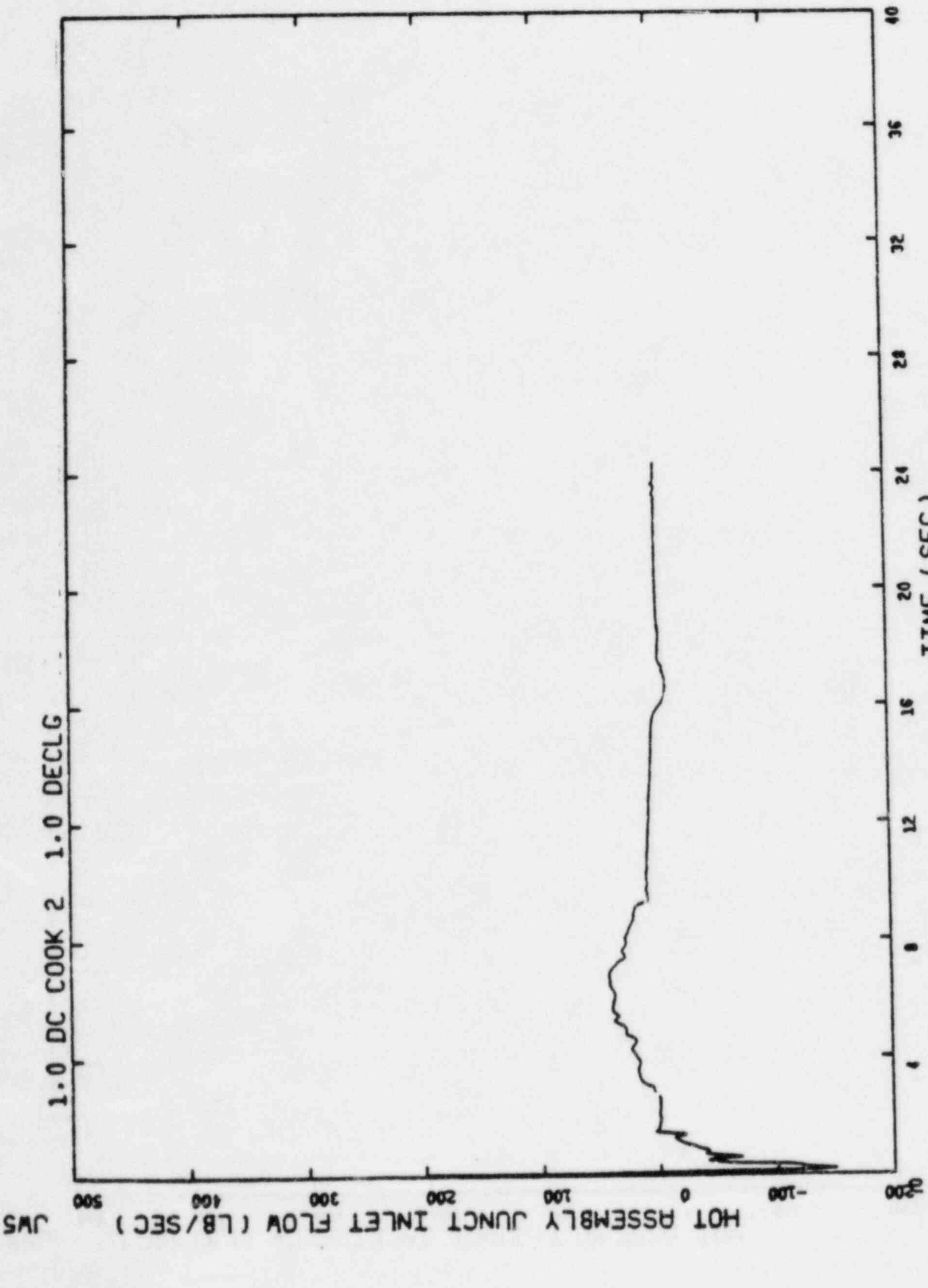

Figure 3.21 Hot Assembly Inlet Flow during Blowdown Period, 1.0 DECLG Break, 10.0 MWD/kg Case

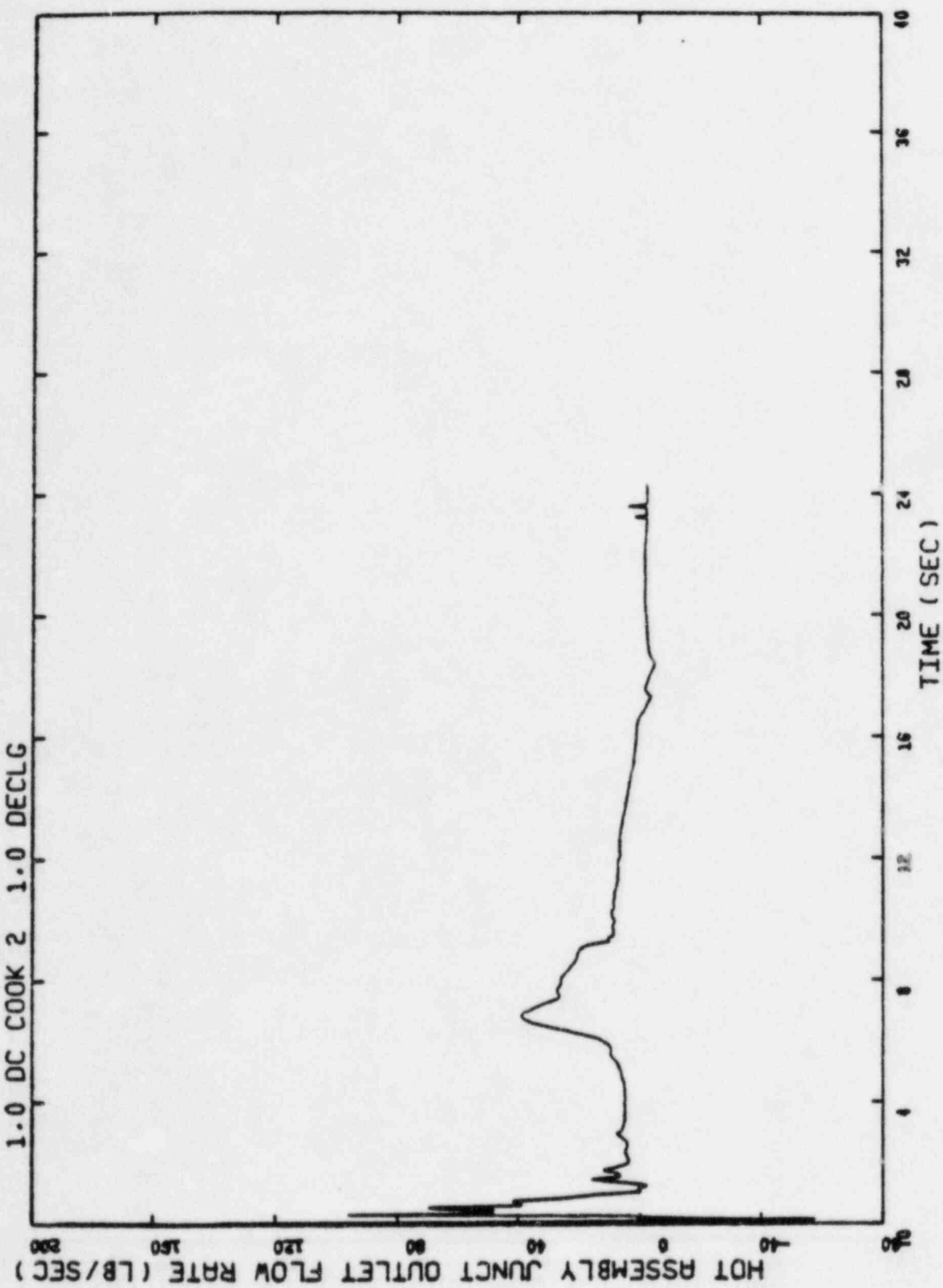

Figure 3.22 Hot Assembly Outlet Flow during Blowdown Period, 1.0 DECLG Break, 10.0 MWD/kg Case

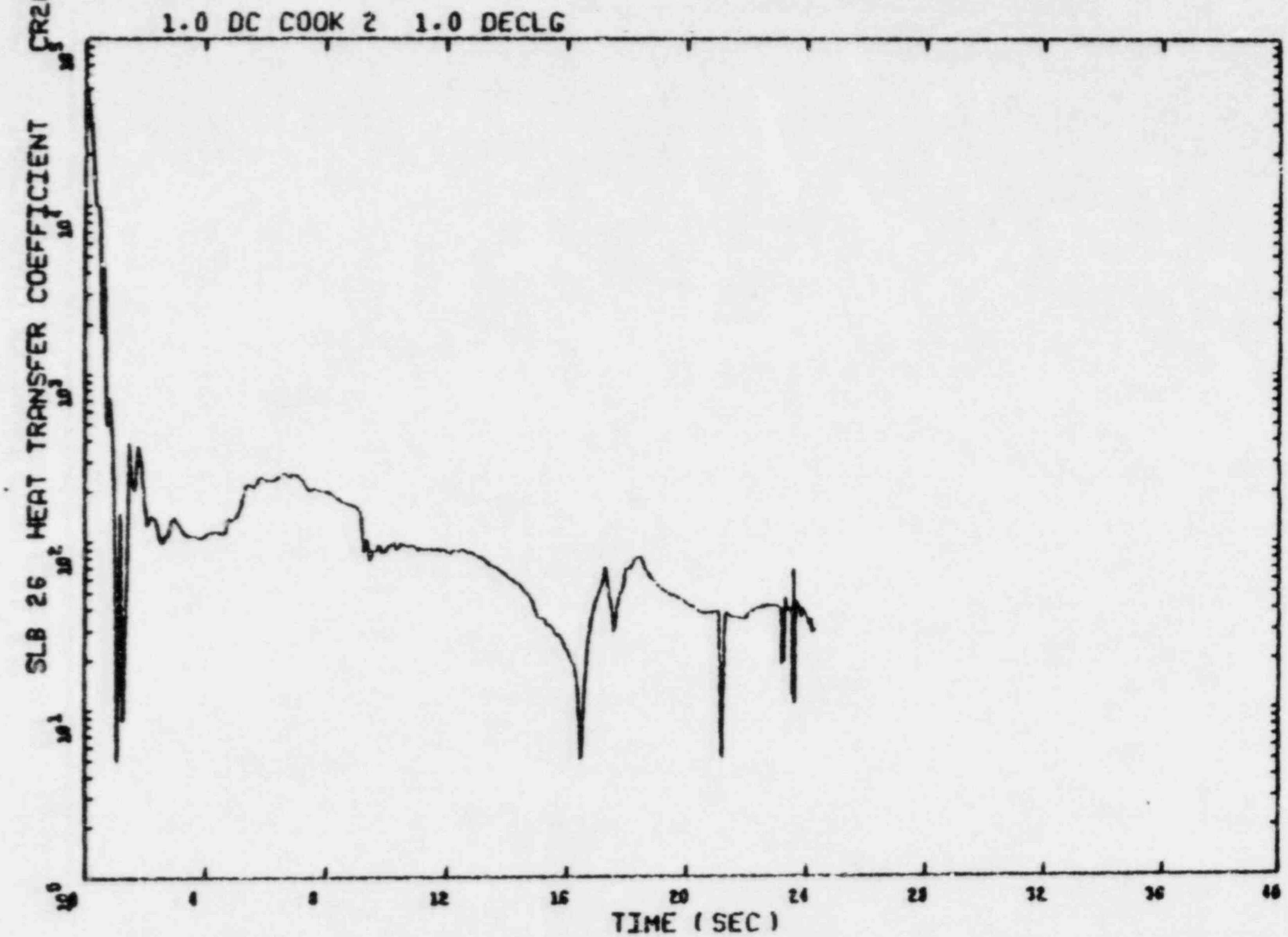

Figure 3.23 Heat Tansfer Coefficient during Blowdown Period at PCT Node, 1.0 DECLG Break, 47.0 MWD/kg Case

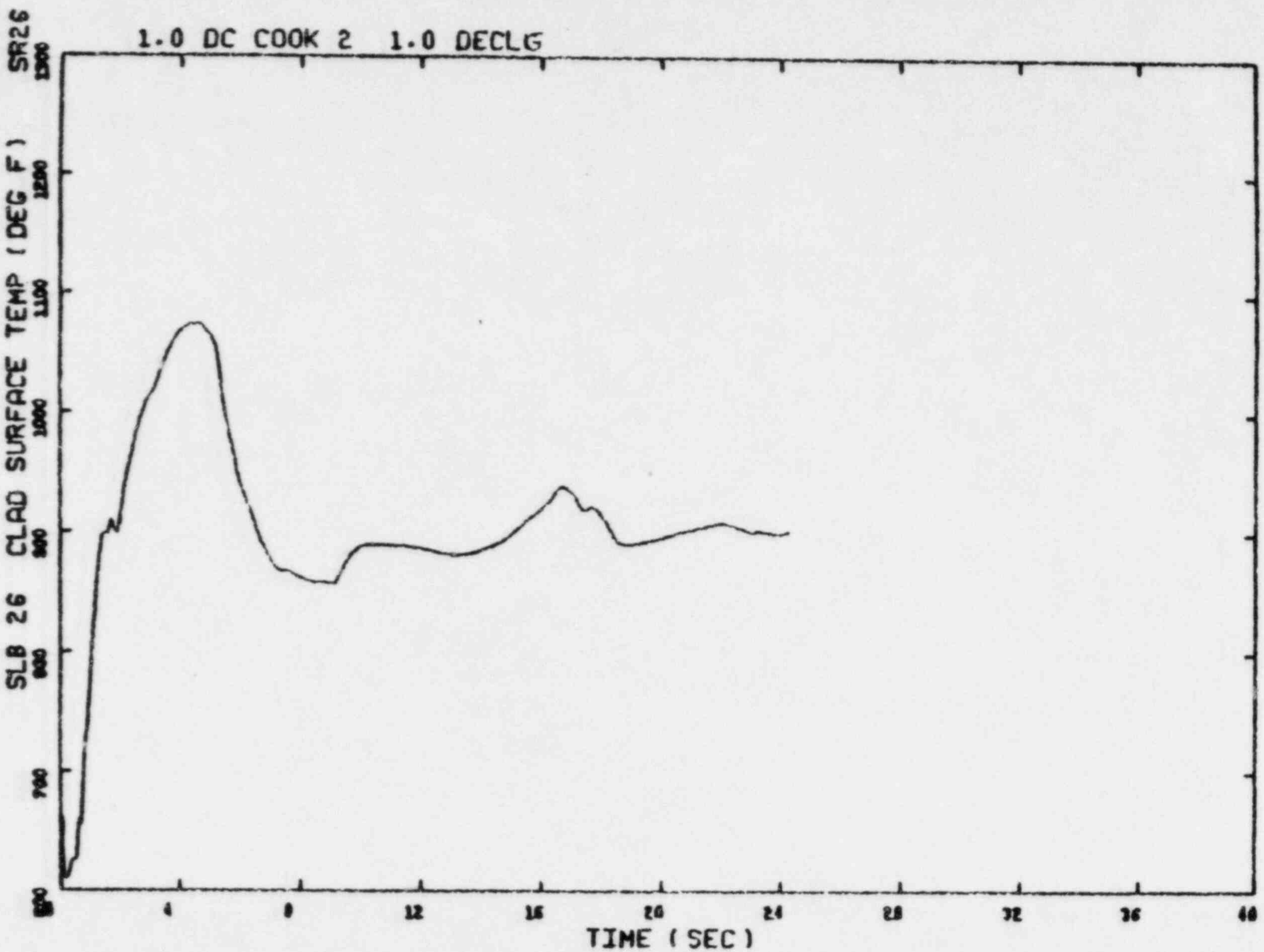

Figure 3.24 Clad Surface Temperature during Blowdown Period at PCT Node, 1.0 DECLG Break, 47.0 MWD/kg Case

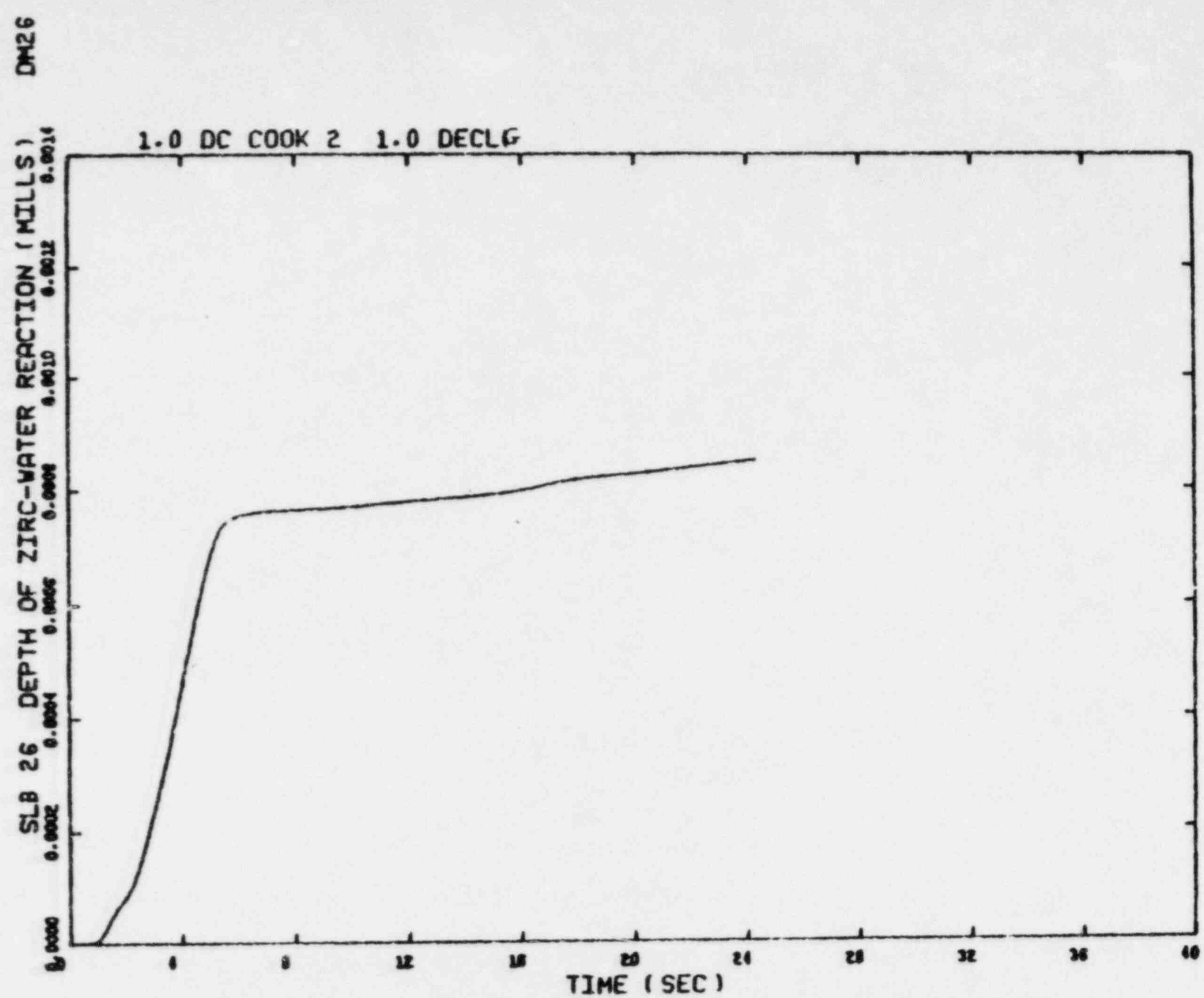

Figure 3.25 Depth of Metal-Water Reaction During Blowdown Period at PCT Node, 1.0 DECLG Break, 47.0 MWD/kg Case

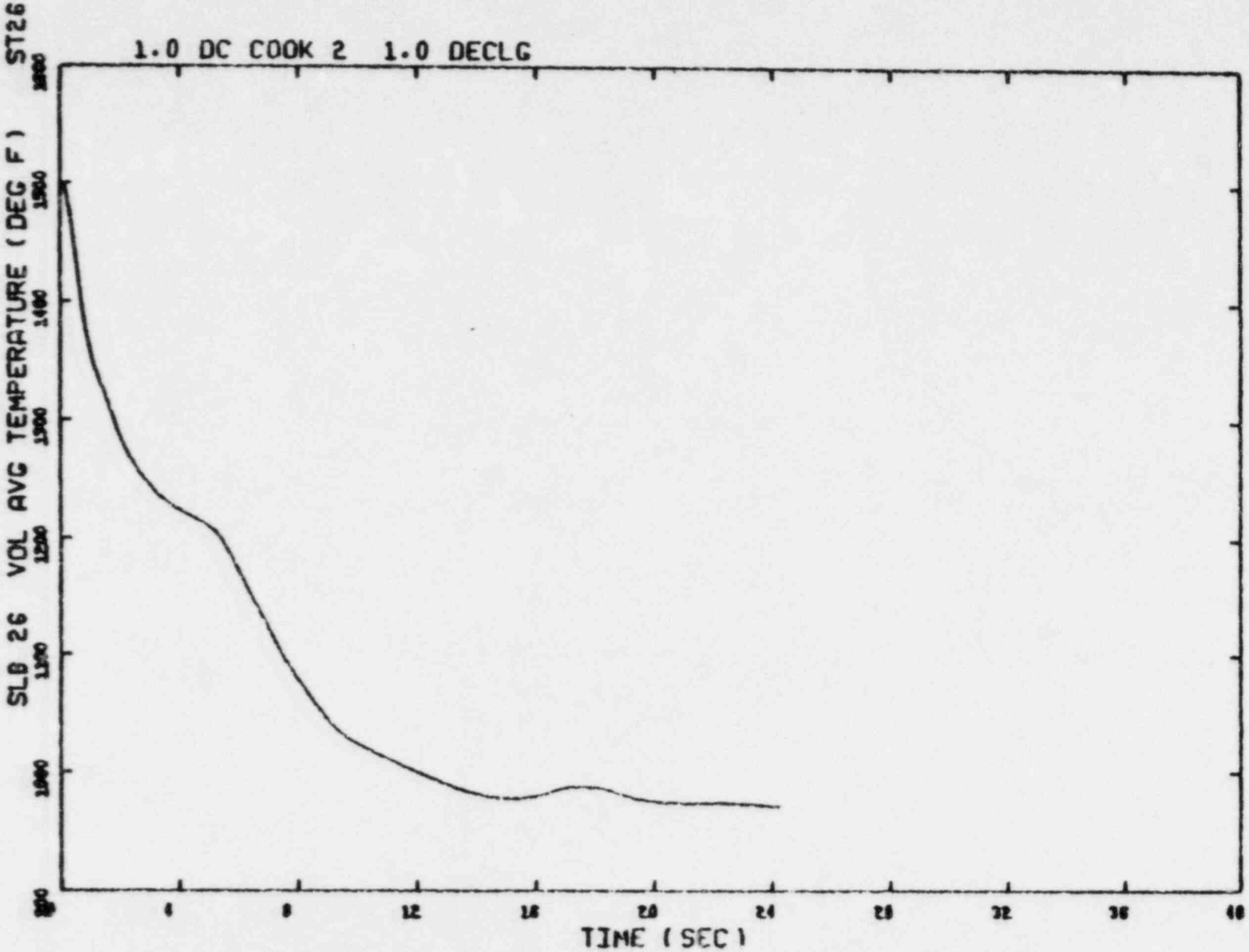

Figure 3.26 Average Fuel Temperature during Blowdown Period at PCT Location, 1.0 DECLG Break, 47.0 MWD/kg Case

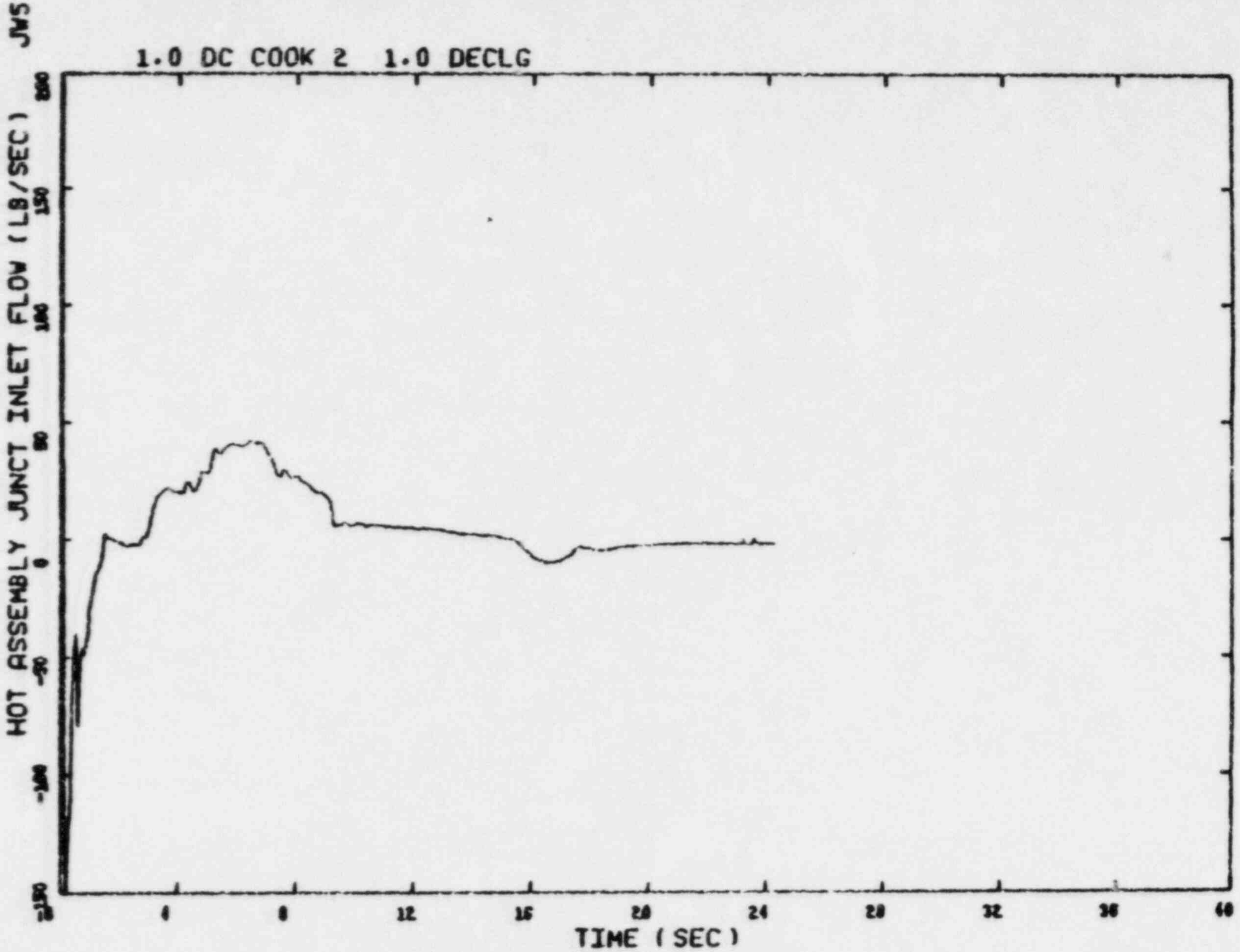

Figure 3.27 Hot Assembly Inlet Flow during Blowdown Period, 1.0 DECLG Break, 47.0 MWD/kg Case

JWB

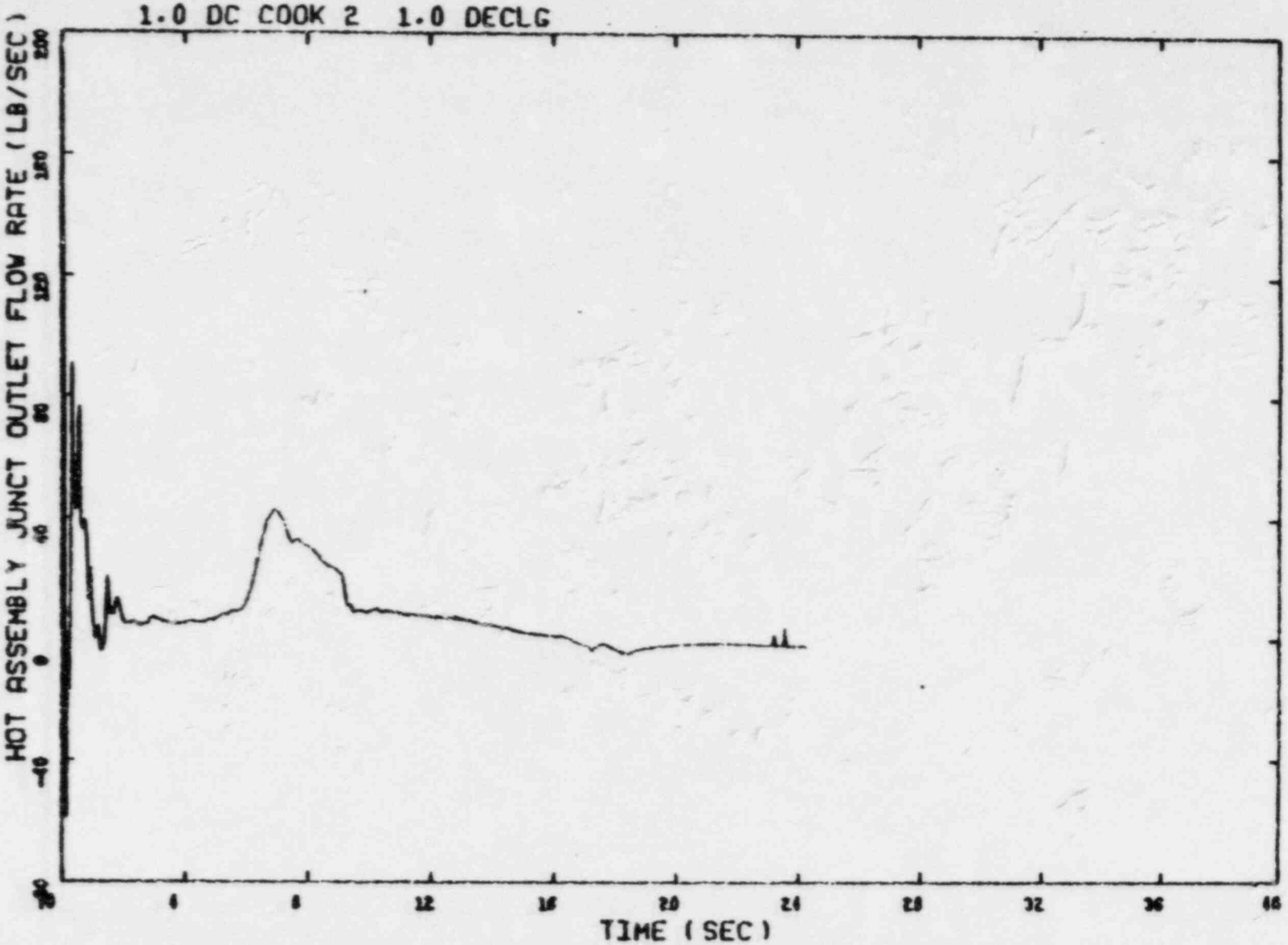

Figure 3.28 Hot Assembly Outlet Flow during Blowdown Period, 1.0 DECLG Break, 47.0 MWD/kg Case

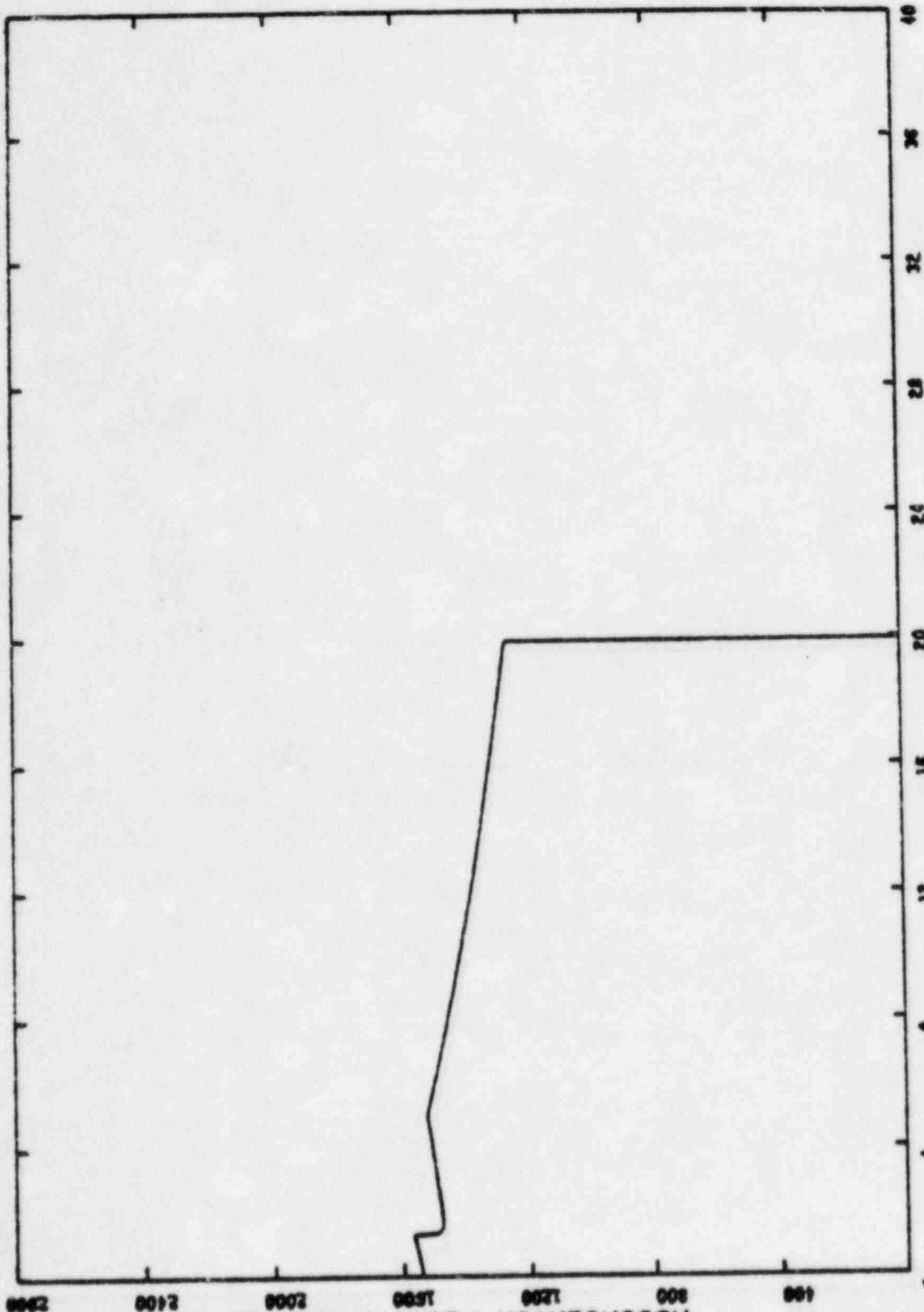

Figure 3.29 Accumulator Flow during Refill and Reflood Periods, Broken Loop, 1.0 DECLG Break

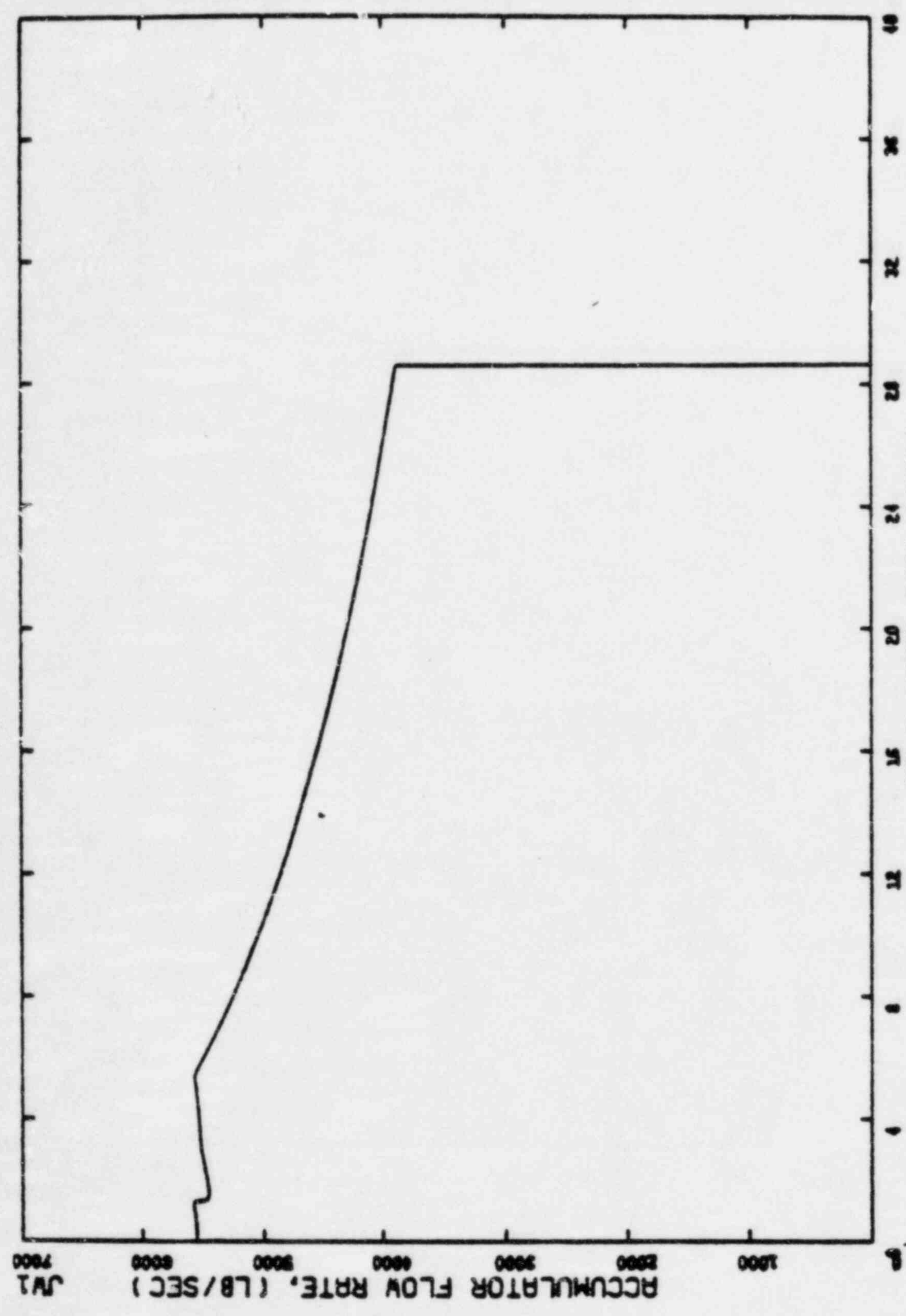

Figure 3.30 Accumulator Flow during Refill and Reflood Periods, Intact Loop, 1.0 DECLG Break

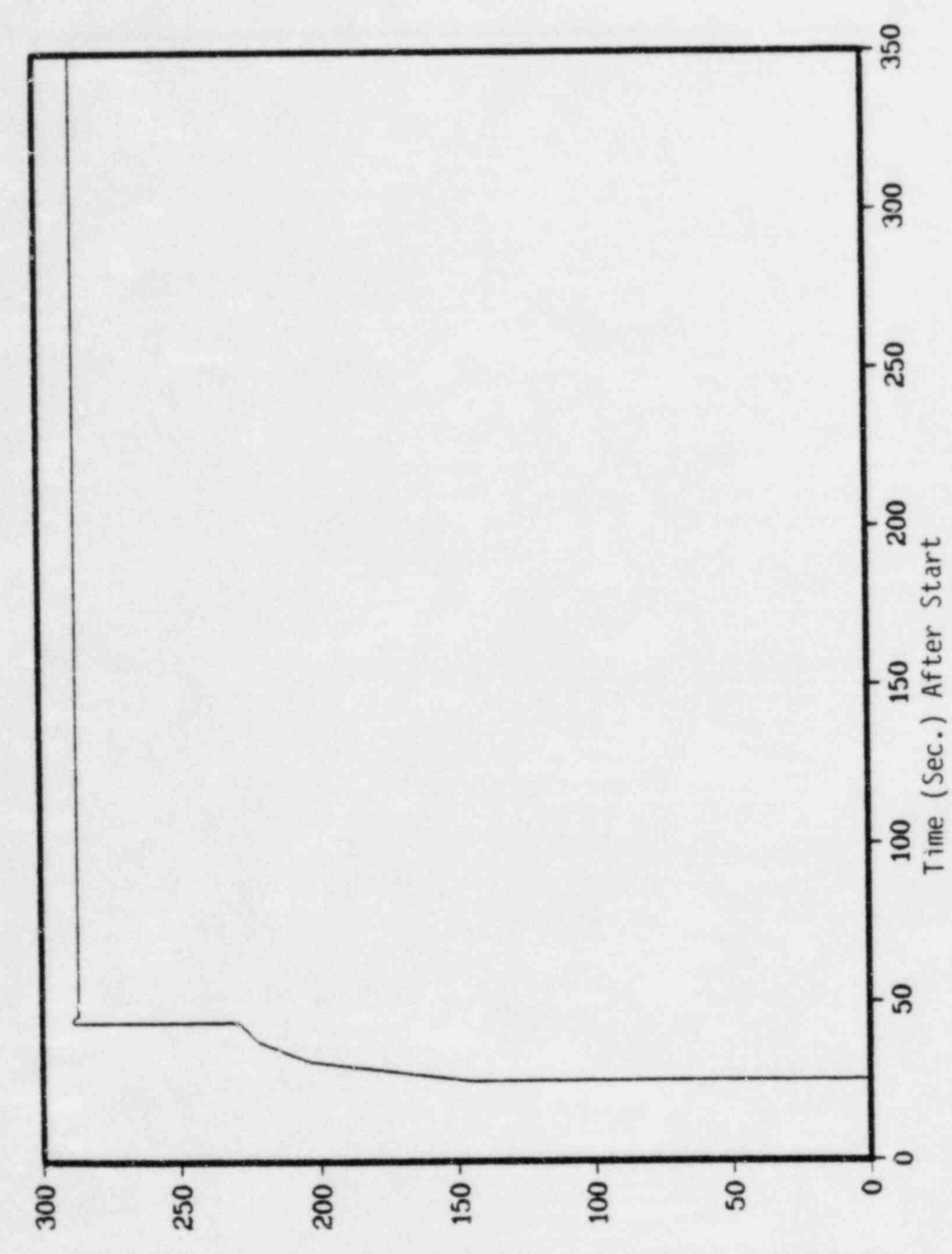

Figure 3.31 HPSI & LPSI Flow during Refill and Reflood Periods, Broken Loop, 1.0 DECLG Break

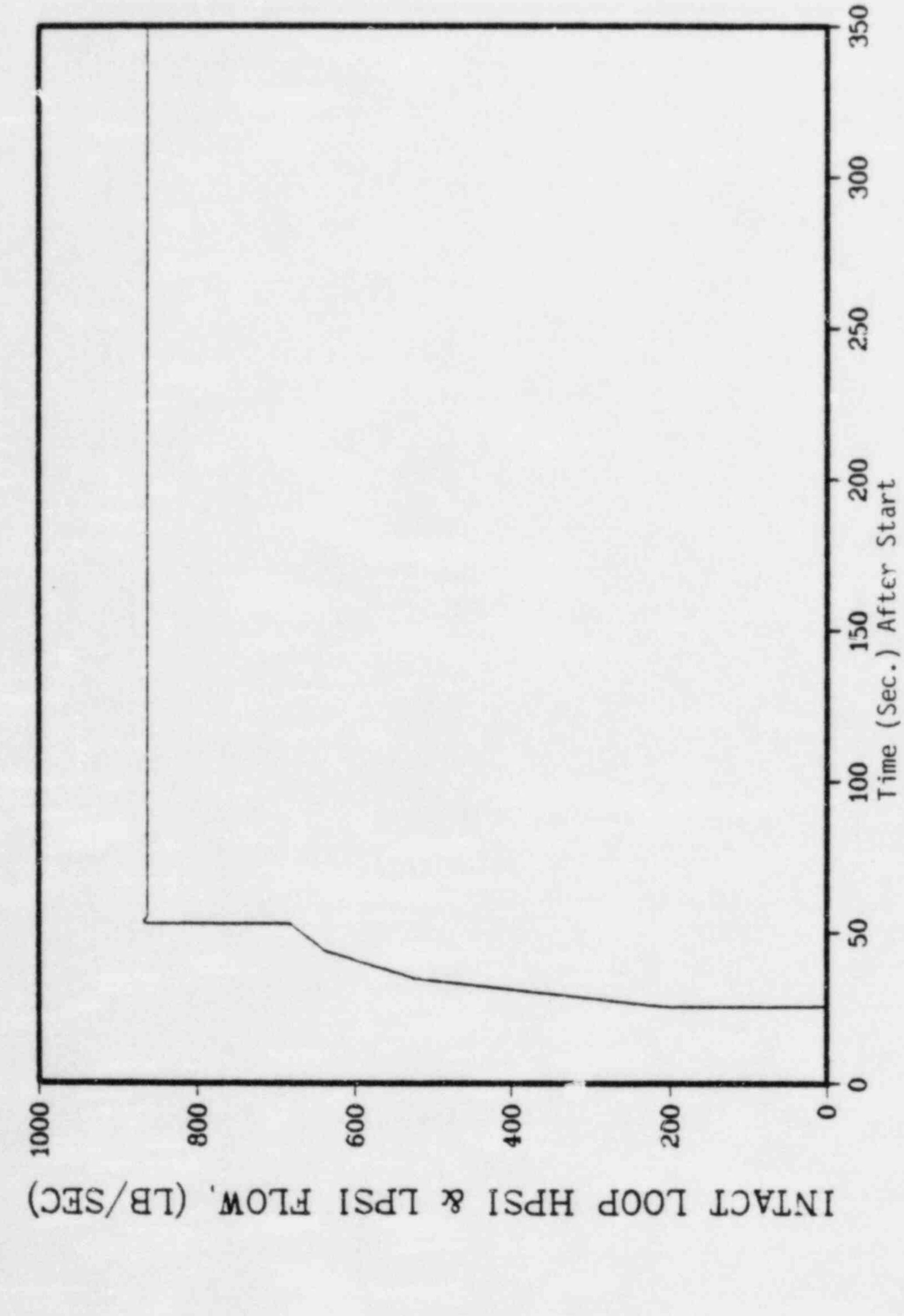

Figure 3.32 HPSI & LPSI Flow during Refill and Reflood Periods, Intact Loop, 1.0 DECLG Break

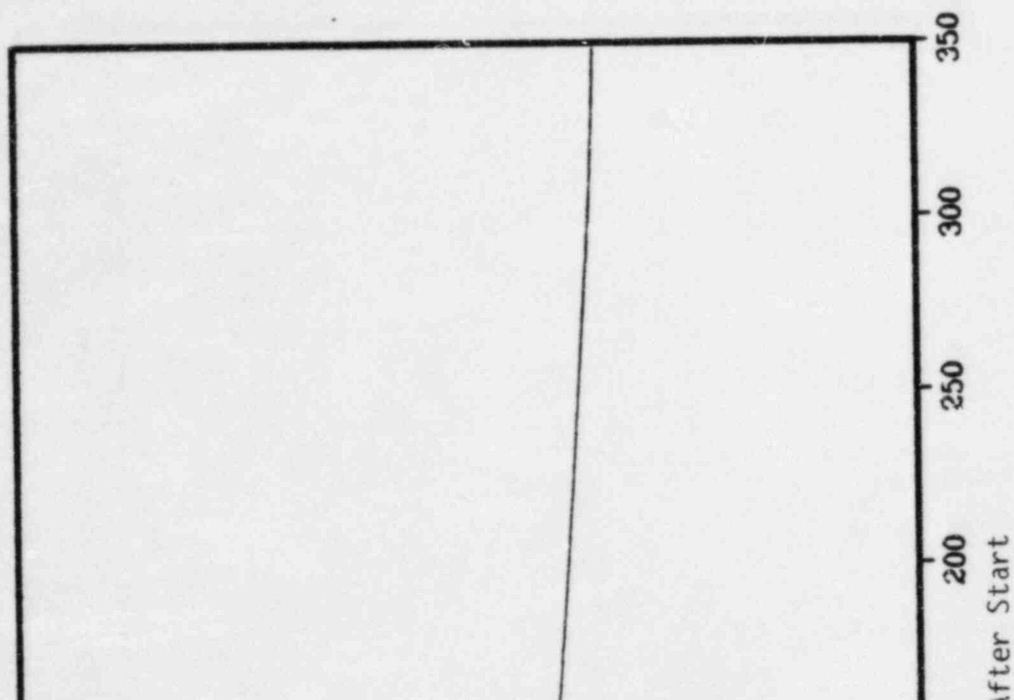

Figure 3.33 Containment Back Pressure, 1.0 DECLG Break

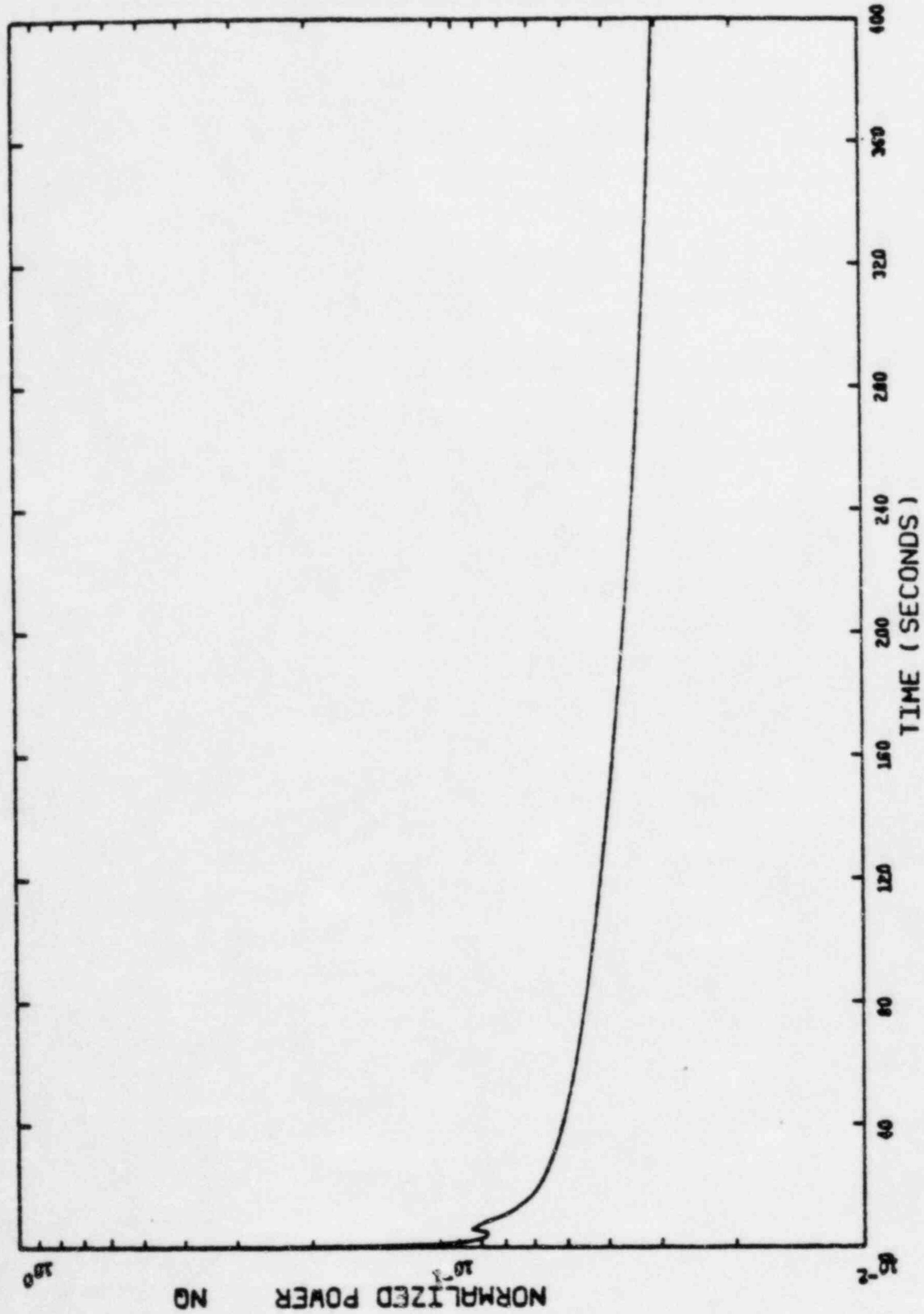

Figure 3.34 Normalized Power, 1.0 DECLG Break, 2.0 MWD/kg Case

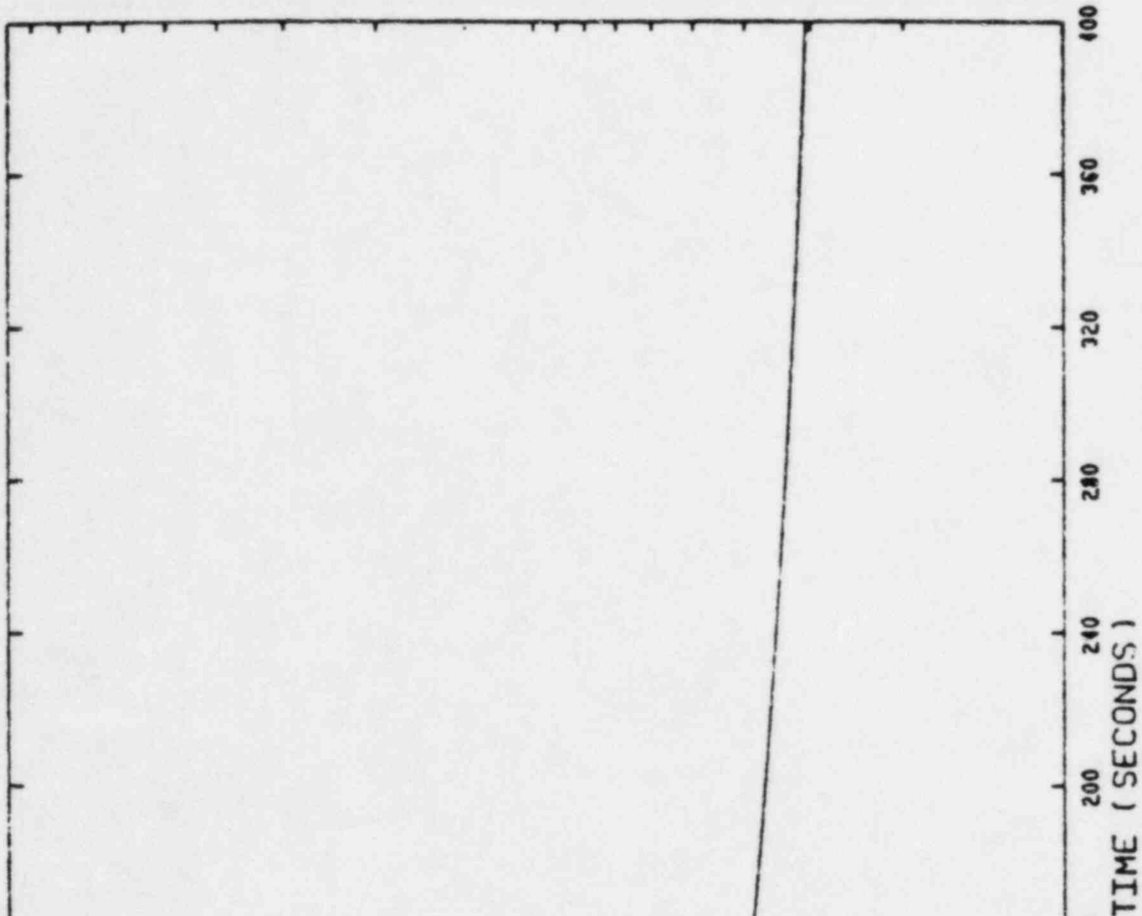

Figure 3.35 Normalized Power, 1.0 DECLG Break, 10.0 MWD/kg Case

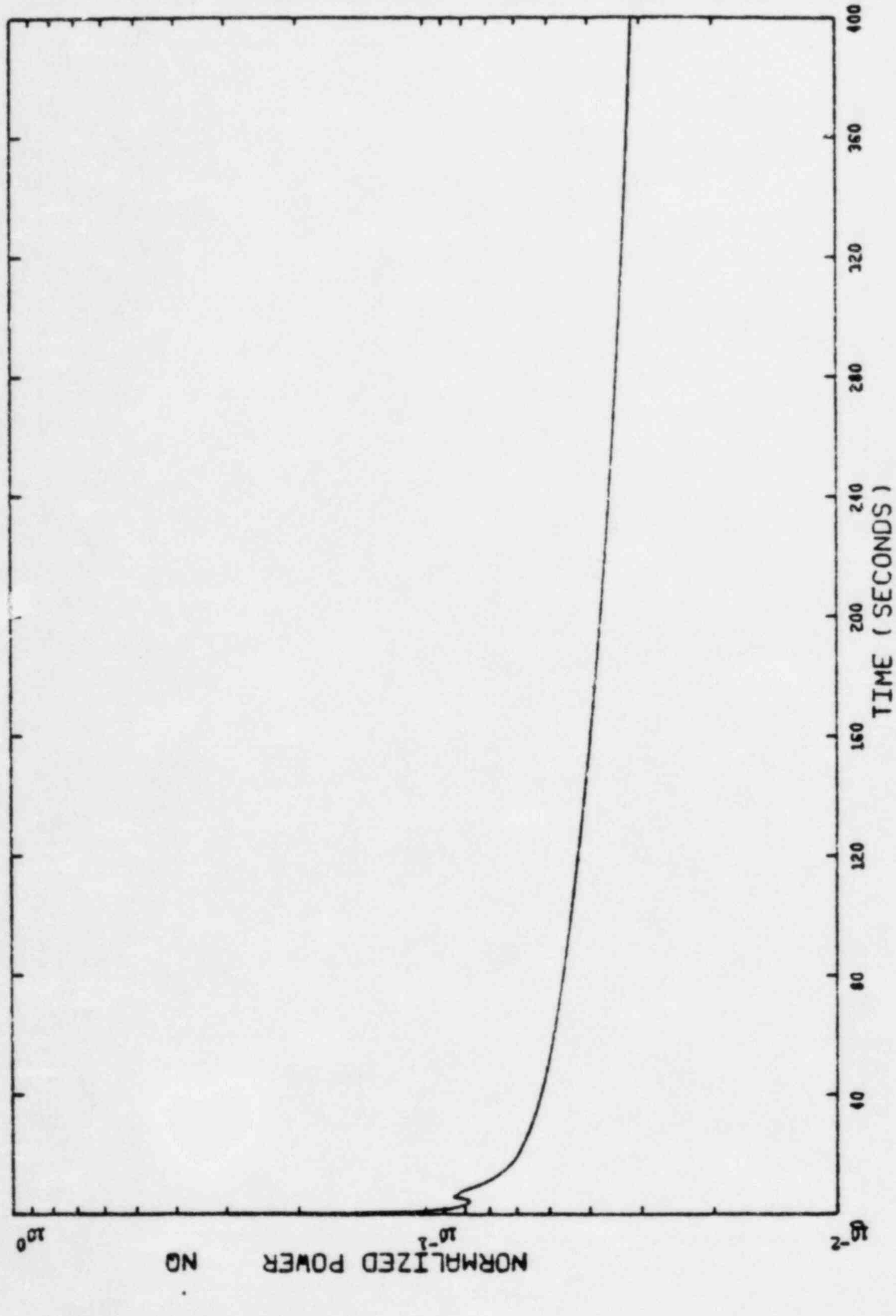

Figure 3.36 Normalized Power, 1.0 DECLG Break, 47.0 MWD/kg Case

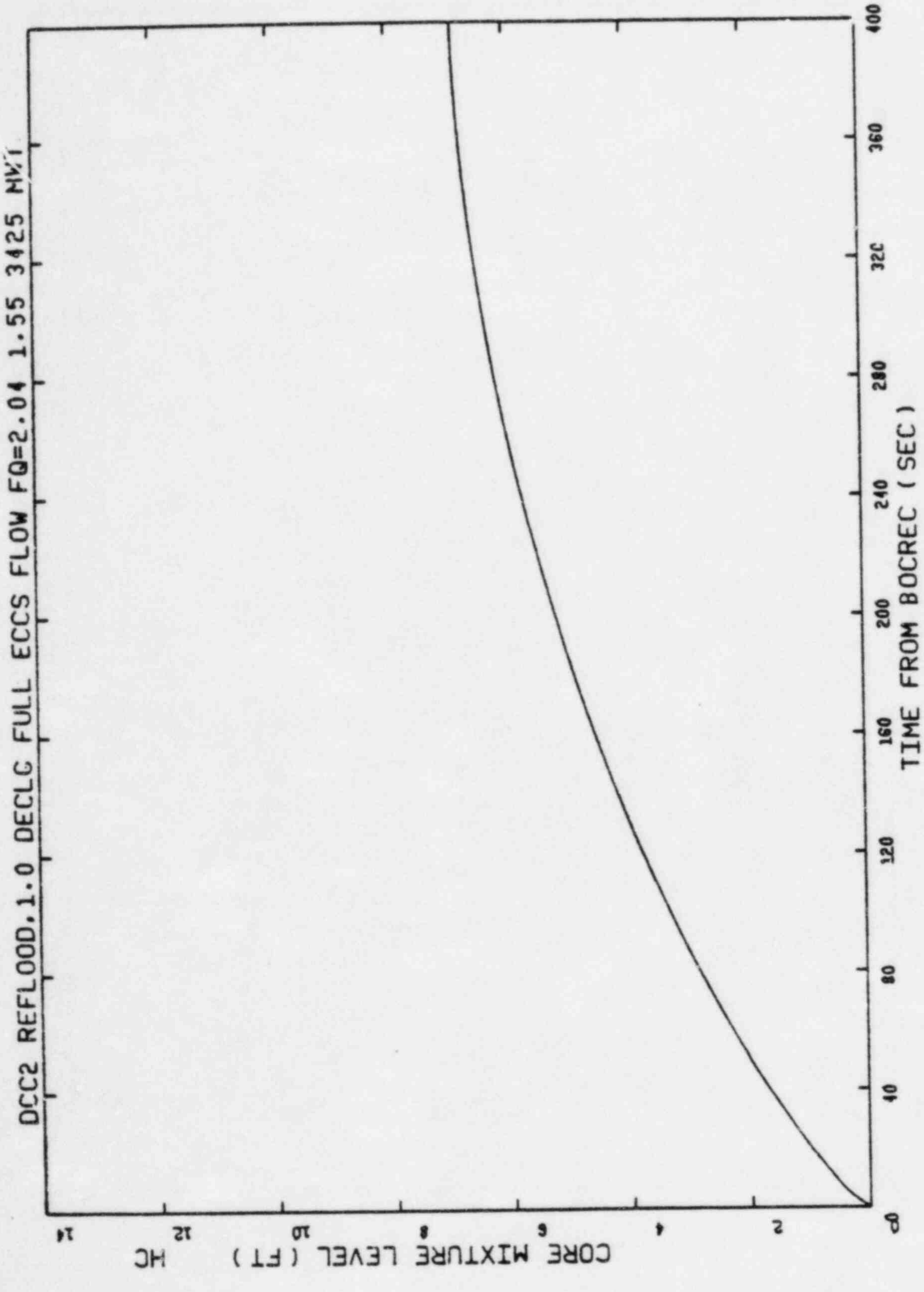

Figure 3.37 Reflood Core Mixture Level, 1.0 DECLG Break

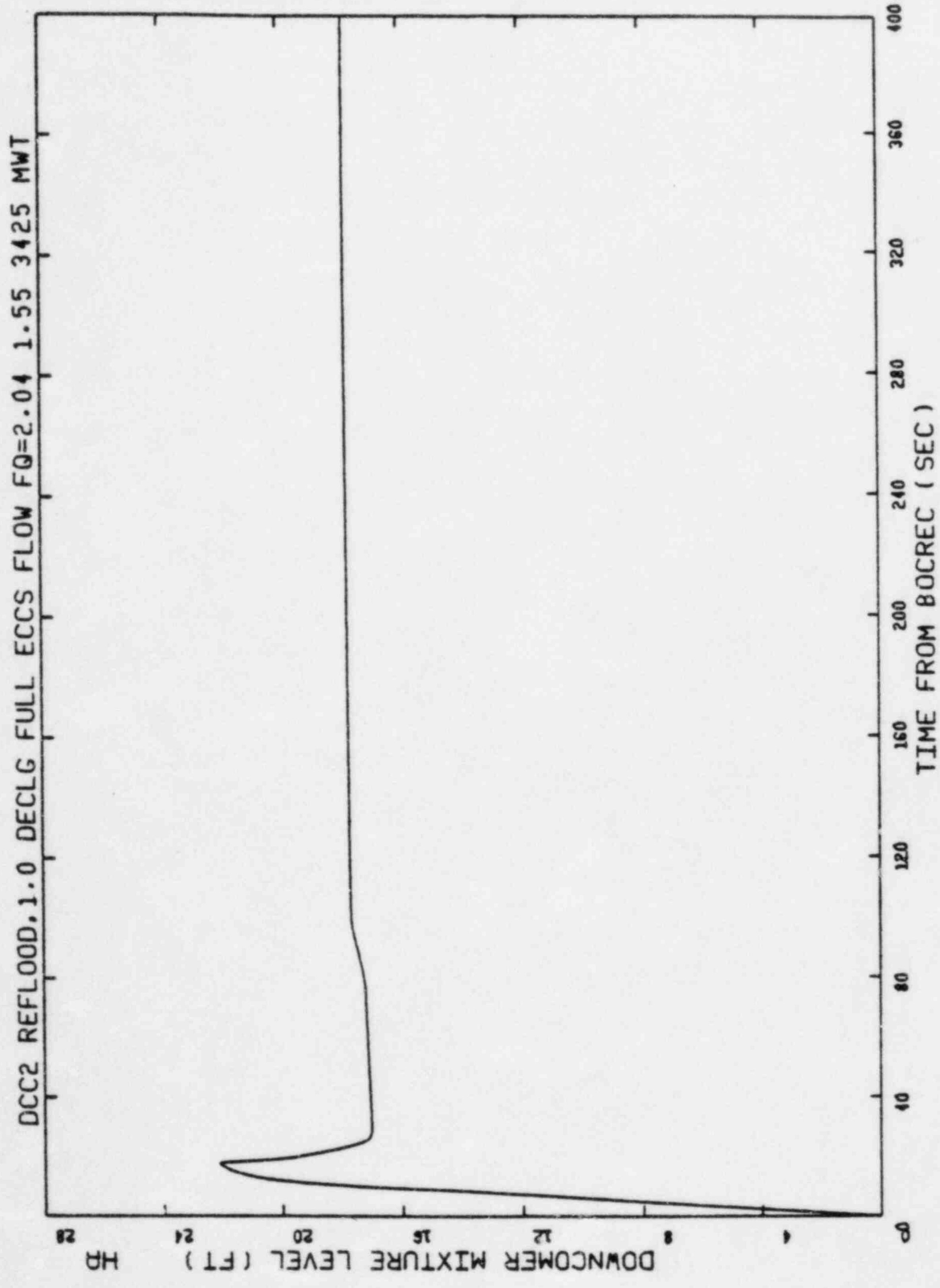

Figure 3.38 Reflood Downcomer Mixture Level, 1.0 DECLG Break

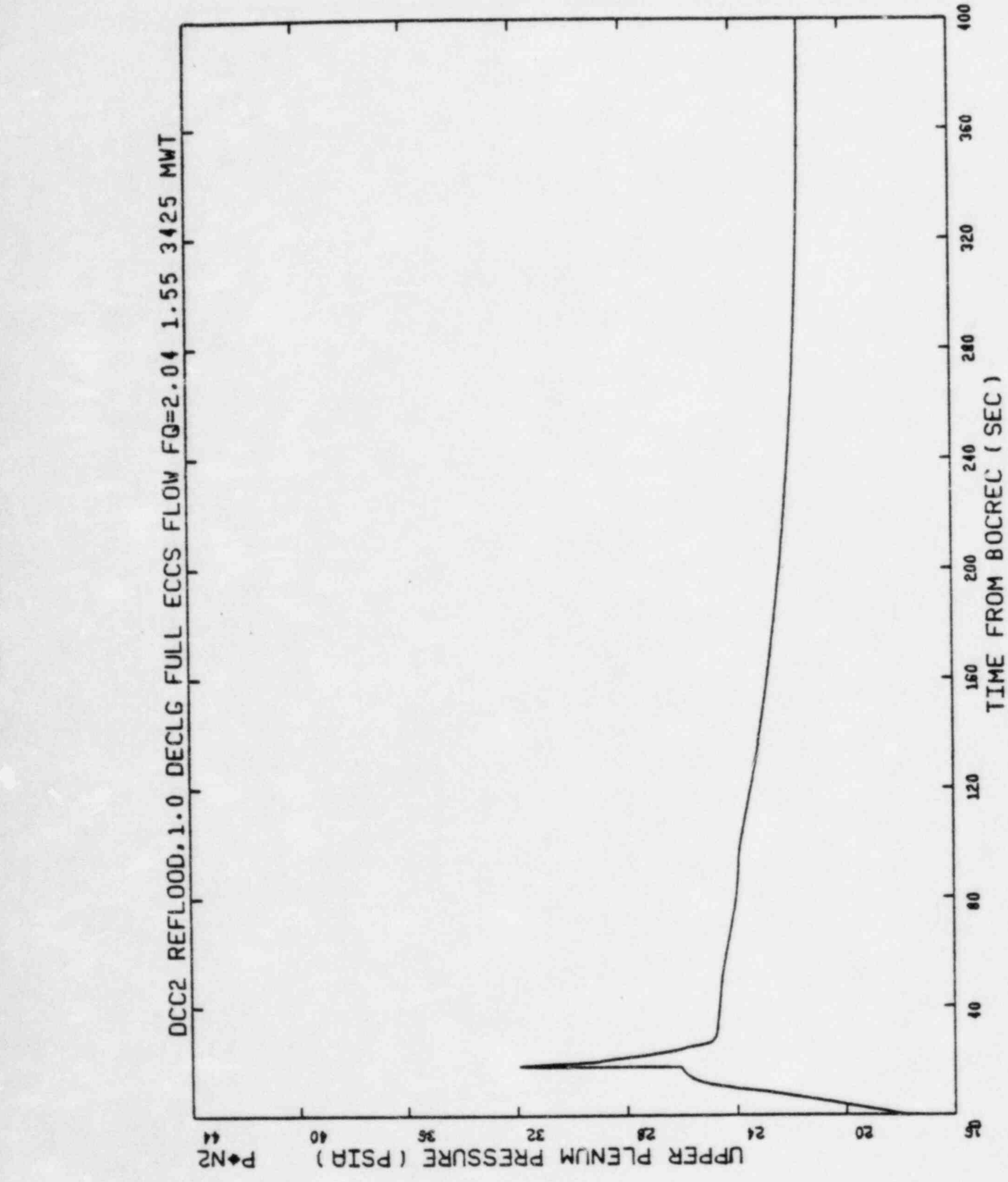

Figure 3.39 Reflood Upper Plenum Pressure, 1.0 DECLG Break

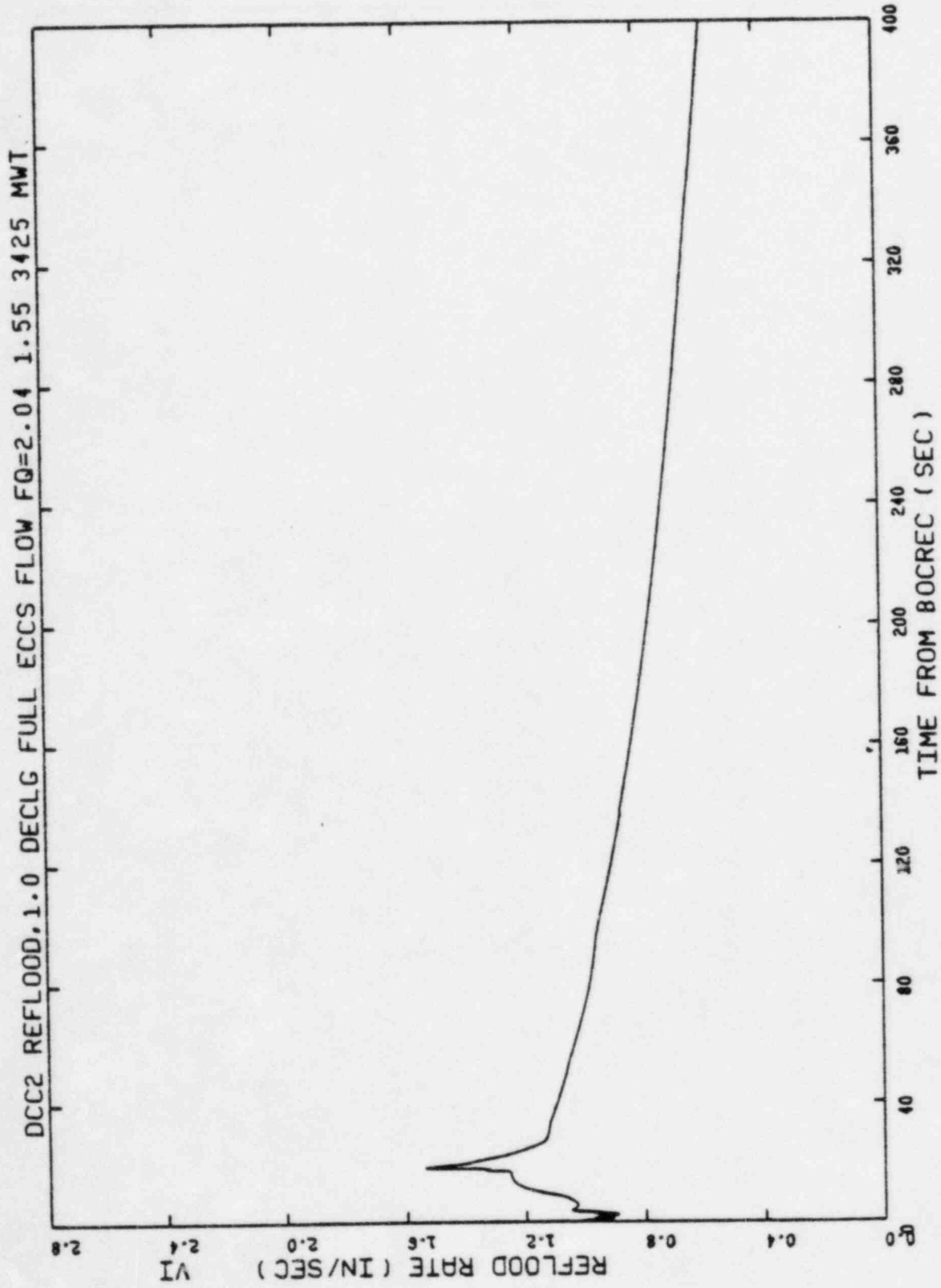

Figure 3.40 Core Flooding Rate, 1.0 DECLG Break

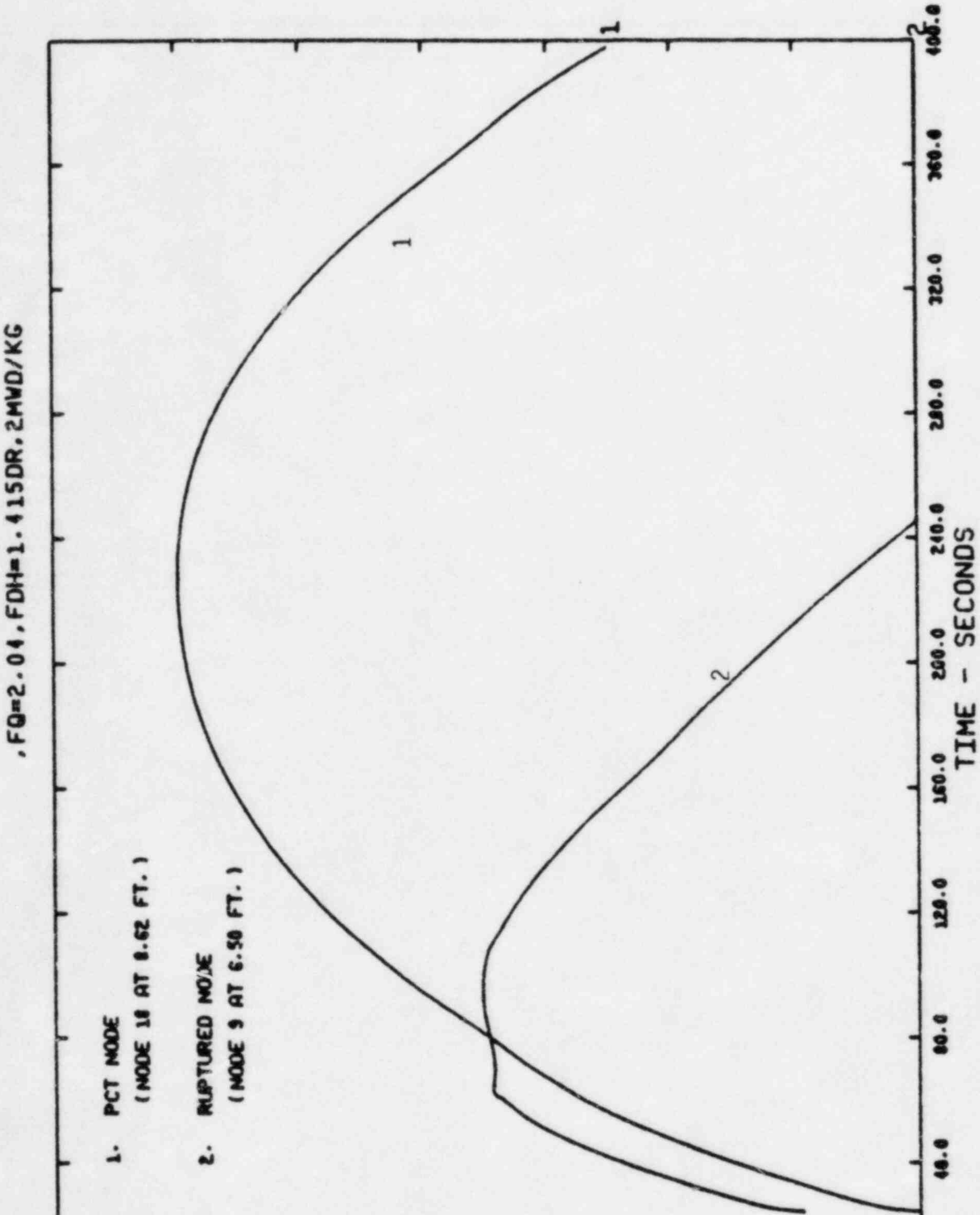

Figure 3.41 TOODEE2 Cladding Temperature versus Time, 1.0 DECLG Break, 2. MWD/Kg Case

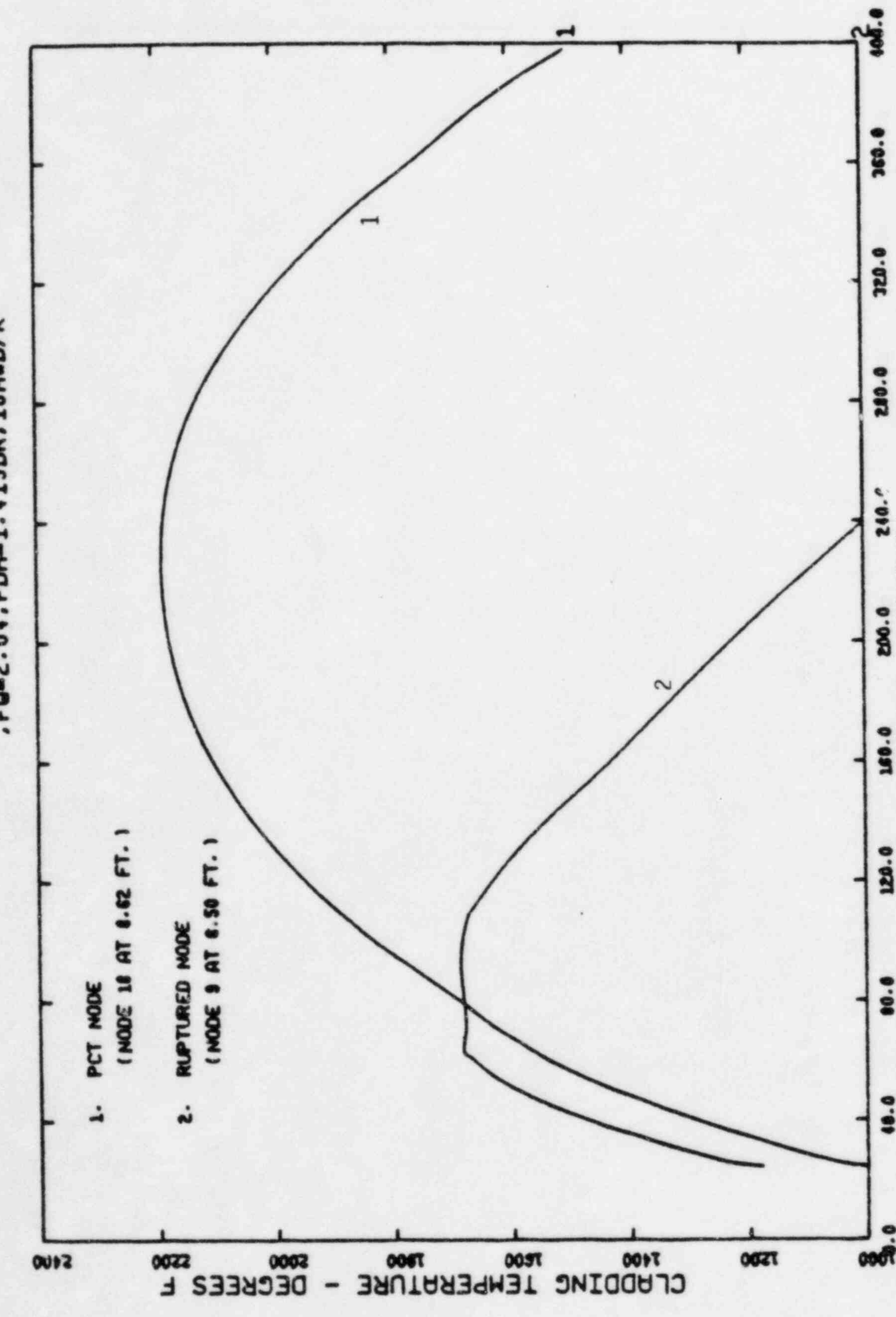

Figure 3.42 TOODEE2 Cladding Temperature versus Time, 1.0 DECLG Break, 10. MWD/Kg Case

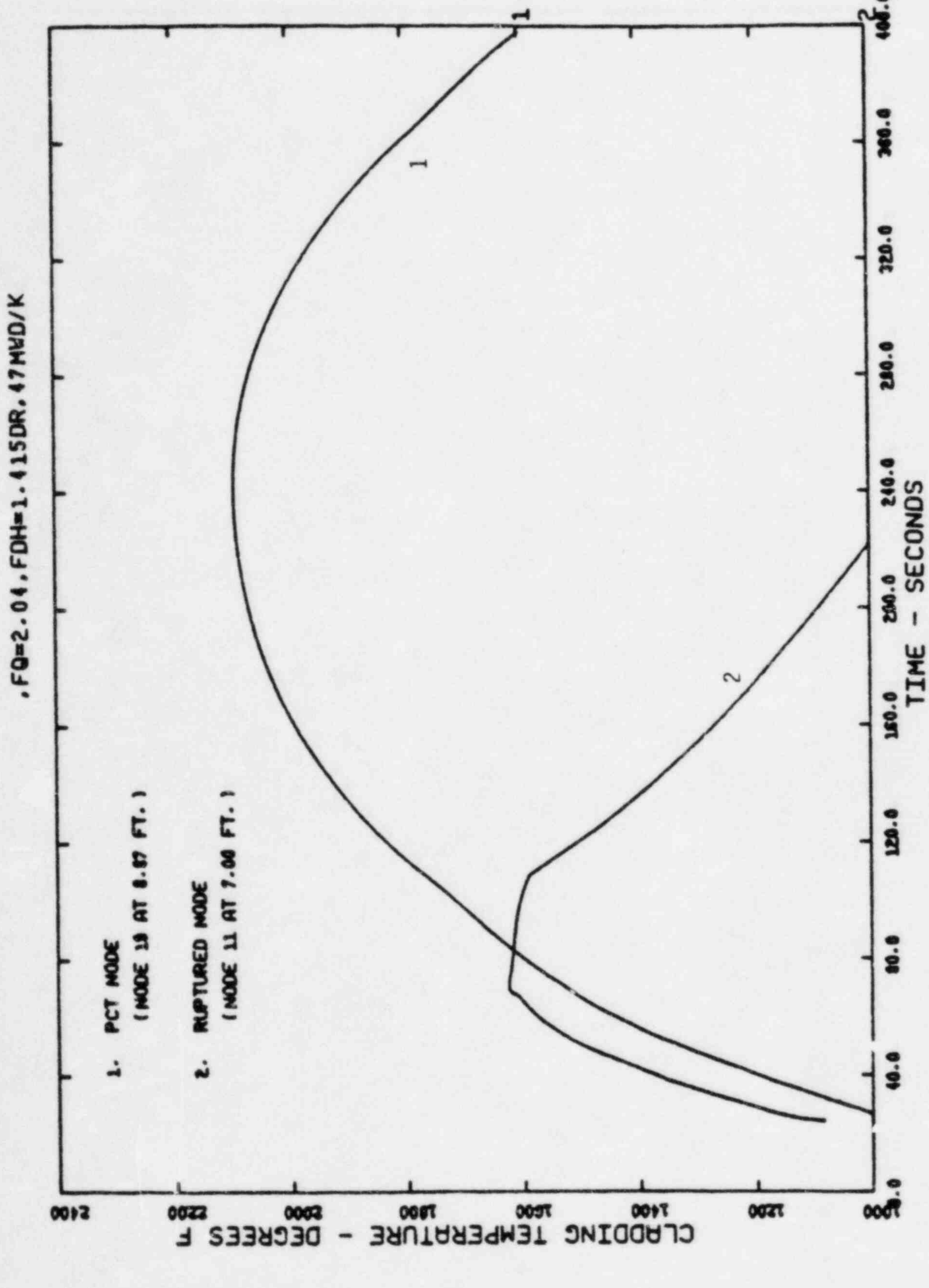

Figure 3.43 TOODEE2 Cladding Temperature versus Time, 1.0 DECLG Break, 47. MWD/Kg Case

4.0 CONCLUSIONS

For breaks up to and including the double-ended severance of a reactor coolant pipe, the Donald C. Cook Unit 2 Emergency Core Cooling System will meet the Acceptance Criteria as presented in 10 CFR 50.46 for operation with ENC 17x17 fuel operating in accordance with the LHGR limits noted in Table 2.1. That is:

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.

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(7) U.S. Nuclear Regulatory Commission letter, T.A. Ippolito (NRC) to W.S. Nechodom (ENC), "SER for ENC RELAP4-EM Update," March 1979.

(8) XN-CC-39, Rev. 1, "ICECON: A Computer Program Used to Calculate Containment Backpressure for LOCA Analysis (Including Ice Condenser Plants)," Exxon Nuclear Company, Inc., Richland, WA 99352, November 1977.

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(13) XN-NF-82-32(P), Revision 2, "Plant Transient Analysis for the Donald C. Cook Unit 2 Reactor at 3425 MWt: Operation with 5% Steam Generator Tube Plugging," Exxon Nuclear Company, Inc., Richland, WA 99352, February 1984.

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DONALD C. COOK UNIT 2 CYCLE 5 5% STEAM GENERATOR TUBE PLUGGING

LIMITING BREAK LOCA/ECCS ANALYSIS

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