XN-NF-82-35

Supplement 1

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DONALD C. COOK UNIT 2 CYCLE 4
LIMITING BREAK LOCA-ECCS ANALYSIS
USING EXEM/PWR

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE		PAGE

1.0 INTRODUCTION AND SUMMARY

This document presents additional analytical results for a postulated large break loss-of-coolant accident (LOCA), performed for the Donald C. Cook Unit 2 nuclear power plant, operating at 3425 MWt, and fueled by Exxon Nuclear Company (ENC). Calculations were performed using the EXEM/PWR ECCS Evaluation Model(1) with the RODEX2 stored energy model replaced by the GAPEX(2) model which has been previously approved by the United States Nuclear Regulatory Commission (NRC). The analyses are applicable to Cycle 4 operation of D.C. Cook Unit 2 and include both the worst single failure assumption of loss of one low pressure safety injection (LPSI) pump and the no single failure assumption of full ECCS operation. The results of the analyses show that within the limits established, the criteria specified by 10 CFR 50.46(3) are satisfied.

The break spectrum calculations for the large break LOCAs were previously reported and the limiting break from the spectrum analysis was shown to be the large double-ended cold leg guillotine (DECLG) break with a discharge coefficient of 1.0. The limiting break was recalculated with the EXEM/PWR model and the GAPEX stored energy model. For this break, with the assumption that one of the LPSI pumps has failed and with a total power peaking factor (F_Q^T) of 2.10, the Peak Cladding Temperature (PCT) is 2091°F, occurring at 282 seconds into the accident at a location 9.13 feet from the bottom of the active core. With no failure of LPSI pumps assumed the 1.0 DECLG break LOCA yielded a PCT of 2198°F, which occurred 341 seconds into the accident at 9.63 feet from the bottom of the active core. The maximum linear heat generation rate for the no failure case with full ECCS flow is 11.66 kW/ft, including 1.02 factor for power uncertainties, which corresponds to a total peaking factor (F_Q^T) of 2.04. Table 1.1 shows the calculated peak cladding temperatures and metal-water reaction results for both cases. In all cases, the emergency core cooling system is shown to meet the Acceptance Criteria as presented in 10 CFR 50.46.

For the limiting large break LOCA bounding exposure conditions were assumed for the cycle. These bounding conditions included the highest initial fuel temperatures and greatest fission gas release, for Cycle 4 operation with ENC fuel. The maximum exposure used for the maximum power fuel rod was 22.11 GWD/MTM.

Table 1.1 Donald C. Cook Unit 2, Cycle 4, DECLG (C_D=1.0) Break Analysis for Full ECCS Flow, and One LPSI Pump Operation.

Analysis Results	Single Failure of One LPSI Pump	Full ECCS Flow
Peak Clad Temperature (PCT) ^oF	2091.	2198.
Time of PCT, sec.	282	341.
Peak Clad Temperature location, ft.	9.13	9.63
Local Zr/H_2O Reaction (max.), %*	5.91	7.62
Local Zr/H_2O Location, ft. from bottom	9.13	9.38
Total H_2 Generation, % of total Zr Reacted	<1.0	<1.0
Hot Rod Burst Time, sec.	59.57	62.97
Hot Rod Burst Location, ft.	6.75	7.00
Calculation		
License Core Power, MWt	3425	3425
Power Used for Analysis, MWt	3493.5	3493.5
Peak Linear Power for Analysis, kW/ft**	12.0	11.66
Total Peaking Factor, F_Q^T	2.10	2.04
Enthalpy Rise, Nuclear, $F^N_{\Delta H}$	1.55	1.55
Peak Rod Burnup Maximum (GWD/MTM)	22.11	22.11

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* Computer value at 400 seconds.

** Including 1.02 factor for power uncertainties

2.0 LIMITING BREAK LOCA ANALYSIS

This report supplements previous LOCA-ECCS analyses performed and documented for D.C. Cook Unit 2. An example application of the EXEM/PWR model was reported in XN-NF-82-20(P) Supplement 2[1]. A spectrum of LOCA breaks was performed and reported in XN-NF-82-35[4]. 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). The analyses performed and reported herein consider:

(1) A revised stored energy model (GAPEX) in place of the previously applied RODEX2 model. The RODEX2 model as applied in the documented analyses[4] requires revision for NRC approval. Until a satisfactory resolution of RODEX2 is achieved, ENC will perform EXEM/PWR calculations using the currently approved GAPEX model for a limited exposure of one cycle.

(2) Both the cases of a single failure of a low pressure safety injection (LPSI) pump as determined by the NSSS vendor, and the full ECCS flow case.

(3) Updates to the latest D.C. Cook Unit 2 application to reflect all model revisions as documented in XN-NF-82-20(P) Revision 1[1].

2.1 LOCA ANALYSIS MODEL

The Exxon Nuclear Company EXEM/PWR-ECCS evaluation model was used to perform the analyses required. This model[1] consist of the following computer codes: GAPEX[2] code for initial stored energy; RELAP4-EM[5] for the system blowdown and hot channel blowdown calculations; ICECON[6] for the computation of the ice condenser containment backpressure; REFLEX[1,7] for computation of system reflood; and TOODEE2[1,8,9], 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" as described in XN-NF-82-20(P), Supplement 2[1]. The system nodalization is depicted in Figure 2.1. 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. 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 axial power profiles used for the analyses are shown in Figures 2.2 and 2.3, with a maximum axial peaking factor of 1.316 for the full ECCS case, and 1.355 for the single failure of one of the LPSI pumps. 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 2.1.

Both ECCS calculations were performed with input which bounds the fuel history for Cycle 4. The most limiting fuel conditions from beginning-of-life to end-of-cycle exposure conditions (22,110 MWD/MTM peak rod burnup) were determined and used in the calculation. Internal rod pressure and decay power are highest at EOC for the hot rod while stored energy was calculated to be highest at beginning-of-life This combination of highest stored energy, highest rod pressure, and greatest decay power were used to bound Cycle 4 operation. The single failure calculation assumed an all ENC fueled core while the full ECCS flow case used the D.C. Cook Unit 2 Cycle 4 core configuration. These calculations will be redone for future cycles when the RODEX2 code for the stored energy model is approved by the NRC.

2.2 RESULTS

Table 2.2 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, and also for single failure of one LPSI pump.

Prior to pumped safety injection initiation, the transient timing is the same for both cases. After safety injection begins, calculated results differ due to the increased ECCS mass flow for the full ECCS case relative to the single failure case. The principal effects of high ECCS flow on the evaluation model LOCA-ECCS calculation for D.C. Cook Unit 2 are a decreased containment pressure and reduced reflood cooling. As a result, the no single failure case full ECCS flow produces a higher Peak Clad Temperature (PCT) than the single failure case with the loss of one LPSI pump. Table 1.1 presents the peak cladding temperatures and maximum metal-water reaction for the two cases.

Figures 2.4 through 2.6, 2.9-2.12, and 2.20 present plotted results of the analyses of the limiting break (1.0 DECLG) applicable for both the single failure and the full ECCS flow cases. Unless otherwise noted on the figures, time zero corresponds to the time of break initiation. System blowdown results prior to ECCS initiation apply for both single failure and full ECCS cases. Figures 2.7, 2.8, 2.13-2.19 and 2.21-2.26 provide the remainder of the plotted results for the ECCS single failure case. Figures 2.27-2.41 provide the additional results for the full ECCS flow, no single failure case.

The peak cladding temperature calculated for the equivalent double-ended cold-leg guillotine break configuration (C_D=1.0) with single failure is 2091°F at a total linear heat generation rate of 12.0 kw/ft ($F_Q{}^T$= 2.1) for ENC fuel Cycle 4. The maximum local metal-water reaction for this case is 5.91% after 400 seconds, and the total core metal-water reaction reached is less than 1.0%. The peak cladding temperature calculated for the equivalent double-ended cold leg guillotine break configuration (C_D=1.0) with full ECCS flow is 2198°F at a total linear heat generation rate of 11.66 kw/ft ($F_Q{}^T$=2.04) for Cycle 4. The maximum local metal-water reaction for this case is 7.62% after 400 seconds, and the total core metal-water reaction reached is less than 1.0%, all below the limits set by the criteria of 10 CFR 50.46.

The results of the limiting break calculation with single failure are essentially the same as those reported in XN-NF-82-35[4] for the break spectrum and exposure analyses. Thus, the net effect of the revised stored energy model and the updated D.C. Cook Unit 2 application on final ECCS results is minimal.

Table 2.1 Donald C. Cook Unit 2 System Input Parameters

Primary Heat Output, MWt*	3425
Primary Coolant Flow, lbm/hr	142.7×10^6
Primary Coolant Volume, ft^3	11,892
Operating Pressure, psia	2250.
Inlet Coolant Temperature, ^oF	542
Reactor Vessel Volume, ft^3	4,945
Pressurizer Volume, Total, ft_3	1800.
Pressurizer Volume, Total, 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	51,500
Steam Generator Secondary Flow, lbm/hr	$4(3.685 \times 10^6)$
Steam Generator Secondary Pressure, psia	820
Reactor Coolant Pump Head, ft	277.
Reactor Coolant Pump Speed, rpm	1189.
Moment of Inertia, lbm-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, ft^2**	53.703

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* Primary Heat Output used in RELAP4-EM Model = 1.02 x 3425 = 3493.5 MWt

** ENC fuel parameters

Table 2.2 Donald C. Cook Unit 2, Cycle 4, DECLG (C_D=1.0) Break Events for Full ECCS Flow, and One LPSI Pump Flow

Events	Time (Seconds) Single Failure of One LPSI Pump	Time (Seconds) Full ECCS Flow
Start	0.0	0.0
Initiation of Break	0.05	0.05
Safety Injection Signal	0.65	0.65
Accumulator Injection, Intact Loop	15.5	15.5
Accumulator Injection, Broken Loop	3.3	3.3
End of Bypass (EOBY)	24.27	24.27
Bottom of Core Recovery (BOCREC)	40.79	40.47
Accumulator Empty, Intact Loop	51.27	53.02
Safety Pump Injection	25.65	25.65
Peak Cladding Temperature Reached	282	341

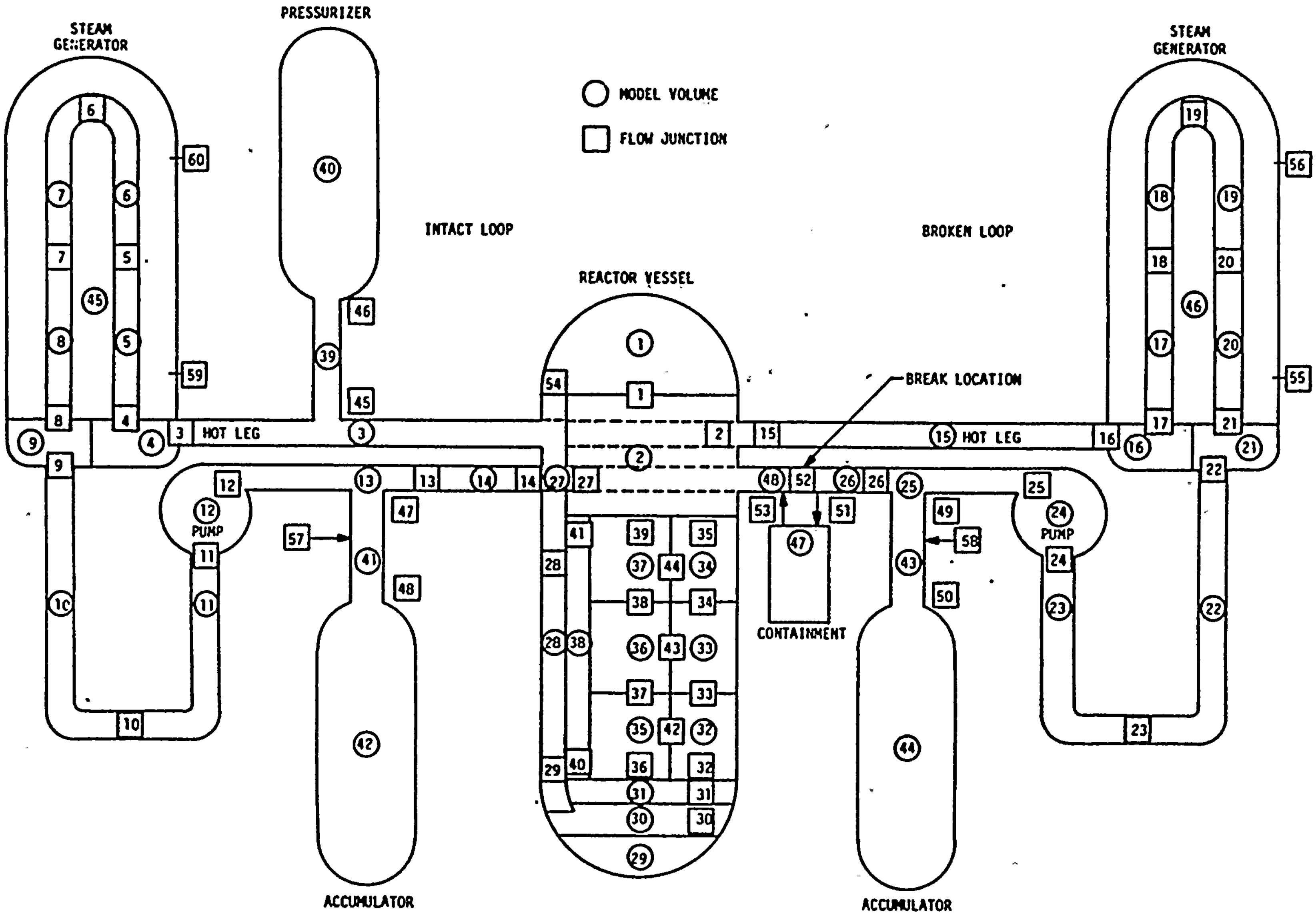

Figure 2.1 System Blowdown Nodalization for the Donald C. Cook Unit 2 PWR

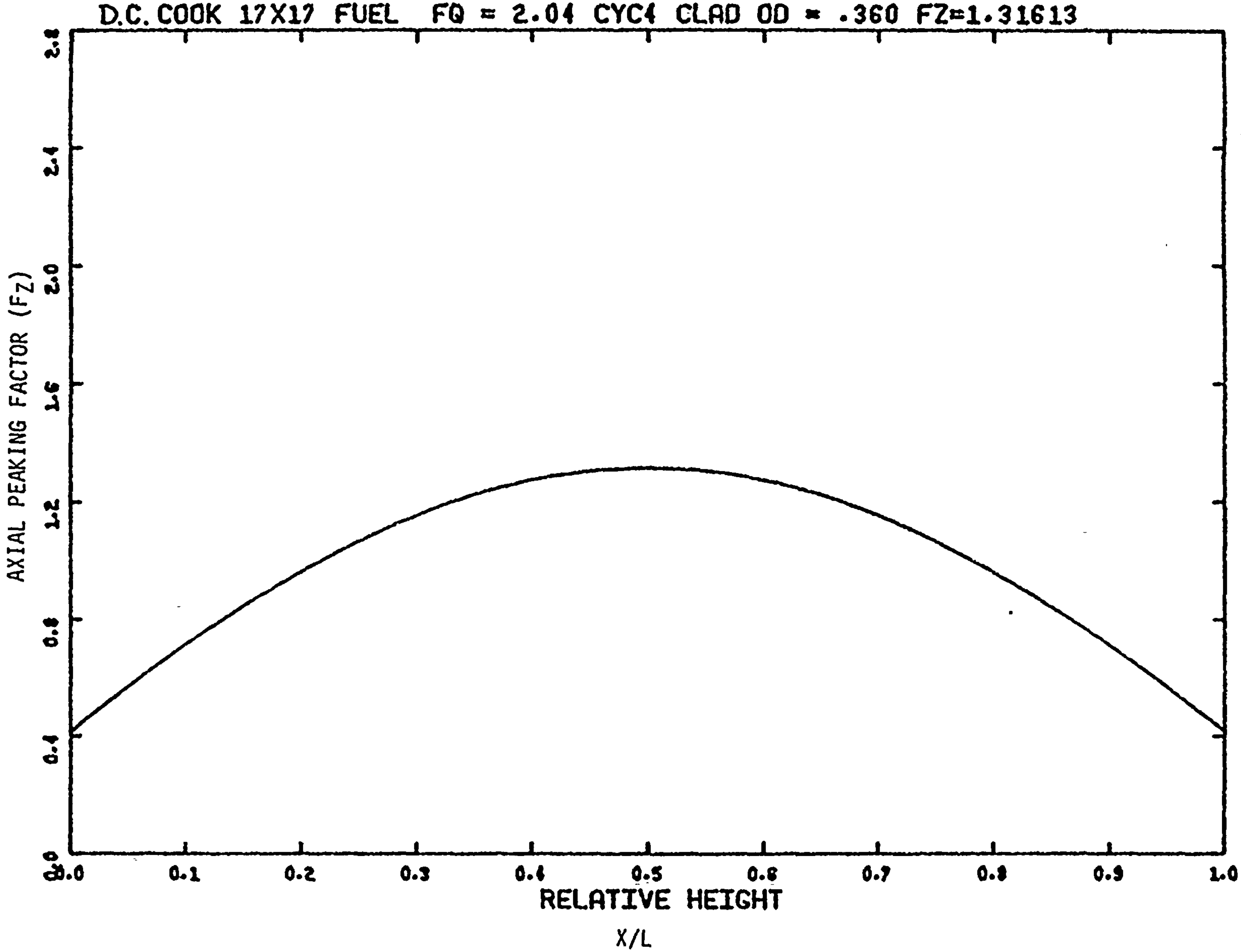

Figure 2.2 Axial Peaking Factor versus Rod Length
1.0 DECLG Break with Full ECCS Flow

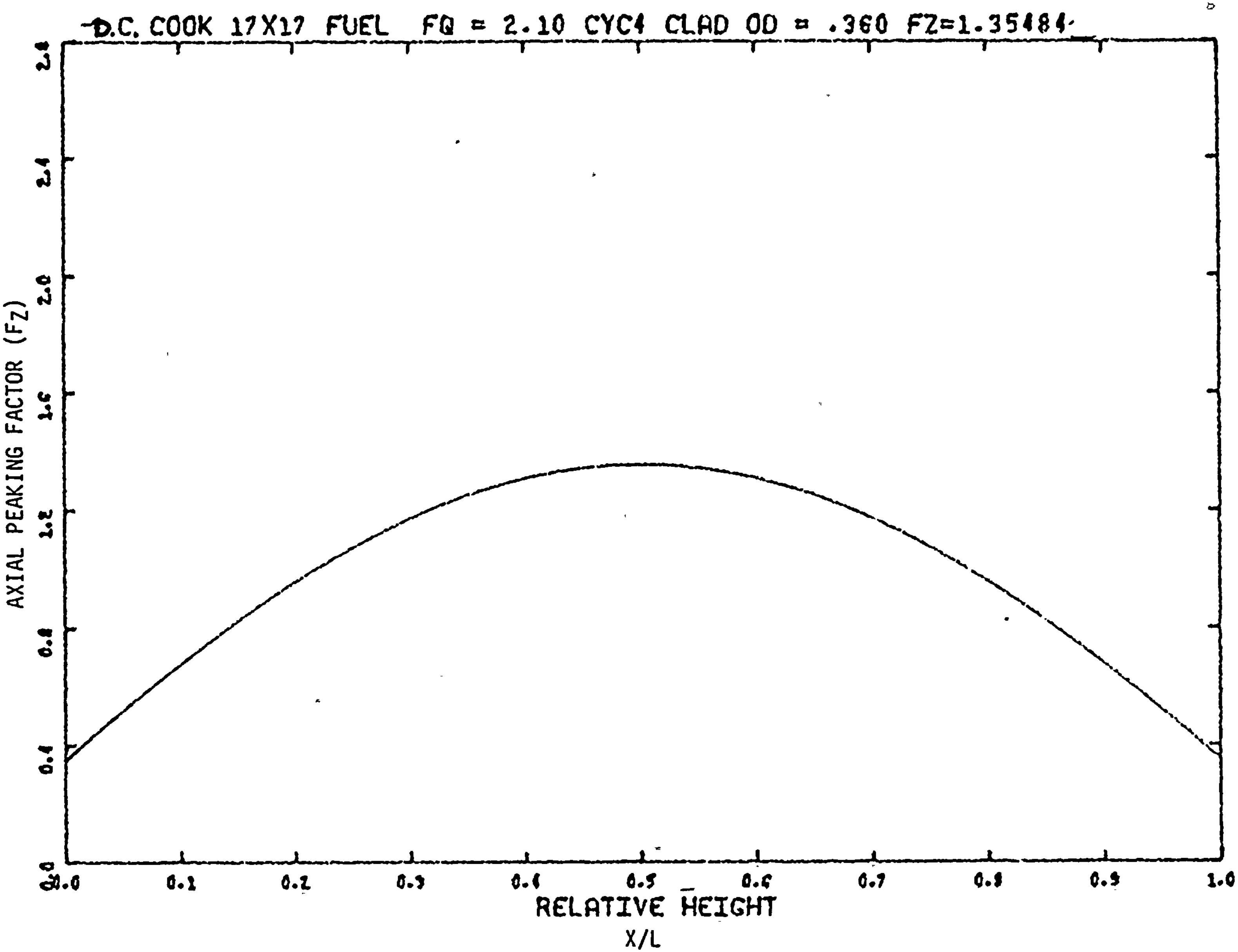

Figure 2.3 Axial Peaking Factor versus Rod Length
1.0 DECLG Break with Single Failure ECCS Flow

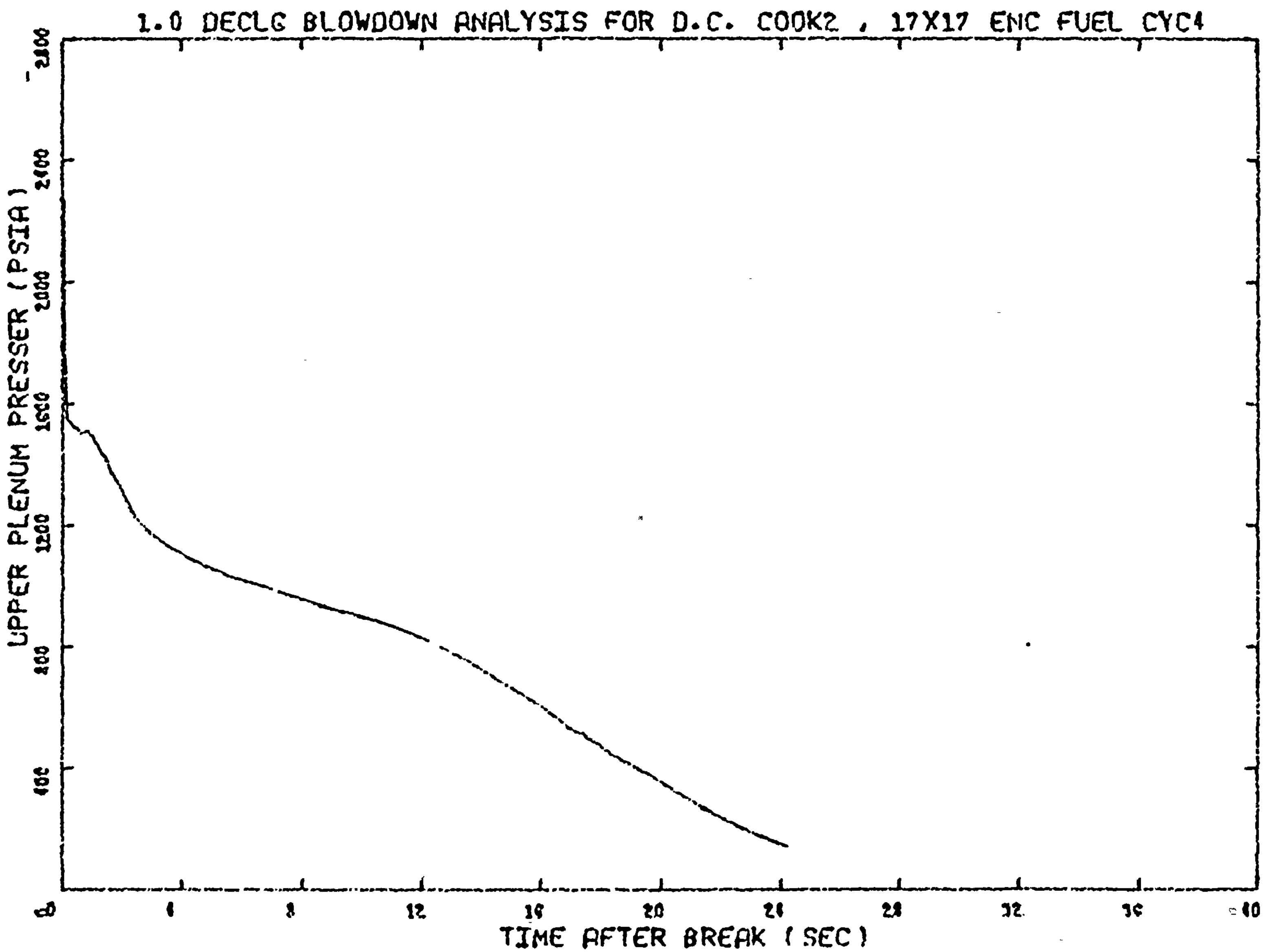

Figure 2.4 Upper Plenum Pressure
1.0 DECLG Break (Single Failure
and Full ECCS Flow)

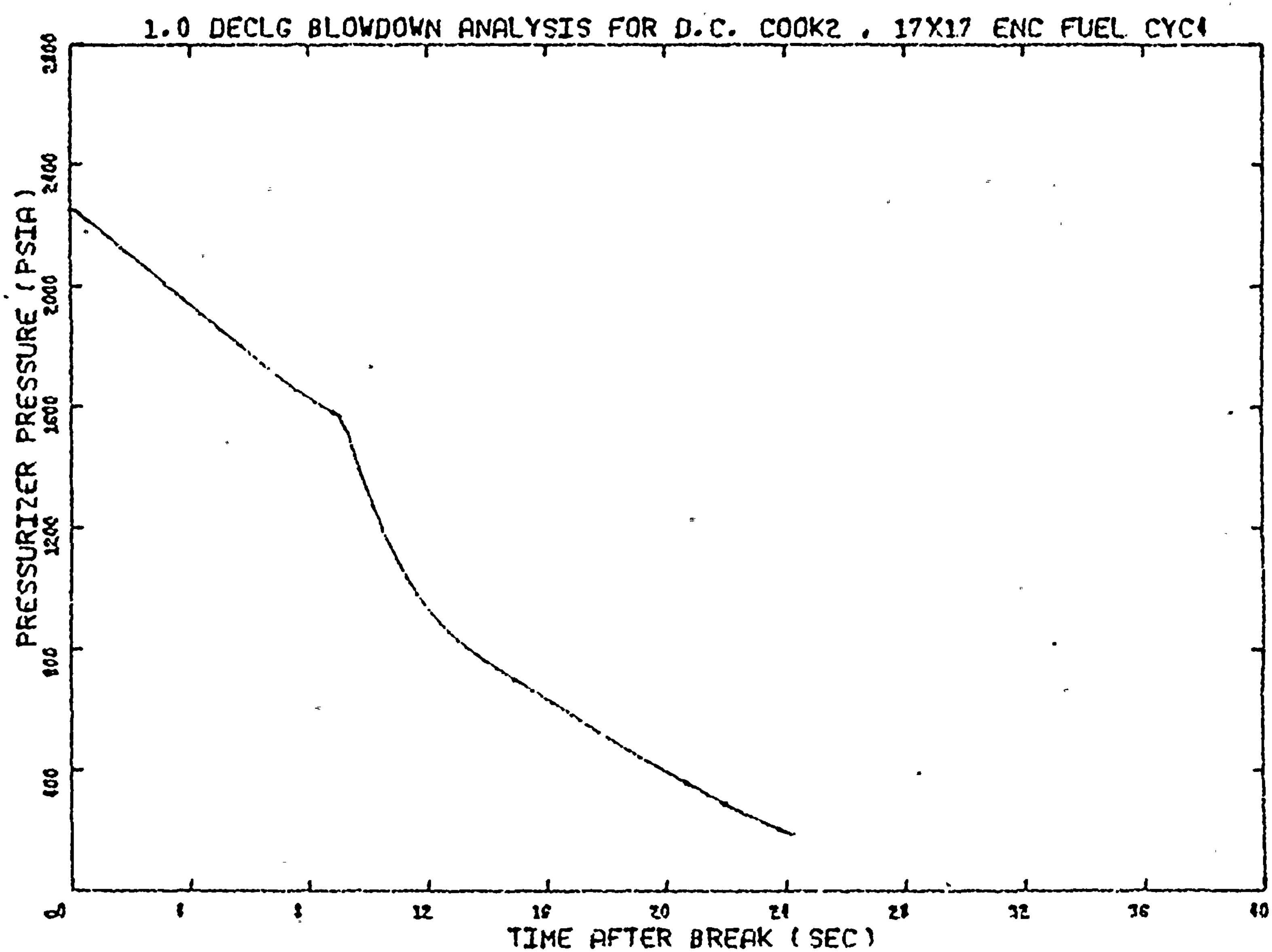

Figure 2.5 Pressurizer Pressure
1.0 DECLG Break (Single Failure and Full ECCS Flow)

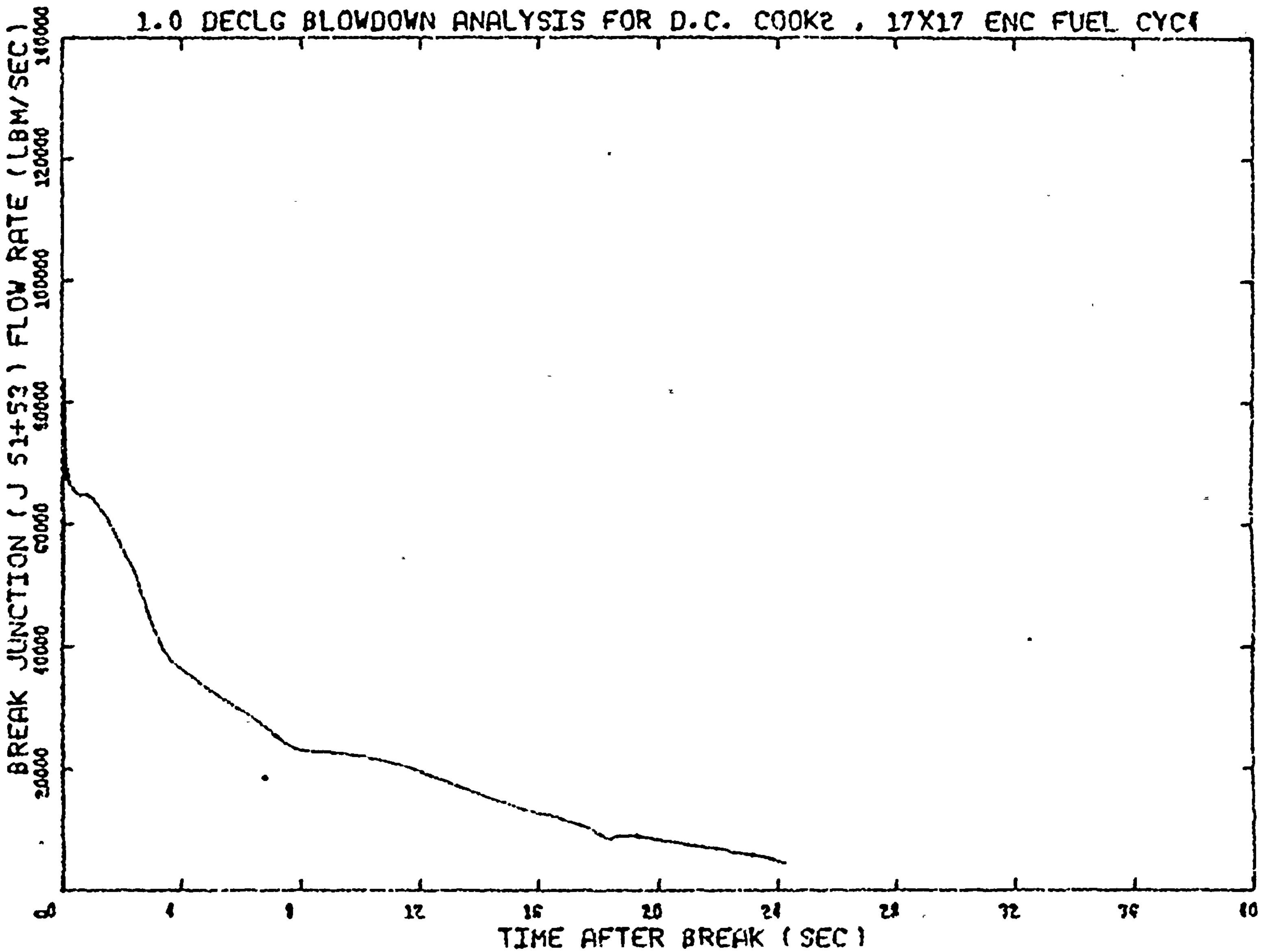

Figure 2.6 Total Break Flow
1.0 DECLG Break
(Single Failure and Full ECCS Flow)

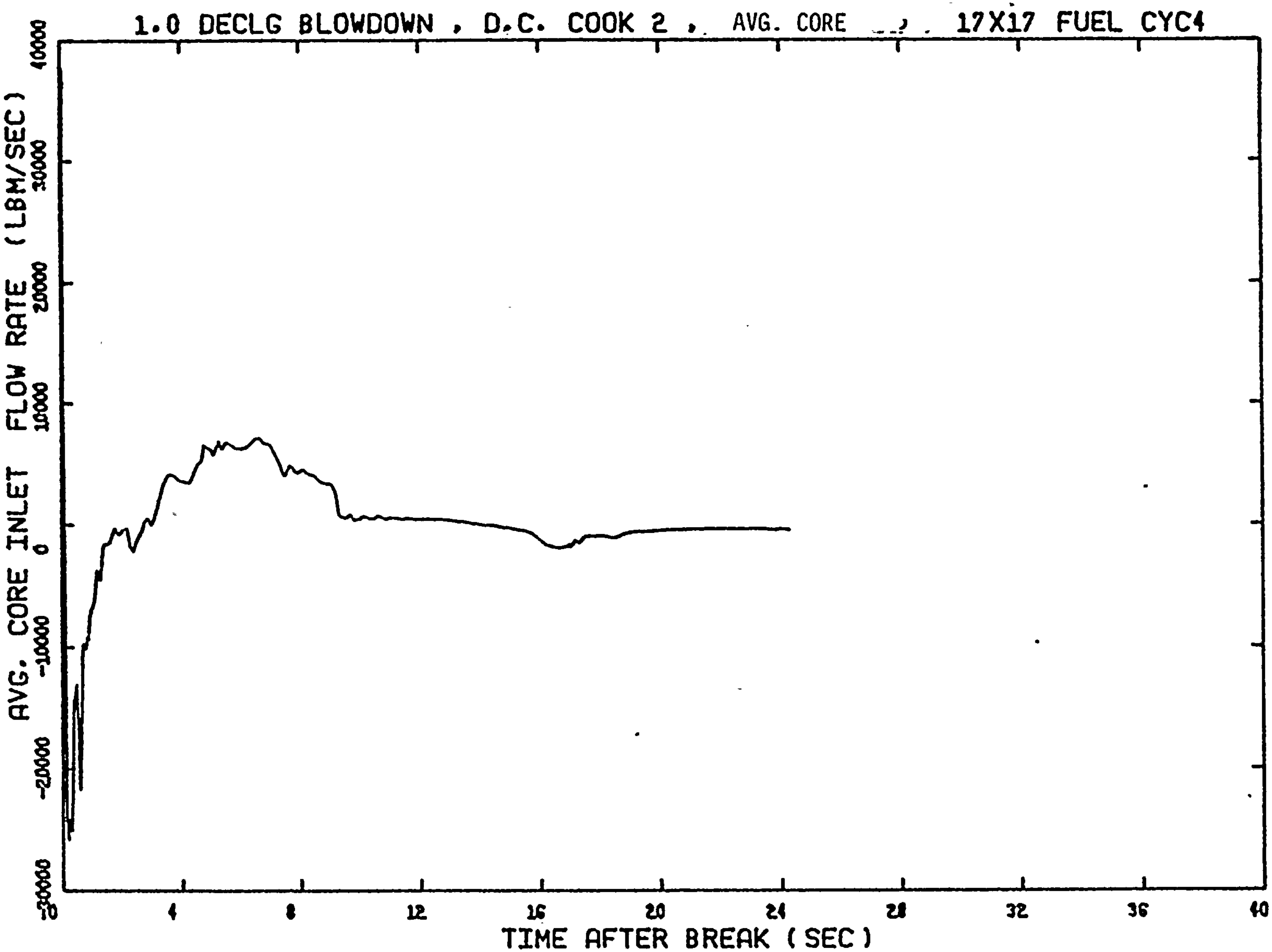

Figure 2.7 Average Core Inlet Flow
1.0 DECLG Break (Single Failure)

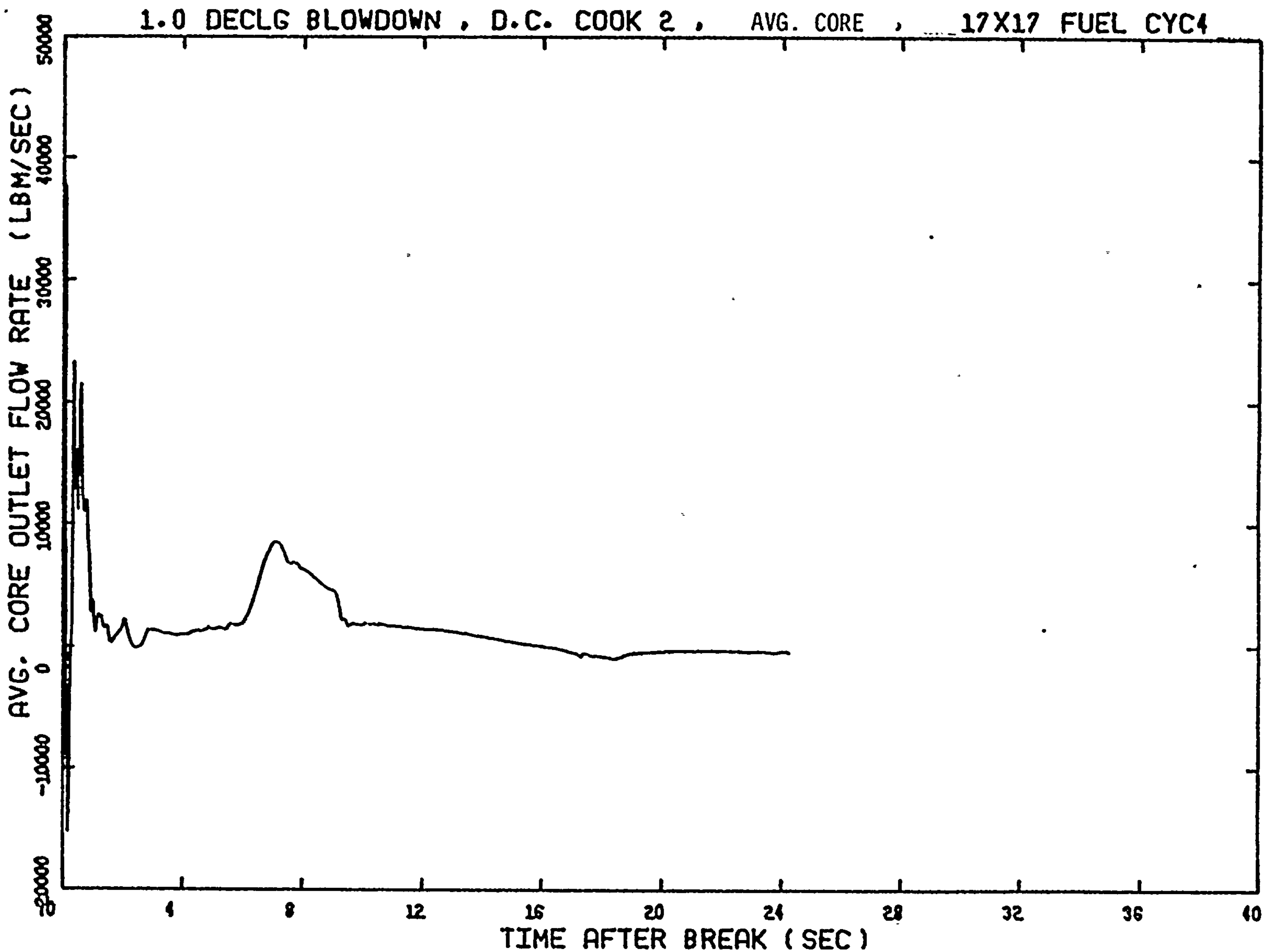

Figure 2.8 Average Core Outlet Flow
1.0 DECLG Break (Single Failure)

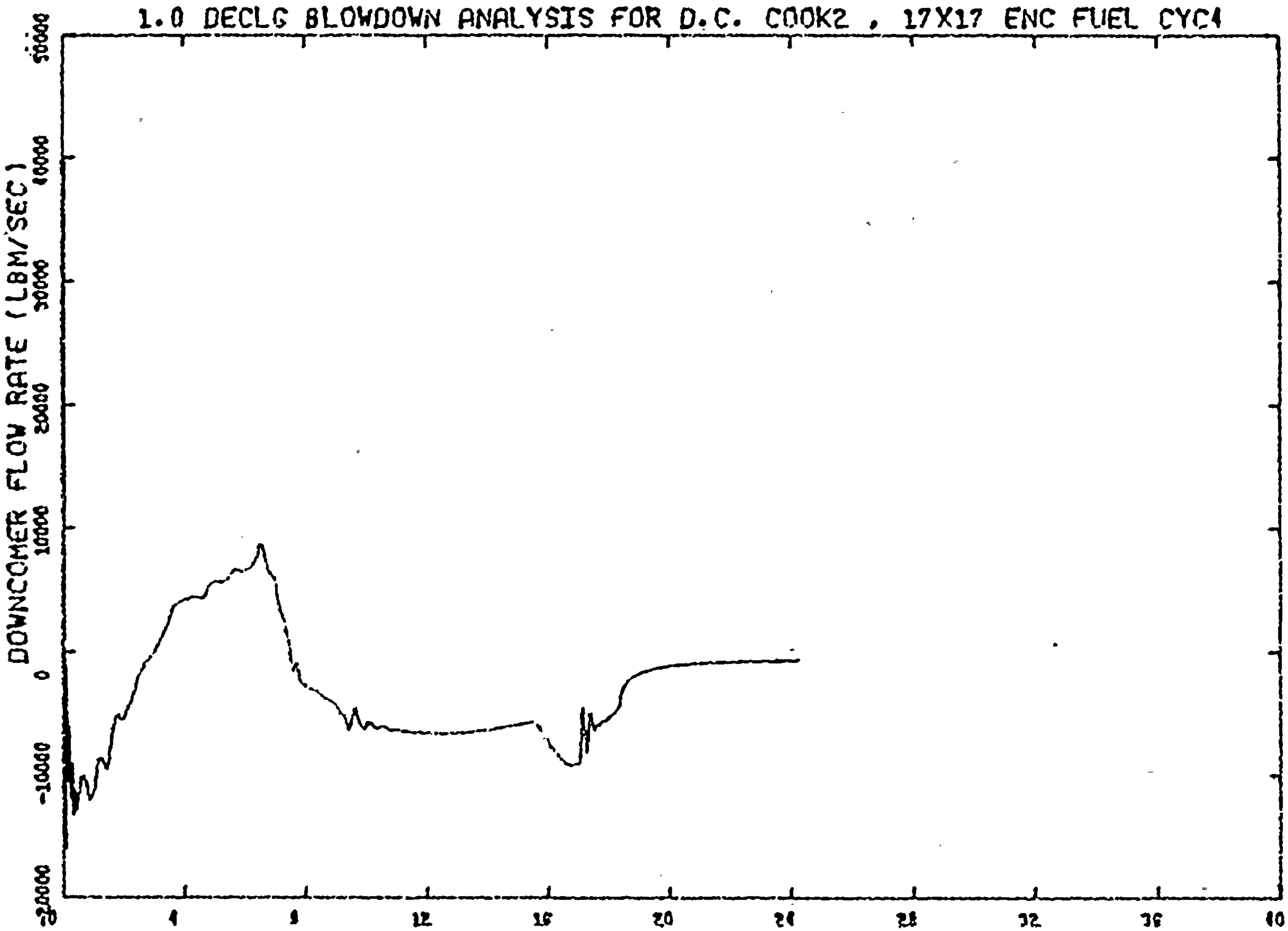

Figure 2.9 Downcomer Flow Rate, 1.0 DECLG Break
(Single Failure and Full ECCS Flow)

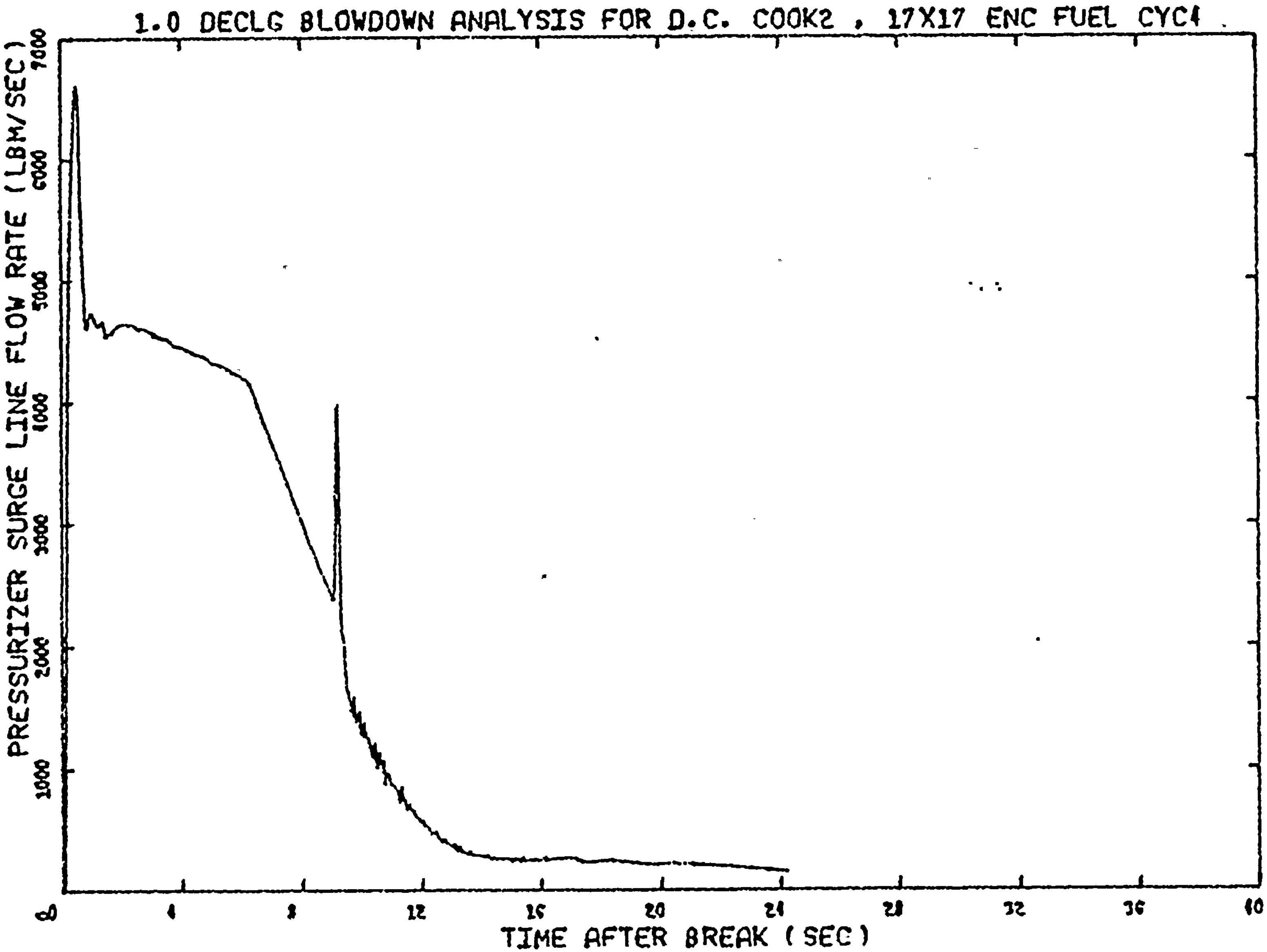

Figure 2.10 Pressurizer Surge Line Flow, 1.0 DECLG Break
(Single Failure and Full ECCS Flow)

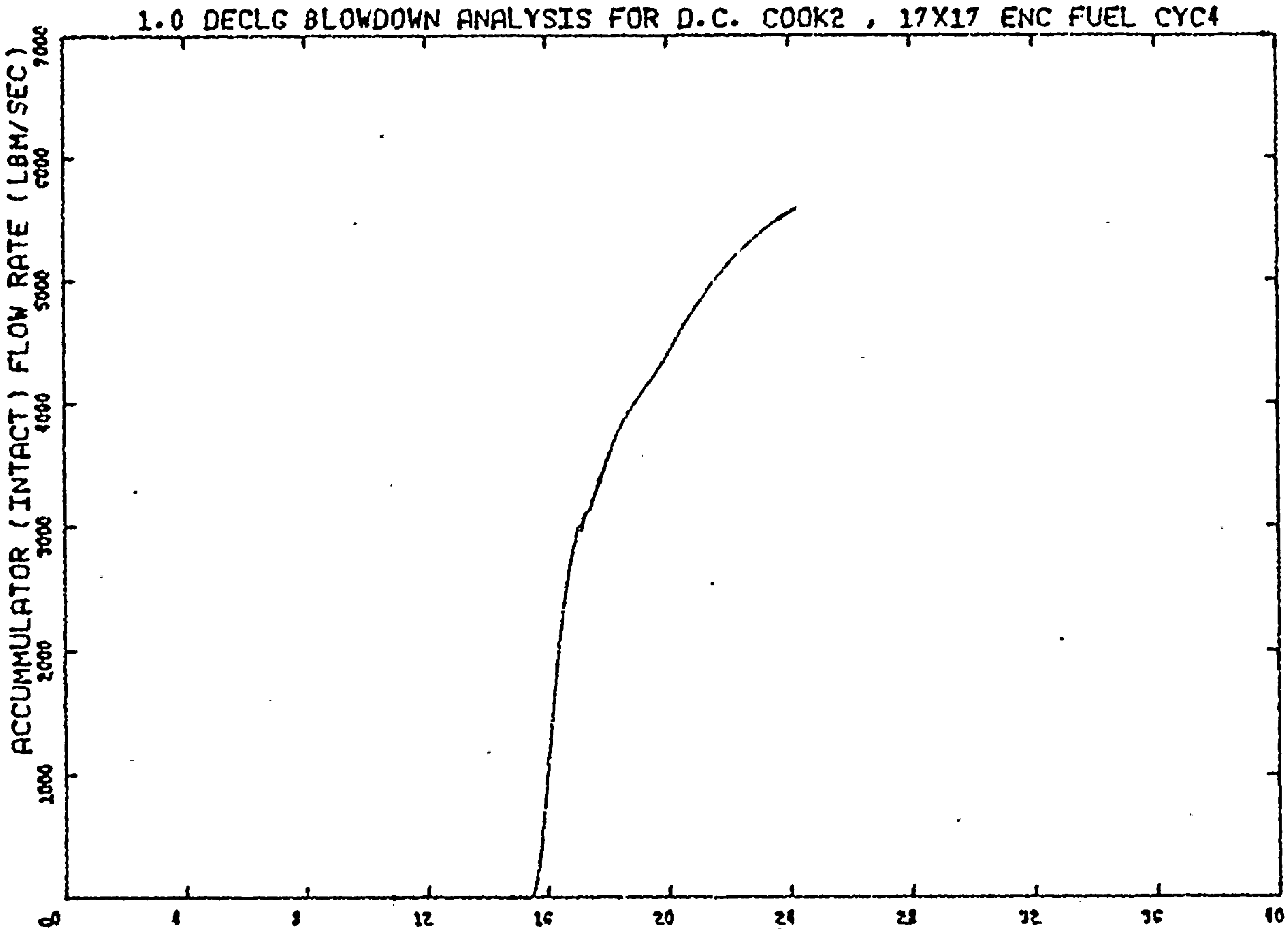

Figure 2.11 Flow From Intact Loop Accumulators, 1.0 DECLG Break
(Single Failure and Full ECCS Flow)

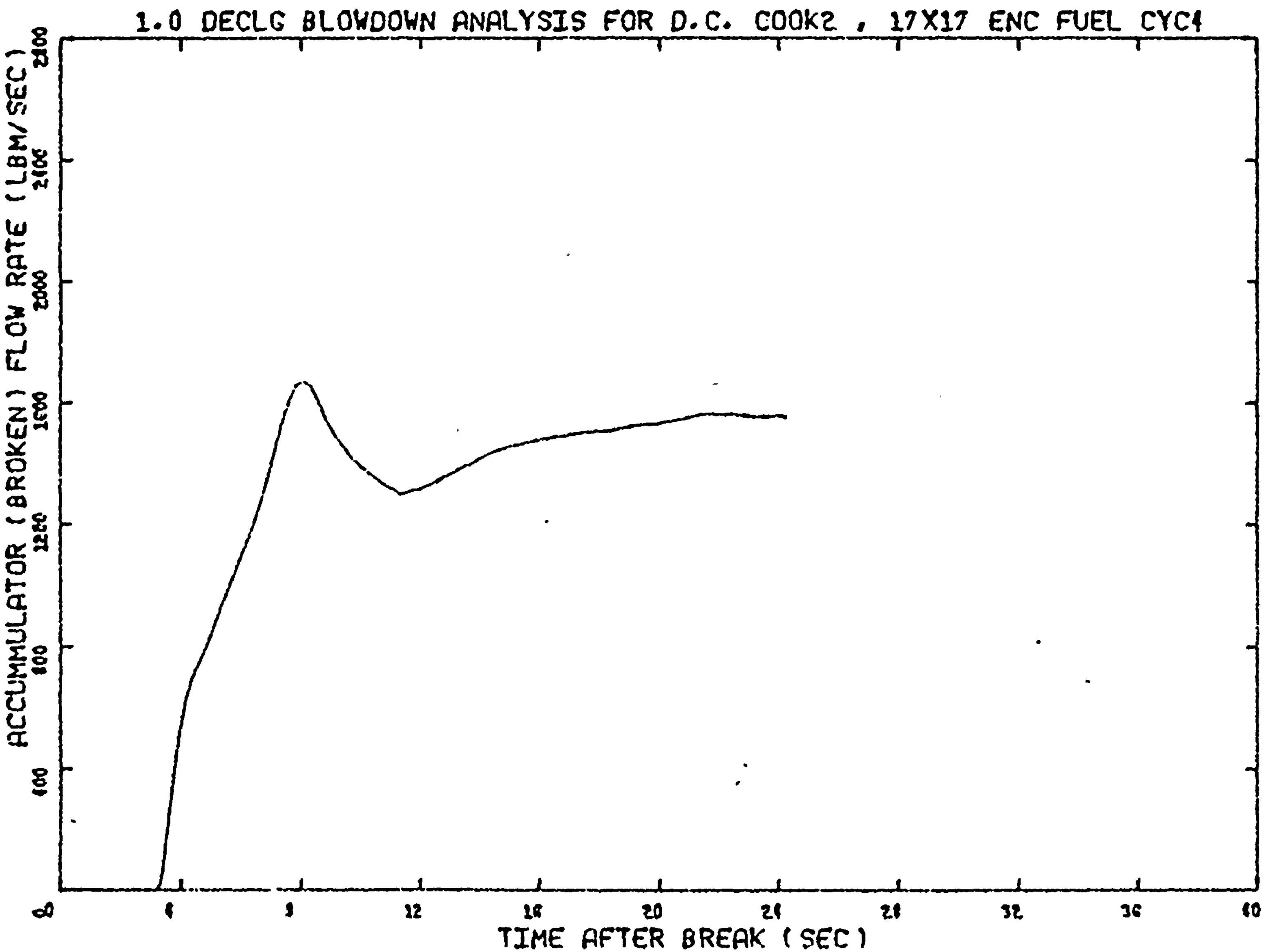

Figure 2.12 Flow From Broken Loop Accumulators, 1.0 DECLG Break
(Single Failure and Full ECCS Flow)

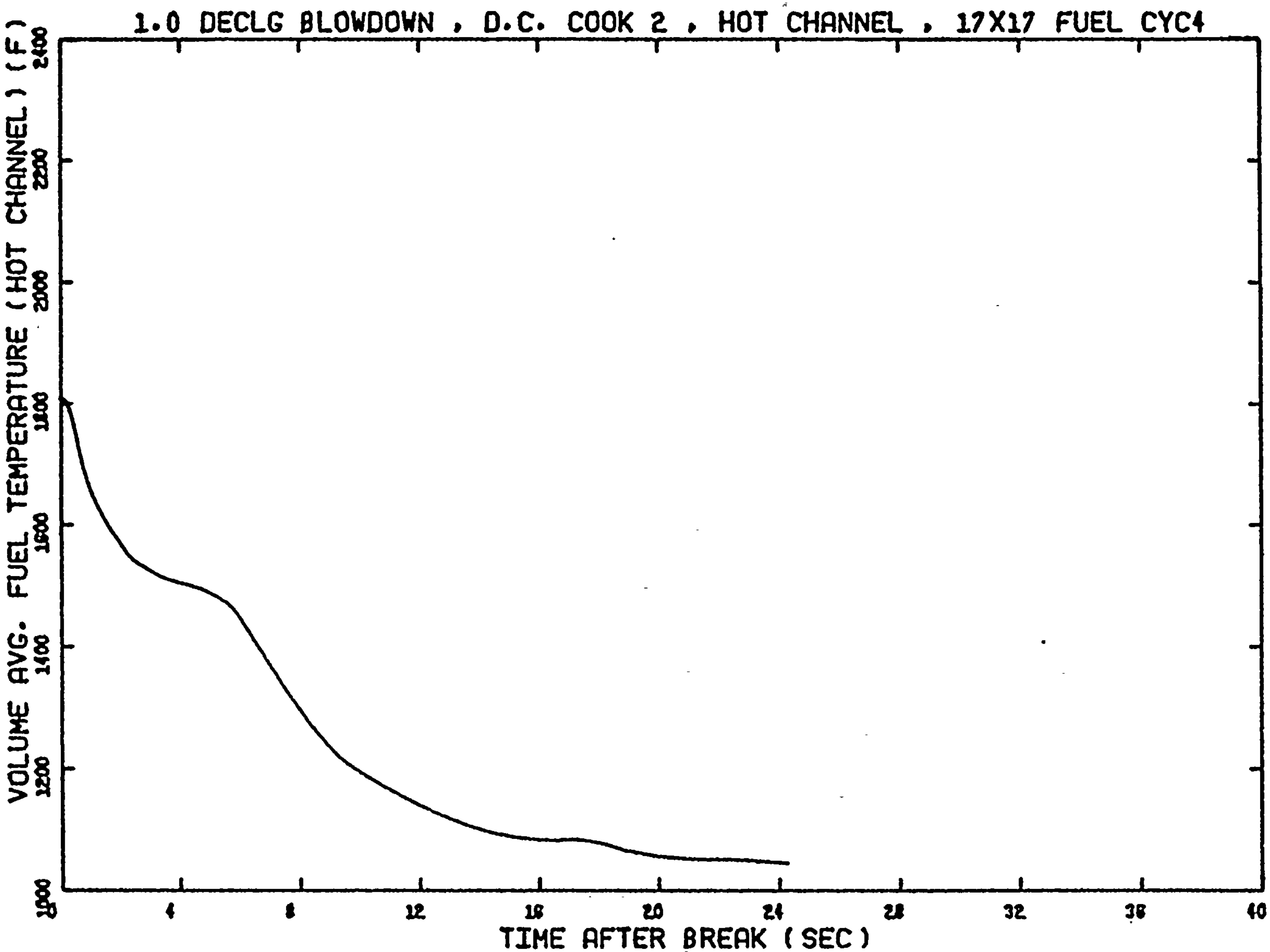

Figure 2.13 Hot Channel Average Fuel Temperature
1.0 DECLG Break (Single Failure)

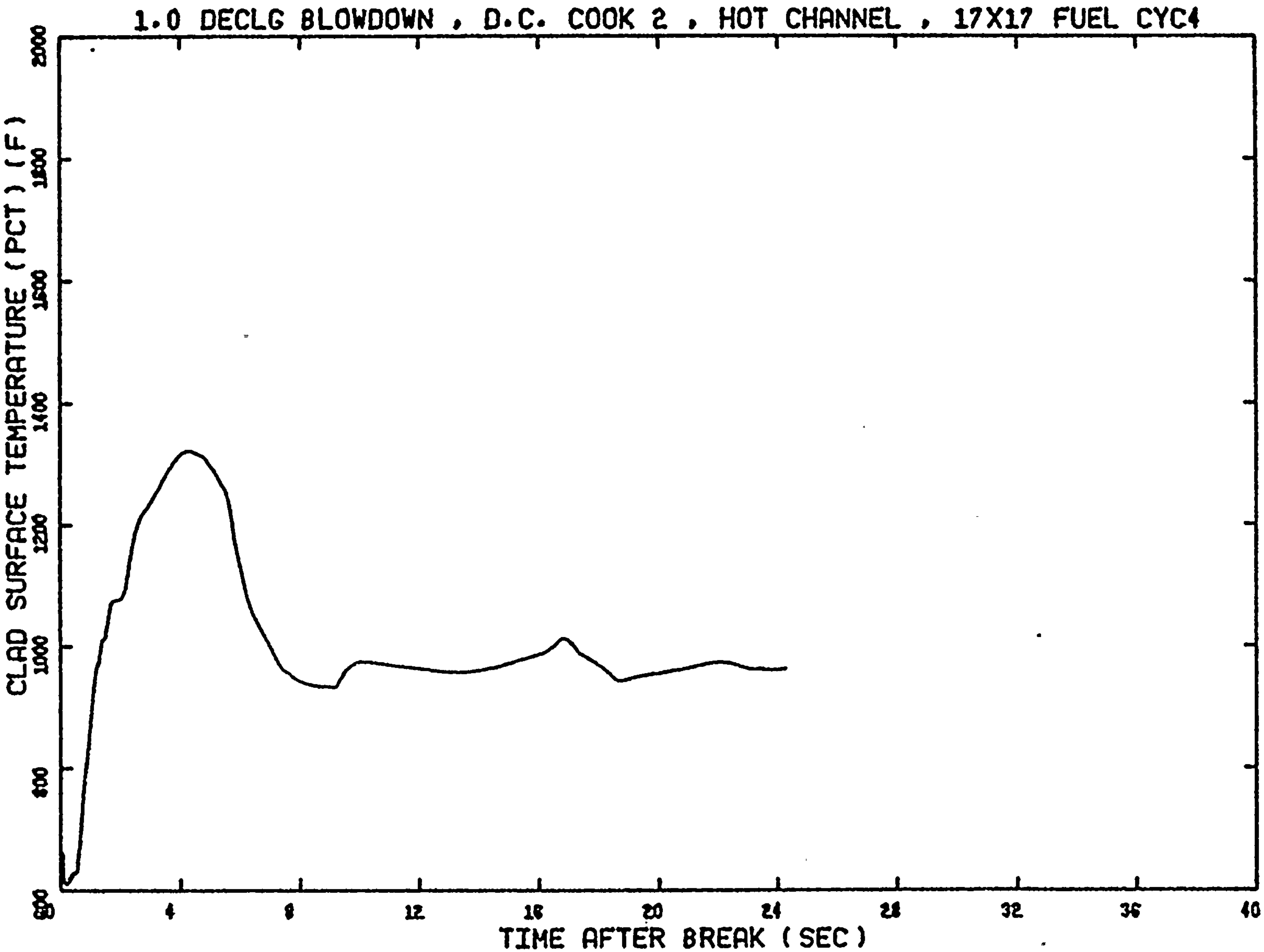

Figure 2.14 Clad Surface Temperature
1.0 DECLG Break (Single Failure)

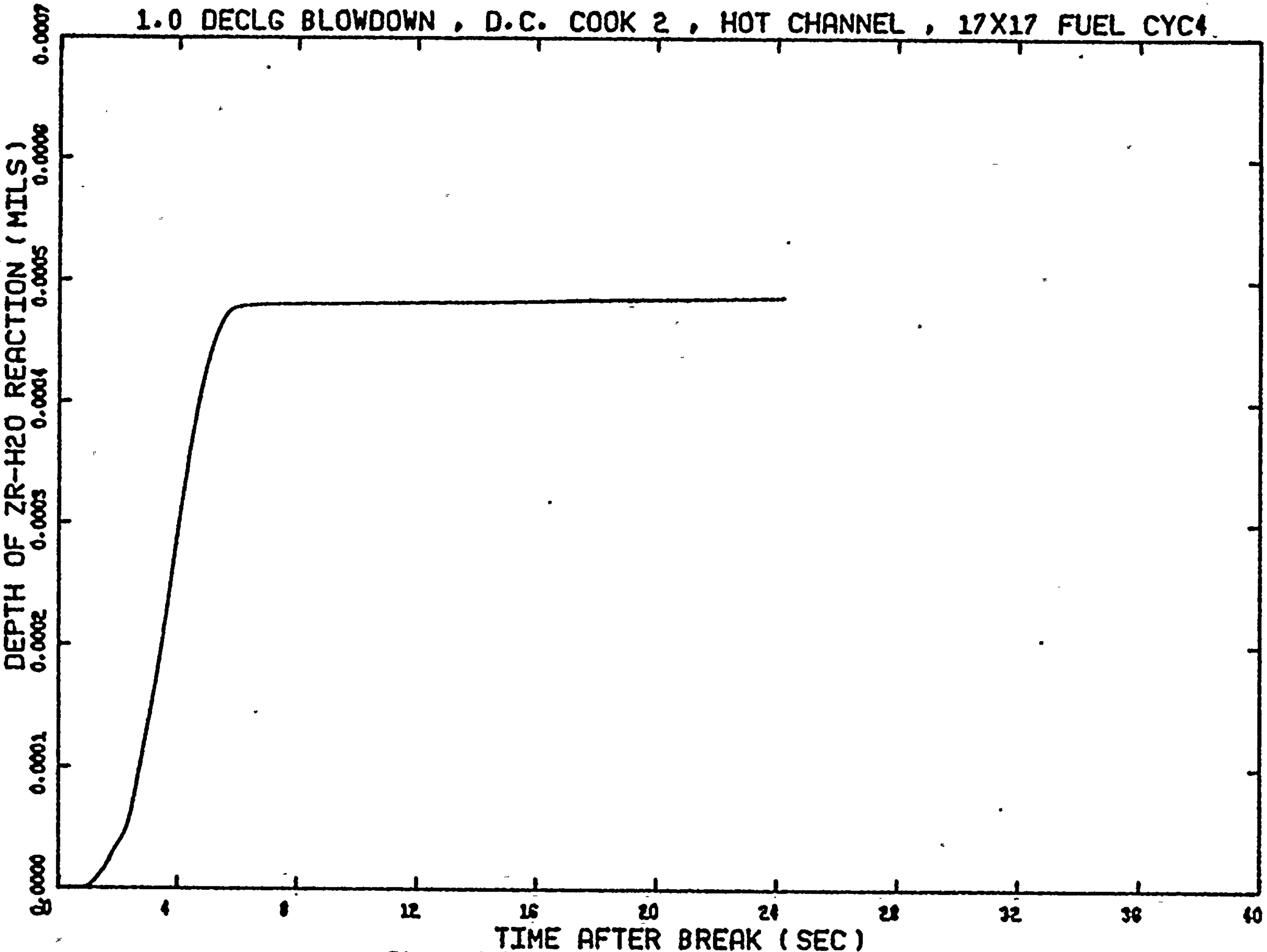

Figure 2.15 Depth of Metal-Water Reaction
1.0 DECLG Break (Single Failure)

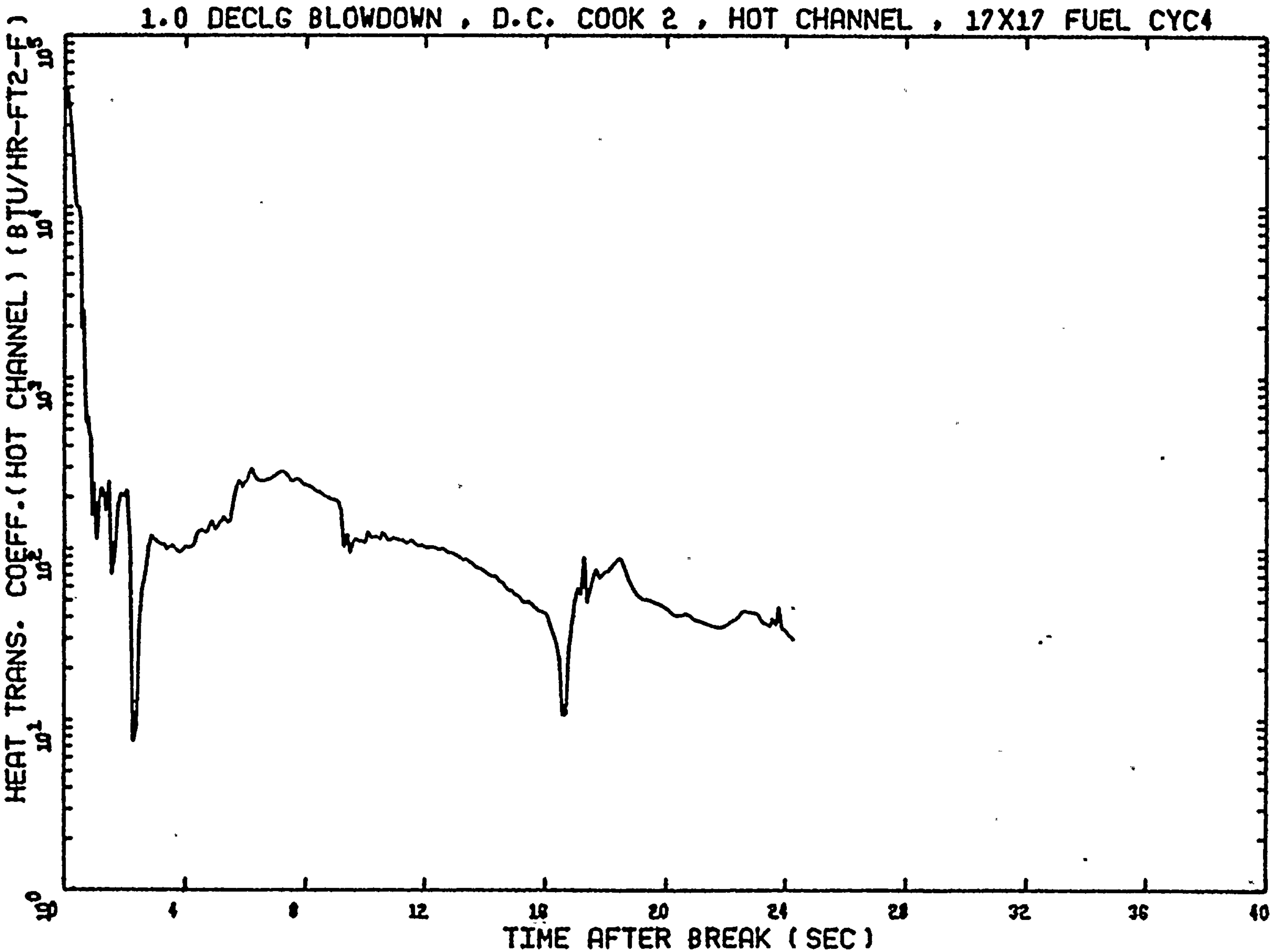

Figure 2.16 Hot Channel Heat Transfer Coefficient
1.0 DECLG Break (Single Failure)

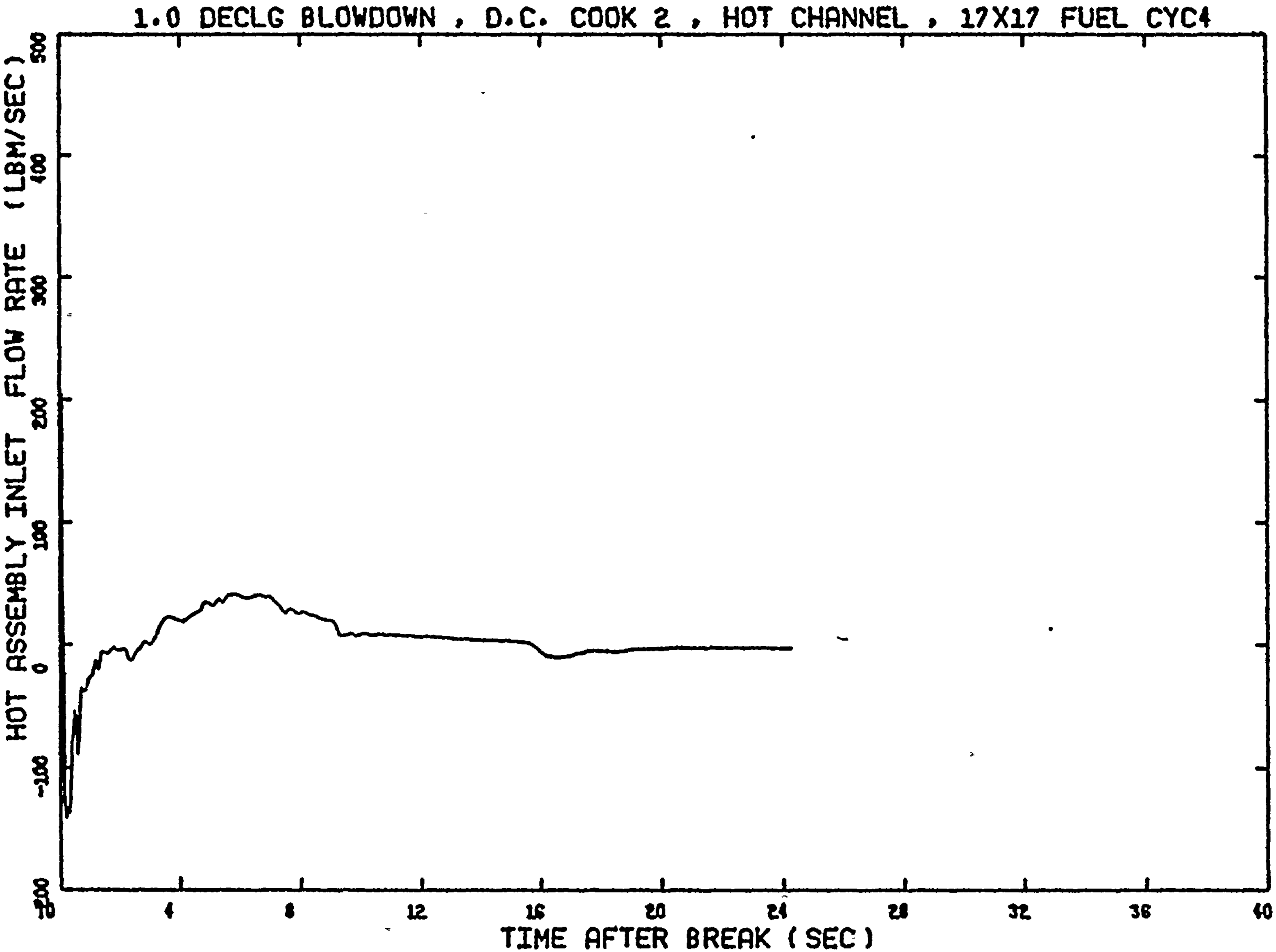

Figure 2.17 Hot Assembly Inlet Flow
1.0 DECLG Break (Single Failure)

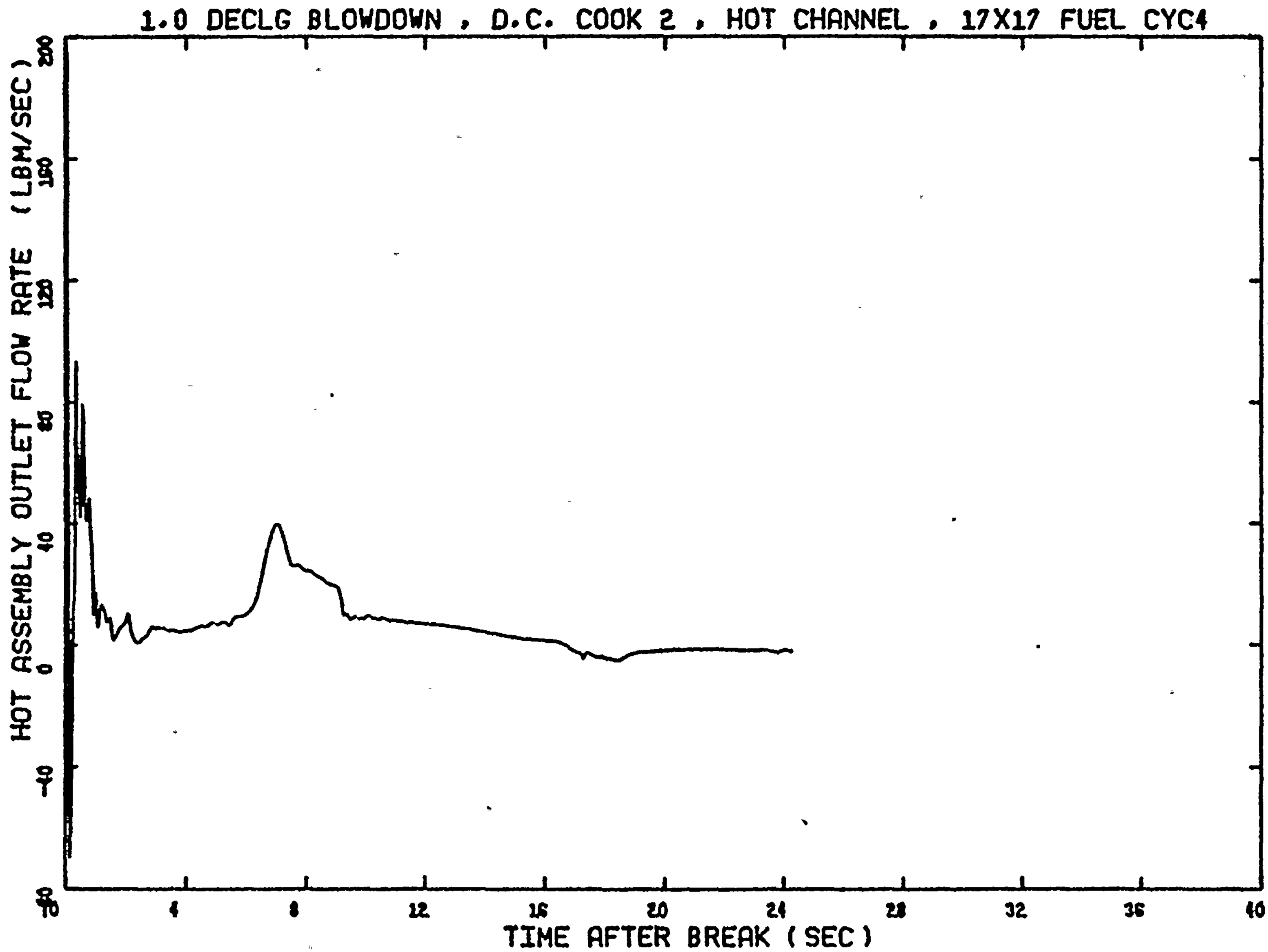

Figure 2.18 Hot Assembly Outlet Flow
1.0 DECLG Break (Single Failure)

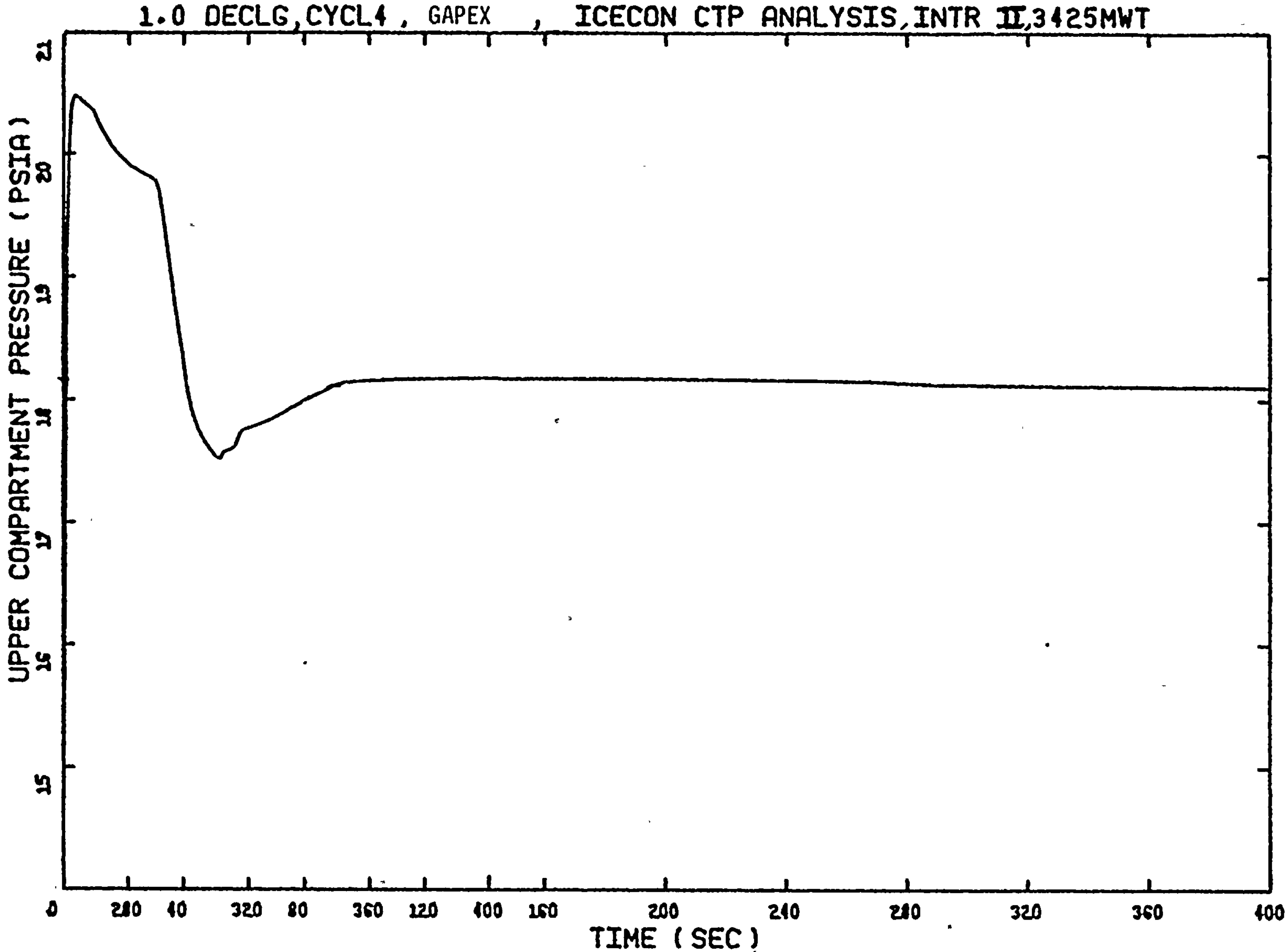

Figure 2.19 ICECON Containment Back Pressure
1.0 DECLG Break (Single Failure)

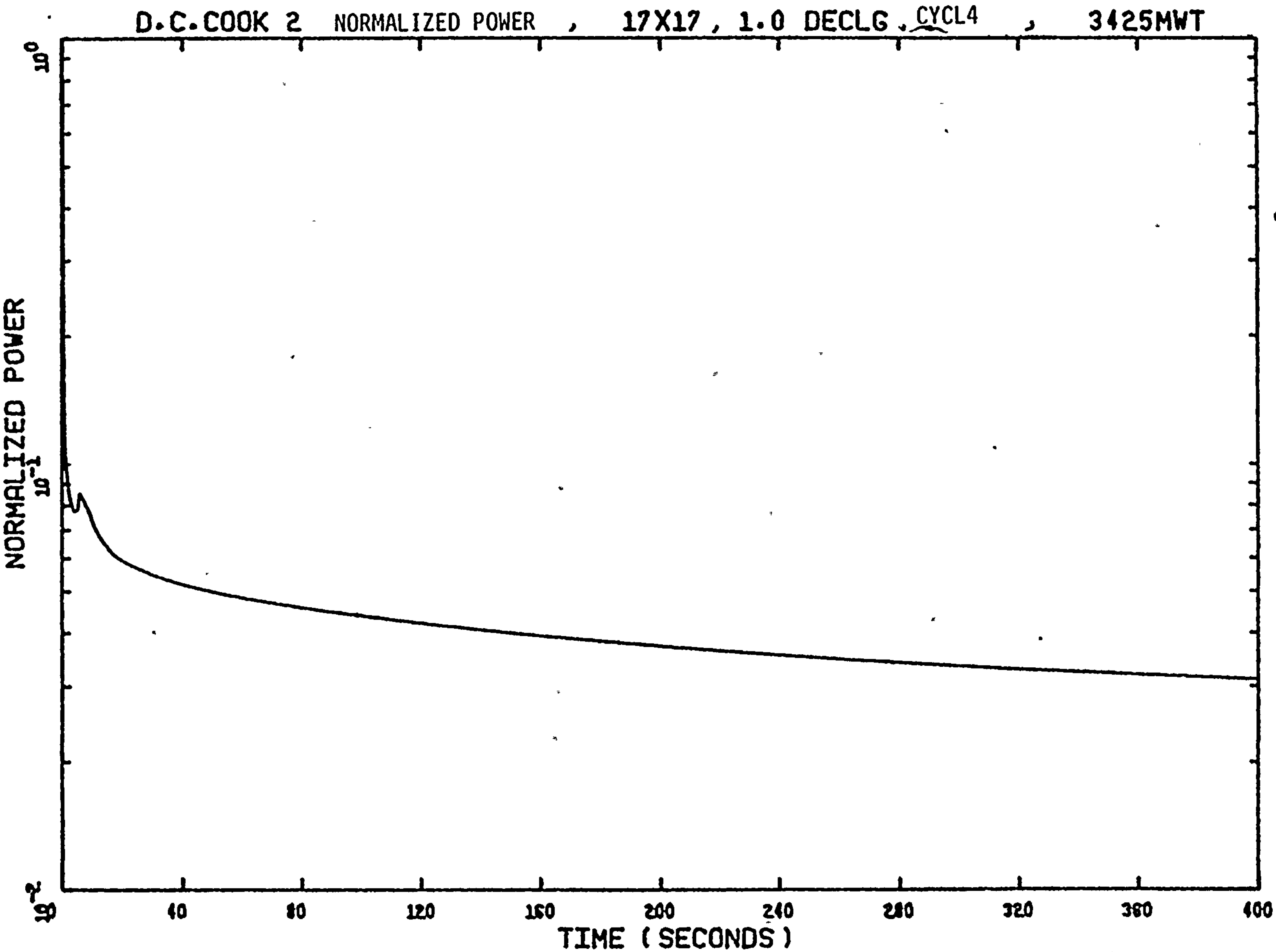

Figure 2.20 Normalized Power 1.0 DECLG Break
(Single Failure and Full ECCS Flow)

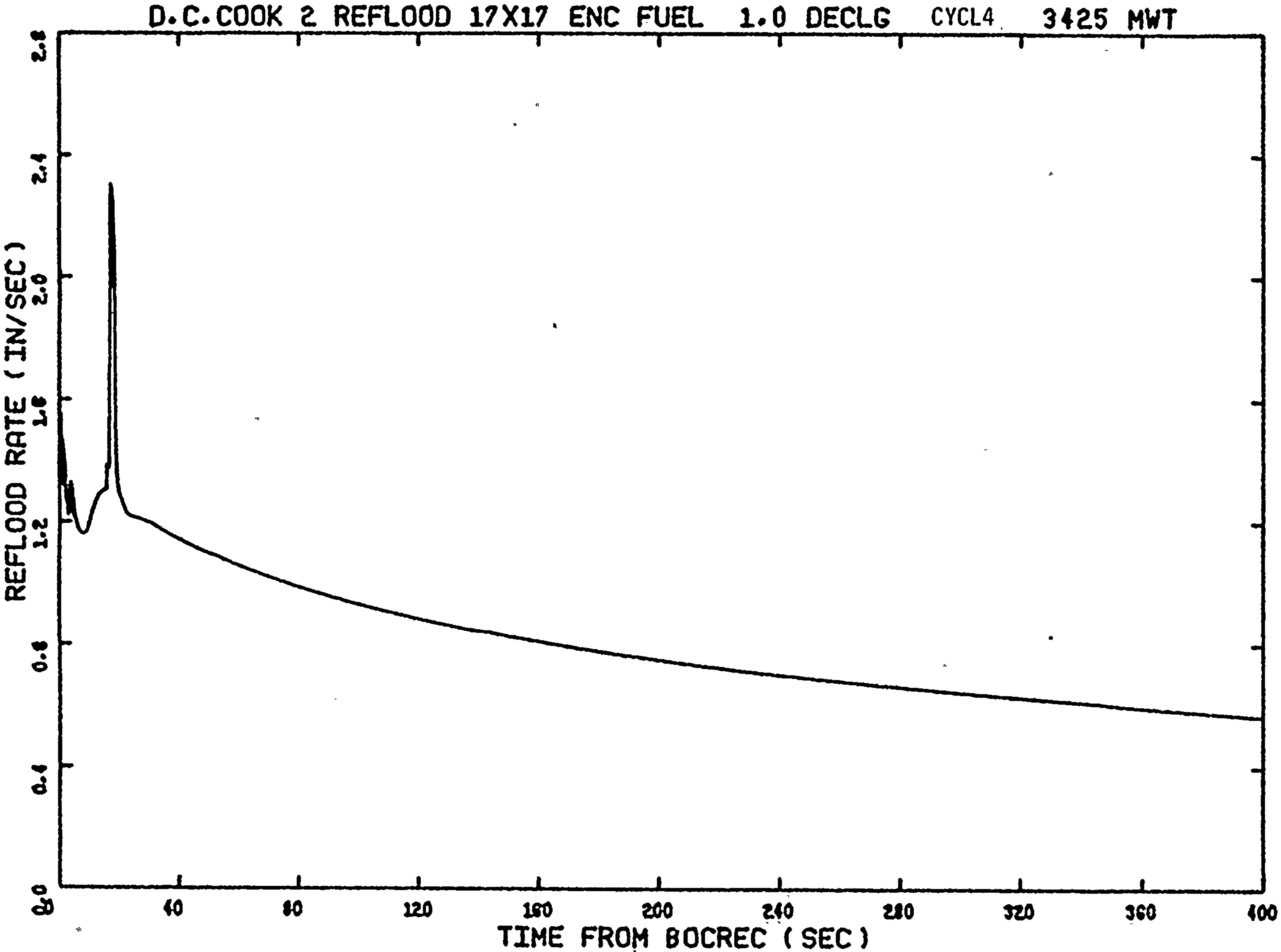

Figure 2.21 Core Flooding Rate 1.0 DECLG Break
(Single Failure)

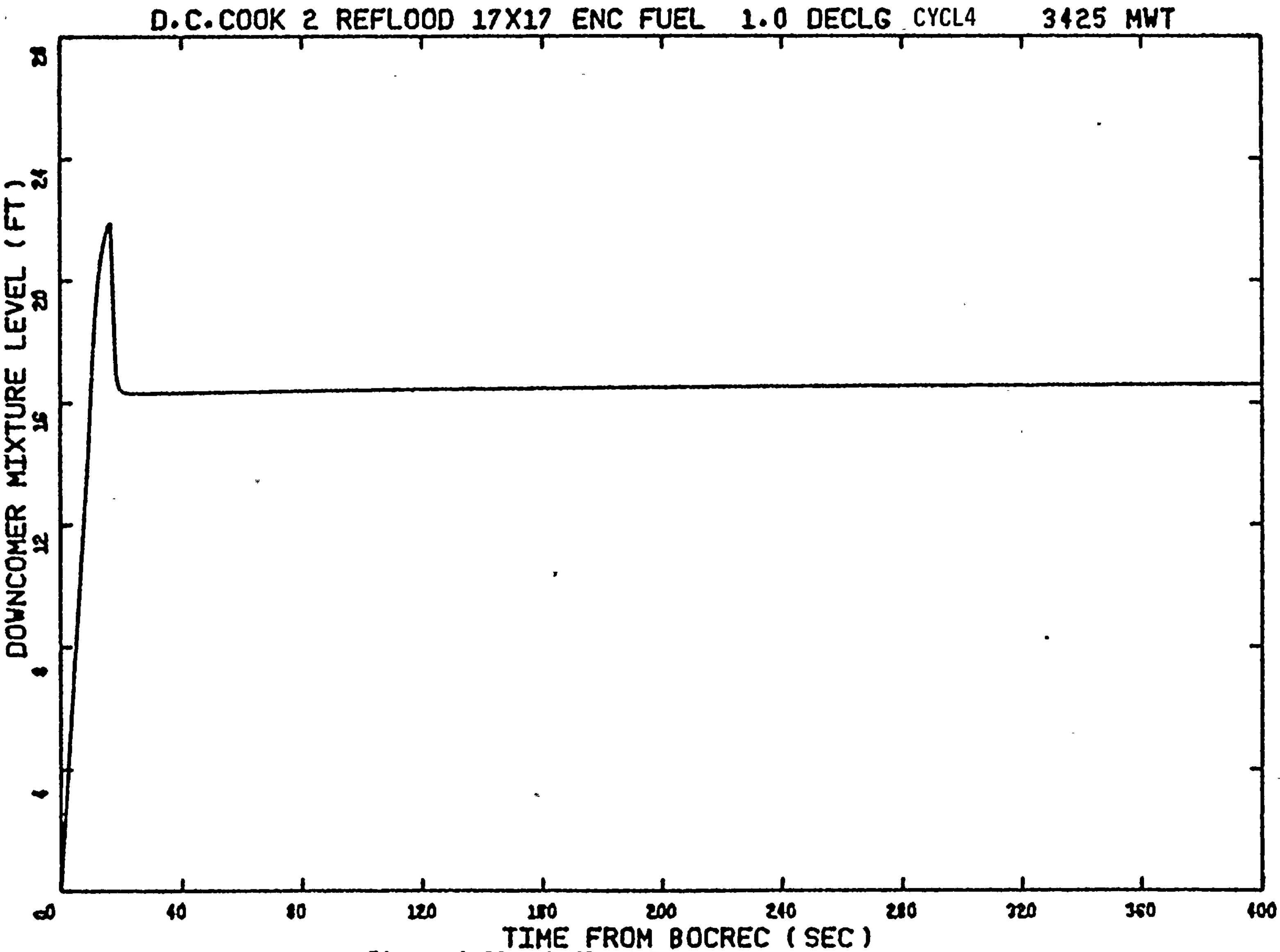

Figure 2.22 Reflood Downcomer Mixture Level
1.0 DECLG Break (Single Failure)

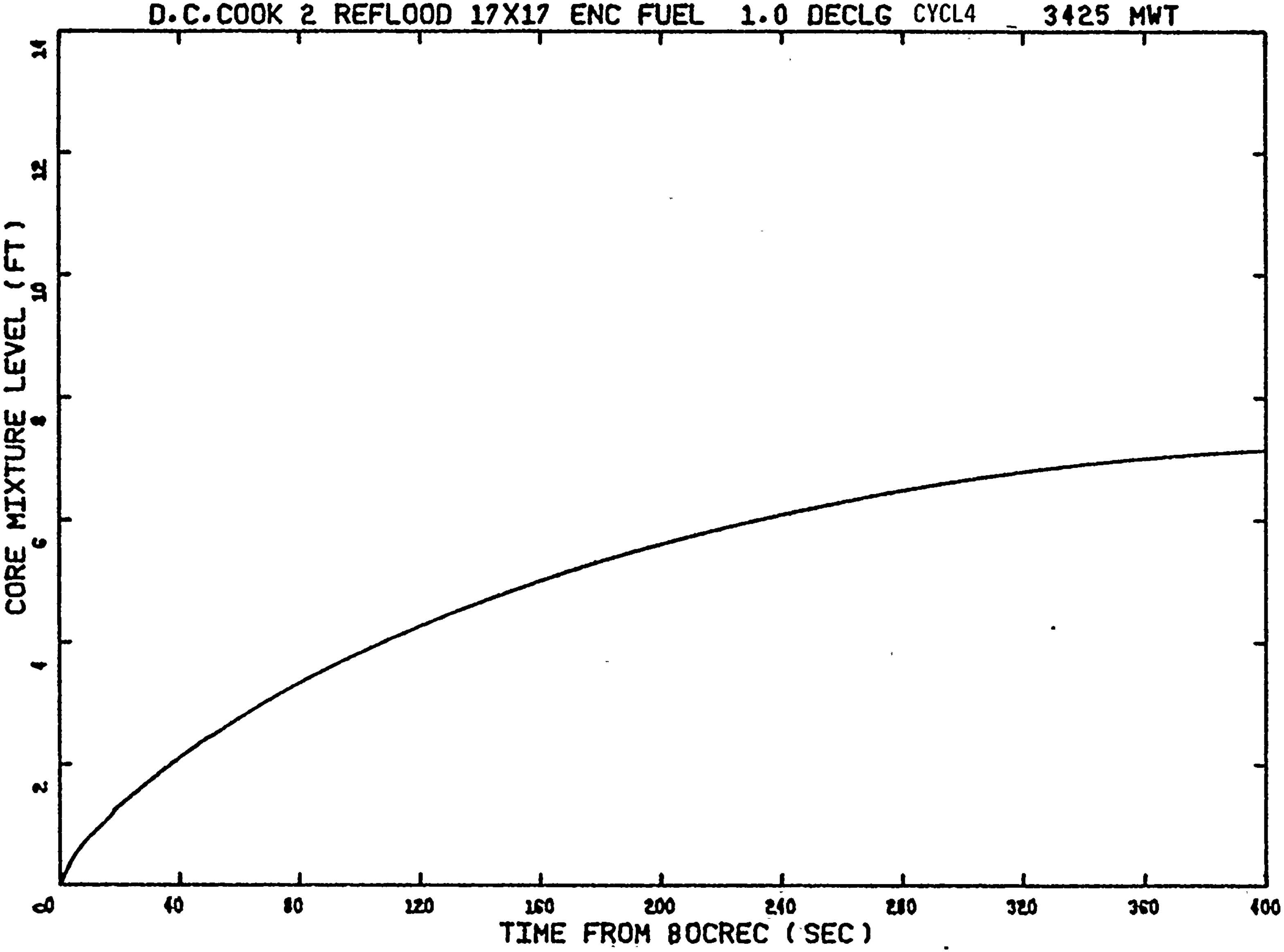

Figure 2.23 Reflood Core Mixture Level
1.0 DECLG Break (Single Failure)

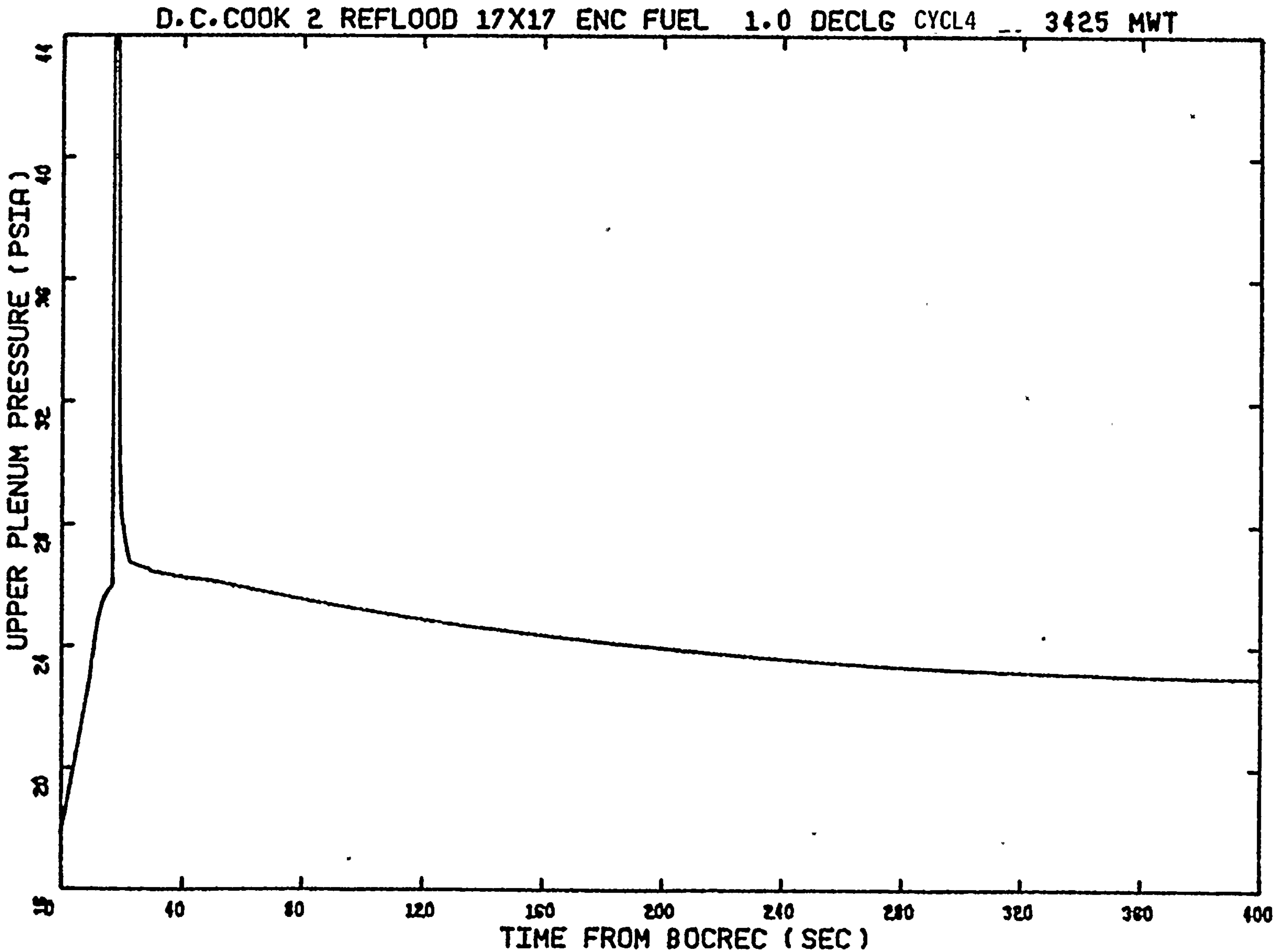

Figure 2.24 Reflood Upper Plenum Pressure
1.0 DECLG Break (Single Failure)

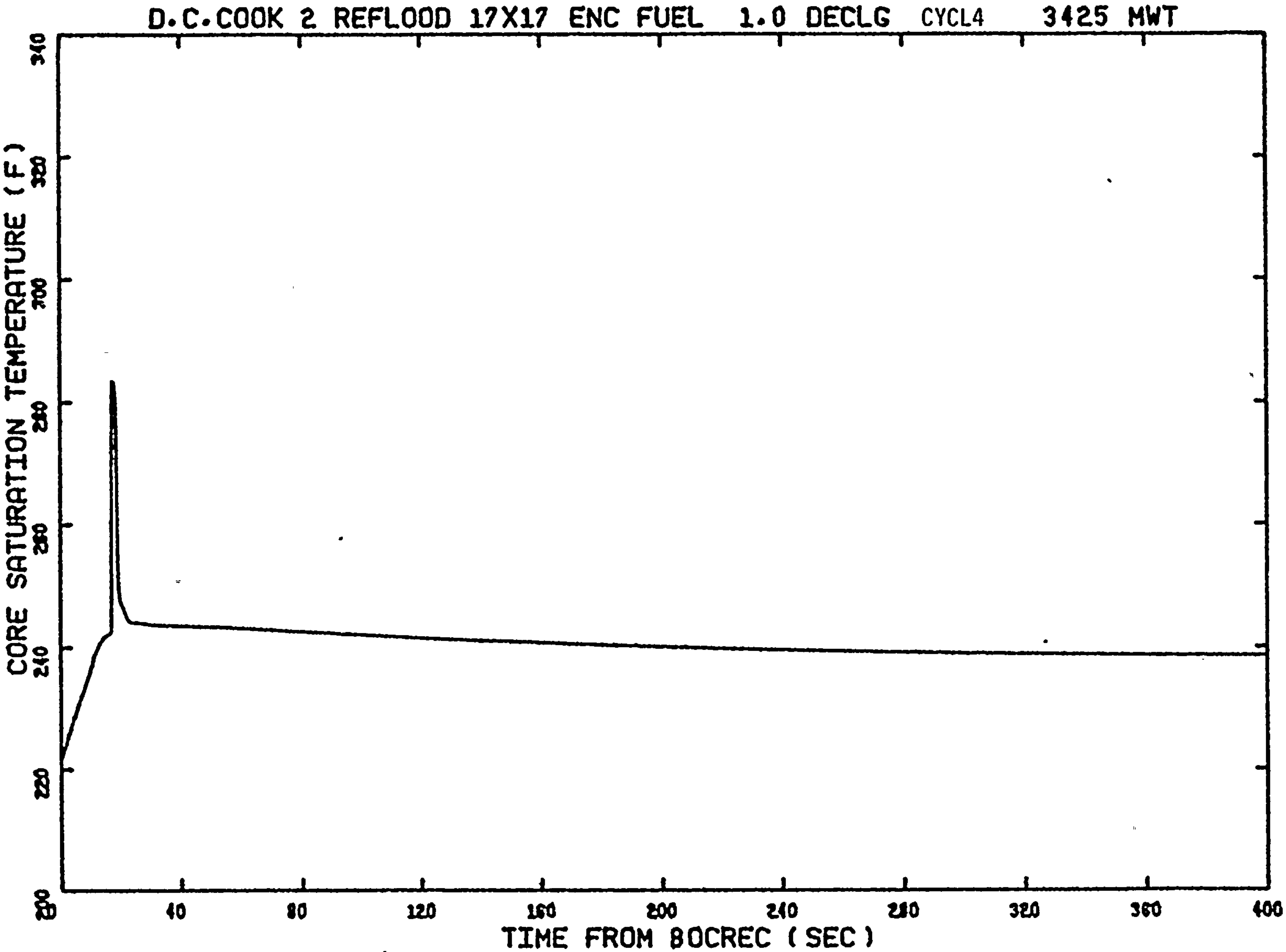

Figure 2.25 Reflood Core Saturation Temperature
1.0 DECLG Break (Single Failure)

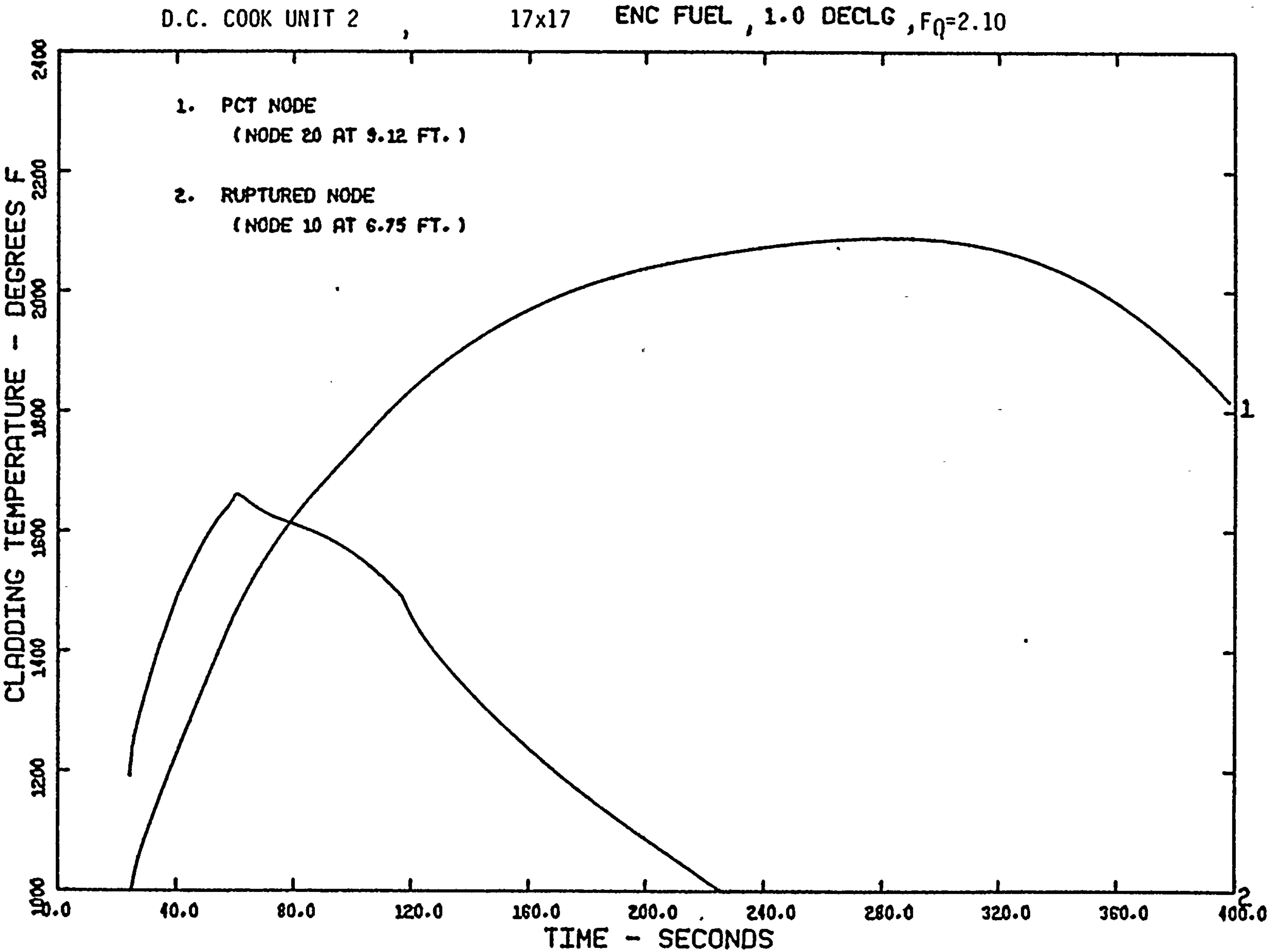

Figure 2.26 TOODEE2 Cladding Temperature vs. Time
1.0 DECLG Break (Single Failure)

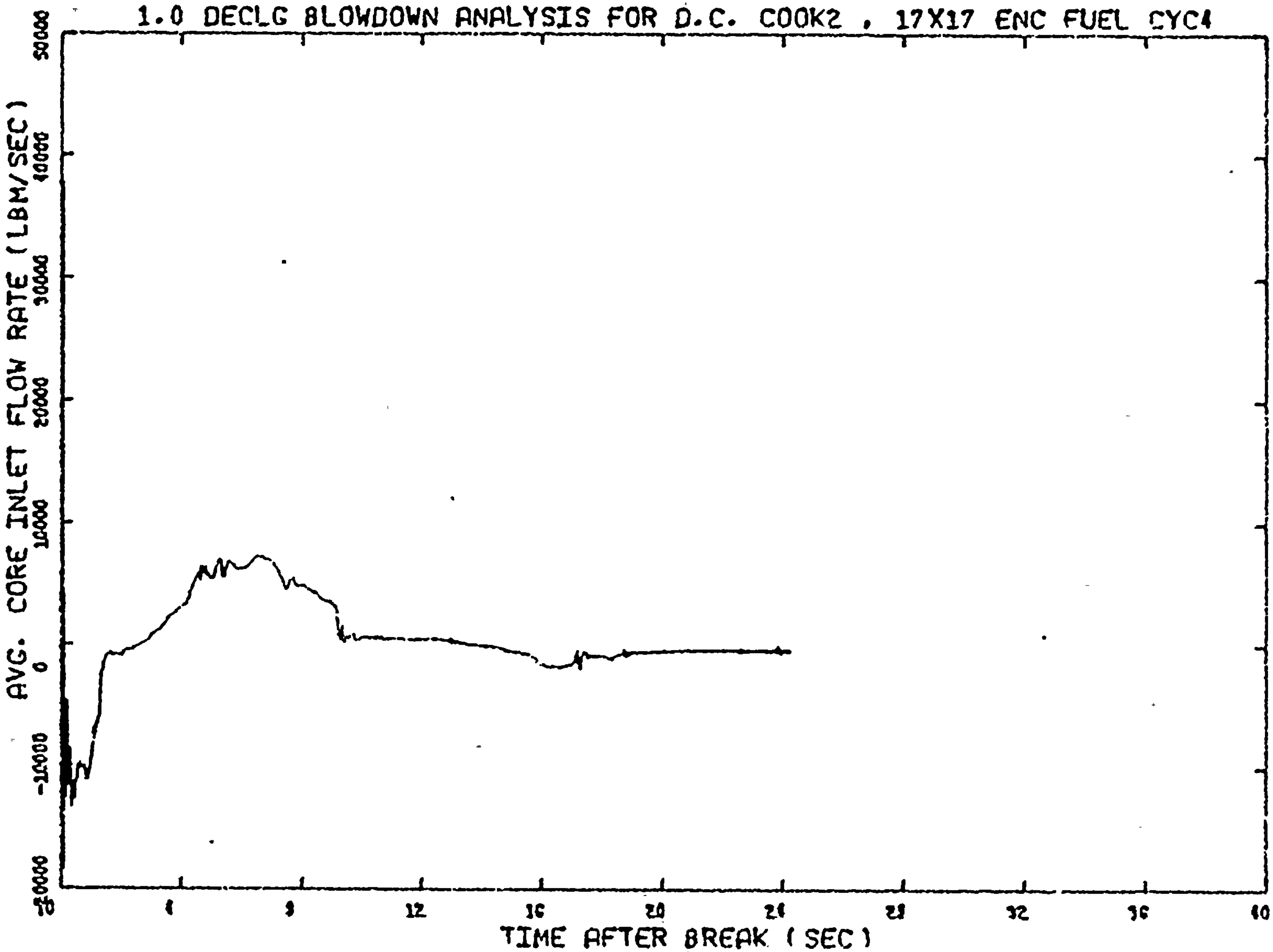

Figure 2.27 Average Core Inlet Flow
1.0 DECLG Break (Full ECCS Flow)

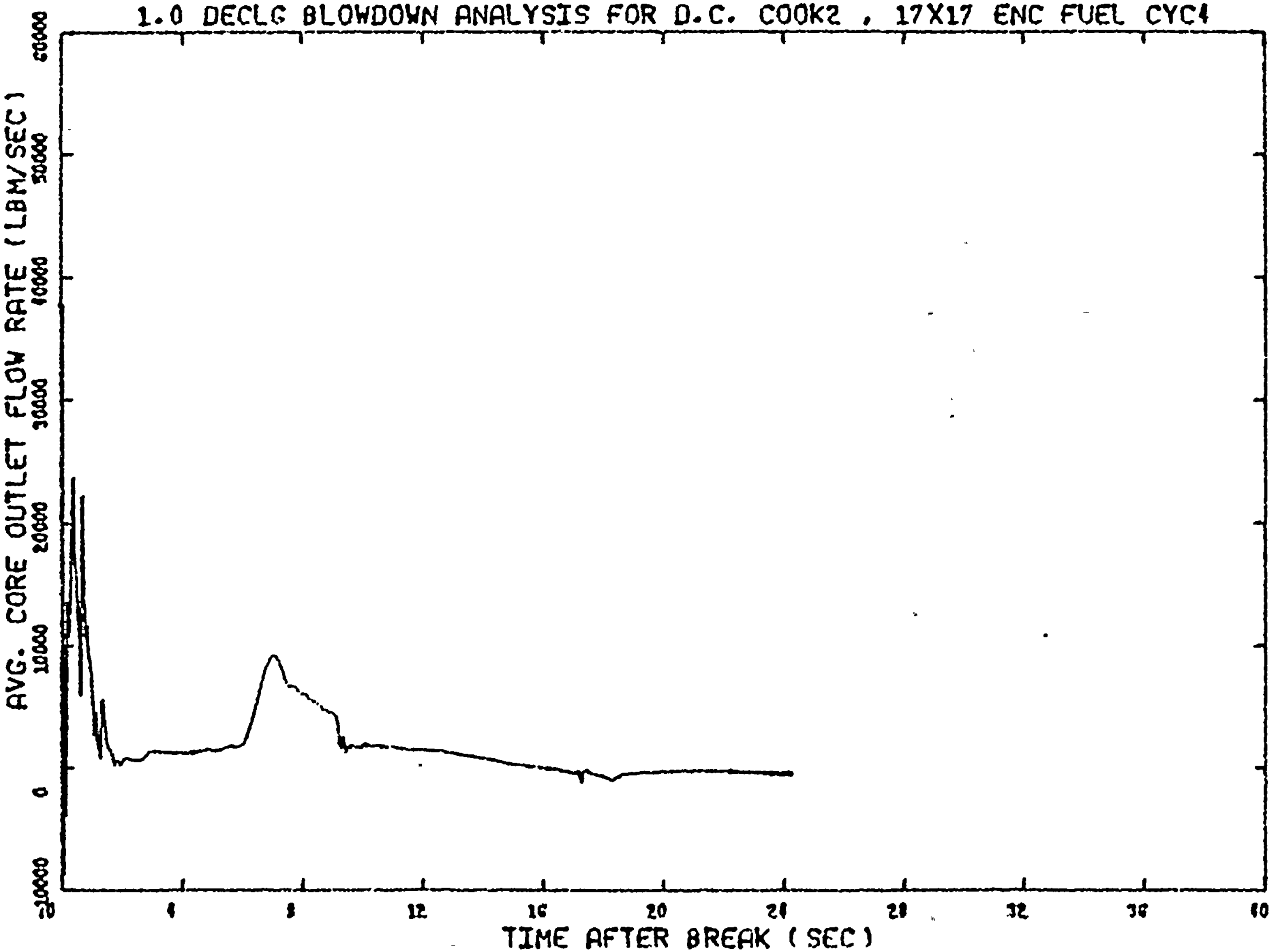

Figure 2.28 Average Core Outlet Flow
1.0 DECLG Break (Full ECCS Flow)

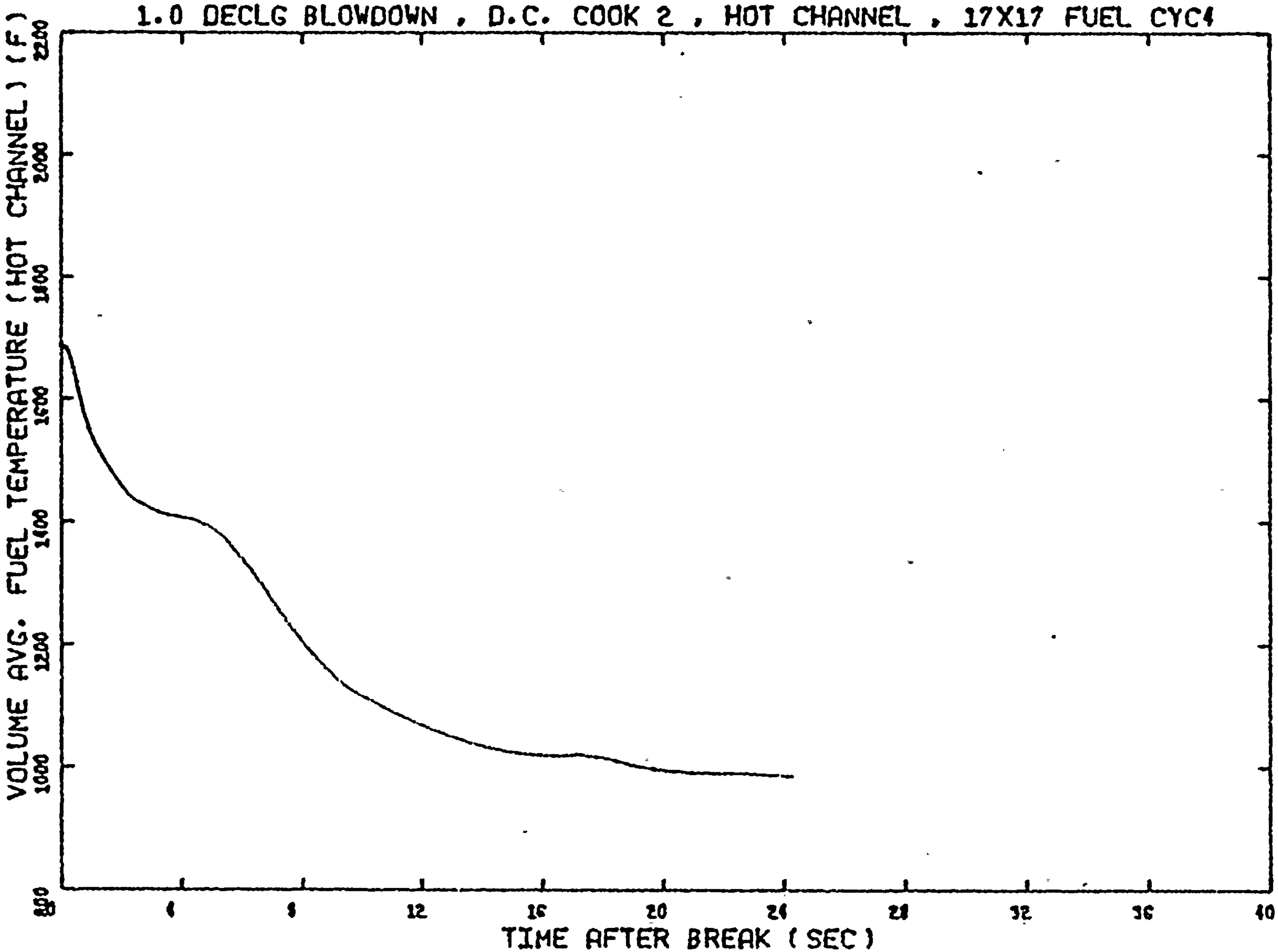

Figure 2.29 Hot Channel Average Fuel Temperature
1.0 DECLG Break (Full ECCS Flow)

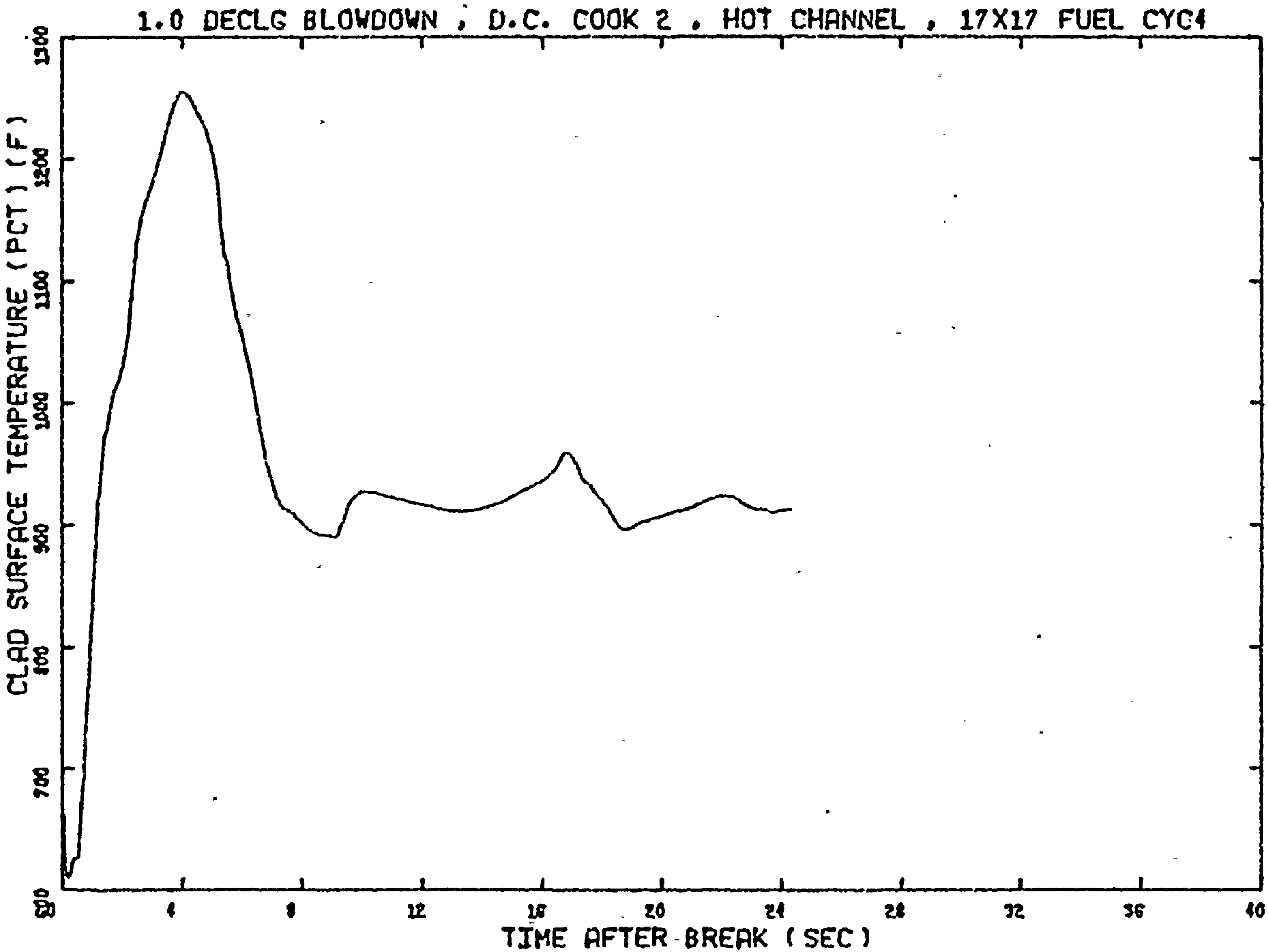

Figure 2.30 Clad Surface Temperature
1.0 DECLG Break (Full ECCS Flow)

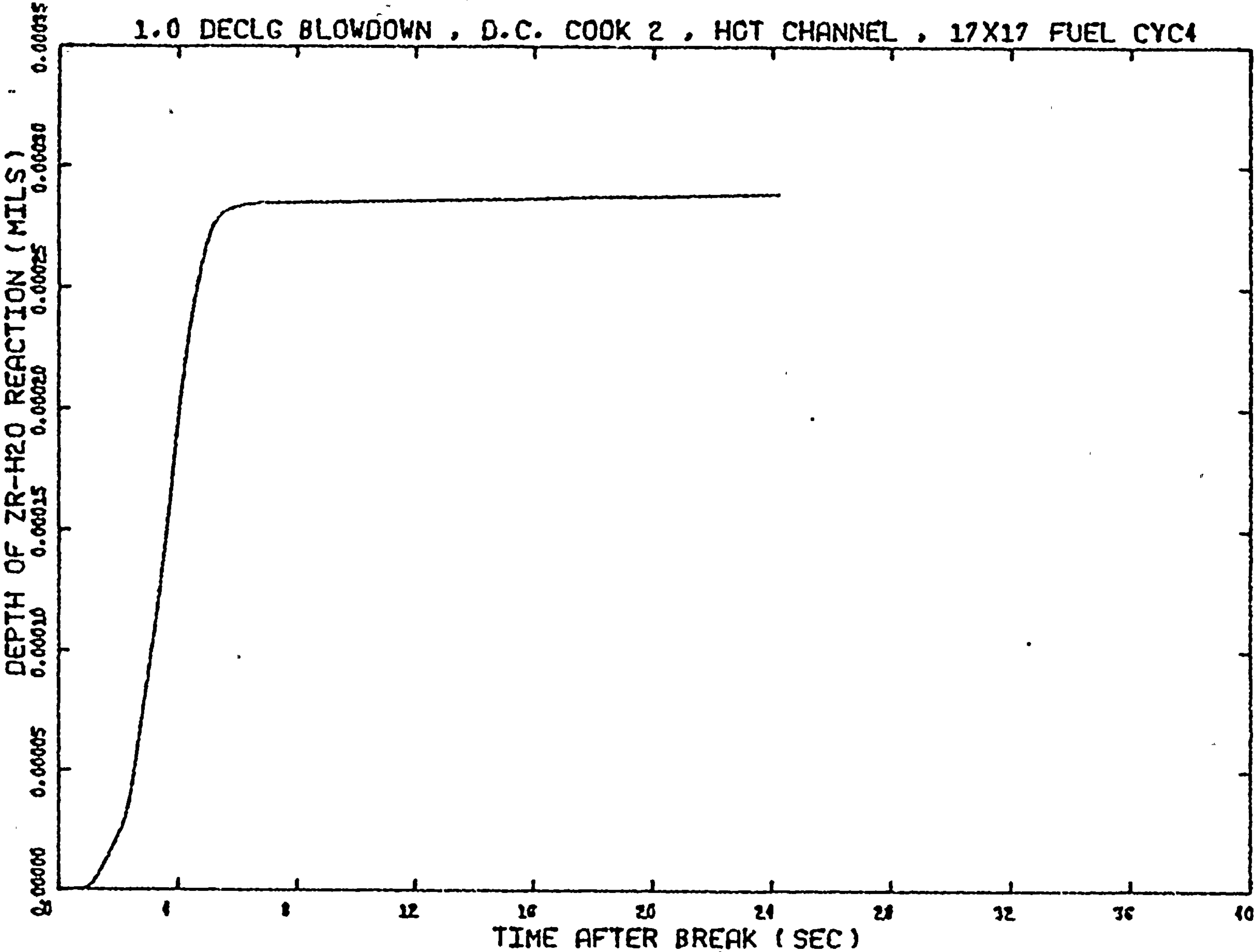

Figure 2.31 Depth of Metal-Water Reaction
1.0 DECLG Break (Full ECCS Flow)

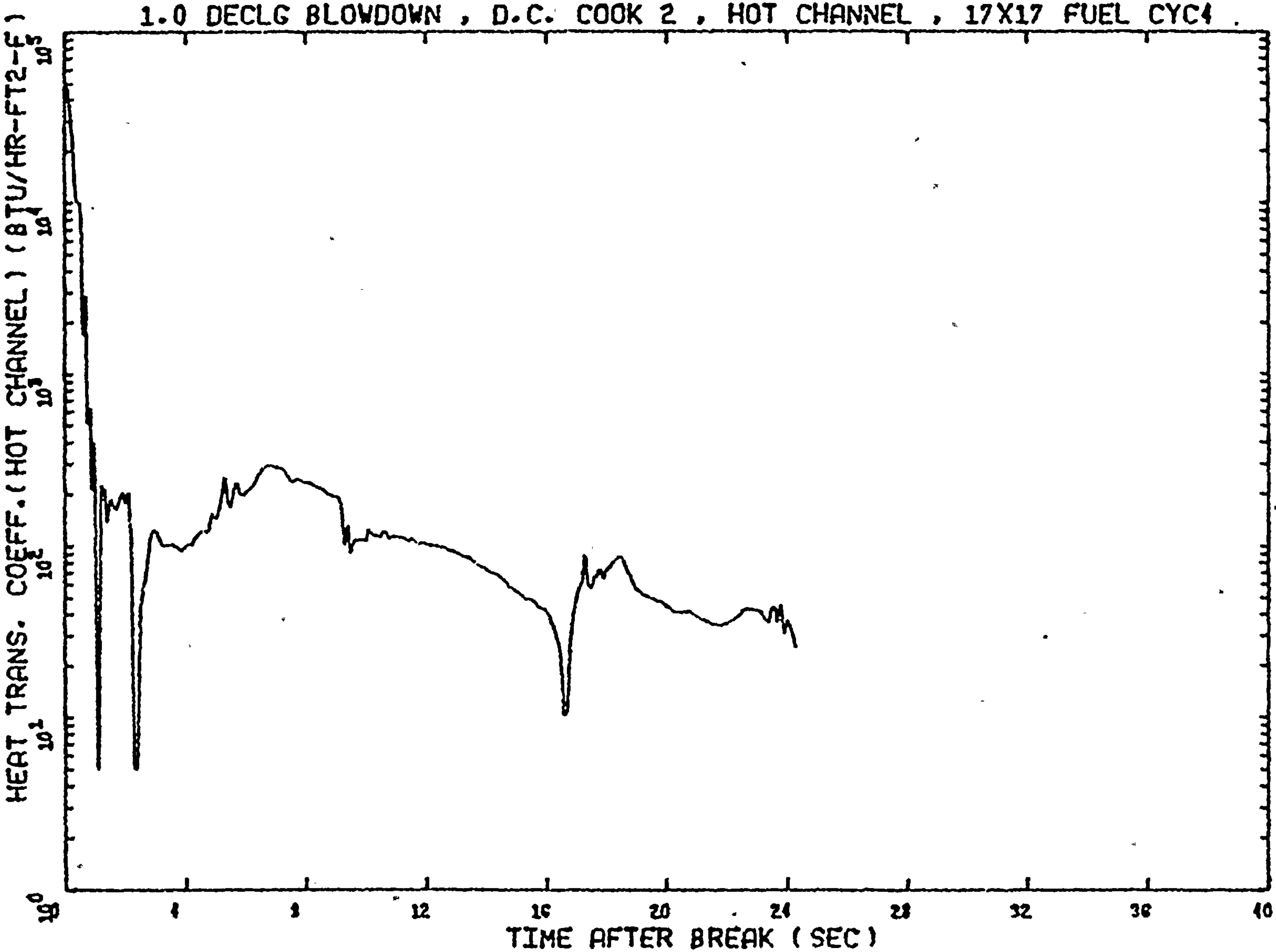

Figure 2.32 Hot Channel Heat Transfer Coefficient
1.0 DECLG Break (Full ECCS Flow)

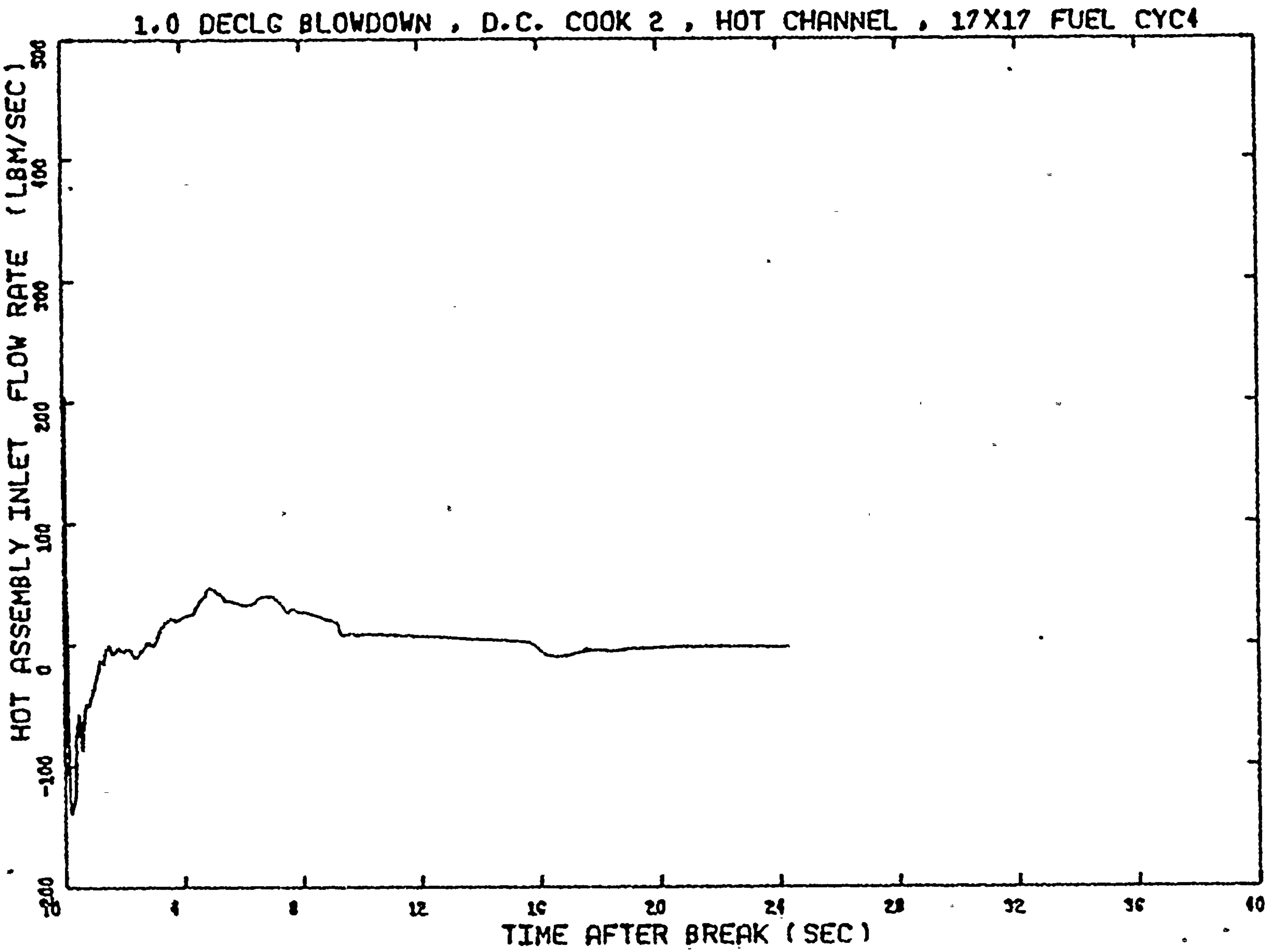

Figure 2.33 Hot Assembly Inlet Flow
1.0 DECLG Break (Full ECCS Flow)

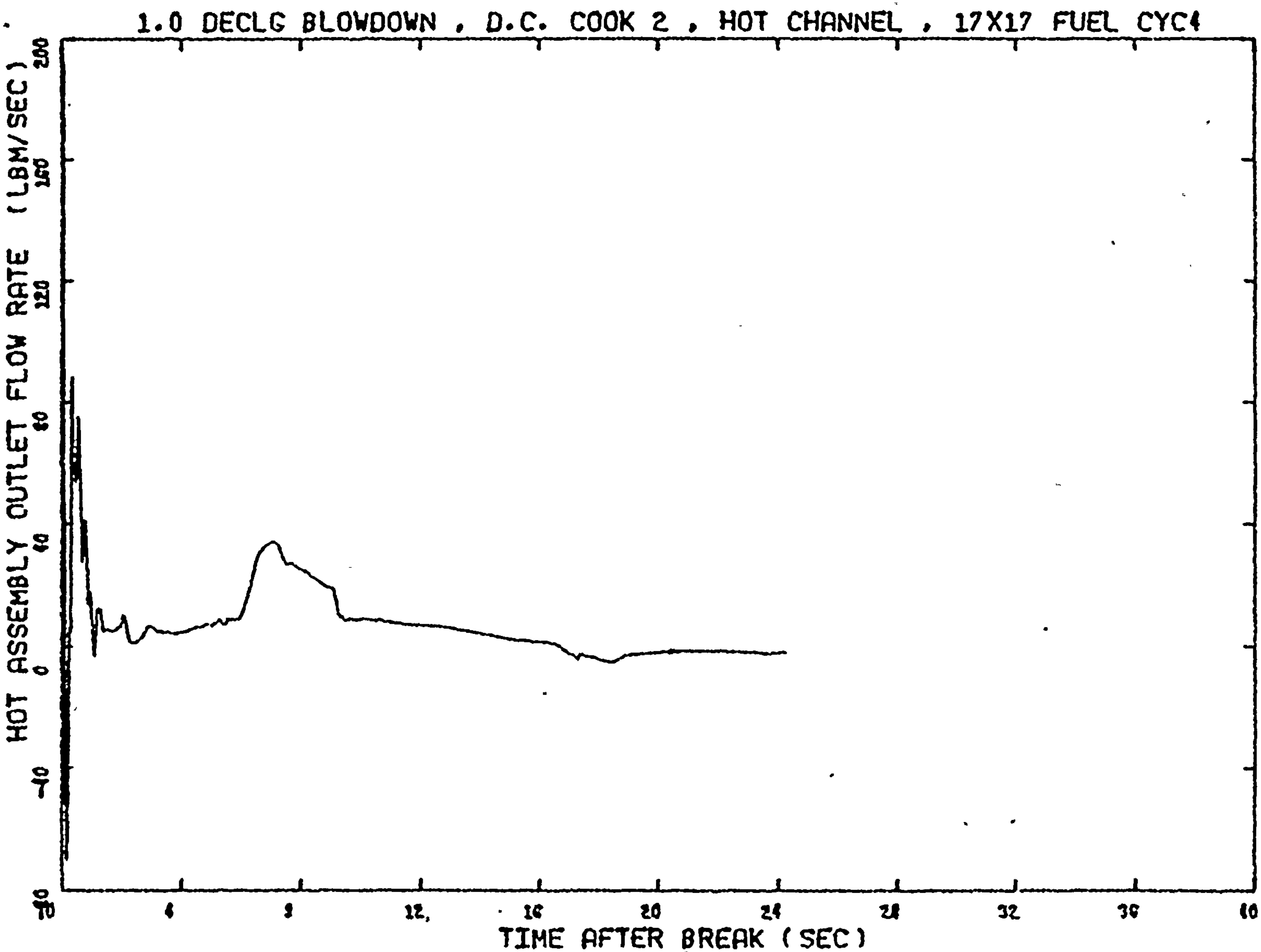

Figure 2.34 Hot Assembly Outlet Flow
1.0 DECLG Break (Full ECCS Flow)

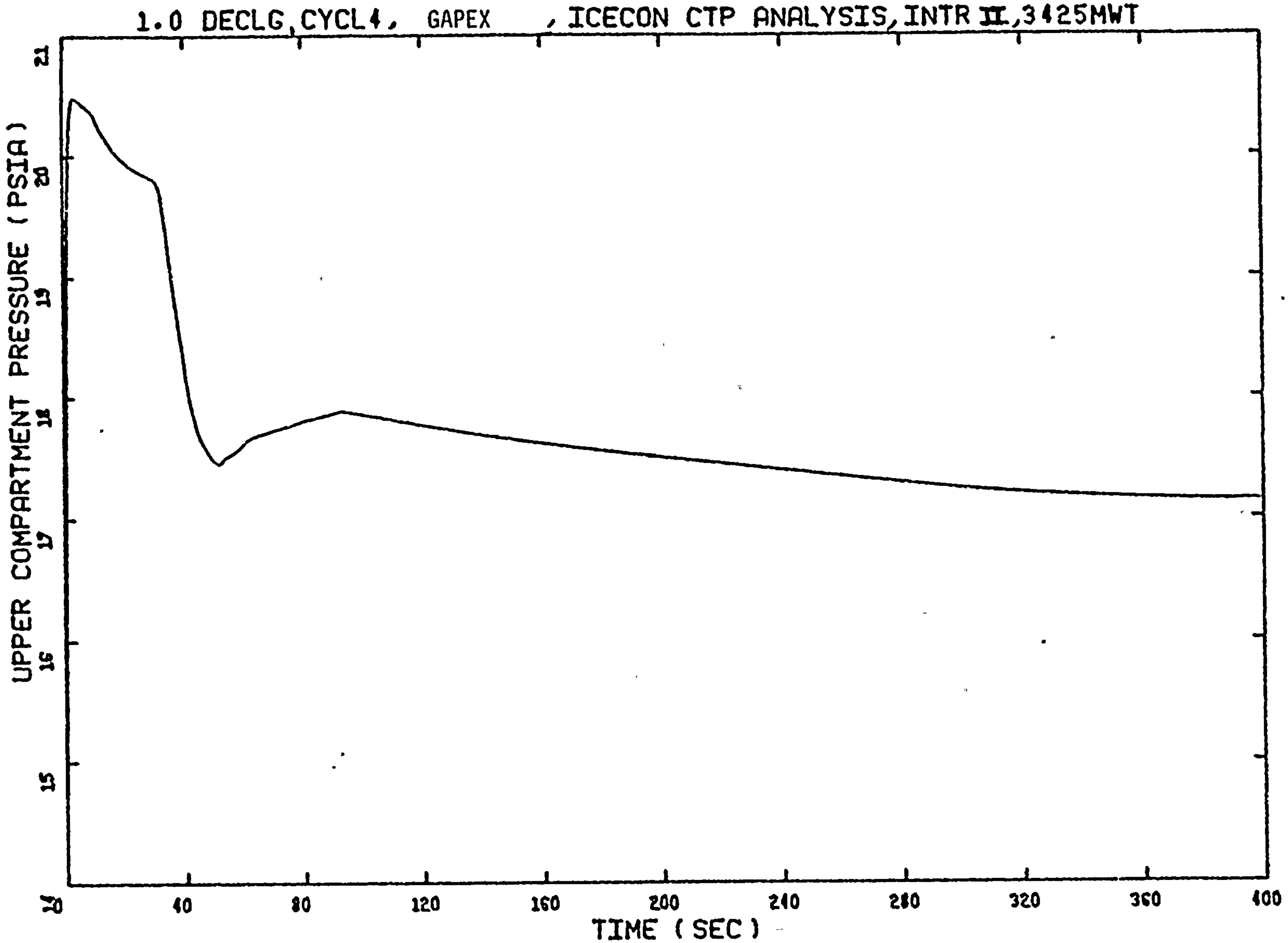

Figure 2.35 ICECON Containment Back Pressure
1.0 DECLG Break (Full ECCS Flow)

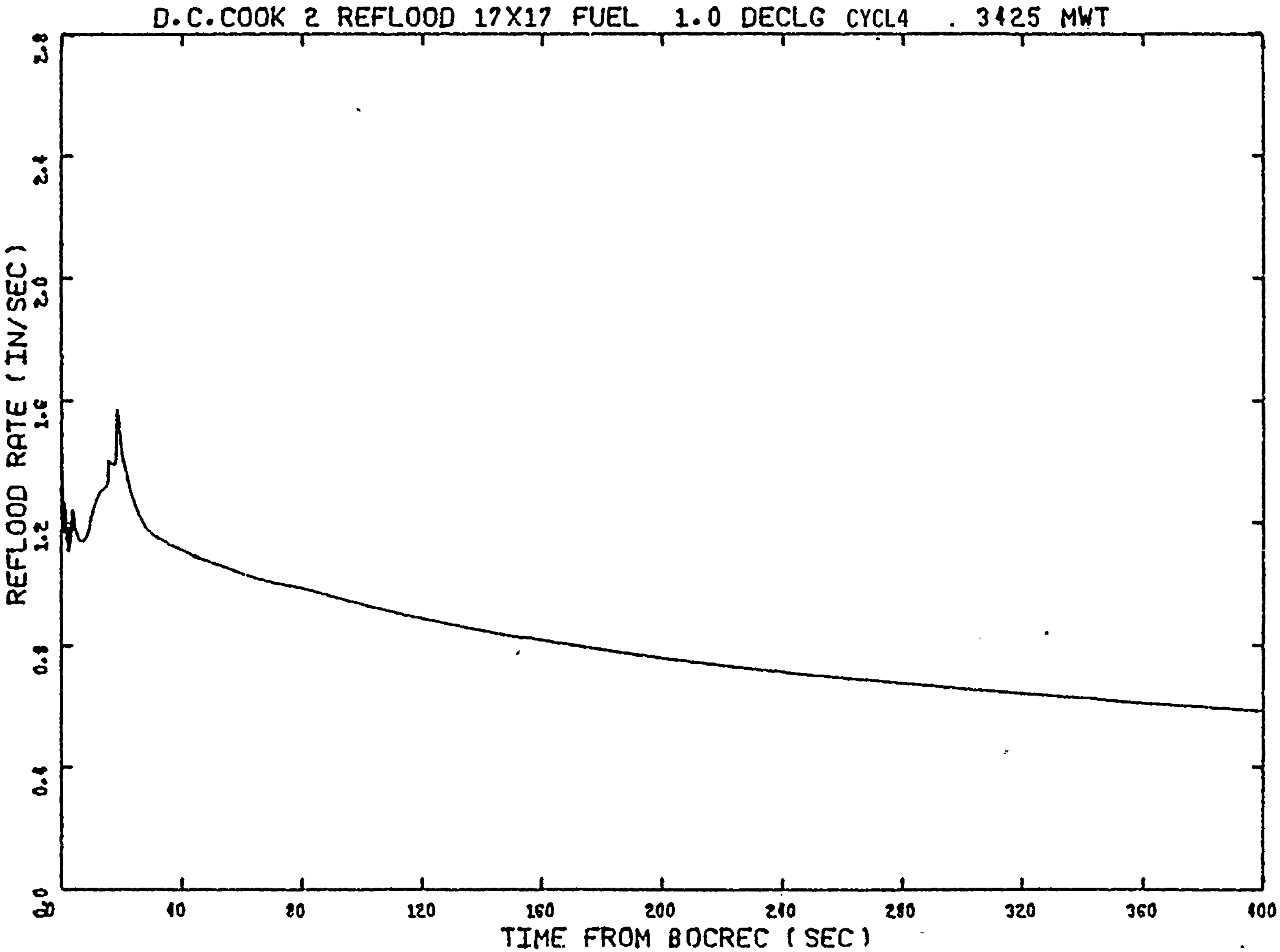

Figure 2.36 Core Flooding Rate
1.0 DECLG Break (Full ECCS Flow)

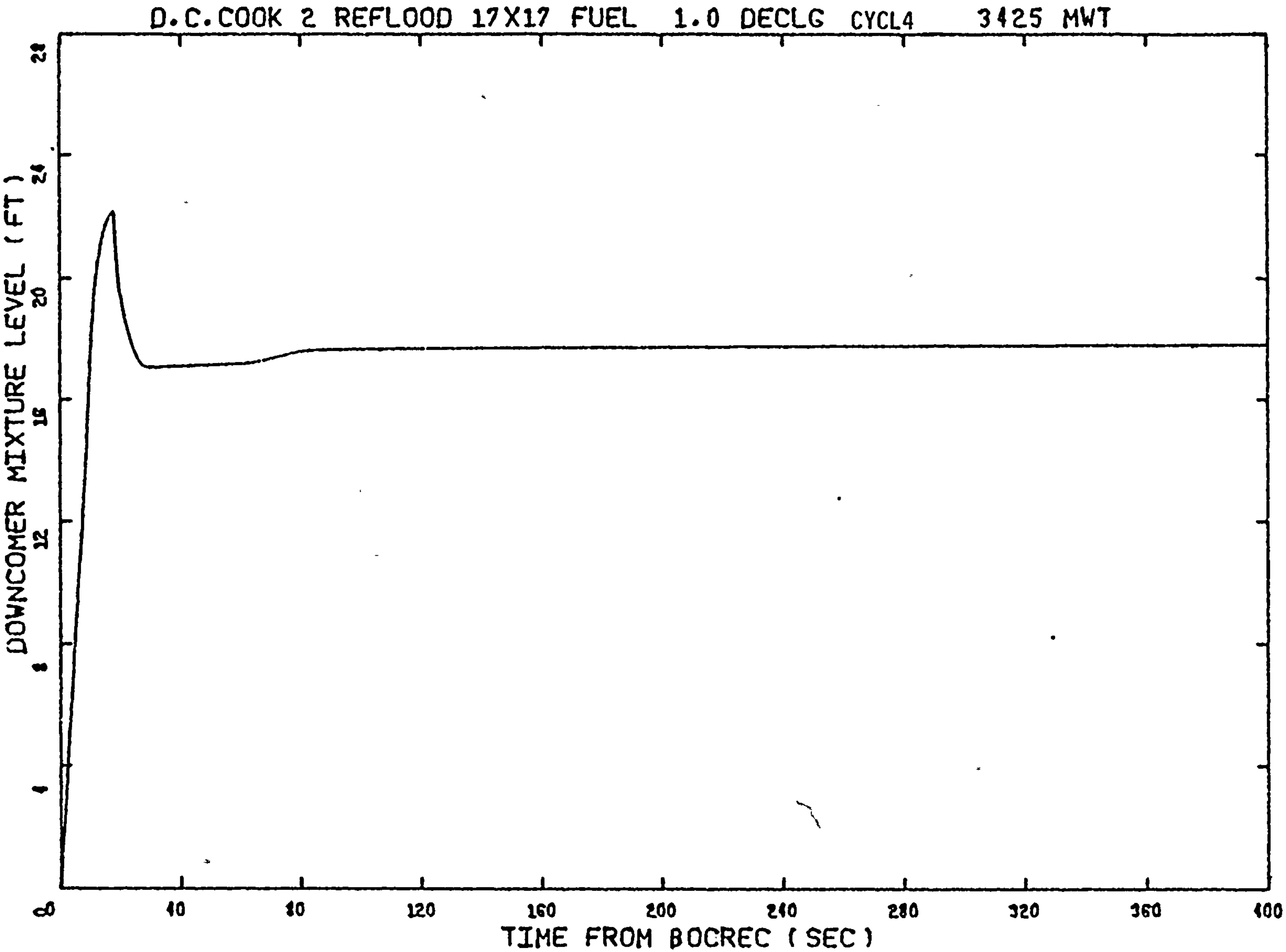

Figure 2.37 Reflood Downcomer Mixture Level
1.0 DECLG Break (Full ECCS Flow)

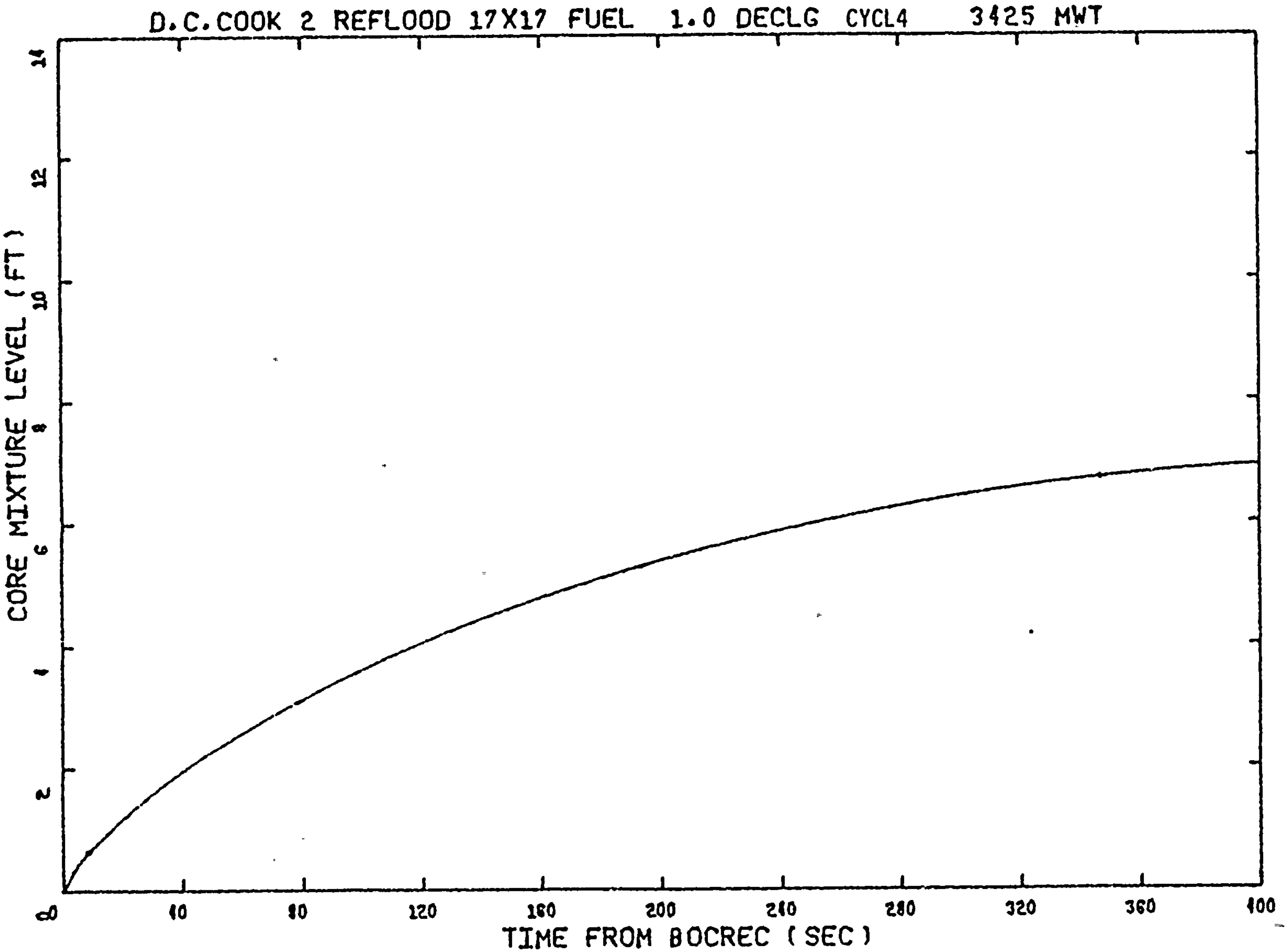

Figure 2.38 Reflood Core Mixture Level
1.0 DECLG Break (Full ECCS Flow)

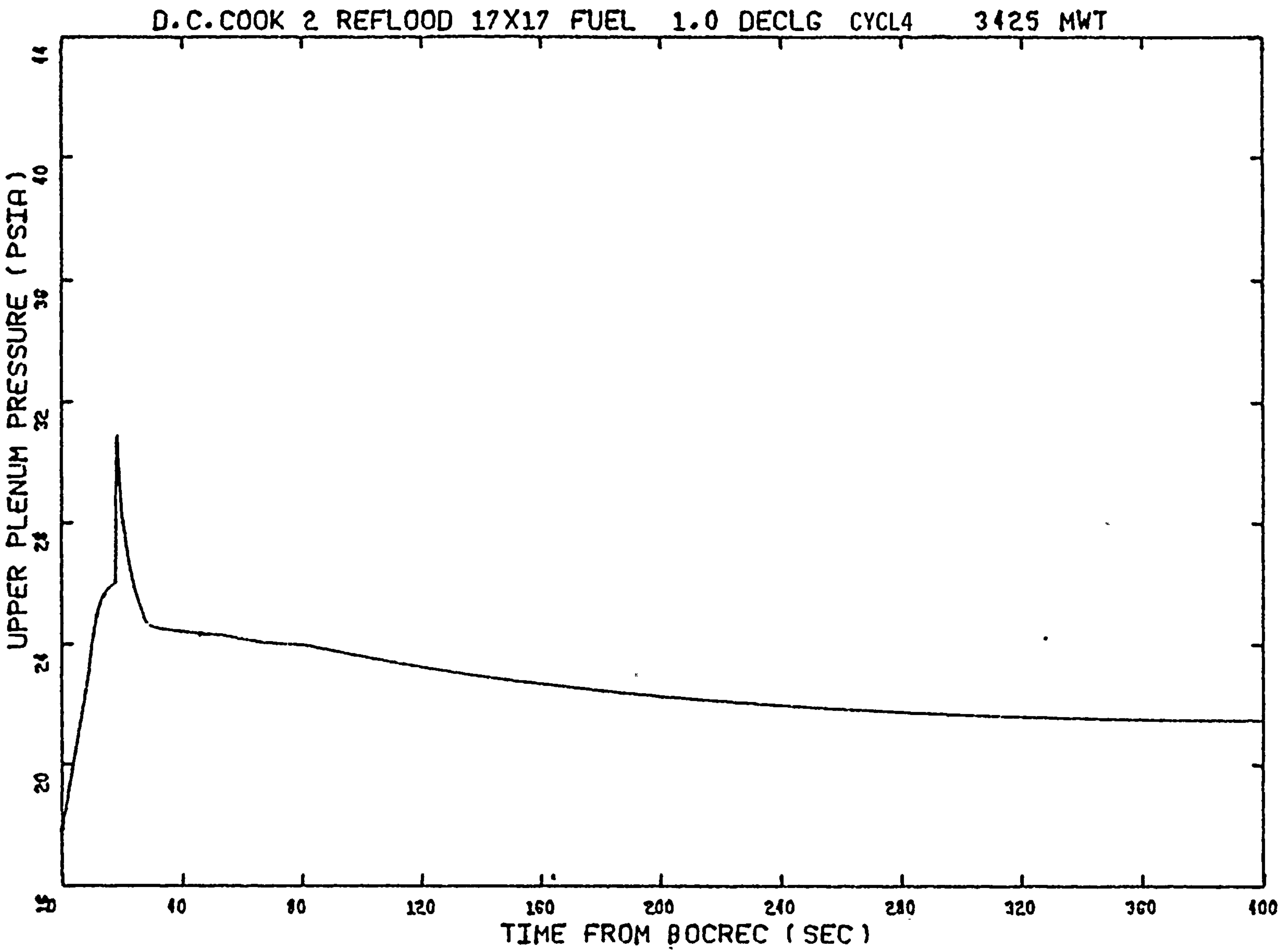

Figure 2.39 Reflood Upper Plenum Pressure
1.0 DECLG Break (Full ECCS Flow)

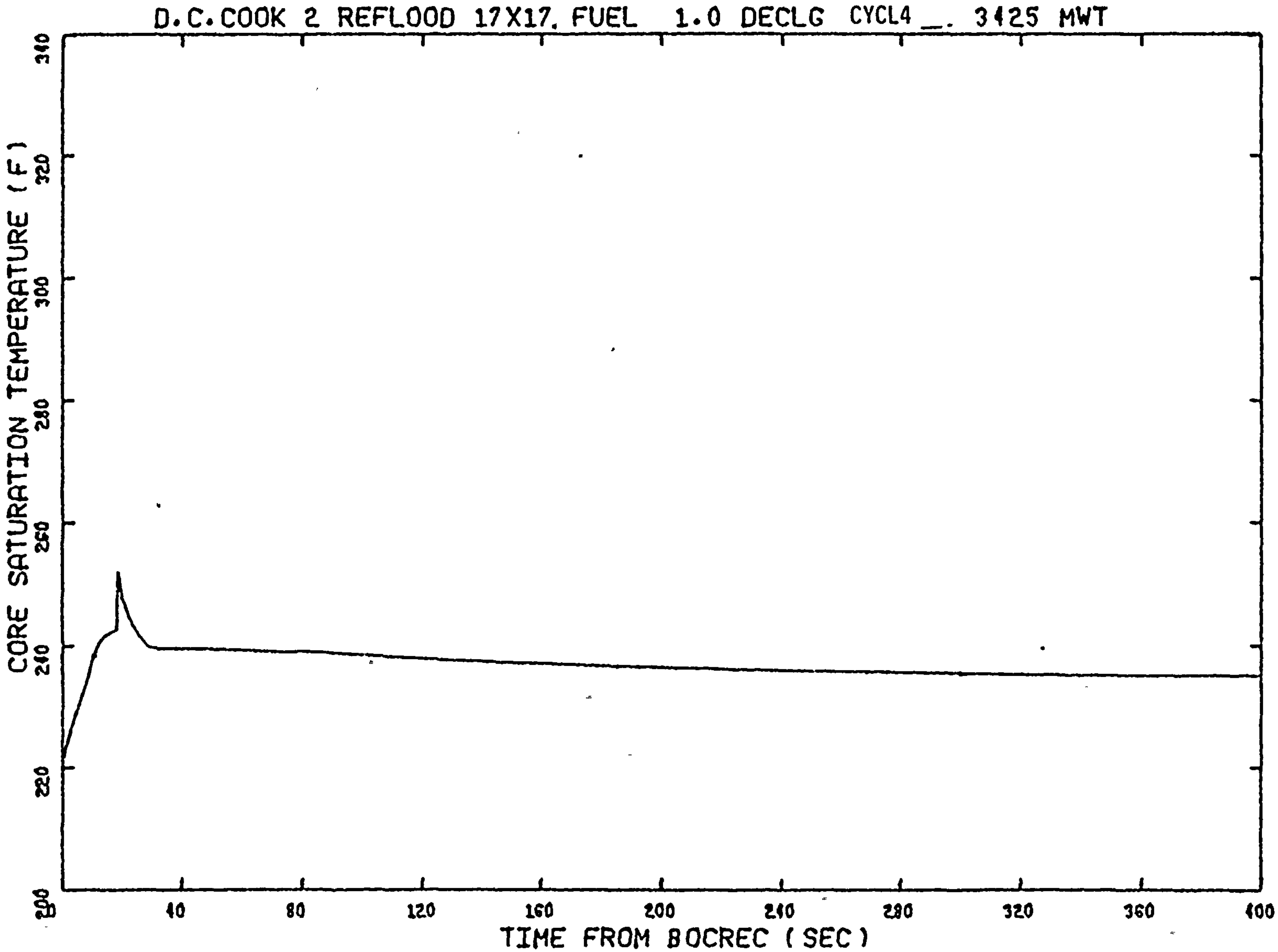

Figure 2.40 Reflood Core Saturation Temperature
1.0 DECLG Break (Full ECCS Flow)

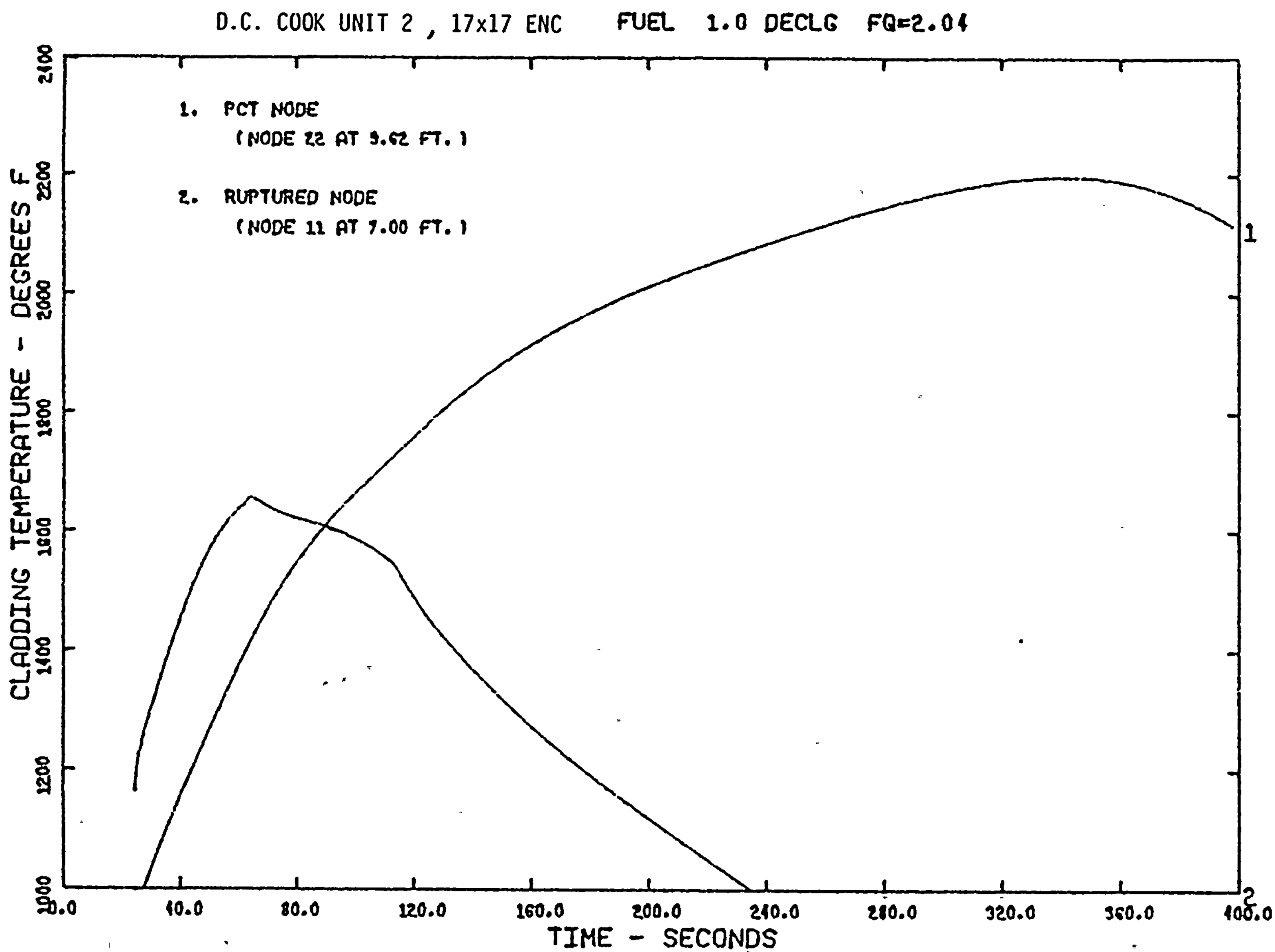

Figure 2.41 TOODEE2 Cladding Temperature vs. Time
1.0 DECLG Break (Full ECCS Flow)

3.0 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 Cycle 4 operation with ENC 17x17 fuel operating in accordance with the LHGR limits noted in Table 1.1. 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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