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## BOTTLED-UP OPERATION OF A BWR

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**ABSTRACT**

*"Bottled-up" operation of a BWR refers to that condition where the main steam isolation valves (MSIVs) are closed, thus preventing any significant steam flow. Historically, there has been a reactor scram condition if vessel pressure rises above 600 psig with the MSIVs closed and with the mode switch in "startup." This document describes the results of a special test conceived and performed on a typical BWR/4 design to determine the necessity of this plant scram function. It is concluded that the pressure scram function can be raised, so that bottled-up hot standby operation is permitted up to full pressure and temperature conditions.*

## 1. INTRODUCTION

Bottled-up operation became an identified topic at an early dual-cycle reactor startup. During heatup, with the main steam isolation valves (MSIVs) closed and pressure at about 600 psi, the operator experienced difficulty in controlling power. The phenomenon was observed as follows: After notching a control rod out, pressure would begin to increase, as would power. There appeared to be no leveling-out tendency, so the rod (or rods) was partially inserted to stop the rise. Pressure and power would then level off and start to fall, as if overcorrected. Rods were then partially withdrawn to stop the fall of pressure and power. Again, as if overcorrected, pressure and power would rise, showing no sign of leveling off. This continued until it was suggested that bypassing steam to gain pressure control (and thus hold void reactivity constant) might stabilize the plant. This method proved to be effective, pressure control was subsequently recommended for use during startup. In addition, scram logic was added to prohibit operation above 600 psi with the MSIVs closed.

Experience on later plant startups indicates that the early experience may not be inherent to the BWR design. In fact, it is reported that heatup is commonly accomplished with the MSIVs open, but with no flow through the turbine bypass valves. In this case, the pressure regulator pressure setpoint is kept above the operating pressure. Thus, steam flow is limited to seal steam, steam to the steam jet air ejectors plus losses. This is very close to the bottled-up condition (MSIVs closed), and leads us to question the possibility of stable operation with the MSIVs closed.

## 2. BOTTLED-UP OPERATION SPECIAL TEST

To demonstrate whatever capability a contemporary BWR might have to operate in the bottled-up condition, a special test was added to the startup test program at Browns Ferry Unit 1, a plant judged to be a typical BWR/4 design. A copy of the procedure used at BF-1 may be found in Appendix A. Data from the test were taken in two basic blocks: reactivity perturbations and pressure perturbations.

Figures 1 through 8 show data taken by the Startup Test Design and Analysis Unit during the reactivity perturbation tests. These traces show no signs of possible instability or generally unpredictable behavior. The maneuvers demonstrated in the figures were performed with MSIVs closed, reactor power at about 0.3%, dome pressure at about 920 psig, and recirculation pumps at minimum speed.

Figure 1 shows reactor wide range pressure as the rods were inserted to drop the pressure to approximately 650 psig, then withdrawn to increase pressure again to approximately 920 psig in about 20 minutes.

Figures 2 and 3 are IRM traces which show only relative power changes. Sudden jumps in the traces on the order of an inch are due to changing the instrument range to keep them on scale.

Figure 4 was taken during the heatup ramp, and Figures 5 through 8 were taken at 920 psig while Control Rod 34-27 was being inserted, withdrawn and scrammed. All traces are broad due to noise, which is common. The APRM and LPRM traces show an amplitude modulated characteristic which is also due to noise.

The pressure perturbation tests were run with the MSIVs open to allow the use of the bypass valves to disturb pressure. The auxiliary boiler was used to supply seal steam and steam to the steam jet air ejectors plus any other losses. In this manner, vessel steam flow was kept at near zero (about 0.25%). Thus, the only effective difference between MSIV open and MSIV closed was the added steam line volume between the MSIVs and the bypass valves. The effect of this extra volume on low power stability is judged to be negligible. Other reactor conditions were the same as for the reactivity perturbations. The pressure perturbation of primary interest is the first one (Figure 9), where one bypass valve is opened quickly (about 0.1 sec), held for a short time (about 15 sec) and closed rapidly (about 0.1 sec). The time of primary importance to the question addressed by the test is that following reclosure of the bypass valves (the bottled-up condition). The traces show that, following the disturbance caused by opening the bypass valves, all parameters return to steady-state values and are well-behaved.



Several events occur during the time that the bypass valve is open in the fast open-fast close event. As soon as the valve is opened, turbine inlet pressure goes through a small oscillation of about 5 psi in magnitude and 1.6 Hz — a hint of possible steam line resonance. After about 0.4 seconds delay (propagation time for the pressure wave in the steam line), the dome pressure begins to drop off, which causes a large inventory density change due to the near-saturated condition of the vessel water at the operating point; this results in the level swell shown. About 3 seconds after dome pressure begins to fall (it has dropped about 16 psi), core flow begins to fall off, suggesting the start of boiling in the channels. This is followed by an oscillation of about 0.36 Hz in pressure and core flow which suggests a "chugging" effect, or thermal hydraulic oscillation. The two cycles before the bypass valves close decay by a factor of about 0.7, and are not considered a detriment to stable control of the plant at this power.

Figure 10 is a trace showing the results of slowly opening and closing two bypass valves. Once again, pressure drops and level swells as the valves are opened, and return to normal when the valves are closed.

Figure 11 is an IRM trace showing response to the two bypass valve transients.

Figure 12 is a process chart showing narrow range water level response to the transients.

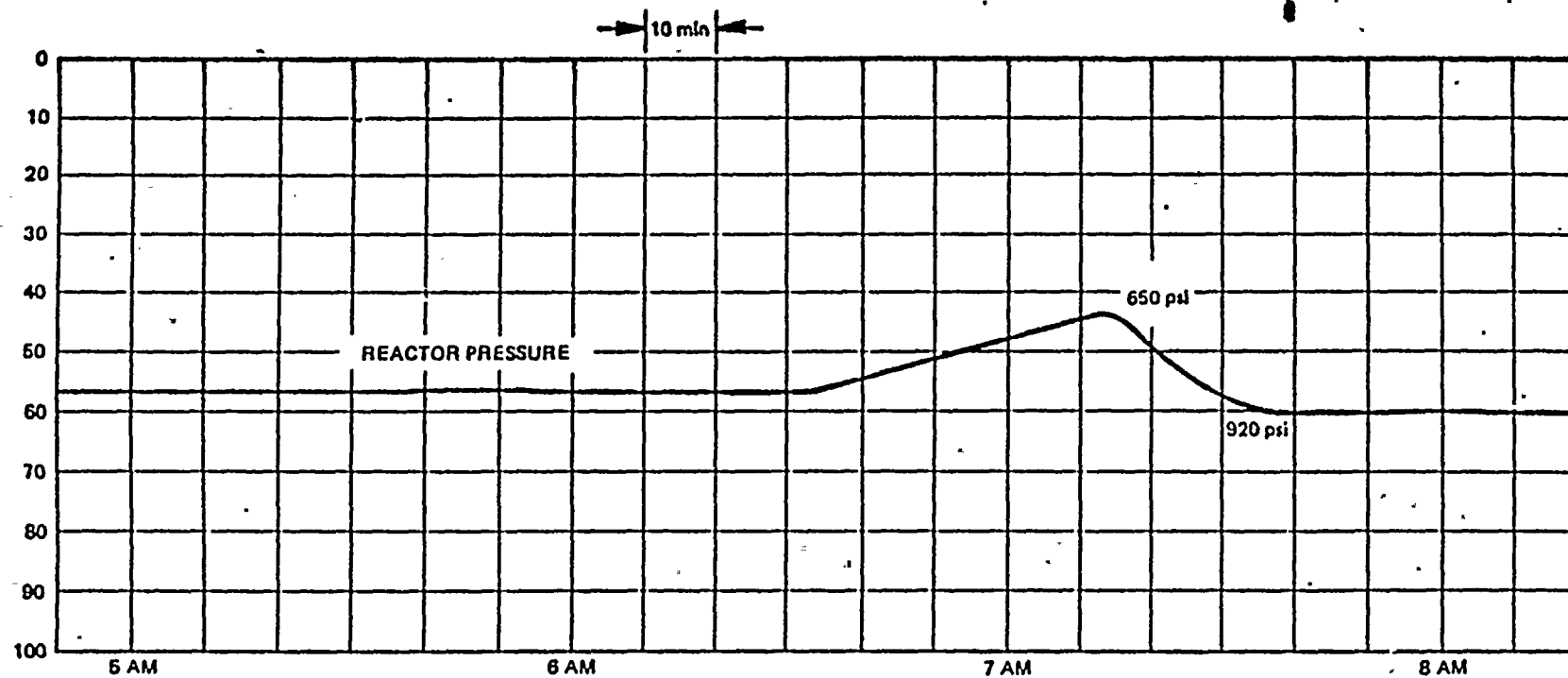
### 3. CONCLUSIONS

The data taken at the Browns Ferry 1 site indicate that BF-1 can be controlled adequately in the bottled-up condition at pressures well in excess of 600 psig. Thus, there is no reason to assume an unacceptable operating region and scram the reactor when vessel pressure exceeds 600 psig with the MSIVs closed. In fact, on the Browns Ferry 1 plant, the scram set point may be set to coincide with the Technical Specification high vessel pressure scram set point with no apparent BWR stability problem.

Browns Ferry is a typical BWR/4 design; therefore, the result of the test at BF-1 may be extended to cover all BWR/4 product line projects.

A test procedure similar to the one found in the Appendix will be performed at each future "first-of-a-product-line" plant during startup testing to verify continued capability for bottled-up operation. Because of its design-unique nature, each pre-BWR/4 product must be considered on an individual basis to determine bottled-up operating capability by a similar test procedure. Thus, no generic BWR/1, 2 or 3 bottled-up operation permission is, or will be, available.





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Figure 1. Bottled-Up Pressure Maneuver Using Control Rods



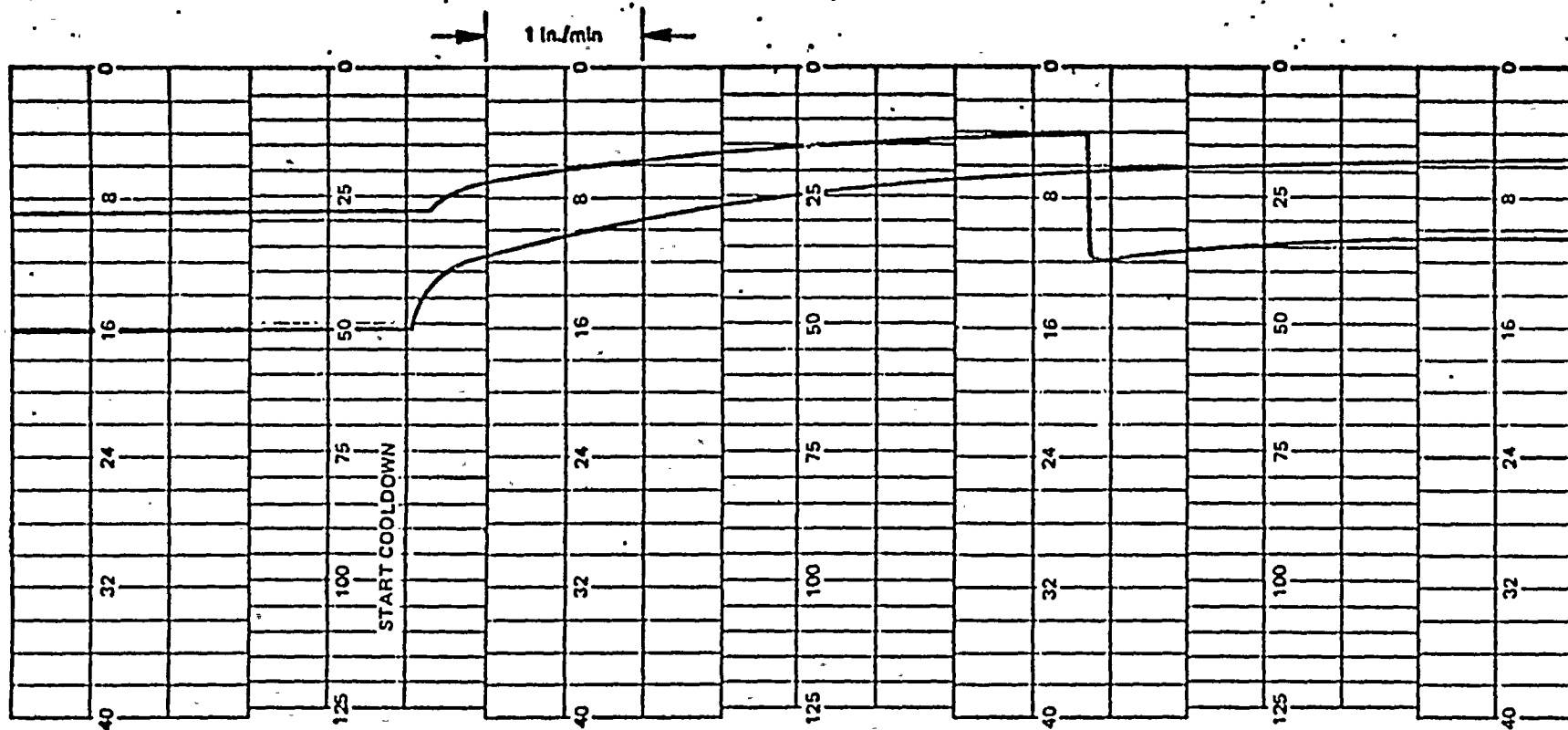


Figure 2. IRM Traces of a Bottled-Up Control Rod Maneuver (Insert)





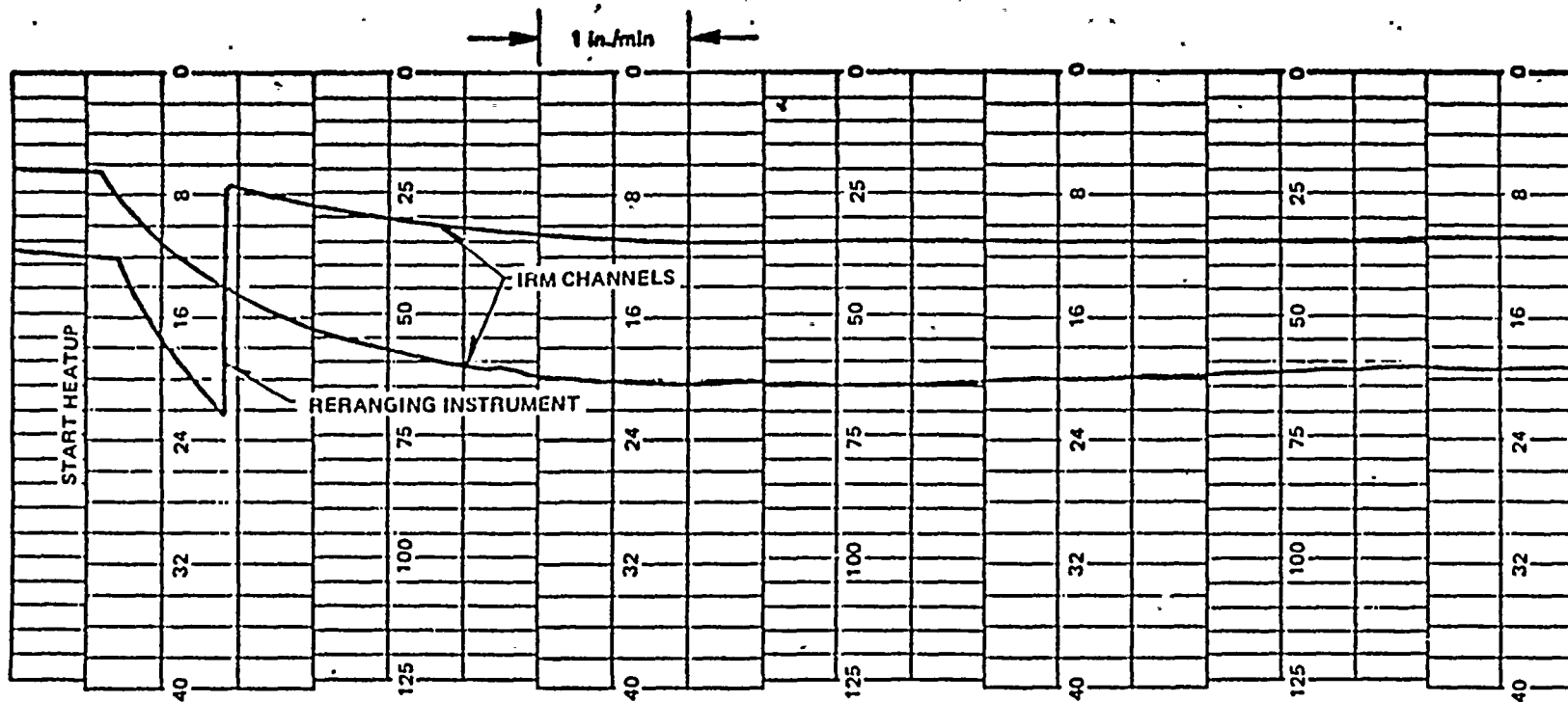


Figure 3. IRM Traces of a Bottled-Up Control Rod Maneuver (Withdraw)



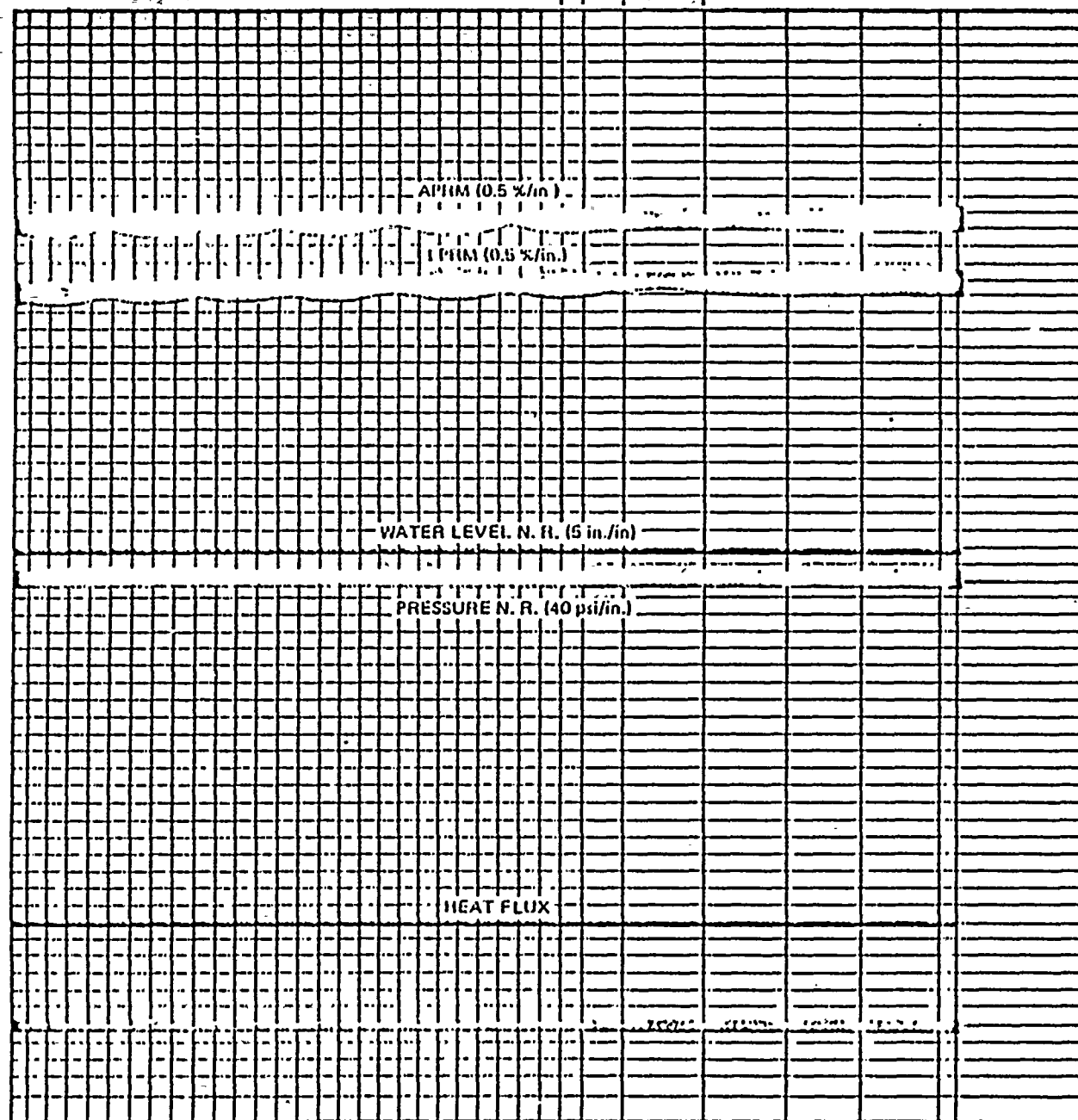


Figure 4. Parameter Behavior During Heatup Ramp



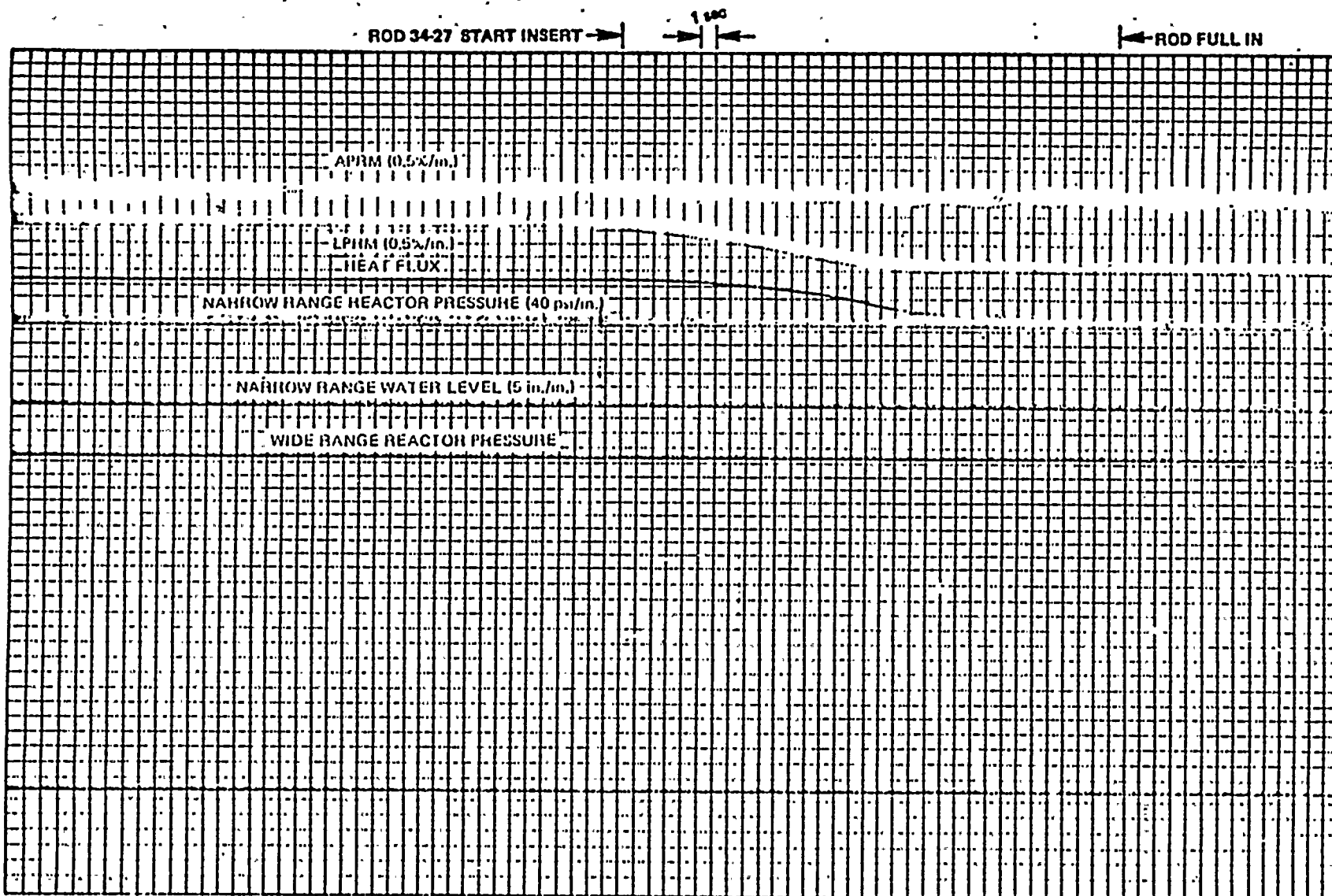


Figure 5. Control Rod Insertion



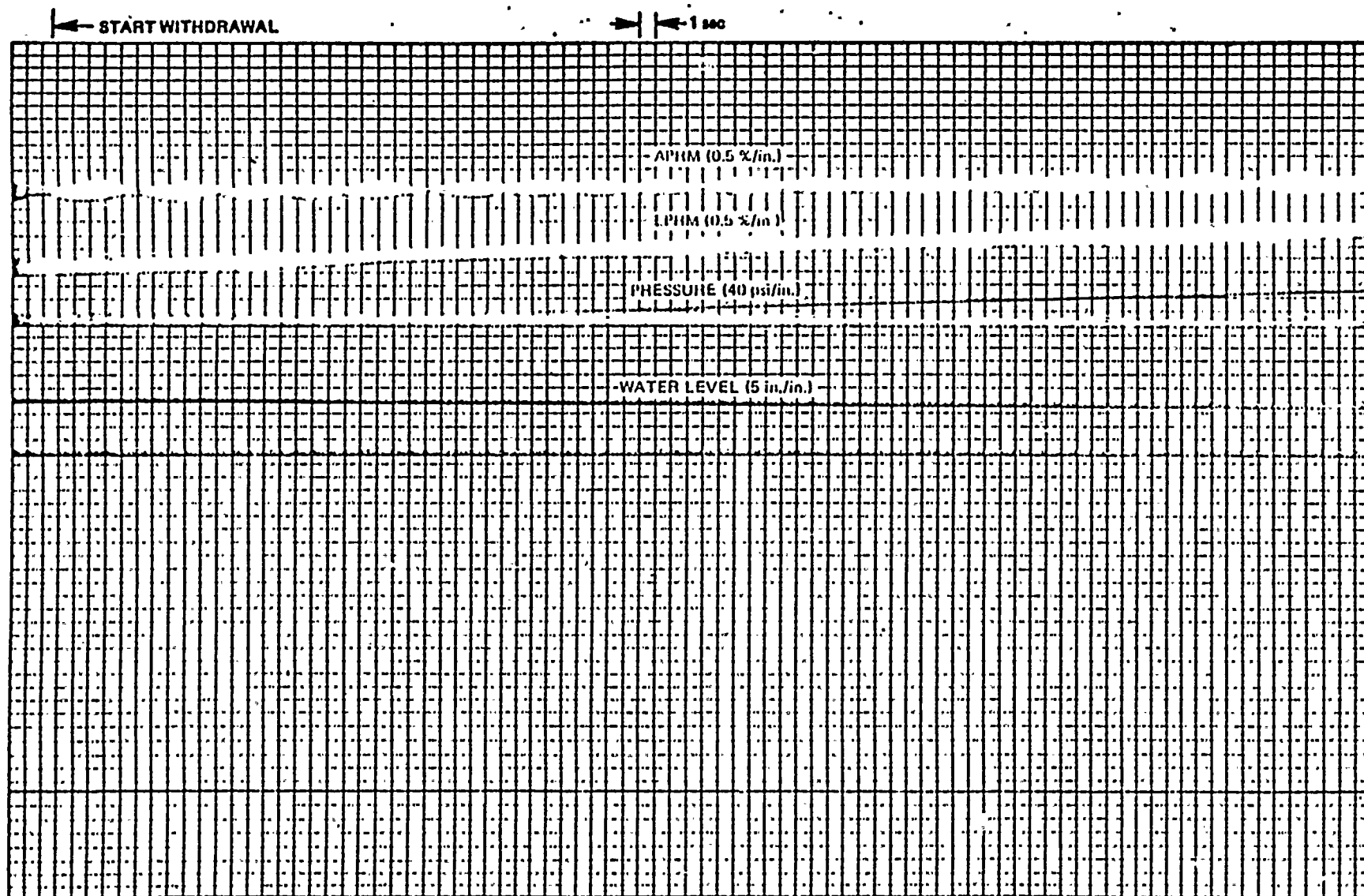
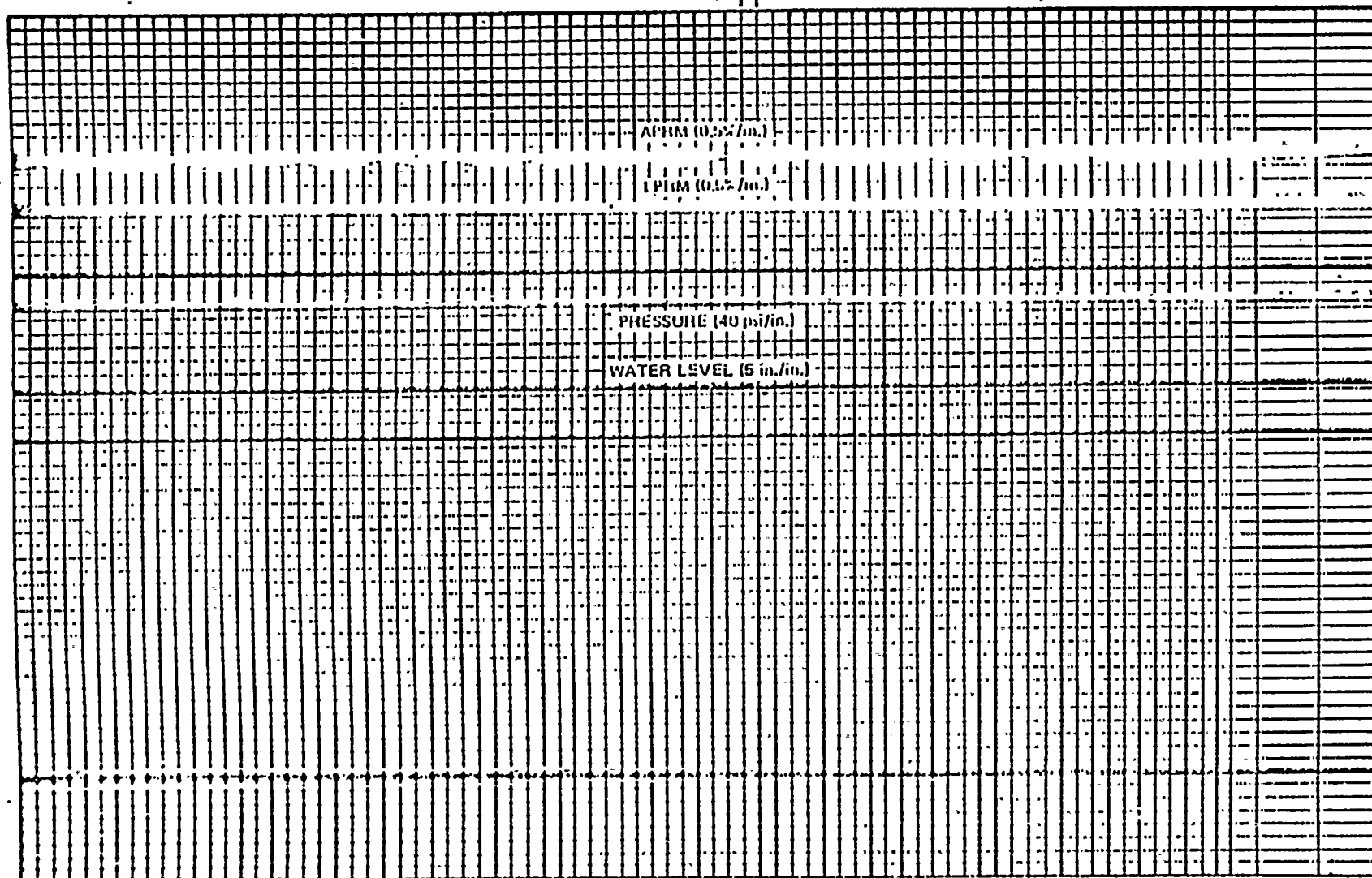


Figure 6. Control Rod Withdrawal





1 sec



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Figure 7. Control Rod Withdrawal



1 sec

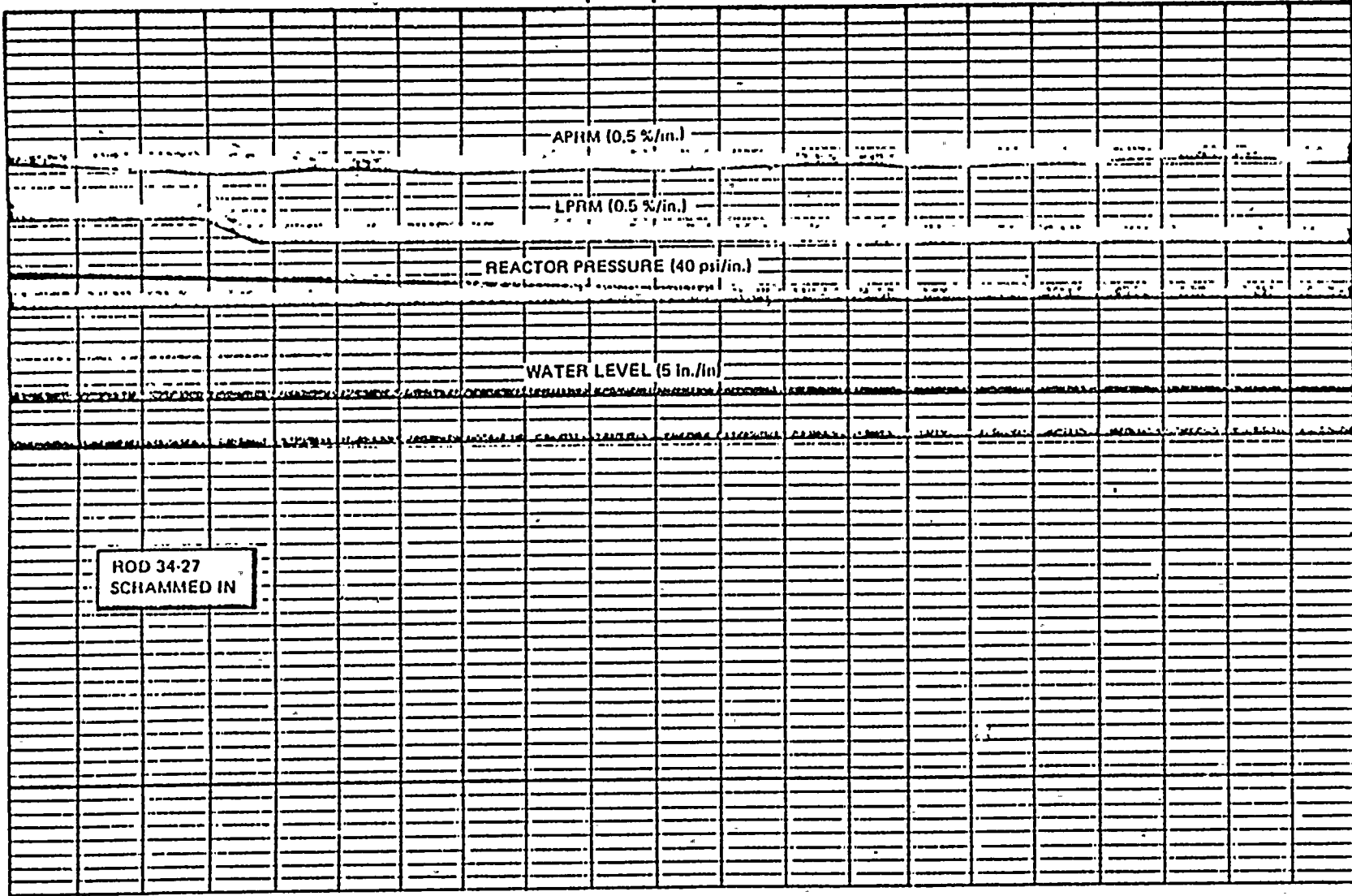


Figure 8. Control Rod 34-27 Scrammed



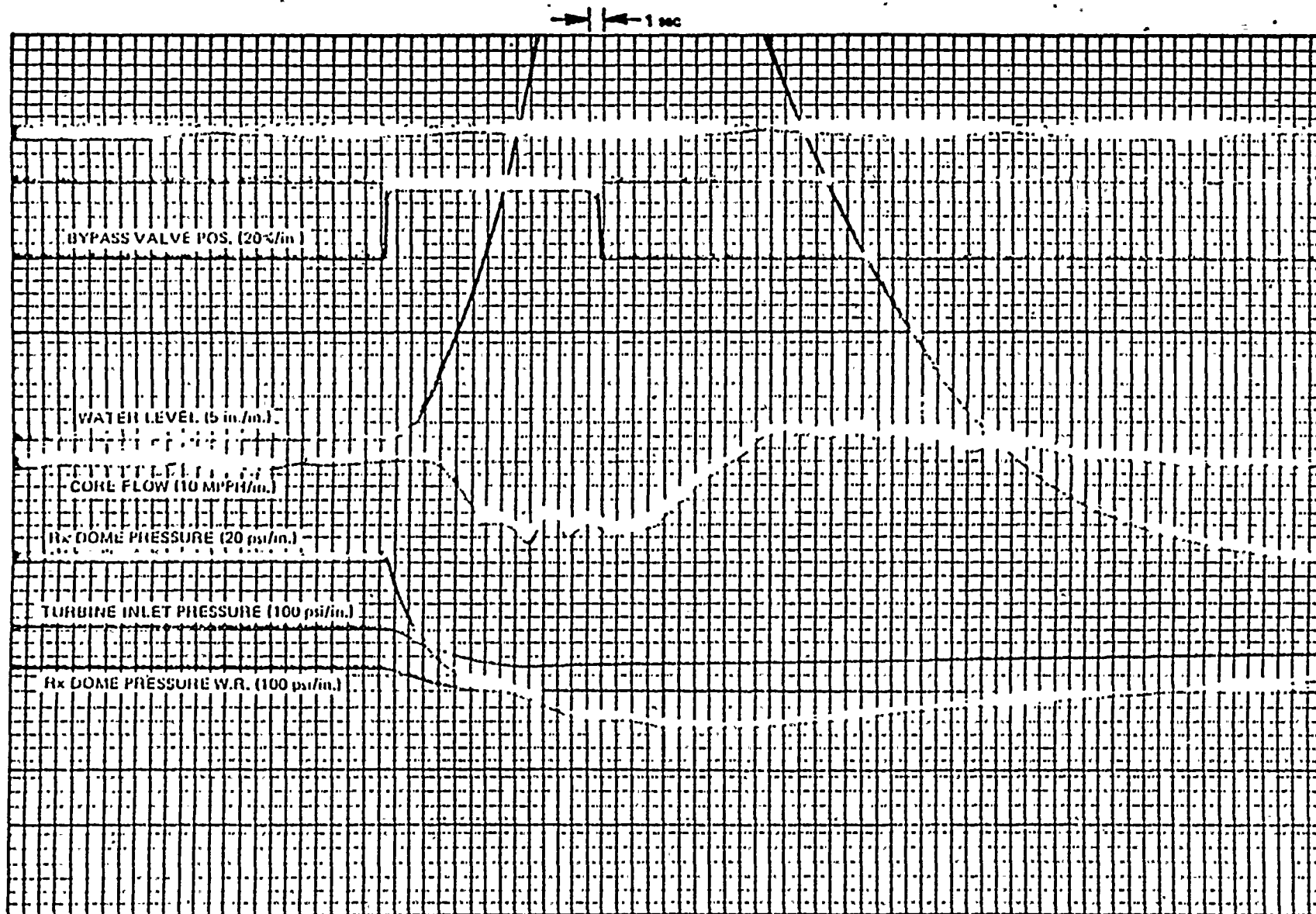


Figure 9. One Bypass Valve, Fast Open-Fast Close



→ | ← 1 sec

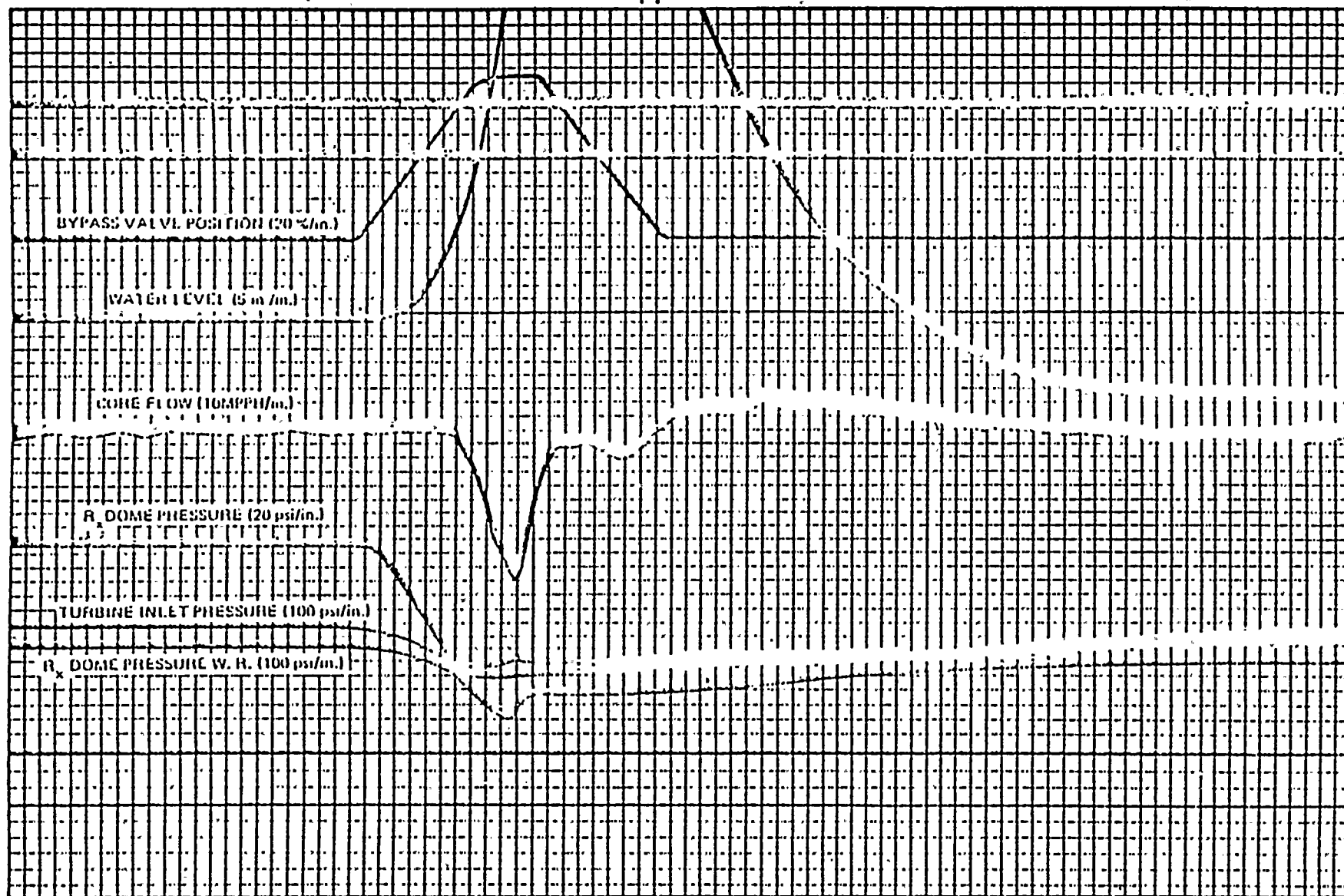


Figure 10. Two Bypass Valves, Ramp Open-Ramp Closed



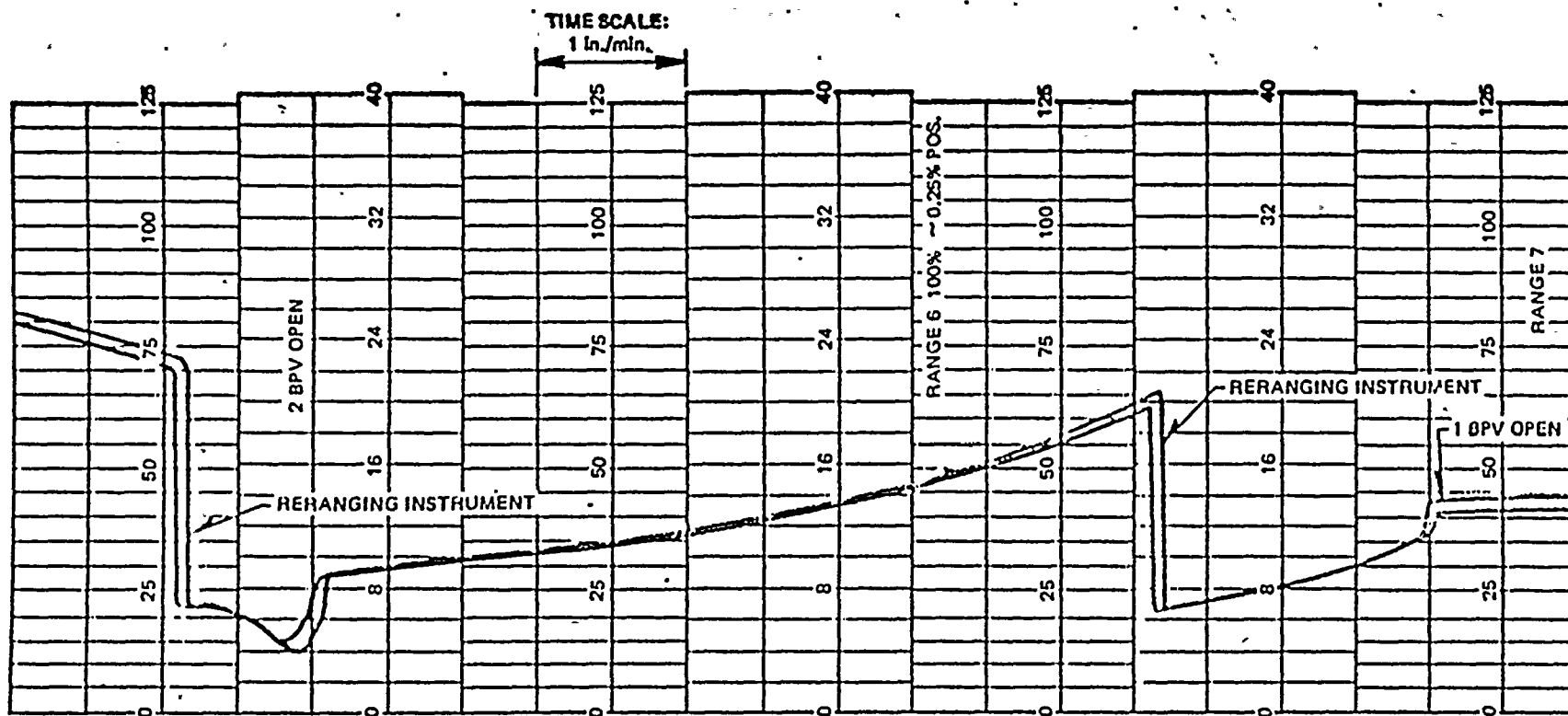
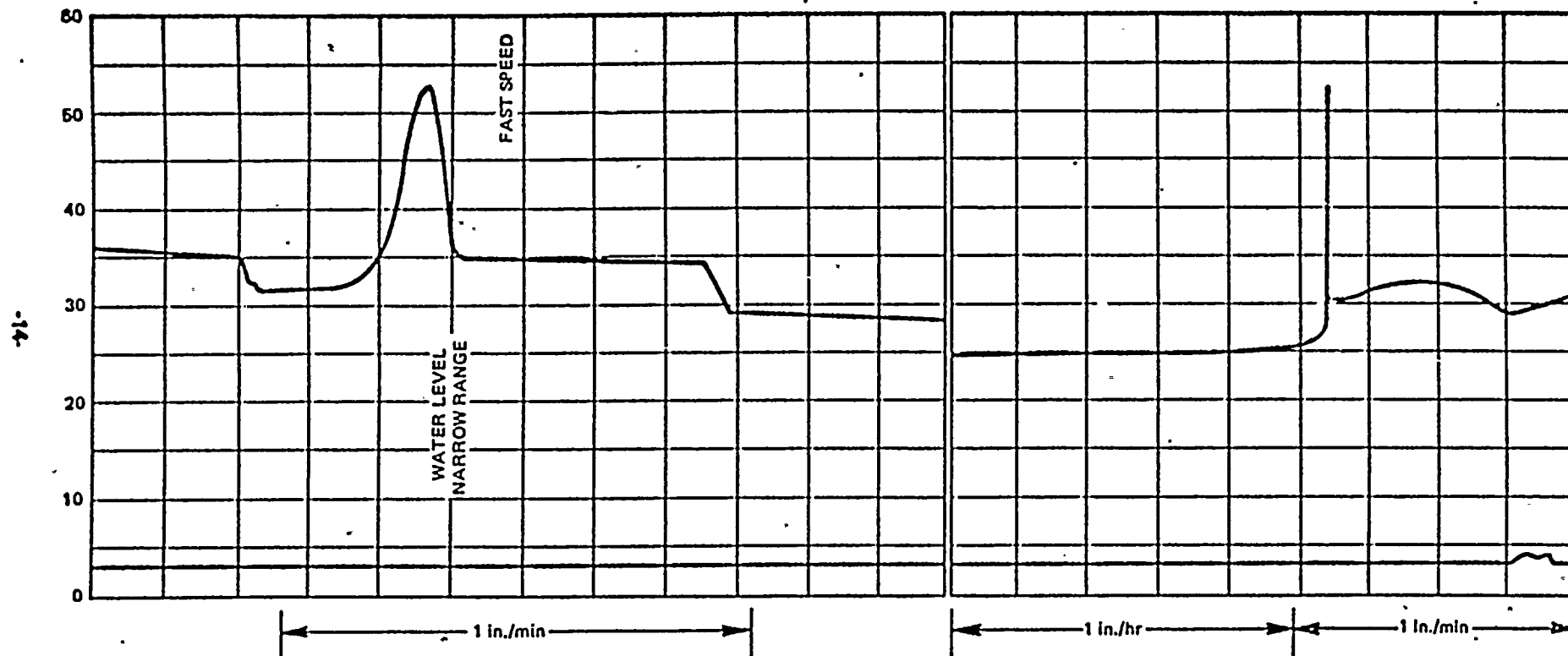


Figure 11. IRM Response to Pressure Disturbances





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Figure 12. Water Level Response to Pressure Disturbances



APPENDIX A

BROWNS FERRY UNIT 1  
BOTTLED-UP STABILITY TEST PROCEDURE



Plant: Browns Ferry Unit 1  
Test Title: Bottled-Up Stability (Special Test)  
Date: December 12, 1973

PREPARED BY: Startup Test Design and Analysis Unit  
Startup and Training Subsection  
Atomic Power Equipment Department  
San Jose, California





## 1. PURPOSE

The purpose of this test is to demonstrate that the reactor can safely withstand pressure and reactivity perturbations at rated pressure while in a bottled-up condition without pressure regulation.

## 2. DESCRIPTION

2.1 Standard operating procedure at this plant permits operating up to rated pressure with the main steam isolation valves (MSIVs) closed. Heatup in this condition and transfer to and from this condition following turbine trips has been satisfactorily accomplished on several occasions. No incipient instabilities were quantitatively observed at any time; however, in an earlier plant (KRB), there were some indications of possible instability when bottled-up above 600 psig. Design Engineering at San Jose General Electric has therefore requested that a formal test be performed to verify bottled-up stability at rated pressure.

2.2 The test will be in two parts. The first will involve making a reactivity perturbation, and the second will be a pressure perturbation. Both will be initiated from bottled-up not standby conditions, with the MSIVs open and the main turbine stop valves (MTSVs) closed. The feedwater turbines will be shut off, and the main turbine gland seal and the steam jet air ejector (SJAE) will be operating from the auxiliary boiler. The pressure regulator will be set approximately 20 psi above the actual reactor pressure. This will produce a bottled-up condition that closely simulates having the MSIVs closed, but will permit lowering of the pressure setpoint to open bypass valves if instability does occur.

2.3 Heatup data will be collected during normal operation with MSIVs closed at close to rated pressure. Normal heatup rates and rod insertions and withdrawals are sufficient for reactivity insertions.

## 3. CRITERIA

### 3.1 Level 1

The test will be terminated if vessel pressure is unstable or if the limit cycle exceeds  $\pm 20$  psi, or if limit cycles with periods less than 10 seconds exceed  $\pm 10$  psi. The test will be terminated if the flux oscillation is so large that a flux-initiated scram is likely. In this case, the Technical Specification will be changed to forbid bottled-up operation above 600 psig.

### 3.2 Level 2

Limit cycles greater than  $\pm 10$  psi will require that the data be analyzed by Design Engineering, and consent be received prior to further bottled-up operation above 600 psig.

## 4. INSTALLATION INSTRUCTIONS

None

## 5. INITIAL CONDITIONS

5.1 The reactor pressure will be at  $920 \pm 5$  psig. All normal plant surveillance procedures shall be satisfied.

5.2 The control rod drive and cleanup systems will be operating to the reactor vessel.

5.3 The reactor feed pumps and their turbines will be off and isolated from the reactor vessel.

5.4 The main turbine will be on turning gear with the gland seal and the (SJAE) operating from an auxiliary boiler.

5.5 The MSIVs will be open, and the MTSVs will be closed.



5.6 The pressure regulator setpoint will be set  $20 \pm 5$  psi above the actual reactor pressure. This will be set by reducing setpoint until incipient bypass action is observed and coming up 20 psi from this point.

5.7 The transient recorder will be ready for operation with the following signals connected: narrow-range reactor pressure, wide-range reactor pressure, narrow-range reactor water level, bypass valve No. 1 position, APRM, LPRM, and core flow.

5.8 Recirculation M/G sets will be at minimum speed.

## 6. PROCEDURE

### 6.1 Reactivity Perturbation

6.1.1 With the reactor operating stably at the initial conditions set forth in Section 5, select a fully withdrawn control rod in the central region of the reactor. Take appropriate data, such as TIP trace, OD-7, and OD-8 computer printouts, to verify that rapid insertion of this rod will not result in the compromise of any fuel warranty limits.

6.1.2 Take base steady-state data and start the transient recorder.

6.1.3 Continuously insert the control rod from Position 48 to Position 00. It is desirable to obtain data on any oscillations that might occur; therefore, if any occur and they are not too large, record them for several minutes, or until Level 1 criteria are approached. To end any such oscillations, reduce the pressure regulator setpoint until the bypass valve opens. If criteria are reached, terminate testing and stop the transient recorder.

6.1.4 If criteria are not reached in Step 6.1.3, keep the transient recorder running and continuously withdraw the control rod to Position 48. When the reactor is again stable, and with the transient recorder running, scram the control rod to Position 00. Continue as in Step 6.1.3.

6.1.5 Withdraw the control rod to its full-out position and stop the transient recorder. This completes the reactivity perturbation test. If either Level 1 or Level 2 criteria are reached, concurrence of Design Engineering is to be obtained before proceeding.

### 6.2 Pressure Perturbation

6.2.1 After satisfactory completion of Step 6.1, and with the reactor operating stably at the initial conditions set forth in Section 5, take base data and start the transient recorder.

6.2.2 Rapidly open fully, and then close, one main steam bypass valve No. 1. Observe and accommodate any oscillations as in Step 6.1.3.

6.2.3 If criteria are not reached in Step 6.2.2, repeat the test for simultaneous full opening of two bypass valves.

6.2.4 The above completes the pressure perturbation test.

### 6.3 Reactivity Perturbation with MSIV Closed (Optional)

6.3.1 If sufficient reactivity perturbation data have not been obtained during normal startup, proceed to Step 6.3.2.

6.3.2 With the reactor at about 600 psig and closed MSIVs, increase power to heatup, maintaining a high, but reasonable, rate of heatup (less than 100°F/hr).

6.3.3 Record rod pattern and the following data at 30-minute intervals: vessel pressure, vessel level, and recirculation loop temperature.



6.3.4 Continue the heatup until rated pressure is reached.

6.3.5 As before, if oscillations are observed, start the transient recorder. It is desirable to obtain data while the reactor state is unchanged; however, if oscillations become large, rapidly insert control rods until the reactor is subcritical, and terminate the test.

6.3.6 If no instabilities are observed during this heatup, repeat Steps 6.1.1 through 6.1.5.

## 7. ANALYSIS

If no oscillations are observed, or if oscillations do not approach the criteria, the system will be considered stable under bottled-up hot standby conditions. If measurable oscillations are observed which approach the criteria, Design Engineering is to evaluate them and recommend subsequent action. Design Engineering is to be supplied with all data, irrespective of results obtained.

## 8. SUPPORTING INFORMATION

8.1 The steam volume of the reactor dome and steam lines out to the MSIVs is approximately 11,740 ft<sup>3</sup>. The corresponding volume of the reactor dome and steam lines out to the MTSVs is approximately 14,540 ft<sup>3</sup>. This difference should not make being bottled-up against the MTSVs significantly different from being bottled-up against the MSIVs, in terms of steam pressure transients.

8.2 One bypass valve full open passes about 400,000 lb/hr of steam. This compares with 800,000 lb/hr for one relief valve. Thus, opening two bypass valves will approximate the transient associated with opening one relief valve.

8.3 In selecting the control rod to be inserted, the main concern would be if an adjacent rod were at a high flux peak location. Such a position would be Position 08, which also corresponds to the end of a gadolinia zone.



GENERAL ELECTRIC

TECHNICAL INFORMATION SERIES

TITLE PAGE

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TITLE		GE CLASS
Bottled-Up Operation of a BWR		GOVT. CLASS
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SUMMARY		
<p>"Bottled-up" operation of a BWR refers to that condition where the main steam isolation valves (MSIVs) are closed, thus preventing any significant steam flow. Historically, there has been a reactor scram condition if vessel pressure rises above 600 psig with the MSIVs closed and with the mode switch in "startup." This document describes the results of a special test conceived and performed on a typical BWR/4 design to determine the necessity of this plant scram function. It is concluded that the pressure scram function can be raised, so that bottled-up hot standby operation is permitted up to full pressure and temperature conditions.</p>		

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### Analog Trip System Information

The instrumentation which will be installed as part of the analog trip system at Browns Ferry is the same or better than the instrumentation which is described in General Electric Company NEDO-21617. The following information demonstrates applicability of this topical report to the system proposed for Browns Ferry.

The analog trip system for unit 1 was approved by amendment No. 93 dated December 16, 1983, and all information concerning the system for unit 1 is applicable to unit 3.





SPECIFIC INSTRUMENT LOOPS

Variable Name	Vendor Model No. Being Deleted	System Involved	Equipment Being Installed		TVA Instrument Loop No. and Division	
			Transmitter Model No.	Trip Unit Model No.		
Reactor low water level	Barton Model No. 278	Reactor Protection	Rosemount 1153	Rosemount 710 DU	L-3-203A (IA) L-3-203B (IB)	L-3-203C (IIA) L-3-203D (IIB)
Reactor high pressure	Barksdale Model No. B2T-A12SS	Reactor Protection	Rosemount 1153	Rosemount 710 DU	P-3-22AA (IA) P-3-22BB (IB)	P-3-22C (IIA) P-3-22D (IIB)
Reactor low low water level	Yarway Model No. 4418C	Primary Containment isolation and recirc pump trip	Rosemount 1153	Rosemount 710 DU	L-3-56A (IA) L-3-56B (IA)	L-3-56C (IIA) L-3-56D (IIB)
Main steam line low pressure	Barksdale Model No. B2T-A12SS	Primary Containment isolation	Rosemount 1153	Rosemount 710 DU	P-1-72 (IA) P-1-76 (IB)	P-1-82 (IIA) P-1-86 (IIB)
Main steam line high flow	Barton Model No. 278	Primary Containment isolation	Rosemount 1153	Rosemount 710 DU	dP-1-13A, -25A, -36A, -50A (IA) dP-1-13B, -25B, -36B, -50B (IB) dP-1-13C, -25C, -36C, -50C (IIA) dP-1-13D, -25D, -36D, -50D (IIB)	
Primary Containment high pressure	Static-o-ring Model No. 12N- AA4-X2PP	Reactor protection and primary contain- ment isolation	Rosemount 1153	Rosemount 710 DU	P-64-56A (IA) P-64-56B (IB)	P-64-56C (IIA) P-64-56D (IIB)
Turbine first stage pres. permissive	Barksdale Model No. B2T-A12SS	Reactor protection and recirc. pump trip	Rosemount 1153	Rosemount 710 DU	P-1-91B (IA) P-1-91A (IB)	P-1-81B (IIA) P-1-81A (IIB)
Reactor high pressure	Static-o-ring Model No. 9N-AA4-X911	Recirc. pump trip	Rosemount 1153	Rosemount 710 DU	P-3-204A (IA) P-3-204B (IB)	P-3-204C (IIA) P-3-204D (IIB)



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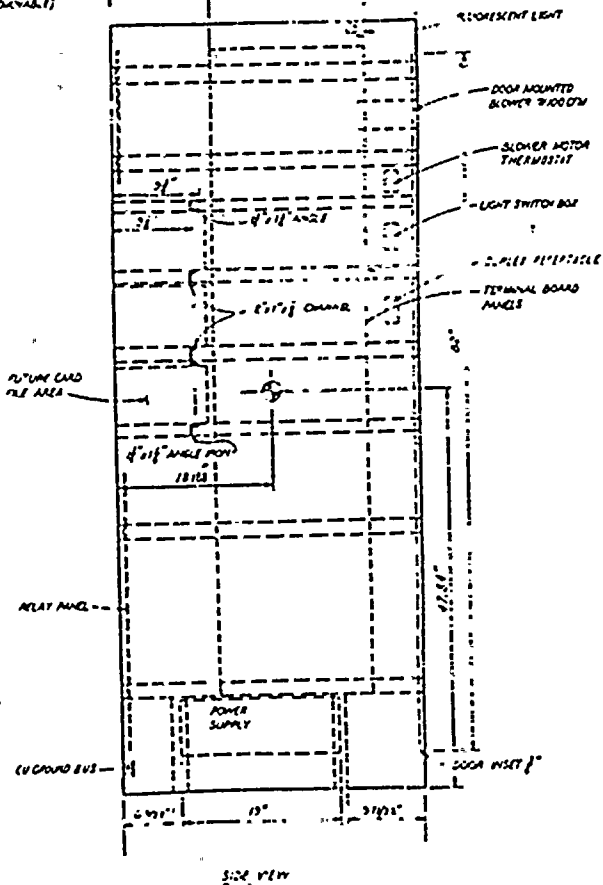
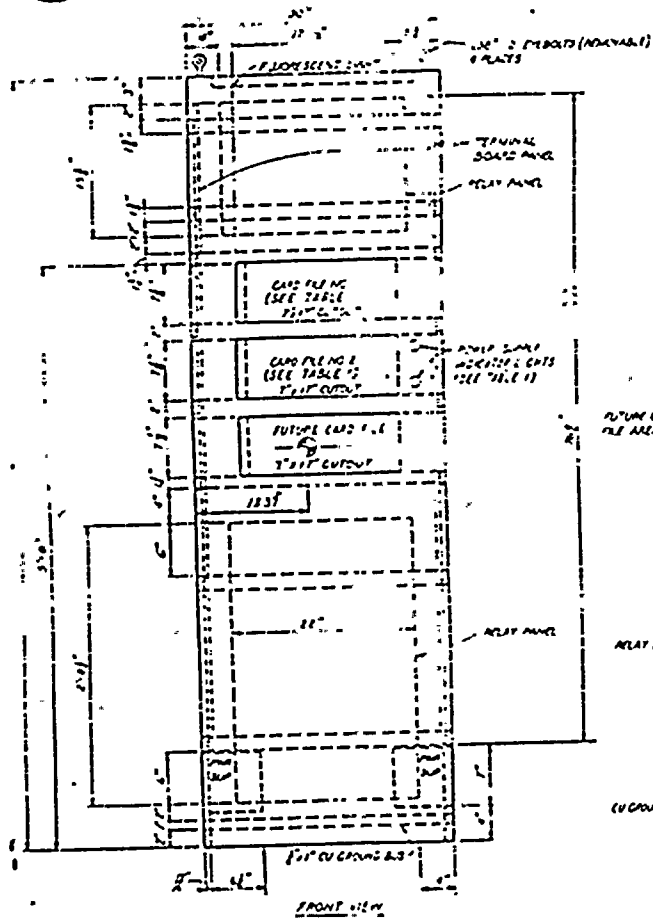
Variable Name	Vendor Model No. Being Deleted	System Involved	Equipment Being Installed		TVA Instrument Loop No. and Division	
			Transmitter Model No.	Trip Unit Model No.		
Reactor low water level	Yarway 4418	Core spray RHR (LPCI)	Rosemount 1153	Rosemount 710 DU	L-3-58A(I) L-3-58B(I)	L-3-58C(II) L-3-58D(II)
Reactor low water level	Yarway 4418	ADS	Rosemount 1153	Rosemount 710 DU	L-3-184(I)	L-3-185(II)
Reactor low water level	Yarway 4418	Containment spray (RHR)	Rosemount 1153	Rosemount 710 DU	L-3-52(I)	L-3-62(II)
Reactor pressure	Barton 288/ Barksdale B2T-M12SS	Recirc, core spray, RHR (LPCI)	Rosemount 1153	Rosemount 710 DU	P-3-74A(I) P-68-95(I)	P-3-74B(II) P-68-96(II)
HPCI Steam- line HI Flow	Barton 288	HPCI	Rosemount 1153	Rosemount 710 DU	dP-73-1A(I)	dP-73-1B(II)
RCIC Steam- line HI Flow	Barton 288	RCIC	Rosemount 1153	Rosemount 710 DU	dP-71-1A(I)	dP-71-1B(II)
Primary Containment pressure	Static-o-ring Model No. 12N-AA4	Containment spray (RHR)	Rosemount 1153	Rosemount 710 DU	P-64-58E(I) P-64-58G(I)	P-64-58F(II) P-64-58H(II)
Primary Containment Pressure	Static-o-ring Model No. 12N-AA4	Core spray RHR (LPCI) HPCI	Rosemount 1153	Rosemount 710 DU	P-64-58B(I) P-64-58D(I)	P-64-58A(II) P-64-58C(II)
Primary Containment Pressure	Static-o-ring Model No. 12N-AA4	ADS	Rosemount 1153	Rosemount 710 DU	P-64-57B(I) P-64-57D(I)	P-64-57A(II) P-64-57C(II)

TEB:VD  
1/03/84

B4262D.VD



## TRIP UNIT CABINET

[illegible]

ENVIRONMENTAL INTERFACE TEMPERATURE  
AND HUMIDITY

Transmitter No.	Normal Temp.(1)	Normal Humidity(1)	Accident Temp.(1)	Accident Humidity(1)	Qualified Temp.(1)	Qualified - Humidity(i)
3-LT-3-203 A, B, C, D	90°F	98%	180°F	100%	303°F	100%
3-PT-3-22 A, B, C, D	90°F	98%	180°F	100%	303°F	100%
3-LT-3-56 A, B, C, D	90°F	98%	180°F	100%	350°F	100%
3-PDT-1-13 A, B, C, D	95°F	98%	117°F	100%	350°F	100%
3-PDT-1-25 A, B, C, D	95°F	98%	117°F	100%	350°F	100%
3-PDT-1-36 A, B, C, D	95°F	98%	117°F	100%	350°F	100%
3-PDT-1-50 A, B, C, D	95°F	98%	117°F	100%	350°F	100%
3-PT-64-56 A, B, C, D	90°F	98%	110°F	100%	303°F	100%
3-PT-3-204 A, B, C, D	90°F	98%	100°F	100%	303°F	100%
3-PT-1-72, 76, 82, 86	90°F	98%	N/A(2)	N/A(2)	303°F	100%
3-PT-1-81 A, B, 91A, B	90°F	98%	N/A(2)	N/A(2)	303°F	100%

(1) Maximum

(2) Equipment located where it will not be subjected to environmental conditions produced by LOCAs and HELBs.

## Continued

Transmitter No.	Normal Temp.(1)	Normal Humidity(1)	Accident Temp.(1)	Accident Humidity(1)	Qualified Temp.(1)	Qualified Humidity(1)
3-LT-3-58 A, B, C, D	90°F	98%	183°F	100%	303°F	100%
3-LT-3-184 -185	90°F	98%	135°F	100%	303°F	100%
3-LT-3-52 -62	90°F	98%	117°F	100%	350°F	100%
3-PT-3-74 A, B	90°F	98%	183°F	100%	303°F	100%
3-PT-68-95 -96	90°F	98%	163°F	100%	303°F	100%
3-PdT-73-1A -1B	95°F	98%	123°F	100%	350°F	100%
3-PdT-71-1A -1B	95°F	98%	118°F	100%	350°F	100%
3-PT-64-58 E, F, G, H	90°F	98%	122°F	100%	303°F	100%
3-PT-64-58 A, B, C, D	90°F	98%	122°F	100%	303°F	100%
3-PT-64-57 A, B, C, D	90°F	98%	110°F	100%	303°F	100%

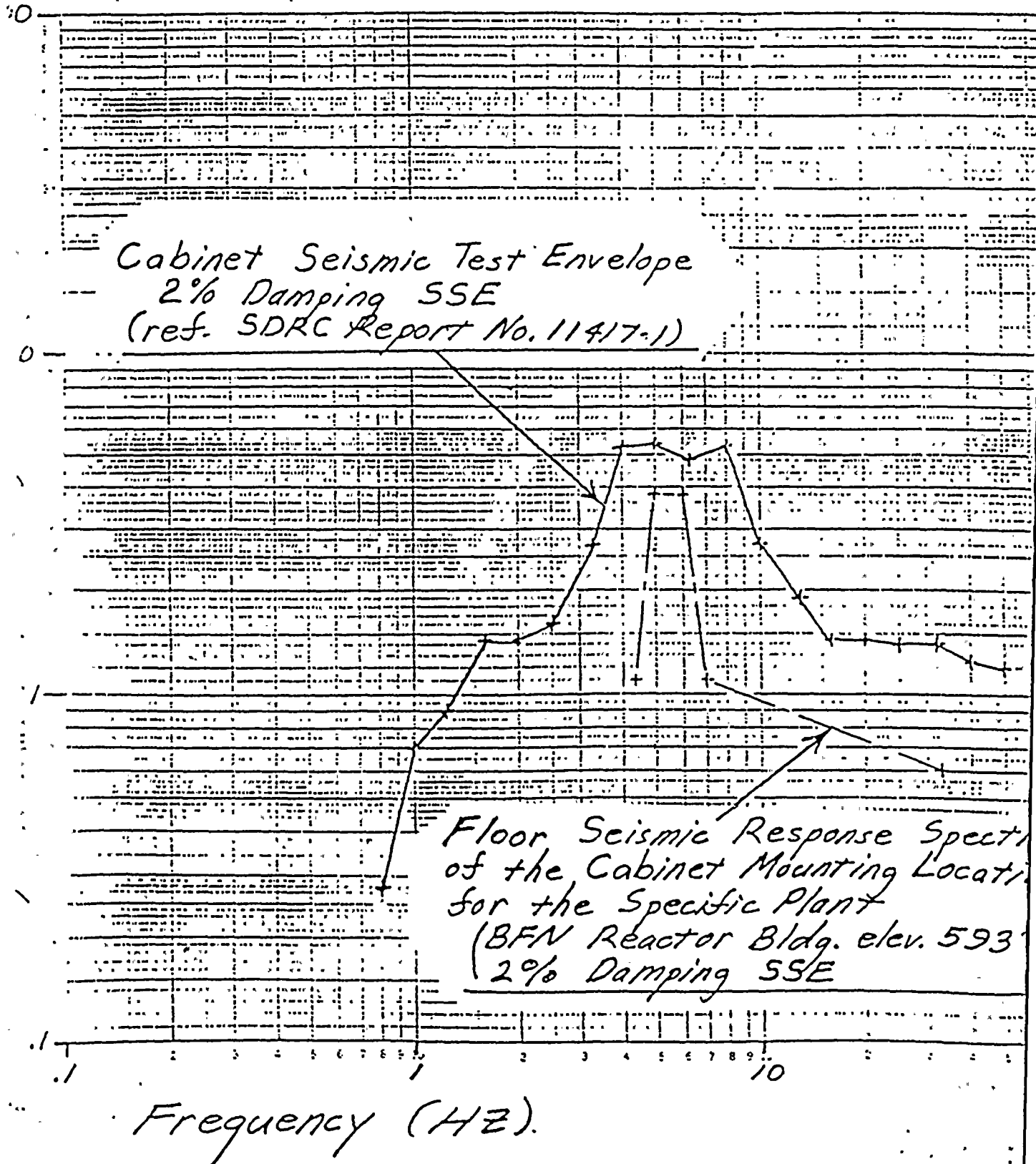
TEB:VD  
1/03/84

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ENVIRONMENTAL INTERFACE  
SEISMIC RESPONSE



## Environmental Interface

All equipment except the transmitters are located in the preferred location in accordance with paragraph 5.1.4.



# PLANT INTERCONNECTION

