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St. Lucie Unit 1 Large Break LOCA/ECCS Analysis With 25±7% SGTP

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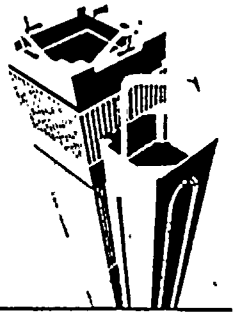

Siemens Power Corporation

Nuclear Division

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St. Lucie Unit 1 Large Break LOCA/ECCS Analysis With 25±7% SGTP

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February 1993

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1.0 INTRODUCTION

This report documents the results of a large break LOCA/ECCS analysis that was performed for St. Lucie Unit 1. The large break LOCA event required re-analysis due to increased steam generator tube plugging (SGTP). The analysis was performed with an average steam generator tube plugging of 25%, with a tube plugging asymmetry of ±7%. The analysis was performed at an increased radial peaking factor of 1.75, even though the maximum allowed radial peaking factor (Fr) in the Technical Specifications remains unchanged at 1.70. The purpose of incorporating the increased radial peaking factor was to support potential future increases in the Technical Specification radial peaking factor. The analysis also addresses primary coolant temperature coastdown at full power End-of-Cycle conditions with a maximum reduction in primary coolant temperature of 26°F. The Cycle 10 fuel design remains bounded by Reference 1 and was not re-analyzed as part of this analysis.

2.0 SUMMARY OF RESULTS

The large break LOCA (LBLOCA) analysis was performed at the previously determined limiting break size, which was a 0.8 Double-Ended-Cold-Leg-Guillotine (DECLG) break(2). System and hot channel blowdown calculations were performed with steam generator tube plugging of 25 ±7% to reconfirm the 0.8 DECLG break as the limiting break size. Calculations for 0.6, 0.8, and 1.0 DECLG break sizes reconfirmed the 0.8 DECLG break as the limiting break size.

Two cases were analyzed at the limiting break size to support an axially and exposure independent LHR limit of 15 kW/ft. The first case combined the maximum fuel stored energy, which occurs at a hot rod average burnup of 1.8 MWd/kg, with a bounding axial power shape which conservatively represents axial shapes that may exist between Beginning-of-Cycle (BOC) and Middle-of-Cycle (MOC). The second case combined the fuel stored energy at MOC with a bounding axial shape which conservatively represents axial shapes that may exist between MOC and End-of-Cycle (EOC). This approach conservatively bounds the possible combinations of fuel rod stored energy and axial power shapes in the St. Lucie Unit 1 plant. The results for these two cases are summarized in Table 2.1. The peak cladding temperature was calculated to be 1912°F for the case with the EOC axial shape.

Calculations were performed in Reference 2 to support an End-of-Cycle full power primary coolant system T_{ave} coastdown of 26°F. The PCT for that case was demonstrated to be significantly lower than the limiting case due to a significant decrease in fuel stored energy at End-of-Cycle. Although, a specific calculation was not performed in this analysis for an End-of-Cycle T_{ave} coastdown of 26°F, the PCT for this case would also be significantly lower than the limiting PCT reported above due to a significantly lower fuel stored energy at End-of-Cycle. Therefore, an End-of-Cycle T_{ave} coastdown of 26°F is supported for an increased steam generator tube plugging of 25% with an asymmetry of ±7%.

The Cycle 10 fuel remains bounded by the analysis performed in Reference 1. The Cycle 10 fuel will be third cycle fuel in Cycle 12 and will operate at significantly lower power levels than fresh fuel. The lower power level will more than offset any adverse effects of increased steam generator tube plugging and asymmetry. The Technical Specification F_r remains at 1.7 for the Cycle 10 fuel.

Table 2.1 Summary of LBLOCA Results for 0.8 DECLG Cases

Parameter	BOC Stored Energy, MOC Axial Shape (X/L = 0.77)	MOC Stored Energy, EOC Axial Shape (X/L = 0.85)
Maximum LHR (kW/ft)	15	15
Hot Rod Burst		
- Time (sec)	41.79	44.10
- Elevation (ft)	8.97	9.97
- Channel Blockage Fraction	0.399	0.434
Peak Cladding Temperature		
- Temperature (°F)	1852	1912
- Time (sec)	56.15	73.03
- Elevation (ft)	8.97	10.47
Metal-Water Reaction		
- Local Maximum (%)	2.12*	2.09*
- Elevation of Local Maximum (ft)	8.97	9.97
- Hot Pin Average (%)	0.39*	0.34*
- Core Wide Maximum (%)	<<1.0*	<<1.0*

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* At 200 seconds.

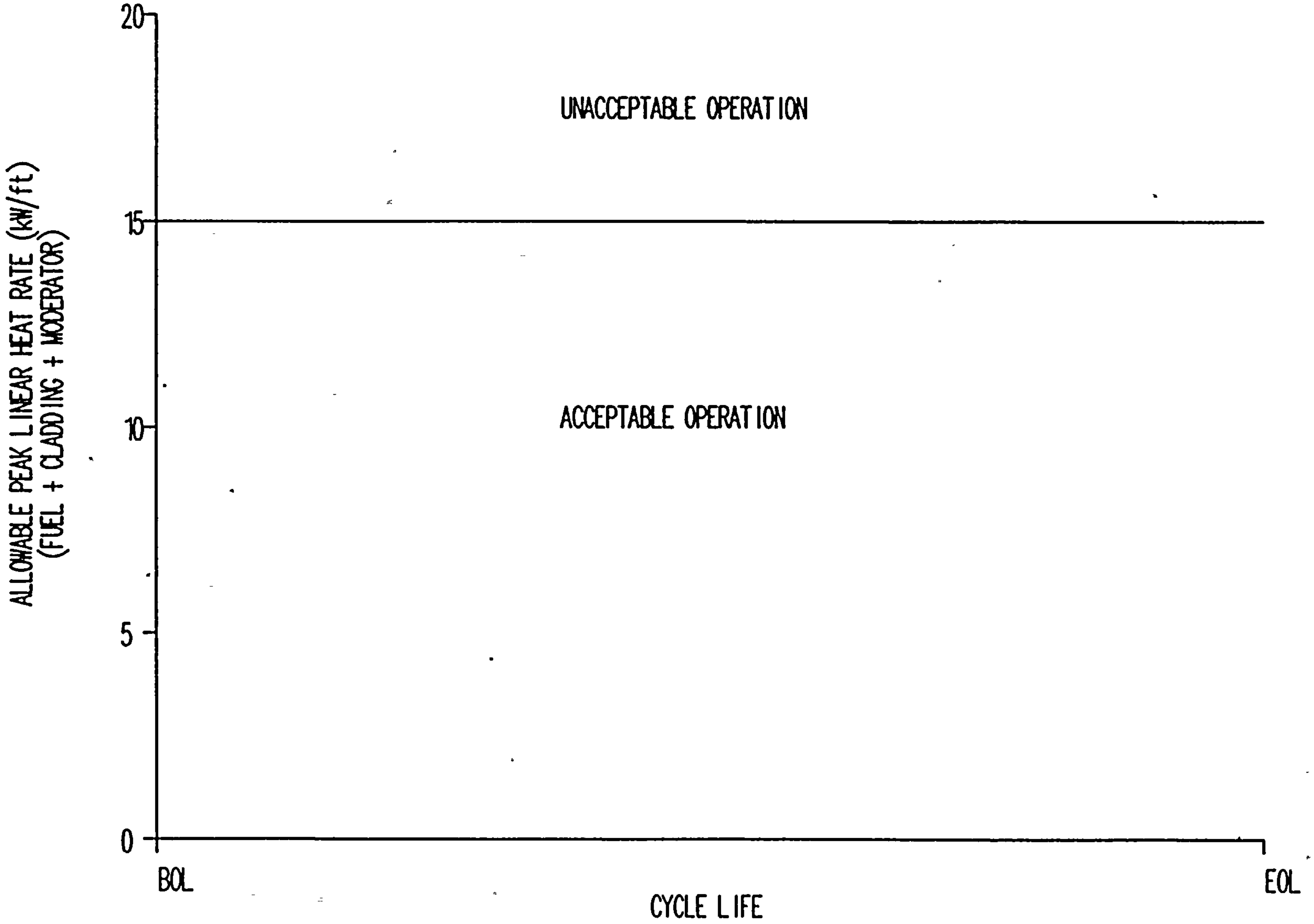

FIGURE 2.1 ALLOWABLE PEAK LINEAR HEAT RATE VS BURNUP

3.0 LARGE BREAK LOCA/ECCS ANALYSIS

Section 3.1 of this report provides a description of the postulated large break loss-of-coolant transient. Section 3.2 describes the analytical models used in the analysis. Section 3.3 provides a description of the St. Lucie Unit 1 plant and a summary of plant and fuel parameters used in the LOCA analysis. Section 3.4 describes the results of the LOCA analysis including justification to support a full power primary coolant temperature coastdown at end-of-cycle.

3.1 Description of LBLOCA Transient

A loss-of-coolant accident (LOCA) is defined as the rupture of the Reactor Coolant System (RCS) primary piping up to and including a double-ended guillotine break. The limiting break occurs on the pump discharge side of a cold leg pipe. The LOCA is assumed to result from an earthquake and is co-incident with the loss-of-offsite power. Primary coolant pump coastdown occurs co-incident with the loss-of-offsite power. Following the break, depressurization of the reactor coolant system, including the pressurizer, occurs. A reactor trip signal occurs when the pressurizer low pressure trip setpoint is reached. Reactor trip and scram are conservatively neglected in the LOCA analysis. Early in the blowdown, the reactor core experiences flow reversal and stagnation which causes the fuel rods to pass through critical heat flux (CHF). Following CHF, the fuel rods dissipate heat through the transition and film boiling modes of heat transfer. Rewet is precluded during blowdown by Appendix K of 10 CFR 50.

A Safety Injection System (SIS) signal is actuated when the appropriate setpoint (high containment pressure) is reached. Due to loss-of-offsite power, a time delay for startup of diesel generators and SIS pumps is assumed. Once the time delay criteria is met and the system pressure falls below the shutoff head of the High Pressure Safety Injection (HPSI) and Low Pressure Safety Injection (LPSI) pumps, SIS flow is injected into the cold legs. When the system pressure falls below the Safety Injection Tank (SIT) pressure, flow from the SITs is injected into the cold legs. Single failure criteria is met by assuming that one LPSI pump is not available for operation. Flow from the Emergency Core Cooling System (ECCS) is assumed to bypass the core and flow to the break until the end-of-bypass (EOBY) is predicted to occur (sustained downflow in the downcomer). Following EOBY, ECCS flow fills the downcomer and lower plenum until the liquid level reaches the bottom of the active core (beginning-of-core-recovery or BOCREC time). During the refill period, heat is transferred from the hottest fuel rod to surrounding rods by radiation heat transfer.

The reflood period begins at BOCREC time. ECCS fluid fills the downcomer and provides the driving head to move coolant through the core. As the mixture level moves up the core, steam is generated. Steam binding occurs as the steam flows through the intact and broken loop steam generators and pumps. The pumps are assumed to have a locked rotor (per Appendix K of 10 CFR 50) which tends to reduce the reflood rate. The fuel rods are eventually cooled and quenched by radiation and convective heat transfer as the quench front moves up the core. The reflood heat transfer rate is predicted through experimentally determined heat transfer and carry-over rate fraction correlations.

The purpose of the LBLOCA analysis is to demonstrate that the criteria stated in 10 CFR 50.46(b) are met. The criteria are:

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 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.

3.2 Description of Analytical Models

The SPC EXEM/PWR evaluation model(3) was used to perform the analysis. This evaluation model consists of the following computer codes:

1) RODEX2(4) for computation of initial fuel stored energy, fission gas release, and gap conductance;

2) RELAP4-EM for the system and hot channel blowdown calculations;

3) CONTEMPT/LT-22 as modified in accordance with NRC Branch Technical Position CSB 6-1 for computation of containment back pressure;

4) REFLEX for computation of system reflood; and

5) TOODEE2 for the calculation of fuel rod heatup during the refill and reflood portions of the LOCA transient.

The quench time, quench velocity, and carryover rate fraction (CRF) correlations in REFLEX, and the heat transfer correlations in TOODEE2 are based on SPC's Fuel Cooling Test Facility (FCTF) data.

The governing conservation equations for mass, energy, and momentum transfer are used along with appropriate correlations consistent with Appendix K of 10 CFR 50. The reactor core in RELAP4 is modeled with heat generation rates determined from reactor kinetics equations with reactivity feedback, and with actinide and decay heating as required by Appendix K. Appropriate conservatisms specified by Appendix K of 10 CFR 50 are incorporated in all of the EXEM/PWR models.

3.3 Plant Description and Summary of Analysis Parameters

The St. Lucie Unit 1 plant is a Combustion Engineering (CE) designed pressurized water reactor which has two hot leg pipes, two U-tube steam generators, and four cold leg pipes with one recirculation pump in each cold leg. The plant utilizes a large dry containment. The reactor coolant system was nodalized into control volumes representing reasonably homogeneous regions, interconnected by flow paths or "junctions". The two cold legs connected to the intact loop steam generator were assumed to be symmetrical and were modeled as one intact cold leg with appropriately scaled input. The model considers four SITs, a pressurizer, and two steam generators with both primary and secondary sides of the steam generators modeled. ECCS flow from the HPSI and LPSI pumps was modeled using fill junctions at the SIT lines, with conservative flow rates given as a function of system back-pressure. The primary pump performance curves are characteristic of CE pumps. The reactor core was modeled radially with an average core and a hot assembly as parallel flow channels, each with three axial nodes. A steam generator tube plugging level of 25% was assumed with an asymmetric steam generator tube plugging of ±7%.

The break was conservatively assumed to have occurred in the most highly plugged loop since this results in more steam binding during reflood and a higher peak cladding temperature.

Values for system parameters used in the analysis are shown in Table 3.1. Core and fuel design parameters are shown in Table 3.2. The primary coolant loop flow split was re-calculated in this analysis due to the increase in assumed steam generator tube plugging to 25%. The calculation of loop flow rates used a Technical Specification loop flow rate of 355,000 gpm. The minimum measured flow rate allowed for plant operation is the Technical Specification loop flow rate plus measurement uncertainty. Therefore, the flow rate used in the analysis is conservatively low relative to allowed plant operation.

3.4 LBLOCA Results

System and hot channel blowdown calculations were performed at the increased steam generator tube plugging of 25 ±7% to reconfirm the 0.8 DECLG break size as the limiting break. Calculations were performed for DECLG break sizes of 0.6, 0.8, and 1.0. The fuel and cladding temperatures at EOBY confirmed that the 0.8 DECLG break size remains the limiting break size.

Two cases were analyzed at the limiting break size to support an axially and exposure independent LHR limit of 15 kW/ft. The first case combined the maximum fuel stored energy, which occurs at a hot rod average burnup of 1.8 MWd/kg, with a bounding axial power shape which conservatively represents axial shapes that may exist between BOC and MOC (peaked highest in the core at a relative core height of 0.77). The second case combined the fuel stored energy at MOC with a bounding axial shape which conservatively represents axial shapes that may exist between MOC and EOC (peaked highest in the core at a relative height of 0.85). Axial shapes at 100% power with ASIs from 0.0 to -0.2 were reviewed to determine the shape peaked highest in the core. Rod positions included ARO, rods at their 100% power PDIL, and rods at their 90% PDIL. The limiting axial shapes occurred at the ARO condition. This approach conservatively bounds the possible combinations of fuel rod stored energy and axial power shapes in the St. Lucie Unit 1 plant.

The results for the two axial shape cases analyzed are summarized in Table 2.1. The peak cladding temperature was calculated to be 1852°F for the case with the MOC shape and 1912°F for the case with the EOC axial shape. The maximum local cladding oxidation was calculated to be less than 3%, which is much less than the allowed local oxidation of 17%. Core wide oxidation was determined to be much less than the allowable 1%.

Plots of various parameters for the EOC shape limiting case are shown in Figures 3.1 through 3.26. Event times for the limiting EOC shape case are shown in Table 3.3.

An End-of-Cycle full power primary coolant temperature coastdown with a maximum reduction in primary coolant temperature of 26°F is also supported for the plant. The justification for the support is based on the primary coolant temperature coastdown calculations from the Cycle 11 LBLOCA analysis. The calculations used fuel stored energy at an EOC burnup combined with a bounding axial shape representative of EOC, peaked at a relative core height of 0.85. The Cycle 11 primary coolant temperature coastdown analysis predicted a significantly lower PCT than the PCT calculated for the limiting case. A lower PCT was predicted due to a lower fuel stored energy at EOC. A similar effect will occur for the case with increased steam generator tube plugging. The limiting case would bound the primary coolant temperature coastdown case. Therefore, a re-analysis of the T_{ave} coastdown case was not necessary. The Cycle 11 analysis justifies a reduction in the average temperature of 26°F at 100 percent power and at EOC for ST. Lucie Unit 1, with 25 ±7% SGTP.

The Cycle 10 fuel design was analyzed in Reference 1 for a steam generator tube plugging level of 15%. The Cycle 10 fuel will be in its third cycle during Cycle 12 and will be operating at a significantly lower power level than fresh fuel. The lower power level will more than offset any adverse effects of increased steam generator tube plugging to 25 ±7%. The Cycle 10 fuel is therefore bounded by the Reference 1 analysis for the LBLOCA event. The Technical Specification Fr limit for Cycle 10 fuel remains at 1.70.

Table 3.1 St. Lucie Unit 1 System Analysis Parameters

Primary heat output, MWt	2700*
Primary coolant flow rate, lbm/hr	1.339×10^8** (355,000 gpm)
Primary coolant system volume, ft^3	18,897***
Operating pressure, psia	2250
Cold leg coolant temperature (hottest loop), °F	549
Reactor vessel volume, ft^3	4522
Pressurizer volume (total), ft^3	1500
Pressurizer volume (liquid), ft^3	888
SIT Volume (total), ft^3 (one of four)	2020
SIT Volume (liquid), ft^3	1090
SIT pressure, psia	230
Steam generator tube plugging	32% - 18% split
Steam generator secondary pressure, psia	790
Steam generator feedwater temperature, °F	435
Reactor coolant pump rated head, ft	272
Reactor coolant pump rated torque, ft-lbf	32,495
Reactor coolant pump rated speed, rpm	886
Reactor coolant pump moment of inertia, lbm-ft^2	101,900

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* Primary heat output used in RELAP4-EM model = 1.02 x 2700 = 2754 MWt

** Technical Specifications minimum loop flow rate

*** Includes total SIT, pressurizer volume and 25% SGTP

Table 3.1 St. Lucie Unit 1 System Analysis Parameters (Continued)

Containment volume, ft^3	2.511×10^6
Containment temperature, °F	100
SIS Fluid temperature, °F	55
HPSI delay time, sec	30
LPSI delay time, sec	30
Containment fan coolers initiation time, sec	30
Containment sprays initiation time, sec	30

Table 3.2 Core and Fuel Design Parameters

Cladding O. D., in.	0.440
Cladding I. D., in.	0.384
Fuel O. D., in.	0.377
Fuel rod pitch, in.	0.580
Fuel assembly pitch, in.	8.180
Active fuel length, in.	136.7
Core flow area, ft^2	53.19
Core bypass flow, %	3.90

Table 3.3 Event Times for 0.8 DECLG Break Limiting Case (EOC Shape)

Event	Timing of Event (sec)
Start	0.0
Break is fully open	0.05
Safety injection signal	0.89
SIT flow begins in broken loop	11.54
SIT flow begins in single intact loop	16.07
SIT flow begins in double intact loop	16.08
End-of-bypass (EOBY)	21.11
SIS flow begins	30.89
Beginning-of-core-recovery (BOCREC)	38.35
Cladding rupture	45.11
SIT flow ends in broken loop	61.60
SIT flow ends in single intact loop	65.30
SIT flow ends in double intact loop	65.30
Peak cladding temperature is reached	73.03

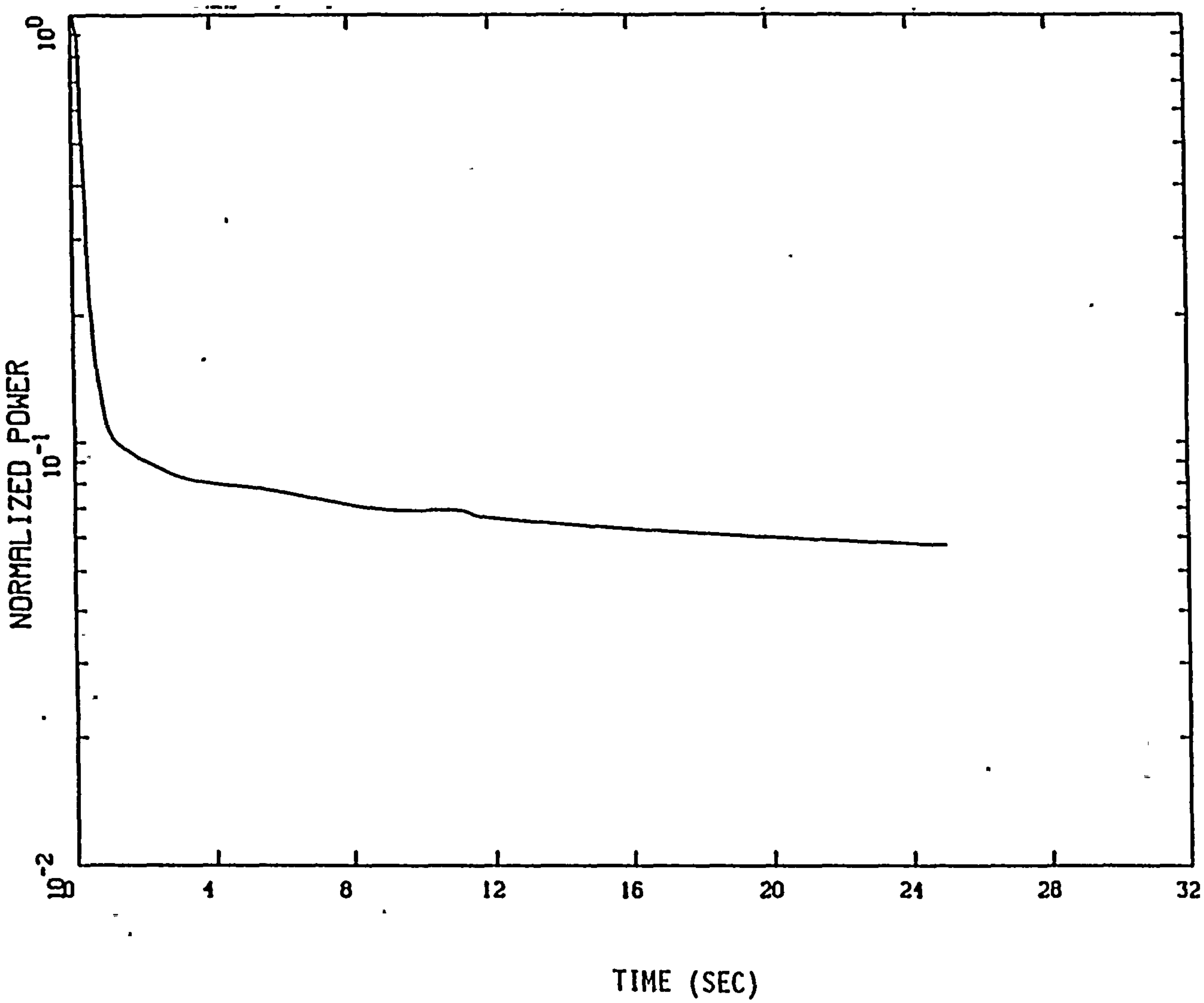


FIGURE 3.1 NORMALIZED POWER VS TIME

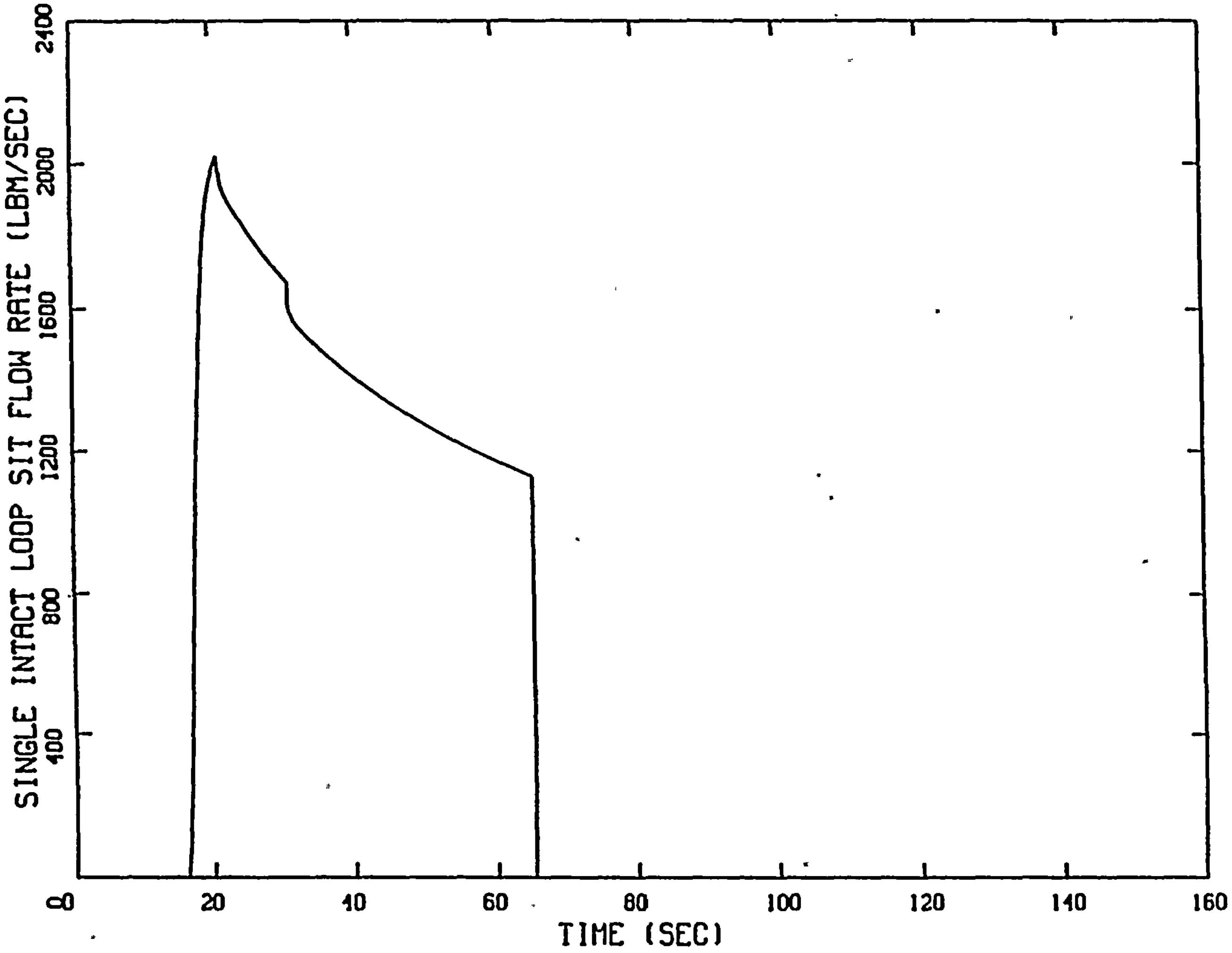


FIGURE 3.2 SINGLE INTACT LOOP SAFETY INJECTION TANK FLOW RATE VS TIME

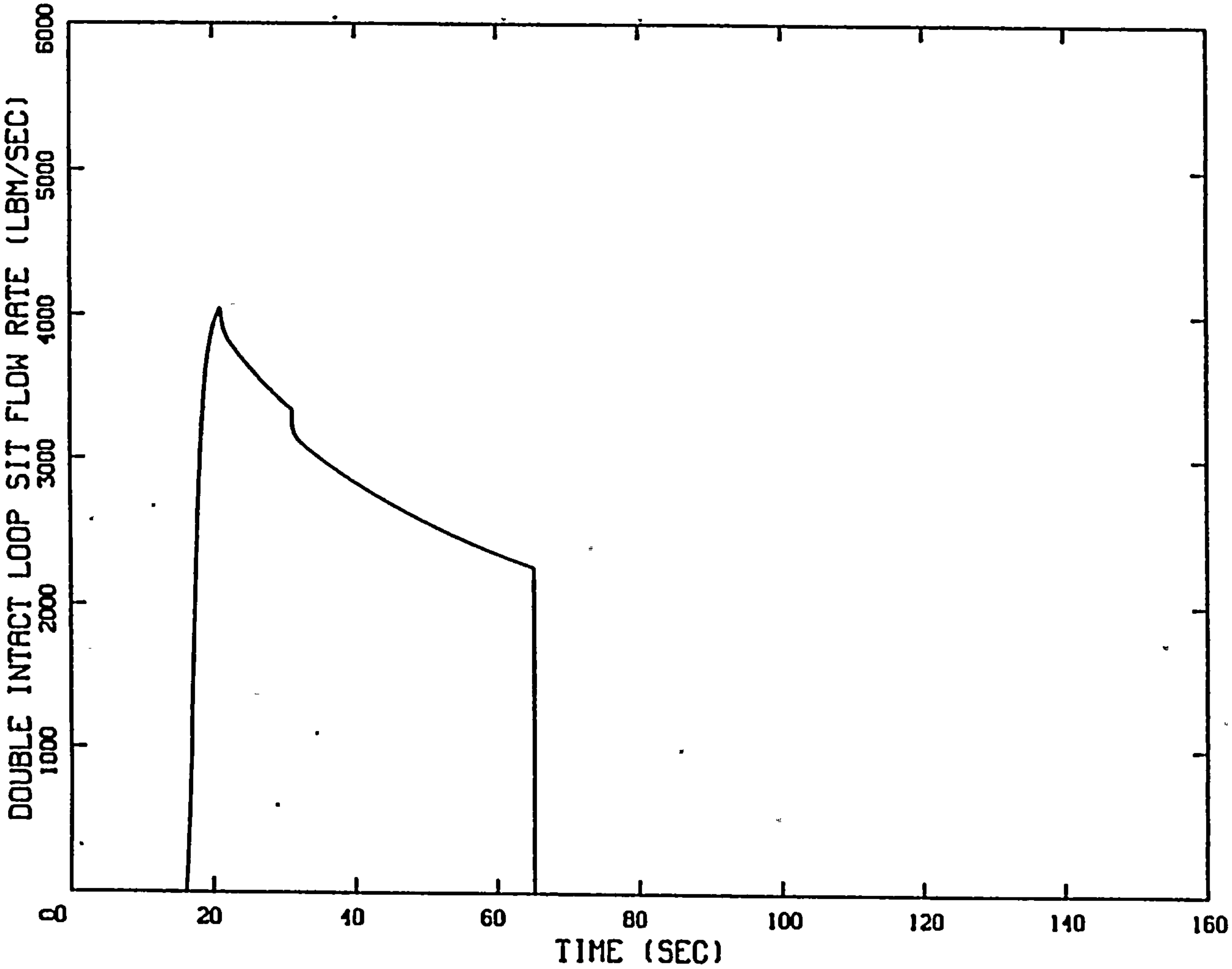


FIGURE 3.3 DOUBLE INTACT LOOP SAFETY INJECTION TANK FLOW RATE VS TIME

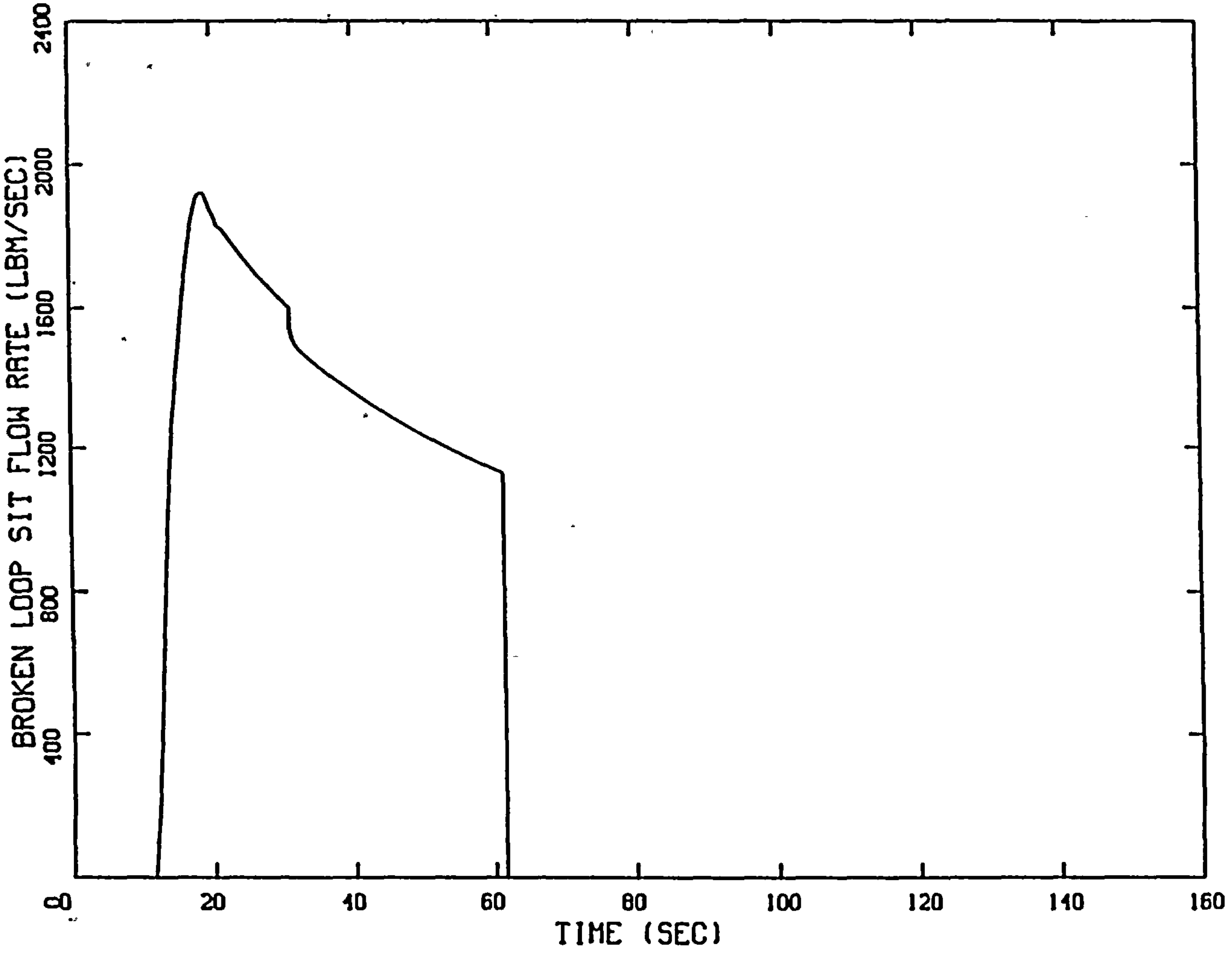


FIGURE 3.4 BROKEN LOOP SAFETY INJECTION TANK FLOW RATE VS TIME

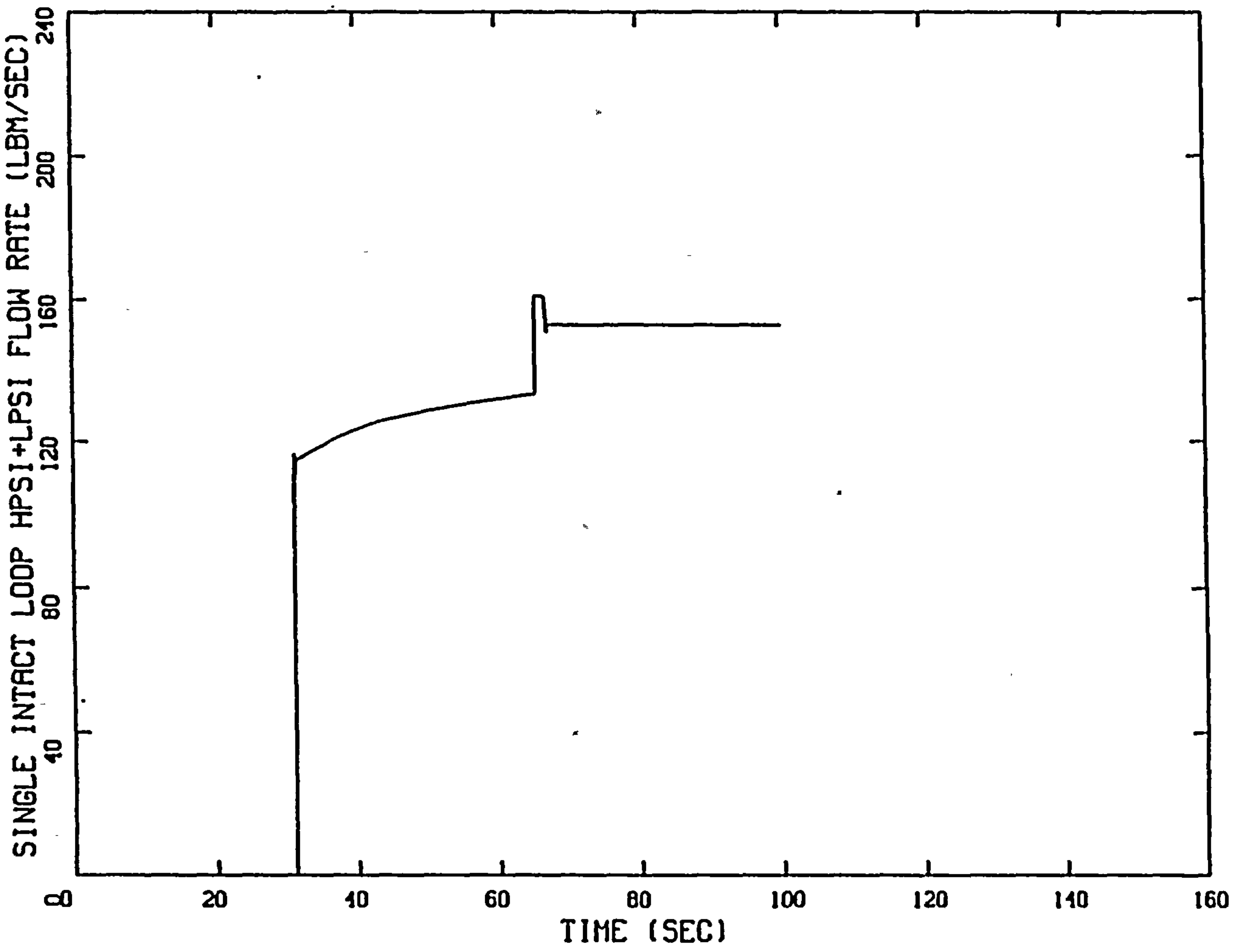


FIGURE 3.5 SINGLE INTACT LOOP HPSI PLUS LPSI FLOW RATE VS TIME

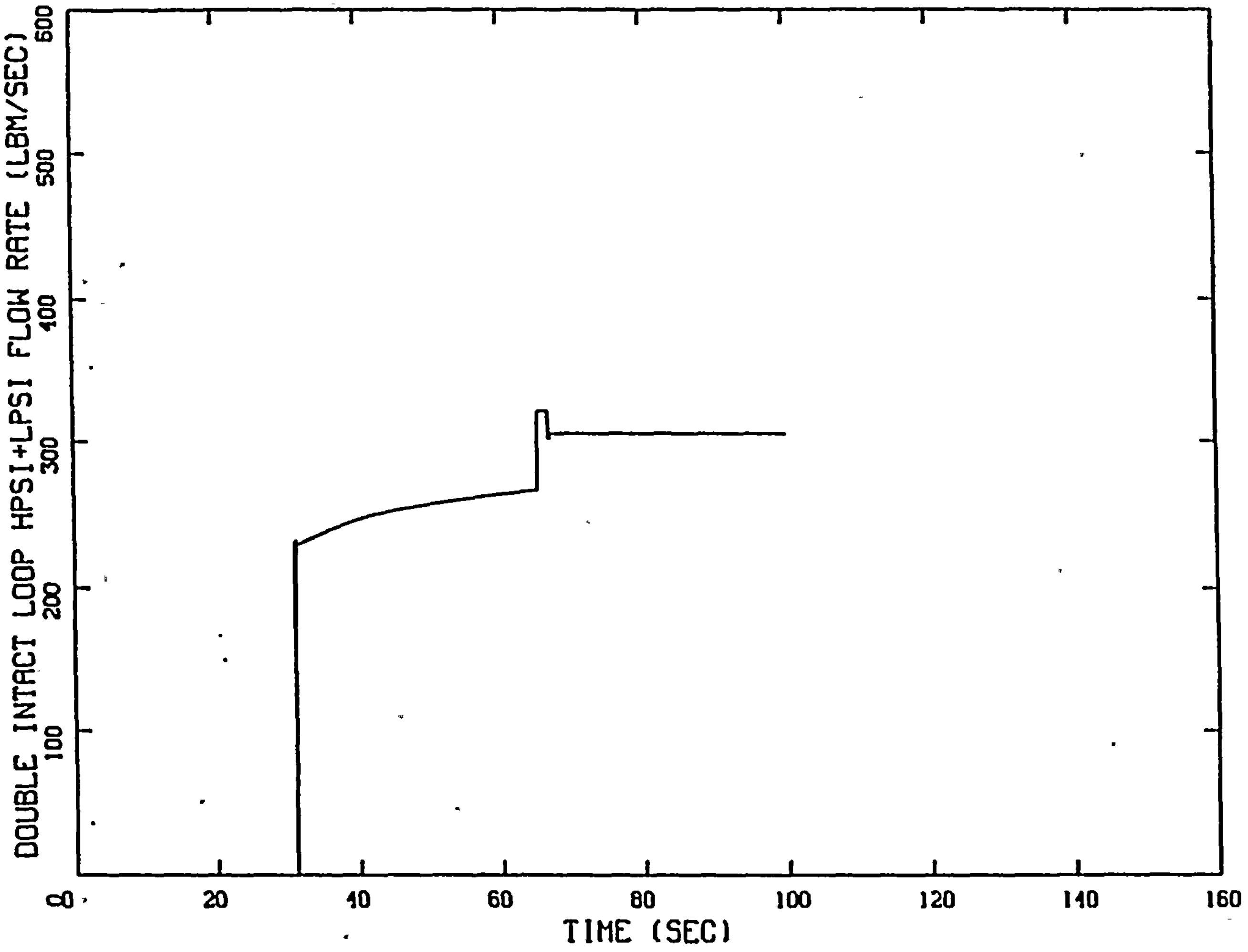


FIGURE 3.6 DOUBLE INTACT LOOP HPSI PLUS LPSI FLOW RATE VS TIME

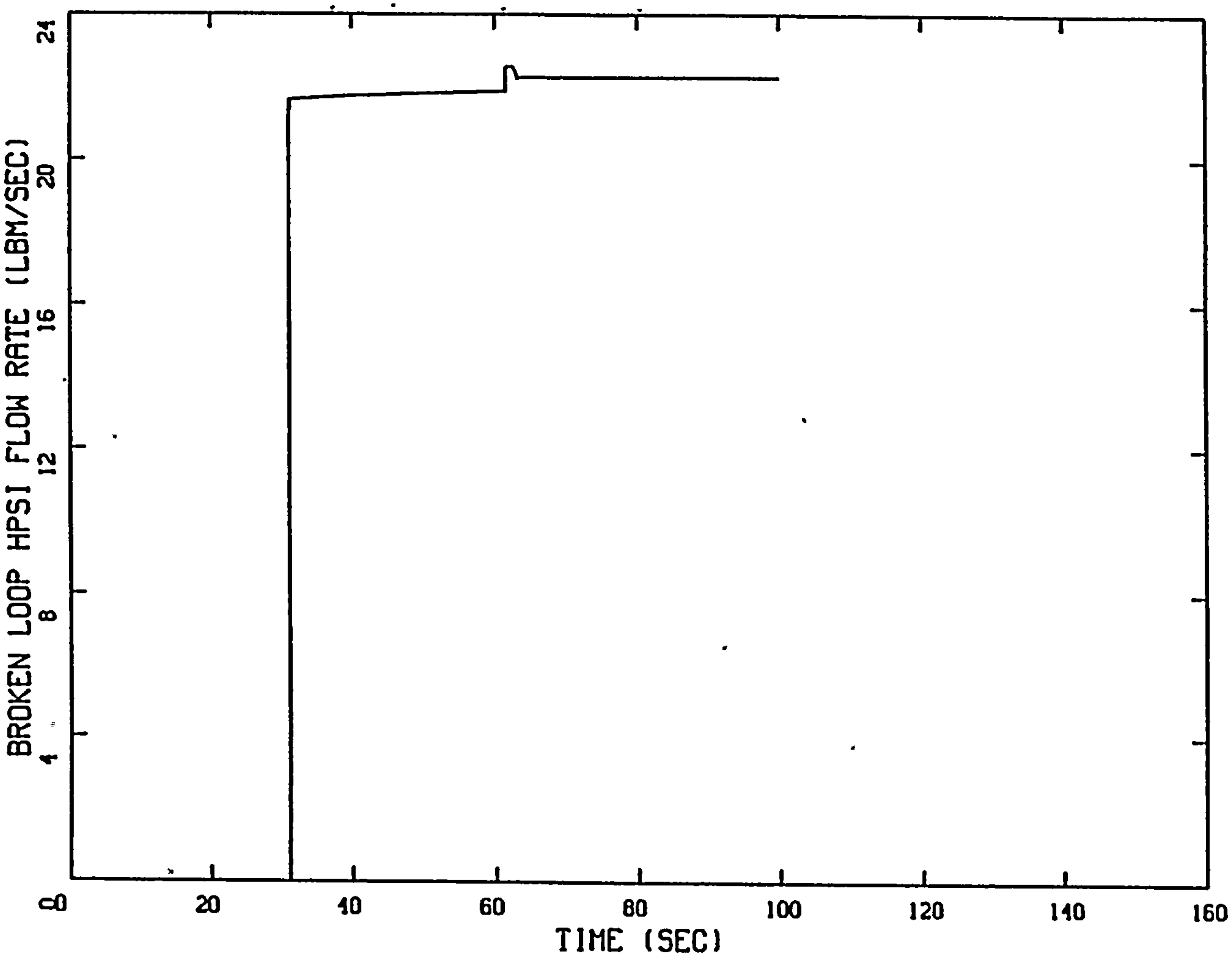


FIGURE 3.7 BROKEN LOOP HPSI FLOW RATE VS TIME

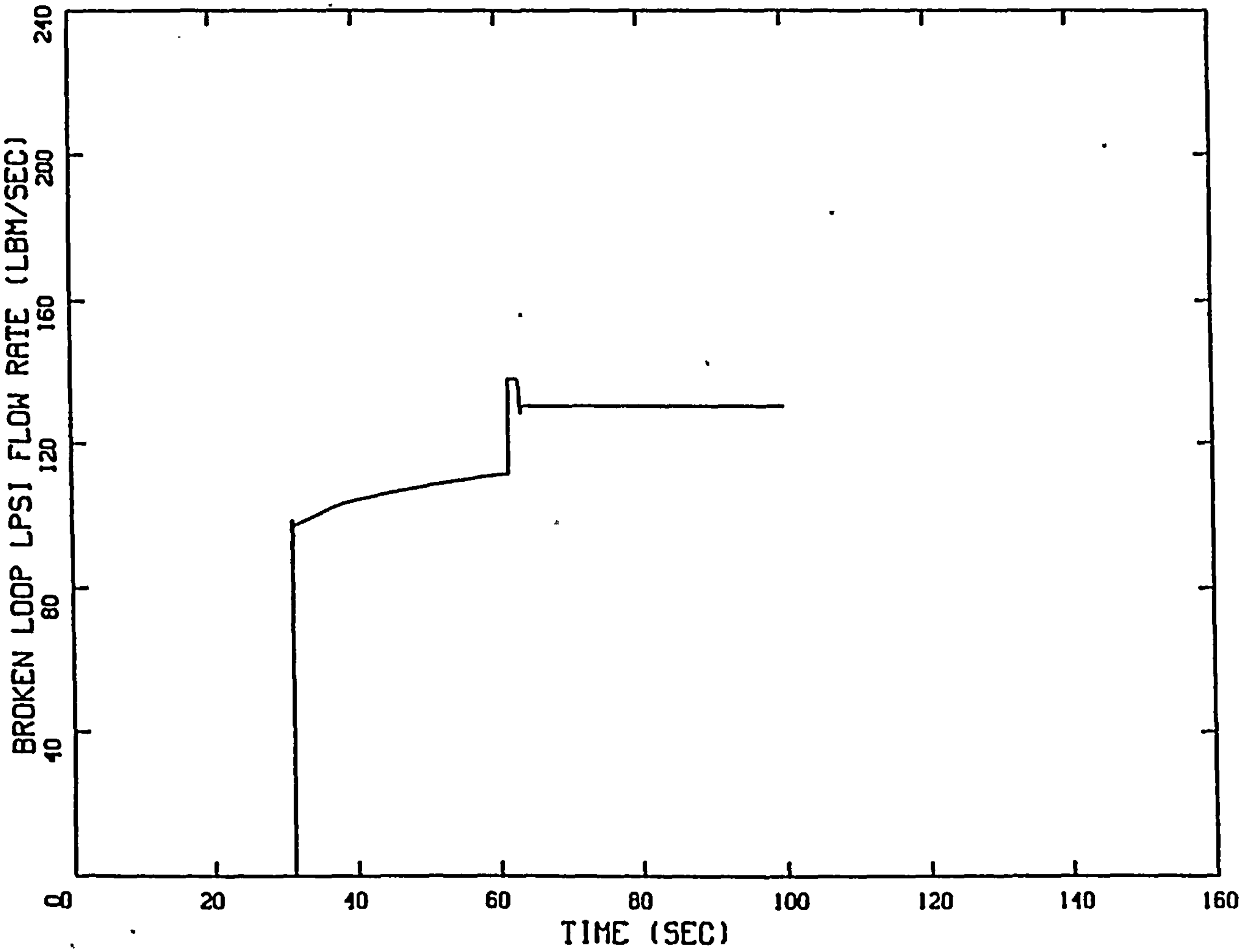
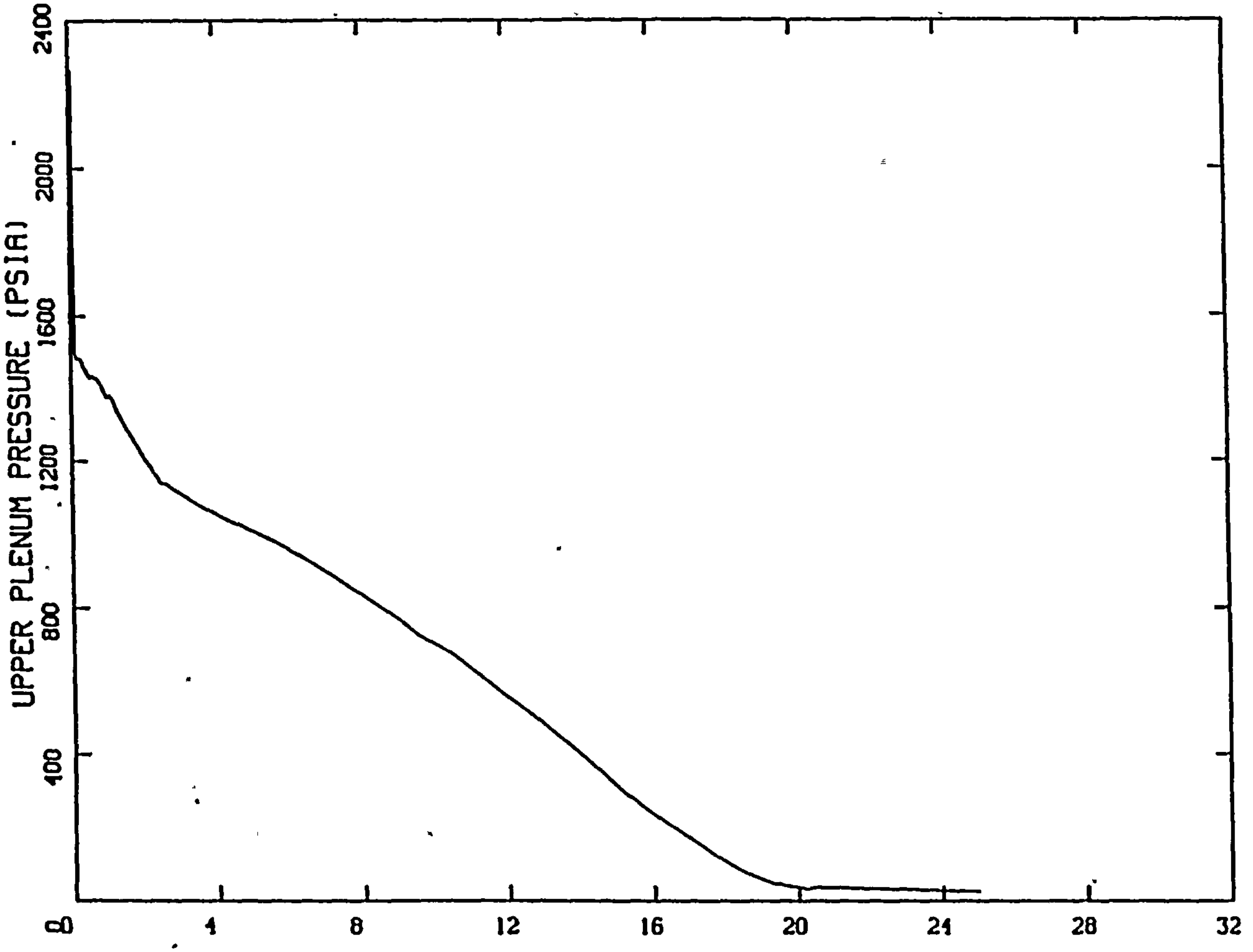


FIGURE 3.8 BROKEN LOOP LPSI FLOW RATE VS TIME



TIME (SEC)

FIGURE 3.9 UPPER PLENUM PRESSURE VS TIME

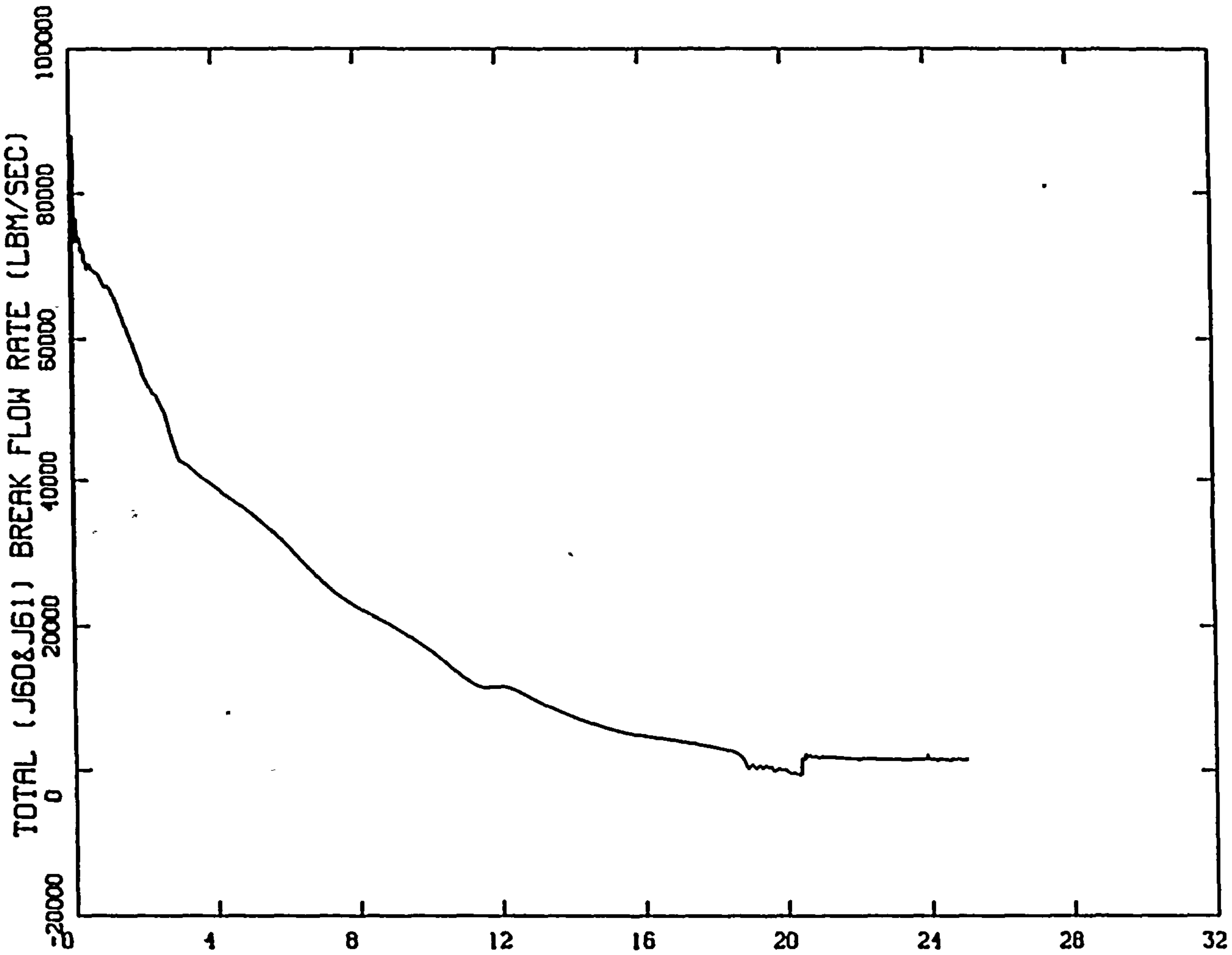


FIGURE 3.10 TOTAL BREAK FLOW RATE VS TIME

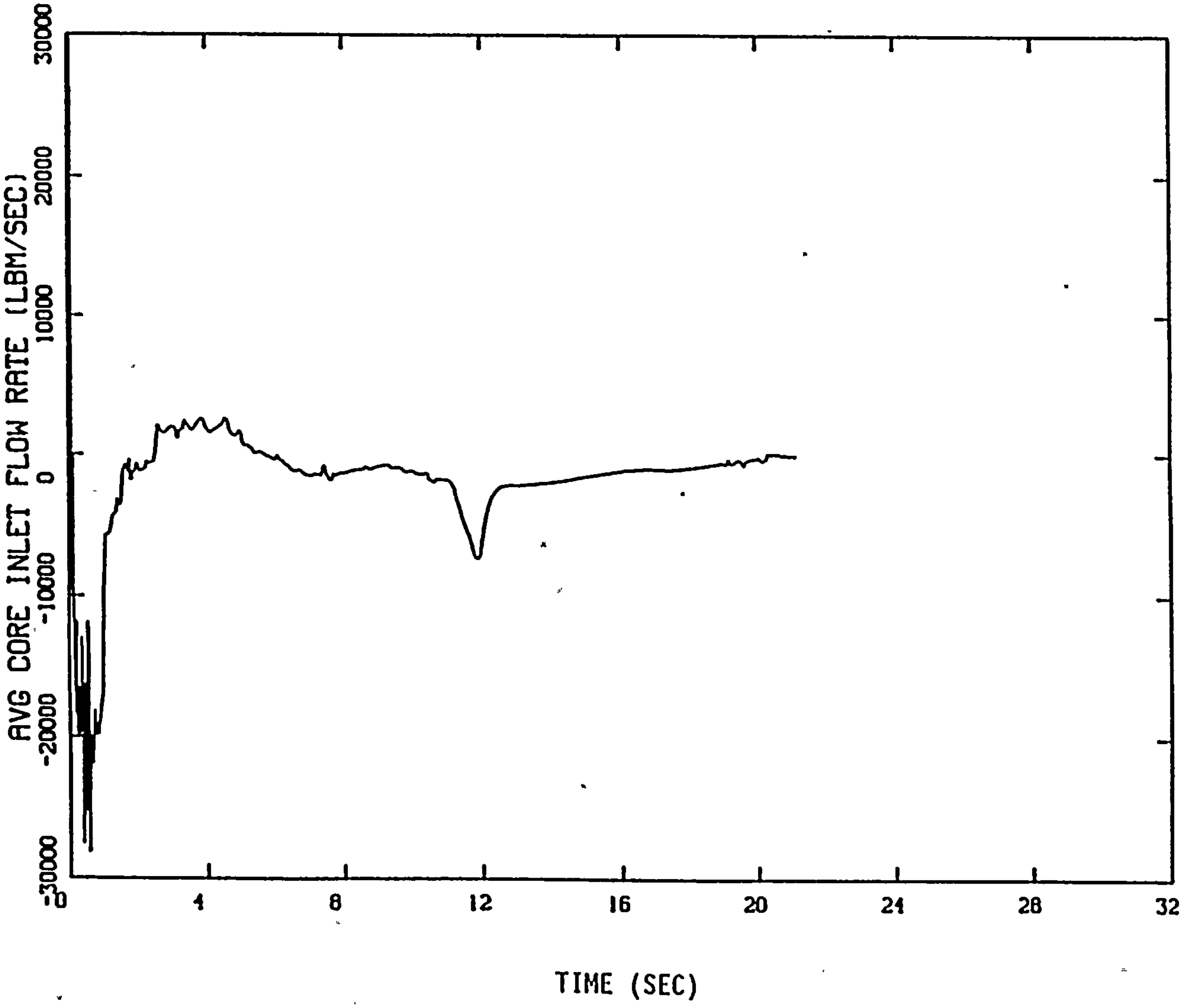


FIGURE 3.11 AVERAGE CORE INLET FLOW RATE VS TIME FOR EOC SHAPE (HC RUN)

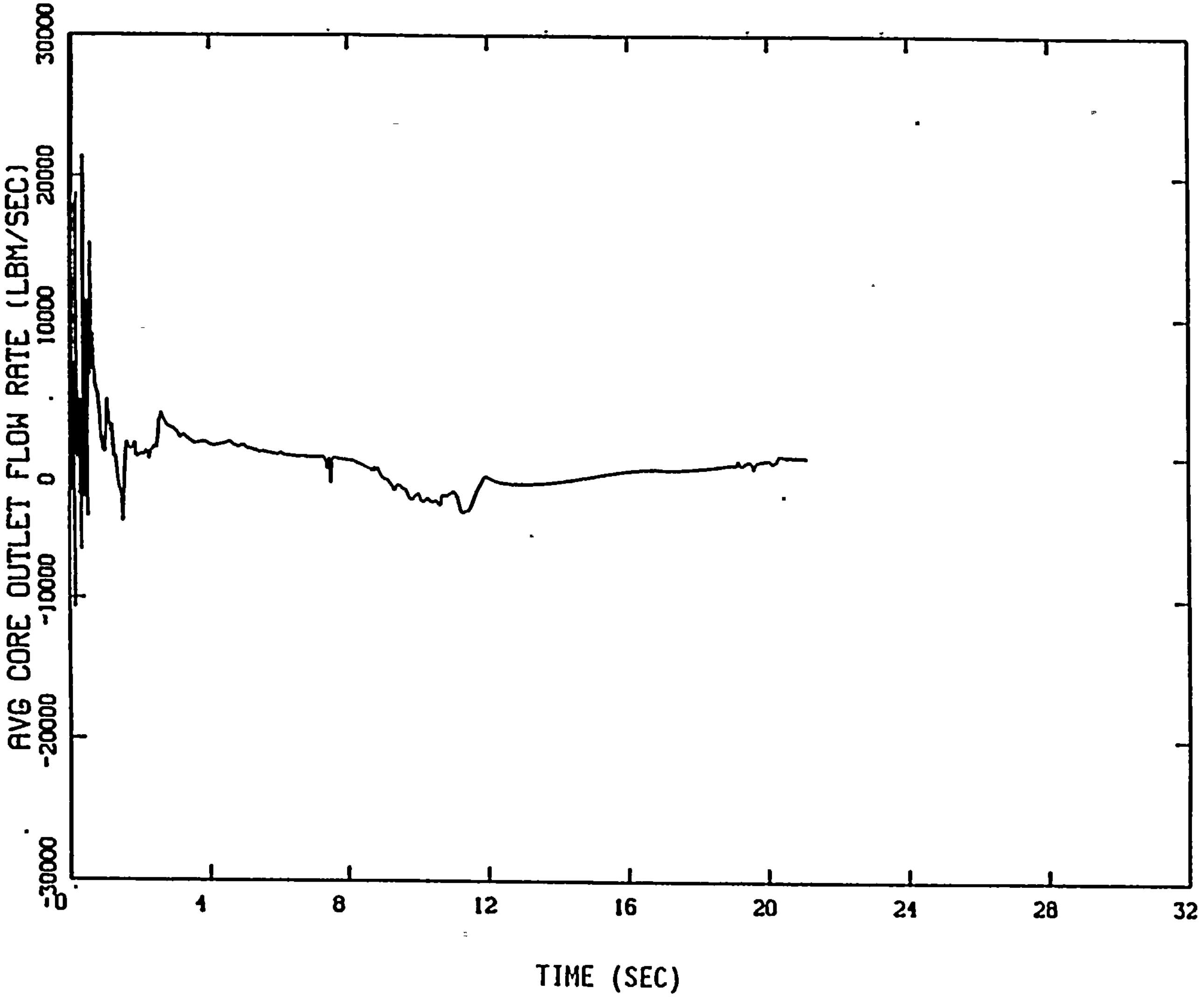


FIGURE 3.12 AVERAGE CORE OUTLET FLOW RATE VS TIME FOR EOC SHAPE (HC RUN)

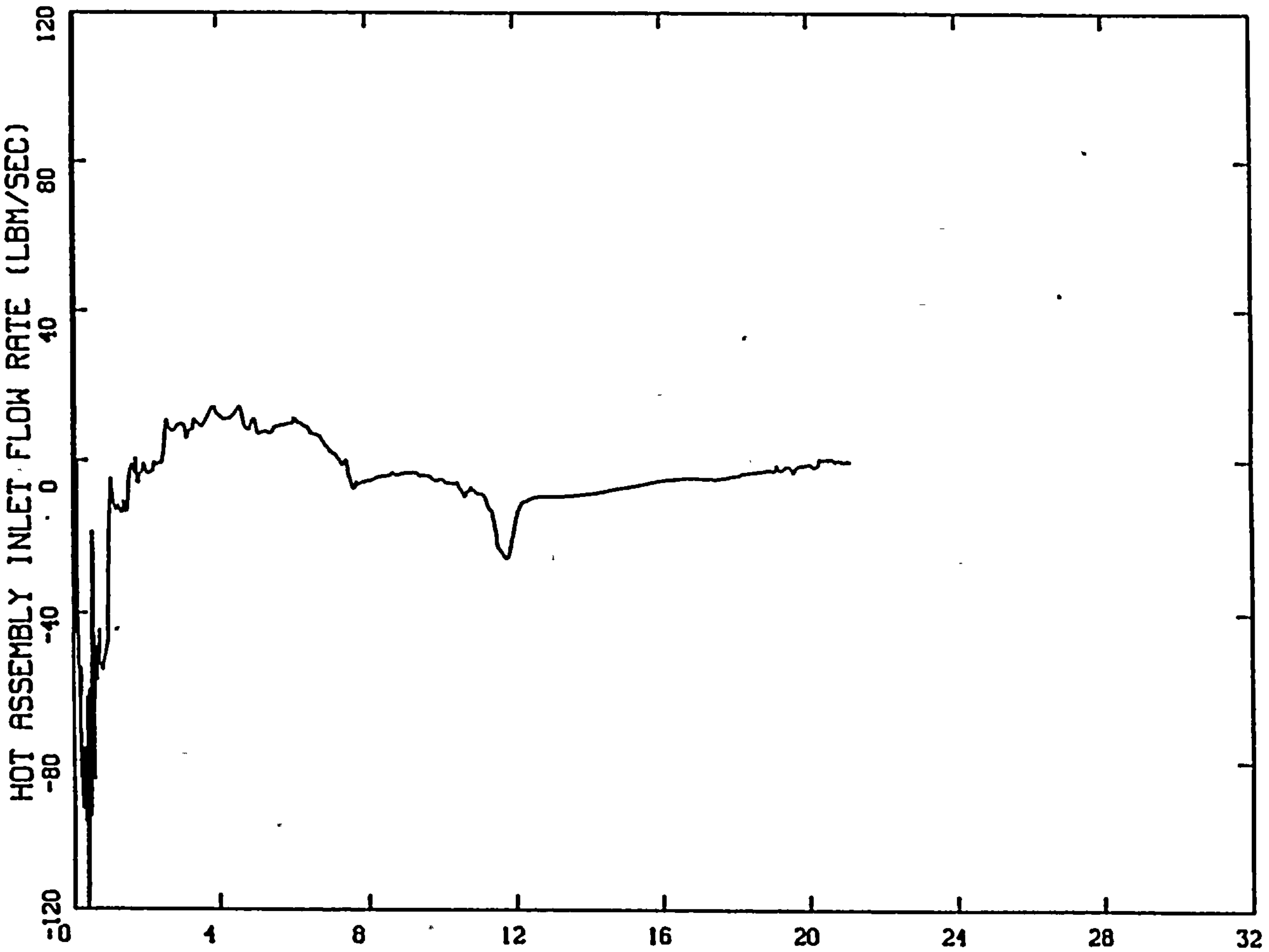


FIGURE 3.13 HOT ASSEMBLY INLET FLOW RATE VS TIME FOR EOC SHAPE (HC RUN)

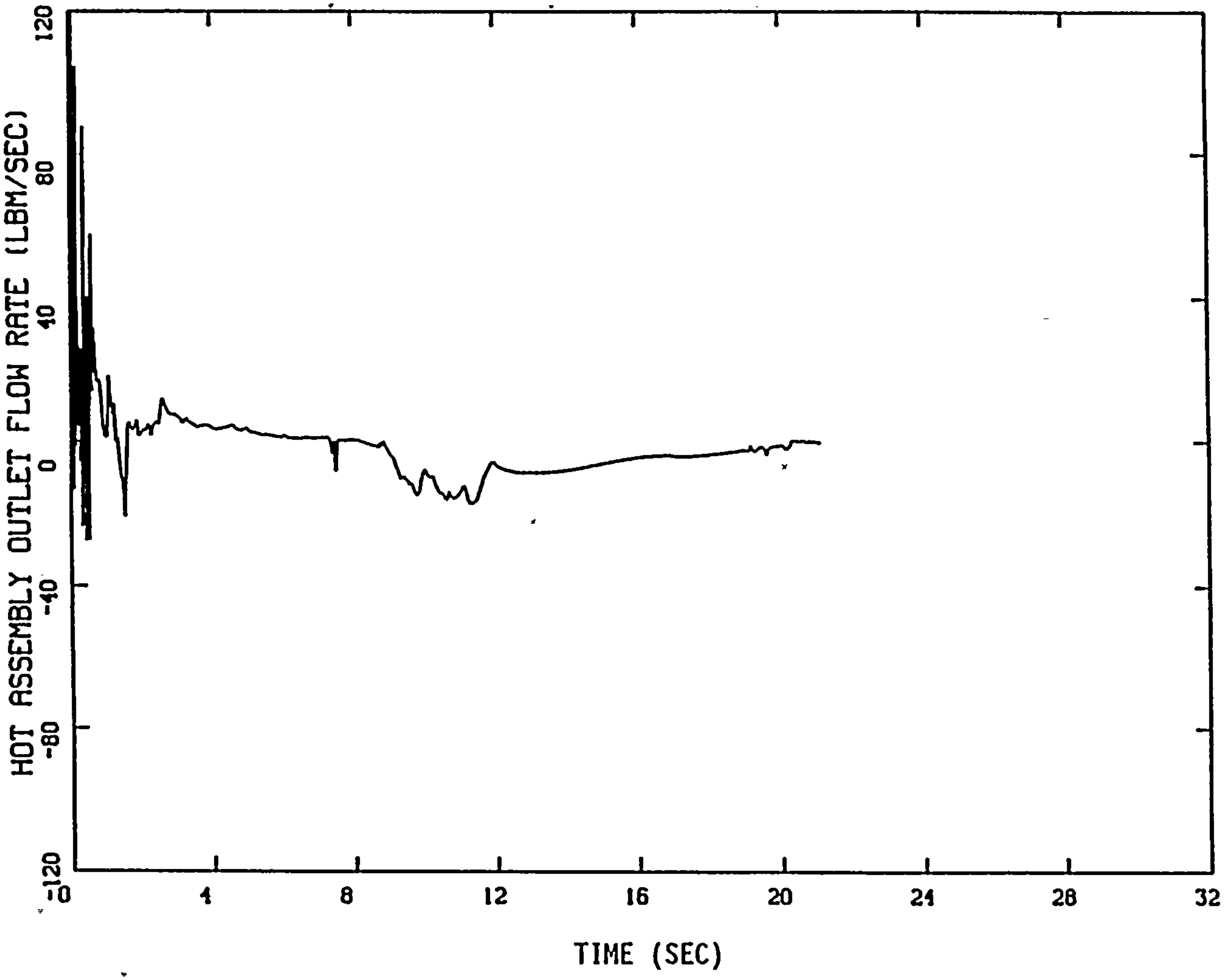


FIGURE 3.14 HOT ASSEMBLY OUTLET FLOW RATE VS TIME FOR EOC SHAPE (HC RUN)

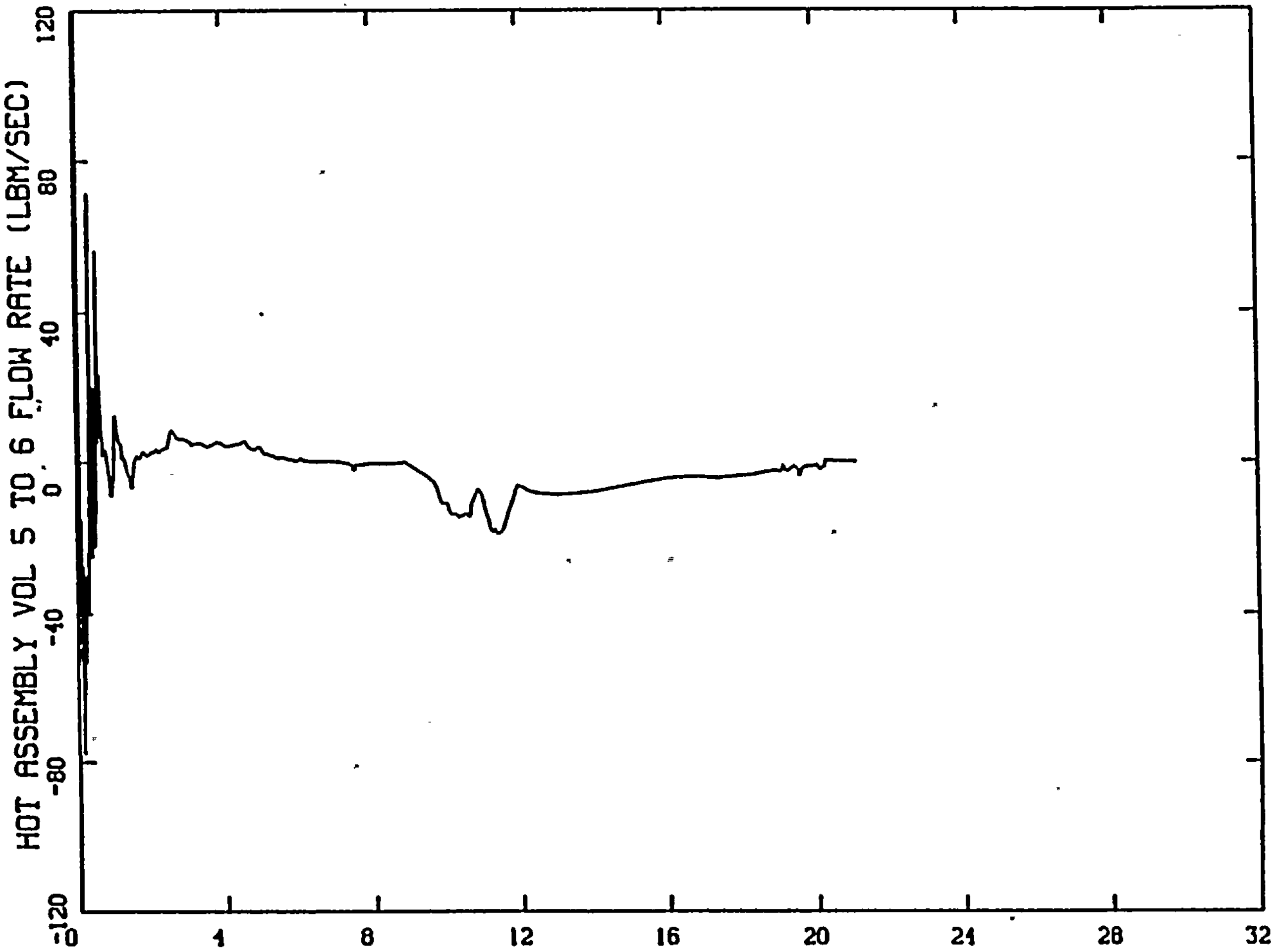


FIGURE 3.15 HOT ASSEMBLY FLOW RATE FROM MIDDLE CORE VOLUME TO UPPER CORE VOLUME VS TIME FOR EOC SHAPE (IIC RUN)

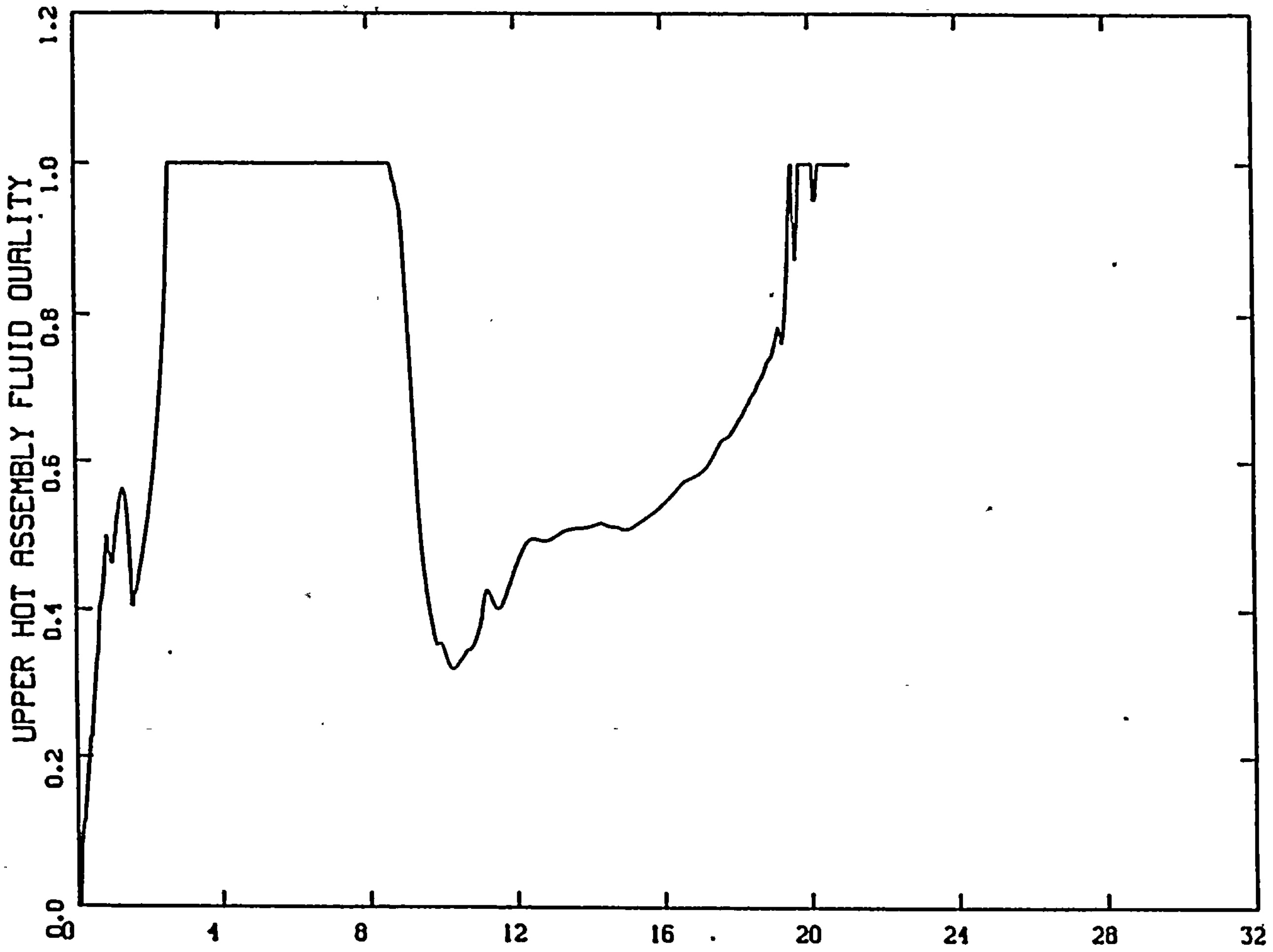


FIGURE 3.16 HOT ASSEMBLY UPPER CORE VOLUME FLUID QUALITY VS TIME FOR EOC SHAPE (HC RUN)

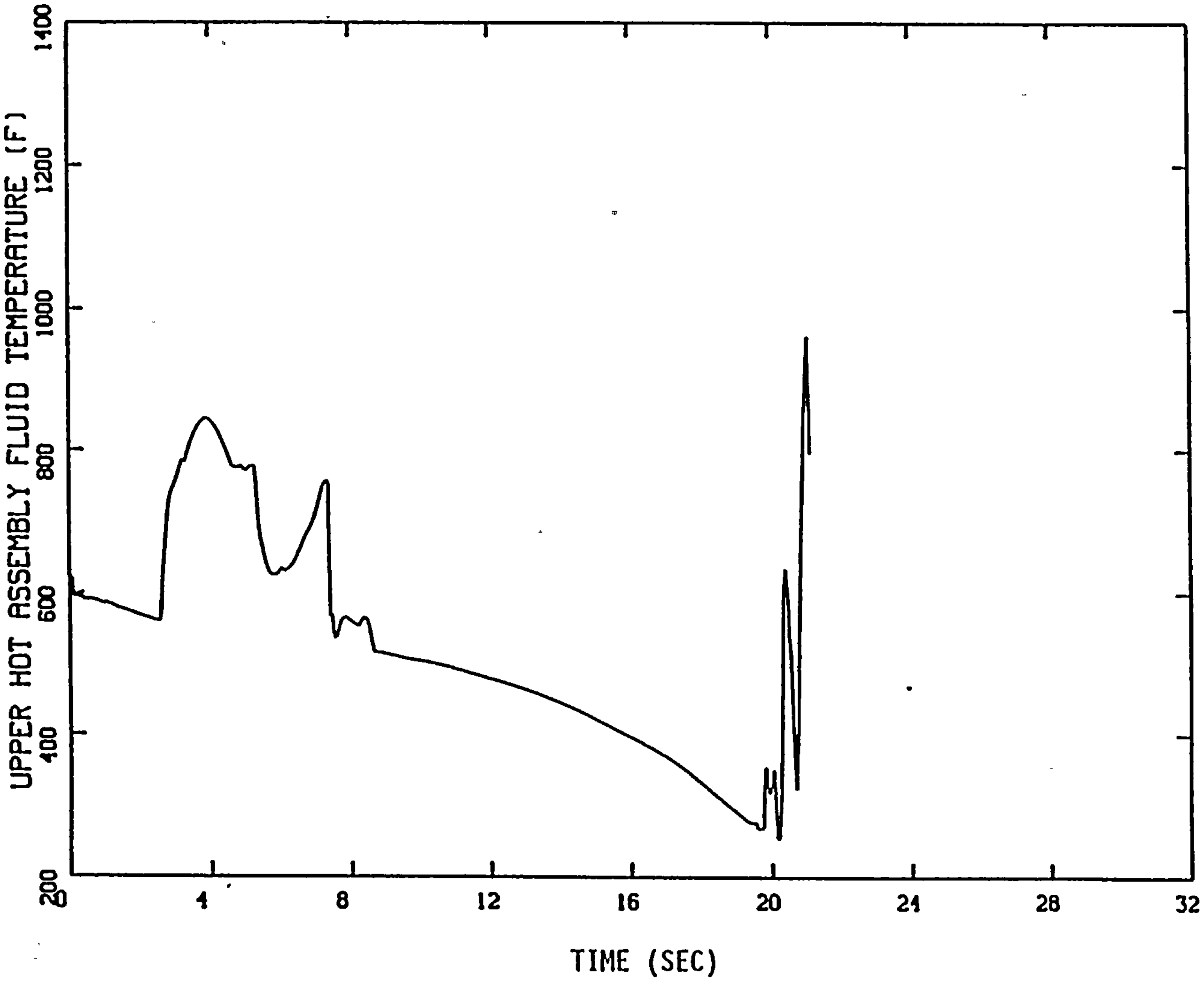


FIGURE 3.17 HOT ASSEMBLY UPPER CORE VOLUME FLUID TEMPERATURE VS TIME FOR EOC SHAPE (HC RUN)

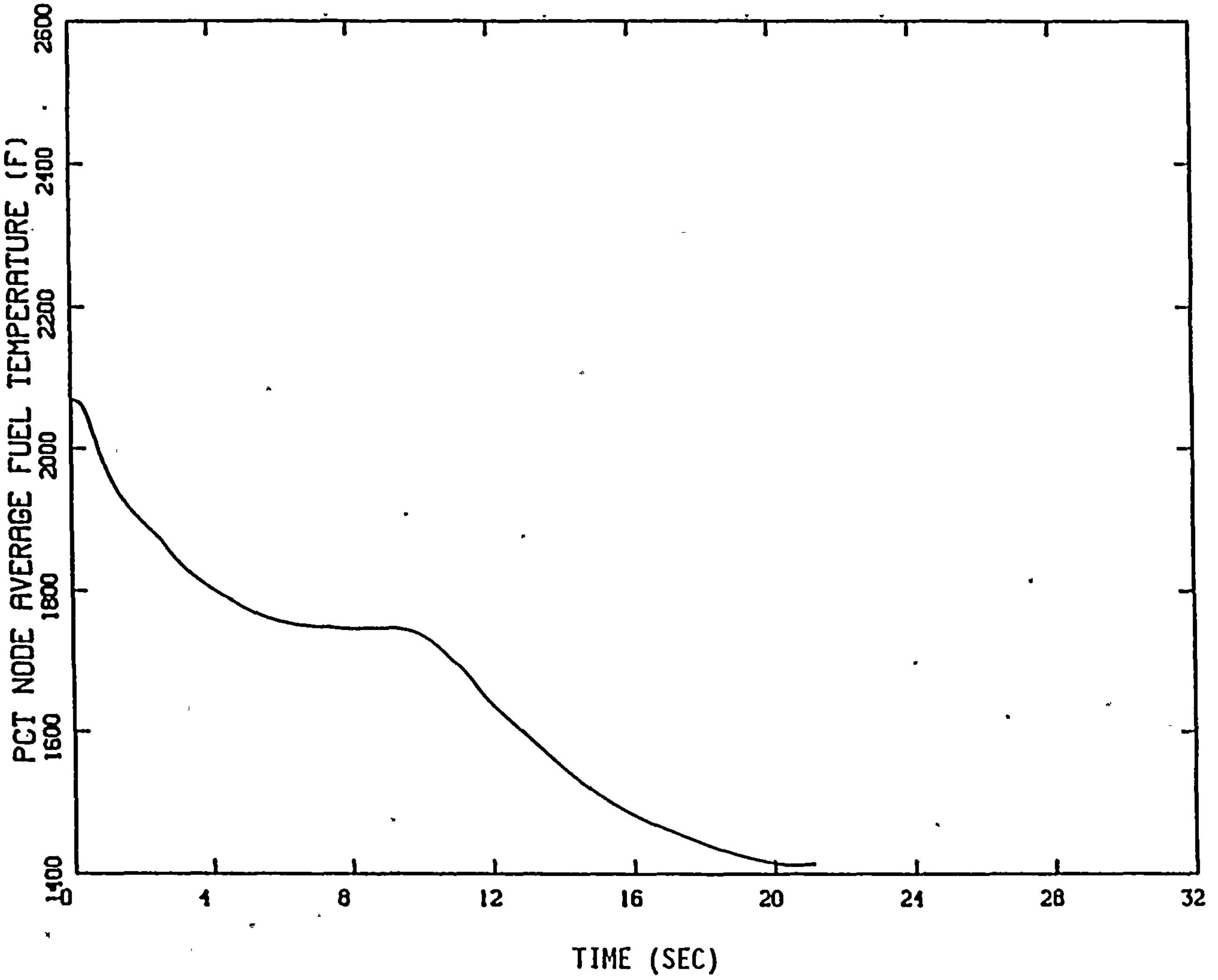


FIGURE 3.18 PCT NODE FUEL AVERAGE TEMPERATURE VS TIME FOR EOC SHAPE (HC RUN)

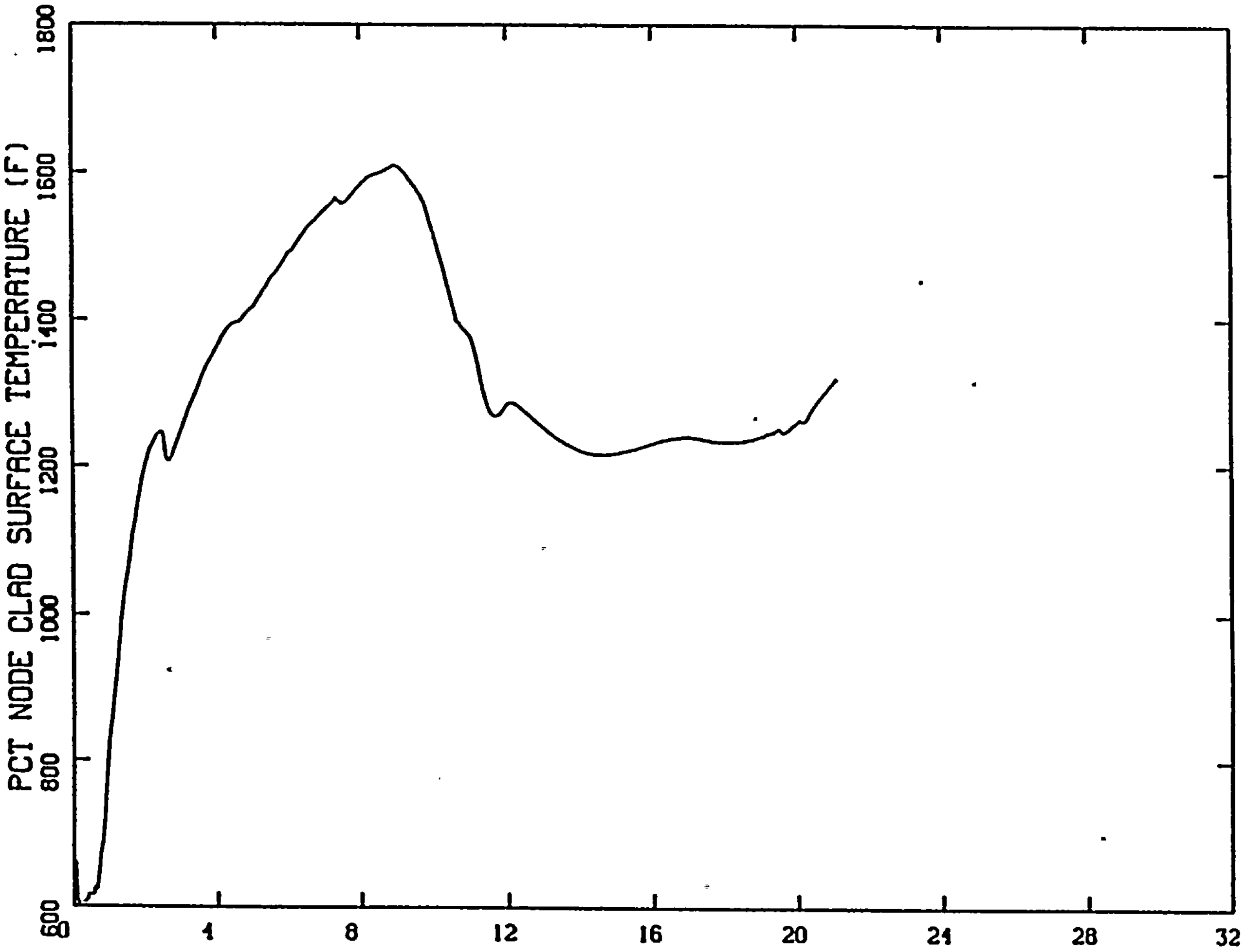


FIGURE 3.19 PCT NODE CLADDING SURFACE TEMPERATURE VS TIME FOR EOC SHAPE (HC RUN)

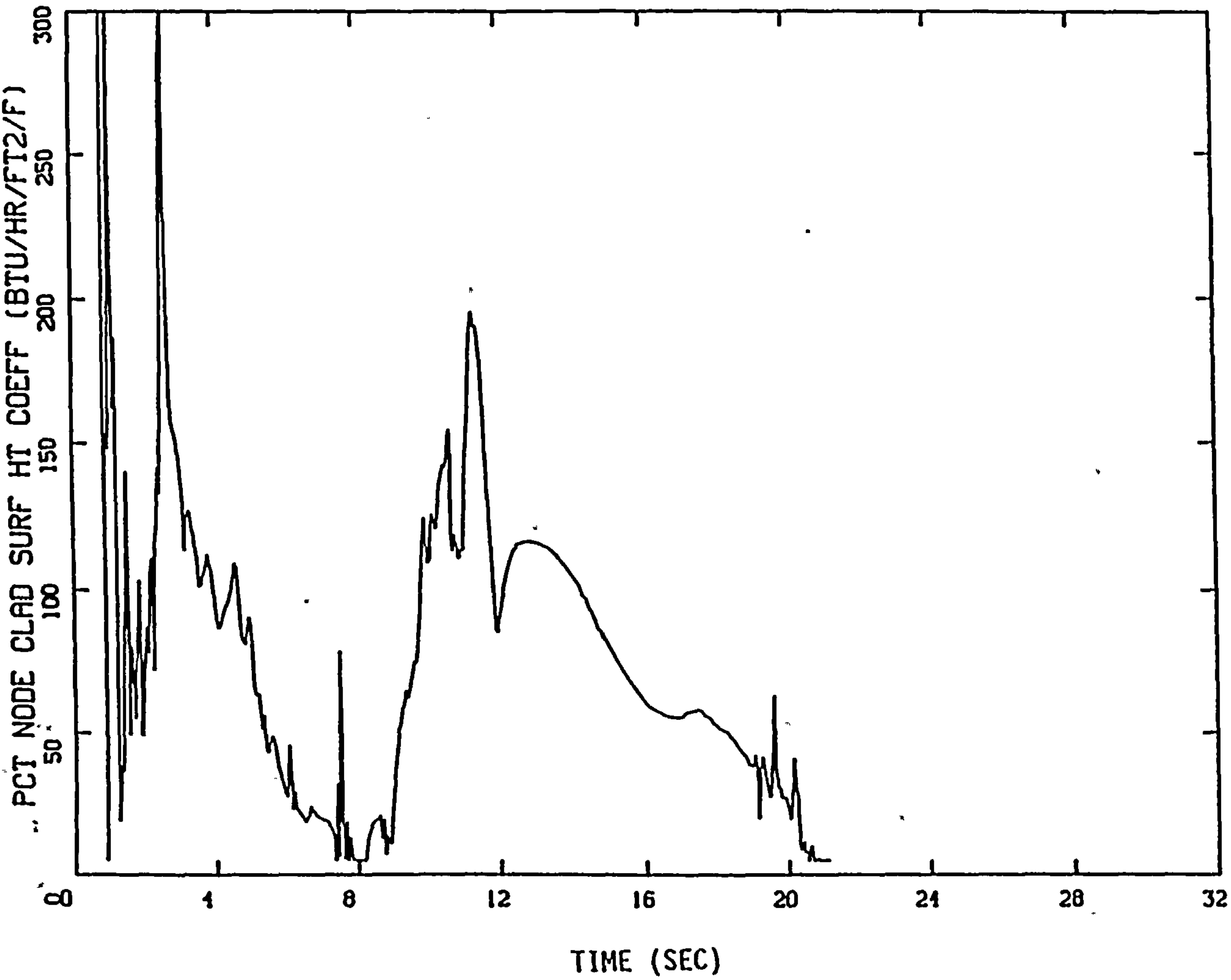


FIGURE 3.20 PCT NODE HEAT TRANSFER COEFFICIENT VS TIME FOR EOC SHAPE (HC RUN)

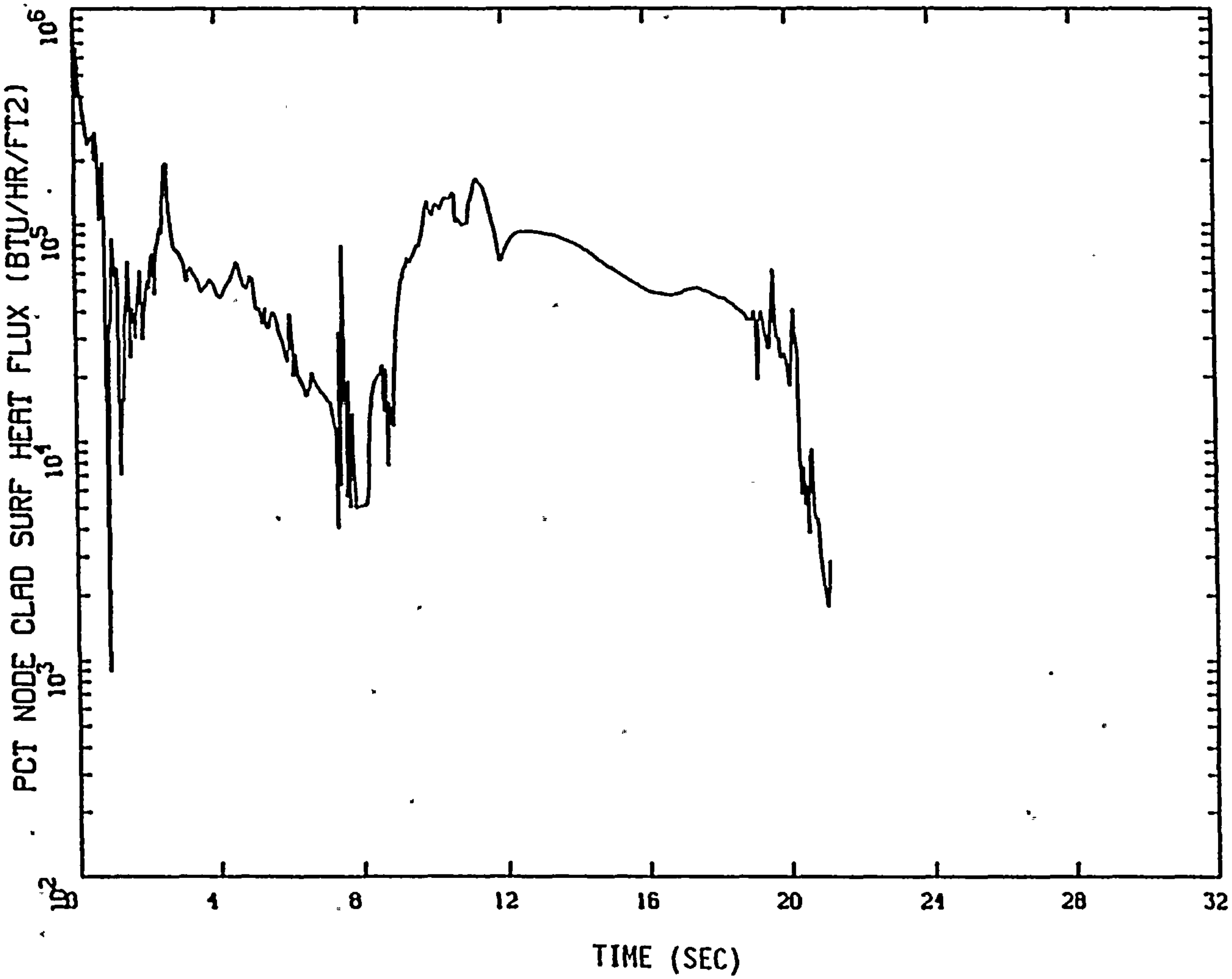


FIGURE 3.21 PCT NODE HEAT FLUX VS TIME FOR EOC SHAPE (HC RUN)

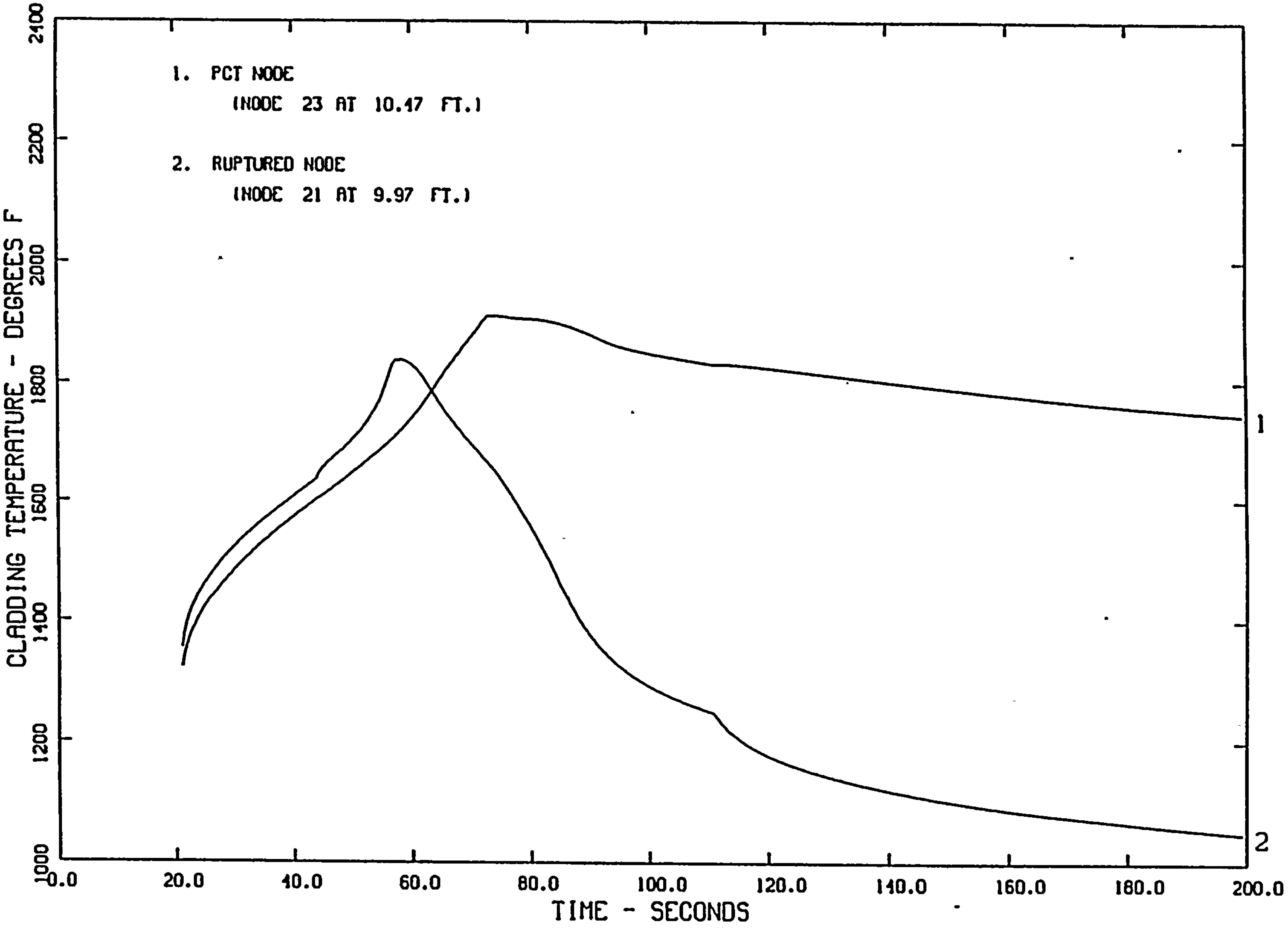


FIGURE 3.22 PCT NODE CLADDING SURFACE TEMPERATURE VS TIME FOR EOC SHAPE (TOODEE2 RUN)

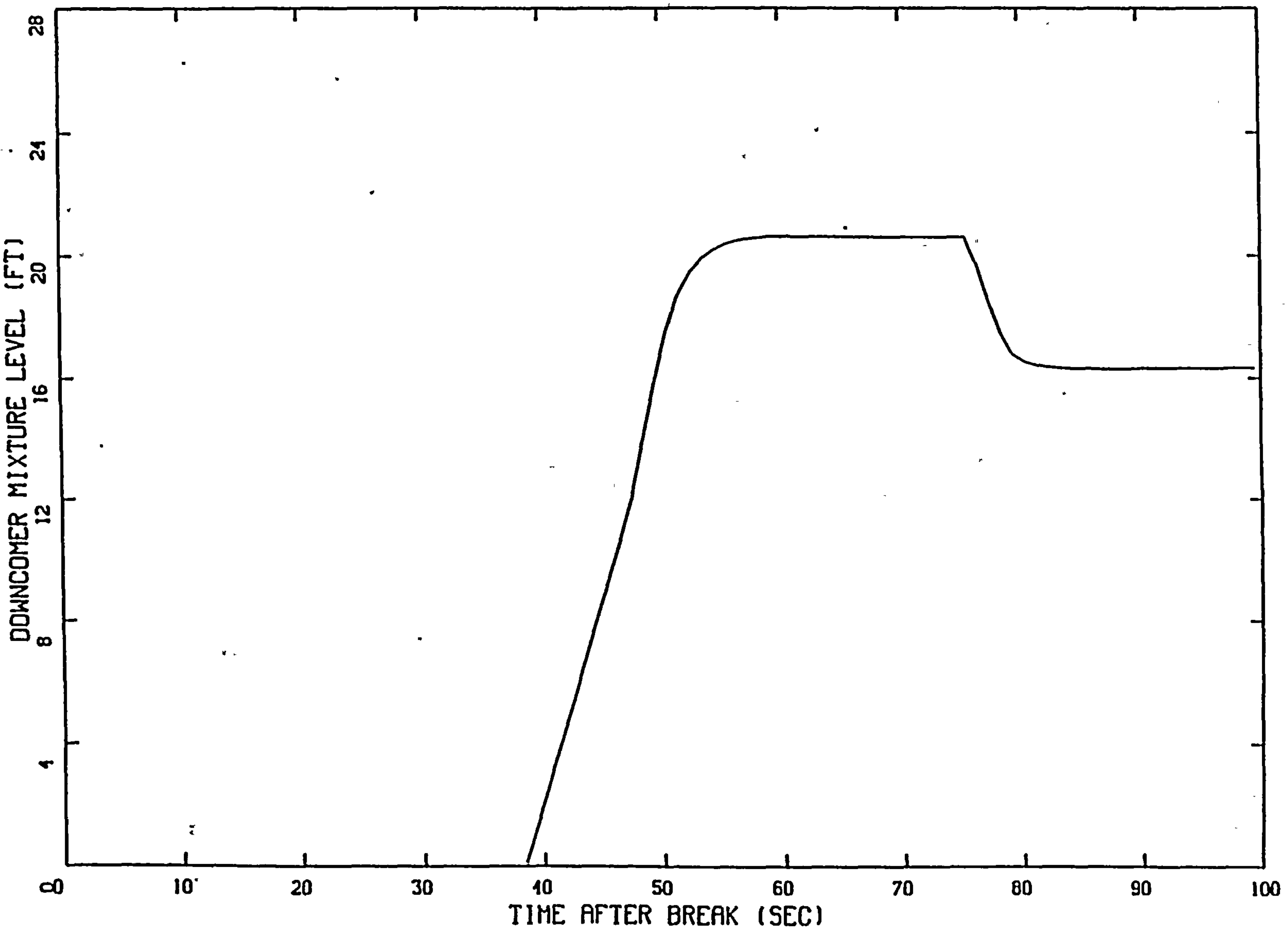


FIGURE 3.23 DOWNCOMER MIXTURE LEVEL VS TIME FOR EOC SHAPE

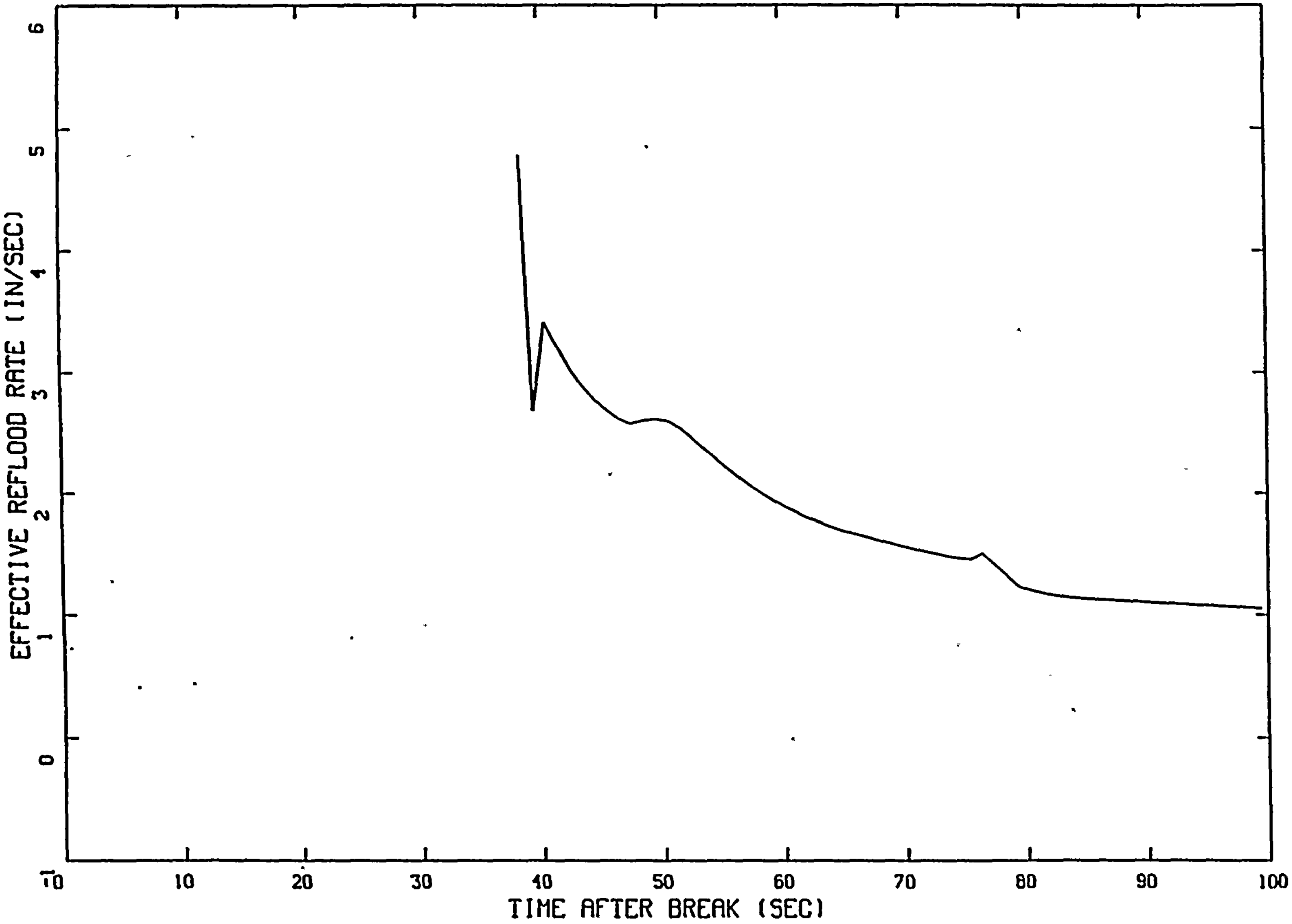


FIGURE 3.24 EFFECTIVE REFLOOD RATE VS TIME FOR EOC SHAPE

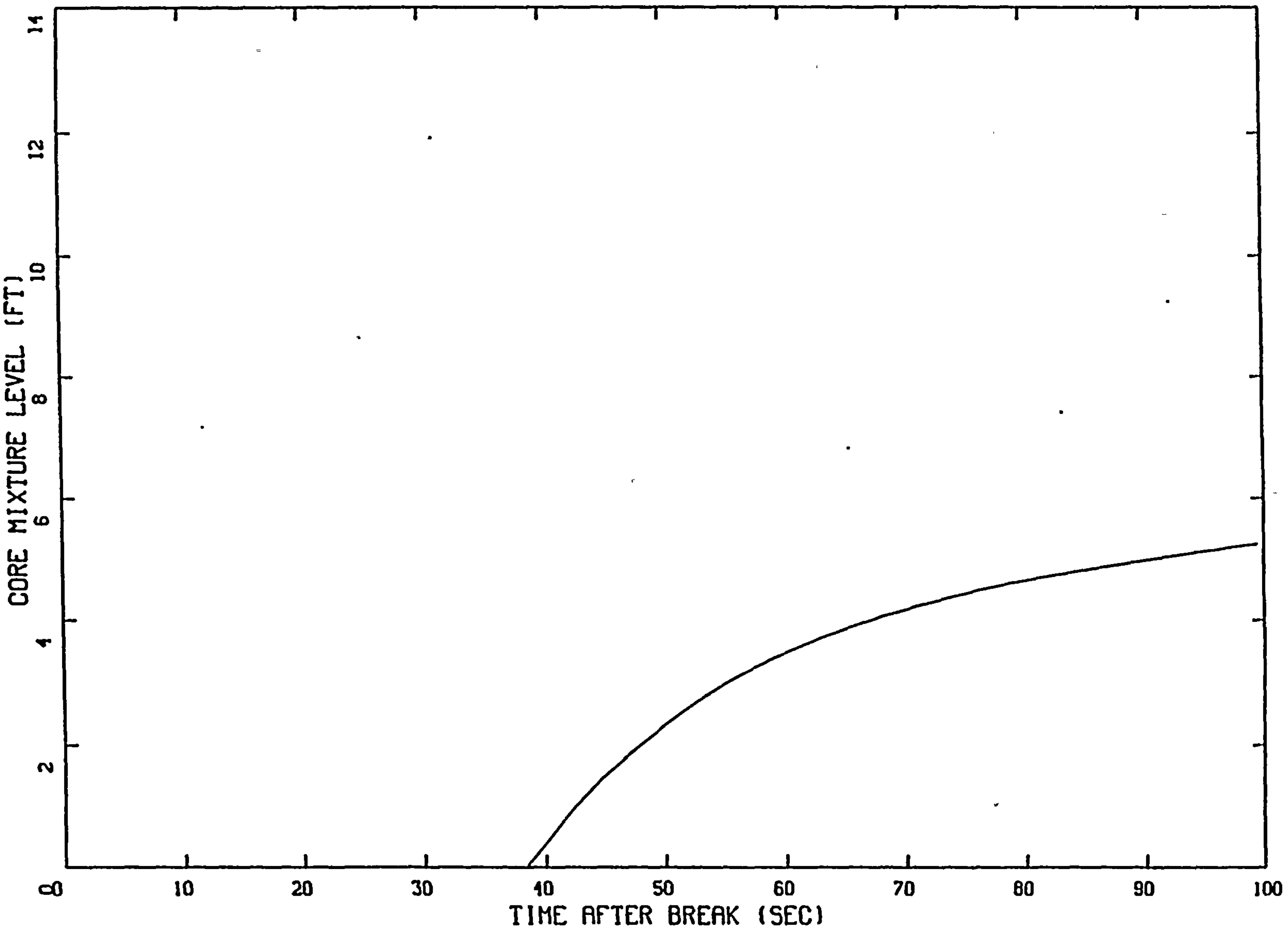


FIGURE 3.25 CORE MIXTURE LEVEL VS TIME FOR EOC SHAPE

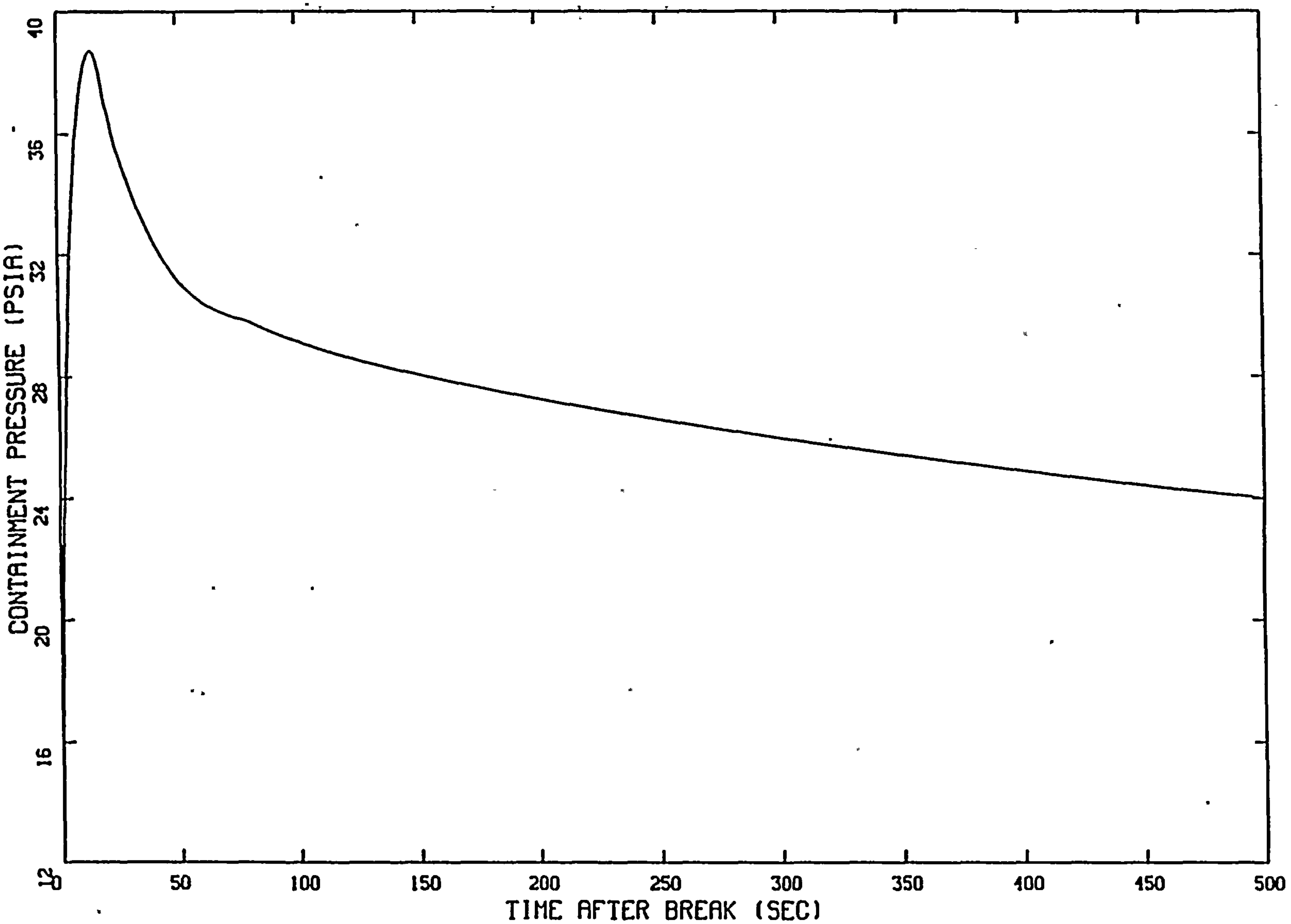


FIGURE 3.26 CONTAINMENT PRESSURE VS TIME FOR EOC SHAPE

4.0 CONCLUSIONS

A revised LOCA/ECCS analysis has been performed to support an increased asymmetric steam generator tube plugging level of 25 ±7%. The analysis supports operation of the St. Lucie Unit 1 plant at a nominal full power of 2700 MWt with an average steam generator tube plugging level of 25%. The analysis supports a maximum LHR of 15 kW/ft that is independent of core height and exposure. It also supports a radial peaking factor of 1.75. This analysis also supports a primary coolant temperature coastdown at EOC and at full power with a maximum reduction in primary coolant temperature of 26°F. This analysis will support future cycles unless any future changes in fuel design, Technical Specifications, or plant operation indicate that a re-analysis is required.

The extended exposure LOCA/ECCS analysis performed in Reference 5 continues to support an assembly average exposure of up to 52,500 MWd/MTU, with a corresponding peak rod average exposure of 56,800 MWd/MTU. The new fuel design does not alter the conclusions of Reference 5 in that reduced fuel stored energy at End-of-Life (EOL) dominates any adverse effect of increased rod pressure at EOL on the peak cladding temperature (PCT). In addition, third cycle fuel does not operate near the Technical Specification peaking limits which are used in the analysis.

Operation of the St. Lucie Unit 1 plant with SPC 14x14 fuel at or below the LHR limit shown in Figure 2.1 assures that the NRC acceptance criteria [10 CFR 50.46(b)] for Loss-of-Coolant Accident pipe breaks up to and including the double-ended severance of a reactor coolant pipe will be met with the emergency core cooling system for the St. Lucie Unit 1 plant.

5.0 REFERENCES

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2. St. Lucie Unit 1 Large Break LOCA/ECCS Analysis, SNP-91-151, Siemens Nuclear Power Corporation, Richland, WA 99352, September 1991.

3. Dennis M. Crutchfield (USNRC Asst. Director Division of PWR Licensing-B), "Safety Evaluation of Exxon Nuclear Company's Large Break ECCS Evaluation Model EXEM/PWR and Acceptance for Referencing of Related Licensing Topical Reports," dated July 8, 1986.

4. RODEX2: Fuel Rod Thermal Mechanical Response Evaluation Model, XN-NF-81-58(P)(A), Revision 2, Supplements 1 and 2 dated March 1984 and Supplements 3 and 4 dated June 1990, Exxon Nuclear Company, Richland, WA 99352.

5. St. Lucie Unit 1 LOCA/ECCS Extended Exposure Analysis, ANF-87-148, Advanced Nuclear Fuels Corporation, Richland, WA 99352, November 1987.

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ST. LUCIE UNIT 1 LARGE BREAK LOCA/ECCS ANALYSIS WITH 25±7% SGTP

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St. Lucie Unit 1
Docket No. 50-335
Proposed License Amendment
St. Lucie Unit 1 Reduction of
Reactor Coolant System Design Flow

ENCLOSURE 3

EMF-92-148, "ST. LUCIE UNIT 1 SMALL BREAK LOCA ANALYSIS": Siemens Power Corporation, February 5, 1993.