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REVISION 1

ST. LUCIE UNIT 1 LOCA/ECCS ANALYSIS WITH 11% STEAM GENERATOR TUBE PLUGGING

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EXXON NUCLEAR COMPANY, INC.

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1.0 BACKGROUND AND SUMMARY

In November 1985, Exxon Nuclear Company (ENC) reported revised LOCA/ECCS analyses for St. Lucie Unit 1 which corrected errors in previous analyses and increased the level of analyzed steam generator tube plugging to 15%.(1) Reference 1 reported the first phase of the analysis and provided axially dependent linear heat rate (LHR) limits for St. Lucie Unit 1 operating with ENC 14x14 fuel for Cycle 7 and future cycles. The LHR limits were established by LOCA/ECCS analysis calculations for the limiting break (0.8 double-ended cold leg guillotine). The calculations were performed at the exposure at which the peak stored energy occurred.

Analyses confirming that the conditions for the analysis in Reference 1 are limiting are documented in Reference 2. These results confirmed the 0.8 double-ended cold leg guillotine as the limiting break. These results also confirmed that the peak cladding temperature occurs at the exposure where the stored energy is maximum (1.8 MWD/kg peak rod average burnup). The axially dependent linear heat rate (LHR) limits resulting from the analyses presented in References 1 and 2 for St. Lucie Unit 1 are shown in Figure 2.1 of Reference 1. These limits provide for an allowable LHR of 15 kW/ft up to a relative core height of 0.6, and decreasing linearly to 13.4 kW/ft at a relative core height of 0.81 and to 10.07 kW/ft at a relative core height of 1.0.

The purpose of the analysis presented in this report was to support an increase in the allowable LHR at relative core heights above 0.6; specifically, 14 kW/ft at a relative core height of 0.81. This analysis assumed an average steam generator tube plugging of 11%, and included several other modifications in plant data and operation that are listed in Section 2.0 of this report. A top peaked axial power profile was used which bounded the predicted profiles for EOC conditions.

The results of this analysis showed the peak cladding temperature to be 2183°F for the top peaked profile analyzed. These results support operation at up to 14 kW/ft at a relative core height of 0.81. Combining these results with those in References 1 and 2, the axially dependent LHR limits can be defined as shown in Figure 1.1. This provides for increased operating margin compared to the current Technical Specification limits. These results bound expected conditions for Cycle 7 and future cycles using the current ENC fuel design, and are valid for up to an average of 11% steam generator tube plugging.

Operation of the St. Lucie Unit 1 reactor with ENC 14x14 fuel at or below the LHR limits of Figure 1.1 assures that the U.S. NRC acceptance criteria for Loss-of-Coolant Accident breaks up to and including the double-ended severance of a reactor coolant pipe (specified by 10 CFR 50.46(b)) will be met with the emergency core cooling system for the St. Lucie Unit 1 reactor. That is:

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

(2) The amount of fuel element cladding which 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 is still amenable to cooling. The hot fuel rod cladding oxidation limit of 17% is not exceeded during or after quenching.

(4) The system long-term cooling capabilities provided for the initial core and subsequent reloads remain applicable to ENC fuel.

The Local Power Density Limiting Condition for Operation (LPD-LCO) was determined as part of this analysis since it is a function of the axially dependent LHR limits shown in Figure 1.1. The proposed LPD-LCO barn is shown in Figure 4.1. The barn limits power to 88% over an ASI range of 0.02 to 0.08.

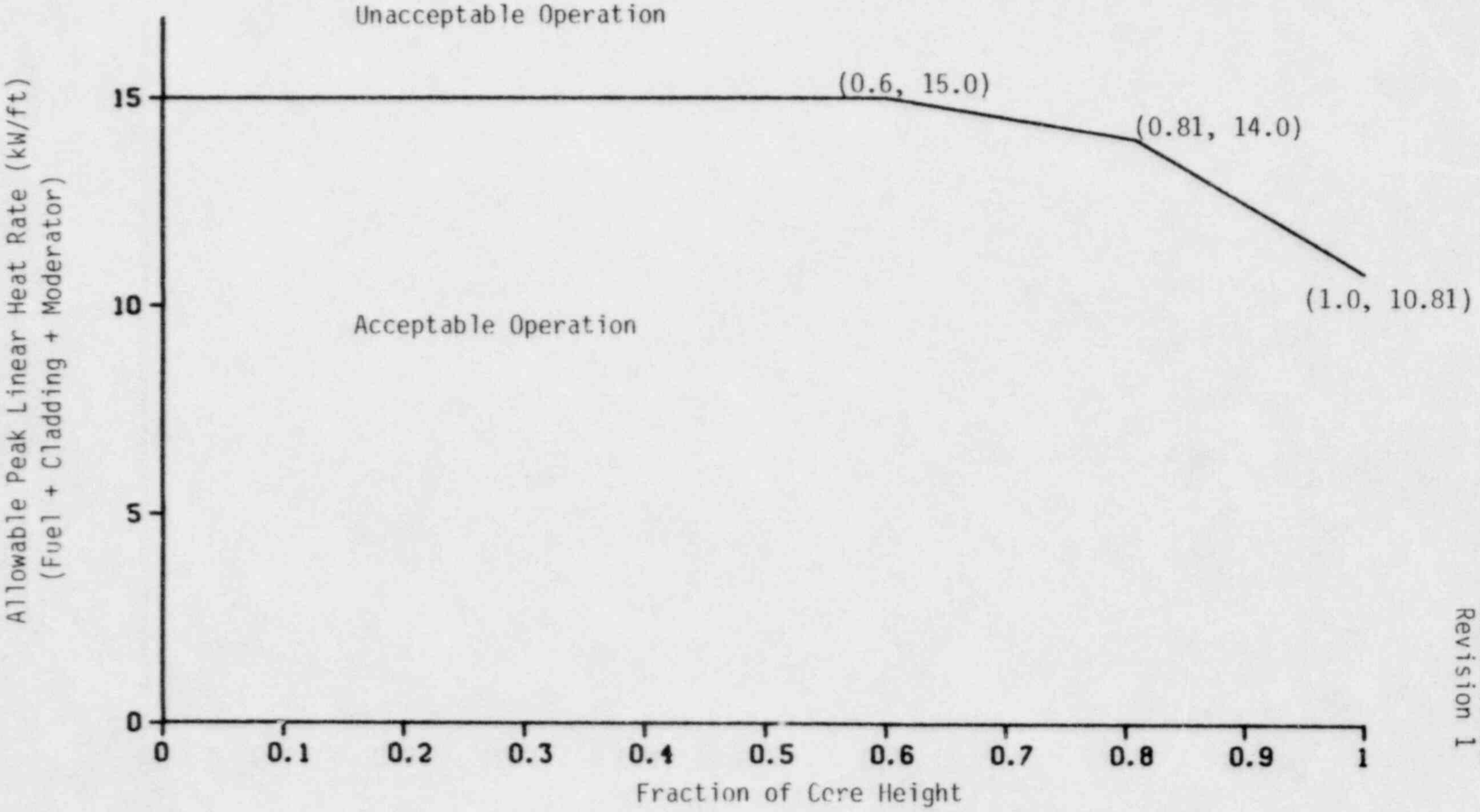

Figure 1.1 St. Lucie Unit 1 Axial LHR Limit

2.0 LOCA/ECCS ANALYSIS - ASSUMPTIONS AND METHODOLOGY

The LOCA/ECCS analysis used the EXEM/PWR ECCS evaluation model(3) as described in Reference 1. The St. Lucie Unit 1 system input was the same as that in References 1 and 2 with the exceptions noted in Table 2.1. These changes were justified by actual plant operation and comparison of the system input values to plant data. The revised analysis supports higher LHR values than supported by the analyses reported in References 1 and 2.

The axial power profile used in the analysis is shown in Figure 2.1. This profile has a peak at a relative core height of 0.81 and bounds the predicted EOC shapes, including uncertainties. The axial peaking factor was 1.17. A radial peaking factor of 1.84 was used in the analysis. This value is larger than the Technical Specification value of 1.7 to account for measurement uncertainties and control rod peaking factor augmentation. An assembly local peaking factor of 1.1 for the hot assembly was used.

Primary system measured flow rate (395,877 gpm) and pressure drops at the current steam generator tube plugging level were used as a basis to establish the initial primary system flow rate used in the analysis. Best estimate system loss coefficients were determined from the measured flow rate and pressure drop. The loss coefficients were then adjusted for asymmetric steam generator tube plugging of 9 and 13 percent. The primary system flow split to each steam generator was then calculated. The resulting best estimate loop flow rate was determined to be 386,121 gpm. Since a best estimate loop flow rate is used, no additional limit is placed on the core flow rate over those imposed by DNBR considerations. The analysis is applicable only up to a steam generator plugging level of 11%.

St. Lucie Unit 1 system parameters used in the analysis are shown in Table 2.2. Table 2.3 shows the core and fuel design parameters used in the analysis.

Table 2.1 St. Lucie Unit 1 - Changes in Analysis

	Ref. 1 & 2	This Analysis
Average steam generator tube plugging	15% (17% broken loop, 13% intact loop)	11% (13% broken loop, 9% intact loop)
Steam generator secondary side initial liquid mass	90,367 lbm	131,745 lbm
Accumulator line resistance	7.5	5.94
Initial containment temperature	90°F	100°F
Secondary steam flow and feedwater flow	Instantaneous	100% steam flow for 1.4 sec after break initiation, followed by a linear ramp to 0.0 flow in 0.3 sec. Linear coastdown in feedwater flow to 0.0 in 2 sec following break initiation.
Core cross-flow resistance	10	30
Core average LHR, kW/ft*	6.42	6.35

* The number of active rods in Cycle 7 was already considered in References 1 and 2 except for the system blowdown calculation. This change only applies to the system blowdown calculation.

Table 2.2 St. Lucie Unit 1 System Analysis Parameters

Primary Heat Output, MWt	2700*
Primary Coolant Flow Rate, lbm/hr	1.452×10^8** (386,121 gpm)
Primary Coolant System Volume, ft^3	19217***
Operating Pressure, psia	2250
Inlet Coolant Temperature (hottest loop), °F	549
Reactor Vessel Volume, ft^3	4522
Pressurizer Volume, Total, ft^3	1500
Pressurizer Volume, Liquid, ft^3	888
Accumulator Volume, Total, ft^3 (one of four)	2020
Accumulator Volume, Liquid, ft^3	1090
Accumulator Pressure, psia	230
Steam Generator Tube Plugging	13% - 9% split
Steam Generator Secondary Side Heat Transfer Area, 13% SGTP, ft^2	78474
Steam Generator Secondary Side Heat Transfer Area, 9% SGTP, ft^2	82082
Steam Generator Secondary Flow Rate, lbm/hr (49-51% power split)	5.868×10^6 (13% SGTP) 6.108×10^6 (9% SGTP)
Steam Generator Secondary Pressure, psia	823
Reactor Coolant Pump Head, ft	272
Reactor Coolant Pump Speed, rpm	886
Moment of Inertia, lbm-ft^2	101,900
Cold Leg Pipe, I.D., in.	30
Hot Leg Pipe, I.D., in.	42
Pump Suction Pipe, I.D., in.	30

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*Primary Heat Output used in RELAP4-EM Model - 1.02 x 2700 = 2754 MWt.

**Best Estimate Flow (3% flow measurement uncertainty not subtracted).

***Includes total accumulator and pressurizer volume, 11% SGTP.

Table 2.3 St. Lucie Unit 1 Core and Fuel Design Parameters, ENC Fuel

Fuel Assembly Rod Diameter, in.	.440
Fuel Assembly Rod Pitch, in.	.580
Fuel Assembly Pitch, in.	8.180
Fueled (Core) Height, in.	136.7
Fuel Heat Transfer Area for Cycle 7 (heated rods), ft^2	48,967
Fuel Total Flow Area, ft^2	53.19
Fuel Total Flow Area for Reflood Calculation (excludes area due to spacer volume), ft^2	52.70

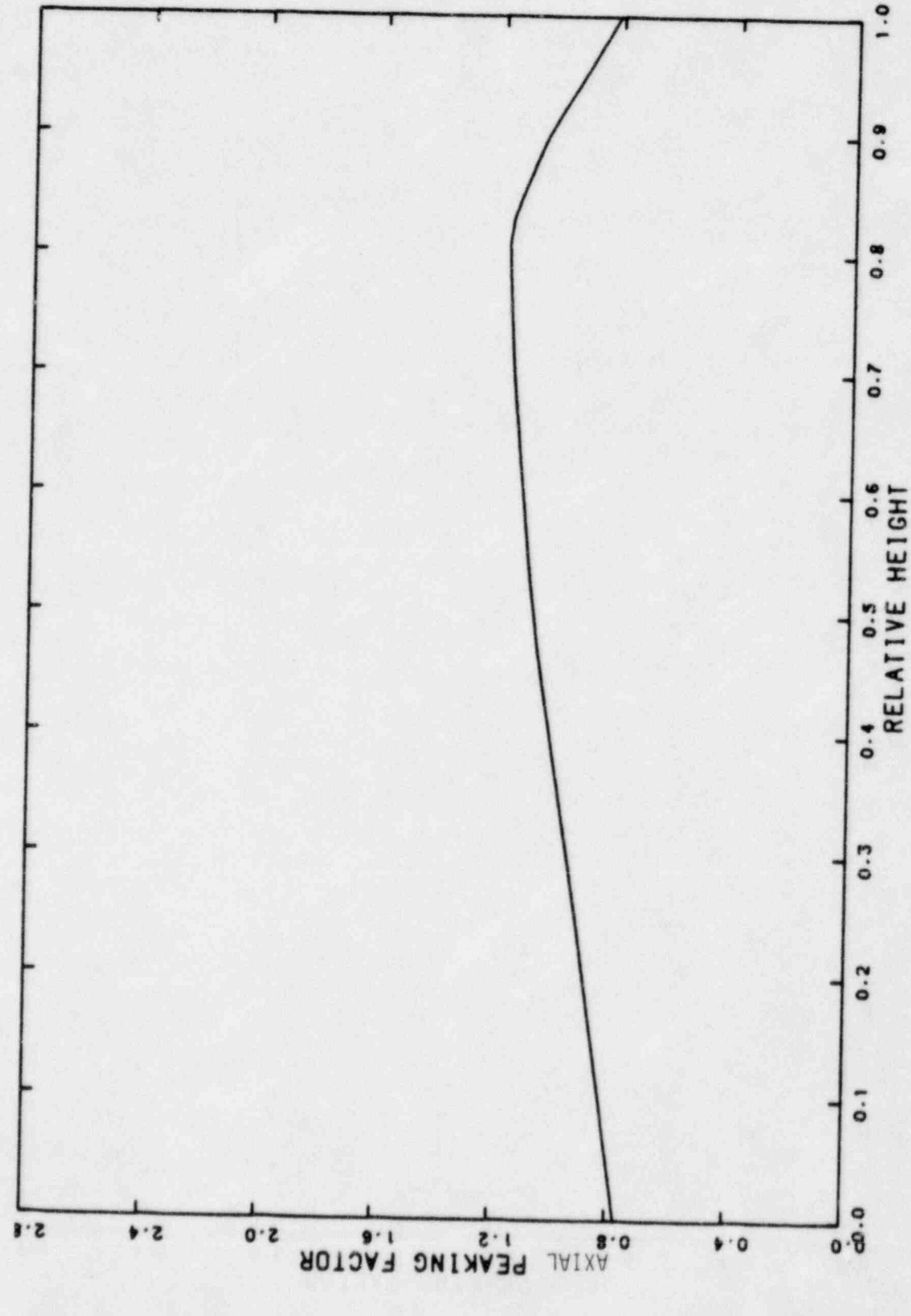

Figure 2.1 Axial Power Profile for 14 kW/ft at X/L = 0.81

3.0 RESULTS

The significant event timings for the Loss-of-Coolant Accident (0.8 DECLG) analyzed are shown in Table 3.1. The event timings are similar to those given in Table 3.5 of Reference 1 except for the start of reflood time. The start of reflood time for this analysis was 38.78 sec, as compared to 39.71 sec in the previous analysis.(1) This is due to the lower accumulator line resistance which allows slightly higher accumulator flow rates and the lower plenum and downcomer to fill more quickly. Also, the end-of-bypass time was 21.64 sec, as compared to 21.25 sec in the previous analysis. The difference in the heatup time during refill of 1.32 sec had a significant effect on the temperature of the ruptured node during reflood. A metal-water reaction excursion was prevented for the case with an LHR of 14 kW/ft at the 0.81 elevation.

The effect of the other changes in the analysis listed in Table 2.1 are discussed below. The majority of these changes resulted in small effects on the calculated PCT.

The reduced steam generator tube plugging level relative to the previous analysis had the effect of increasing the reflood rate and reducing the peak cladding temperature (PCT). This effect is not large since the change in resistance in the steam generator is not large compared to the total line resistance and the resistance due to the locked pump rotor.

The larger initial secondary liquid mass has a small effect on the results. During the reflood portion of the transient when heat is transferred from the secondary to the primary system, the larger secondary mass tends to maintain higher steam temperatures on the primary side, which results in a reduced reflood rate and higher PCT. However, an opposite and compensating effect occurs during blowdown when heat is transferred from the primary to the secondary system. The overall effect of increased secondary liquid mass on PCT is estimated to be less than a 10°F increase.

The change in the initial containment temperature from 90°F to 100°F also had a small effect on PCT. The higher initial containment temperature caused the containment pressure to be slightly higher during the transient, which resulted in a higher reflood rate. This higher reflood rate results in a small reduction in the PCT, about 15°F.

The change in the modeling of the operation of the secondary feedwater and steam valves had a significant effect on the transient during the blowdown period as compared to the previous analysis with instantaneous isolation of the secondary system. The increased feedwater flow is estimated to have a minor effect on the transient. However, the increased steam flow over a period of 1.7 sec removed more heat from the primary system. This caused the fluid in the cold legs to remain subcooled slightly longer and resulted in increased pump head and more flow for a few seconds. The additional flow to the core resulted in a higher heat transfer coefficient for a short period of time and more energy removal from the rods. The overall result was a reduction in the average fuel temperature of 50°F for the hot node at the end-of-bypass. The reduced stored energy at the end-of-bypass led to a lower PCT.

The sensitivity in the results due only to a change in the core cross-flow resistance from 10 to 30 was not quantified in this analysis. However, little difference in the cross-flows between the hot channel and average core volumes was seen between this analysis and previous analyses. It was estimated that the change in core cross-flow resistance did not have a significant effect on the results.

The core average LHR for Cycle 7 is less than for previous cycles due to a larger number of active rods (37,316 versus 36,932). This effect was accounted for in the previous analyses described in References 1 and 2 in all but the system blowdown calculation. The larger number of active rods and lower core average LHR were included in the system blowdown calculation for this analysis. The effect of this change alone was not quantified. However, it is estimated that this effect on the system response during blowdown is minor and that the system boundary conditions placed on the hot channel calculation are unaffected.

The peak cladding temperature for this analysis was calculated to be 2183°F at a relative core height of 0.875 (9.97 ft). Significant results of the analysis are tabulated in Table 3.2. Plots of various system parameters are shown in Figures 3.2 through 3.28.

In the break spectrum calculations reported in Reference 2, the only break size with a PCT relatively close to the 0.8 DECLG case was the 1.0 DECLG. The 1.0 DECLG case blowdown and hot channel calculations were rerun with the system parameter changes mentioned in Section 2 to verify that the 0.8 DECLG case was still the limiting break size. The average fuel temperature at the peak power node at the end-of-bypass was found to be 92°F lower for the 1.0 DECLG case, thus verifying that the limiting break size is still the 0.8 DECLG.

Table 3.1 Calculated Event Times

Event	Time of Event (sec)
Start	0.0
Break is Fully Open	0.05
Safety Injection Signal	0.90
Pressurizer Empties	9.1
Accumulator Injection begins, Broken Loop	12.5
Accumulator Injection begins, Single Intact Loop	16.7
Accumulator Injection begins, Double Intact Loop	16.7
End-of-Bypass	21.64
Safety Injection Flow, SIS	30.90
Start of Reflood	38.78
Accumulators Empty, Broken Loop	59.09
Accumulators Empty, Single Intact Loop	62.54
Accumulators Empty, Double Intact Loop	62.44
Peak Clad Temperature is Reached	180.0

Table 3.2 Analysis Results

Peak LHR, kW/ft	14.0 @ X/L = 0.81
Hot Rod Burst	
- Time (sec)	41.74
- Elevation (ft)	9.22
- Fraction of Flow Area Reduction	.441
Peak Clad Temperature	
- Temperature (°F)	2183
- Time (sec)	180.0
- Elevation (ft)	9.97
Metal-Water Reaction	
- Local Maximum, %	4.5*
- Elevation of Local Max. (ft)	9.97
- Core Maximum, %	<1.0

*At 200 seconds.

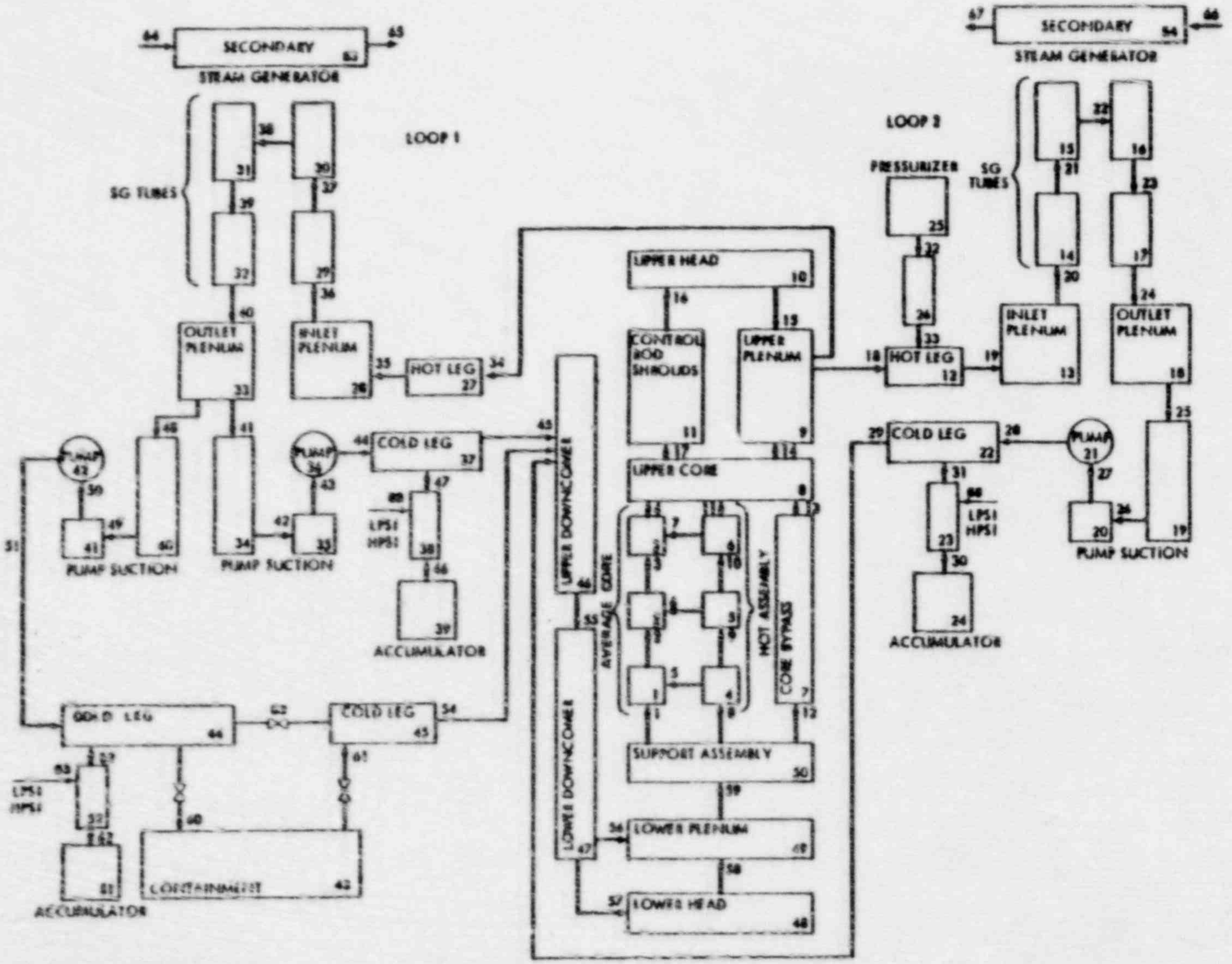

Figure 3.1 RELAP4-EM Blowdown System Nodalization For St. Lucie Unit 1

Figure 3.2 Total Break Flow Rate vs Time

Figure 3.3 Pressurizer Surge Line Flow Rate vs Time

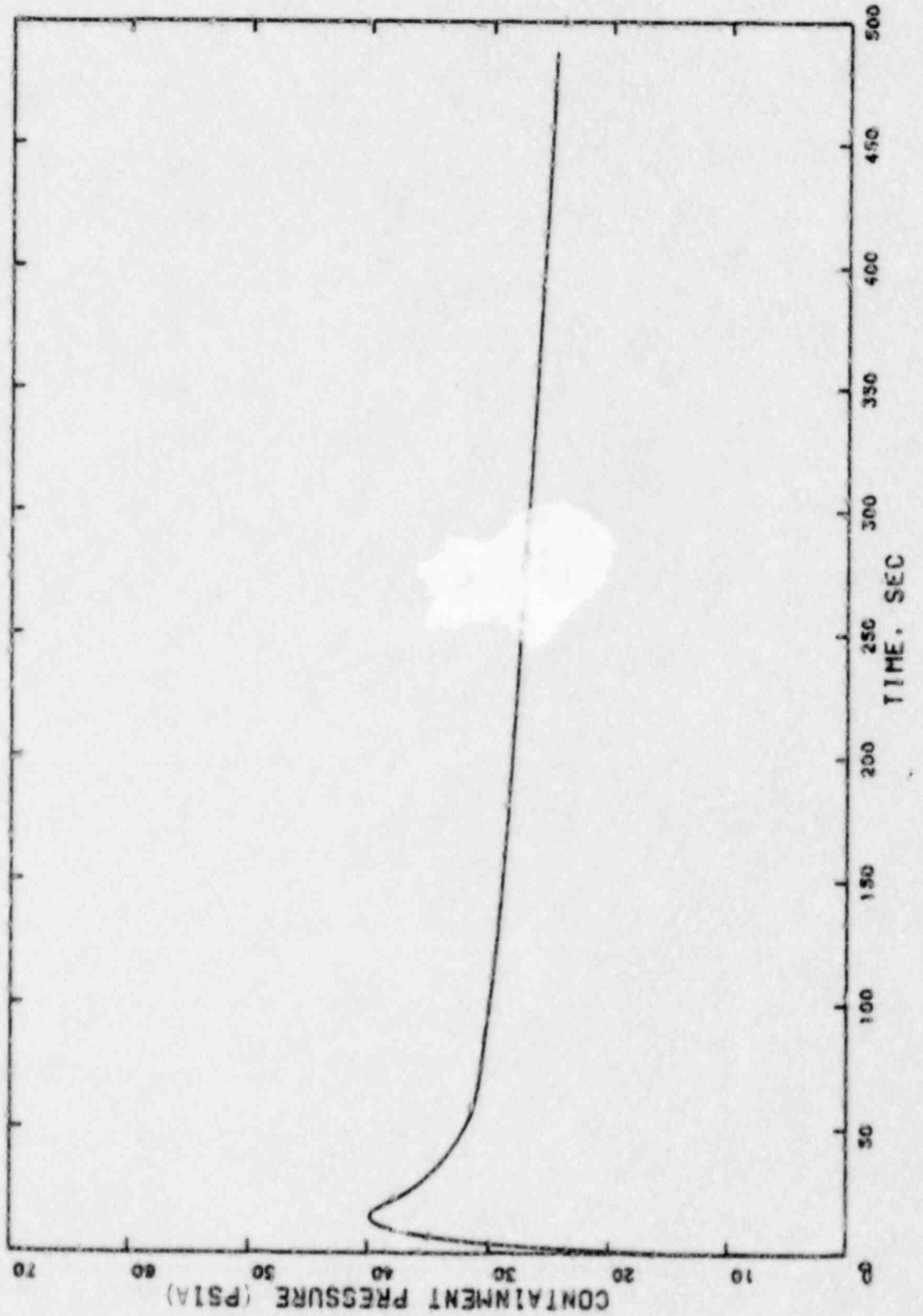

Figure 3.4 Containment Pressure versus Time

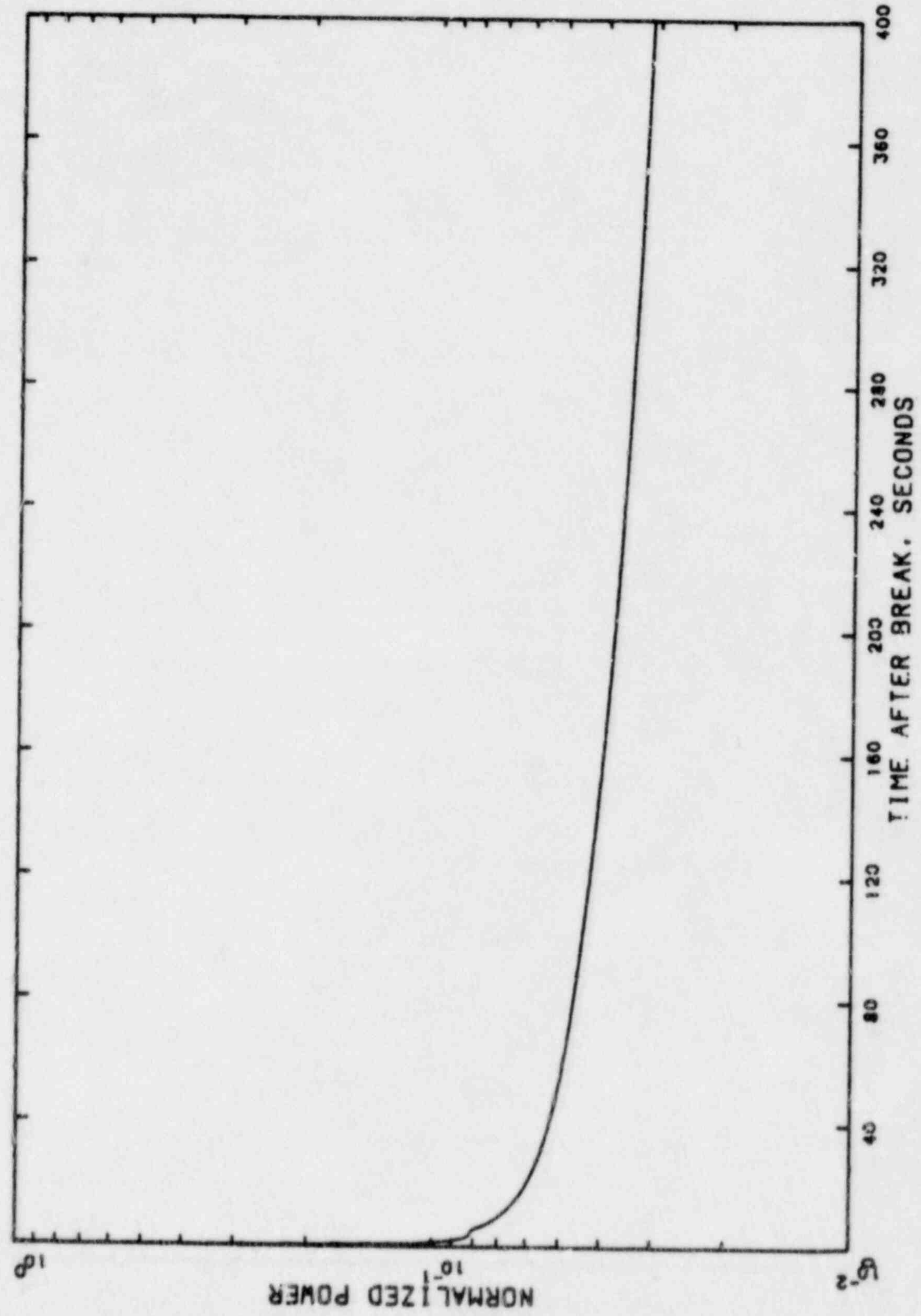

Figure 3.5 Normalized Power versus Time

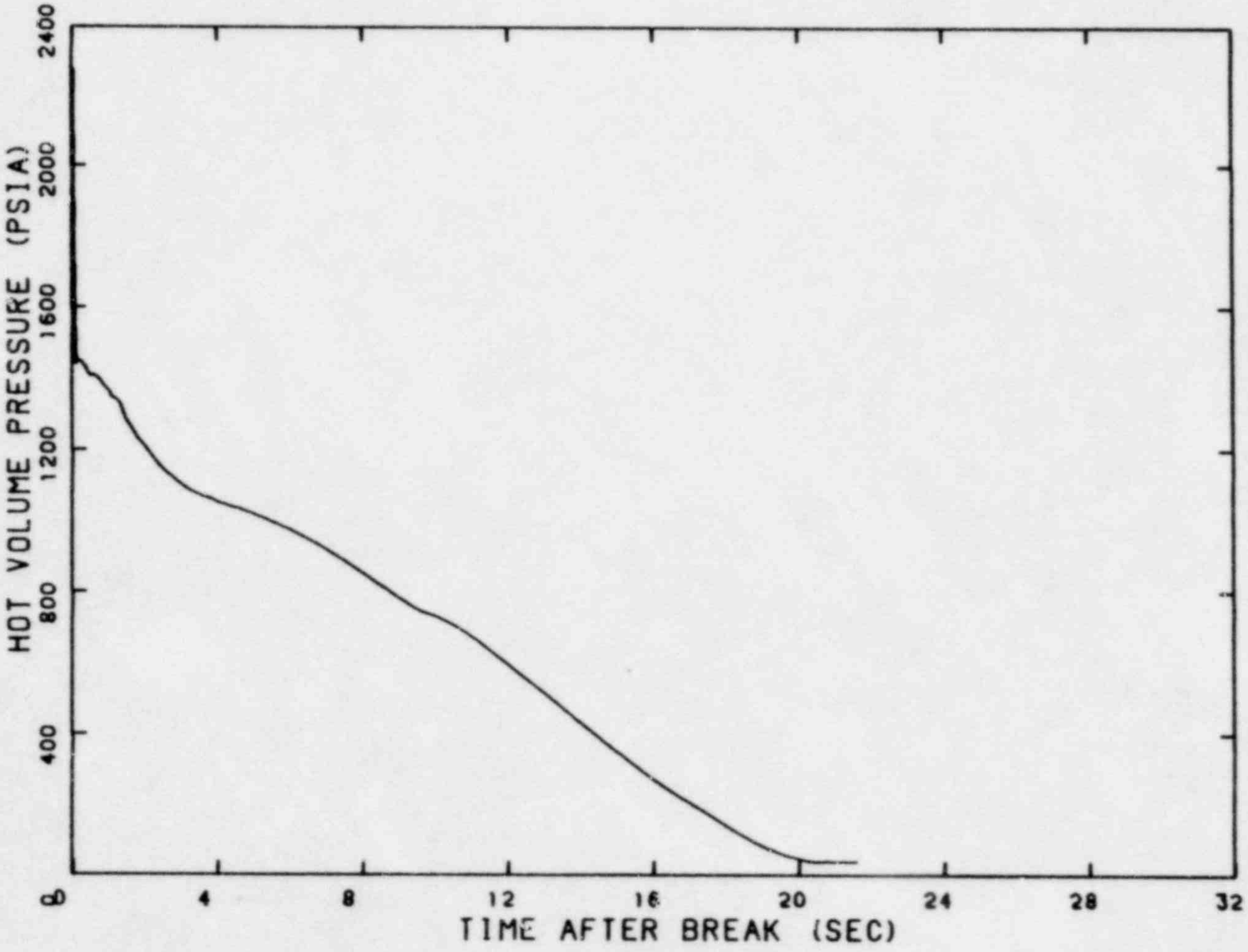

Figure 3.6 Upper Core Volume,Pressure versus Time

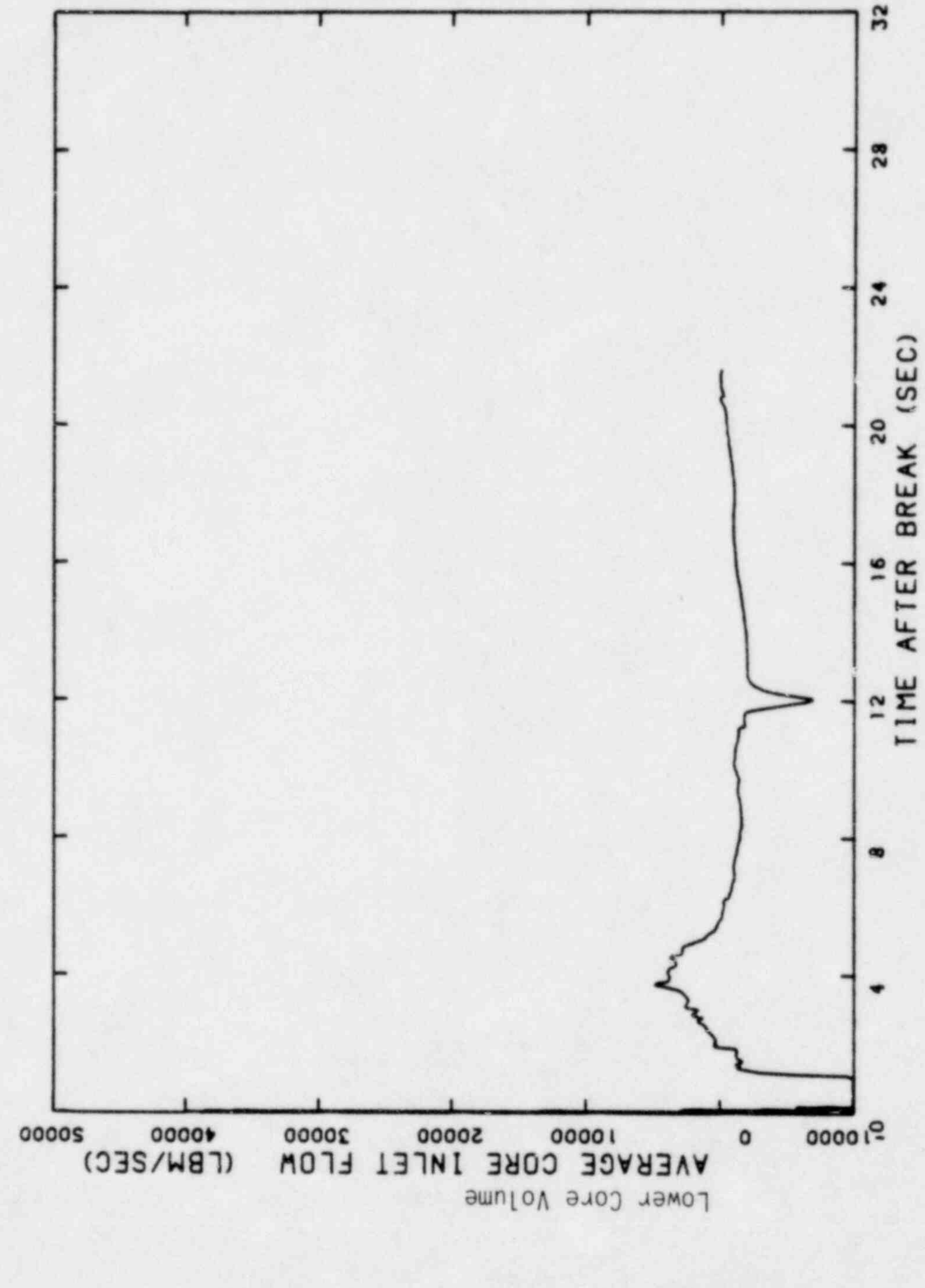

Figure 3.7 Lower Core Volume, Average Core Inlet Flow Rate versus Time

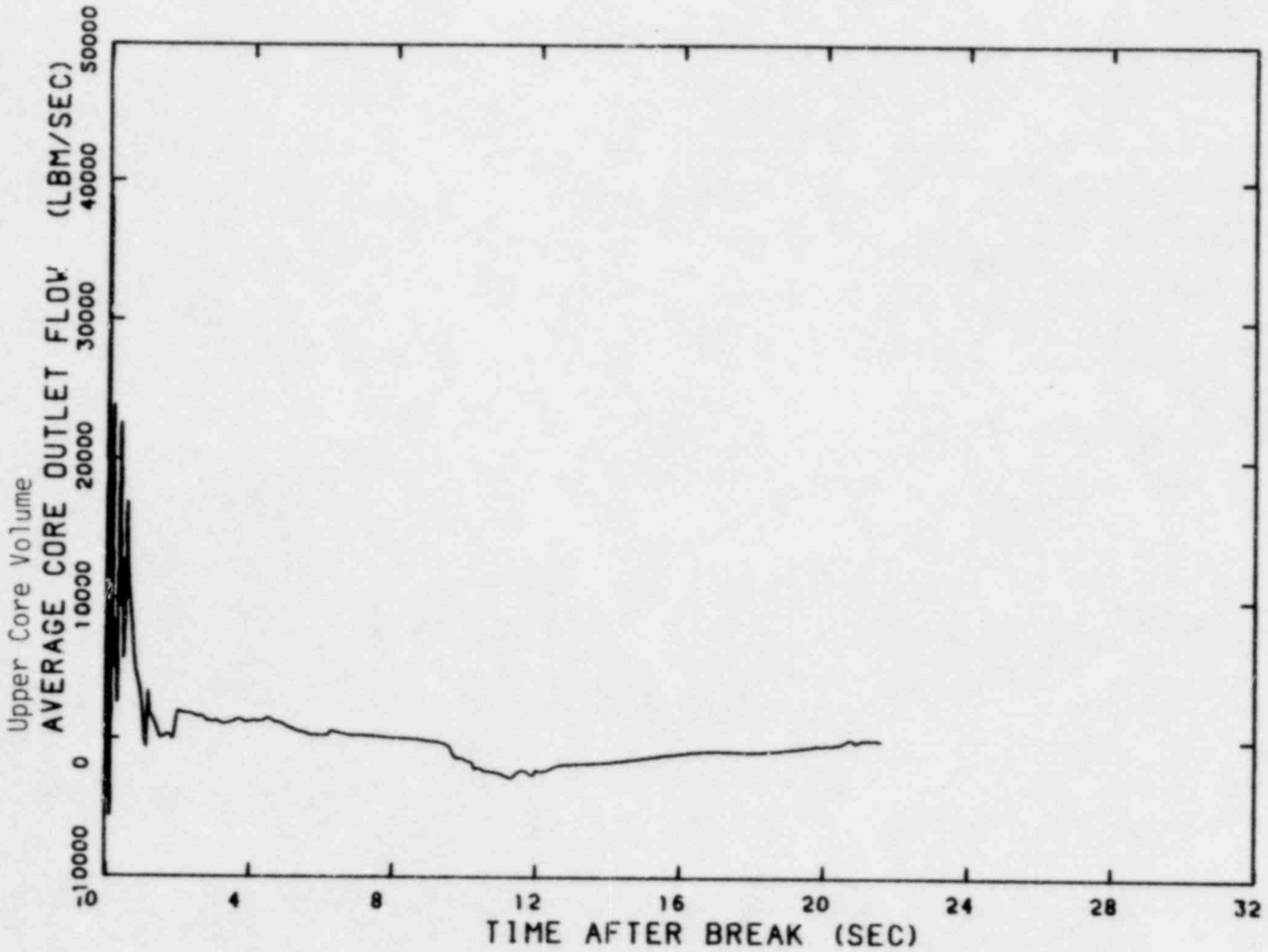

Figure 3.8 Upper Core Volume, Average Core Outlet Flow Rate versus Time

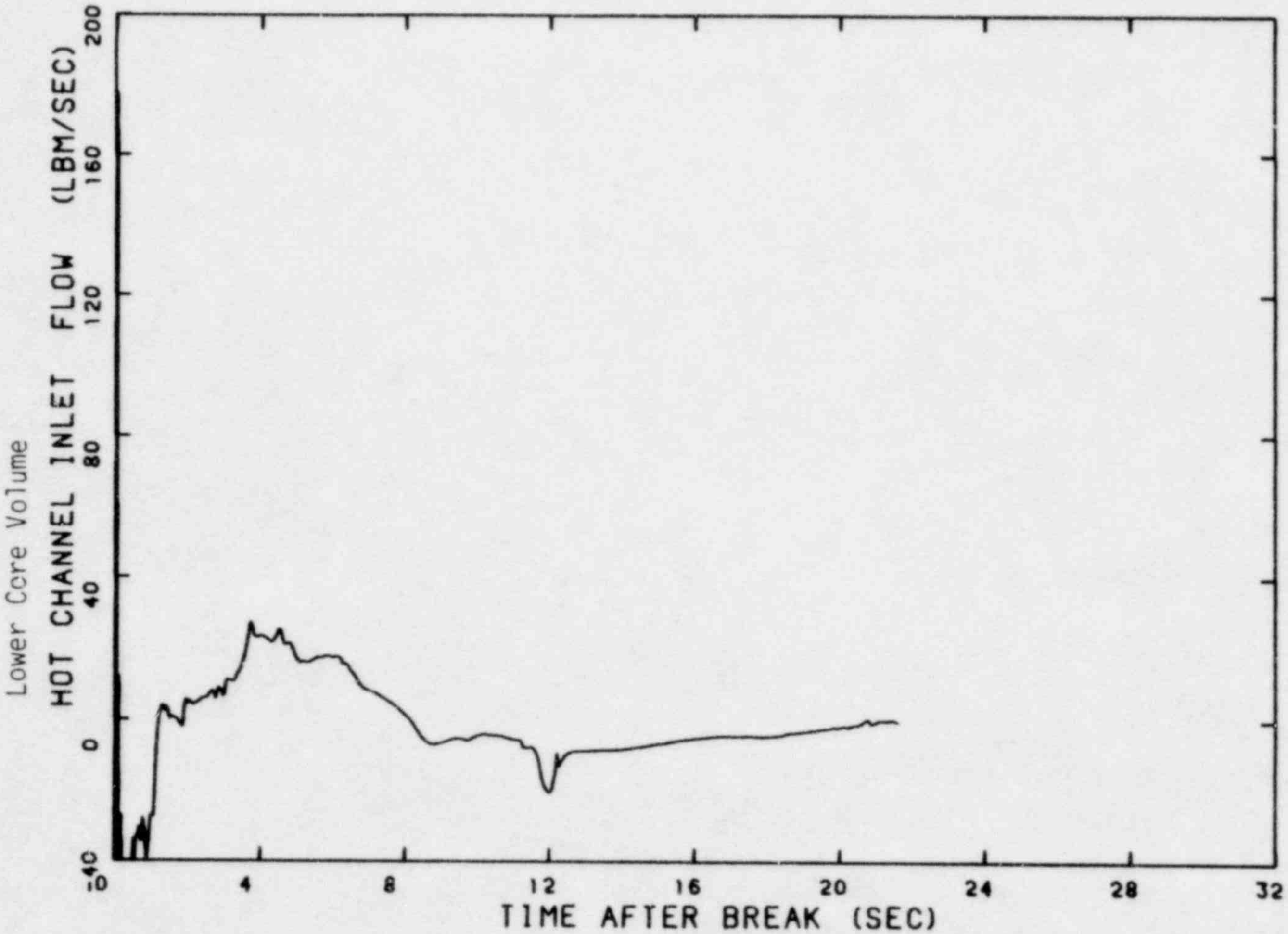

Figure 3.9 Lower Core Volume, Hot Channel Inlet Flow Rate versus Time

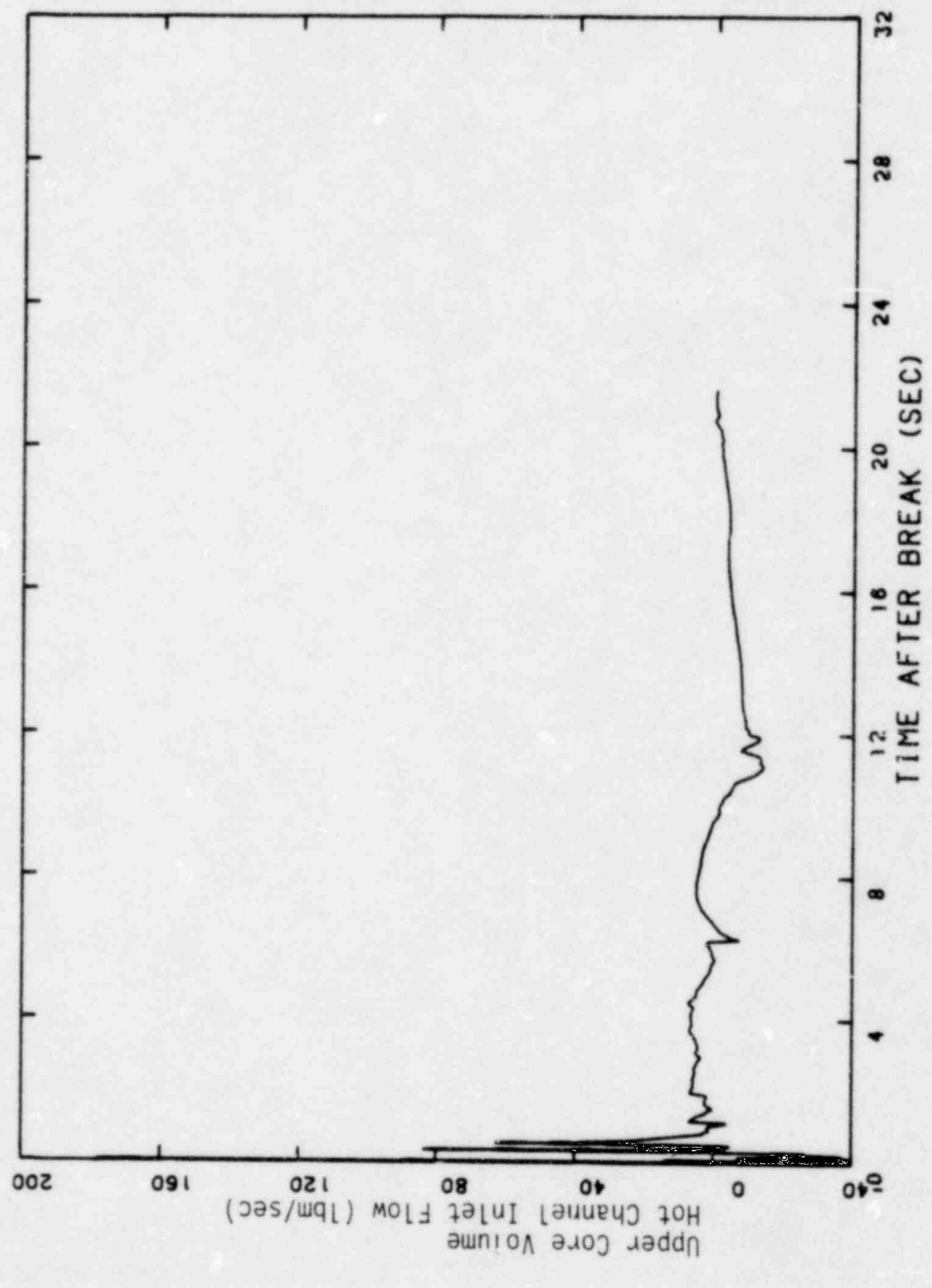

Figure 3.10 Upper Core Volume, Hot Channel Inlet Flow Rate versus Time

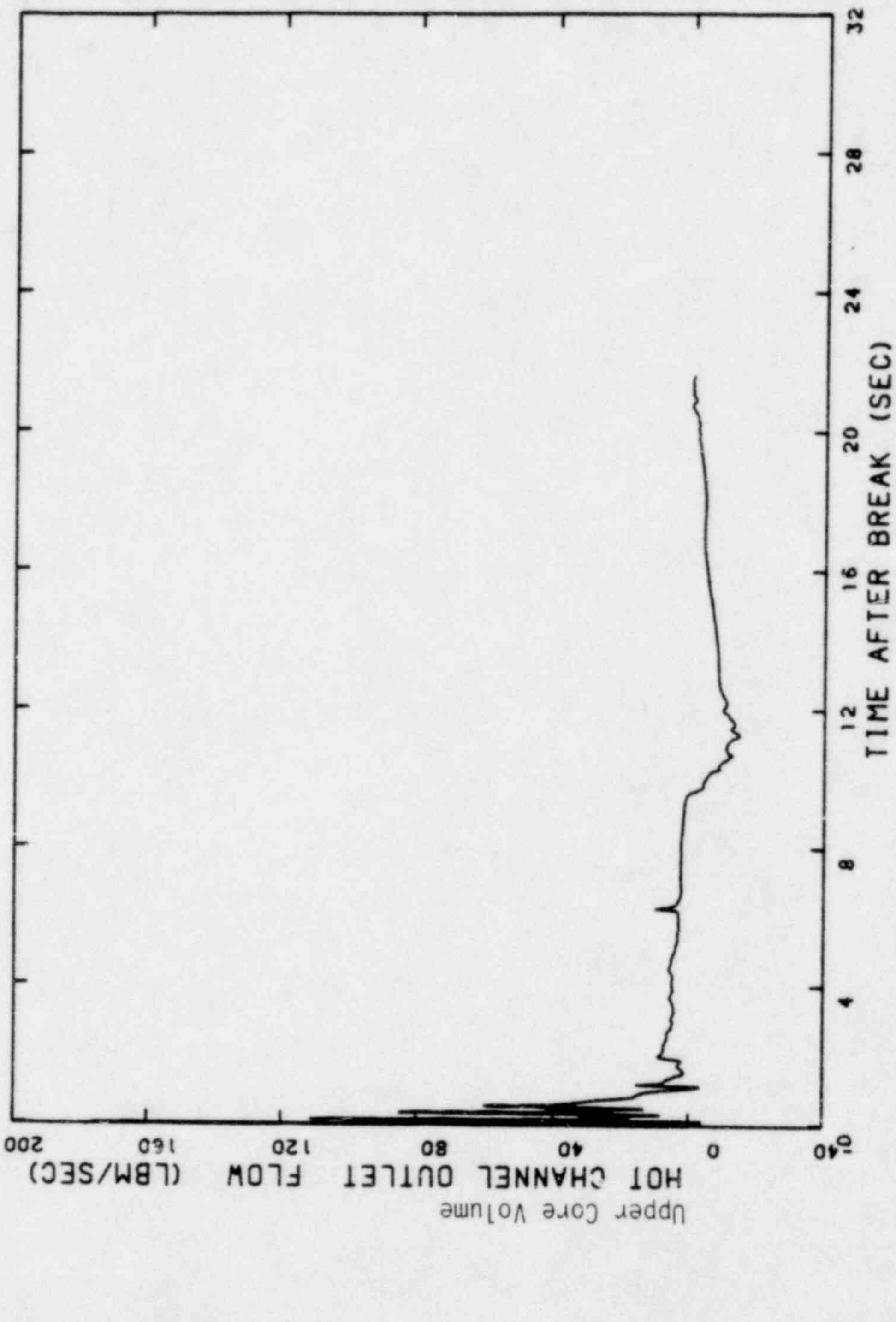

Figure 3.11 Upper Core Volume, Hot Channel Outlet Flow Rate vs Time

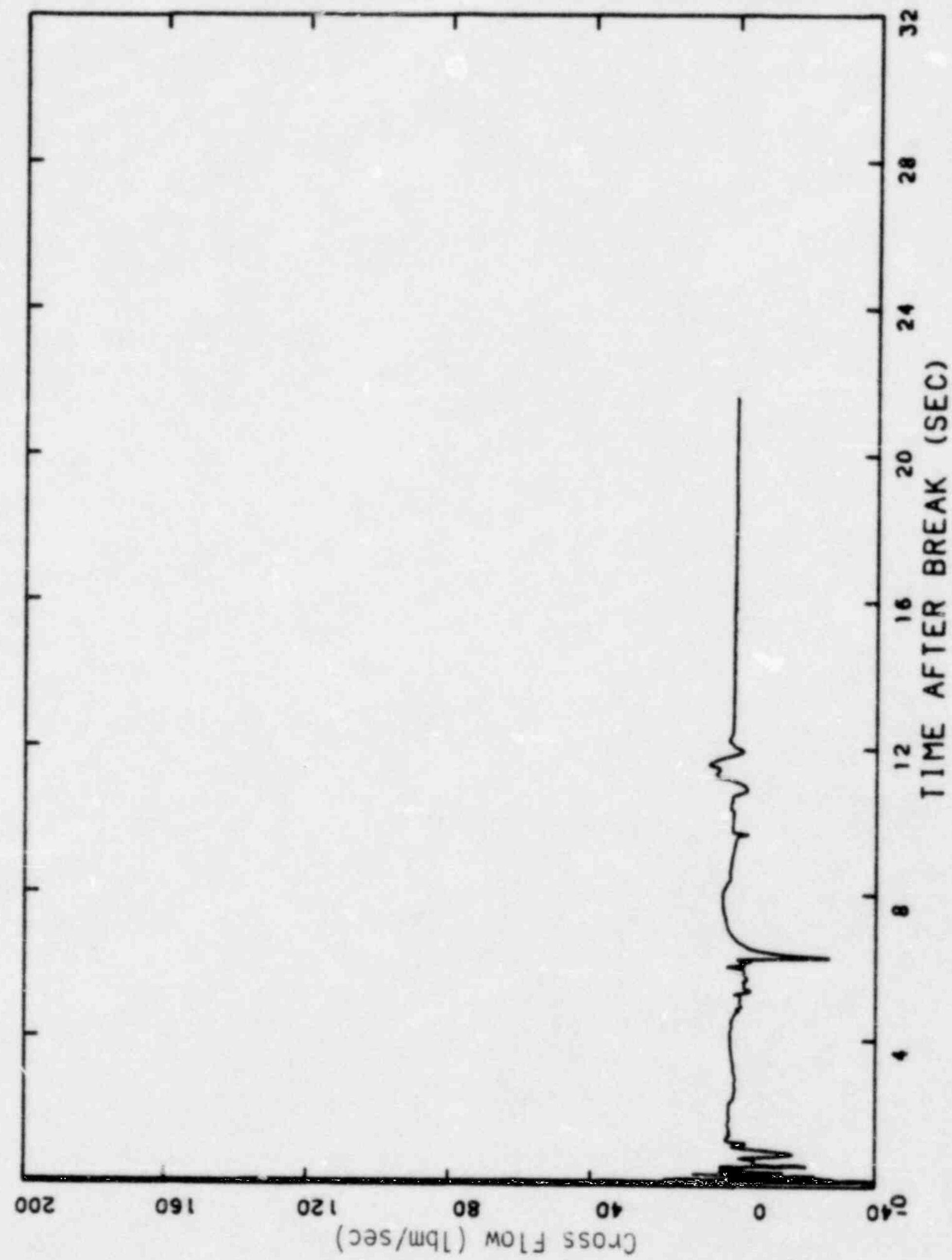

Figure 3.12 Upper Core Volume, Hot Channel Cross Flow versus Time

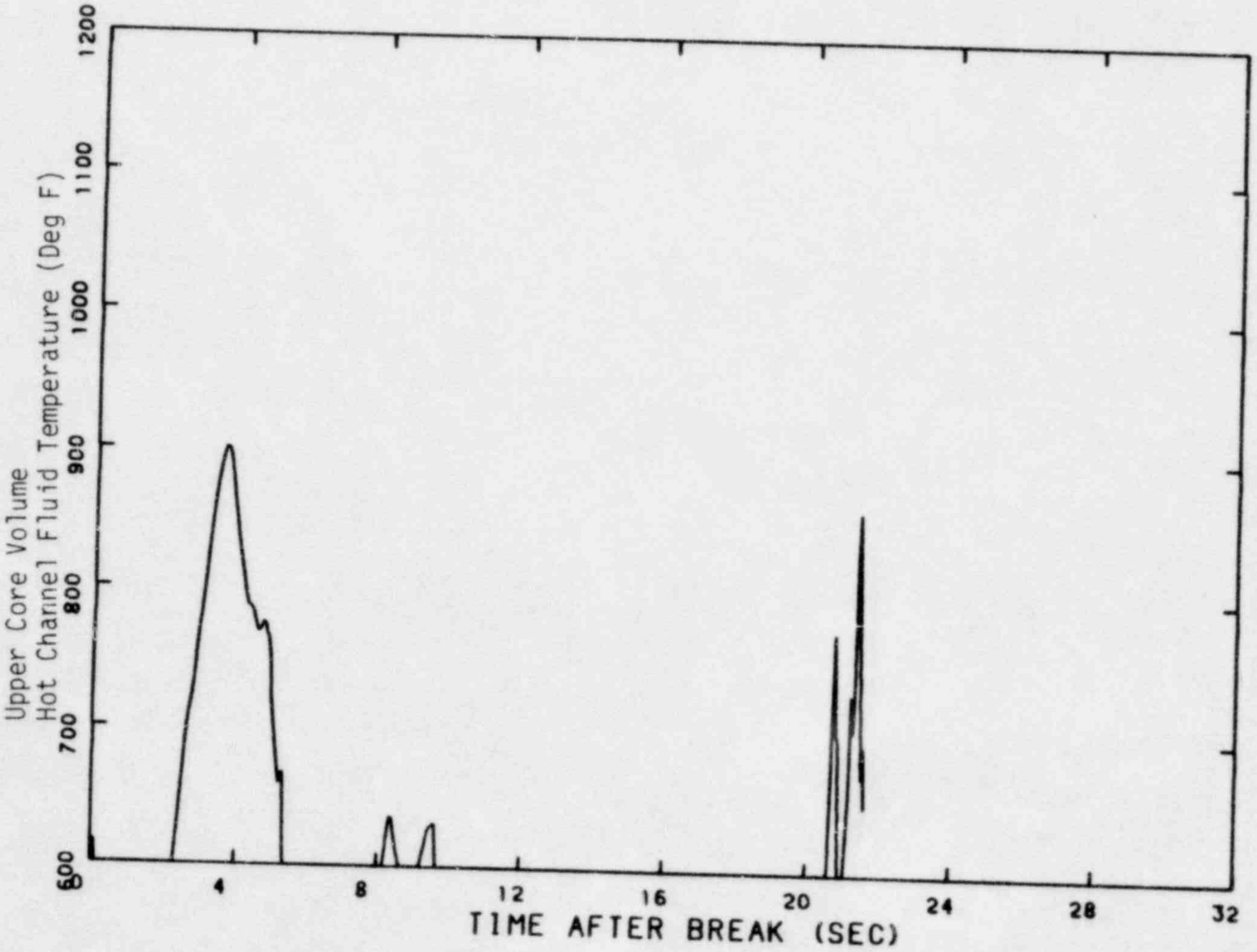

Figure 3.13 Upper Core Volume Hot Channel Fluid Temperature vs Time

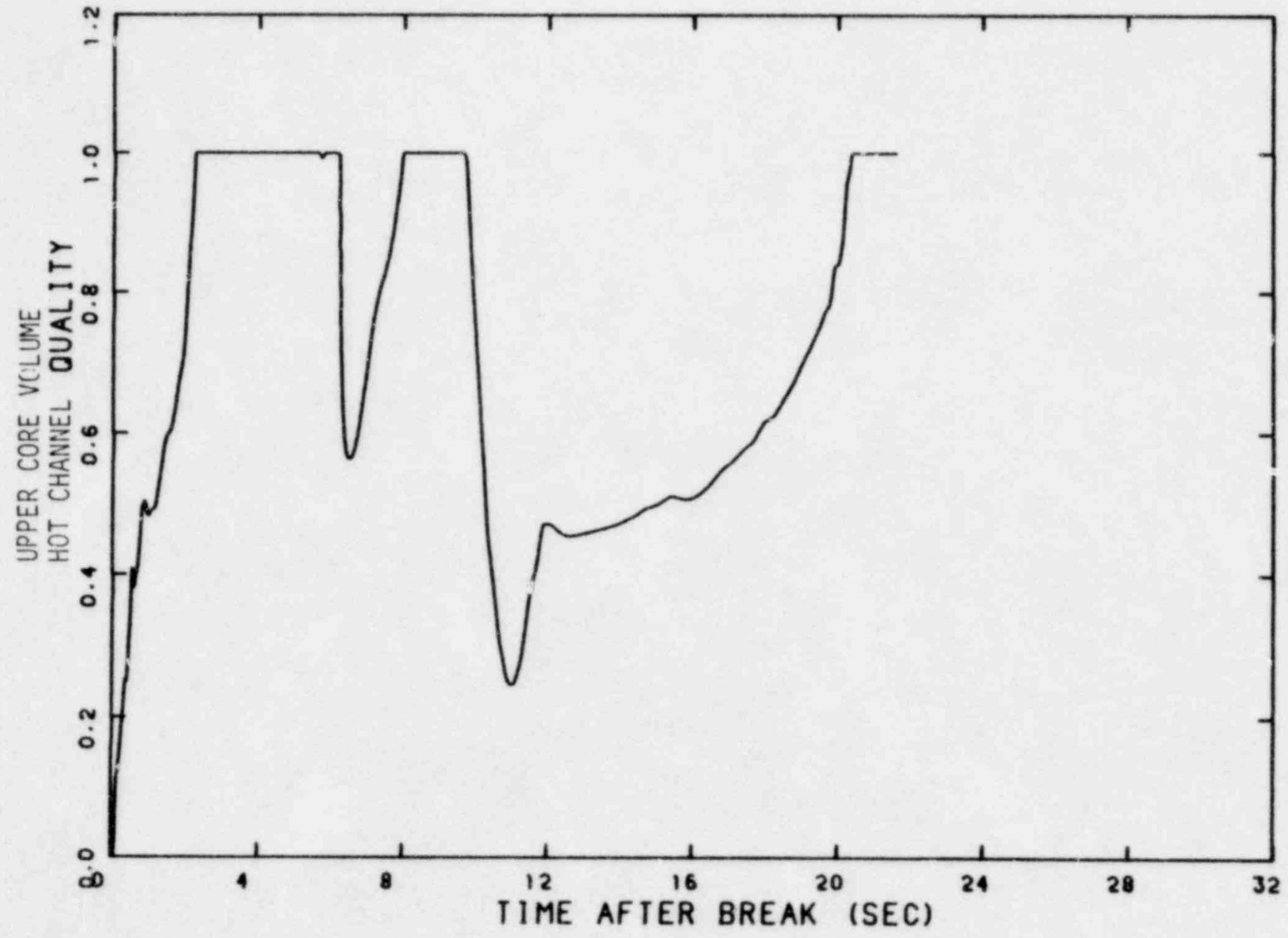

Figure 3.14 Upper Core Volume Hot Channel Quality versus Time

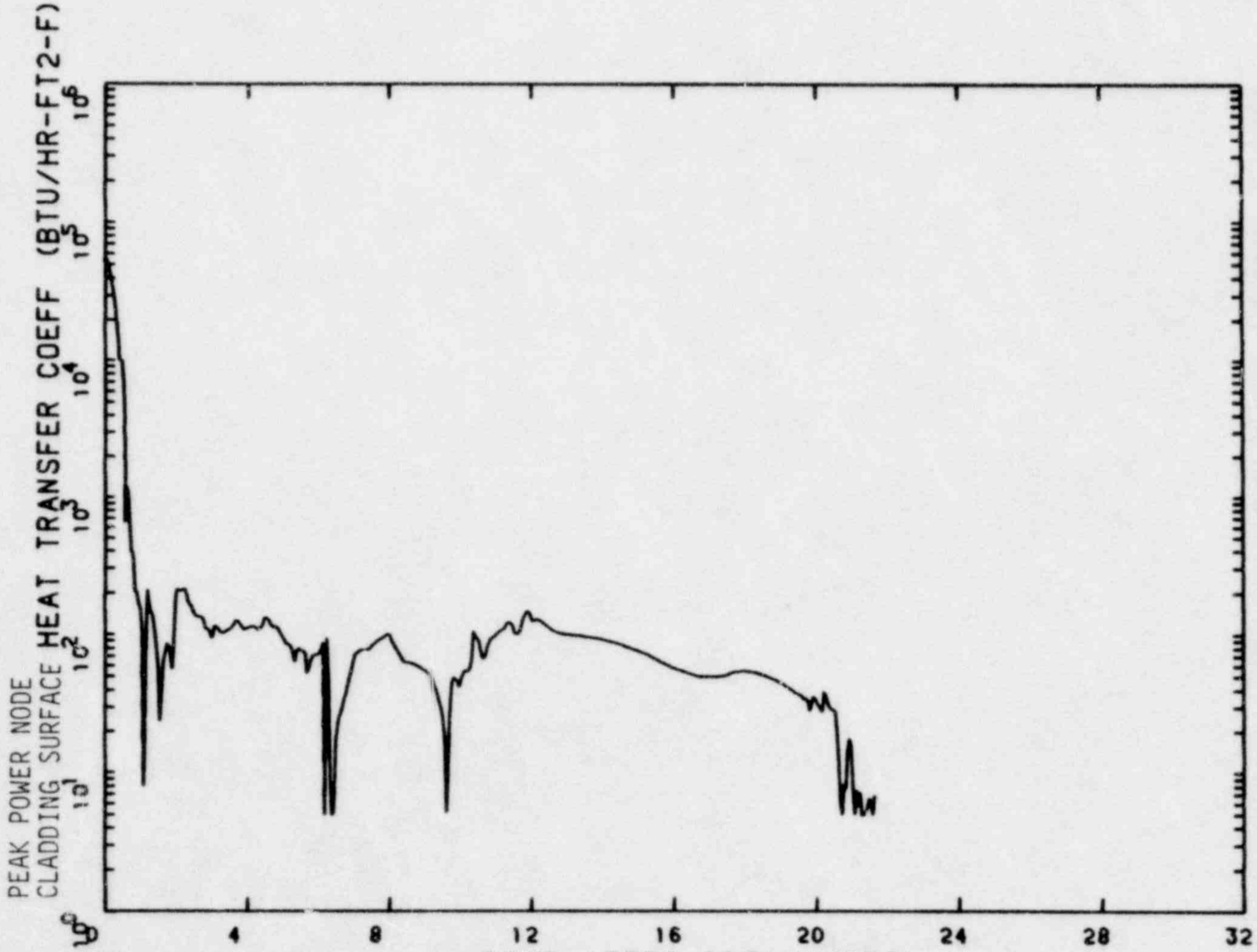

Figure 3.15 Peak Power Node Cladding Surface Heat Transfer Coefficient versus Time, X/L=0.81

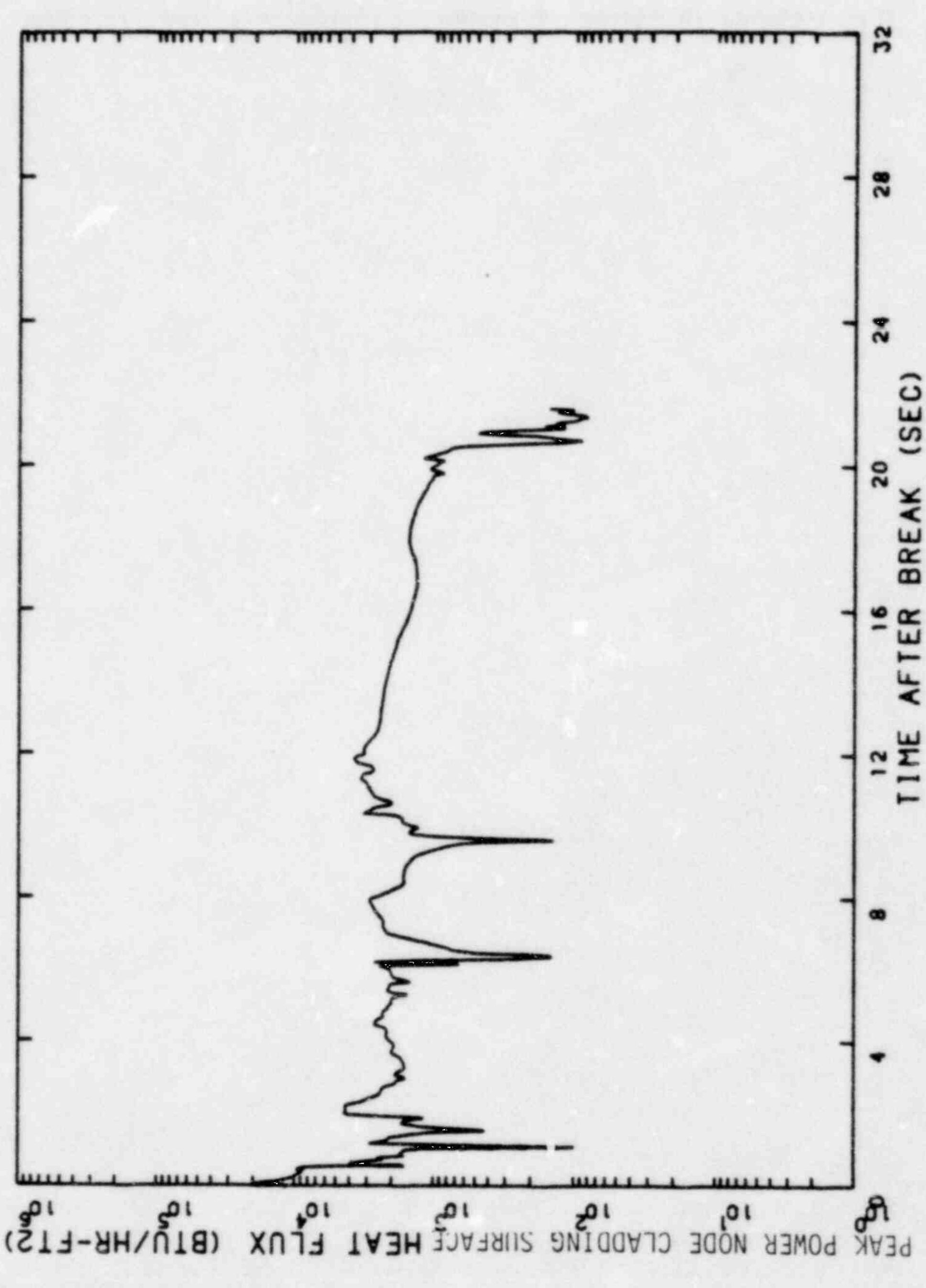

Figure 3.16 Peak Power Node, Cladding Surface Heat Flux versus Time, X/L=0.81

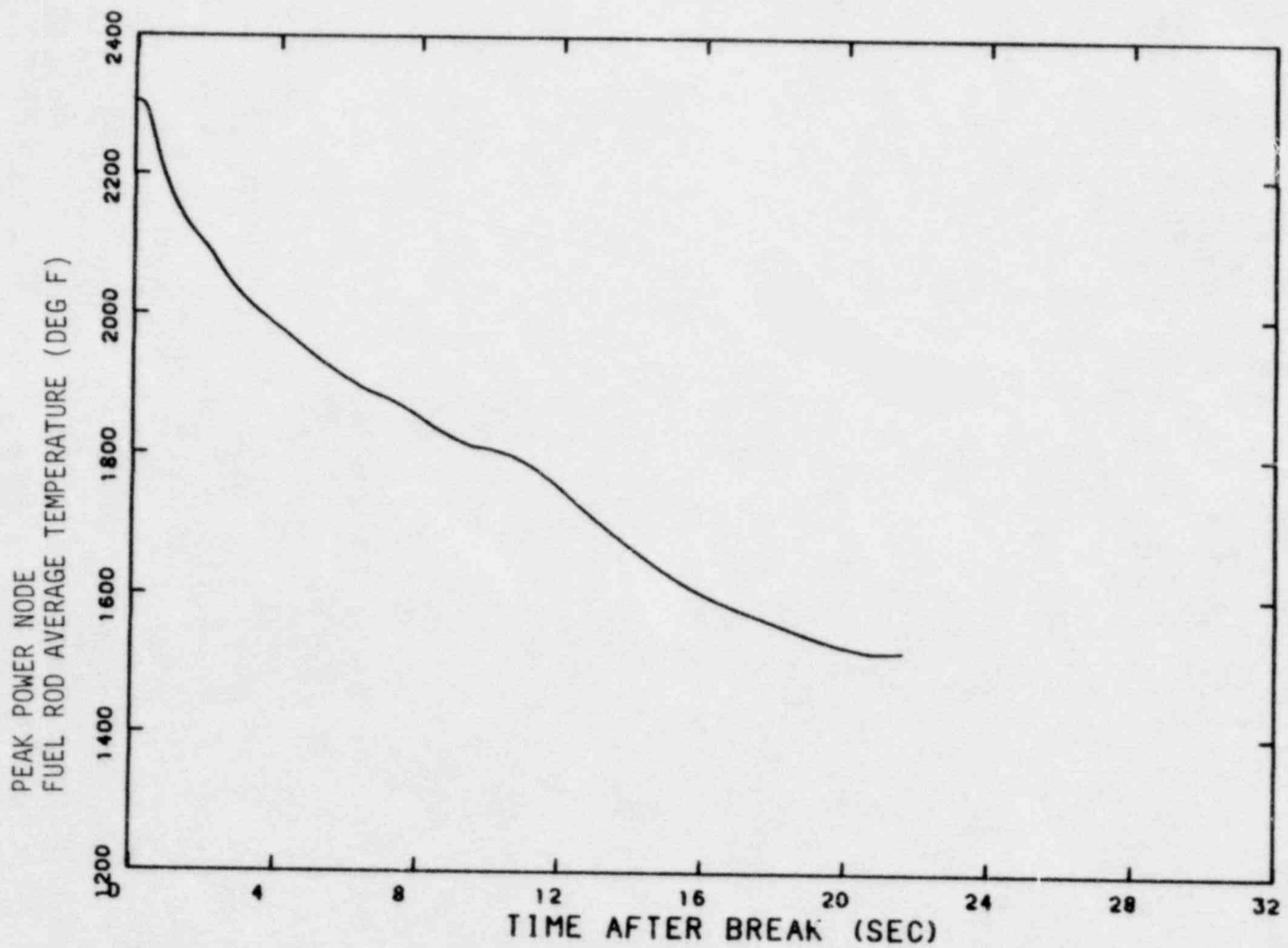

Figure 3.17 Peak Power Node, Fuel Rod Average Temperature vs Time, X/L=0.81

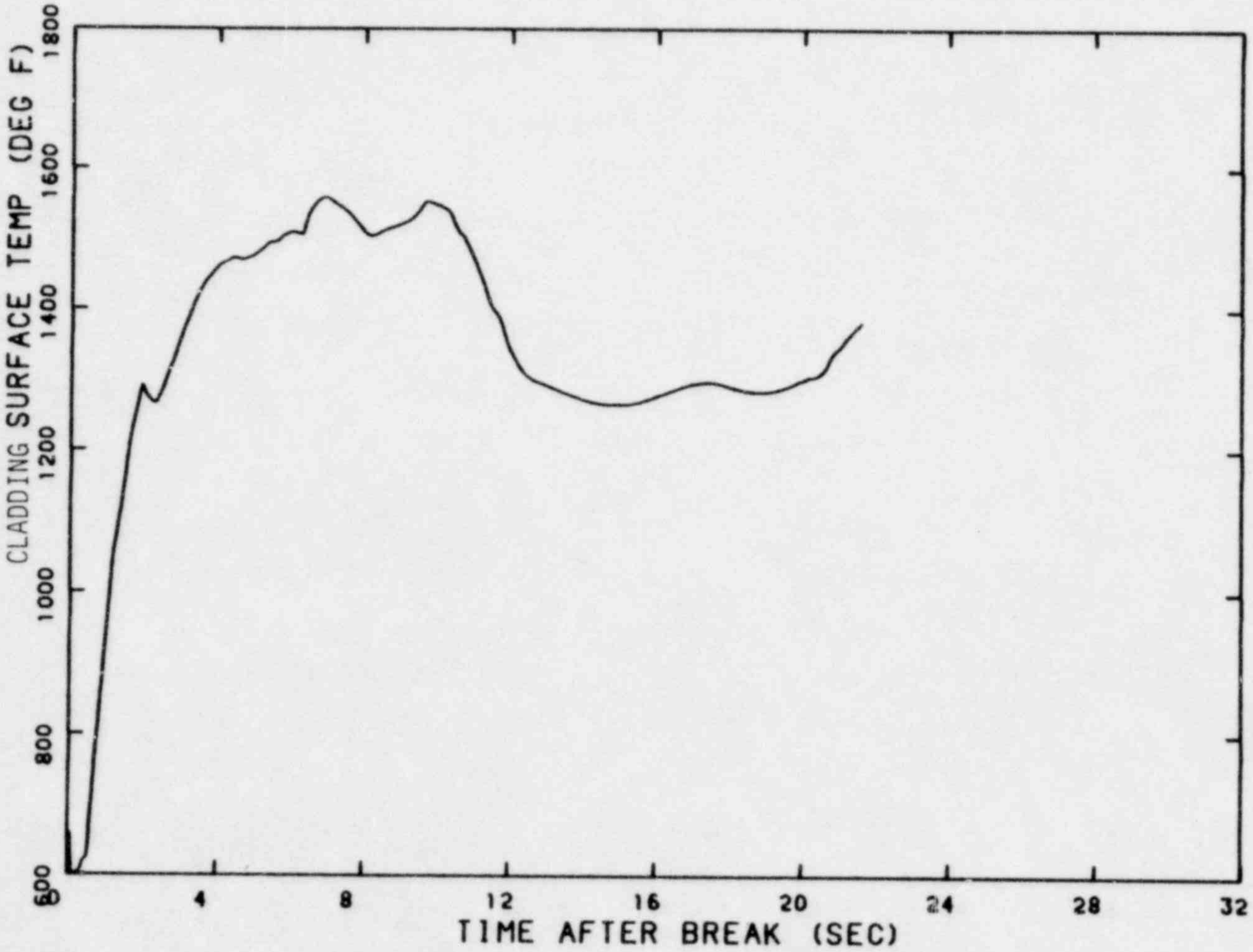

Figure 3.18 Peak Power Node, Cladding Surface Temperature vs Time, X/L=0.81

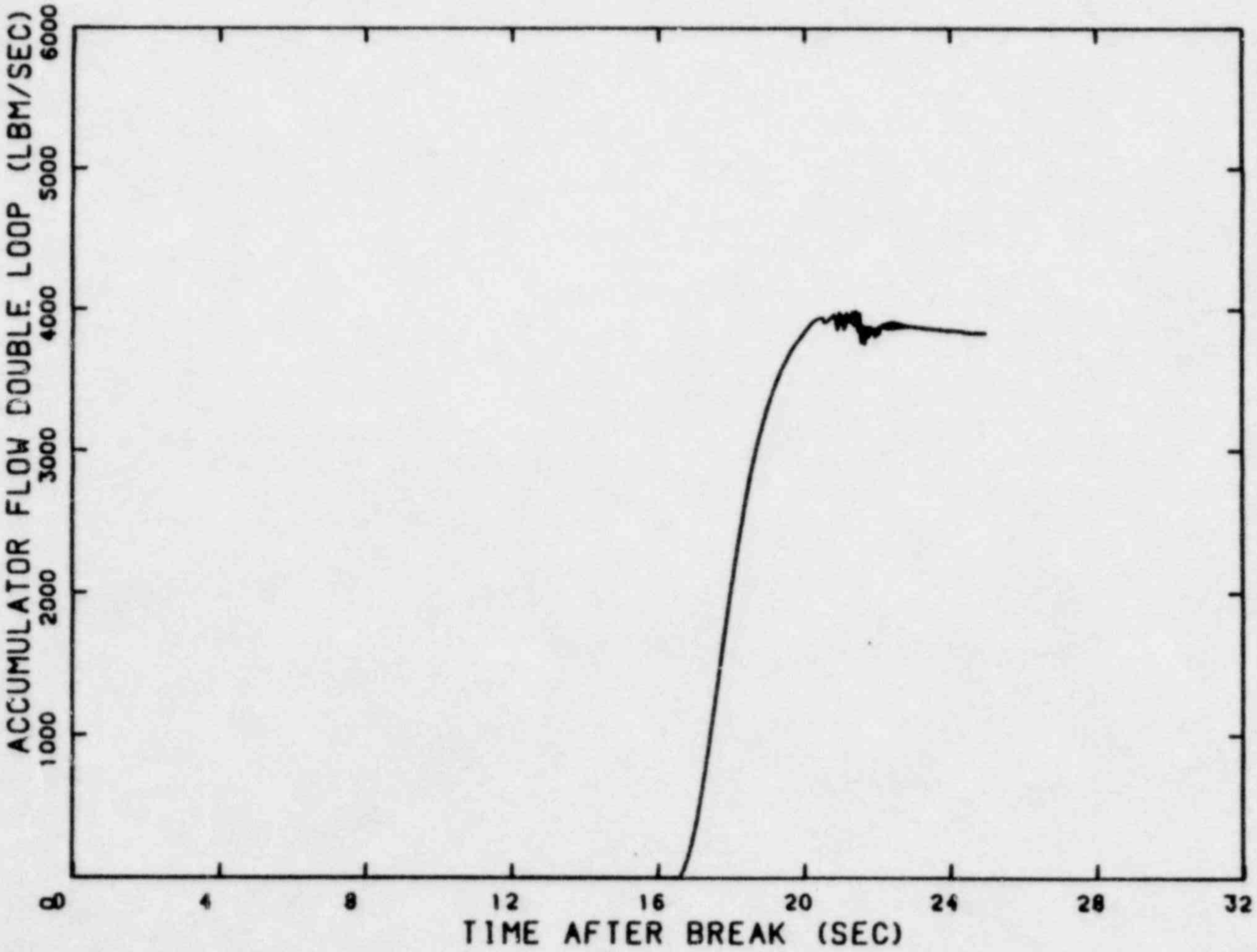

Figure 3.19 Double Intact Loop,Accumulator Flow Rate versus Time

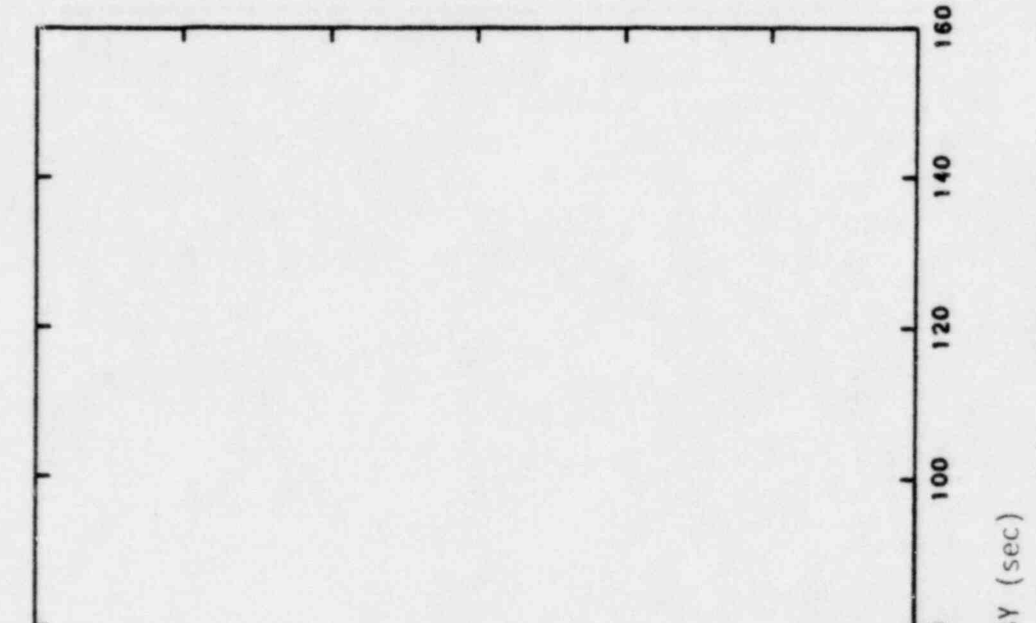

Figure 3.20 Double Intact Loop, Accumulator Flow Rate versus Time after EOBY

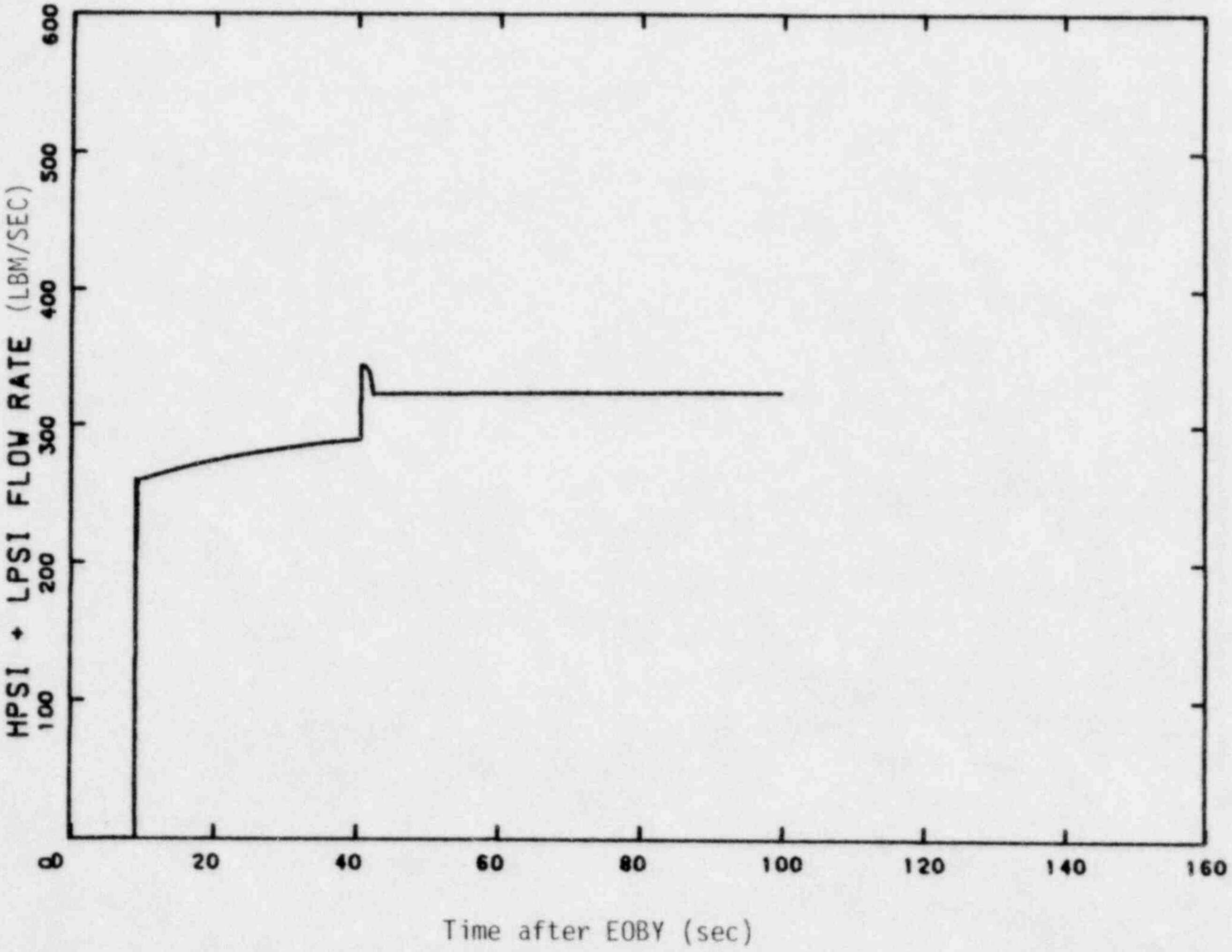

Figure 3.21 Double Intact Loop, SIS Flow Rate versus Time after EOBY

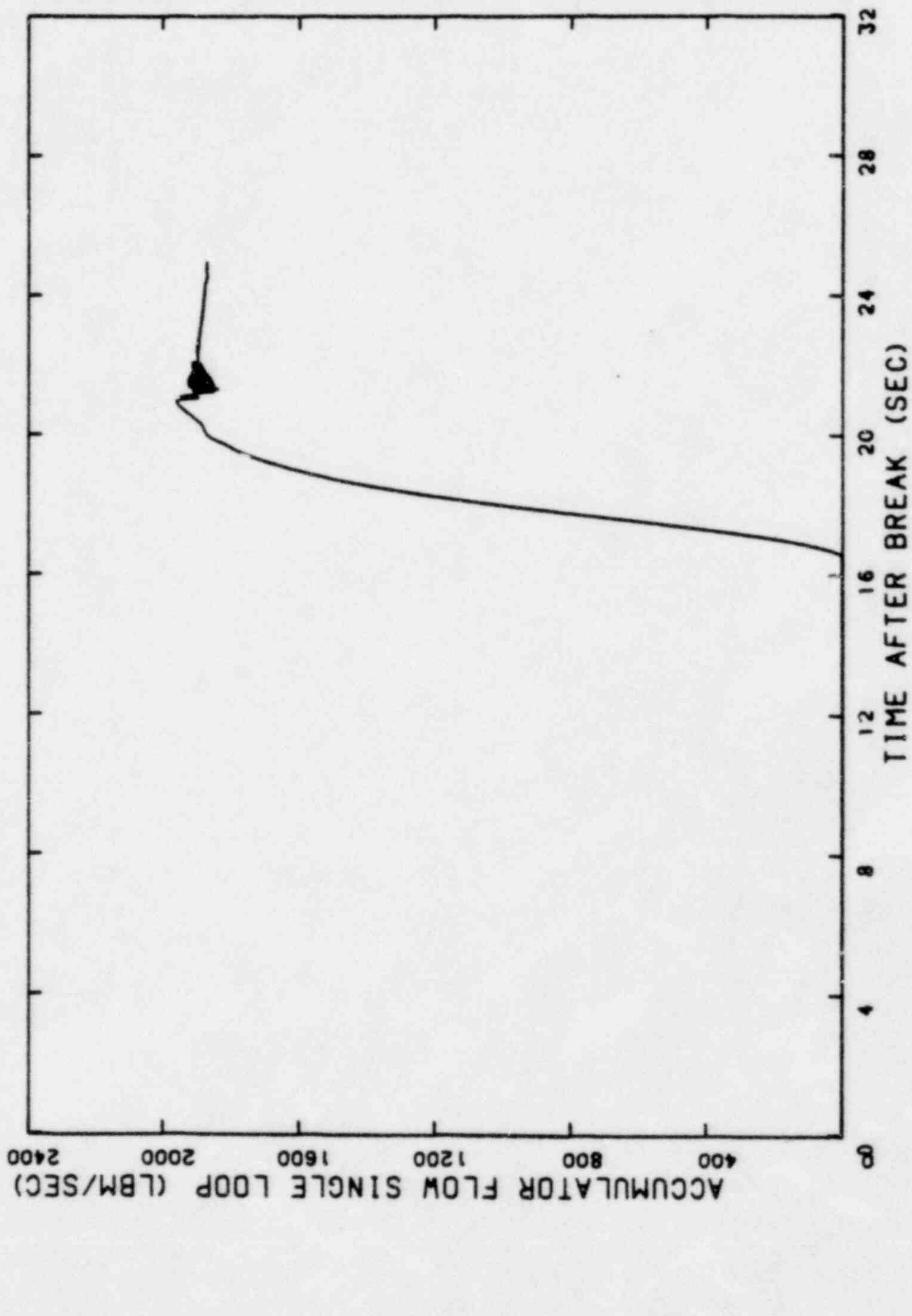

Figure 3.22 Single Intact Loop, Accumulator Flow Rate vs Time

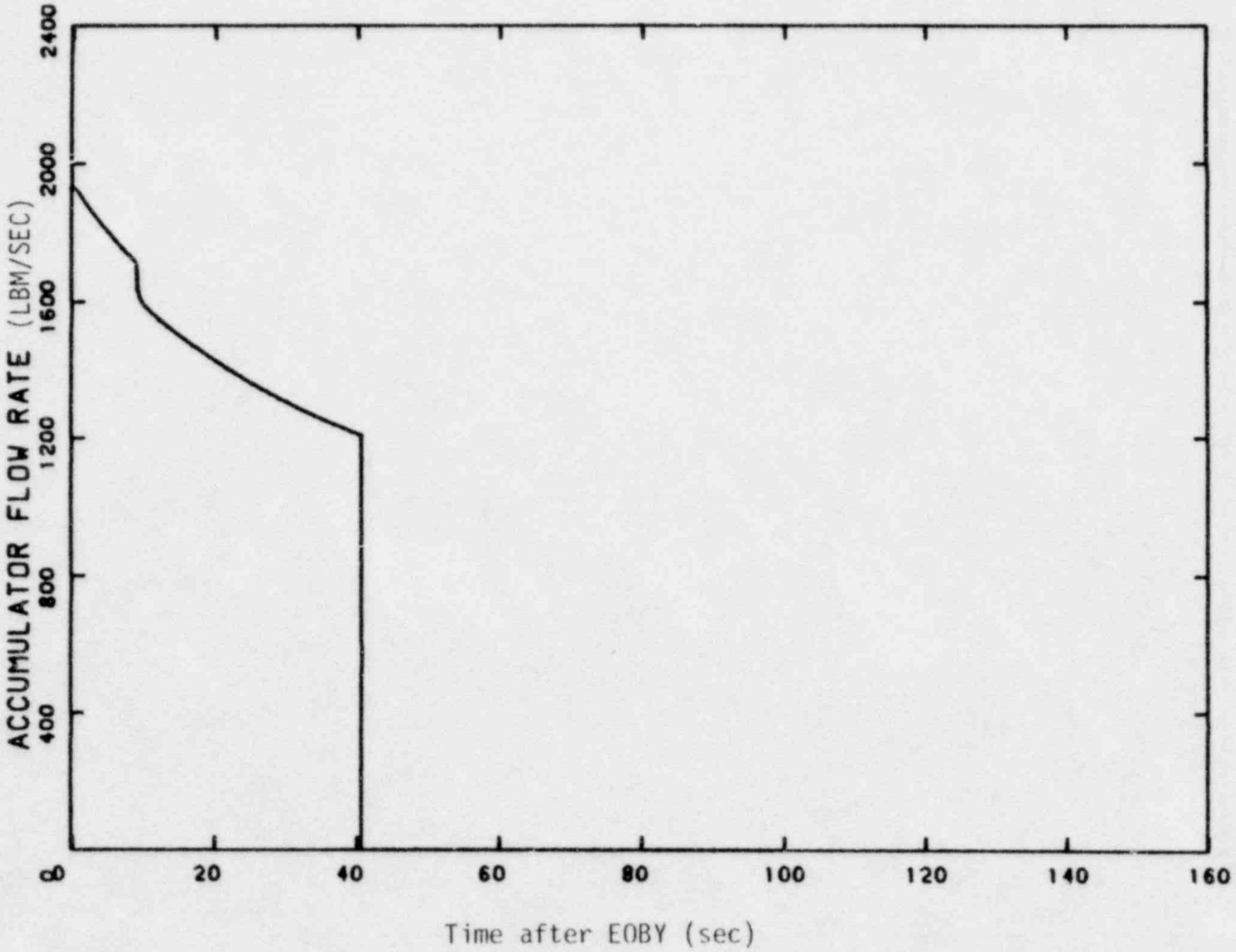

Figure 3.23 Single Intact Loop, Accumulator Flow Rate vs Time after EOBY

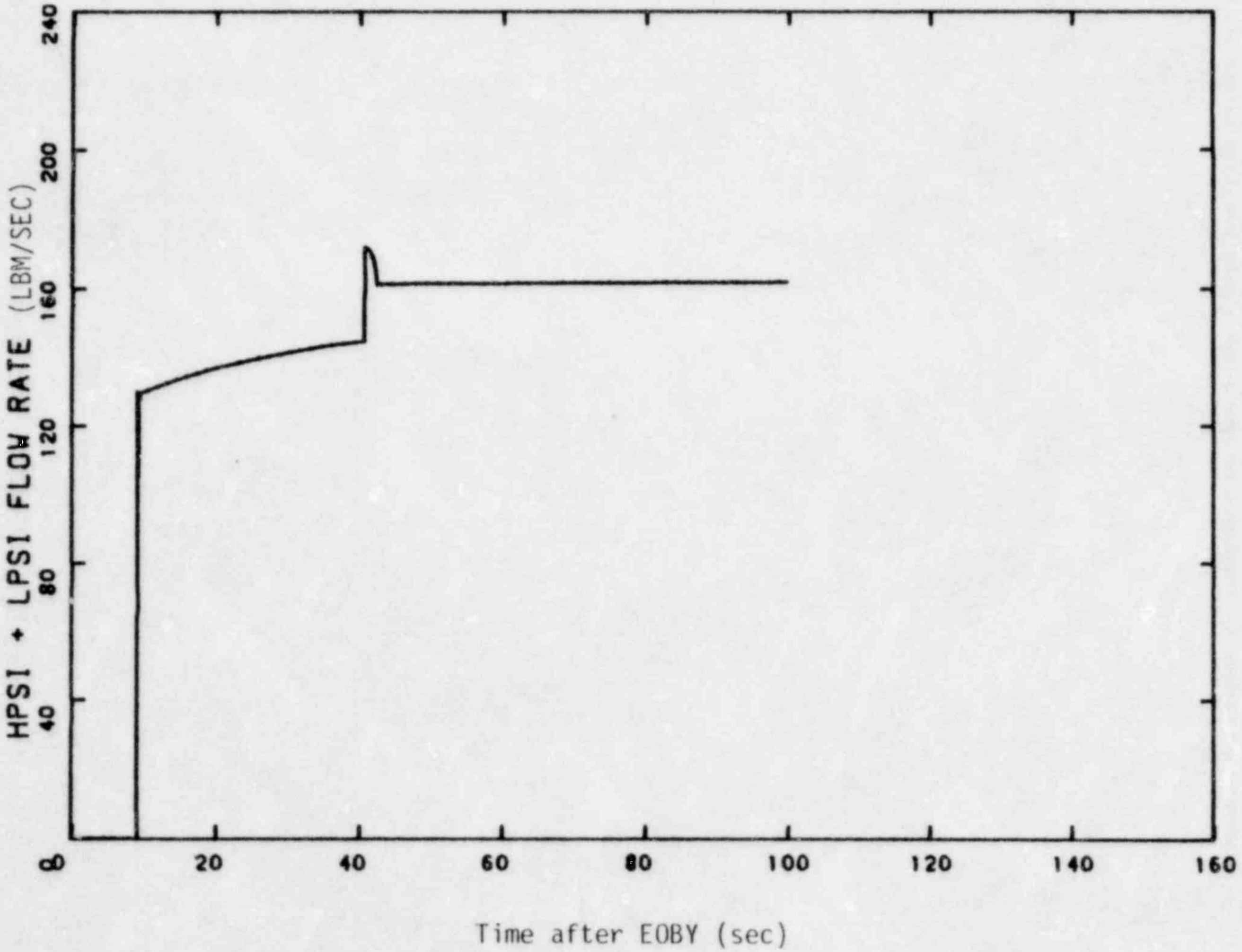

Figure 3.24 Single Intact Loop,SIS Flow Rate vs Time after EOBY

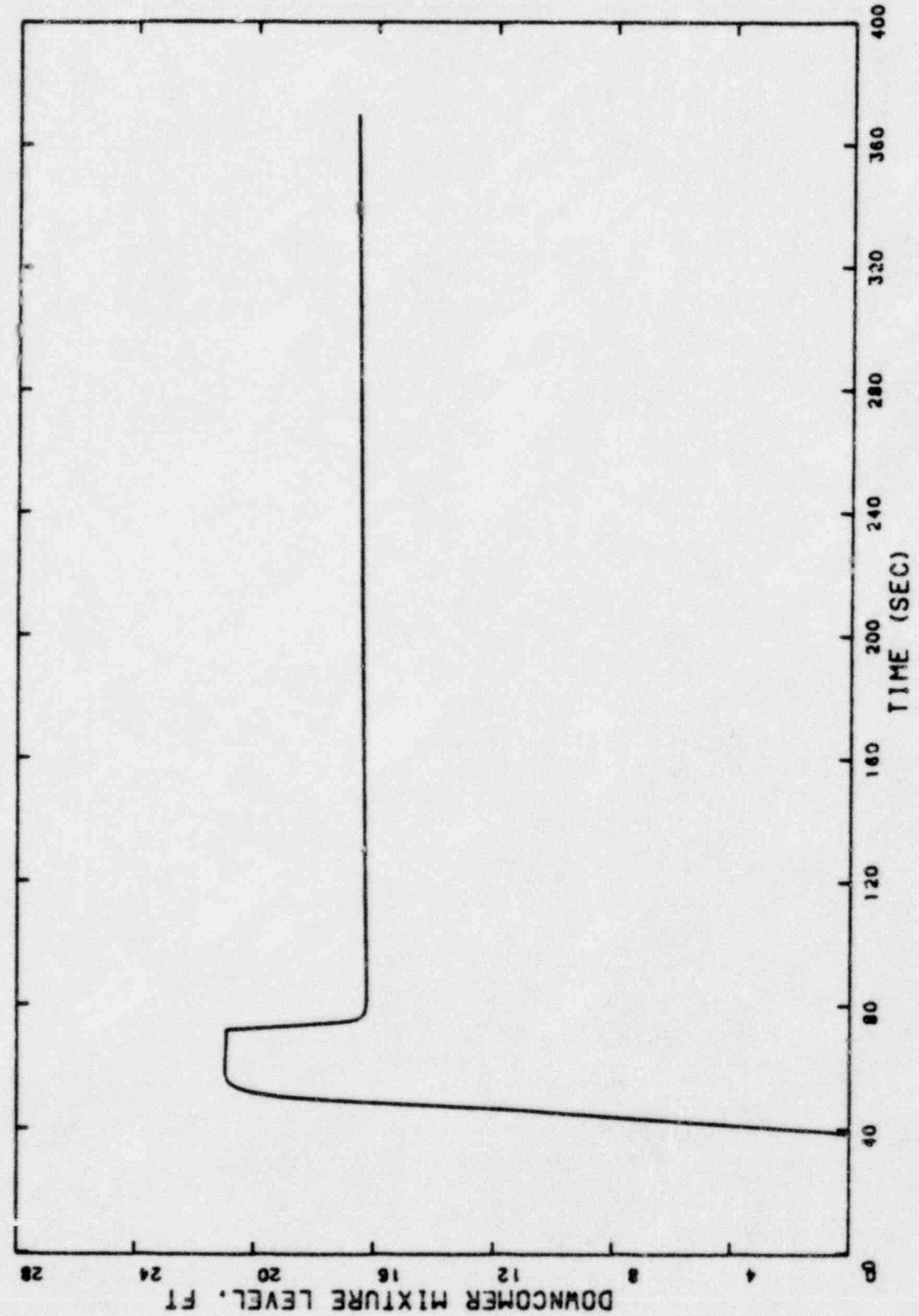

Figure 3.25 Downcomer Mixture Level versus Time
(Note: Zero level represents bottom of core)

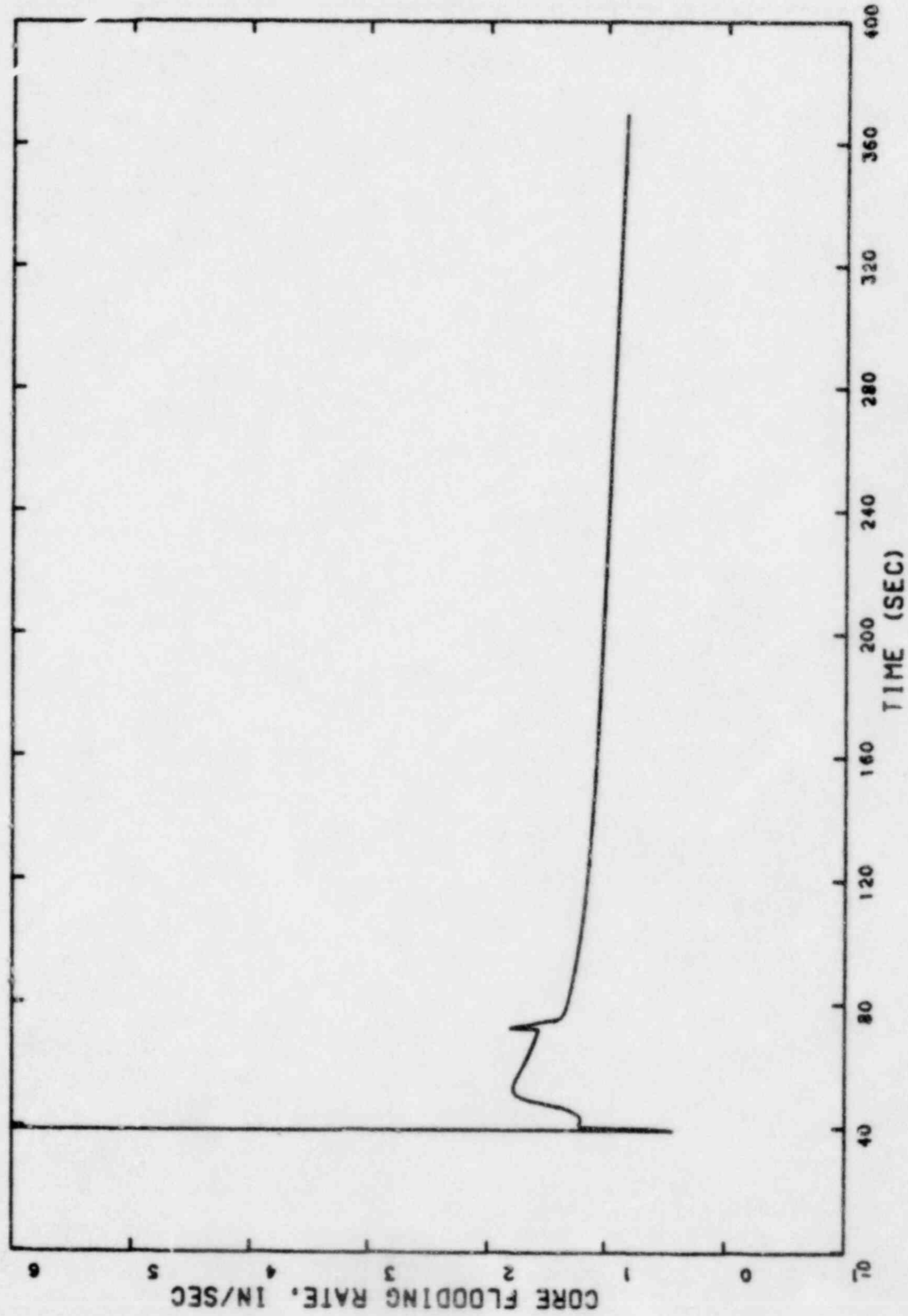

Figure 3.26 Core Flooding Rate versus Time

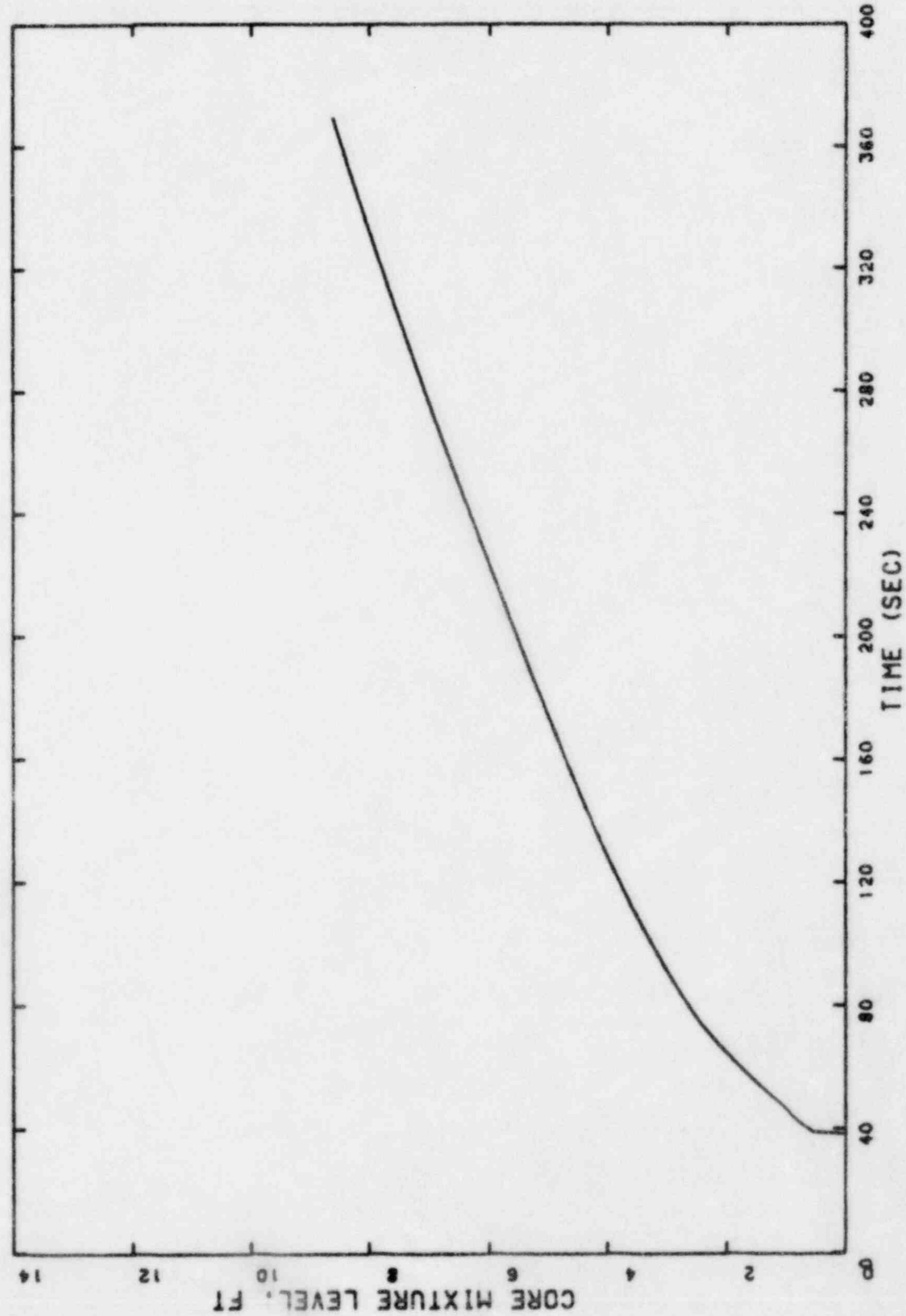

Figure 3.27 Core Mixture Level versus Time

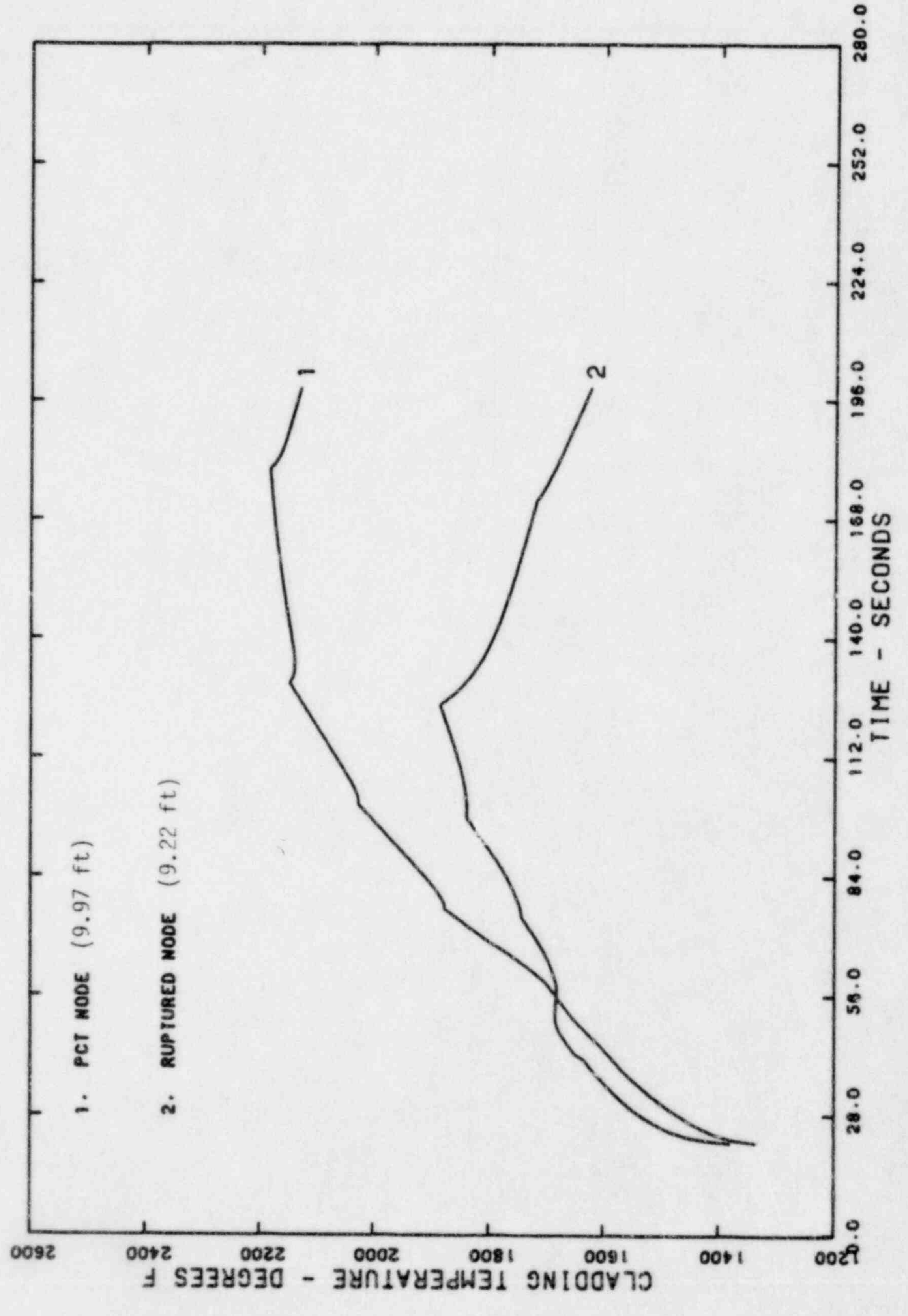

Figure 3.28 TOODEE2, Cladding Temperature versus Time, 0.8 DECLG, 14 kW/ft at 0.81 X/L

4.0 SETPOINT ANALYSIS RESULTS

The setpoint analysis results for Cycle 7 were reported in Reference 4 except for the Local Power Density Limiting Condition for Operation (LPD-LCO). The LPD-LCO is a function of the allowable LHR. This report justifies a revision in the allowable LHR and thus a change in the LPD-LCO.

The plant technical specifications allow plant operation for limited periods of time with the in-core detectors out of service. In this situation, the LPD-LCO barn provides protection in steady state operation against penetration of the LHR limit established by LOCA considerations. ENC statistical methodology used to define the LPD-LCO is described in References 5, 6 and 7. The axially dependent LHR limit shown in Figure 1.1 was used to determine the allowed power versus ASI. The statistical analysis included the effect of appropriate uncertainties. These uncertainties are listed in Table 4.1. The points in Figure 4.1 are calculated as described in Reference 6. The proposed LPD-LCO barn is shown in Figure 4.1.

Table 4.1 Uncertainties Applied for the LCO Based on LPD

Source	Value*
Engineering tolerance	± 0.03
Peaking uncertainty (%)	± 8.5
Power measurement	± 0.02 of rated
ASI uncertainty	± 0.05

* The distributions are treated as normal and the uncertainty range represents ± 2 σ.

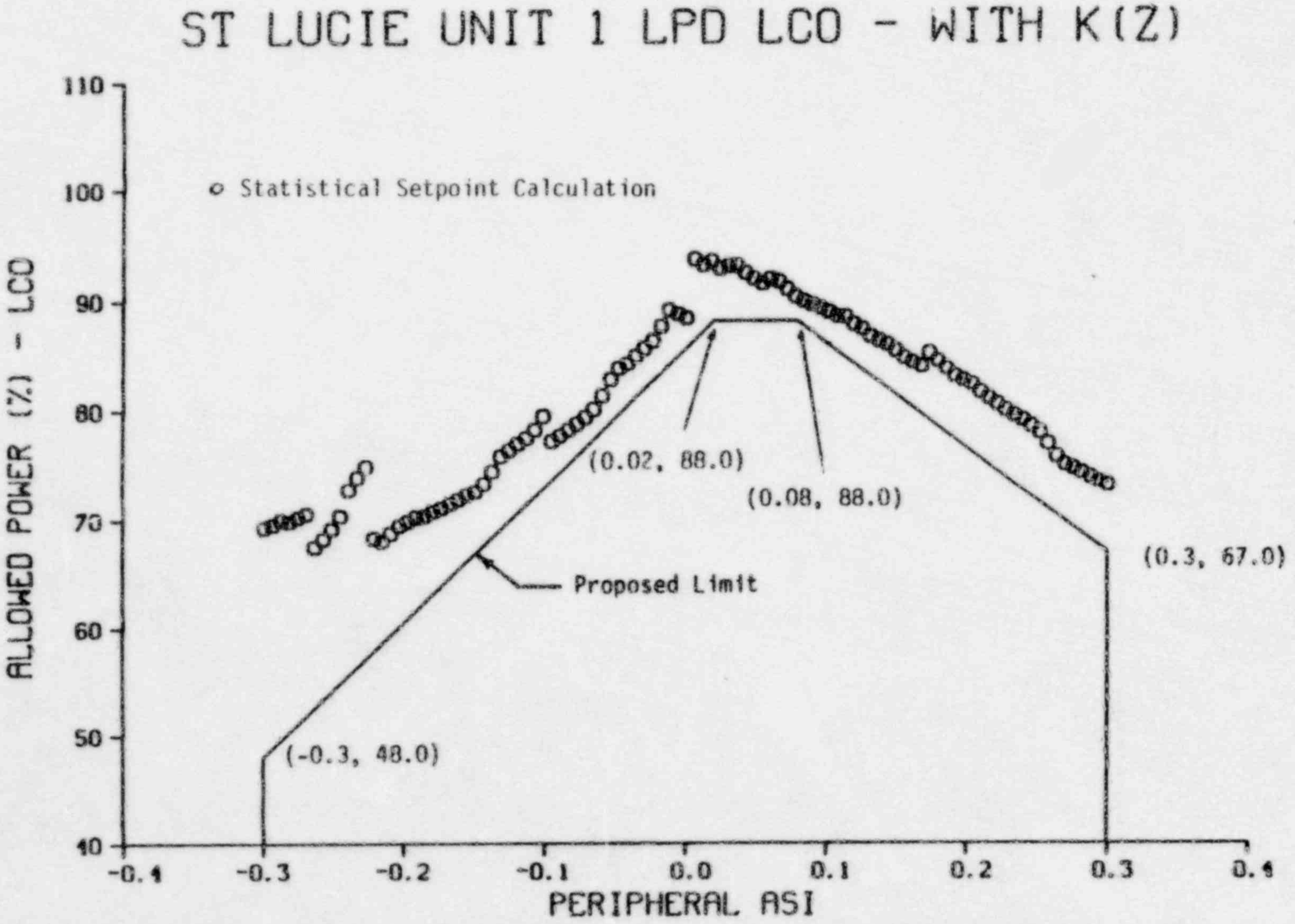

Figure 4.1 Verification of LCO on Local Power Density

5.0 CONCLUSIONS

A LOCA/ECCS analysis was performed for St. Lucie Unit 1 with ENC 14x14 fuel using the EXEM/PWR ECCS Evaluation Model in conformance with Appendix K of 10CFR50. The purpose of the analysis was to support an increase in the allowable LHR limits at relative core heights above 0.6 and specifically 14 kW/ft at a relative core height of 0.81. The analysis was performed for the previously determined limiting break size (0.8 DECLG) and considered an average 11% steam generator tube plugging along with several other changes in system parameters. The analysis was performed for bounding exposure conditions, and applies for St. Lucie Unit 1 Cycle 7 and beyond using ENC supplied fuel.

Axially dependent LHR limits, shown in Figure 1.1 and supported by the calculations documented in References 1, 2 and this report were determined and assure conformance with NRC criteria. The limits calculated for ENC fuel are equal to or conservative with respect to those currently in place for C.E. fuel. Additionally, the C.E. fuel will operate with LHRs significantly below those of ENC fuel due to the C.E. fuel exposures relative to the ENC fuel exposures. It is therefore conservative to monitor the C.E. fuel to the limits established for the ENC fuel.

Operation of the St. Lucie Unit 1 reactor with ENC 14x14 fuel within the limits given in Figure 1.1 assures that the St. Lucie 1 emergency core cooling system will meet the acceptance criteria as required by 10 CFR 50.46. That is:

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

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

(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 limit of 17% is not exceeded during or after quenching.

(4) The system long term cooling capabilities provided for previous cores remain applicable to cores containing ENC reload fuel.

6.0 REFERENCES

(1) "St. Lucie Unit 1 Revised LOCA-ECCS Analysis with 15% Steam Generator Tube Plugging," XN-NF-85-117, Exxon Nuclear Company, Richland, WA, November 1985.

(2) "St. Lucie Unit 1 Revised LOCA-ECCS Analysis with 15% Steam Generator Tube Plugging - Break Spectrum and Exposure Results," XN-NF-85-117, Supp. 1, Exxon Nuclear Company, Richland, WA, December 1985.

(3) "St. Lucie Unit 1 LOCA Analysis Using the EXEM/PWR ECCS Model," XN-NF-82-98, Supp. 1, Revision 1, Exxon Nuclear Company, Richland, WA, January 1983.

(4) "St. Lucie Unit 1 Cycle 7 Safety Analysis Report," XN-NF-85-73, Revision 2, Exxon Nuclear Company, Richland, WA, October 1985.

(5) "ENC Setpoint Methodology for CE Reactors," XN-NF-507, Revision 1, Exxon Nuclear Company, Richland, WA, July 1980.

(6) "ENC Setpoint Methodology for CE Reactors, Statistical Setpoint Methodology," XN-NF-507(P), Supplement 1, Exxon Nuclear Company, Richland, WA, September 1982.

(7) "ENC Setpoint Methodology for CE Reactors, Sample Program," XN-NF-507(P), Supplement 2, Exxon Nuclear Company, Richland, WA, November 1982.

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ST. LUCIE UNIT 1 LOCA/ECCS ANALYSIS
11% STEAM GENERATOR TUBE PLUGGING

Distribution

MJ Ades
KA Bryan
RA Copeland
NF Fausz
LJ Federico
RC Gottula
TJ Helbling
JS Holm
JW Hulsman
SE Jensen
WV Kayser
JN Morgan
GL Ritter
T Tahvili
GN Ward
HE Williamson

CE Slater (ITI)

FPL/TJ Helbling (25)

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