

SPECIAL REPORT ON STEAM GENERATOR DENTING  
DERIVED FROM 1985 EDDY CURRENT INSPECTION DATA  
FOR THE FORT CALHOUN STATION

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INTRODUCTION

This report is issued as a supplement to two previous reports issued by OPPD to the Commission:

"Steam Generator Tube Rupture Incident Final Report"  
dated June 19, 1984

"Request for Waiver of NRC Requirement for Mid-Cycle Steam Generator Inspections at the Fort Calhoun Station" dated February 2, 1985.

The summary and results of previous eddy current inspections are described in those reports.

SUMMARY OF RESULTS

During the period from October 21 thru November 2, 1985, multi-frequency eddy current and profilometry inspections were performed in Steam Generators A and B at Fort Calhoun. 100% of the tubes in the vertical strap (VS) region, all tubes with previous indications greater than or equal to 20% and 50 tubes in the tight radius U-bends (steam blanket region) were inspected in each generator for a total of 977 tubes in Generator A and 1010 tubes in Generator B. Included in these numbers were 50 tubes that were tested to the 1st support in the sludge region of Generator B.

The recorded multi-frequency eddy current examination data was analyzed for the presence of defect indications and dents. The data was analyzed by certified Level IIA individuals with extensive training and experience in the evaluation of non-ferromagnetic steam generator tube eddy current data. The data was analyzed and independently verified, as was done with the 1984 post-failure inspections. Tube wall degradation was evaluated using the phase analysis technique for the determination of the origin and percentage of tube wall loss represented by the indication. Dent data was evaluated by comparison of dent indications to a dent standard of known dimensions for which one volt corresponds to one mil reduction in radius for an axisymmetric dent.

A list of indications and their locations is provided in Table I. Figure 1 contains the support notation used throughout this report for OPPD steam generators. There were no tubes examined in either generator containing indications greater than or equal to 40%. Two indications were found in Steam Generator B at the first vertical strap (VS1). The 1984 data was reviewed and these indications were not present, indicating an active flaw mechanism at VS1. Due to the growth over the last 18 months and the fact that all indications at VS1 were plugged in 1984, it was recommended that these tubes also be plugged. It was also recommended that the 39% indication and Undefined Signal (UDS) in Generator A be plugged.

All tubes determined to have deformation sufficient to restrict the passage of the 0.560 inch diameter probe were reinspected with a 0.540 inch diameter probe to determine presence of tube wall degradation and dent deformation. Those tubes restricting the passage of both a 0.560 and 0.540 inch diameter probe are indicated in Tables II and III. These tubes were all subsequently plugged. By comparing the number of restrictions identified during this year's outage to the number restricted during the 1984 inspection, it is evident that the denting in the vertical support (VS) region is progressing.

During the initial defect analysis, conductive deposit type signals were observed in the sludge-pile region. Consequently, an additional 50 tubes were inspected in the sludge "kidney" region from the cold leg to the 1st support in Steam Generator B; no flaw indications were found.

The multi-frequency eddy current data was used to evaluate average radial dents for all tubes in the VS region in both steam generators. The results show that both the magnitude and frequency of tube denting is greater in Steam Generator B than in Steam Generator A. Also, tubes at VS1 displayed more severe denting than VS2 or VS3. A comparison to last year's dent analysis results showed a definite increase in average radial dent size.

A total of 356 tubes were programmed to be re-examined this year with the 8 coil profilometry probe. The profile probe has the advantage over the standard eddy current probe in that eight separate radial dent measurements are taken at any tube cross section. Results from the profilometry examination show significant positive growth over the last cycle. The average growth at VS1 was 2.9 mils in Generator A and 8.6 mils in Generator B, which are 26.7% and 51.8% growths, respectively.

#### DENT/DEFECT EXAMINATION SUMMARY

Multi-Frequency Bobbin. The initial inspection consisted of 514 tubes in Generator A and 503 tubes in Generator B. This represented all tubes with previously identified dents in the vertical support region and all tubes with previous indications of 20-40%. The tubes were tested full length from the cold leg plenum. It also included 50 tubes in the tight radius U-bends in each generator (Rows 1 through 4) which were tested from the cold leg through the apex of the bend to monitor the steam blanket region.

A 0.560 inch diameter spring flex saturation probe was used to perform the examination at the following frequencies:

400KHz Differential and Absolute  
200KHz Differential and Absolute  
100KHz Differential and Absolute  
300KHz Differential and Absolute

By mixing the 400 KHz and 200 KHz frequencies, interfering signals caused by the tube supports were minimized.

All tubes that restricted passage of the 0.560 probe were retested with a 0.540 inch diameter probe at the same frequencies listed above. Upon completion of the initial program, seven (7) tubes in each generator were found to

be restricted to the 0.540 inch diameter probe. Based on the number of restrictions and the increased growth rate of denting over the last cycle, the program was expanded to include all the remaining tubes in the vertical support (VS) region of both generators. In addition, one tube adjacent to every previously identified degradation of 20-40% (1984 results) was added to the program. In Steam Generator B, 50 tubes in the sludge pile "kidney" region were tested to the first support.

Maps of the inspection patterns are included in Figures 2 and 3.

At the completion of the entire inspection program, a total of three (3) tubes in Generator A and four (4) tubes in Generator B had flaws greater than 20% (See Table I). In Generator A, one (1) tube was evaluated as UDS (undefined signal).

Approximately 88 tubes in Steam Generator A restricted passage of a 0.560 inch diameter probe. Of those, fourteen (14) were restricted to a 0.540 inch diameter probe. In Generator B, approximately 110 tubes restricted passage of the 0.560 probe. When retested with the 0.540 inch diameter probe, fourteen (14) were restricted. Lists of those tubes with restrictions and the pluggable indications are contained in Tables II and III. A comparison of the number of restrictions encountered in this inspection to the number from last year shows a significant growth rate.

During an examination in Steam Generator B, the top four coils of a probe became lodged in tube L75R94. It stuck in the dent at VS1. Repeated attempts to dislodge the probe from both plenums were unsuccessful. The tube was later plugged.

#### PROFILOMETRY EXAMINATION SUMMARY

Profilometry inspections were also conducted in the steam generators. This included a specialized test to examine the horizontal run vertical strap intersections. This test revealed that a majority of the vertical strap intersections were ovalized, with the largest size and greatest occurrence of denting at the hot leg vertical support strap. The profilometry was performed to complement the hobbin coil eddy current examinations which had been performed. This was done to provide improved detection and characterization of the dent signals.

The "U-bend" profilometry inspection program consisted of tubes profiled in 1984. The purpose of the inspection was to provide an estimate of tube deformation at the three vertical supports. A total of 121 tubes in Steam Generator A and 205 tubes in Steam Generator B were tested from the cold leg plenum. Data was taken from the #8 support on the hot leg through the U-bend and out the CL tubesheet. Only the vertical supports intersections were analyzed.

Figures 4 and 5 show the profilometry inspection pattern for each generator.

A comparison to last year's profilometry data showed significant dent growth over the last 18 months. Comparisons of 1984 and 1985 dent data are presented in Table IV. The average growth and percent growth are shown in Table V.

## ACTIONS TAKEN

OPPD management is strongly committed to operating the Fort Calhoun Station with prudent chemistry control. More restrictive secondary chemistry guidelines and operating limits, which are virtually identical to the current recommendations of Steam Generator Owners Group II, have been formally adopted. Hold points for chemistry during startup and shutdown have been mandated to ensure optimum chemistry conditions in the generators. These guidelines and limits include corrective action levels, shutdown levels, and the actions necessary to return chemistry parameters within specifications.

In addition to taking steps to reduce the contaminant concentrations in the Fort Calhoun steam generators, OPPD has also taken steps to reduce their ingress from the condenser. OPPD is committed to prompt and prudent corrective action in the event that chemistry limits relating to condenser inleakage are exceeded. In addition to the traditional visual examinations performed during each outage, a condenser eddy current surveillance program was initiated during the 1985 refueling outage and will continue to be a part of future outages. There were no indications of condenser water in-leakage problems during the last operating cycle.

OPPD replaced the copper alloy low pressure feedwater heater tubing with stainless steel tube bundles during the 1985 refueling outage. This will reduce future deposition of copper and copper oxides in the steam generators.

OPPD has investigated the advisability of applying boric acid neutralization to the steam generators. Laboratory data by both Combustion Engineering and Westinghouse indicates that boric acid may effectively neutralize caustic-induced denting and/or IGA/IGSCC. OPPD has performed a boric acid soak during low power startup (approximately 30% power) following the 1985 refueling outage. The low power soak will be followed by on-line boric acid injection during the ensuing cycle. Secondary system boric acid concentration was maintained at approximately 50 ppm during the 30% power soak and will be maintained at 5 to 10 ppm through the balance of the cycle by varying the injection rate with the steam generator blowdown rate. Eddy current testing results from inspections performed during the next refueling outage should determine whether or not boric acid treatment has been effective in reducing steam generator dent growth rates.

## CONCLUSIONS

The integrity of the steam generators at the Fort Calhoun Station is a matter of prime concern to OPPD. Actions taken to improve steam generator integrity since the 1984 outage have been: improving secondary chemistry limits and employing corrective actions; implementing a condenser integrity program; utilizing chemistry holdpoints during startups and shutdowns to flush contaminants from the secondary side; and replacing feedwater heater tube bundles to reduce copper deposit levels in the steam generators. Although there are thus far only two data points for monitoring steam generator dent growth rates (those obtained from the 1984 and 1985 inspections), it is apparent that denting has progressed. Because of this, OPPD has resolved to implement a boric acid treatment program for the secondary side to retard dent growth. The results of the 1987 examinations will determine the effectiveness of the boric acid program and provide the third data point for monitoring dent growth rates. The District believes that every operational alternative known at this time to retard denting has been taken. Even so, new developments concerning denting rate reduction will be evaluated and implemented on an on-going basis. Actions that have already been taken are only the first steps in an on-going denting mitigation process.

OPPD still believes that the steam generator tube rupture of May 16, 1984, was an isolated occurrence. The 1985 eddy current examination results support this. None of the tubes inspected in 1985 exhibited characteristics that would indicate susceptibility to failure within one operating cycle. When compared with the condition of other steam generators throughout the industry, the problems at Fort Calhoun Station are relatively minor. OPPD concludes that the steam generators are acceptable for continued operation.

OPPD believes that this special report on Steam Generator Denting provides the information required to satisfy the requirements for reporting of eddy current testing results, as stated in Technical Specification 3.3(2)e(ii).

TABLE I

The following tubes were found to have wall degradation as indicated:

Steam Generator A

<u>Line/Row</u>	<u>Indication</u>	<u>Location</u>
46 35	23%	CTS + 7.2"
62 27	<20%	C4 + 31.8"
73 42	29%	HTS + 6.6"
75 66	UDS*	C2 + 14.0"
77 42	<20%	CTS + 9.0"
80 35	<20%	HTS + 6.9"
80 91	39%	C7 + 1.8"
85 22	<20%	CTS + 4.1"

Steam Generator B

<u>Line/Row</u>	<u>Indication</u>	<u>Location</u>
36 29	<20%	HTS + 6.6"
57 64	31%	C3 + 5.0"
62 57	29%	C1 + 15.1"
83 88	<20%	H7 + 2.4"
85 84	29%	VS1
91 82	24%	VS1
98 73	<20%	C5 + 22.1"

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\*Undefined signal (UDS). This indication forms like a defect but the phase rotation is unusual. Recommended plugging based on signal formation and fact that was not present in 1984 data.



TABLE II

Steam Generator A - Plug List

<u>Line/Row</u>	<u>Reason</u>
80 91	39% @ C7 + 1.8 inches
75 66	UDS @ C2 + 14.0 inches
51 96	restricted @ H6
53 92	restricted @ H6
63 96	restricted @ H6
67 76	restricted @ VS1
69 84	restricted @ VS1
70 95	restricted @ VS1
72 97	restricted @ VS1
75 84	restricted @ VS1
75 86	restricted @ H6
75 88	restricted @ H6
76 89	restricted @ H6
76 87	restricted @ H6
76 85	restricted @ H6
83 96	restricted @ VS1

16 total plugged  
14 plugged due to 0.540 probe restrictions



TABLE III

Steam Generator B - Plug List

<u>Line/Row</u>	<u>Reason</u>
85 84	29% @ VS1
91 82	24% @ VS1
51 82	restricted @ VS1
54 83	restricted @ H7
56 97	restricted @ VS1
57 76	restricted @ VS1
57 94	restricted @ VS1
59 82	restricted @ VS1
62 97	restricted @ VS1
67 78	restricted @ H5
68 103	restricted @ H8
70 81	restricted @ H3
75 98	restricted @ VS1
76 85	restricted @ H6
77 98	restricted @ VS1
79 92	restricted @ H6
75 94	probe head stuck @ VS1

17 total plugged

14 plugged due to 0.540 probe restrictions

TABLE IV

The numbers recorded are in terms of magnitude of dent size in mils. The following table presents a comparison of 1984 and 1985 dent data at each vertical support location for the tubes inspected during the 1985 examination.

Steam Generator A  
(121 Tubes Profiled)

<u>Location</u> Number of Dents	<u>Approximate Size of Dents</u> (Number of Dents)		
	<u>0-10 Mils</u>	<u>10-20 mils</u>	<u>20 mils</u>
VS1 - 1985 (117)	( 68)	(21)	(28)
- 1984 (117)	( 85)	( 4)	(28)
VS2 - 1985 (117)	( 91)	(11)	(15)
- 1984 (117)	( 90)	(17)	(10)
VS3 - 1985 (117)	(112)	( 2)	( 3)
- 1984 (117)	(113)	( 1)	( 3)

Steam Generator B  
(205 Tubes Profiled)

<u>Location</u> Number of Dents	<u>Approximate Size of Dents</u> (Number of Dents)		
	<u>0-10 Mils</u>	<u>10-20 mils</u>	<u>20 mils</u>
VS1 - 1985 (193)	(104)	(16)	(73)
- 1984 (193)	(125)	(10)	(58)
VS2 - 1985 (194)	(178)	(13)	( 3)
- 1984 (194)	(180)	(09)	( 5)
VS3 - 1985 (174)	(154)	( 8)	(12)
- 1984 (174)	(156)	(12)	( 6)

TABLE V

PROFILOMETRY RESULTS  
DENT GROWTH SINCE LAST OUTAGE

	<u>Elevation</u>	<u>Avg-growth (mils)</u>	<u>% Growth</u>
Generator A	VS1	2.9	26.7
	VS2	0.7	10.8
	VS3	0.2	5.8
Generator B	VS1	8.6	51.8
	VS2	0.2	5.1
	VS3	1.9	43.3

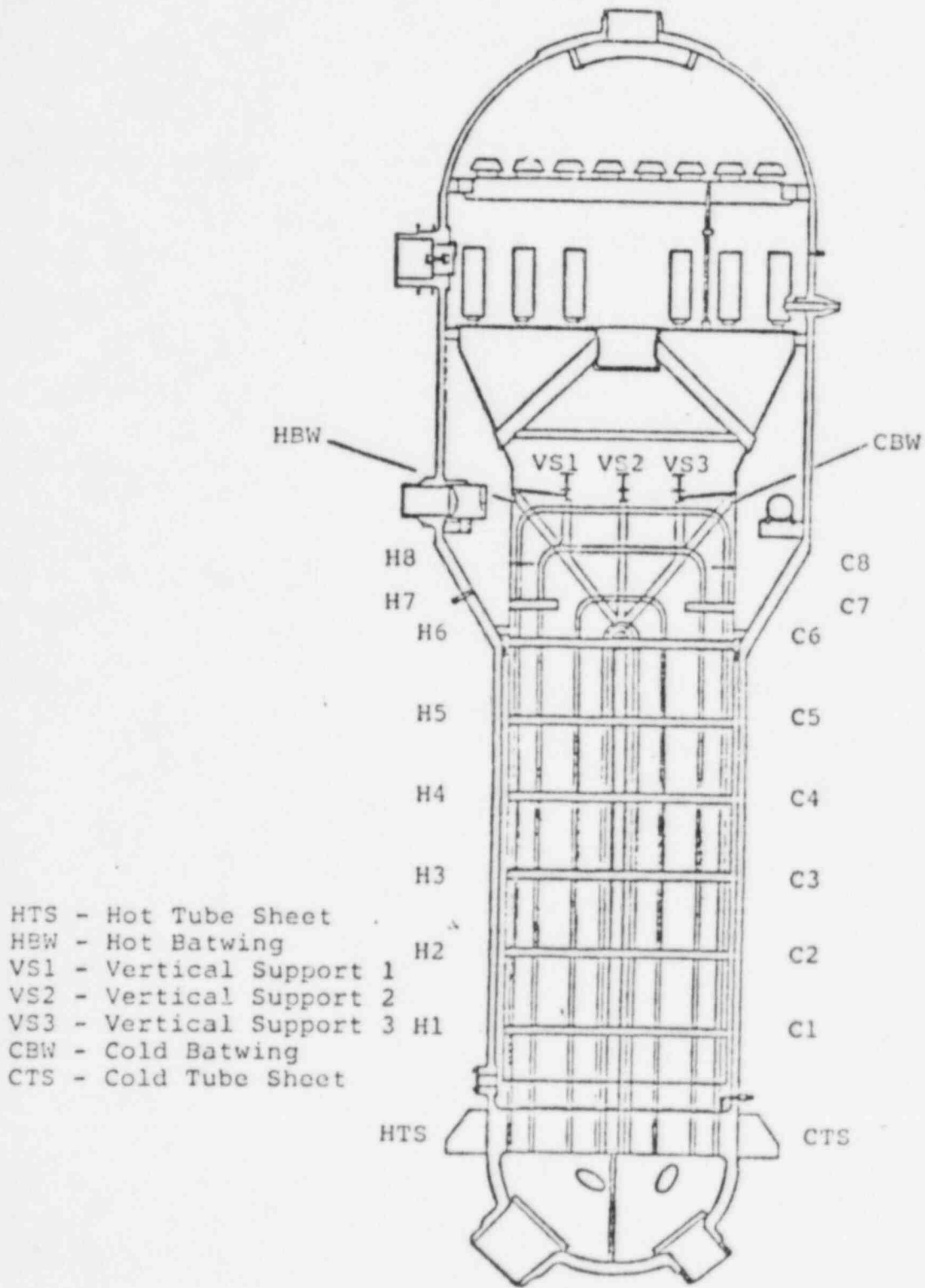


FIGURE 1  
 OPPD Steam Generator  
 Support Notation

PRINT DATE 85/11/75.

INSPECTION PROGRAM OCT 1985

ALL TUBES TESTED ON C SIDE

LEGEND

- MI NO INDICATION
- MR POT REFORTABLE
- DS DISTORTED SIGNAL
- DT DISTORTED TS SIGNAL
- PV PERMEABILITY VAR. ( )
- ID ID VARIATION
- OB OBSTRUCTED
- IN INCOMPLETE
- 21 21 PERCENT THRU WALL
- PL PLUG
- \*\* STAY

FIGURE 2

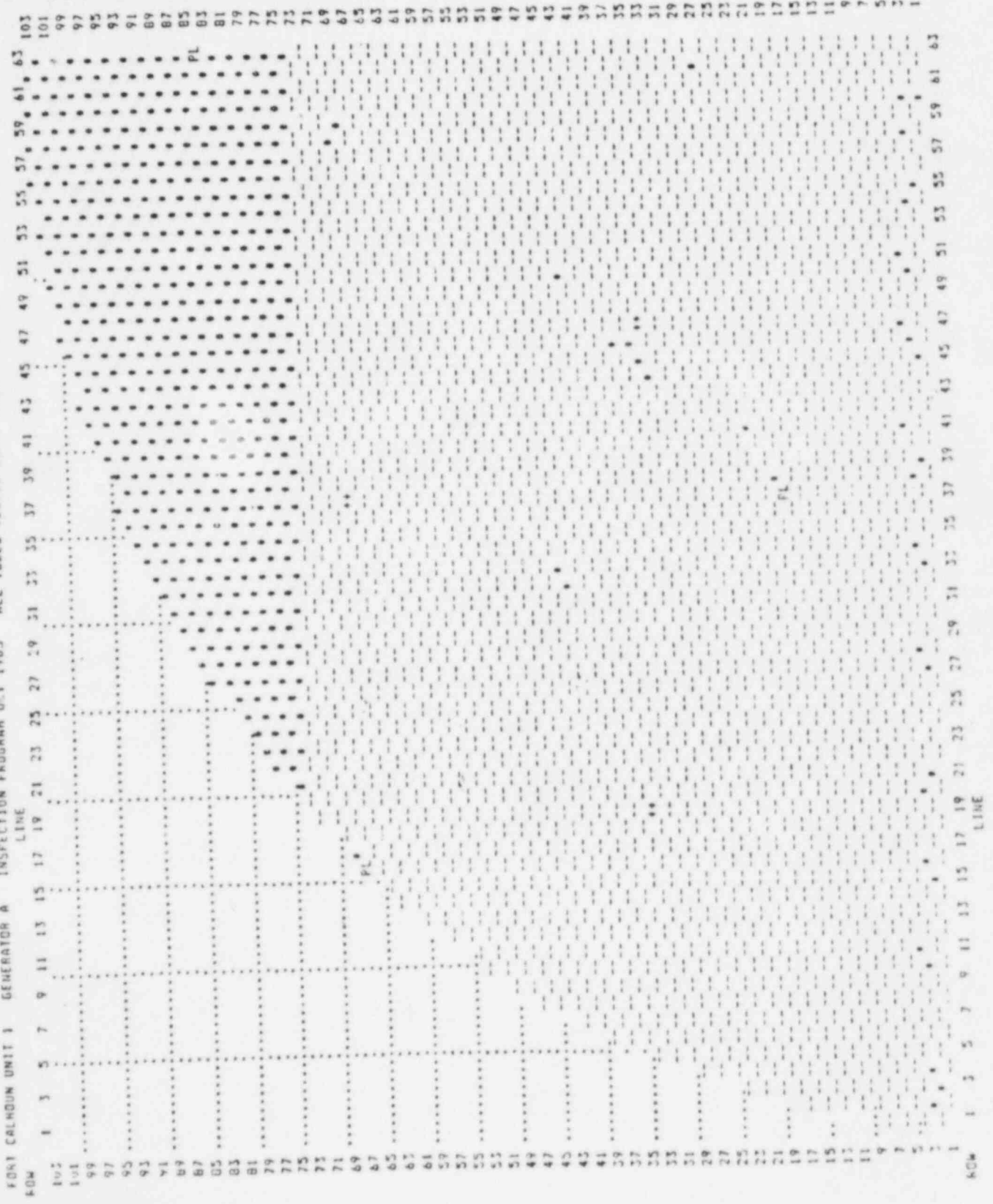
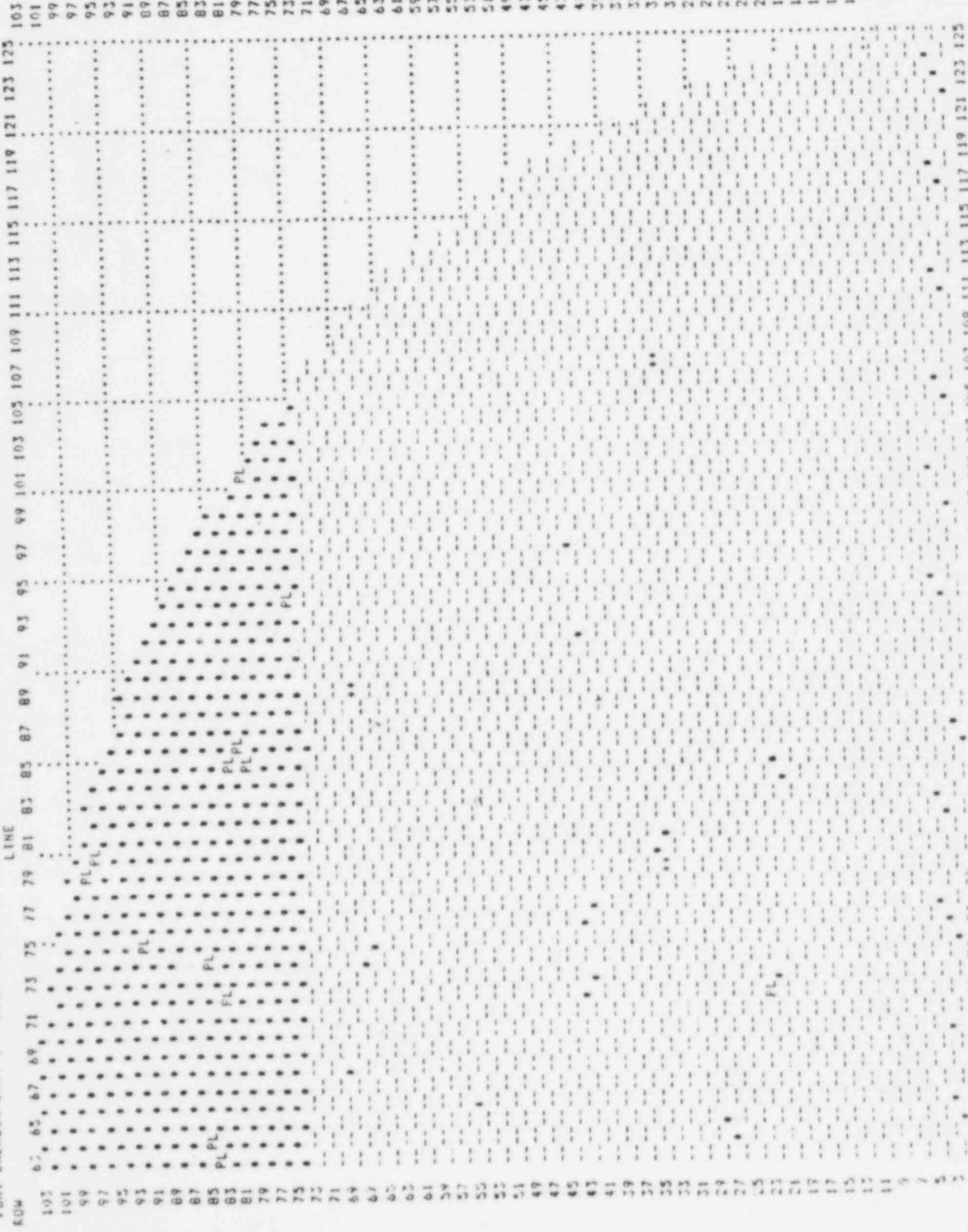


FIGURE 2 CON'T.

PUMP CALMOUN UNIT 1 GENERATOR A INSPECTION PROGRAM OCT 1985 ALL TULLS TESTED ON C SIDE PRINT DATE 85/11/25.

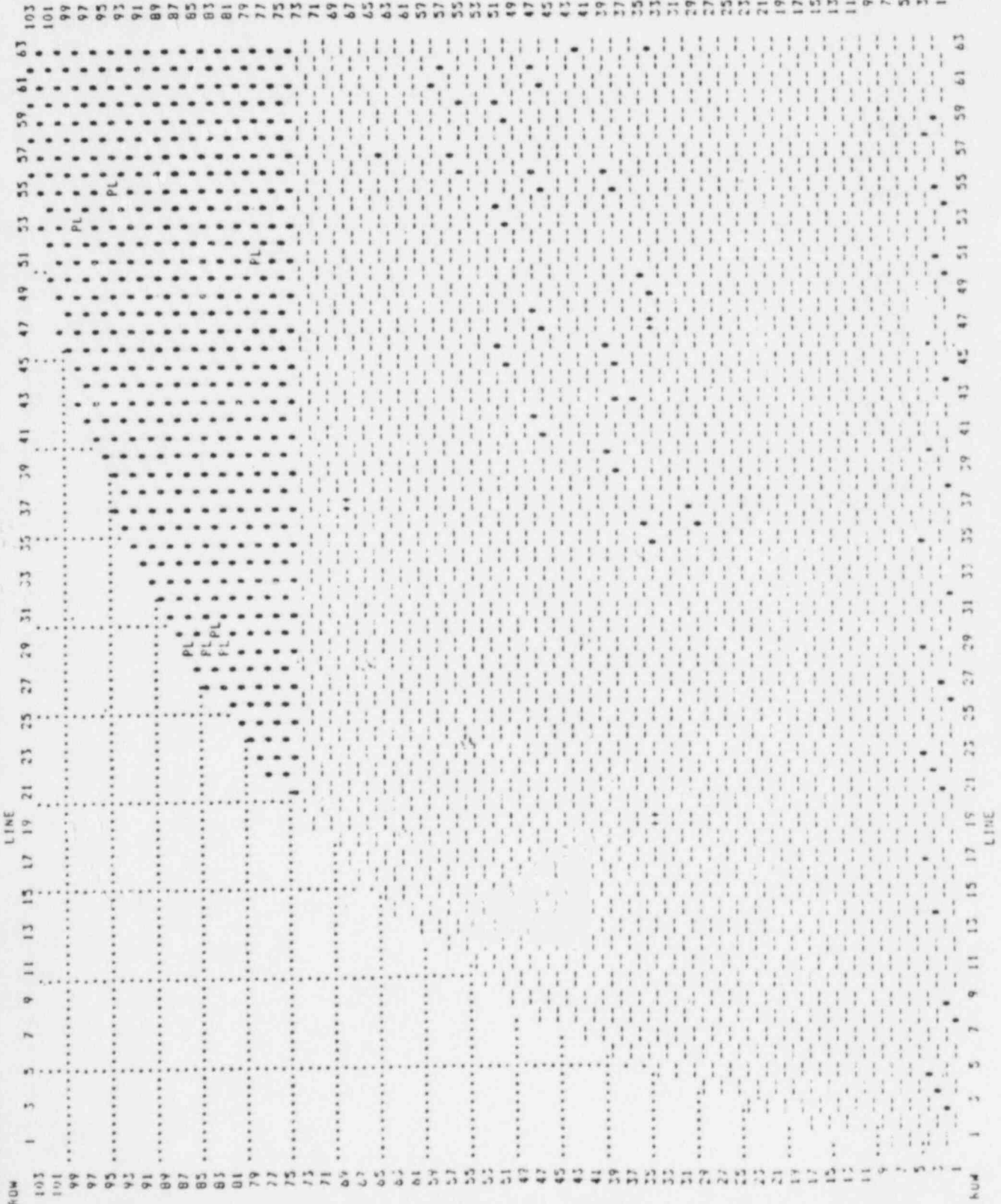
LEGEND  
 NI NO INDICATION  
 NR NOT REPORTABLE  
 DS DISTORTED SIGNAL  
 DT DISTORTED TS SIGNAL  
 PV PERMEABILITY VAR.  
 ID ID VARIATION  
 OB OBSTRUCTED  
 IN INCOMPLETE  
 21 21 PERCENT THRU WALL  
 PL PLUG  
 \*\* STAY



ROW 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95 97 99 101 103 105 107 109 111 113 115 117 119 121 123 125  
 LINE

Figure 3

FORT CALHOUN UNIT 1 GENERATOR B INSPECTION PROGRAM OCT 1985 ALL TUBES TESTED ON C SIDE PRINT DATE 85/11/25.



LEGEND

- MI NO INDICATION
- NR NOT REPORTABLE
- DS DISTORTED SIGNAL
- DT DISTORTED TS SIGNAL
- PV PERMEABILITY VAR.
- ID ID VARIATION
- OB OBSTRUCTED
- IM INCOMPLETE
- ZI 21 PERCENT THRU WALL
- FL PLUG
- \*\* STAY



FIGURE 3 (Cont'd)

PRINT DATE 85/11/25.

LEGEND  
 NI NO INDICATION  
 NR NOT REPORTABLE  
 DS DISTORTED SIGNAL  
 DT DISTORTED TS SIGNAL  
 FV FERREABILITY VAR.  
 IC IC VARIATION  
 OB OBSTRUCTED  
 IN INCOMPLETE  
 T1 21 PERCENT THRU WALL  
 FL FLUG  
 \*\* STAY

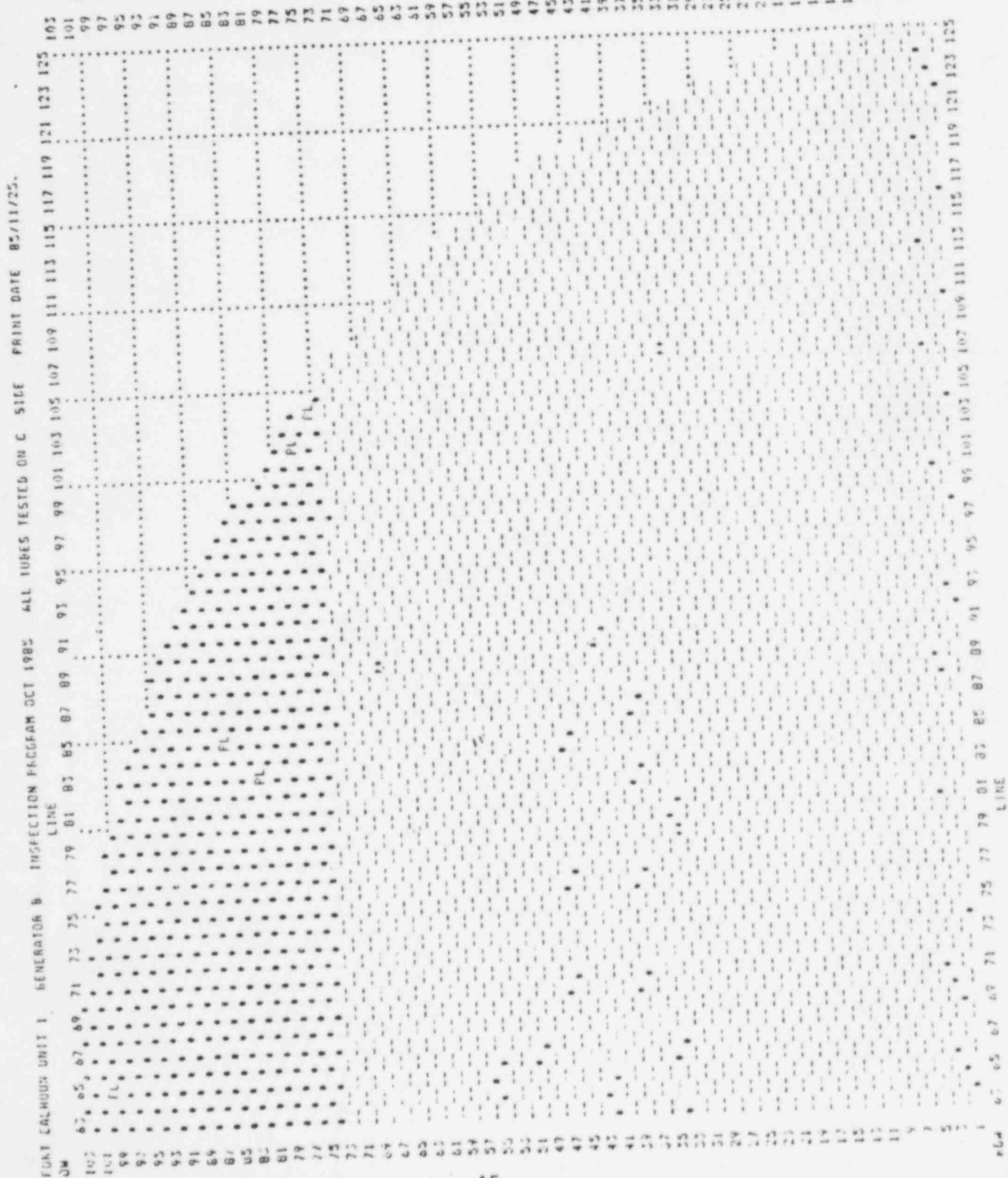


FIGURE 4

FOAT CALHOUN UNIT 1 GENERATOR A C SIDE ----- INSPECTION PROGRAM OCT 1985 PROGRAMMED TUBES PRINT DATE 05/12/09.

LEGEND  
 !! PROGRAMMED TUBE  
 ?? RETEST REQUIRED  
 \*\* COMPLETED  
 PL PLUG  
 \*\* STAY

ROW	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	103		
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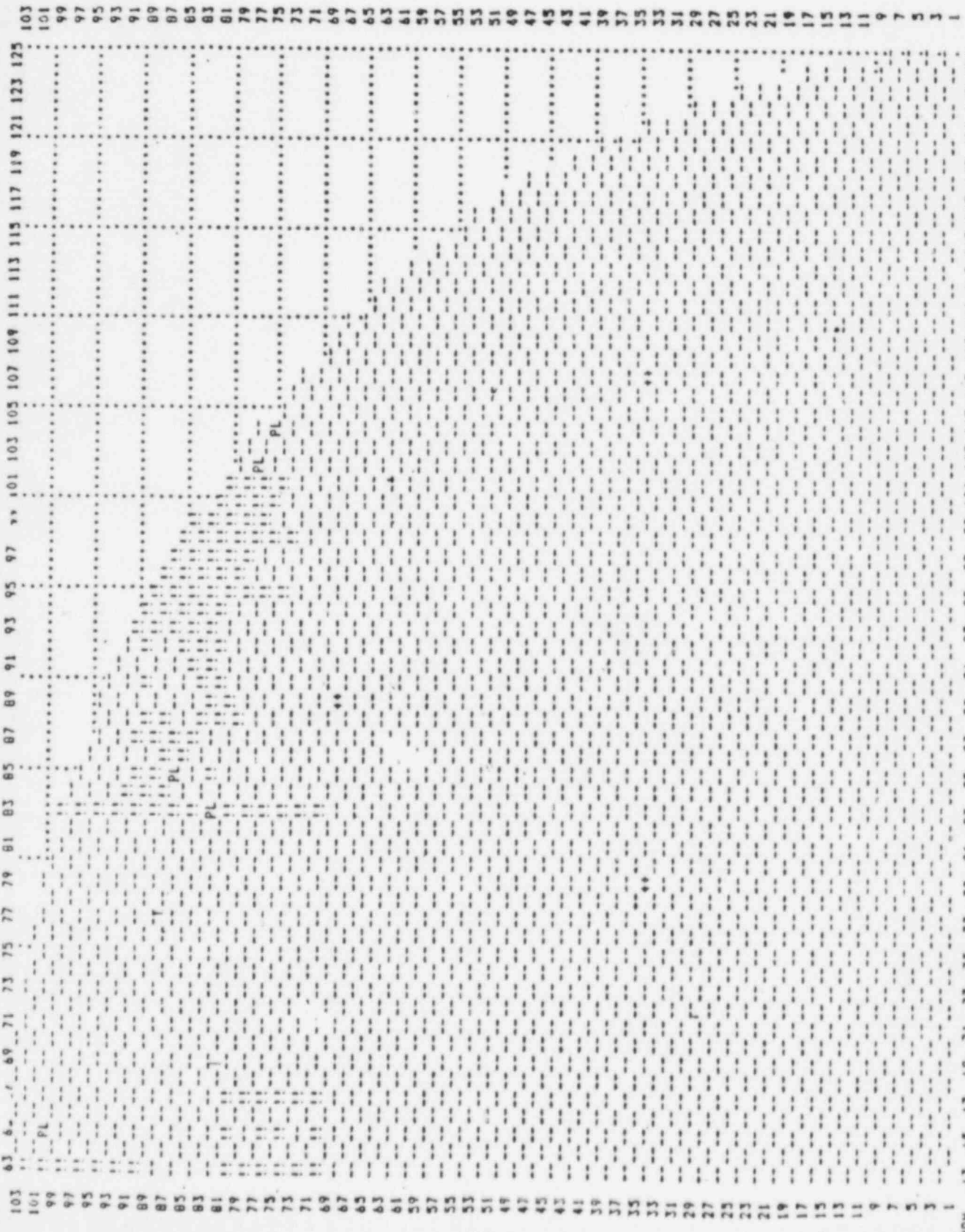






FIGURE 5 (Cont'd)

ROM 63 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95 97 99 101 103 105 107 109 111 113 115 117 119 121 123 125



LEGEND  
 !! PROGRAMMED TUBE  
 77 RETEST REQUIRED  
 68 COMPLETED  
 PL PLUB  
 44 STAY

ROM 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95 97 99 101 103 105 107 109 111 113 115 117 119 121 123 125