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DONALD C. COOK UNIT 2 CYCLE 5 5% STEAM GENERATOR TUBE PLUGGING LIMITING BREAK LOCA-ECCS ANALYSIS: K(Z) CURVE

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DONALD C. COOK UNIT 2 CYCLE 5

5% STEAM GENERATOR TUBE PLUGGING

LIMITING BREAK LOCA-ECCS ANALYSIS: K(Z) CURVE

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1.0 INTRODUCTION

This report documents the results of a large break LOCA-ECCS analysis performed to determine the axial dependence of permissible limits on power peaking, i.e., the K(Z) curve.

A large break LOCA-ECCS analysis for the Cycle 5 operation of the D.C. Cook Unit 2 reactor at 3425 MWt with ENC fuel was performed and reported in July 1984.(1) This previous analysis addressed only cosine axial power distributions. The results presented in Reference 1 were performed for the previously identified limiting break using the EXEM/PWR(2) ECCS models. An earlier report(3) presented analytical results for a spectrum of postulated large break LOCAs. The limiting break was identified as the 1.0 Double Ended Cold Leg Guillotine (DECLG) break.

The calculations presented in this report are updates to the earlier report(14) with upskew axial power distributions for determiniation of K(Z) curve. The analysis made use of ENC's EXEM/PWR(2) ECCS models as discussed in Reference 1 with one exception: the revised FLECHT-based heat transfer correlations were used as reported in Reference 4. The difference between the analysis herein and that of Reference 14 is that the upskew power distributions are for higher peak kw/ft values. The K(Z) curve which is supported by this analysis has greater values in the upper core elevations than that supported by the previous analysis.

2.0 SUMMARY

A large break LOCA-ECCS analysis has been performed to determine the axial dependence of permissible limits on power peaking, K(Z). The axial dependence of the power peaking limit is denoted K(Z) and is defined as K(Z) = $F_Q^L(Z)$/max $F_Q^L(Z)$, where $F_Q^L(Z)$ is the maximum peaking allowed at any elevation Z. The upper portion of K(Z) curve represents the small break LOCAs which is based upon the current Linear Heat Generation Rate (LHGR) limits presented in the D.C. Cook Unit 2 Technical Specification.

The determination of the limits on power peaking versus axial location from the large break LOCA-ECCS analysis is based on three power distributions: a center peaked chopped cosine power distribution; a power distribution representative of the largest axial offset (+9%) anticipated at BOC conditions; and finally a power distribution representative of the largest axial offset anticipated (+3.2%) at EOC conditions. Axial offset is defined as the power in the top of the core minus the power in the bottom of the core divided by the total core power. The power distributions are analyzed at the exposure at which they are expected to occur. A summary of these results is presented in Table 2.1.

Lines are constructed tangent to these power distributions. These lines as well as the LHGR limits on the small break LOCAs define the K(Z) limit shown in Figure 2.1 on core power peaking for ENC fuel in D.C. Cook Unit 2. The K(Z) curve presented in the report is identical to the current K(Z) that exists in the D.C. Cook Unit 2 Technical Specifications without any modifications.

Table 2.1 D. C. Cook Unit 2 K(Z) Determination Results

Calculational Basis	
License Core Power, MWt*	3411
Break Size, DECLG	1.0
Steam Generator Tube Plugging, %	5.

	Peaked** X/L = 0.50	Peaked X/L = 0.63	Peaked X/L = 0.79
Peak Rod Average Exposure, MWD/kg	10.0 (BOC)	2.0 (BOC)	20.0 (EOC)
Axial Offset	0%	+9.0%	+3.2%
Peak Linear Heat Generation Rate (LHGR)*	11.61	11.38	11.10
Total Peaking Factor, F_Q^T	2.04	2.0	1.95
Peak Cladding Temperature, ^oF	2014	1857	2008
Peak Temperature Location, ft	9.63	10.88	11.13
Local Zr/H_2O Location, ft	9.63	10.63	11.13
Local Zr/H_2O Reaction (Max.), %	4.7	2.62	4.44
Time for Max. LOCA Zr/H_2O Reaction, sec	400	450	450
Total Zr/H_2O	<1%	<1%	<1%
Hot Rod Burst Time, sec	70.51	88.91	83.91
Hot Rod Burst Location, ft	7.0	7.75	10.63

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

** This case was analyzed in Reference 1.

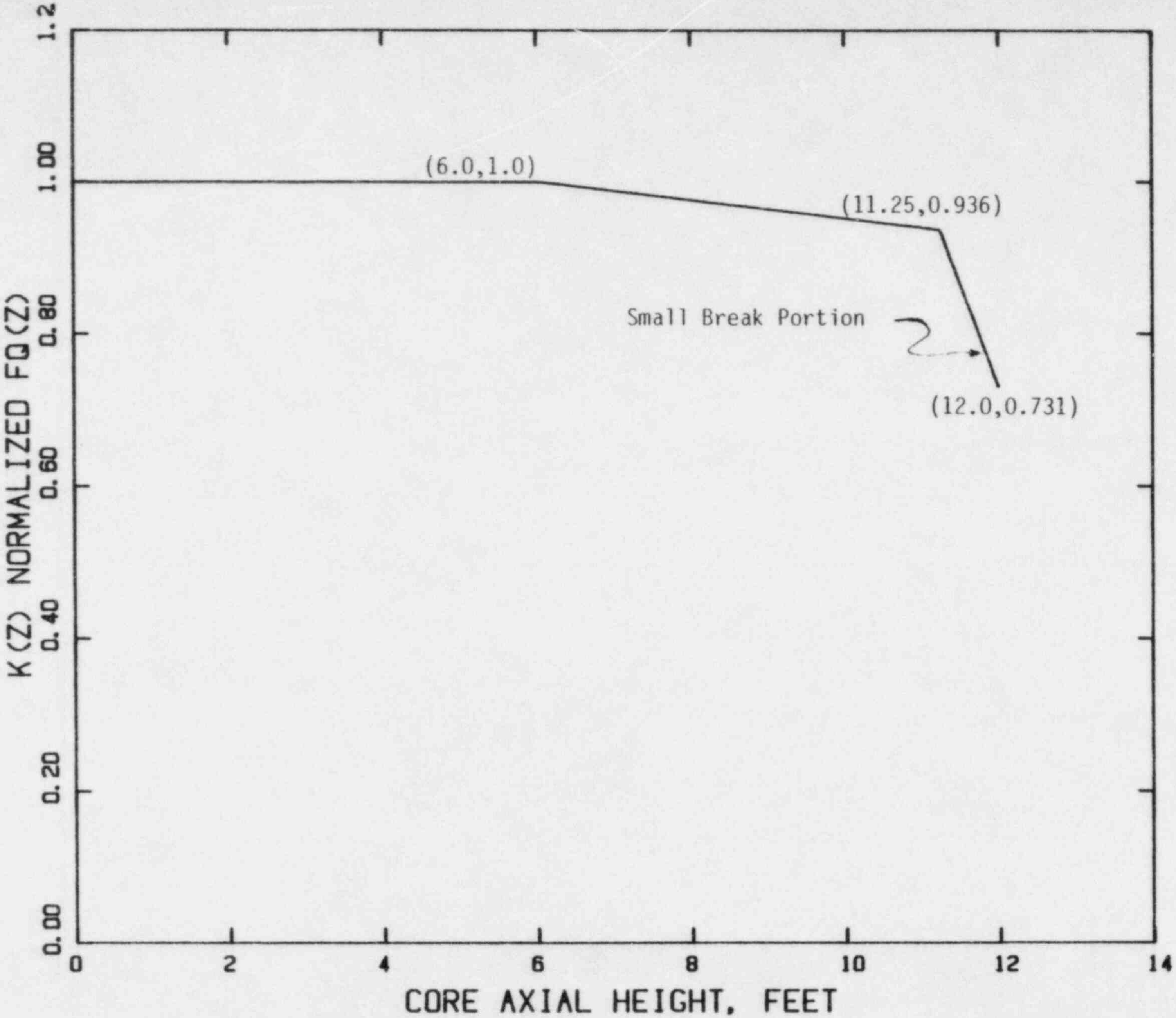

Figure 2.1 D.C. Cook Unit 2; K(Z) - Normalized $F_Q^L(Z)$ as a Function of Core Height for ENC Fuel

3.0 ANALYSIS RESULTS

The K(Z) curve is the variation of the limit on power peaking with axial elevation in the core. The allowed power peaking is reduced at the top of the core to offset the effect on peak cladding temperature (PCT) of reduced coolant heat transfer from (1) the short uncovery periods at the top of the core during small break LOCAs, and (2) reduced coolant heat capacity at the top of the core during the reflood period of the large break LOCAs. The analysis model and the results of the analysis are described below.

3.1 LOCA ANALYSIS MODEL

The Exxon Nuclear Company EXEM/PWR-ECCS evaluation model was used to perform the analysis required. This model(2) consists of the following computer codes: RODEX2(6) 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(2,9) for computation of system reflood; and TOODEE2(2,10,11) for the calculation of final fuel rod heatup. TOODEE2 calculations performed for this analysis are similar to those reported in Reference 1 in that the heat transfer coefficient multiplier for the presence of mixing vanes was set to 1.0, and the heat transfer coefficient multiplier for local peaking was adjusted as per Reference 5. The TOODEE2 and REFLEX calculations are also similar to those in Reference 1 in that the FLECHT-based heat transfer correlations have been modified to account for the difference in axial power distribution between those used in the D.C. Cook Unit 2 analysis and that used in the FLECHT tests upon which the correlations were developed. The FLECHT-based heat transfer correlations that were used in the analysis presented in this report are discussed in Reference 4.

3.2 K(Z) DETERMINATION

The limits on axial power peaking are defined by drawing tangent lines to power distributions for which the acceptance criteria in 10 CFR 50.46 for LOCA-ECCS analysis are met. For the purpose of this analysis, three power distributions have been considered. These are a center peaked chopped cosine axial power distribution and two top skewed power distributions peaked at 7.5 ft (X/L = .63) and peaked at 9.5 ft (X/L = .79).

The cosine axial power distribution has been analyzed previously in Reference 1. The analysis in Reference 1 did not use the heat transfer correlation presented in Reference 4 but used a more conservative heat transfer correlation. The analysis for the cosine axial power distribution considered three exposures: 2.0, 10.0 and 47.0 MWD/kg. For the Cycle 5 core, the resulting peak clad temperatures from this previous analysis were 2007^{o}F, 2014^{o}F, and 1993^{o}F, respectively. The analysis thus indicated no significant exposure dependency for the peak clad temperatures. The analysis also indicated no significant exposure dependency for the maximum local Zr-H_2O reaction and the total Zr-H_2O reaction.

Previous calculations have indicated that the higher in the core at which a particular value of power peaking occurs, the larger the calculated peak clad temperature will be. For this reason, two power shapes representative of the maximum power peaking in the core top have been chosen to be analyzed for the determination of the limit on power peaking versus core height. These power distributions were calculated for D.C. Cook Unit 2 at

BOC5 and EOC5 conditions. The two power distributions represent the most top skewed shapes anticipated to occur at the cycle conditions and with the power distribution control procedures (PDC-II)[13] in effect at the plant. Because there is no significant exposure dependence in the calculated peak clad temperatures, each power shape is analyzed at the exposure conditions at which it is anticipated to occur.

The axial power distributions used in the analysis are normalized to 1.0. They thus represent a relative axial power distribution $F_Z(Z)$. The total power distribution $F_Q(Z)$ is determined by multiplying the relative axial power distribution by a constant value for $F_{\Delta H}$, $F_Q(Z) = F_{\Delta H} * F_Z(Z)$. The method for determining the limiting $F_Q(Z)$ entails increasing $F_{\Delta H}$ until the peak clad temperature for the resulting $F_Q(Z)$ approaches 2200°F.

The power distributions utilized in the analysis are plotted in Figure 3.1. As shown in Table 2.1, these axial power distributions result in conformance to the criteria of 10 CFR 50.46 with significant margin remaining to the criteria. The power distributions plus the tangent lines constructed to define the $F_Q^L(Z)$ limits are shown in Figure 3.2. The lines tangent to the power distributions represent the limit resulting from the large break LOCA-ECCS analysis.

The operating conditions on fuel parameters for the current analysis are given in Tables 3.1 and 3.2. The operating conditions and fuel parameters are identical to those used in the XN-NF-84-21(P), Rev. 2 analysis. Boundary condition input from the XN-NF-84-21(P), Rev. 1[13] blowdown was used to drive the RELAP4/hot channel analysis. Use of the results for previous containment pressures, safety injection system transients, and refill reported in XN-NF-84-21(P), Rev. 1 analysis was made to calculate REFLEX/reflood and TOODEE2/hot rod heatup.

As indicated previously, the results of the K(Z) determination are summarized in Table 2.1. For the limiting break, the 1.0 DECLG break, RELAP4/hot channel, REFLEX/reflood, and TOODEE2/hot rod heatup calculations were performed. The results for the center peaked axial power distribution are reported in Reference 1. The results for the skewed power distributions are presented in Figures 3.3 through 3.12 for BOC, and in Figures 3.13 through 3.22 for EOC, respectively. Time zero on all plots corresponds to the time of break initiation.

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-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 x 3425 = 3493.5 MWt
**ENC Fuel Parameters.

Table 3.2 1.0 DECLG Break Analysis Parameters

Peak Rod Average Burnup (MWD/kg)	10.0 (BOC)	2.0 (BOC)	20.0 (EOC)
Axial Offset (%)	0.	+9.0	+3.2
Total Core Power (MWt)*	3411	3411	3411
Total Peaking (F_Q^T)	2.04	2.00	1.95
Fraction Energy Deposited in Fuel			
• Fully Moderated Core	0.974	0.974	0.974
• Voided Core	0.954	0.954	0.954
<u>Cycle 5 (85% ENC Fuel)</u>			
Peaking			
• Axial	1.316	1.229	1.129
• Enthalpy Rise ($F^T{}_H$)	1.55	1.63	1.73

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

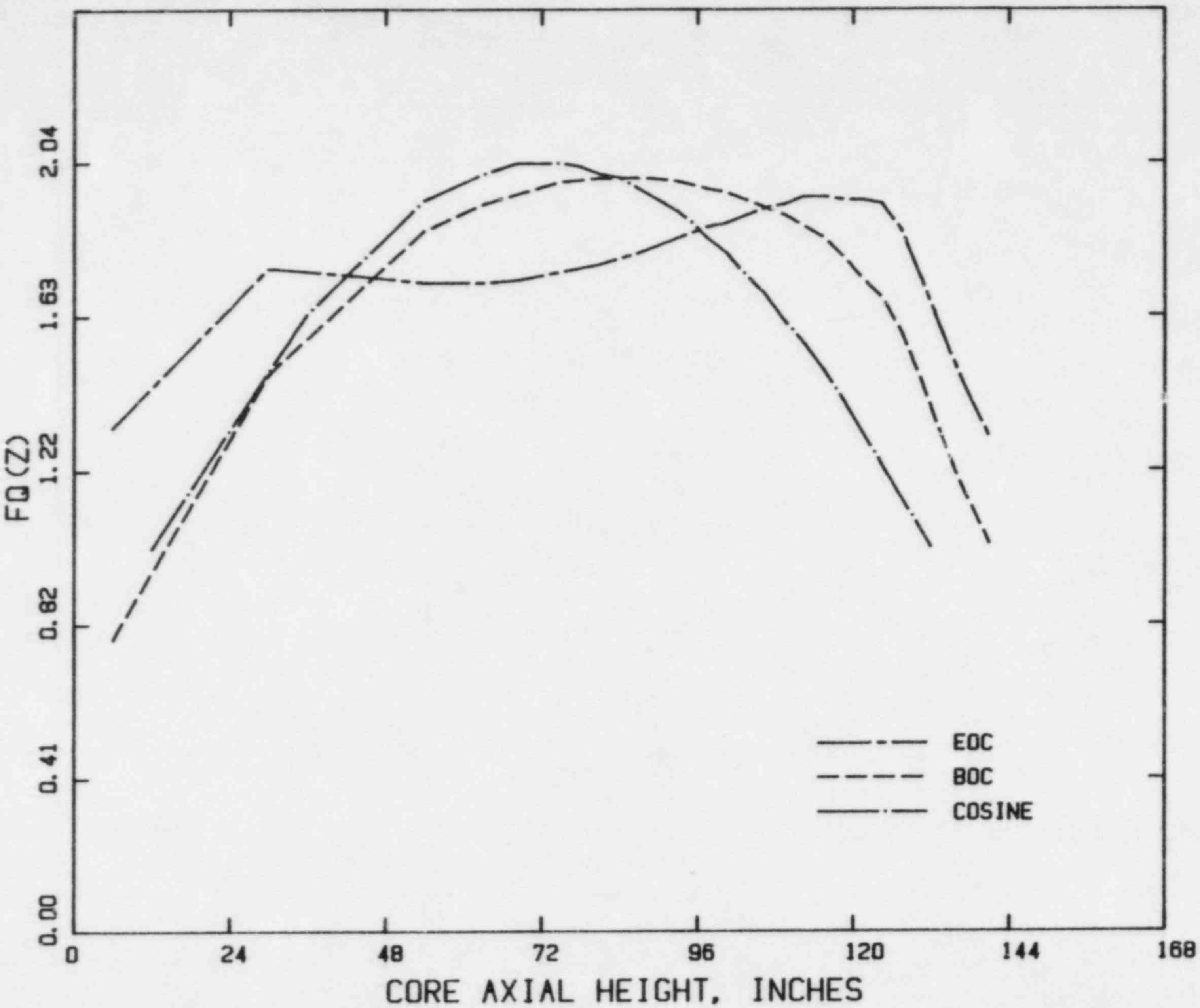

Figure 3.1 D.C. Cook Unit 2 $F_Q(z)$ Distributions Used in LOCA-ECCS Analysis

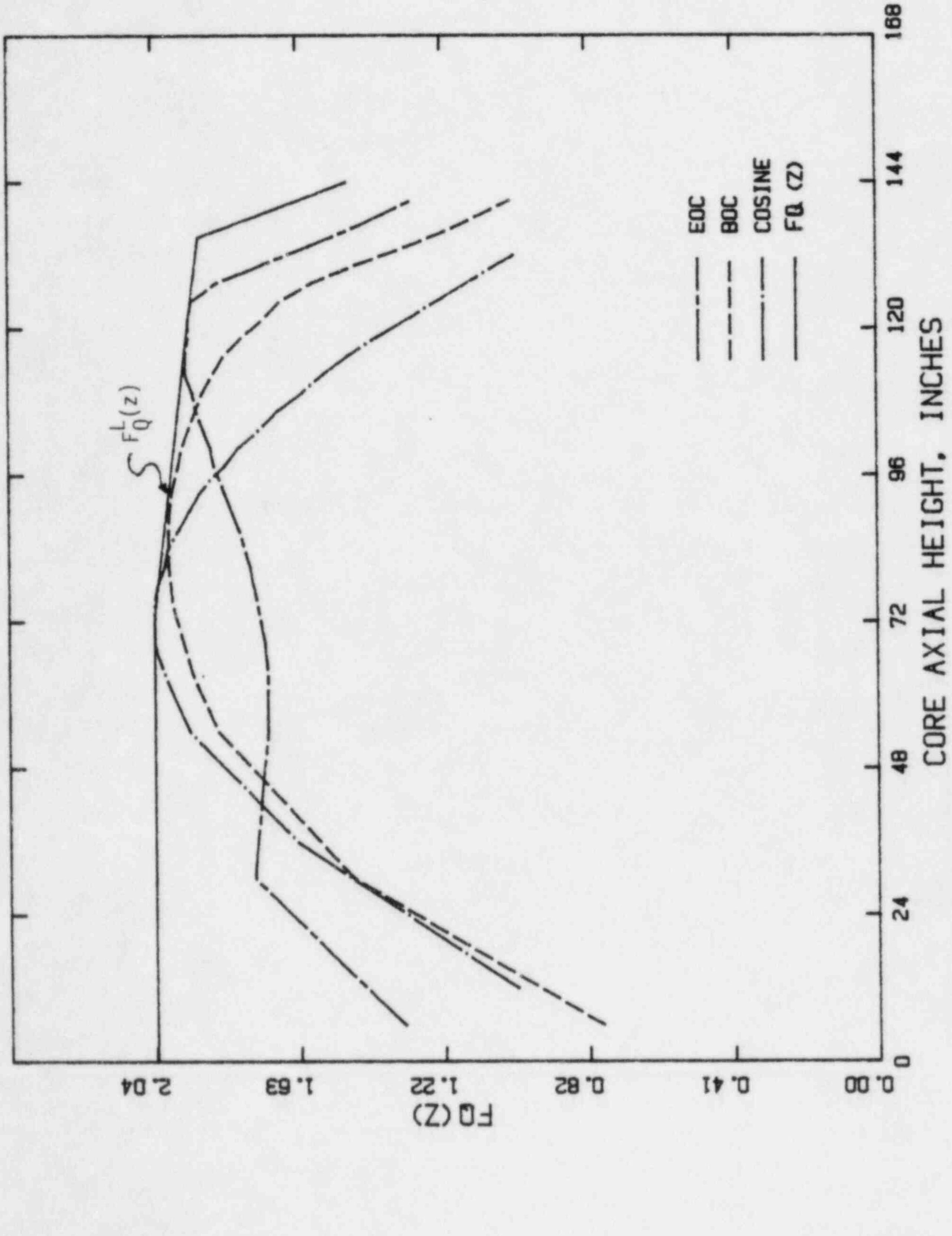

Figure 3.2 D.C. Cook 2 $F_Q^L(z)$ - LOCA-ECCS Analysis Limit

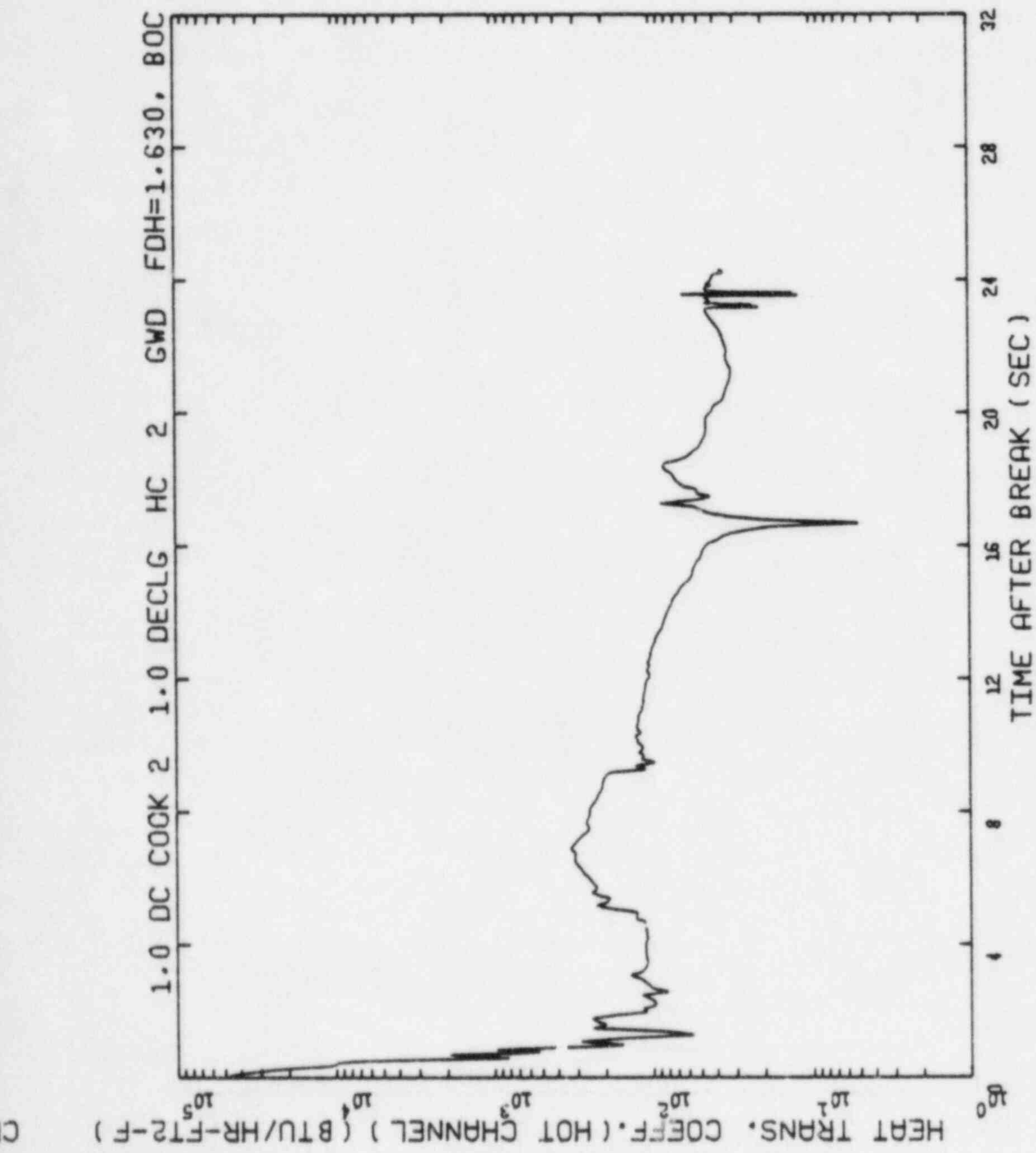

Figure 3.3 Heat Transfer Coefficient During Blowdown Period at PCT Node, 1.0 DECLG Break, BOC, Axial Offset of +9.0%

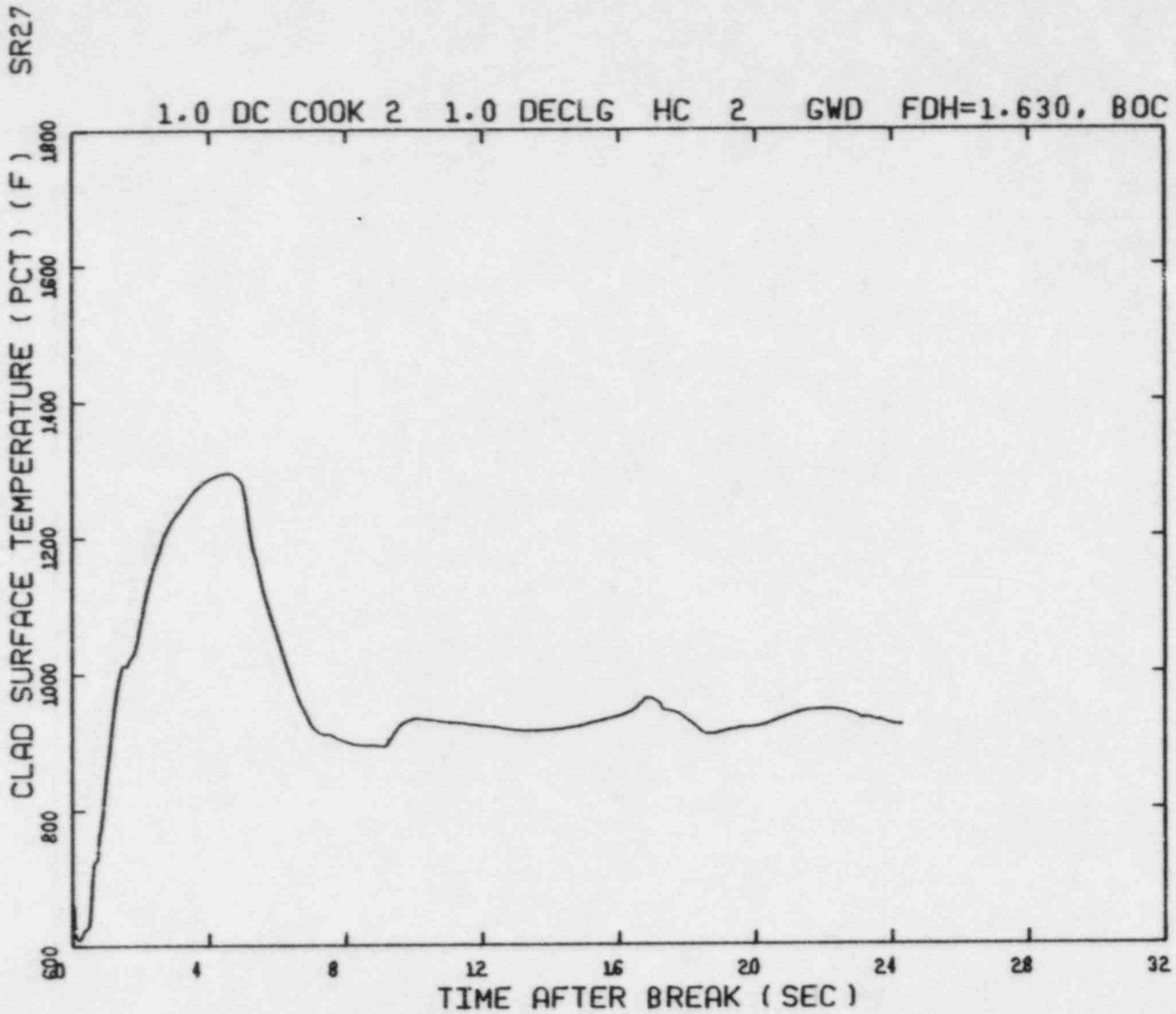

Figure 3.4 Clad Surface Temperature During Blowdown Period at PCT Node, 1.0 DECLG Break, BOC, Axial Offset of +9.0%

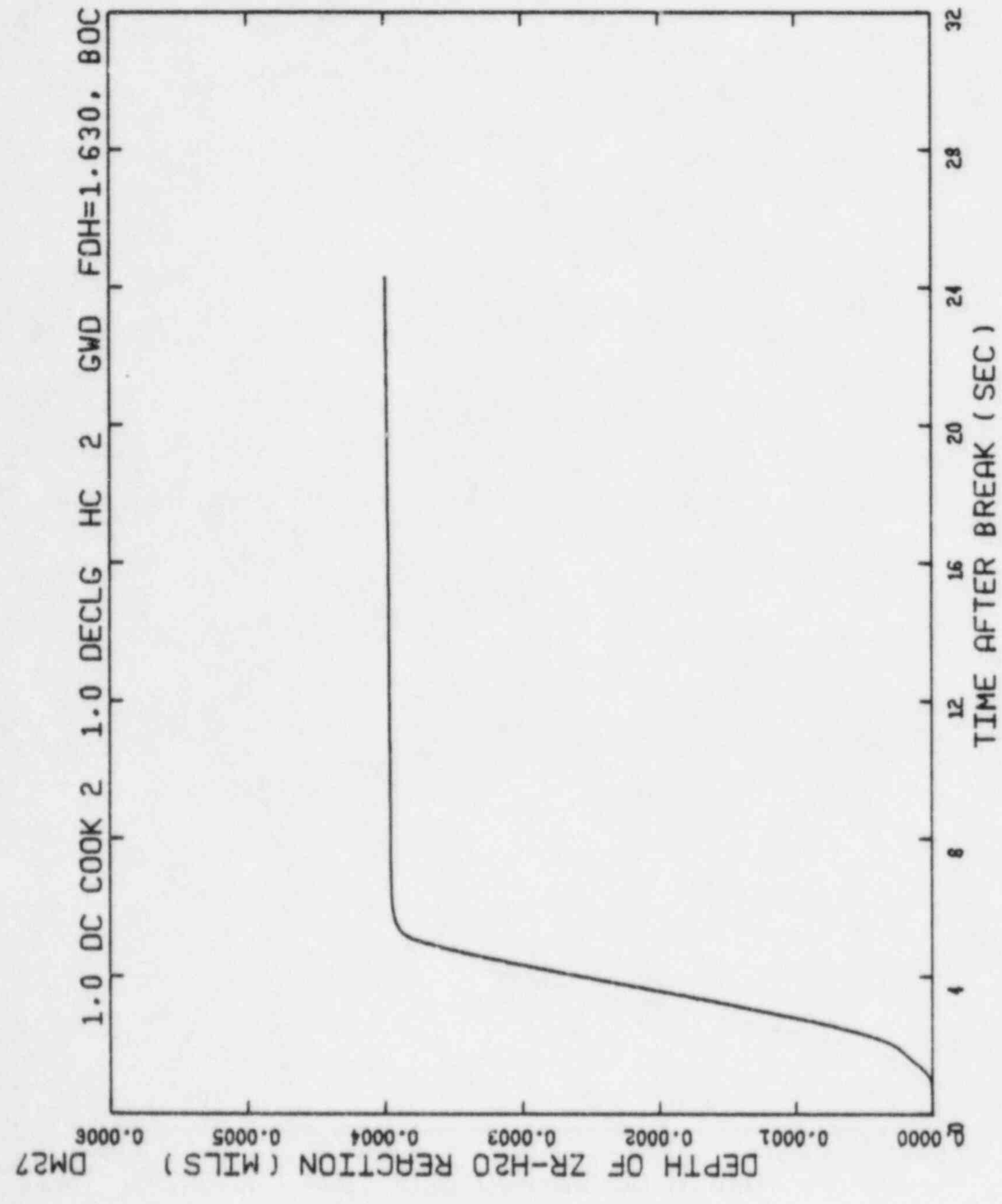

Figure 3.5 Depth of Metal - Water Reaction During Blowdown Period at PCT Node, 1.0 DECLG Break, BOC, Axial Offset of +9.0%

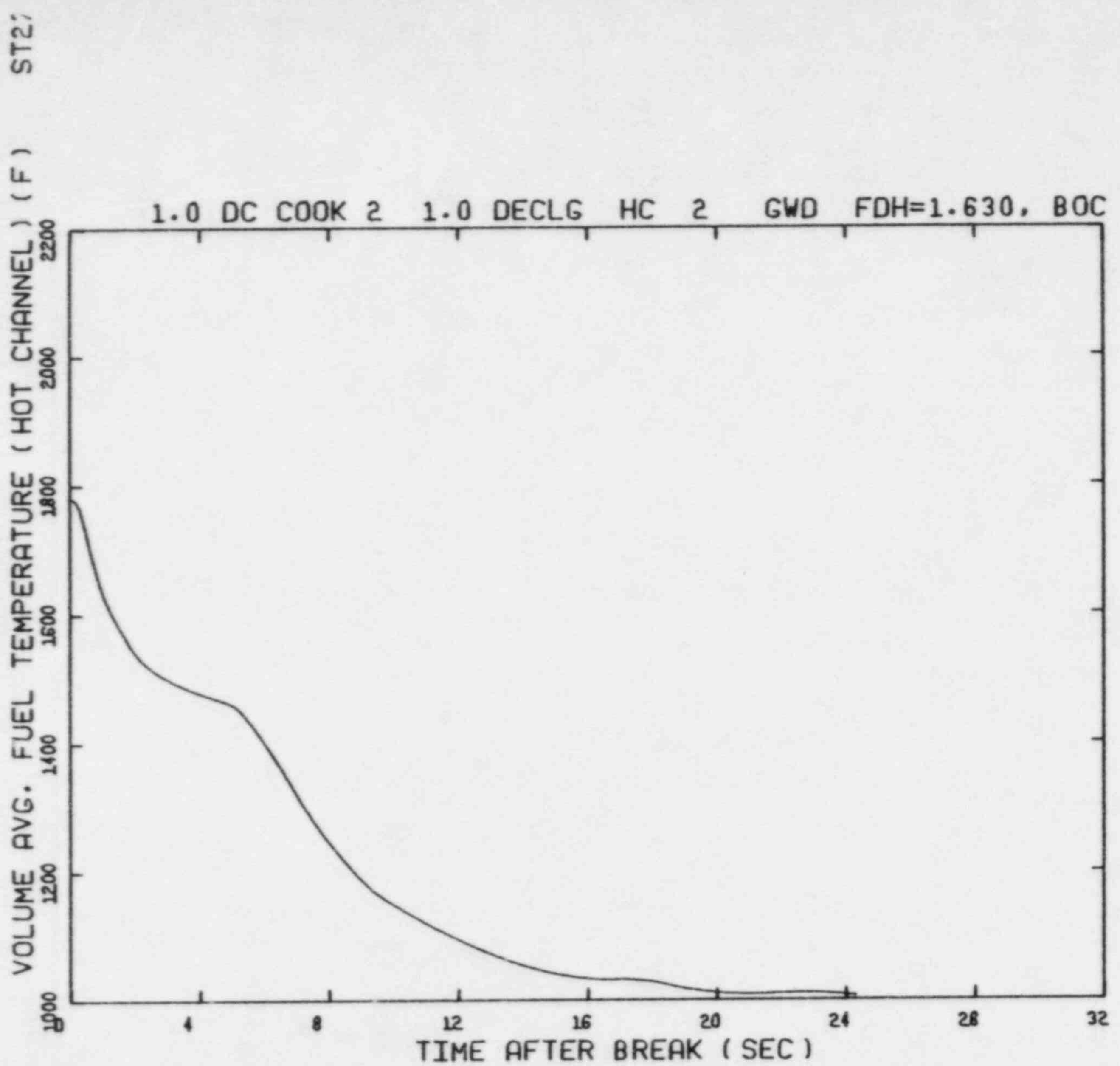

Figure 3.6 Average Fuel Temperature during Blowdown Period at PCT Node, 1.0 DECLG Break, BOC, Axial Offset of +9.0%

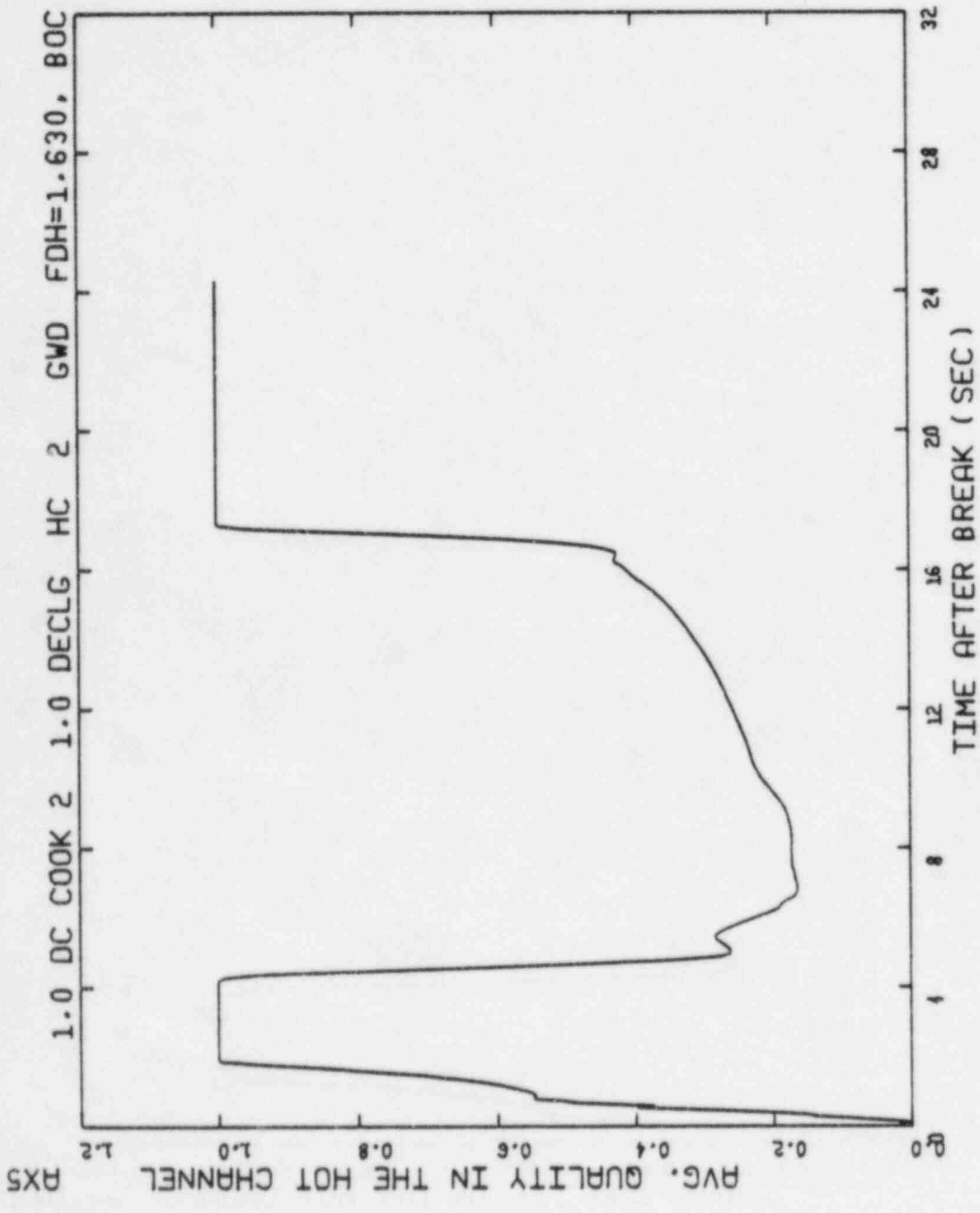

Figure 3.7 Hot Channel Average Quality, Center Volume, 1.0 DECLG Break, BOC, Axial Offset of +9.0%

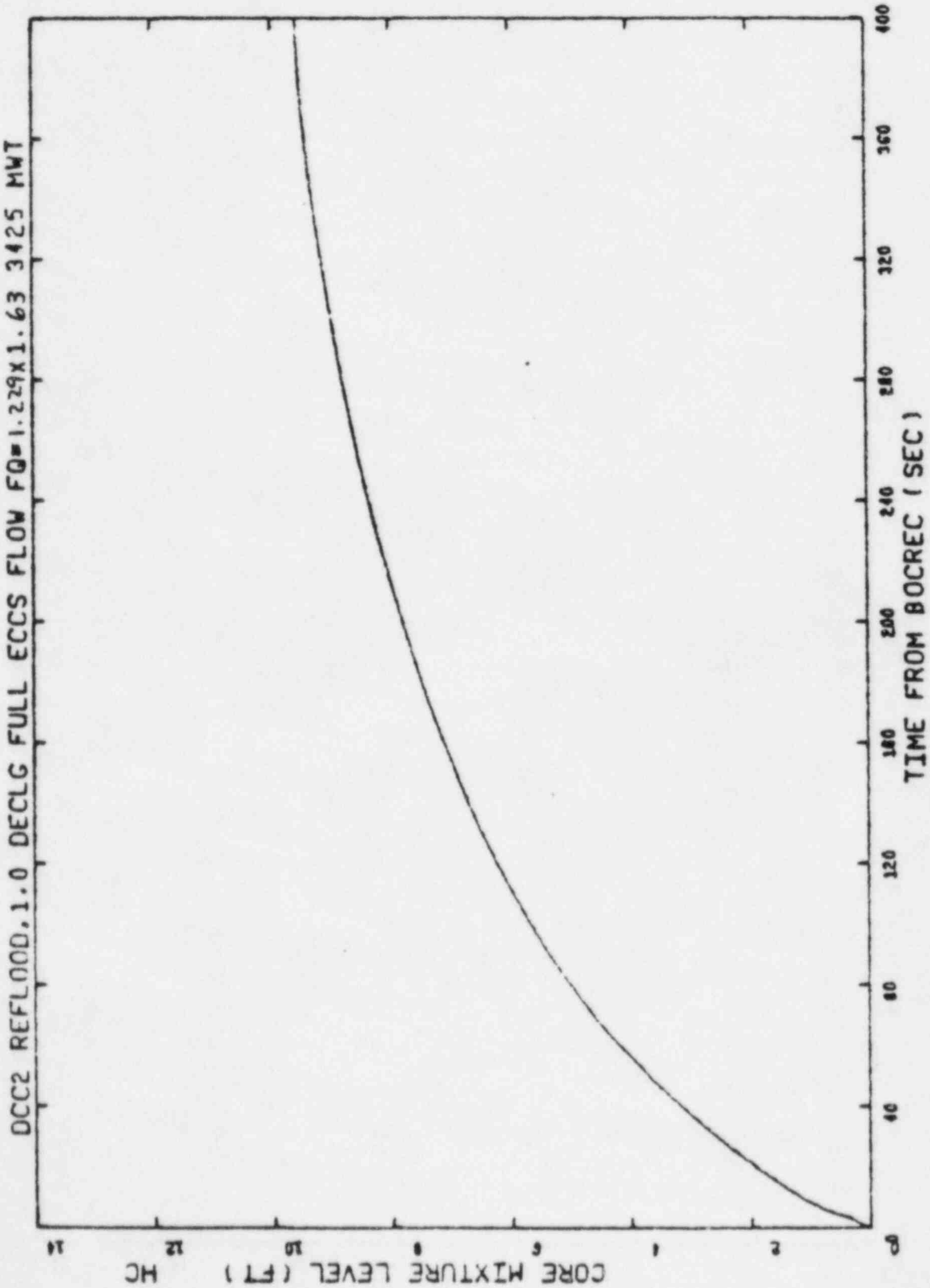

Figure 3.8 Reflood Core Mixture Level, 1.0 DECLG Break, BOC, Axial Offset of +9.0%

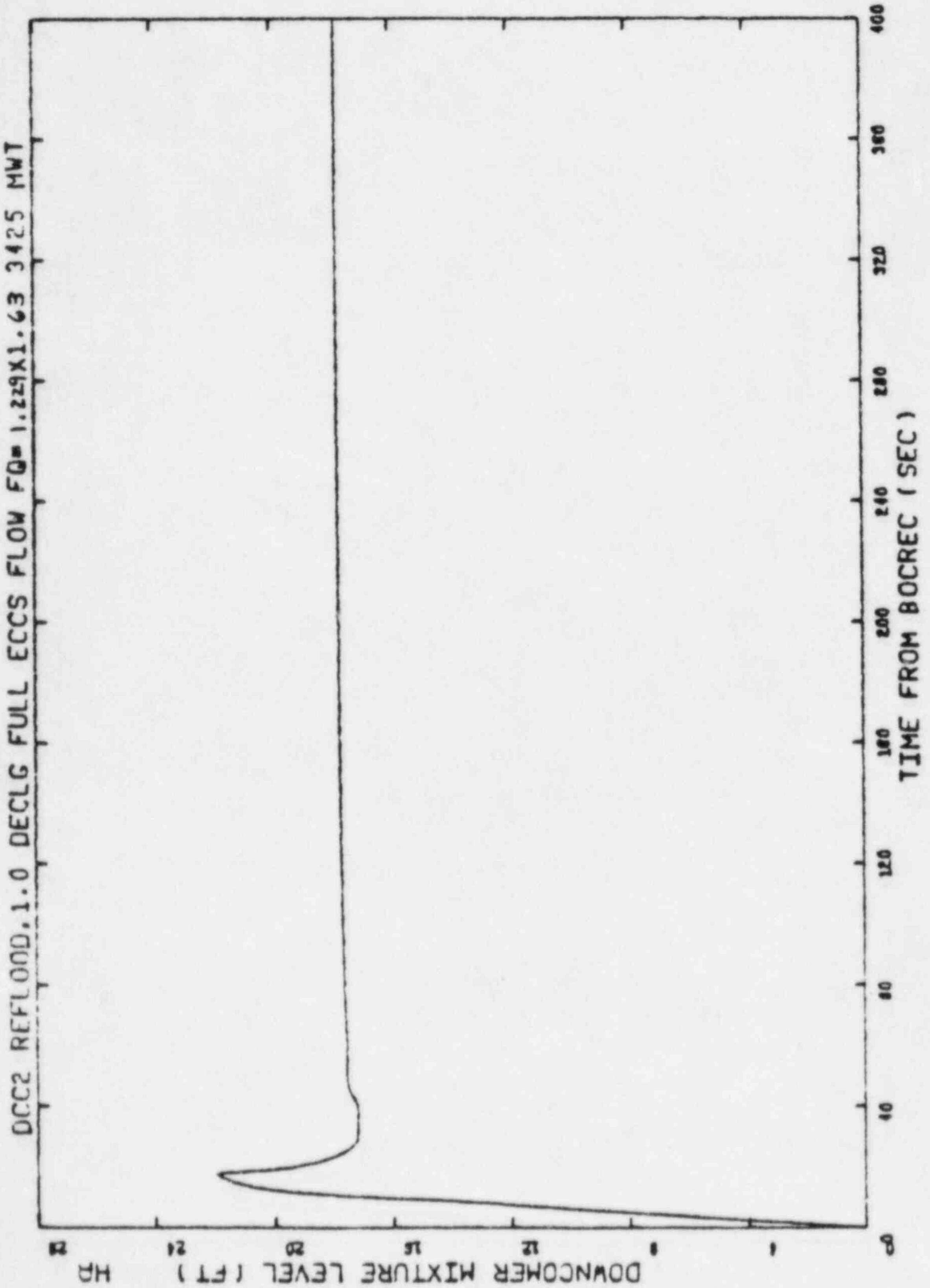

Figure 3.9 Reflood Downcomer Mixture Level, 1.0 DECLG Break, BOC, Axial Offset of +9.0%

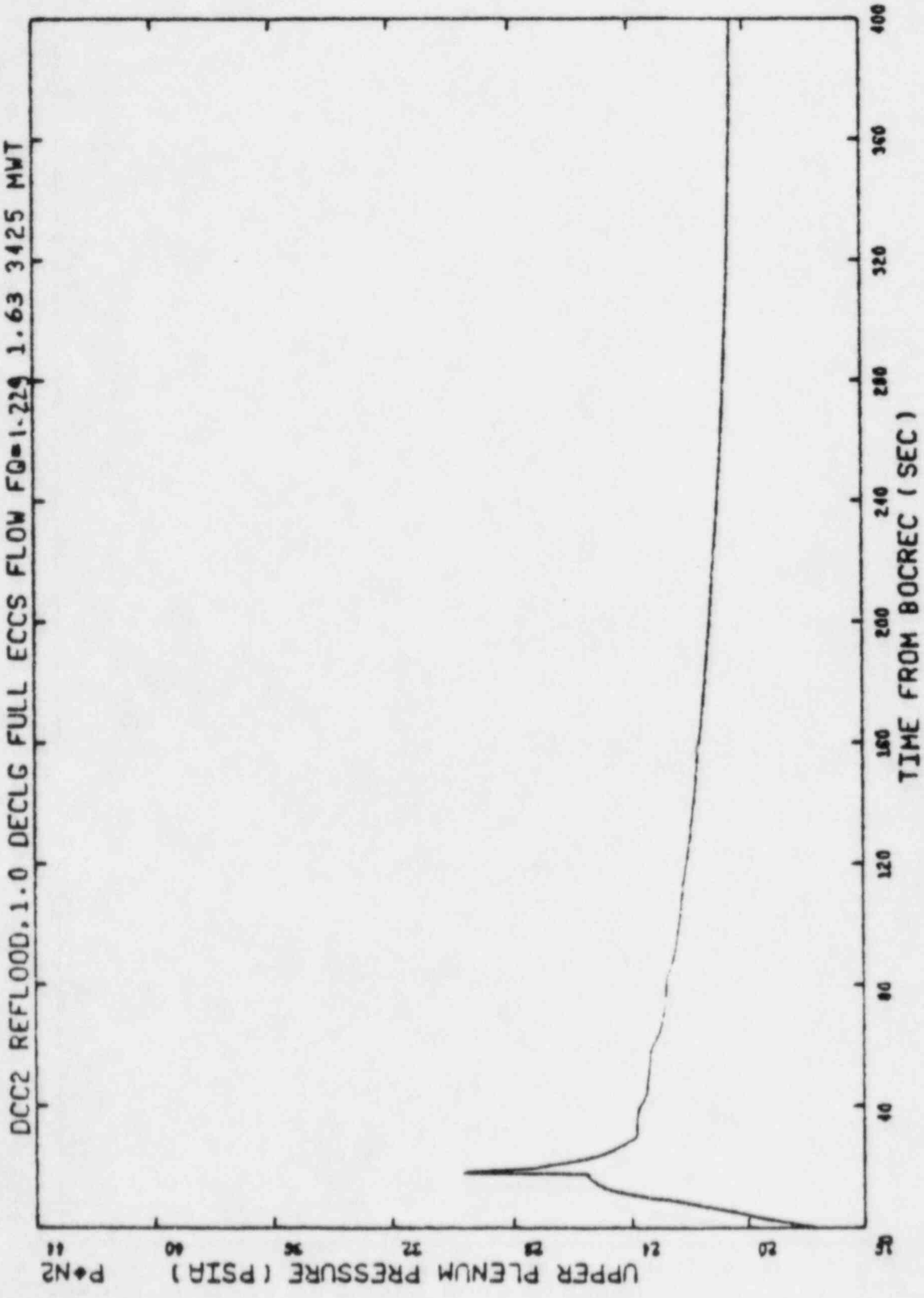

Figure 3.10 Reflood Upper Plenum Pressure, 1.0 DECLG Break, BOC, Axial Offset of +9.0%

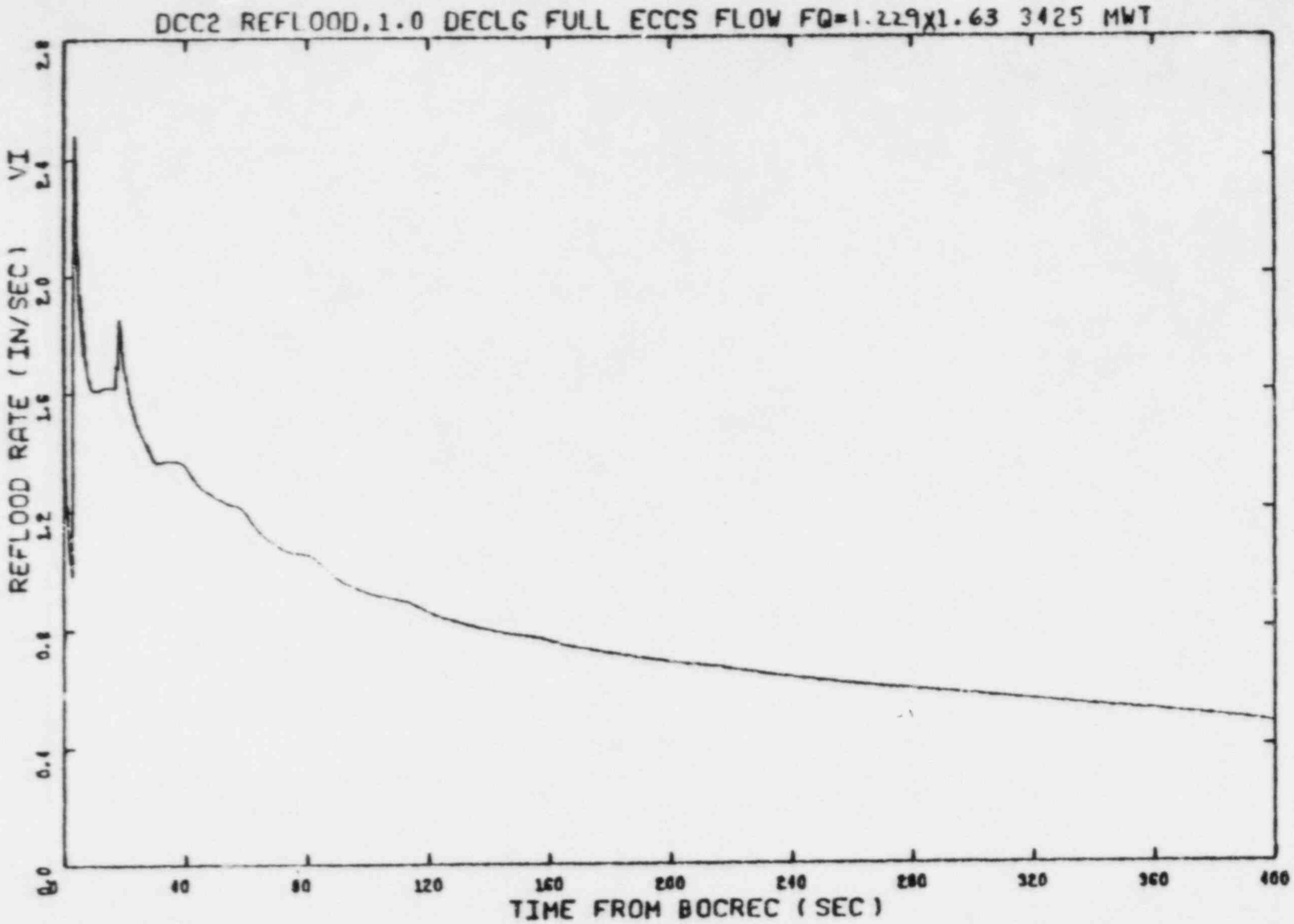

Figure 3.11 Core Reflooding Rate,
1.0 DECLG Break, BOC, Axial Offset of +9.0%

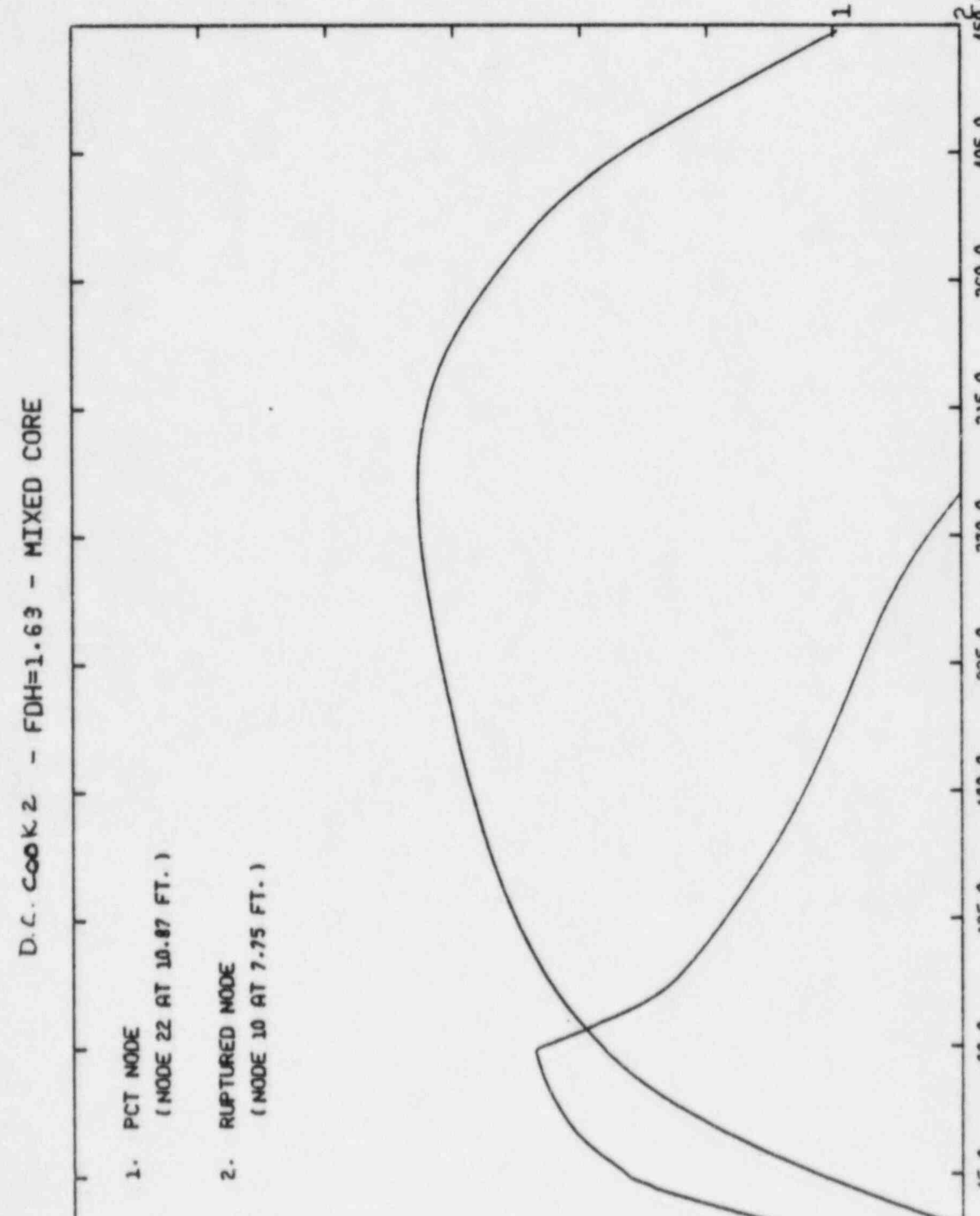

Figure 3.12 TOODEE2 Cladding Temperature versus Time, 1.0 DECLG Break, BOC, Axial Offset of +9.0%

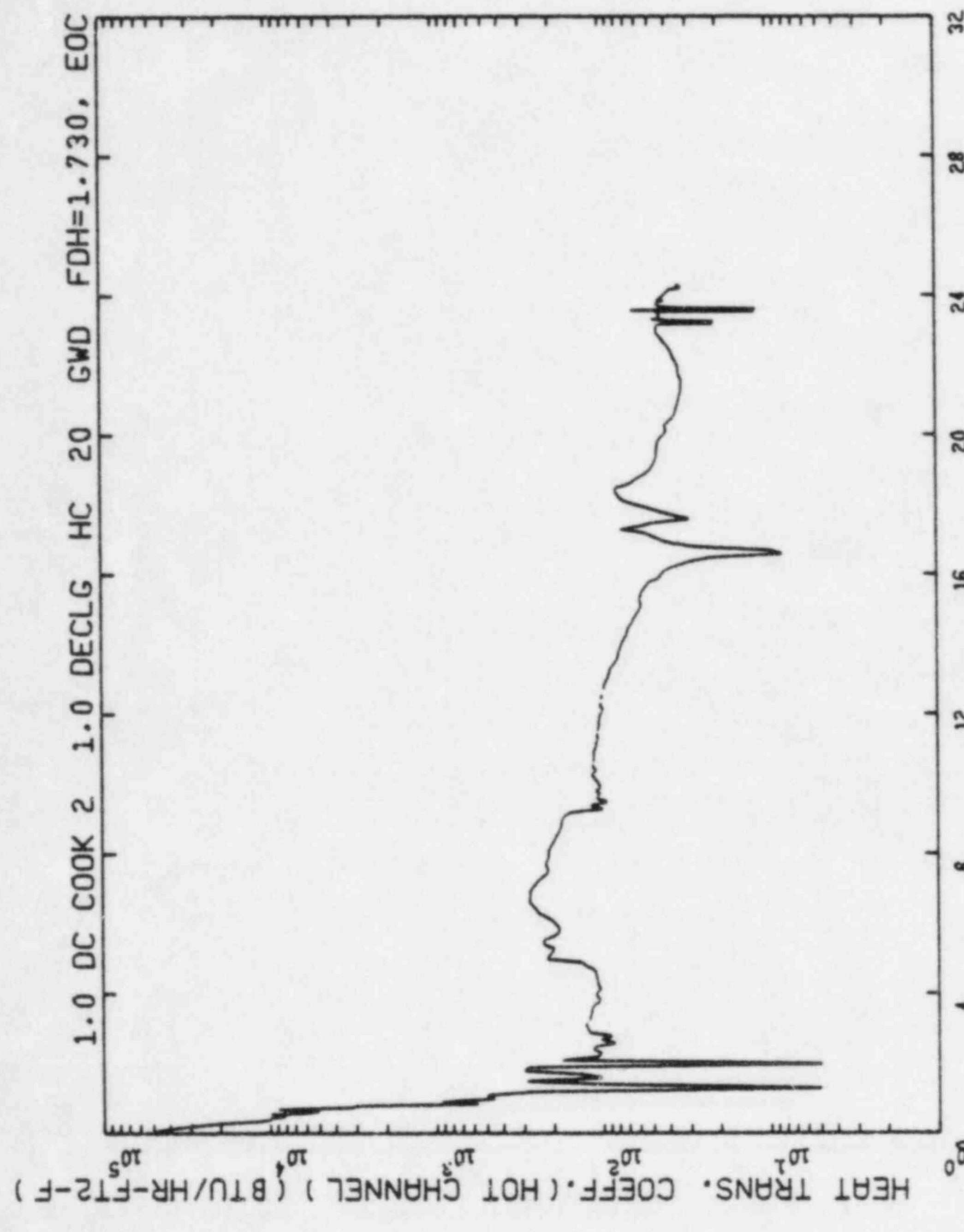

Figure 3.13 Heat Transfer Coefficient during Blowdown Period at PCT Node, 1.0 DECLG Break, EOC, Axial Offset of +3.2%

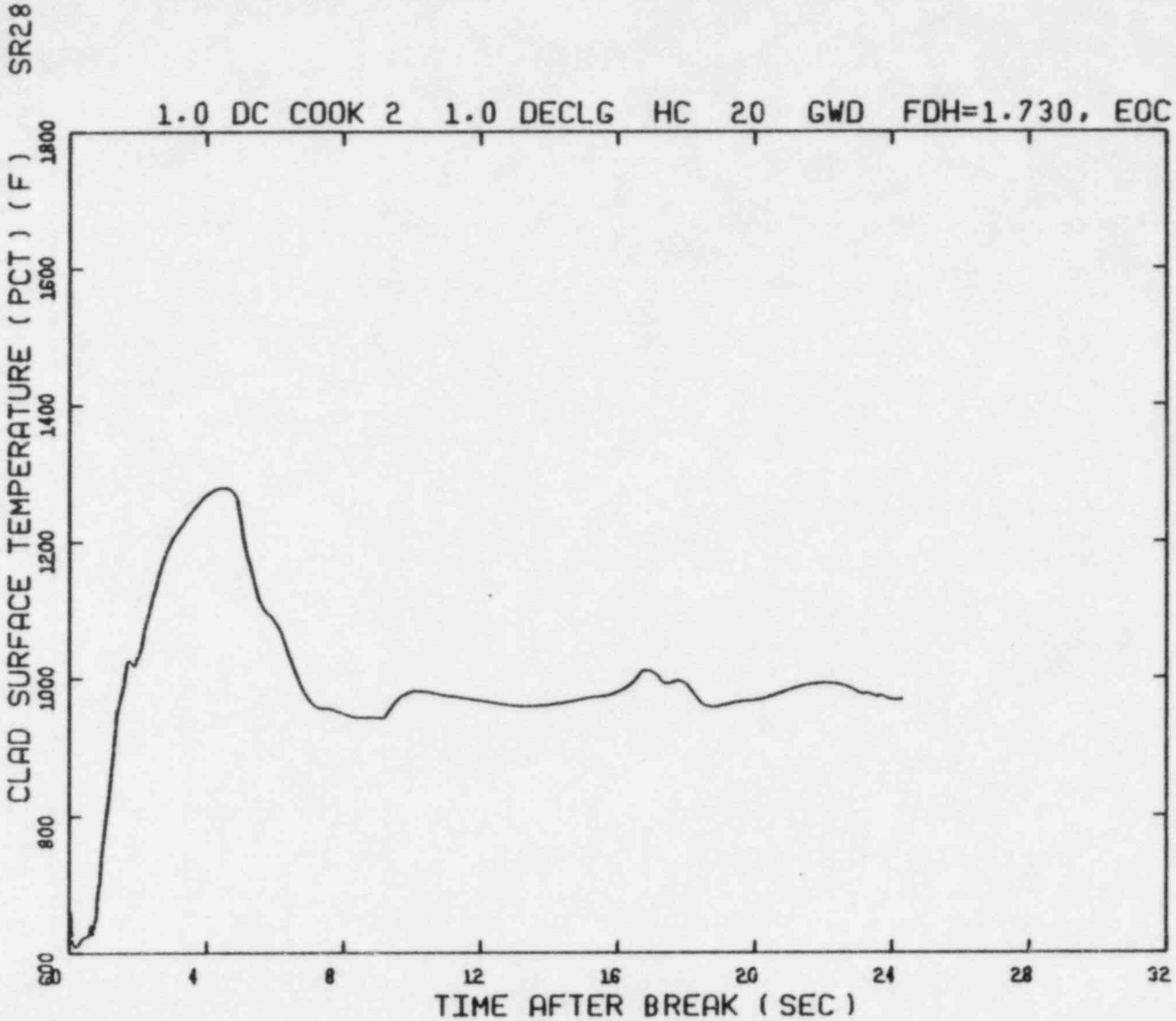

Figure 3.14 Clad Surface Temperature during Blowdown Period at PCT Node, 1.0 DECLG Break, EOC, Axial Offset of +3.2%

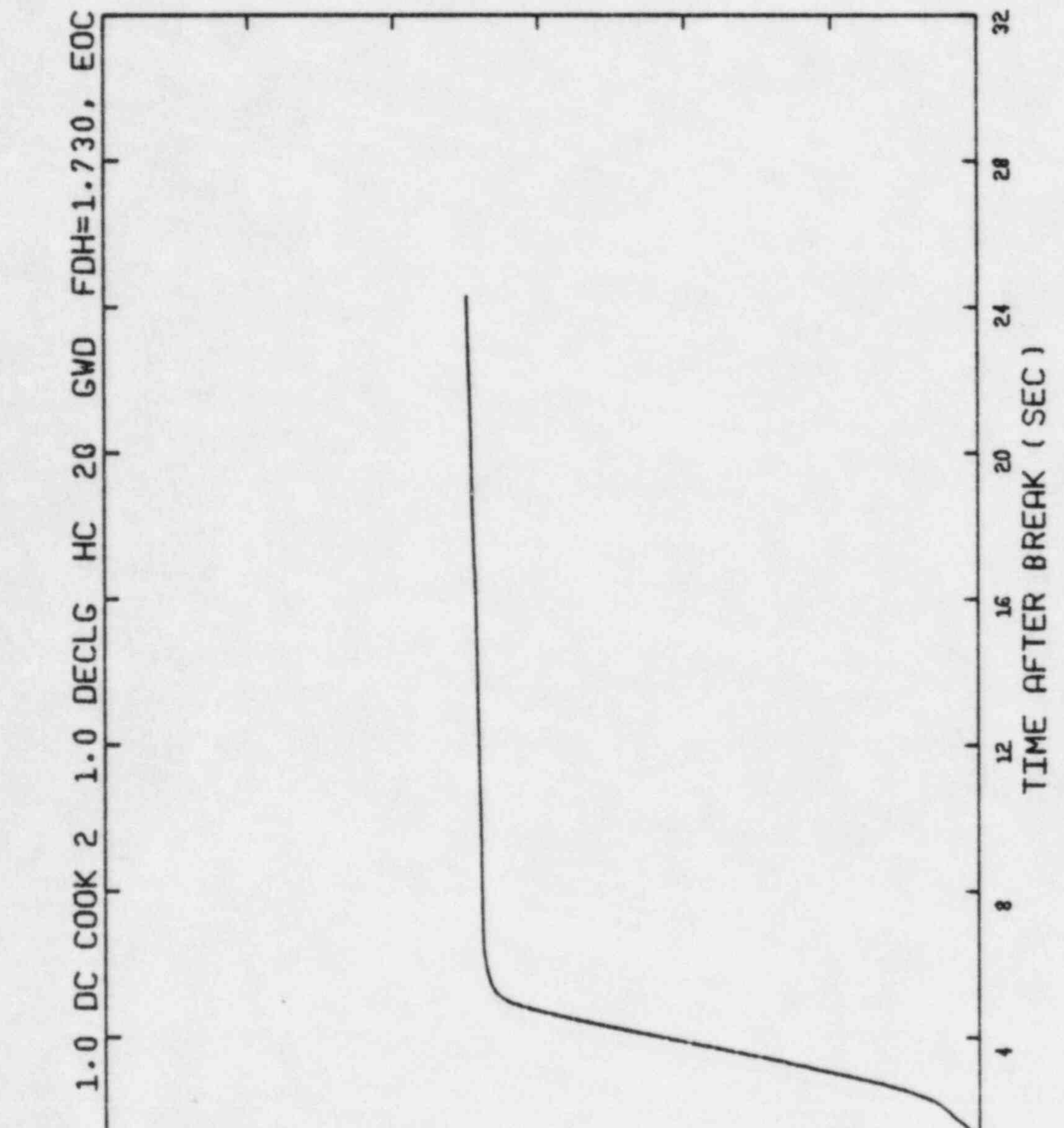

Figure 3.15 Depth of Metal-Water Reaction during Blowdown Period at PCT Node, 1.0 DECLG Break, EOC, Axial Offset of +3.2%

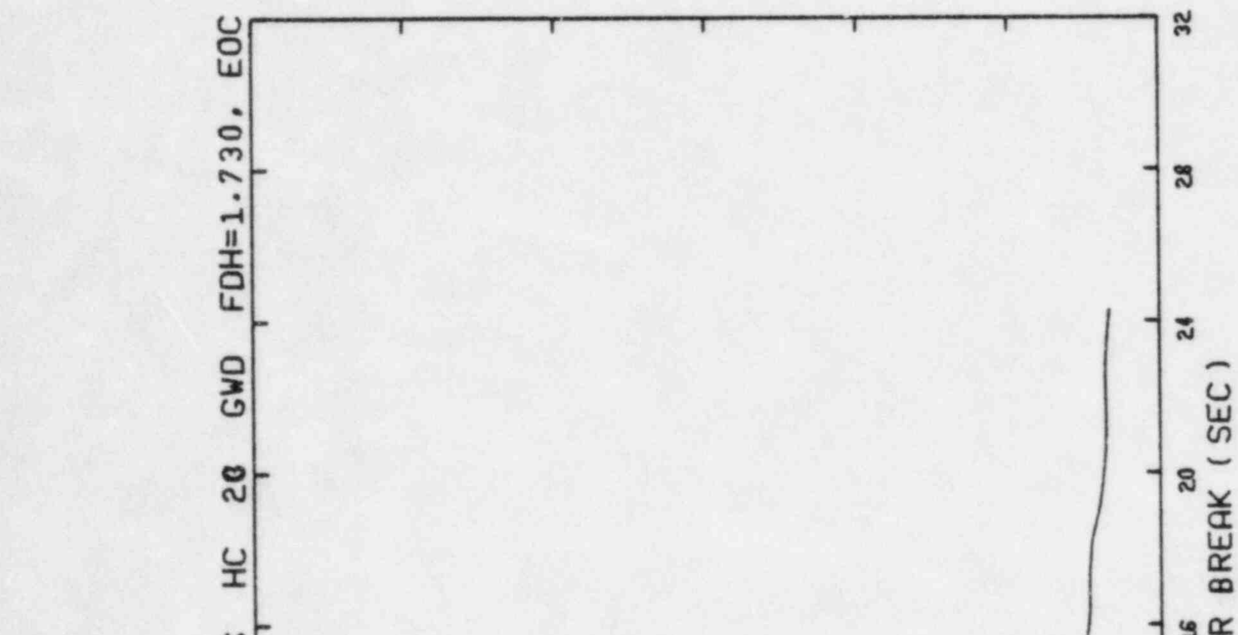

Figure 3.16 Average Fuel Temperature During Blowdown Period at PCT Node, 1.0 DECLG Break, EOC, Axial Offset of +3.2%

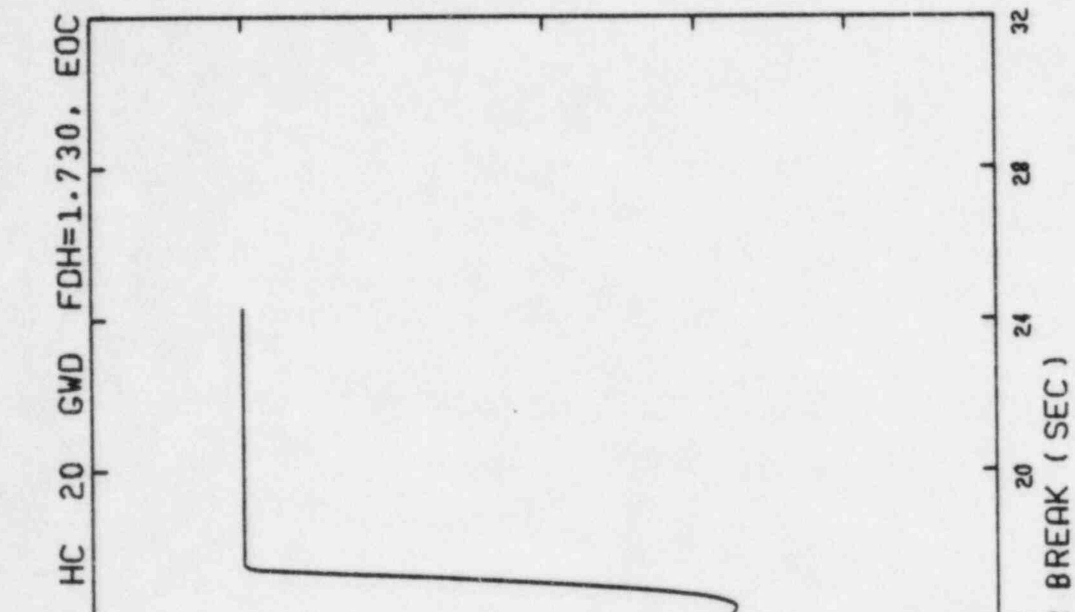

Figure 3.17 Hot Channel Average Quality, Center Volume, 1.0 DECLG Break, EOC, Axial Offset of +3.2%

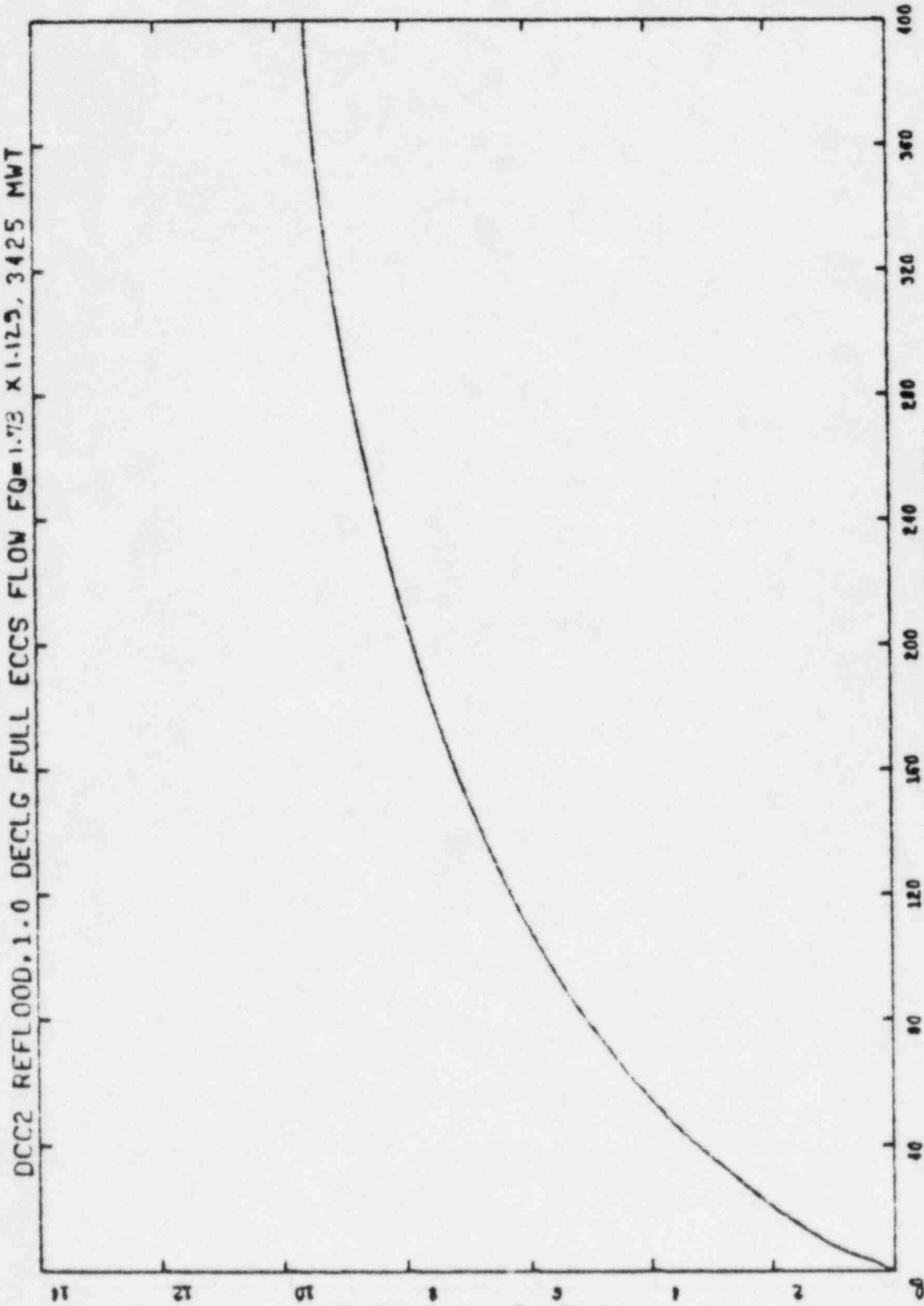

Figure 3.18 Reflood Core Mixture Level, 1.0 DECLG Break, EOC, Axial Offset of +3.2%

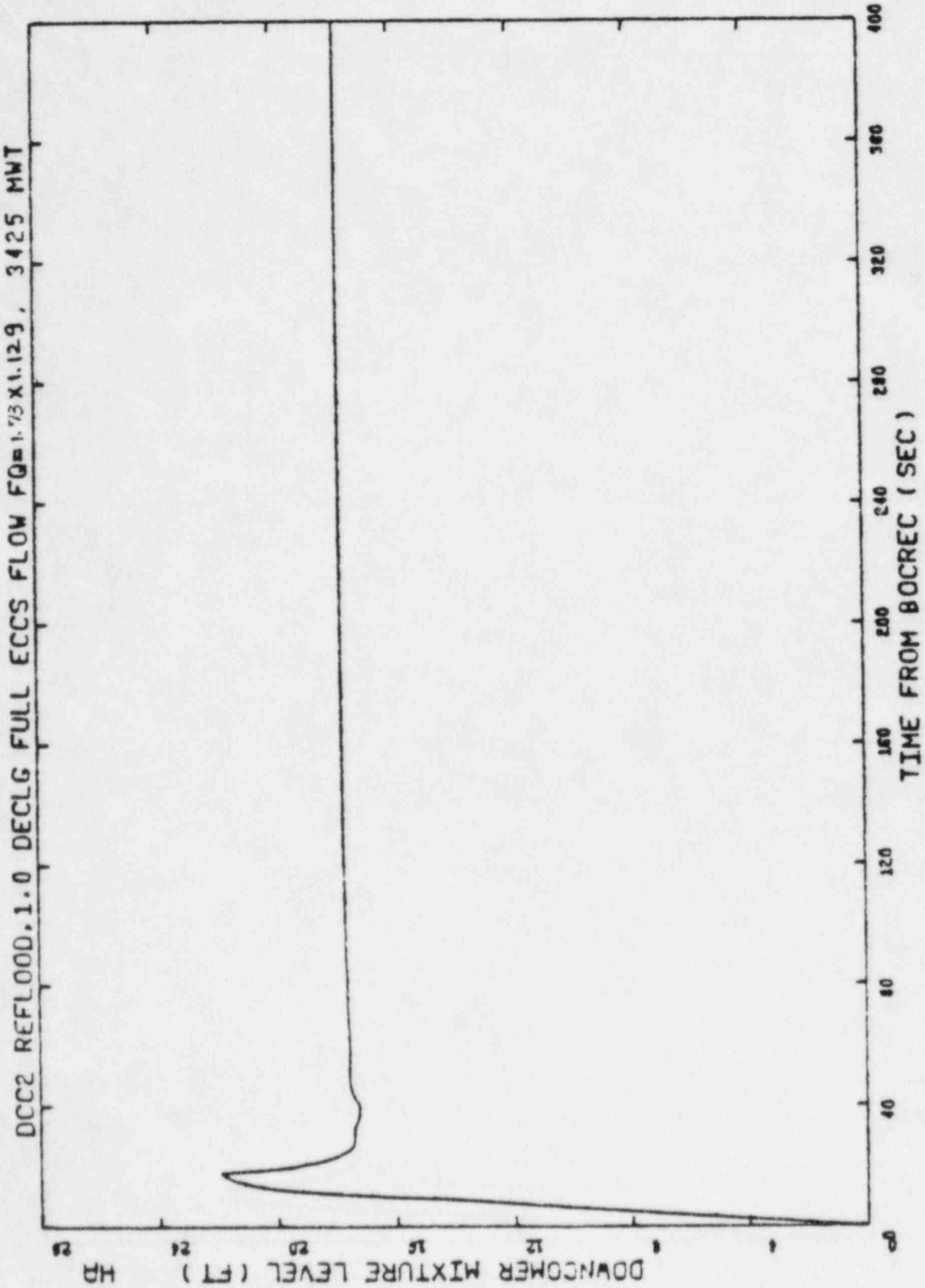

Figure 3.19 Reflood Downcomer Mixture Level, 1.0 DECLG Break, EOC, Axial Offset of +3.2%

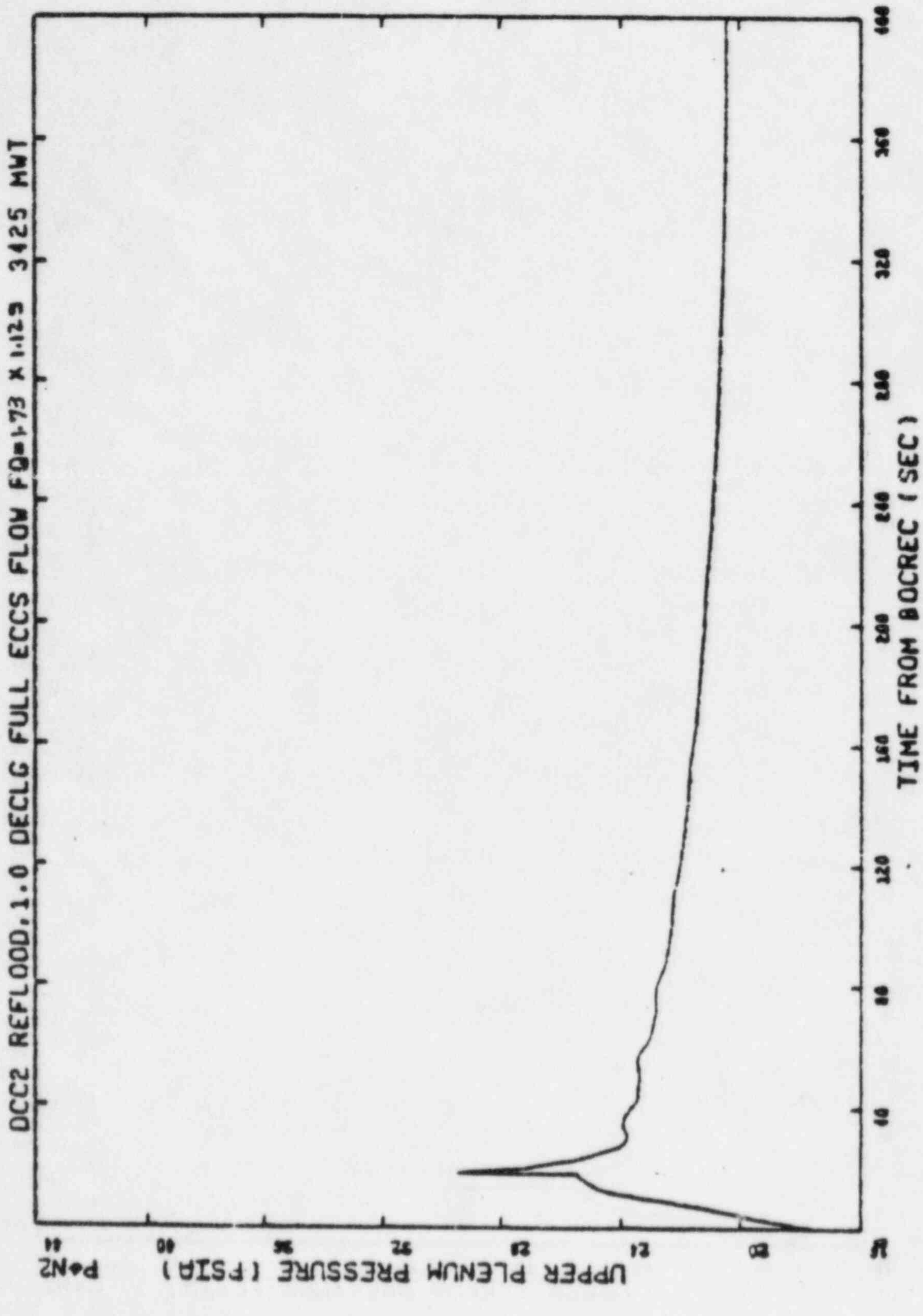

Figure 3.20 Reflood Upper Plenum Pressure, 1.0 DECLG Break, EOC, Axial Offset of +3.2%

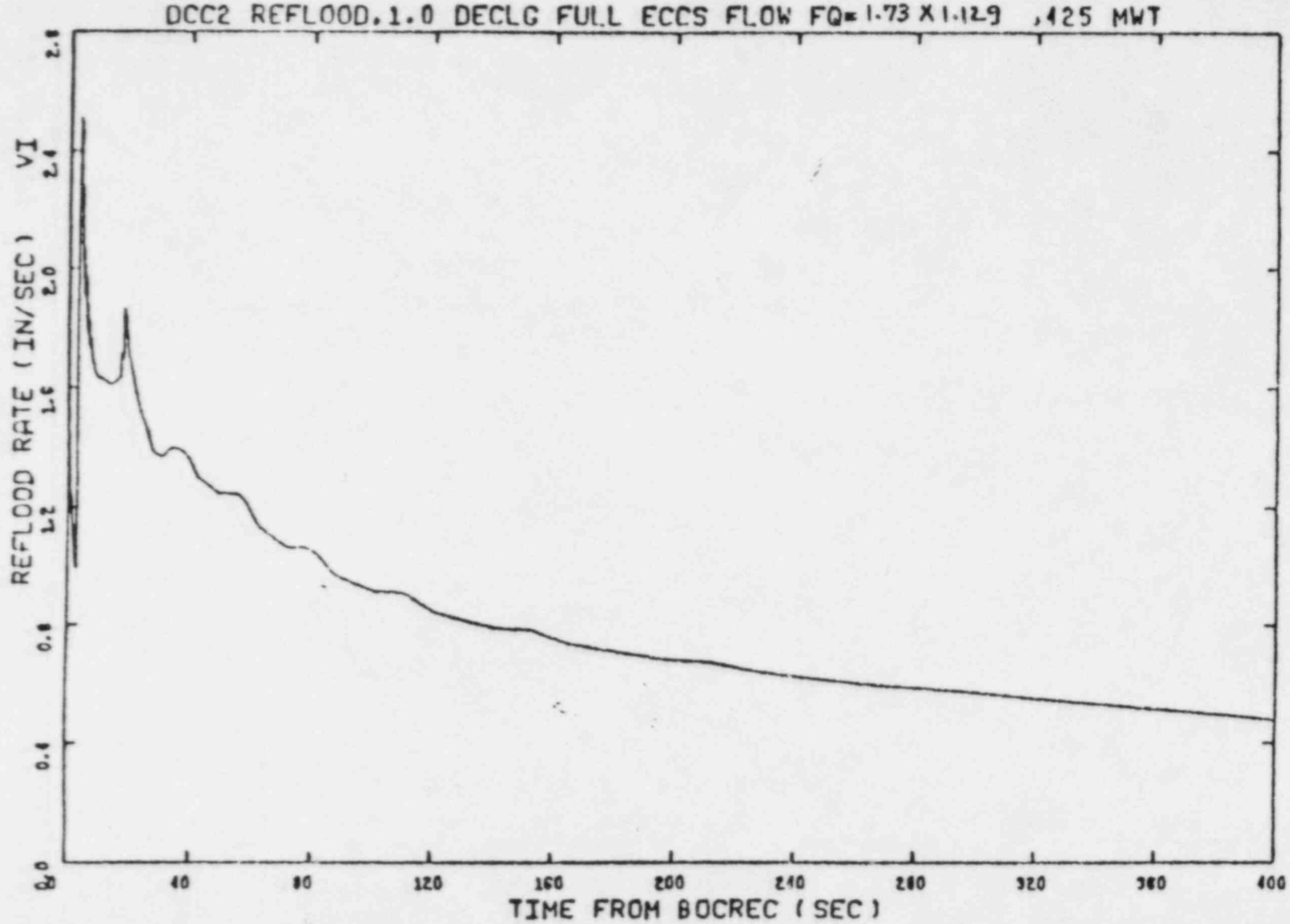

Figure 3.21 Core Reflooding Rate,
1.0 DECLG Break, EOC, Axial Offset of +3.2%

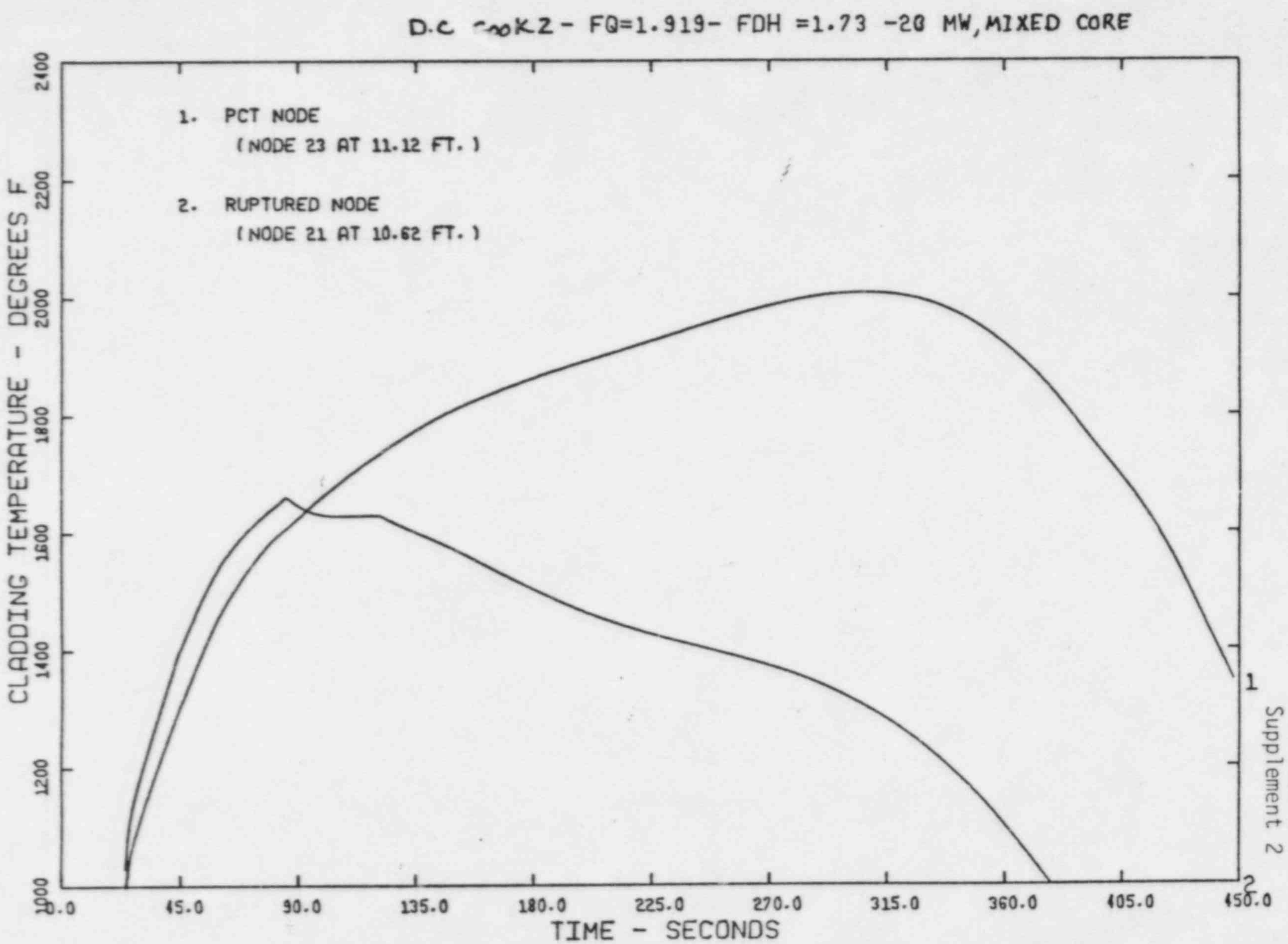

Figure 3.22 TOODEE2 Cladding Temperature versus Time
1.0 DECLG Break, EOC, Axial offset of

4.0 CONCLUSIONS

For breaks up to and including the double-ended severance of a reactor coolant pipe with axial power distributions representative of the largest axial offsets anticipated during the Cycle 5 operation, the D.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 and shown in Figure 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.

5.0 REFERENCES

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

LIMITING BREAK LOCA-ECCS ANALYSIS: K(Z) CURVE

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