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DRESDEN UNIT 3 ANALYSIS FOR REDUCED FLOW OPERATION

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Prepared by: Richard H Kelley
Richard H. Kelley
Plant Transient Analysis

Prepared by: G. C. Cooke
G. C. Cooke, Manager
Plant Transient Analysis

Concur: GF Owsley
G. F. Owsley, Manager
Reload Fuel Licensing

Approve: JN Morgan
J. N. Morgan, Manager
Licensing & Safety Engineering

Approved: George Sofer
G. A. Sofer, Manager
Fuel Engineering & Technical Services

gf

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1.0 INTRODUCTION AND SUMMARY

The reloading of fresh fuel into a nuclear reactor core requires consideration of anticipated transient events with the dynamic core characteristics of the current cycle loading. Exxon Nuclear Company, in supplying reload fuel for Dresden Unit 3, has minimized its impact upon plant operation by requiring its fuel design to be hydraulically, kinetically, and thermally compatible with the co-residing fuel design which was previously supplied. The Minimum Critical Power Ratio, MCPR, for safe operation at the 100% power and flow condition was established through evaluation of anticipated operational transients expected to be the most limiting(1,2). Providing adequate margins of safety at full reactor power is generally expected to bound requirements for events occurring at other expected operating states. However, operation at less than rated recirculation pump capacity may require an augmentation of the MCPR operating limit margins of safety specific to the lower flow condition. This is due to the potential for reactor power increases which may occur following pump flow increase toward maximum pump capacity.

The present analysis establishes the necessary MCPR limit to protect the reactor fuel against boiling transition during normal and anticipated transient operation from off-rated core flow conditions. This is shown in Figures 1.0 and 1.1 respectively for all operation and automatic flow control. When these figures are applied during Cycle 8, violation of the MCPR operating limit or safety limit is not expected for normal operation and anticipated transient operation from reactor conditions characterized by less than rated recirculation pump flow when operating with the allowed power versus flow envelope for Dresden Unit 3.

[redacted]

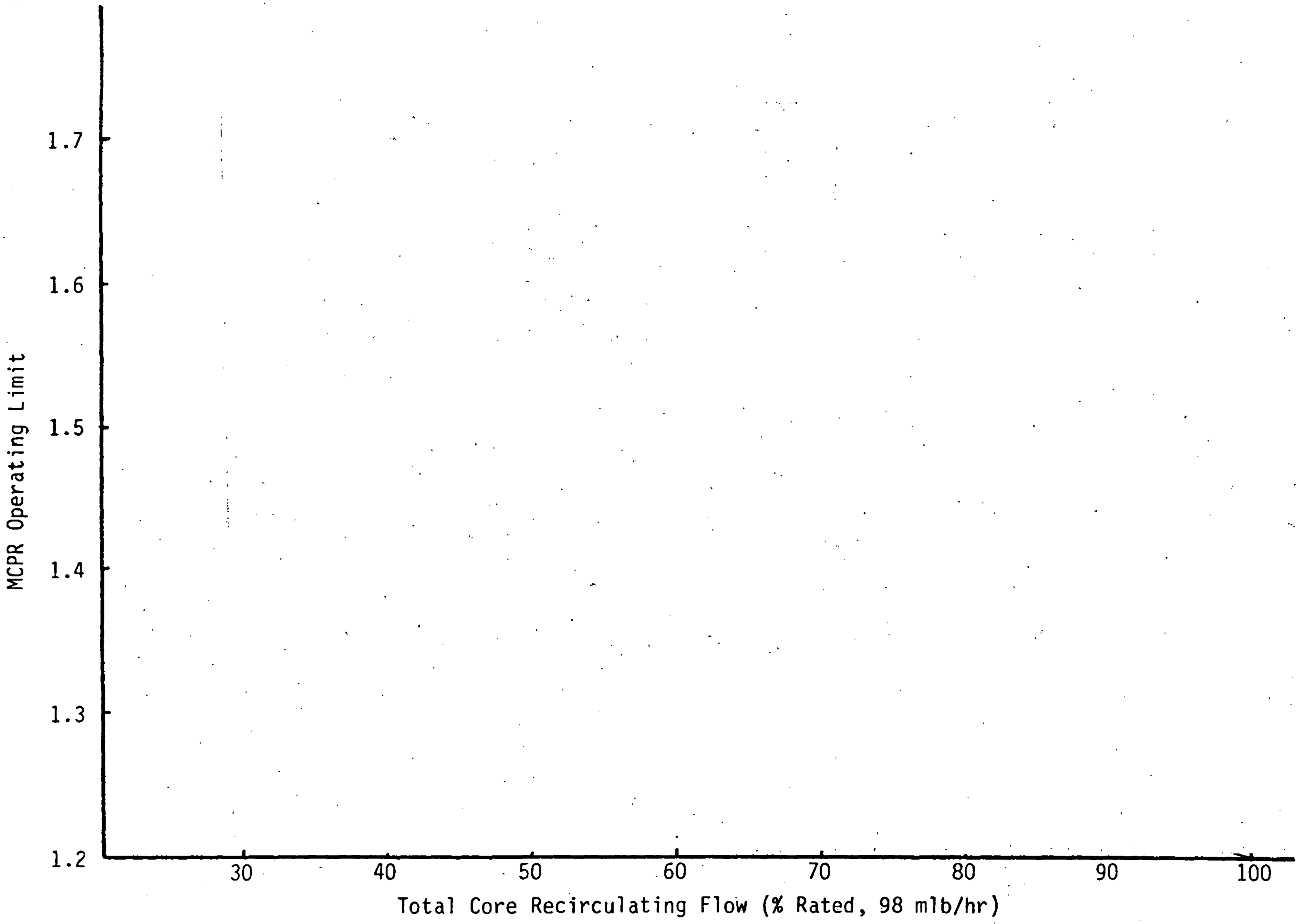

Figure 1.0 MCPR for Automatic Flow Control (AFC)

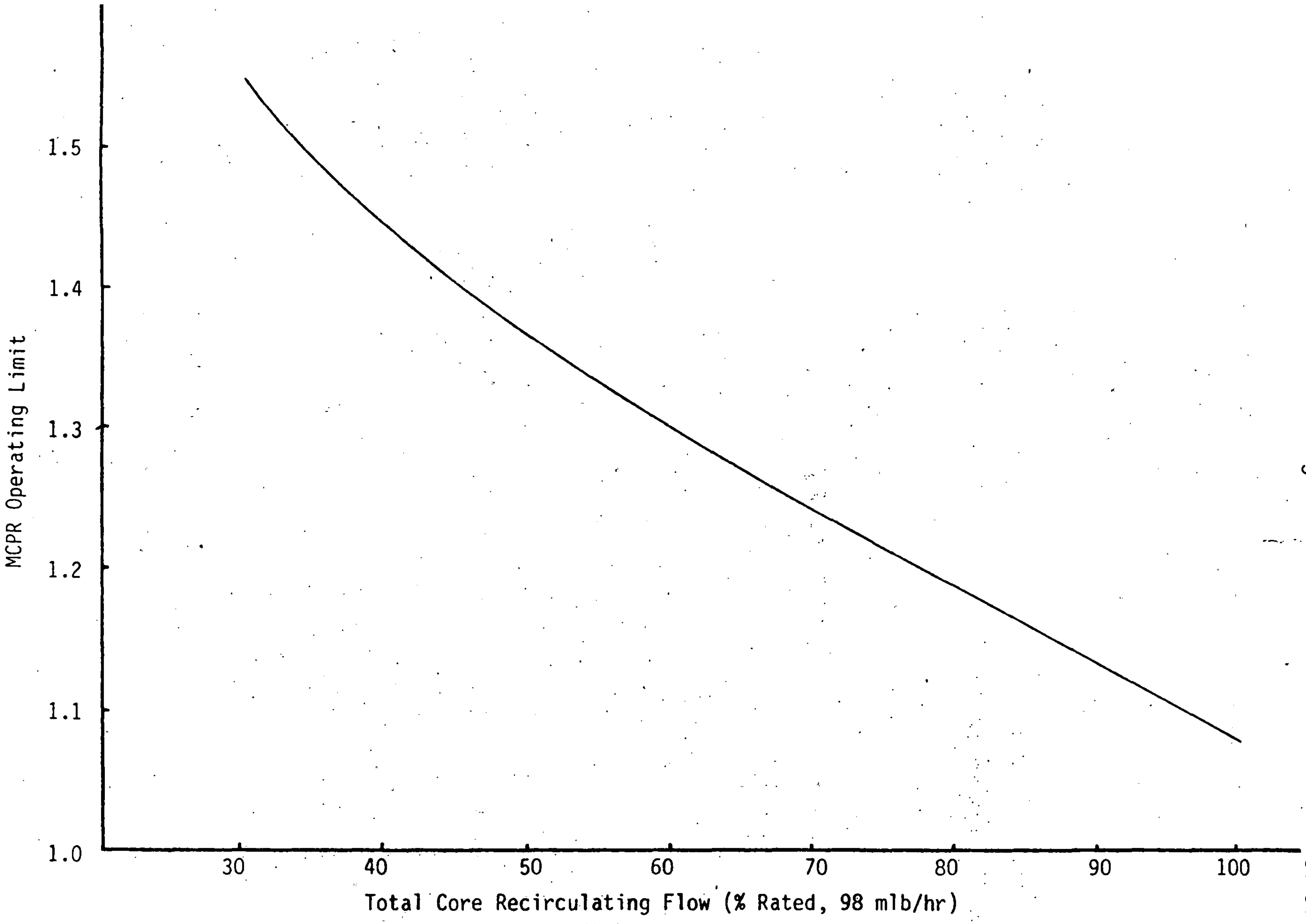

Figure 1.1 MCPR for All Conditions

2.0 EVALUATION AND RESULTS

Two considerations are made in the protection of fuel thermal margin during off-rated operations:

- assure that the reference(1) Minimum Critical Power Ratio (MCPR) established for normal operation at rated conditons is maintained during operation of the plant in the automatic flow control mode;
- assure that boiling transition conditions will be avoided following anticipated flow excursion transients

2.1 AUTOMATIC FLOW CONTROL (AFC)

If the reactor is operated in the AFC mode, variations in core power should not result in critical power ratios less than the established MCPR operating limit for rated conditions. If this MCPR limit is observed at an off-rated condition, a subsequent increase in power may result in inadvertent degradation of fuel critical power ratios to below this reference MCPR operating limit. The probability of boiling transition conditions occuring during a subsequent anticipated transient event may increase beyond acceptable levels if this is the case.

Exxon Nuclear Company has determined the required MCPR operating limit for off-rated conditions to prevent the MCPR from degrading below the Cycle 8 reference value [ ] during AFC operation. [

] The variations in total core power and flow follow their expected relationship for automatic flow control operations. The power distribution chosen was such that MCPR equaled the referenced MCPR [ ] at rated conditions of power and flow. The expected variation of core pressure and inlet coolant subcooling with reactor power level was also considered. This calculation was performed with ENC's thermal hydraulic subchannel model.(6)

Table 2.1 shows the reactor power and flow conditions used to generate the MCPR values. Figure 2.0 graphically depicts the MCPR requirements as a function of total core flow rate for various MCPR operating limits.

2.2 RECIRCULATION COOLANT PUMP FLOW EXCURSIONS

The reactor system at off-rated conditions of recirculation flow is subject to the same potential perturbations as a result of anticipated, but unplanned, equipment malfunctions as at rated conditions. Evaluations of transients from less than rated conditions indicate the severity of the impact on thermal margin is the largest at conditions involving full power and steam flow rate. In most cases, this is because the magnitude of the initiating perturbation is smaller at reduced power and flow. As an example, an isolation of the steam flow path at lower flow rates decelerates the steam velocity from normal velocity to a momentary zero value within the stroke of the isolating valve. At lower powers, the steam velocity is less than at higher powers. Hence, the magnitude of the perturbation caused by the sudden deceleration is less at part power. With the exception of pump flow excursions, evaluations have indicated that, within the range of anticipated operation, the thermal margin degradation during anticipated transients is greatest at maximum allowed power. Flow excursions include both feedwater runout and recirculation pump flow excursions. While the feedwater runout event has been considered, this report will discuss the transients found more limiting, i.e. recirculation pump flow excursions. As there are two recirculation pumps at the reactors of concern, the following analysis will be reported in two parts:

- single pump excursions
- two pump excursions.

2.2.1 Single Pump Excursions

A faulty signal at the speed controller of a recirculation coolant pump could lead to an overspeed of that unit to its maximum capacity. Due to variability of the fluid coupler response characteristics, the rate of pump speed might be variable. ENC has considered three cases:

- Scoop tube moves at the most rapid rate expected
- Scoop tube moves at an intermediate rate
- Scoop tube moves at a gradual rate.

The rapid rate case considers the largest expected power excursion which exceeds and is terminated by the overpower protection trip system. The intermediate case considers the closest approach to the overpower trip without an automatic power shutdown. The gradual rate case considers the situation in which there is no significant lag between power produced in the fuel and its transfer to the coolant.

A rapid power excursion associated with a relatively rapid sweeping of voids from the core by the increasing flow involves potential power distribution variations and control rod motion at critical transient times. [

] Also, initial reactor conditions were chosen which involve the highest expected initial power at the lowest expected initial pump speed and recirculation coolant flow rate. This was designed to anticipate the most reactive (highest void content) core condition and the greatest power excursion. Table 2.2 summarizes the initial conditions considered. Figures 2.1, 2.2, and Table 2.3 summarize the results of a single pump moving to its maximum possible speed in less than 4 seconds. Fuel rod [ ] thermal margin calculations [ ] predicted that the minimum CPR during the event was [ ] above the safety limit [ ] which is established for avoiding boiling transition.

[ ] The initial conditions considered are summarized in Table 2.4. For the intermediate case, the pump speed of a single unit changed [ ]. The maximum power [ ] For the gradual case, the same change in pump speed takes [ ] Generally, the power ascends smoothly to a new level with the clad heat flux maintaining an equivalent pace. While both cases tend toward a common steady state, the momentary excursion of power of the intermediate case results in a momentary clad surface heat flux level which exceeds that established later at the new steady state. The core inlet coolant enthalpy subcooling is less though as the new steady state becomes established. Table 2.5, and Figures 2.4 through 2.7, summarize these results.

2.2.2 Two Pump Excursions

A faulty signal originating in the master flow controller may lead to an unplanned increasing demand for flow simultaneously to both recirculation pumps. Due to the intentional design features of the control system, an error signal within the master controller would be attenuated substantially before being received at the individual pump speed controllers. Thus, the expected pump response to master controller originated demand signals are relatively gradual pump speed increases. In this case, the gradual speed increase results in power ascensions characterized by equivalent increases in clad surface heat flux. The evaluation of this event considered the same initial conditions as assumed for the gradual single pump excursion. An error signal was simulated in the master controller that increased demand. [ ] The overall response at the two pumps was a near linear increase of speed [ ] Core power, vessel pressure, and recirculation flow increase smoothly [ ] to a new level of near steady state. The results are shown in Table 2.6 and Figures 2.7 and 2.8. The results indicate that MCPR may decrease below [ ] the safety limit if the reference MCPR [ ] was observed at initial conditions.

2.2.3 MCPR Augmentation for Part Flow Operation

The evaluation of the two recirculation pump flow excursion suggests that establishment of MCPR limits for this event that prevent boiling transient will bound other events involving single pump failures. The evaluation of this event was performed to determine the maximum expected power increase for a given flow increase, but not necessarily the maximum flow. Thus, the void reactivity assumed was 25% more reactive than expected, and the Doppler reactivity assumed was 10% less than expected. This calculated relationship is graphically displayed in Figure 2.9 compared with the expected flow control line for equilibrium zenon, and both are extrapolated to a maximum anticipated core flow at maximum pump speed. The results of the calculation also provide an expected relationship for core pressure and inlet subcooling as shown on Figure 2.10. Using this information, the required operating MCPR to prevent the safety limit [ ] from being exceeded during the pump speed increase was calculated. This was performed in the same manner as described in Section 2.1. [

] Figure 2.11 summarizes the MCPR required. [

]

Table 2.1 Automatic Flow Control MCPR

Recirculating Flow (% of Rated, 98 mlb/hr)	Power (% of rated, 2527 MWt)	MCPR		
		Case 1	Case 2	Case 3
100				
90				
80				
70				
60				
50				
40				

Table 2.2 Initial Conditions Rapid Single Pump Excursion

Reactor Power (Mwt)	1703.2
Total Core Flow (mlb/hr)	[ ]
Core Pressure (psia)	992.5
Core Inlet Enthalpy (BTU/lbm)	505.0
Steam Flow Rate (mlb/hr)	6.76
Feedwater Enthalpy (BTU/lbm)	331.7
Core Active Flow (mlb/hr)	36.46
Turbine Emission Pressure (psia)	965.0
Initial Pump Speed (% of rated)	30%
MCPR (Initial)	[ ]

Table 2.3 Rapid Single Pump Excursion - Results

Peak Power (% rated)	169%
Maximum Vessel Pressure (psia)	1034
Maximum Steam Line Pressure (psia)	987
Maximum Clad Surface Heat Flux (% of Initial Core Average)	[ ]
MCPR (Transient)	[ ]
Peak Power by Axial Segment (% Initial)	
Bottom	[
2nd	
3rd	
Top	]

Table 2.4 Initial Conditions, Intermediate and Gradual Single Pump Excursion

Reactor Power Level (MWt)	1465.7
Total Core Flow (mlb/hr)	[ ]
Core Pressure (psia)	985
Core Inlet Enthalpy (BTU/lbm)	507.7
Steam Flow Rate (mlb/hr)	5.68
Feedwater Enthalpy (BTU/lbm)	311.5
Core Active Flow (mlb/hr)	37.08
Turbine Emission Pressure (psia)	965.0
Initial Pump Speed (% of rated)	30%
MCPR	[ ]

Table 2.5 Results for Intermediate and Gradual Single Pump Excursion

	Intermediate	Gradual
Maximum Power (% rated)		
Final Power (100 seconds after pump speed change, % rated)		
Maximum Heat Flux (% rated)		
Final Heat Flux (100 sec, % rated)		
Active Core Flow Rate (Average, mlb/hr)		
At Max. heat flux		
At 100 seconds		
Core Inlet Enthalpy (BTU/lbm)		
At Max. heat flux		
At 100 seconds		
Maximum for transient		
Core Exit Pressure (psia)		
Maximum		
At Max. heat flux		
At 100 seconds		
MCPR		

Table 2.6 Results for Two Pump Flow Excursion

Maximum Power (% Rated)	
Final Power (200 seconds after pump speed change, % rated)	
Maximum Heat Flux (% rated)	
Final Heat Flux (200 seconds, % rated)	
Active Core Flow Rate (Average, mlb/hr)	
At Max. Heat Flux	
At 200 seconds	
Core Inlet Enthalpy (BTU/lbm)	
At Max. Heat Flux	
At 200 seconds	
Maximum for Transient	
Core Exit Pressure (psia)	
Maximum	
At Max. Heat Flux	
At 200 seconds	
MCPR	

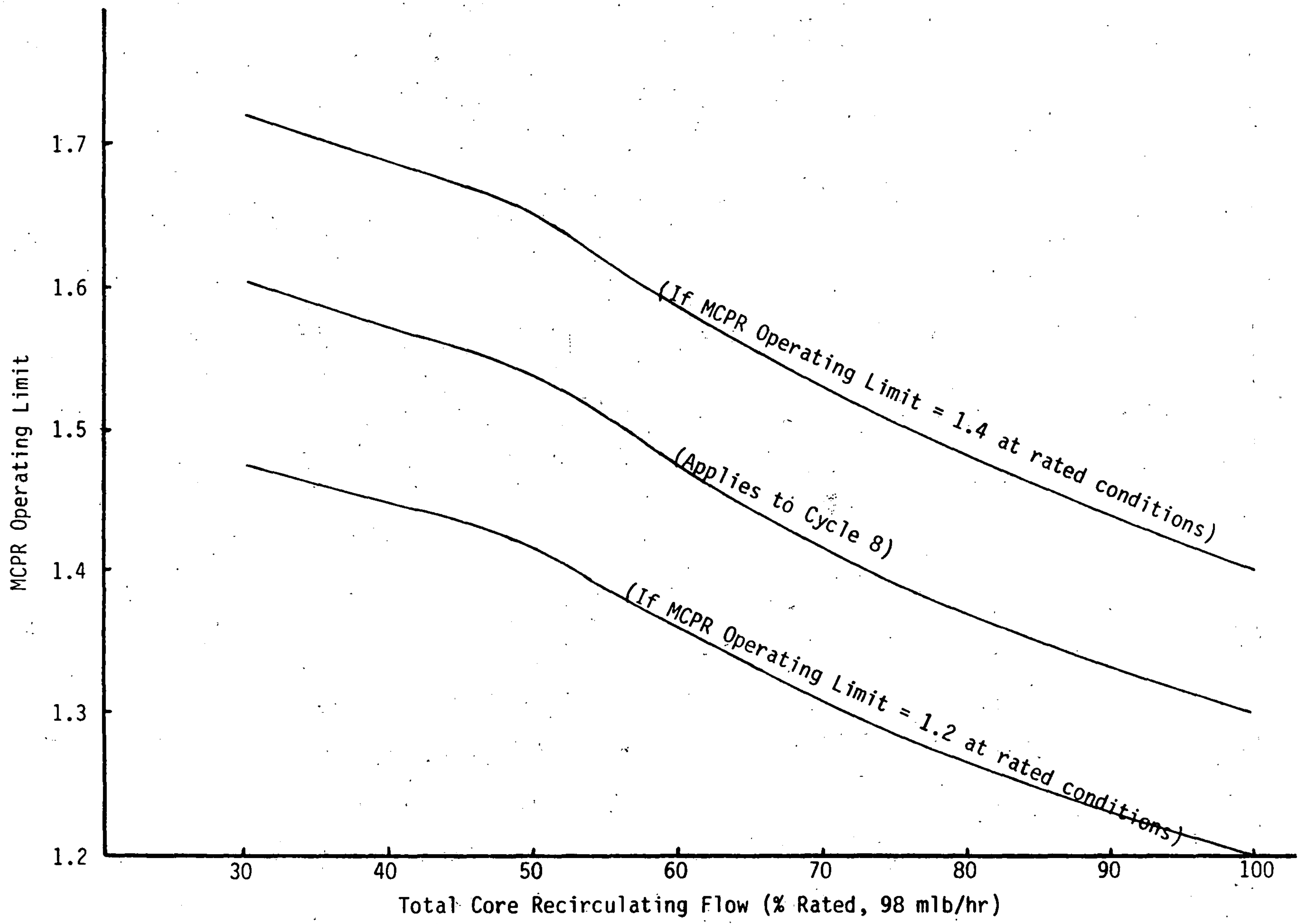

Figure 2.0 MCPR for Automatic Flow Control (AFC)

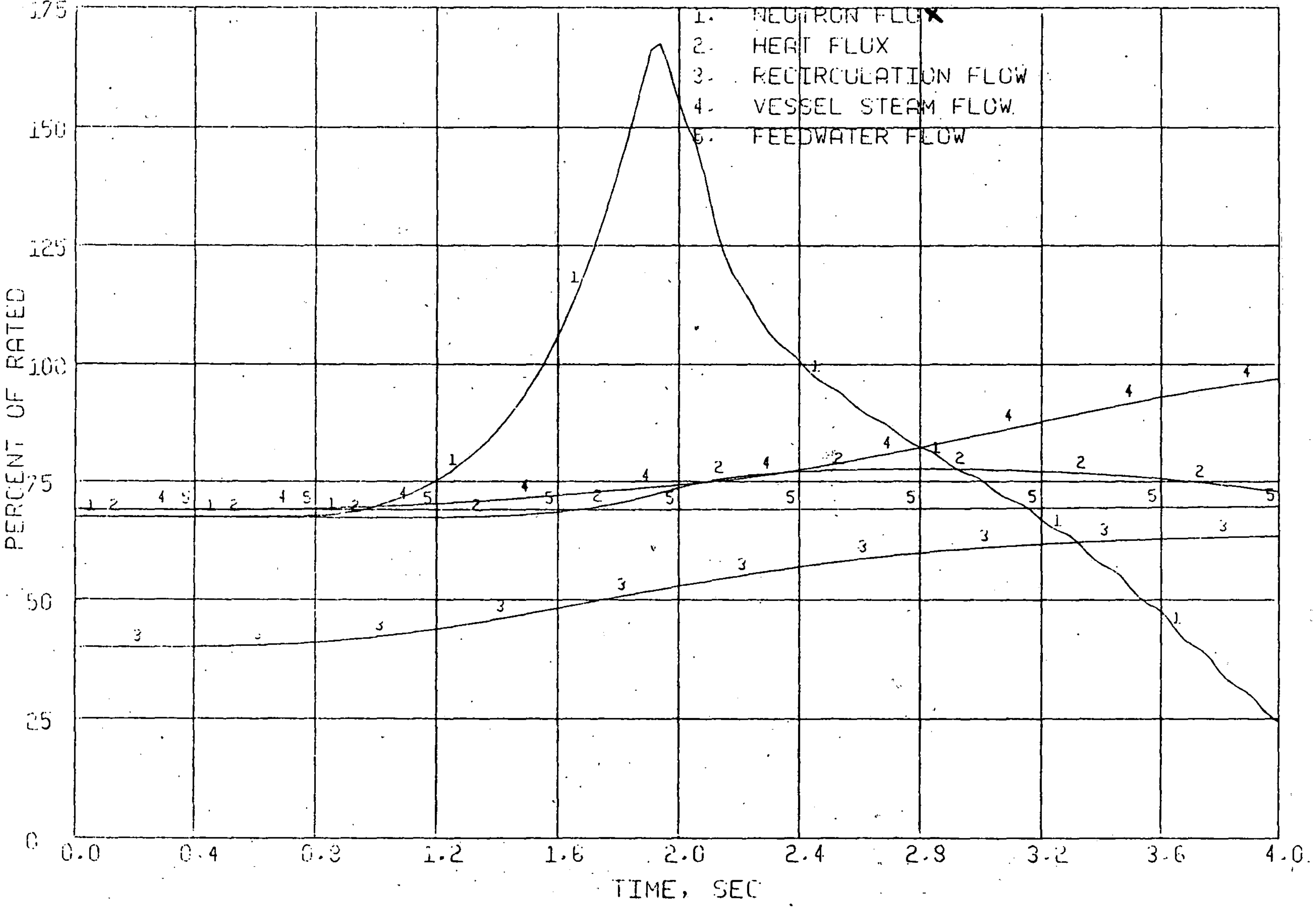

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Figure 2.1 Speed Controller Failure (to Maximum Demand)

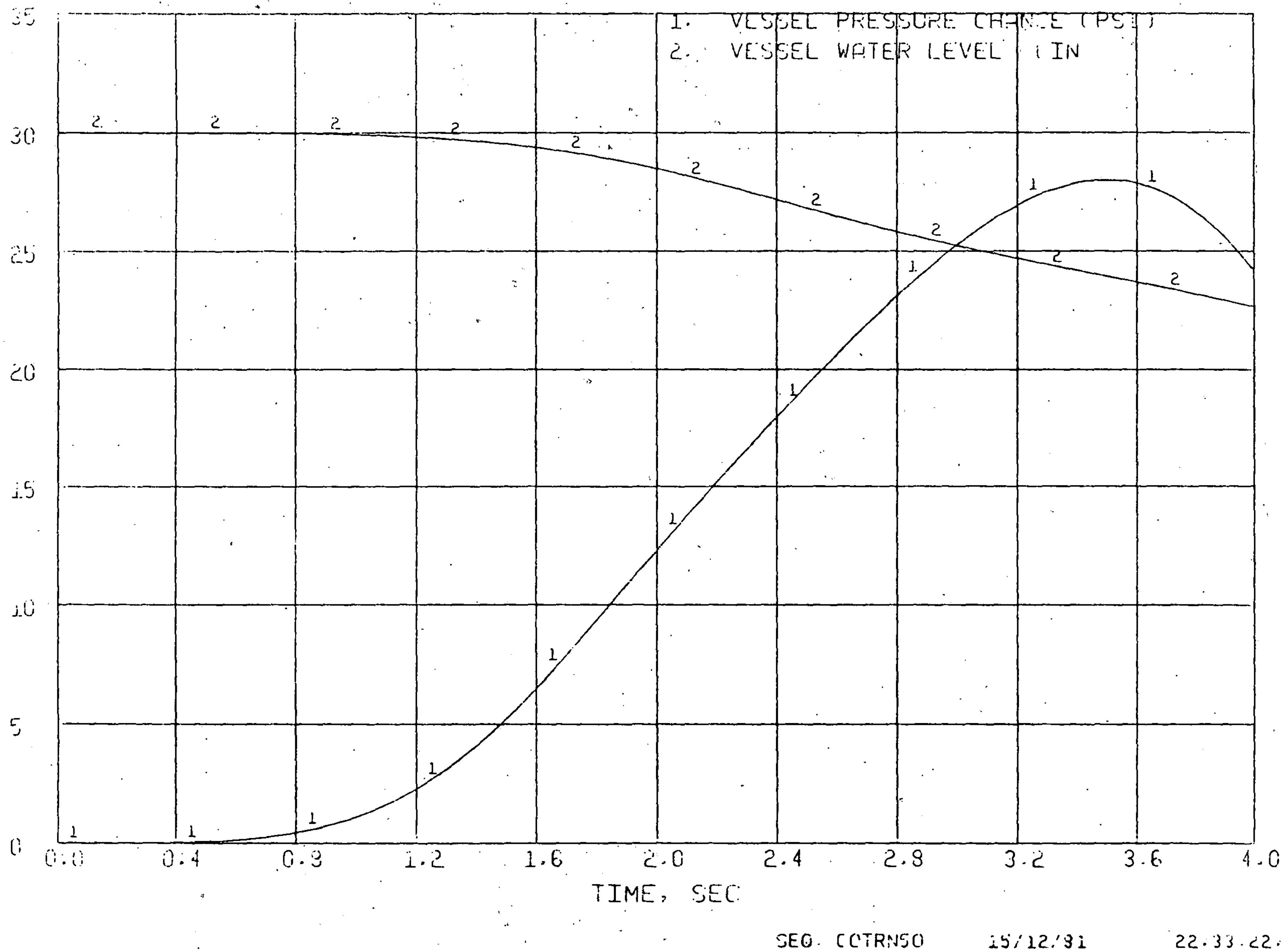

Figure 2.2 Speed Controller Failure (to Maximum Demand)

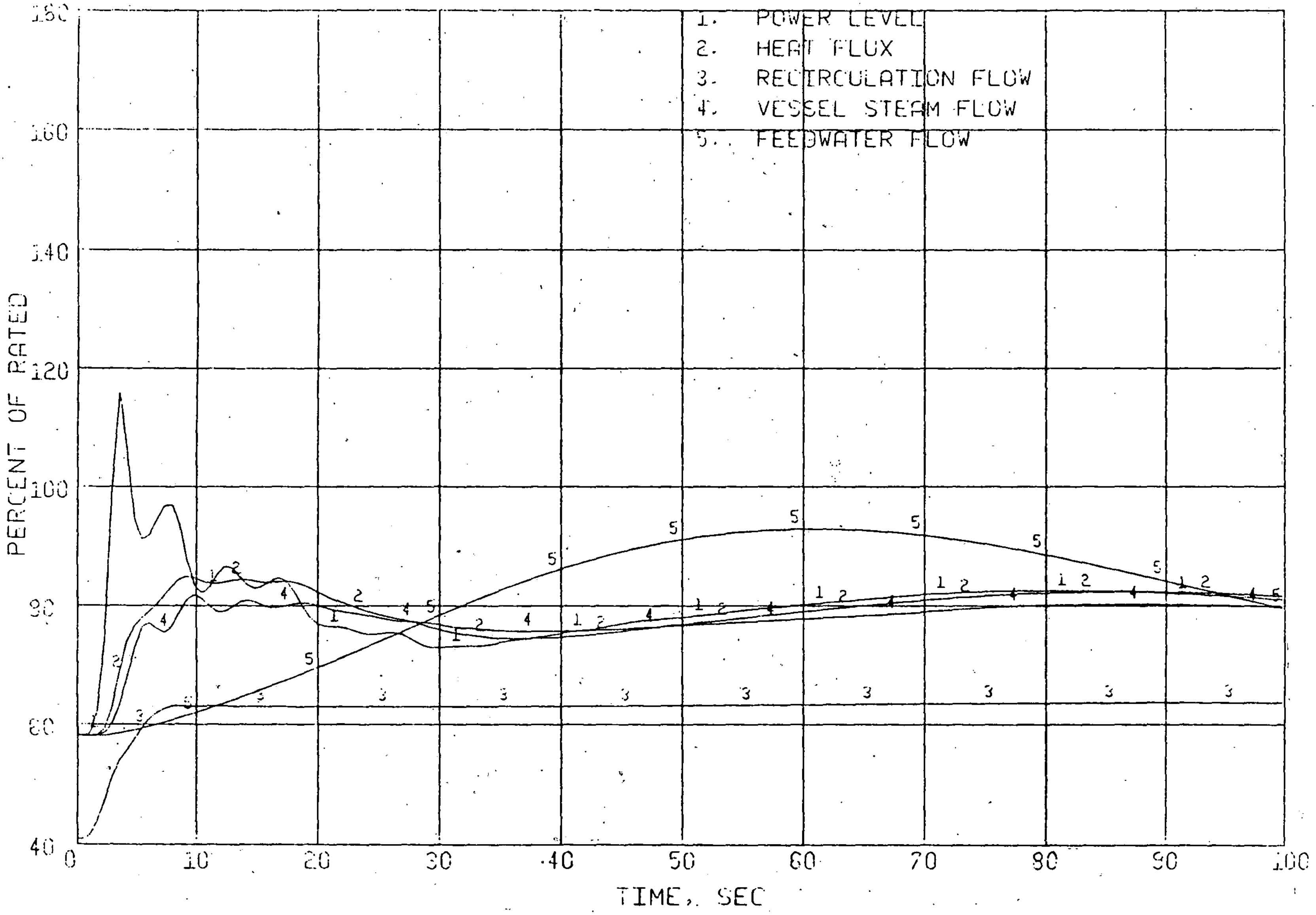

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Figure 2.3 Speed Controller Failure to Maximum Demand (Intermediate)

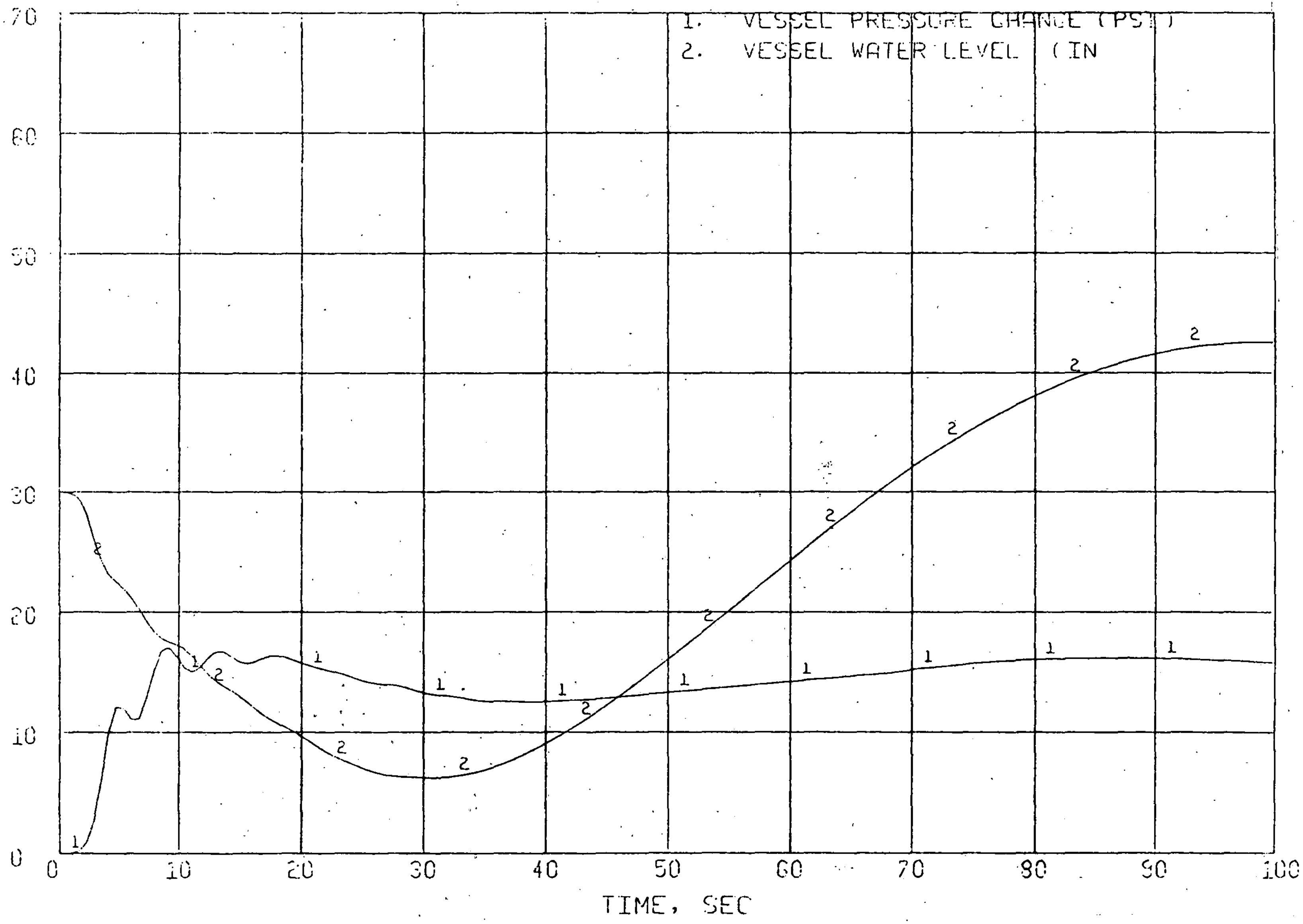

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Figure 2.4 Speed Controller Failure to Maximum Demand (Intermediate)

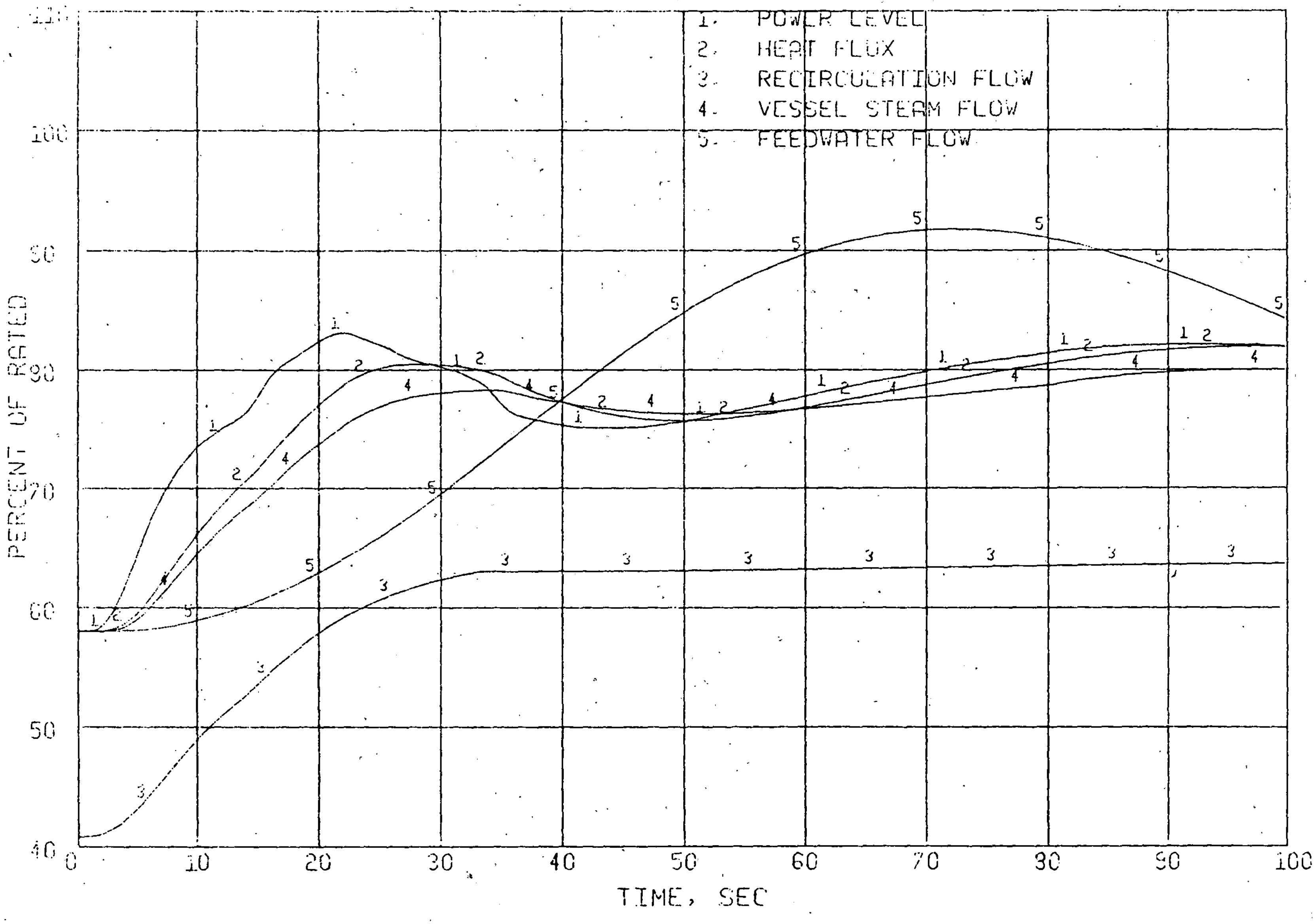

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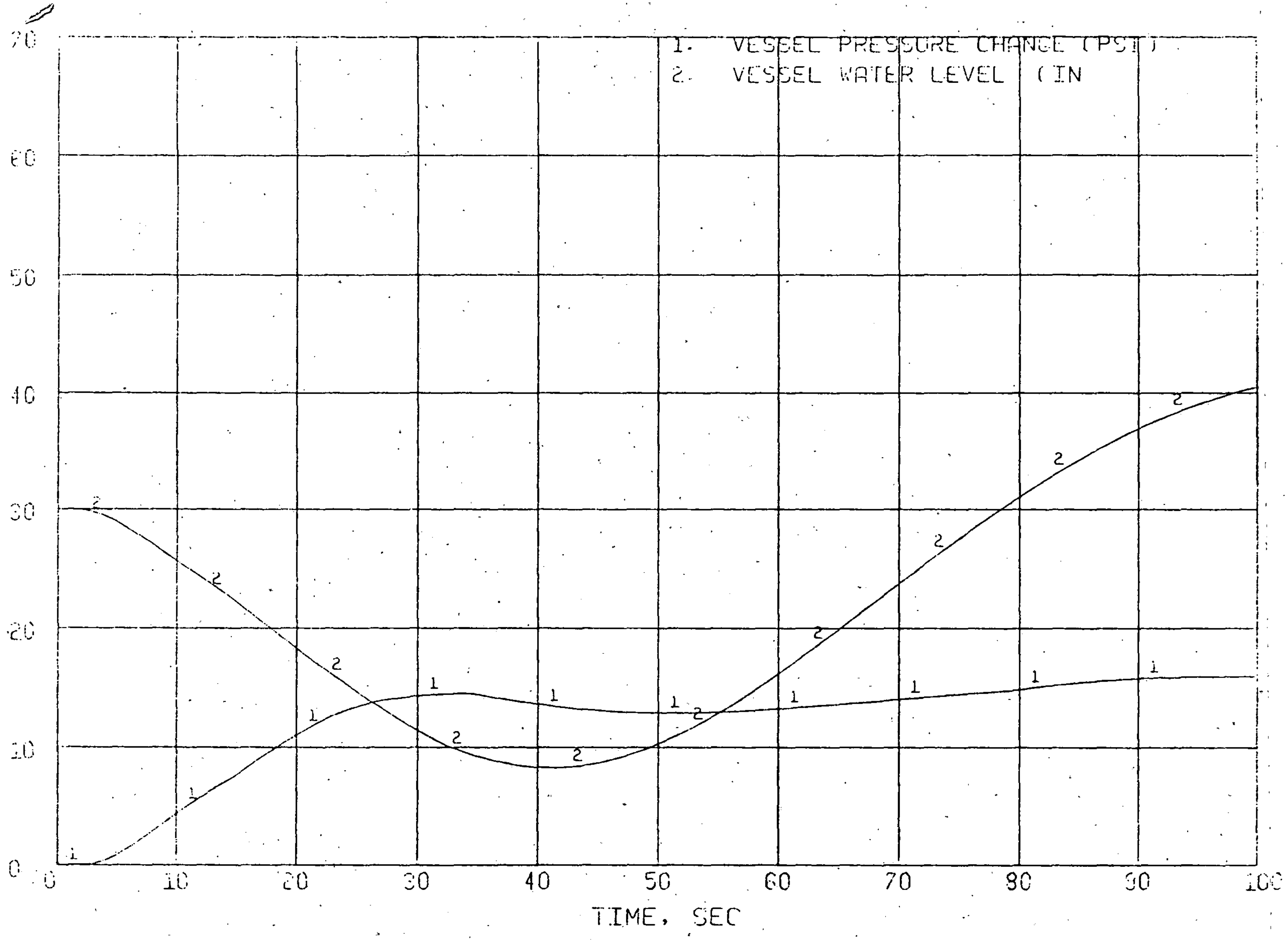
Figure 2.5 Speed Controller Failure to Maximum Demand (Gradual)



SEQ. D3CY8ST 16/12/81 23.30.16.

Figure 2.6 Speed Controller Failure to Maximum Demand (Gradual)

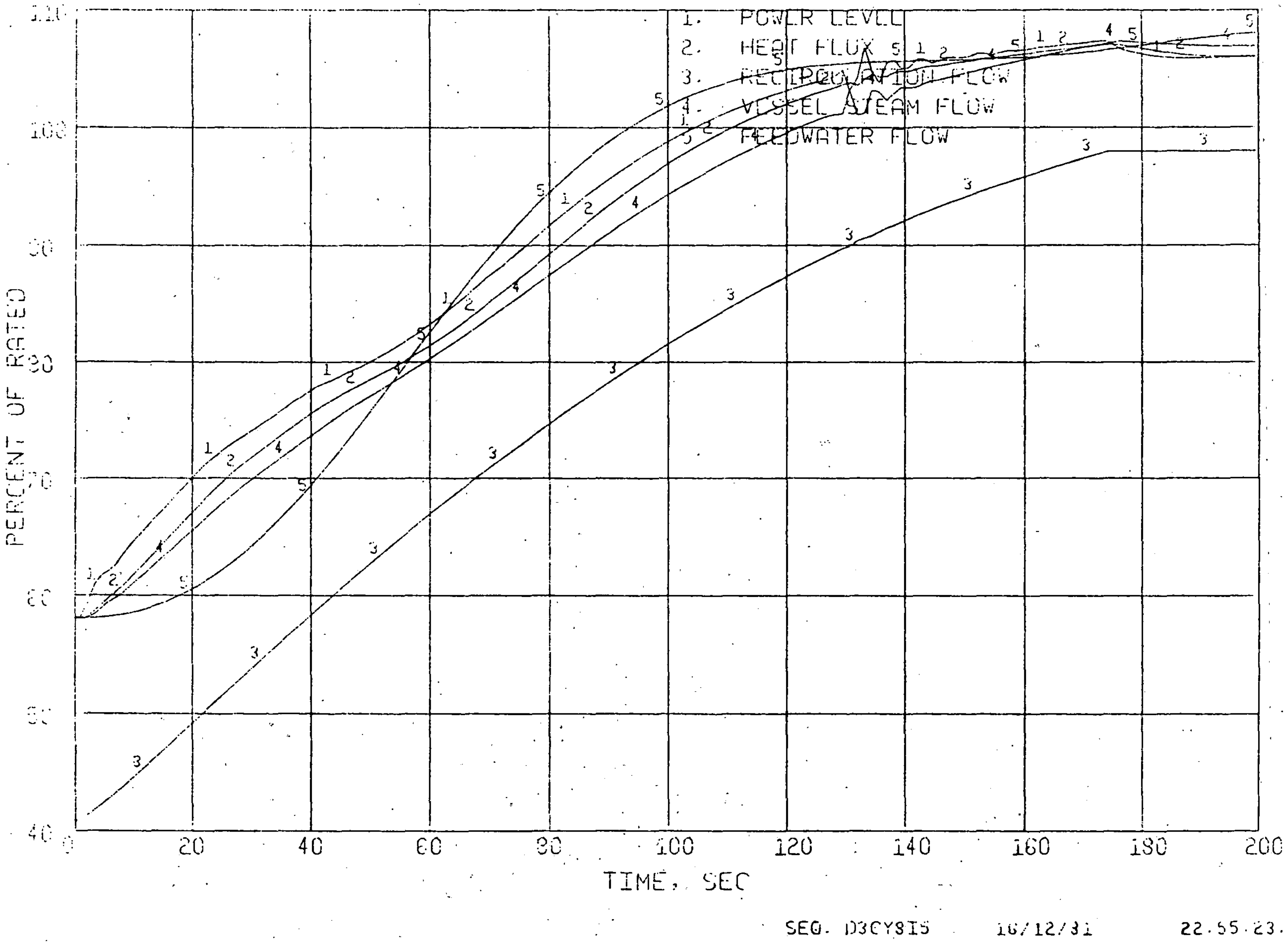
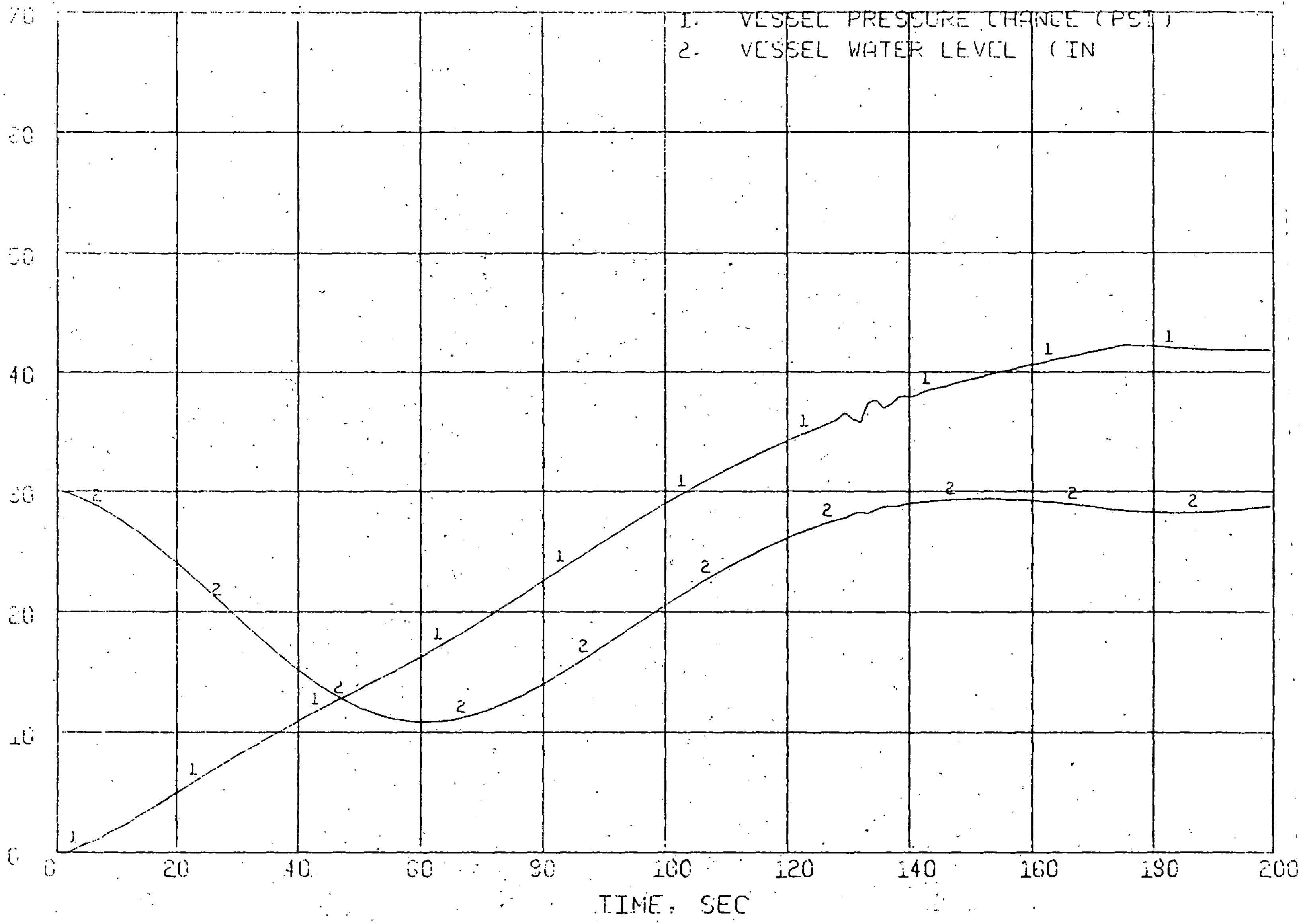


Figure 2.7 Master Flow Controller Failure to Maximum Demand



SEQ. D3CY8I5 16/12/81 22.55.23.

Figure 2.8 Master Flow Controller Failure to Maximum Demand

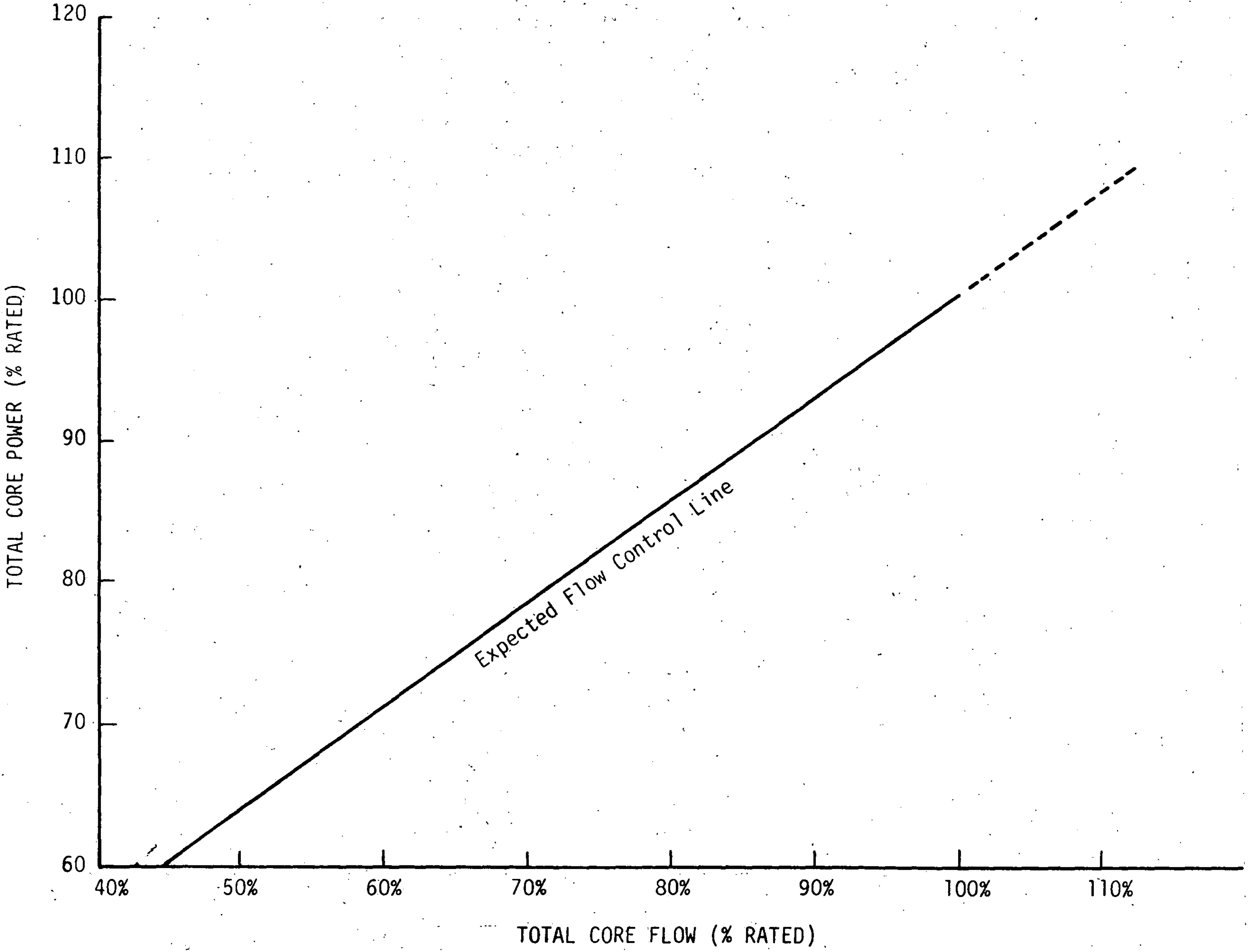


Figure 2.9 Expected [ ] Power/Flow

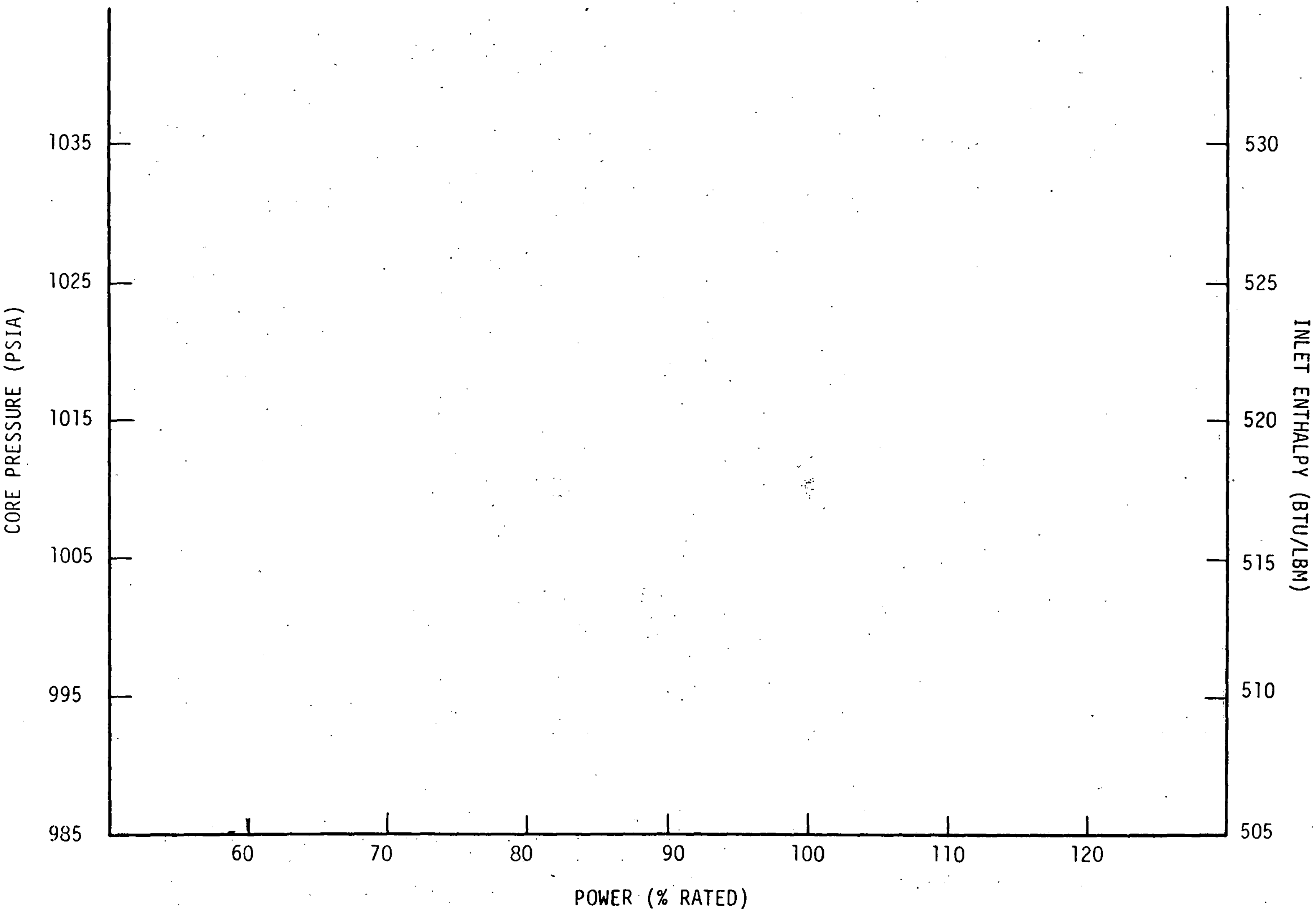


Figure 2.10 Core Pressure and Coolant Enthalpy

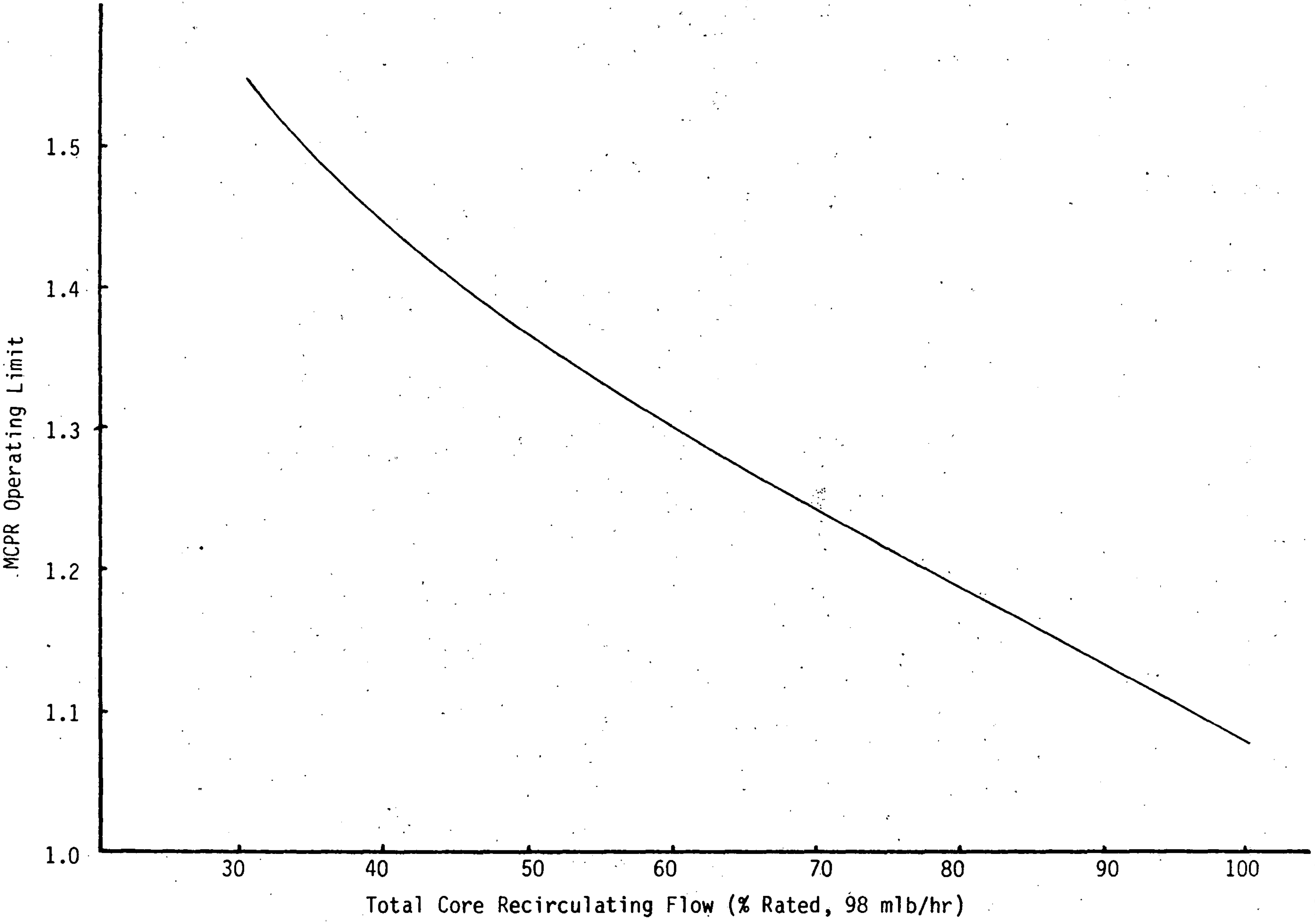


Figure 2.11 MCPR for All Conditions

3.0 REFERENCES

(1) G.C. Cooke et. al., "Dresden Unit 3 Cycle 8 Plant Transient Analysis Report", XN-NF-81-78, Rev. 1, December 1981.

(2) J.C. Chandler, "Dresden Unit 3 Cycle 8 Reload Analysis", XN-NF-81-76, Rev. 1, December 1981.

(3) G.C. Cooke and R.H. Kelley, "Exxon Nuclear Plant Transient Methodology for Boiling Water Reactors", XN-NF-79-71(P), Rev. 2, November 1981.

(4) [ ]

(5) [ ]

(6) [ ]

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Distribution

G. C. Cooke
R. H. Kelley
G. F. Owsley

L. C. O'Malley/Edison (60)

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