ATTACHMENT 2

CRYSTAL RIVER UNIT 3

STEAM GENERATOR REGULATORY GUIDE 1.121 EVALUATION

REVISION 2

Florida Power
CORPORATION

CRYSTAL RIVER UNIT #3
STEAM GENERATOR REGULATORY GUIDE 1.121 EVALUATION
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TABLE OF CONTENTS

List of Figures

List of Tables

1.0 INTRODUCTION

Analysis of eddy current data for the April 1990 and May 1992 refueling outages (RFO) at Crystal River Unit 3 revealed a significant number of indications in the first span of the "B" Once Through Steam Generator (OTSG). These indications are primarily low amplitude signals with low signal-to-noise (S/N) ratios (<5:1)[1], that under plant-specific eddy current analysis guidelines were dispositioned as S/N and left in service.

In addition to the indications in the first span of the "B" steam generator, eddy current inspections have also identified a number of S/N indications at other locations in the Crystal River Unit 3 steam generators. A list of all indications documented as S/Ns was submitted to the NRC via Reference 1.

To investigate S/N indications further, seven (7) tubes with representative indications were pulled from the CR-3 "B" OTSG during the 1992 RFO. These tubes have been subjected to detailed examination under EPRI Project RPS 413-06. The laboratory examination included eddy current testing, tube burst testing, and destructive examination to determine actual defect locations and depths. The objectives of the laboratory examination were:

1. Physically characterize any tube degradation, particularly damage associated with low S/N indications in the boiling/free span regions, for correlation with field non-destructive examination.

2. Obtain burst pressure data to determine the effect of defects on the structural integrity of the tubing.

3. Attempt to establish the damage mechanism responsible for the eddy current indications.

4. Establish correlations between plant chemistry trends and the degradation observed.

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[1] Selection of 5:1 as the S/N ratio below which noise is considered too great to make accurate sizing estimates is intended to limit the error associated with through wall sizing of indications to 10 percent or less. 10 percent is generally accepted as the allowable eddy current technology sizing error band. Additional discussion on the significance of signal to noise ratio to eddy current sizing accuracy is provided in Appendix H.

The laboratory examination identified small patches on the outside diameter of the pulled tubes which were classified as very small "pit-like" intergranular attack (IGA). Burst pressure testing of tubes demonstrated that tubes with pit-like intergranular attack have significant margin above Regulatory Guide 1.121 requirements.

FPC met with members of the NRC staff on September 9, 1993 in Rockville, Maryland to discuss the results of the pulled tube analysis. A draft report summarizing the results of the examination was submitted to the Nuclear Regulatory Commission at that time. The final draft of this report is included as Appendix A.

2.0 PURPOSE

On December 20, 1993, FPC received a request for additional information (RAI) as a followup to the September 9, 1993 meeting regarding CR#3 Steam Generator Tube Examinations. The RAI requested that FPC submit a Regulatory Guide 1.121 evaluation that justifies indications similar to the pit-like indications found during Refuel 8 are acceptable. The original issue of this report documented the evaluation done to determine the maximum allowable tube wall degradation for OTSG tubing in accordance with (draft) Regulatory Guide 1.121 and provided a comparative discussion relative to the S/N indications observed at Crystal River Unit 3. The report also addressed the non-destructive examination methods which will be used to identify tubes with limiting defects and provided a basis for a revision to the existing Technical Specification plugging limit. Revision 2 of this report includes all the information presented in its original issue with expanded discussion in some areas to address questions generated during subsequent meetings and teleconferences with NRC staff.

3.0 SUMMARY OF RESULTS

The existing Technical Specification repair limit is solely based on the percent through wall penetration of an indication. Determination of percent through wall penetration using standard bobbin coil phase angle methodology can be inaccurate for very small volume indications (S/Ns). Therefore, development of an alternative method for dispositioning S/N indications is necessary. This alternative repair limit should be conservative such that it not only ensures structurally significant indications are removed from service, but also ensures that indications which could potentially result in leakage are identified.

CR#3 has performed an extensive investigation of S/N type indications. This investigation has thus far included removal of portions of seven tubes from the "B" steam generator, burst testing of tube samples with multiple S/N indications, and review of eddy current historical data. Examination of pulled tubes revealed the source of the S/N indications to be very small volume pit-like IGA with no associated cracking. Burst testing demonstrated a margin of safety above Regulatory Guide 1.121 limits for the tubes. Review of eddy current bobbin and Rotating Pancake Coil (RPC) historical data for S/N indications resulted in the following findings:

1. S/N type indications in the CR#3 steam generators can be characterized as small, volumetric indications. Conservative estimation of the axial and circumferential size of S/Ns from available RPC clip plots indicates that most are similar in size to the very small pit-like IGA which was identified in the first span of the "B" steam generator. No crack-like indications were identified during review of RPC records for S/Ns. This is consistent with OTSG operating experience. No cracking has been observed in any OTSG outside the open lane/wedge region.[2]

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[2] Preventive upper tube sheet sleeves will be installed in the lane/wedge region of the CR#3 steam generators during Refuel 9. This region is the only region which has been shown to be susceptible to cracking by OTSG field operating experience.

2. Review of eddy current bobbin examination historical data indicates that the S/N type indications in the Cr#3 steam generators are not growing between inspections. Review of data for "B" steam generator first span indications was performed by both BWNS and the EPRI NDE center. The single conclusion of both independent reviews was that there is no evidence of growth. BWNS subsequently performed a side by side comparison of historical eddy current signals for S/N indications outside the "B" first span. The conclusion of this review was that no significant growth rate was observed.

A structural analysis has been performed by MPR Associates, Inc. to determine the maximum allowable indication size which can be present on an OTSG tube while maintaining the margin of safety established by Regulatory Guide 1.121. This analysis is very conservative for all potential defect types and locations. Based on the MPR analysis, the axial and circumferential extent of indications must be limited to 0.25 inch and 122 degrees for 100 percent through wall penetration. Operating experience with no primary to secondary leakage over several cycles since S/Ns were first observed indicates a low probability that 100 percent through wall indications are present. Therefore, establishment of a 0.25 inch axial and 122 degree circumferential limit on indication size is conservative. Axial and circumferential size of indications can be conservatively estimated using RPC clip plots.

Examination of indications using RPC requires a great deal of outage time due to the low pull speed of the RPC probe. Since RPC clip plots are required to estimate the axial and circumferential size of indications, it is desirable to establish a method to disposition S/Ns which would be as conservative as the dimensional repair criteria but would not require performance of 100% RPC on all S/N type indications. Signal amplitude (i.e. voltage) has been shown by experience in recirculating steam generators to be a function of indication size, which can then be directly related to tube structural integrity. Therefore, application of an eddy current bobbin coil voltage limit below which S/Ns are determined acceptable to remain in service for another cycle is a reasonable approach.

Eddy current correlations performed as part of a B&W Owners Group NDE Committee IGA study indicate that bobbin coil voltages up to 6 volts can be observed during examination of indications having dimensions deemed acceptable on OTSG tubing per MPR's OTSG tubing structural analysis. In consideration of NDE uncertainties, data scatter, and the need to minimize the possibility of leakage, the recommended voltage limit is reduced to 2 volts. Tubes with S/N indications which have voltages greater than 2 volts will be removed from service.[3] A sample RPC inspection will be performed on S/N indications with voltages less than 2 volts.

Eddy current indications with signals greater than five times their background noise will continue to be dispositioned by applying the existing 40% through wall criteria.

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3 This excludes indications with signal to noise ratios less than 5:1 which are confirmed to be wear or manufacturer's burnish marks.

4.0 OTSG DESIGN

The Once Through Steam Generator (OTSG) is a straight-tube, straight-shell heat exchanger as shown in Figure 1. Heated reactor coolant enters each OTSG through a single 36 inch ID vertical nozzle in the upper head, flows downward through more than 15,000 tubes, transfers heat to the secondary water, and exits through two 28 inch ID outlet nozzles in the lower head.

On the secondary side, feedwater enters a 14 inch id toroidal header and is distributed through 32 nozzles, which spray the water downward into an annular feedwater heating chamber between the lower shroud and shell. The feedwater is heated to saturation by direct contact condensation of steam aspirated from the tube bundle through bleed ports in the shroud. The saturated feedwater flows downward in the annulus, entering the tube bundle through ports in the lower shroud. The water begins to boil immediately as it flows upward, becoming saturated steam and then superheated steam before exiting the tube bundle in the upper tube span, which is located between the 15th tube support plate and the upper tube sheet. The superheated steam is routed downward in the annulus between the upper shroud and the shell, finally exiting through two 24 inch steam outlet nozzles.

Each OTSG contains 15,531 Inconel 600 tubes, 0.625 inch OD, 0.034 inch wall, 56 ft. 2-3/8 inches long, rolled and sealed-welded into 24 inch thick carbon steel tube sheets at the top and bottom. Following fabrication, the CR#3 OTSGs were subjected to a full-furnace stress relief at 600 to 620° C to reduce residual stresses. This step in the manufacturing process resulted in a sensitized tubing microstructure. Tubes are arranged in a tri-angular pattern distributed over the entire cross section of the OTSG. Half of row 76 was left untubed and is referred to as the "open tube lane" (see Figure 2). Tubes are stabilized by fifteen support plates with tri-lobed holes which allow upward flow. (Figure 3).

OTSG LONGITUDINAL SECTION TERMINOLOGY

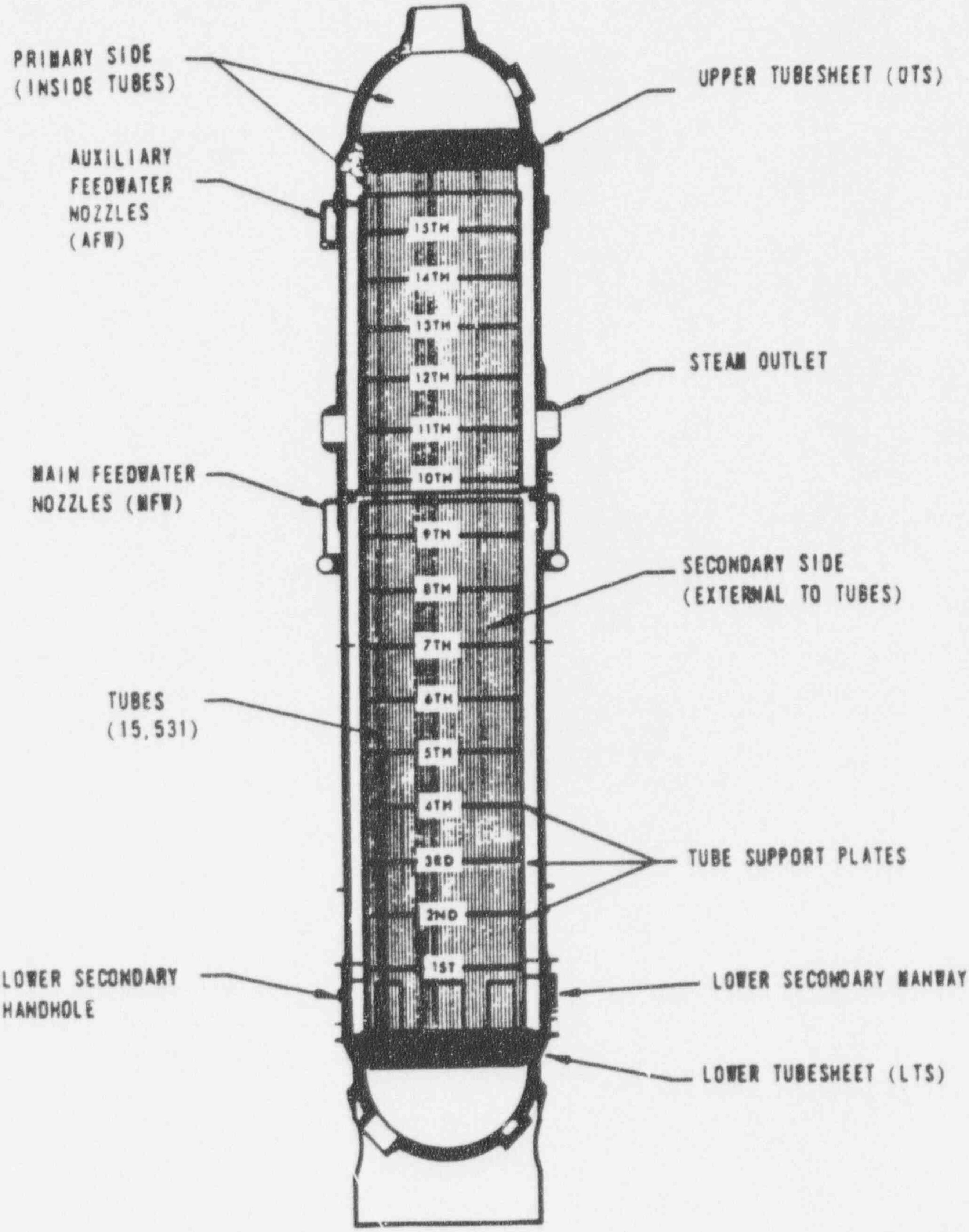

FIGURE 1: OTSG Longitudinal Section

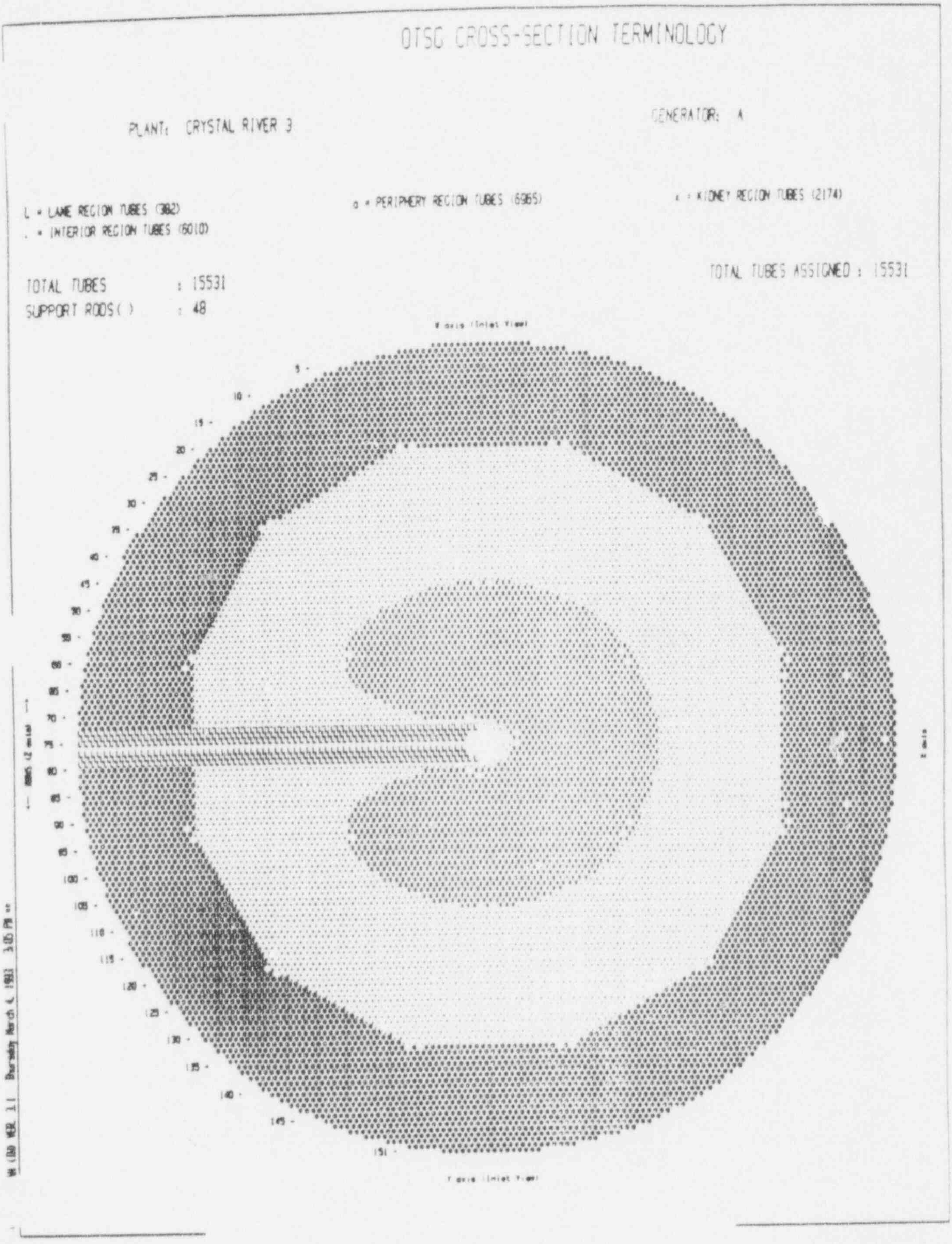

FIGURE 2: OTSG Tubesheet Map

Broached TSP Configuration

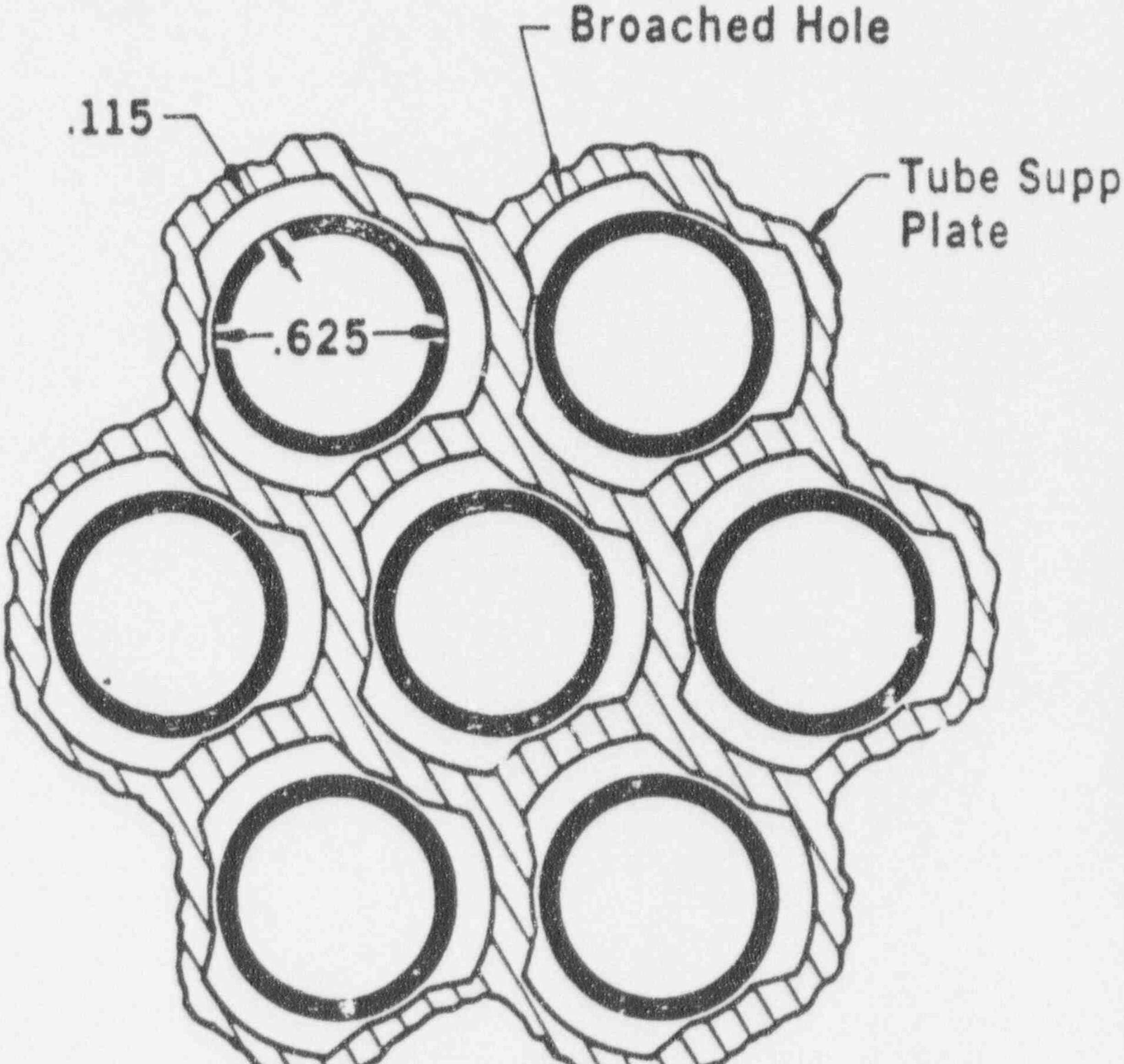

FIGURE 3: OTSG Broached Tube Support Plate

4.1 SUSCEPTIBILITY OF OTSG TUBING TO DEGRADATION

There are several design features of the OTSG which makes the OTSG less susceptible than recirculating steam generators to certain types of degradation:

1) Sensitization of Inconel 600 tubing in OTSGs makes the tubing less susceptible to caustic forms of corrosion.

2) The broached hole design of the OTSG tube support plates allow more flow than a drilled tube support plate. Therefore, there is less small crevice area where contaminants can collect and initiate corrosion.

3) OTSGs also have lower heat fluxes in areas where deposits, which can initiate corrosion, are most predominant (Fourth and Fifth Tube Support Plate region). The lower temperature differential in this region provides less concentrating mechanism to initiate under deposit corrosion; and

4) No large, hard sludge piles which can lead to corrosion have been observed at CR#3. Visual inspection of the CR#3 lower tube sheet secondary face indicates the presence of a very loose flake pile.

Corrosion-assisted high-cycle fatigue cracking is the primary cause of leaker outages in OTSGs. This type of damage mechanism was first confirmed on tubes removed from Oconee 1 and has been identified at other once-through units. The cracking is limited to the lane and wedge regions of the OTSG at elevations between the 14th TSP and upper tube sheet. CR#3 has never experienced a tube leak due to corrosion assisted high cycle fatigue. The area of the OTSG considered most susceptible to this damage mechanism is routinely inspected using RPC probes, with any crack-like indication removed from service. During Refuel 9, CR#3 will be installing upper tube sheet sleeves in tubes considered most susceptible to corrosion-assisted high-cycle fatigue. This will further eliminate the possibility for problems at CR#3 related to this damage mechanism.

Wear or tube fretting is flow related and has occurred at tube support plate intersections in tubes near the periphery of the tube bundle. Wear may be flat or tapered, and may occur at one or more of the broached tube support plate contact areas. It is generally detected at the 9th through 15th tube support plates. Wear indications have been observed in CR#3's "A" and "B" steam generators.

Impingement Erosion is an erosion/corrosion type phenomenon occurring from the flow of secondary side water with contaminants or debris entrapped in the secondary side water fluid steam. This type of damage generally occurs at the 10th tube support plate and above near the outer periphery.

Per reference 7, minor pitting has also been identified on tubes removed from OTSGs.

Intergranular Attack has been observed on tubes removed from four different OTSG plants. As stated in section 1 above, intergranular attack was determined to be the cause of S/N indications detected in the first span of the CR#3 "B" steam generator. The sensitized Alloy 600 microstructure of OTSG tubing is susceptible to IGA in acidic solutions containing reduced sulfur oxyanions, even when the sulfur is present in small quantities.

ECT indications observed at CR#3 predominantly indicate secondary side damage, typically characteristic of wear, pitting, or IGA.

It is important to note that no problems with outside diameter stress corrosion cracking (ODSCC) have been identified at CR#3 or any other operating OTSG plant.

5.0 STRUCTURAL ANALYSIS

5.1 MPR EVALUATION

A structural evaluation of maximum allowable OTSG tubing degradation was performed by MPR Associates, Inc. The report of this work is contained in Appendix B. MPR also provides a point by point discussion of the Regulatory Guide requirements as well as a conservative ASME Code Stress analyses.

Table 2-1 and Figures 1 and 2 of Appendix B provide the results of the structural analysis, which is conservative and bounding for any damage mechanism and defect geometry. Based on these results, it can be concluded that defects with dimensions less than or equal to the following are allowable per Regulatory Guide 1.121.

TABLE 1: MPR Calculated Dimensional Limits

Axial Size	Through-Wall Depth	Circumferential Size
0.25 inch	100%	122 degrees
0.5 inch	65.6%	187 degrees
0.75 inch	62%	198 degrees
1.5 inch	60.3%	204 degrees

The largest dimensional extents identified by metallographic examination of tubes removed from the CR#3 "B" steam generator in 1992 were 0.097 inch axial, 62% through wall, and 15.2 degrees circumferential. These dimensions were documented on three separate indications. Therefore, the actual size of degradation which resulted in eddy current signal to noise indications on pulled tubes examined following Refuel 8 is significantly smaller than those determined by MPR to be structurally significant.

5.2 BURST TESTS OF CR-3 PULLED TUBES

Two of the CR-3 tube samples were subject to burst testing prior to metallographic examination. The tube samples were 106-32 and 97-91. These tube sections contained a combined total of approximately 80 indications. Tube 97-91 contained indications with axial extents up to 0.0756 inches, through wall depths up to 54%, and circumferential extents up to 15.2 degrees. Tube 106-32 contained defects with axial extents up to 0.0979 inches, through wall depths up to 51%, and circumferential extents up to 9.7 degrees. The burst test pressures and location of failure are summarized below.

TABLE 2: CR#3 Burst Test Results

Tube No.	Number of Indications	Burst Pressure	Defect Depth at Burst
97-91	17	12,400 psi	54%
106-32	65	11,400 psi	40%

Both burst pressures are well above the Regulatory Guide 1.121 limit of 3 times operating differential pressure (3 x 1350 psid = 4050 psid). The burst pressure of unflawed OTSG tubing has been determined by testing to be approximately 13,000 psi, so the burst pressure of both defected tubes were above 85% of the virgin tube burst pressure.

5.3 HISTORICAL BURST TEST DATA COMPARISON

Tube burst pressure testing was performed as part of the Steam Generator Tube Integrity Program (SGTIP)/Steam Generator Group Project (SGGP). This three phase project was sponsored by the NRC and conducted by Pacific Northwest Laboratory, and is documented in Reference 2. The goal of the project was to provide the NRC with validated information on the reliability of nondestructive examination techniques to detect and size flaws in generator tubing and to determine the remaining integrity of service-degraded tubing.

The types of defects simulated during the SGTIP included wastage/pitting, uniform thinning, and axial cracks. These defects were both mechanically produced (Phase I) and chemically induced (Phase II). Data from burst pressure tests were used to develop empirical relationships between burst pressure, defect length, and defect depth. In addition, tubes pulled from the Surry 2A steam generator were used to verify the empirical models (Phase III).

This testing resulted in the development of burst pressure parameter curves similar to the one shown in Figure 4. The normalized burst pressure on the y-axis is the ratio of the burst pressure of the defected tube to the burst pressure of a virgin tube. The normalized defect length on the x-axis is a ratio of defect length to the square root of the radius of the tube times the tube thickness. Each curve represents a specific defect depth, expressed as the ratio of depth to the tube thickness.

Additional data of interest is also shown on Figure 4 for comparison to the empirical relationships. The burst test data from pulled Surry tubes reported in Reference 2 is shown. The flaw lengths at the failure location ranged from 0.06" to 0.53" with a percent through wall range of 24% to 80%. Burst pressures ranged from 62% to 97% of the virgin tube pressure. Also represented on the Figure is the Regulatory guide 1.121 limit of 3 times operating differential pressure for OTSG tubing.

Based on the maximum defect length of 0.097 inches reported from the destructive examination of CR-3 pulled tubes, the normalized length for the CR-3 tubes is shown on Figure 4. Since these indications are very small, it would be expected that the burst pressure is a high percentage of the virgin tube burst pressure. This is supported by the burst pressure testing of the two CR-3 samples summarized in the previous section.

It is also apparent that the CR-3 tubes fall into the area of the curve where burst pressure is not strongly related to the depth of the defect. For this axial size indication, even a 100% through wall defect would be expected to burst at a pressure above 70% of the virgin tube pressure (more than 7 times operating differential pressure). It is therefore concluded that the degraded tubes at CR-3 satisfy the Regulatory Guide 1.121 limits for burst pressure.

Figure 4 can also be used to project burst pressures for defects determined by MPR (section 5.2) to be allowable on OTSG tubing.

TABLE 3: Projected Burst Pressures for MPR Calculated Defect Dimensions

Axial Size	Through-Wall Depth	Projected Burst Pressure
0.25 in	100%	4,940 psi
0.5 in	65.6%	6,370 psi
0.75 in	62%	5,720 psi
1.5 in	60.3%	5,200 psi

As shown on Table 3, the projected burst pressures for defects determined by MPR to be allowable on OTSG tubing are well above the Regulatory Guide 1.121 limit of three times operating differential pressure, 4050 psi.

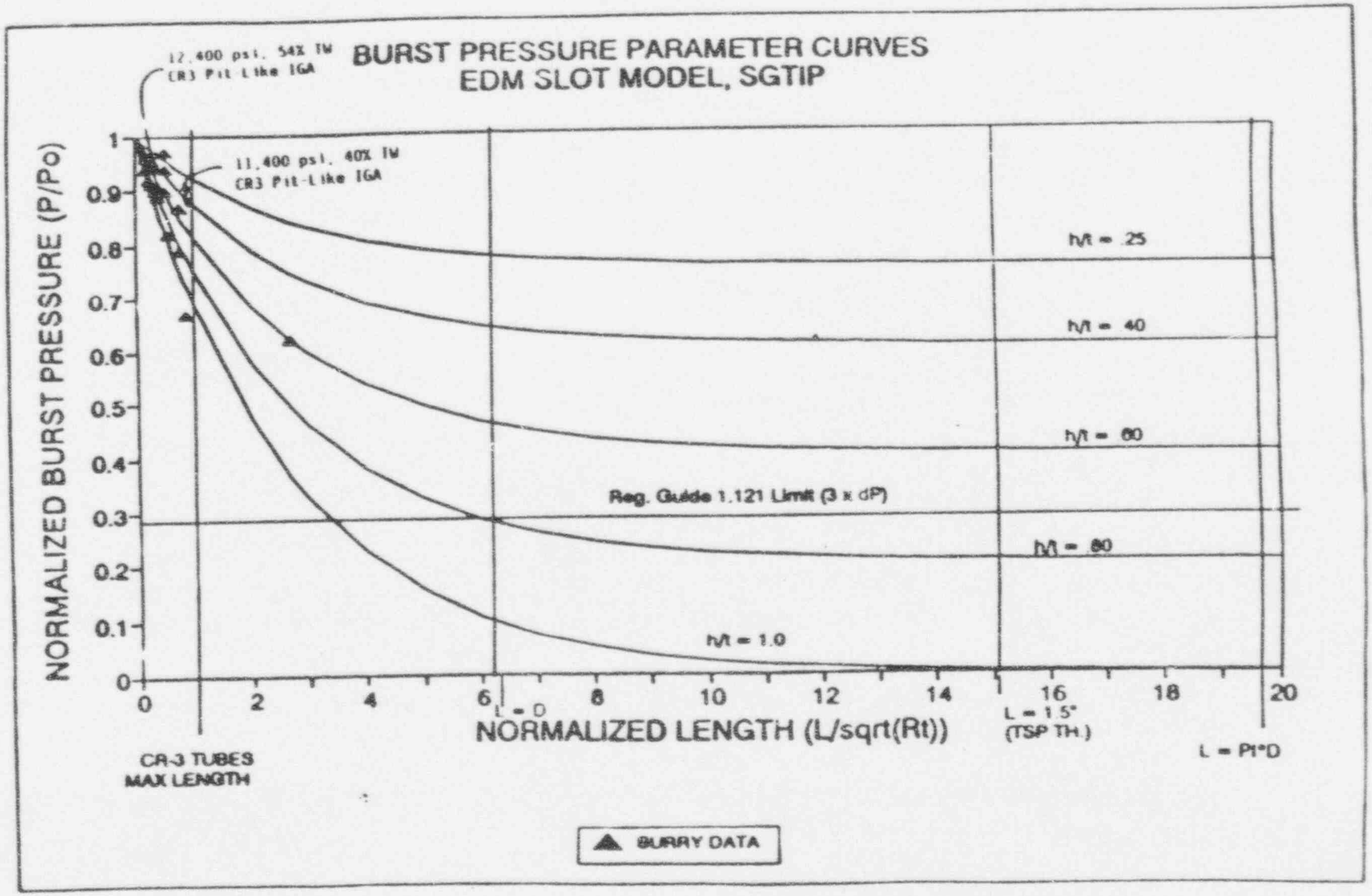

Figure 4: Historical Burst Test Data Burst Pressure Parameter Curve

5.4 COMPARISON OF PULLED TUBES WITH REMAINING TUBES WITH S/N INDICATIONS

Figure 5 shows a comparison of eddy current signals from indications on pulled tubes with the remaining S/N eddy current signals on CR#3 inservice tubes. This Figure plots the amplitude versus phase relationship for indications. It can be seen from this plot that pit-like IGA indications on the pulled tubes exhibit a phase/amplitude relationship typical of the majority of the remaining indications on inservice tubes. Signal amplitudes were generally less than 1 volt for both pulled tube indications and inservice S/Ns.

Review of RPC examination records for S/N indications outside the first span shows similar volumetric characteristics with no crack-like indications observed. Figures 6, 7, and 8 illustrate typical RPC probe terrain maps for pit-like IGA on tubes which were removed from the CR#3 "B" steam generator. Figures 9 through 15 illustrate typical RPC probe terrain maps for inservice S/Ns found at various locations in both the "A" and "B" steam generator.

Estimation by RPC clip plot of the axial and circumferential size of pit-like indications on tubes removed from the CR#3 "B" steam generator resulted in an average size range from 0.11 to 0.19 inch axial and from 0.14 to 0.25 inch circumferential.[4] Estimation of size for inservice S/N indications for which RPC data is available resulted in an average size range from 0.0625 to 0.20 inch axial and from 0.1 to 0.22 inch circumferential. Therefore, reasonable assurance exists that the remaining S/N indications in the "A" and "B" steam generators are approximately the same size as the very small volume pit-like IGA indications found in pulled tubes which have been determined to be structurally insignificant. Similarity in axial and circumferential size is illustrated in Figures 16 and 17.

A statistical analysis has also been performed by MPR Associates, Inc. for purposes of comparing data on pulled tubes to available information on inservice S/Ns. This analysis is included in this report as Appendix C. The MPR statistical analysis demonstrates from a purely mathematical standpoint that the pulled tube indications are a representative sample of the remaining inservice S/N indications with respect to signal amplitude and estimated axial and circumferential size.

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[4] As noted in section 7.5, use of MRPC clip plots to estimate axial and circumferential size of indications is conservative. When comparing the estimated axial and circumferential size of indications on pulled tubes to the actual sizes determined by metallographic examination of the indications, the estimated size is conservatively over estimated. The actual average size range of the indications on pulled tubes ranged from 0.01 to 0.075 inch axial and from 0.01 to 0.07 inch circumferential.

AMPLITUDE VS. PHASE RELATIONSHIP
CR-3 PULLED TUBES VS. REMAINING

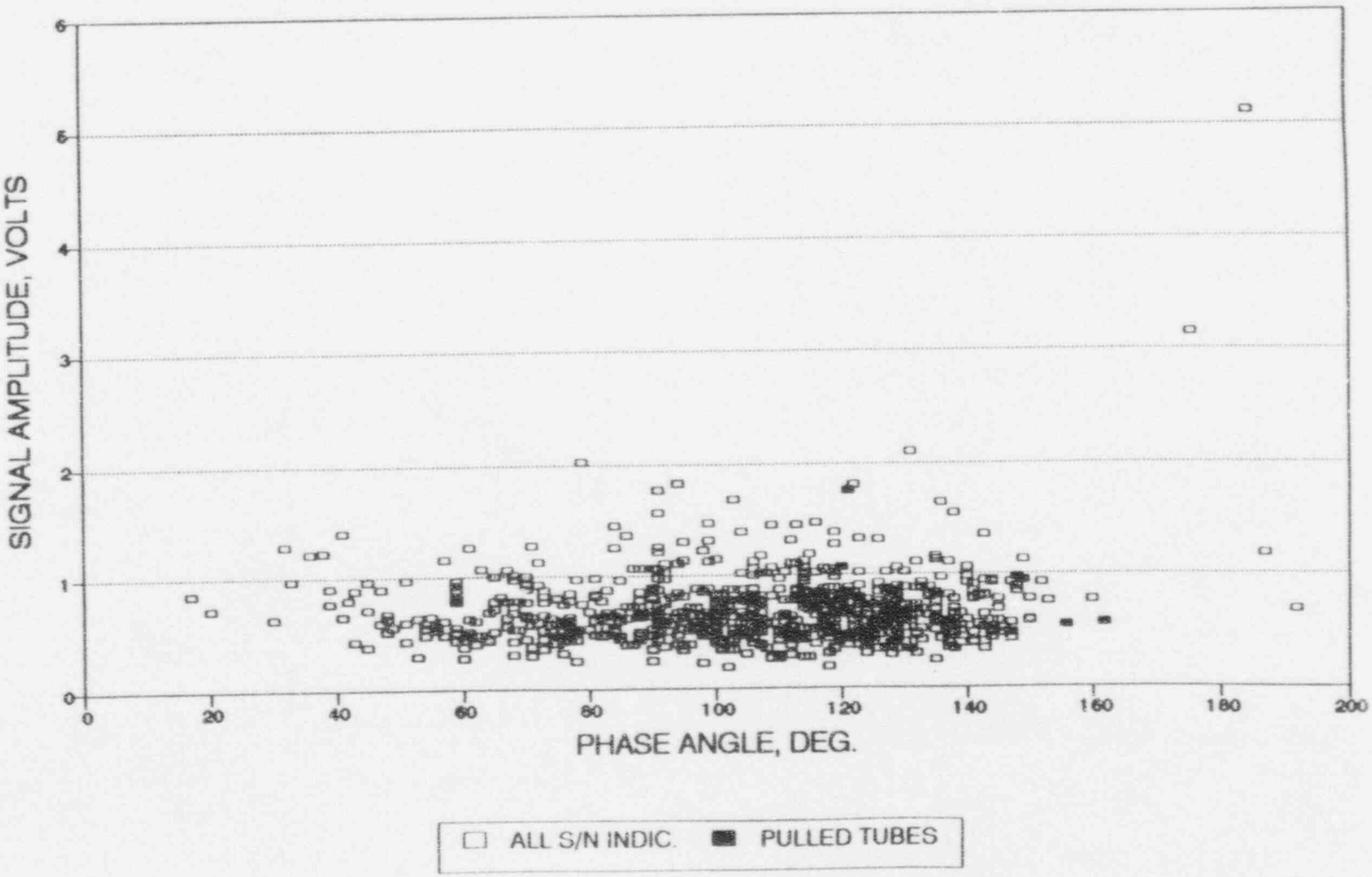

Figure 5: Comparison of S/N indications on pulled tubes to Inservice S/Ns

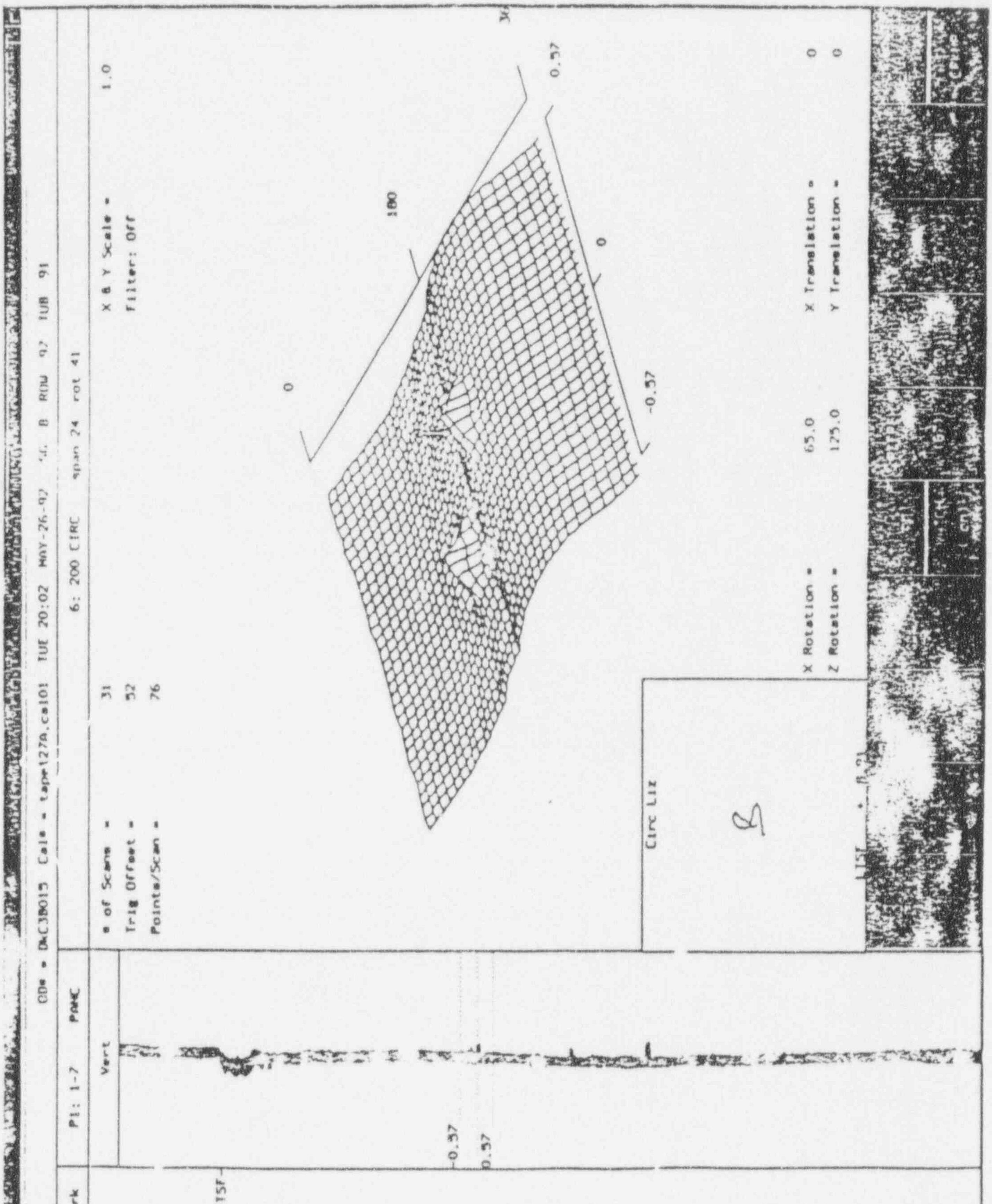

FIGURE 6: RPC Map of Indication on Pulled Tube 97-91

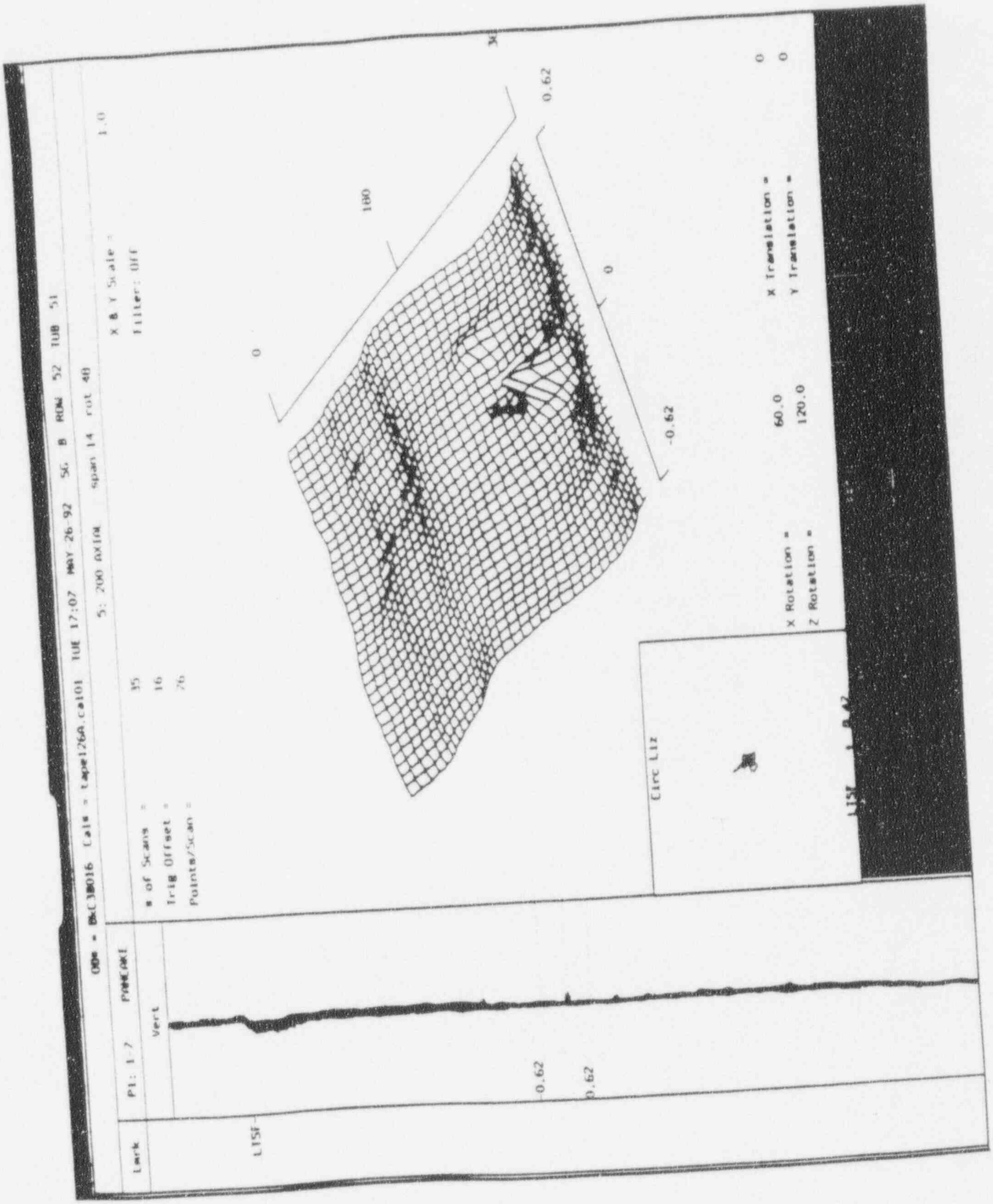

FIGURE 7: RPC Map of Indication on Pulled Tube 52-51

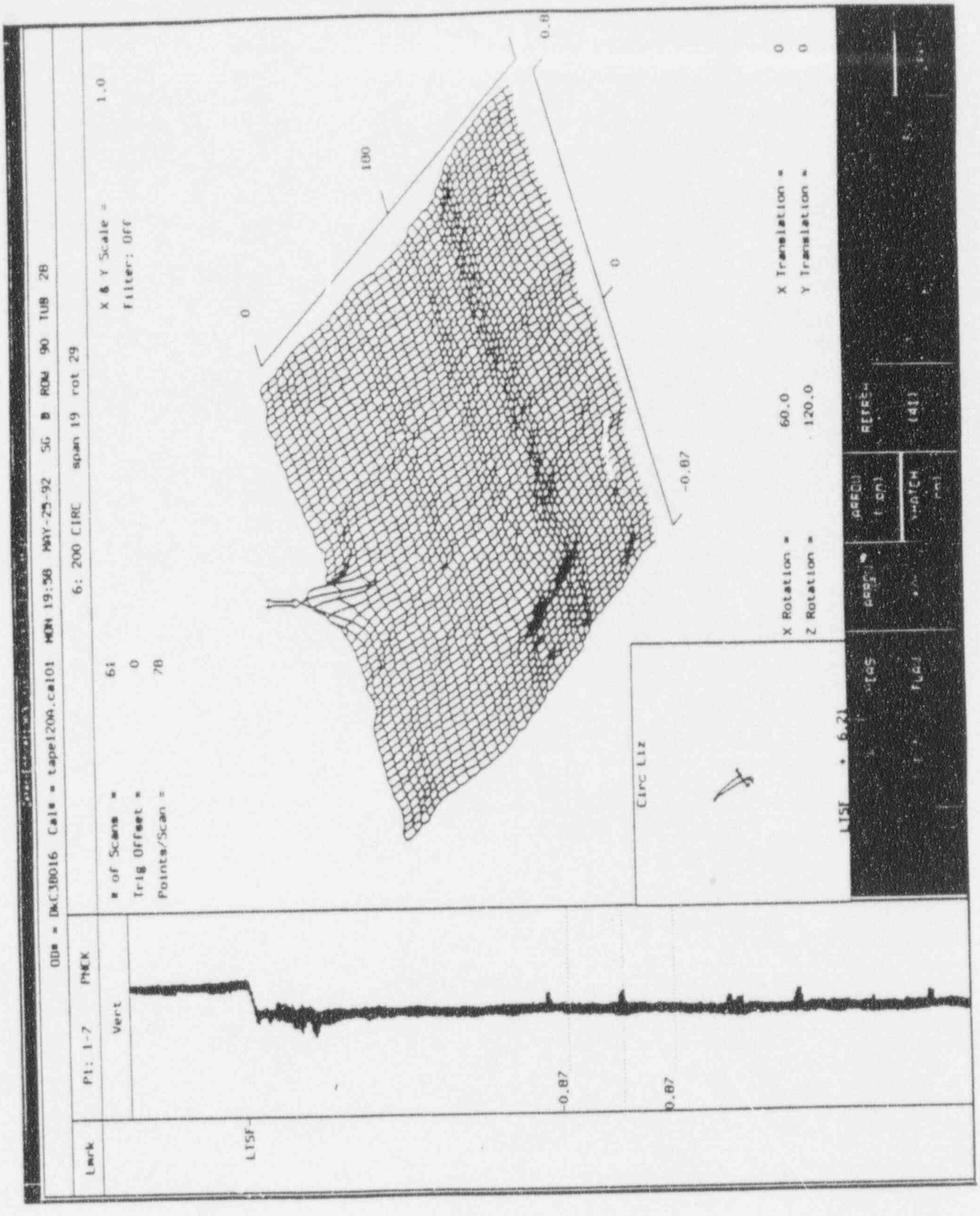

FIGURE 8: RPC Map of Indication on Pulled Tube 90-28

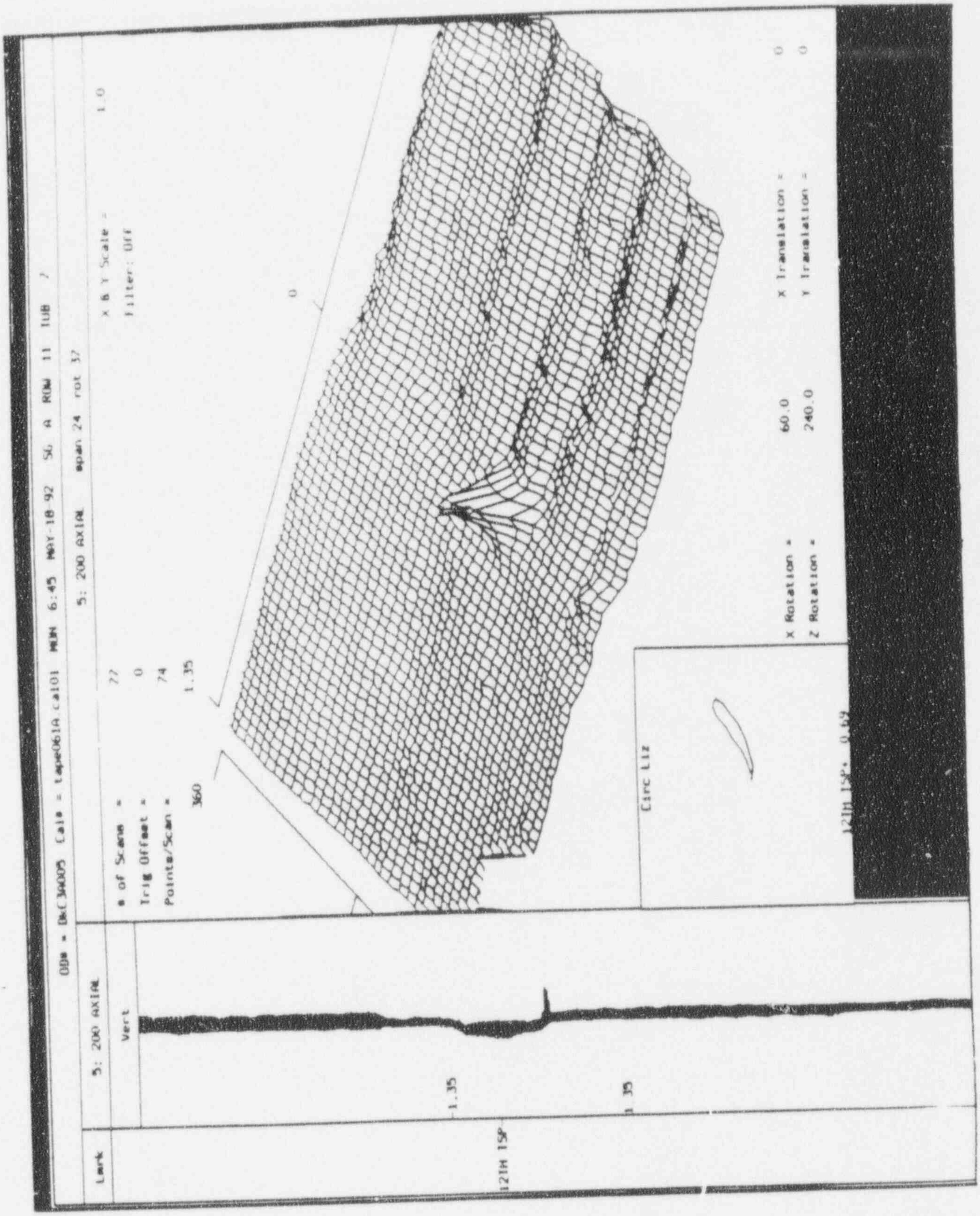

FIGURE 9: RPC Map of Inservice Indication on Tube "A" 11-7

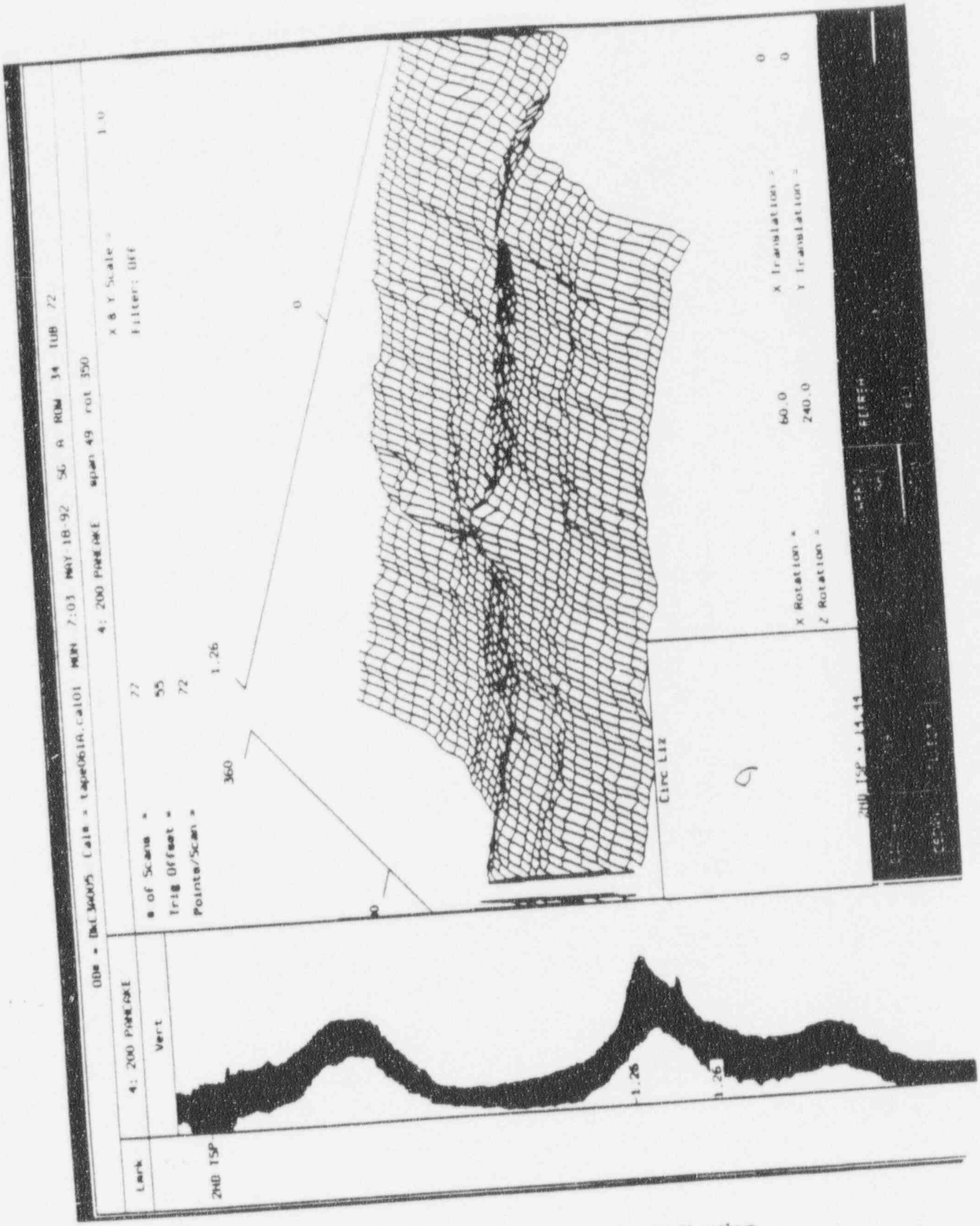

FIGURE 10: RPC Map of Inservice Indication on Tube "A" 34-72

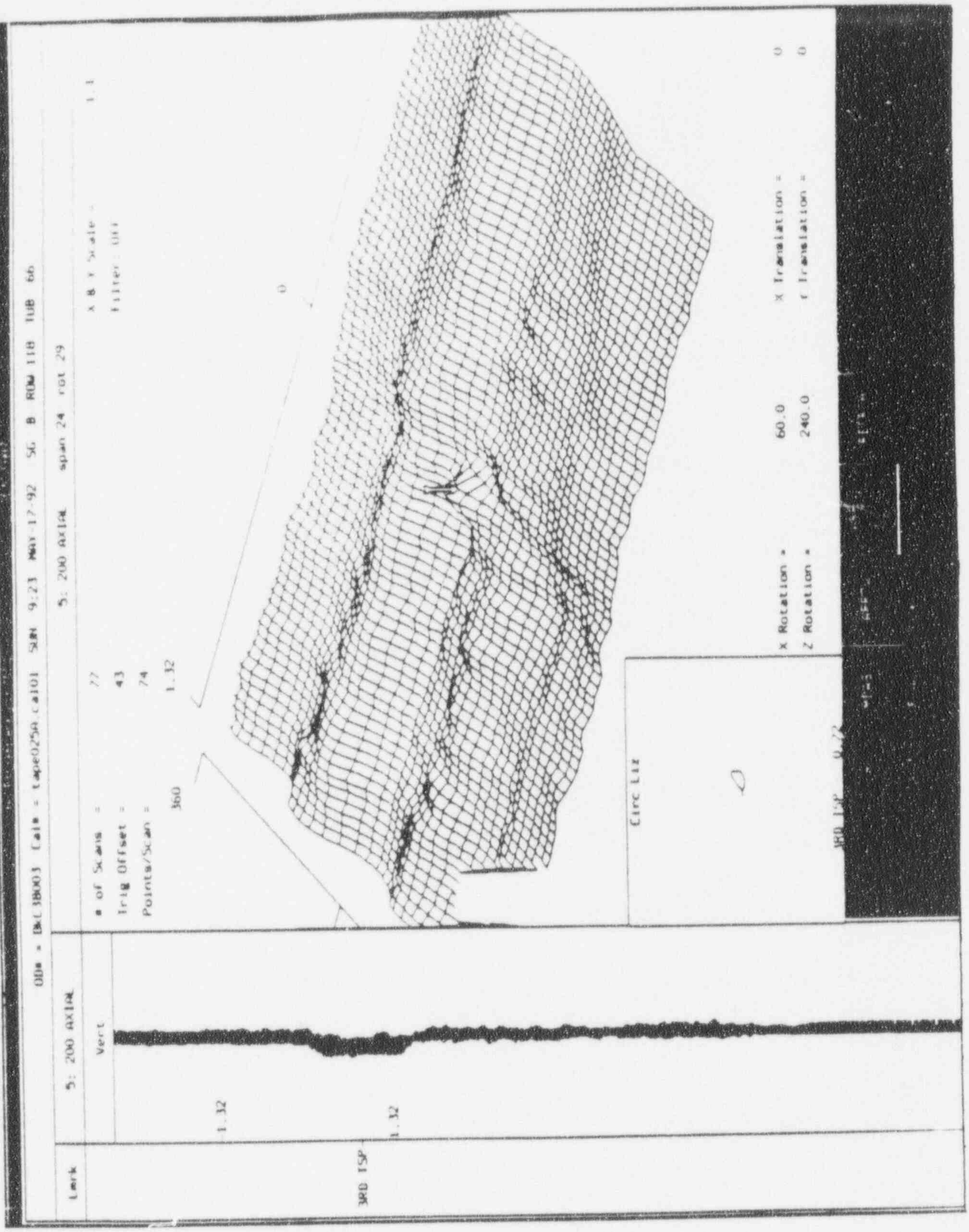

FIGURE 11: RPC Map of Inservice Indication on Tube "B" 118-66

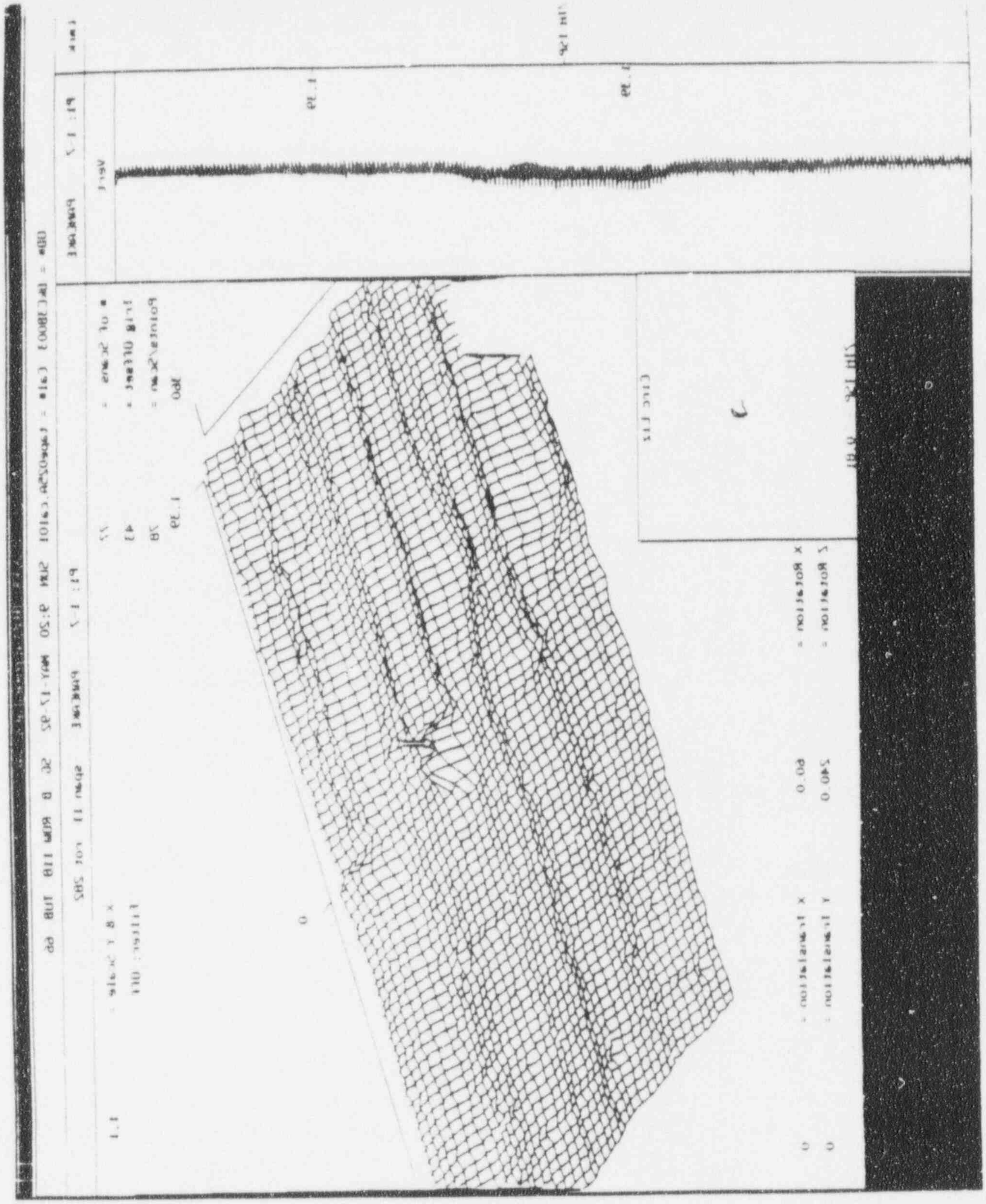

FIGURE 12: RPC Map of Inservice Indication on Tube "B" 118-66

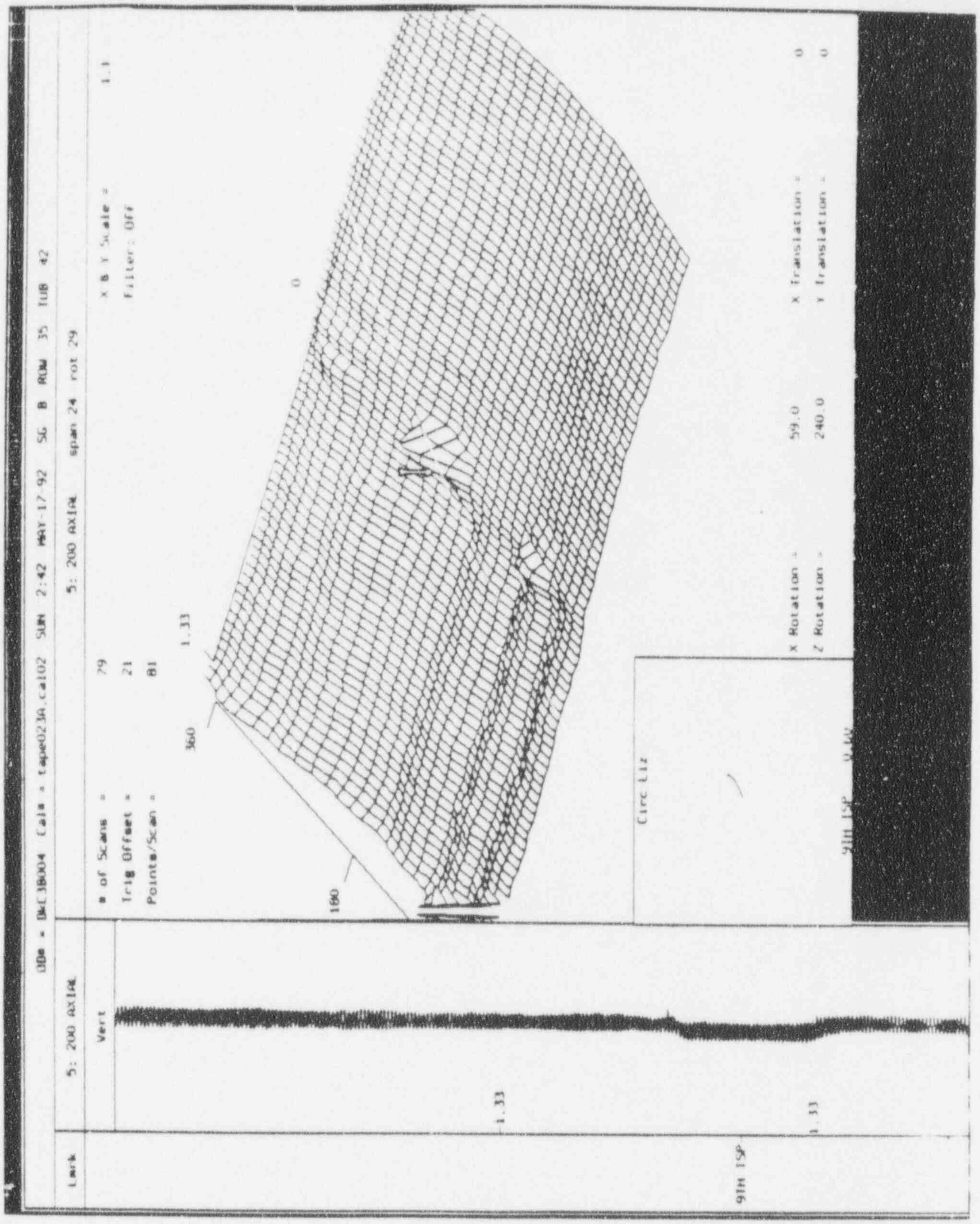

FIGURE 13: RPC Map of Inservice Indicationon Tube "B" 35-42

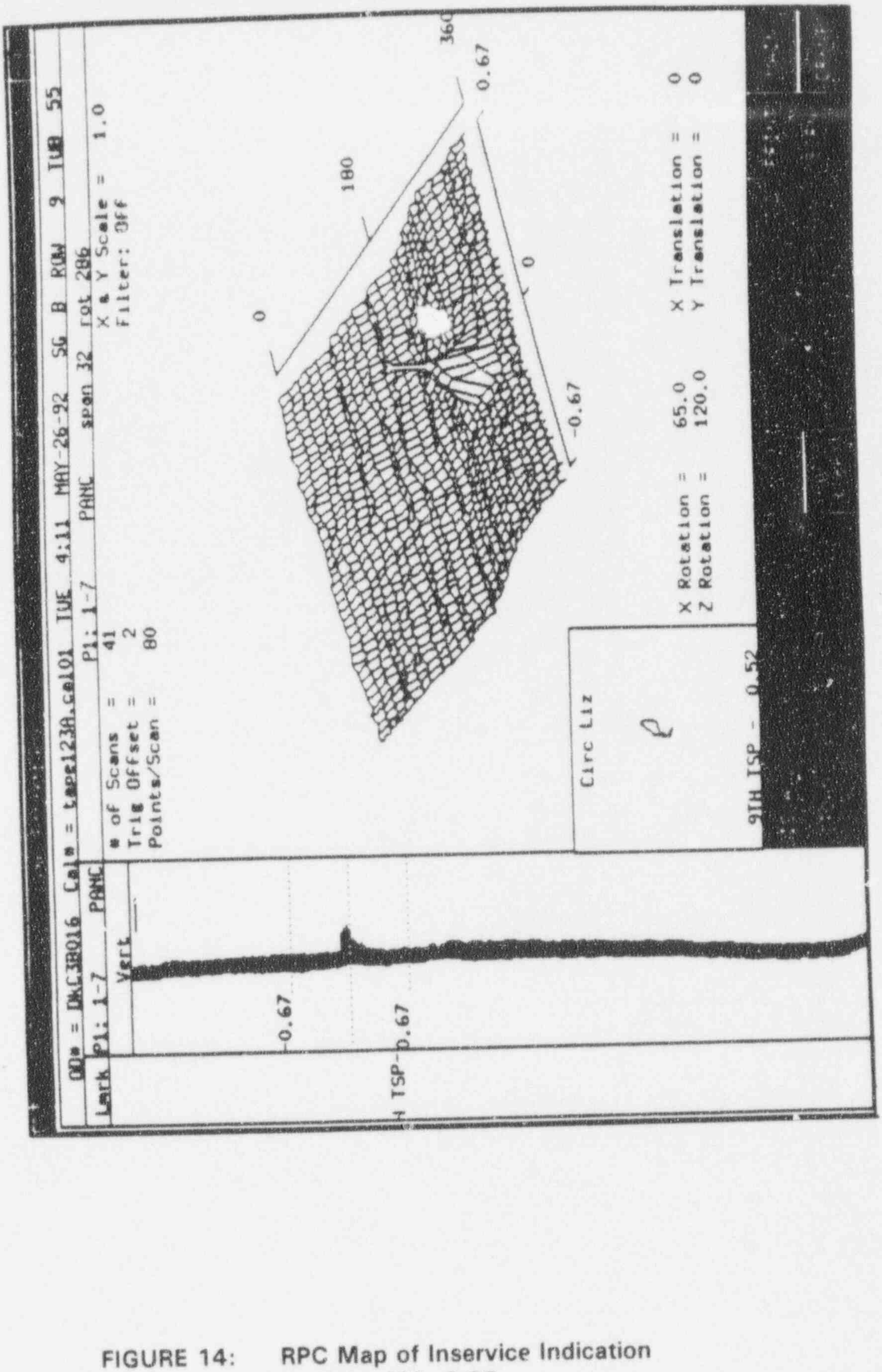

FIGURE 14: RPC Map of Inservice Indication on Tube "B" 9-55

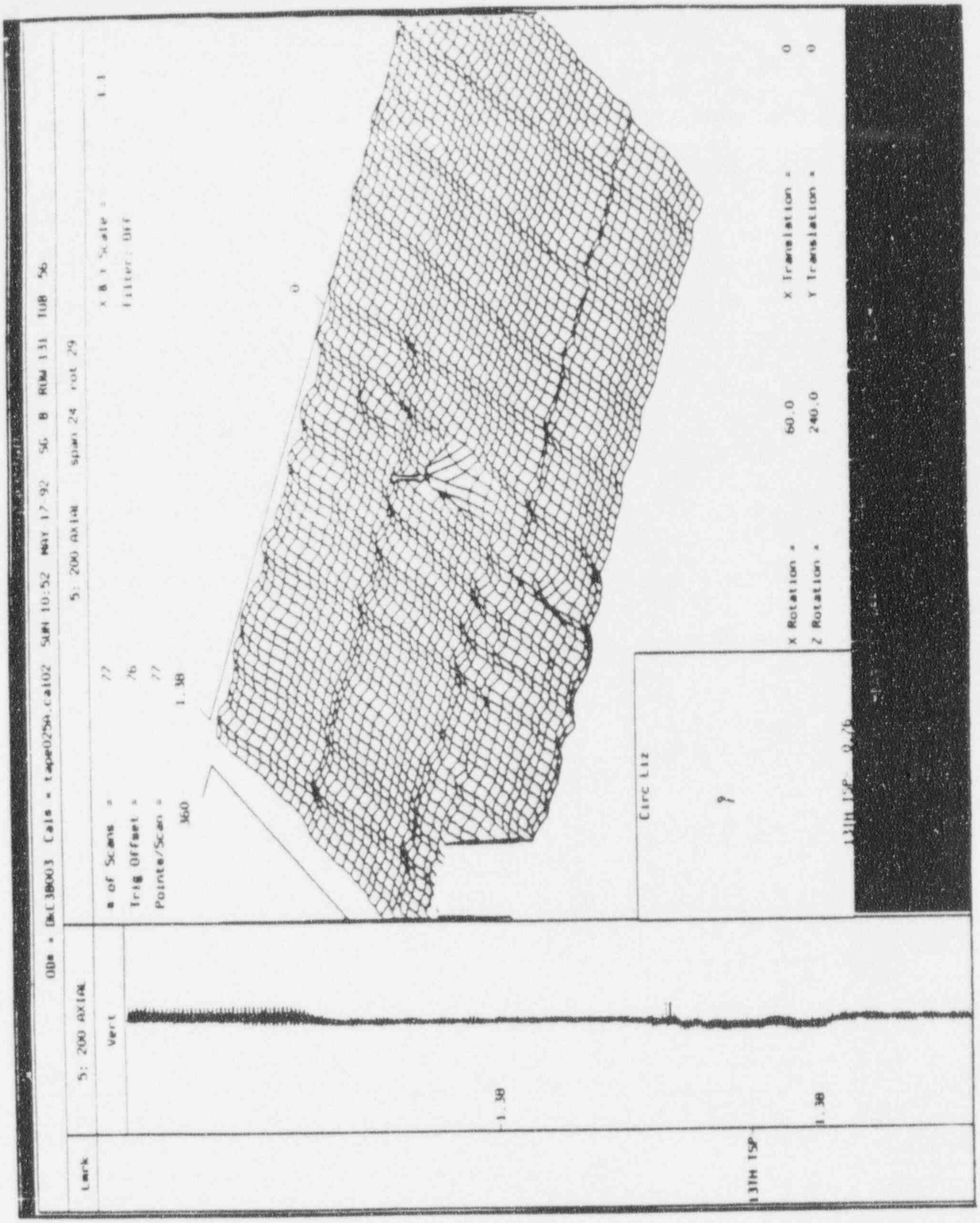

FIGURE 15: RPC Map of Inservice Indication on Tube "B" 131-56

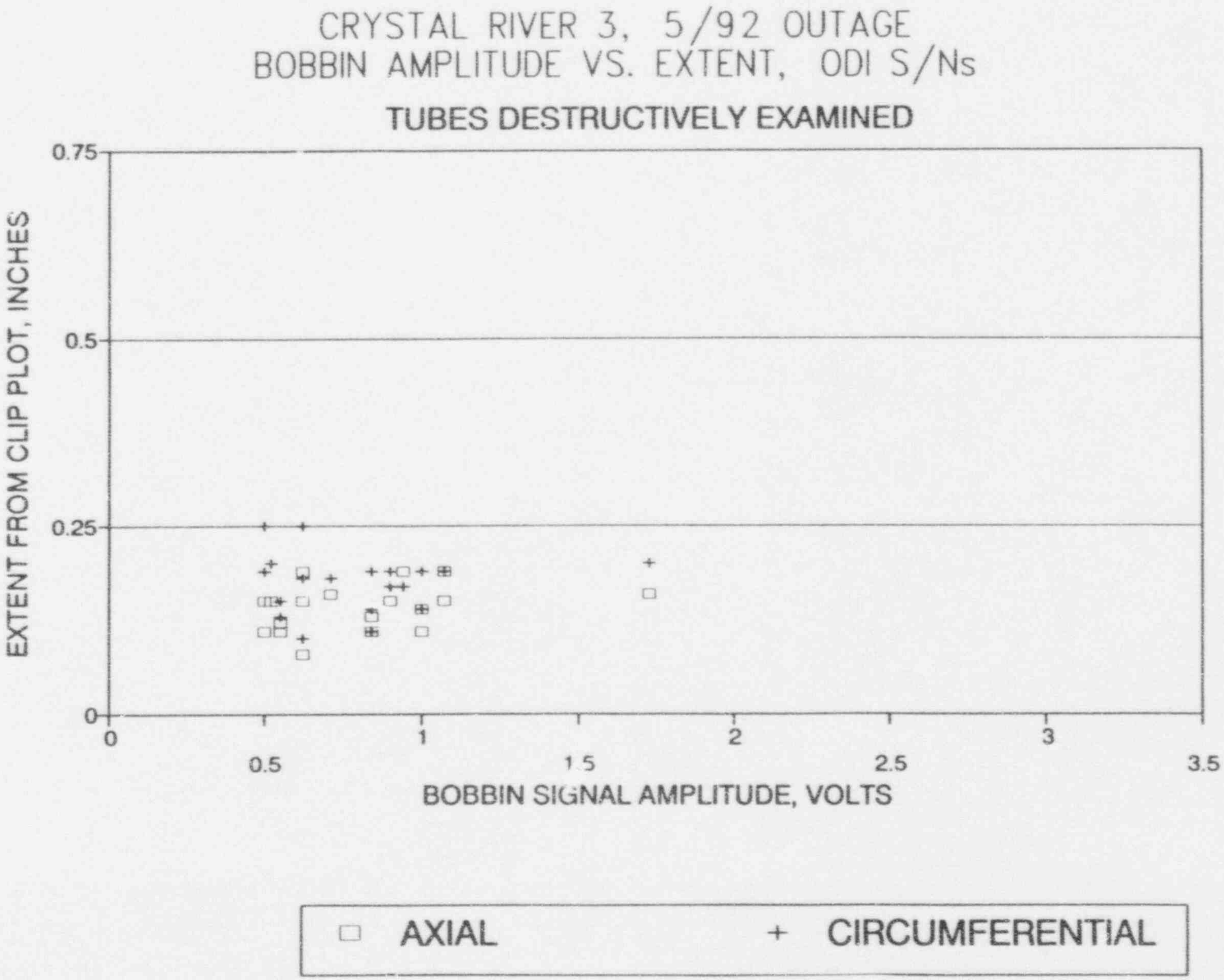

FIGURE 16: RPC estimated size of pulled tube indications

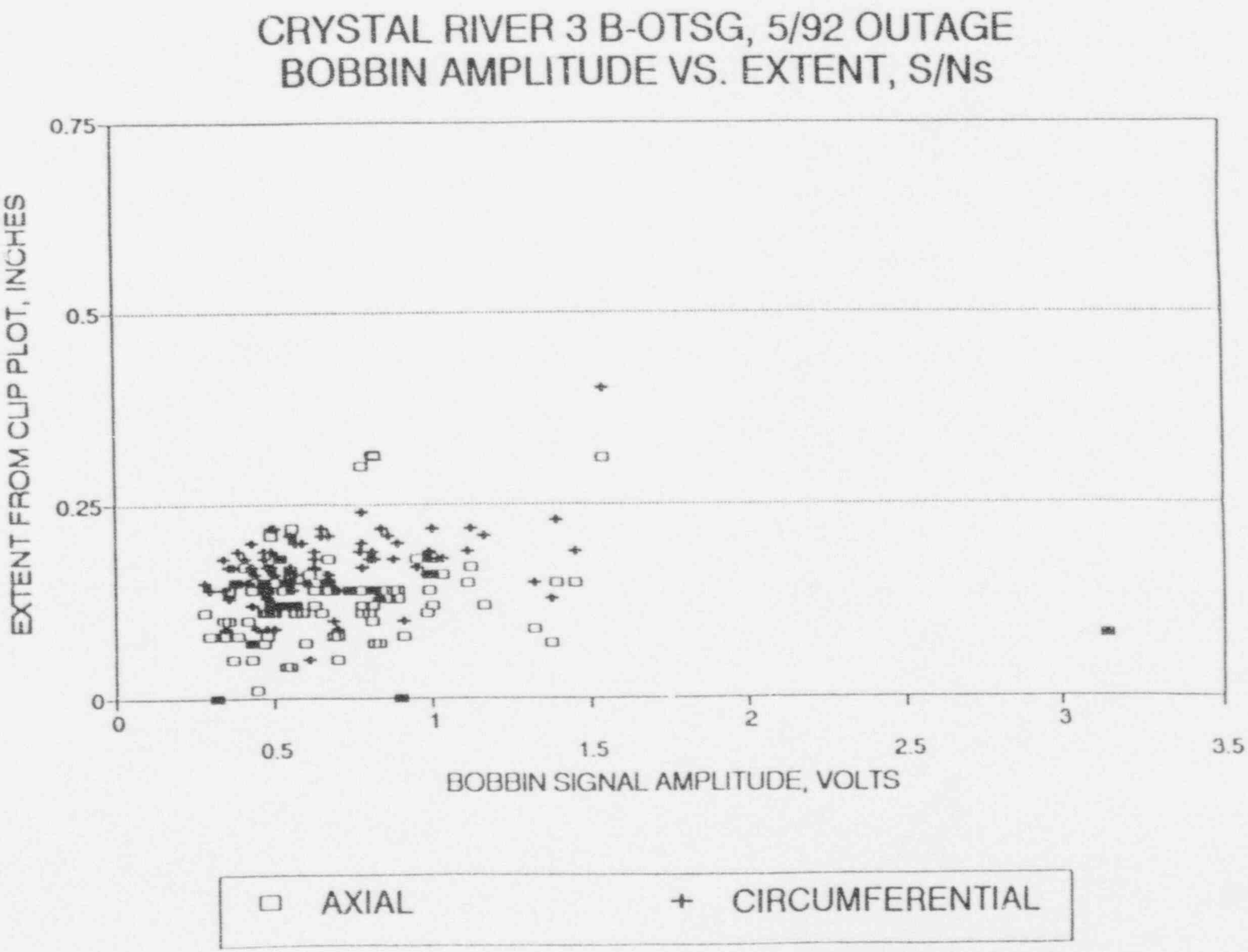

FIGURE 17: RPC estimated size of sample inservice S/Ns

6.0 GROWTH STUDIES

6.1 EPRI NDE CENTER REVIEW

The EPRI NDE Center performed an independent review of eddy current data for selected tubes examined during three previous inspections to assess growth of IGA indications observed in the first span of the "B" steam generator. Per Reference 3 (included as part of Appendix A), any growth or active damage form typically results in higher eddy current signal amplitude, accompanied by reduction in the phase angle. The net result is the overall increase in percent wall loss. Evaluation of data for CR#3 first span indications showed just the opposite effect. Decreased signal amplitude was observed, with only a slight increase in percent wall loss. The increase in percent wall loss was considered well within the sizing error band. Based on this result, EPRI concluded that the first span IGA patches have not grown since they were first detected.

6.2 BWNS REVIEW

In order to assess the growth rate of the tube flaws at CR#3, a growth study was performed on indications from the past three eddy current inspections (1989, 1990, 1992). This study is documented in Reference 10. A side by side comparison of eddy current signals was performed.

For the comparison, all data was normalized to 4 volts on the four 20% through wall flat bottom holes in the ASME calibration standard, using the 400 kHz frequency channel. The results are reproduced in Table 4 of this report for freespan and tube support plate indications. From Table 4 it can be seen that when all freespan indications are considered together, the average change in signal amplitude is +0.01 volts, with a standard deviation of 0.11 volts. The freespan indications therefore do not show evidence of growth, which is consistent with the conclusion reached for first span indications, documented in Reference 3.

The results from the growth study performed on support plate indications is also shown on Table 4. The average change in amplitude for these indications is -0.19 volts, with a standard deviation of 0.30 volts. The largest positive growth over one inspection cycle was 0.20 volts. The larger standard deviation associated with the support plate signal comparison is attributed to the variation in contribution of the support plate signal to the total signal response.

Based on growth studies which have been performed by BWNS, it can be said that neither the freespan nor the support plate indications have significant growth rates in the CR#3 steam generators.

TABLE 4: S/N Growth Study (Sheet 1 of 4)
CR-3 GROWTH EVALUATION OF FREESPAN INDICATIONS

	ROW	COL	LOCATION	1989 VOLTS	1990 VOLTS	1992 VOLTS	DELTA VOLTS	RATIO VOLTS
S/G B	83	56	001 + 31.46		0.60	0.71	0.11	1.18
S/G B	73	26	001 + 34.79		0.59	0.62	0.03	1.05
S/G A	48	111	002 + 24.73	0.47	0.39		-0.08	0.83
S/G B	74	25	002 + 25.96		0.31	0.36	0.05	1.16
S/G B	74	25	002 + 29.55		0.35	0.36	0.01	1.03
S/G B	93	22	002 + 35.20		0.61	0.68	0.07	1.11
S/G B	74	25	002 + 36.25		0.49	0.45	-0.04	0.92
S/G A	4	18	003 + 9.86	1.19	0.96	0.64	-0.55	0.54
S/G A	29	73	003 + 11.90		0.87	1.03	0.16	1.18
S/G A	61	88	004 + 9.63	0.54	0.42		-0.12	0.78
S/G A	25	81	008 + 1.46	0.83	0.75		-0.08	0.90
S/G A	27	93	008 + 3.34	0.15	0.14		-0.01	0.93
S/G A	27	93	008 + 12.40	0.71	0.64		-0.07	0.90
S/G A	27	93	008 + 22.54	0.51	0.52		0.01	1.02
S/G A	27	93	008 + 31.29	0.35	0.35		0.00	1.00
S/G A	61	88	010 + 8.79	0.72	0.65		-0.07	0.90
S/G A	16	41	011 + 16.07		0.57	0.70	0.13	1.23
S/G A	67	73	012 + 23.62		0.54	0.54	0.00	1.00
S/G B	121	1	013 + 16.97	0.42	0.44		0.02	1.05
S/G B	34	70	013 + 18.89		0.37	0.49	0.12	1.32
S/G B	80	41	014 + 11.88		0.65	0.61	-0.04	0.94
S/G B	62	7	015 + 1.67	0.68	0.79	0.54	-0.14	0.79
S/G B	63	5	015 + 6.99		0.82	1.01	0.19	1.23
S/G B	62	7	015 + 9.89	0.57	0.52	0.59	0.02	1.04
S/G B	62	7	015 + 21.19	0.51	0.56	0.70	0.19	1.37
S/G B	27	92	015 + 22.41		0.58	0.61	0.03	1.05
S/G B	27	92	015 + 22.70		0.81	0.78	-0.03	0.96
S/G B	62	7	015 + 24.75	0.73	0.81	0.86	0.13	1.18
S/G A	27	93	015 + 43.29	0.36	0.38		0.02	1.06
S/G A	27	93	015 + 43.65	0.85	0.81		-0.04	0.95
S/G B	89	43	LTS + 5.37		0.34	0.38	0.04	1.12
S/G B	46	44	LTS + 6.03		0.64	0.63	-0.01	0.98
S/G B	90	43	LTS + 6.42		0.82	0.74	-0.08	0.90
S/G B	58	83	LTS + 6.52		0.39	0.50	0.11	1.28
S/G B	64	39	LTS + 6.90		0.37	0.33	-0.04	0.89
S/G B	89	43	LTS + 7.00		0.68	0.78	0.10	1.15

TABLE 4: S/N Growth Study (Sheet 2 of 4)

CR-3 GROWTH EVALUATION OF FREESPAN INDICATIONS

	ROW	COL	LOCATION	1989 VOLTS	1990 VOLTS	1992 VOLTS	DELTA VOLTS	RATIO VOLTS
S/G B	48	47	LTS + 7.28		0.53	0.62	0.09	1.17
S/G B	49	35	LTS + 7.40		0.81	0.97	0.16	1.20
S/G B	46	44	LTS + 7.42		0.54	0.64	0.10	1.19
S/G B	117	44	LTS + 7.47		0.48	0.46	-0.02	0.96
S/G B	48	47	LTS + 7.90		0.60	0.64	0.04	1.07
S/G B	90	44	LTS + 8.22		0.54	0.59	0.06	1.09
S/G B	63	29	LTS + 8.29		0.50	0.59	0.09	1.18
S/G B	46	48	LTS + 8.71		0.64	0.68	0.04	1.06
S/G B	61	38	LTS + 9.36		0.60	0.71	0.11	1.18
S/G B	104	51	LTS + 9.56		0.72	0.76	0.04	1.06
S/G B	104	31	LTS + 9.97		0.81	0.81	0.00	1.00
S/G B	105	36	LTS + 10.11		0.65	0.56	-0.09	0.86
S/G B	69	99	LTS + 11.09	0.52		0.43	-0.09	0.83
S/G B	110	45	LTS + 11.22		0.62	0.51	-0.11	0.82
S/G B	63	29	LTS + 11.49		0.60	0.62	0.02	1.03
S/G B	97	27	LTS + 11.55		0.83	0.78	-0.06	0.94
S/G B	103	44	LTS + 11.66		0.71	0.60	-0.11	0.85
S/G B	64	39	LTS + 12.33		0.38	0.39	0.01	1.03
S/G B	103	44	LTS + 12.36		0.67	0.54	-0.13	0.81
S/G B	63	29	LTS + 12.37		0.39	0.46	0.07	1.18
S/G B	96	43	LTS + 12.54		0.57	0.44	-0.13	0.77
S/G B	52	81	LTS + 12.85	0.54	0.42	0.47	-0.07	0.87
S/G B	46	44	LTS + 13.25		0.49	0.59	0.10	1.20
S/G B	49	49	LTS + 13.61		0.42	0.55	0.13	1.31
S/G B	67	43	LTS + 14.64		0.55	0.57	0.02	1.04
S/G B	70	42	LTS + 14.71		0.76	0.76	0.00	1.00
S/G B	63	39	LTS + 15.42		0.37	0.46	0.09	1.24
S/G B	70	42	LTS + 15.67		0.52	0.55	0.03	1.06
S/G B	46	44	LTS + 24.60		0.52	0.51	-0.01	0.98
	AVG. DEV.						0.01	1.03
	STD. DEV.						0.11	0.16

TABLE 4: S/N Growth Study (Sheet 3 of 4)
CR-3 GROWTH EVALUATION OF SUPPORT PLATE INDICATION

	ROW	COL	LOCATION	1989 VOLTS	1990 VOLTS	1992 VOLTS	DELTA VOLTS	RATIO VOLTS
S/G A	28	93	007 + 0.00	0.85	1.27	0.69	-0.16	0.81
S/G B	59	113	007 - 0.66	0.83	0.77		-0.06	0.93
S/G B	67	52	007 - 0.69	0.90	0.84	0.93	0.03	1.03
S/G B	66	58	007 - 0.72	0.72	0.70		-0.02	0.97
S/G B	88	12	007 - 0.72	0.91	0.74		-0.17	0.81
S/G B	92	36	007 - 0.73		0.80	0.68	-0.12	0.85
S/G B	142	11	007 - 0.73		0.38	0.35	-0.03	0.92
S/G A	114	109	007 - 0.74		0.39	0.28	-0.11	0.72
S/G B	119	63	007 - 0.75	0.68	0.69	0.81	0.13	1.19
S/G B	142	12	007 - 0.75		0.35	0.28	-0.07	0.80
S/G B	130	23	007 - 0.76		0.82	0.58	-0.24	0.71
S/G B	136	32	007 - 0.76		1.24	0.62	-0.62	0.50
S/G B	17	74	007 - 0.77		1.43	0.69	-0.74	0.48
S/G B	109	52	007 - 0.78		0.80	0.53	-0.27	0.66
S/G B	145	34	007 - 0.78		0.51	0.61	0.10	1.20
S/G B	146	14	007 - 0.78		1.05	0.64	-0.41	0.61
S/G A	14	8	007 - 0.79		0.41	0.52	0.11	1.27
S/G B	132	30	007 - 0.79		1.06	0.24	-0.82	0.23
S/G B	132	36	007 - 0.79		0.96	0.31	-0.65	0.32
S/G B	133	35	007 - 0.79		1.41	0.26	-1.15	0.18
S/G B	141	29	007 - 0.79		0.41	0.16	-0.25	0.39
S/G B	128	43	007 - 0.80		0.51	0.34	-0.17	0.67
S/G B	144	15	007 - 0.80		0.76	0.71	-0.05	0.93
S/G B	144	22	007 - 0.81		0.41	0.31	-0.10	0.76
S/G B	144	24	007 - 0.81		0.37	0.14	-0.23	0.38
S/G B	117	73	007 - 0.84		0.51	0.47	-0.04	0.92
S/G B	144	12	007 - 0.84		0.67	0.58	-0.09	0.87
S/G B	57	39	007 - 0.86		0.71	0.52	-0.19	0.73
S/G B	147	24	007 - 0.86		0.53	0.39	-0.14	0.74
S/G B	150	15	007 - 0.87		0.64	0.66	0.01	1.02
S/G B	144	56	007 - 0.90		0.35	0.40	0.05	1.14
S/G B	117	71	007 - 0.95		0.39	0.33	-0.06	0.85
S/G A	73	126	008 + 0.00		0.51	0.53	0.02	1.04
S/G A	28	93	008 + 0.64	0.67	0.44	0.61	-0.06	0.91
S/G B	58	125	008 - 0.73	0.44	0.58		0.14	1.32

TABLE 4: S/N Growth Study (Sheet 4 of 4)

CR-3 GROWTH EVALUATION OF SUPPORT PLATE INDICATION

	ROW	COL	LOCATION	1989 VOLTS	1990 VOLTS	1992 VOLTS	DELTA VOLTS	RATIO VOLTS
S/G A	94	129	008 - 0.74	0.75	0.55	0.65	-0.10	0.87
S/G A	62	128	008 - 0.77		0.40	0.45	0.05	1.13
S/G B	6	46	008 - 0.77		1.44	0.50	-0.94	0.35
S/G B	148	26	008 - 0.81	?????	0.82	0.14	-0.68	0.17
S/G B	59	120	008 - 0.83	0.56	0.76		0.20	1.36
S/G B	31	7	008 - 0.84		0.43	0.57	0.14	1.33
S/G A	61	1	009 + 0.59	1.15	0.83	0.68	-0.47	0.59
S/G B	4	19	009 + 0.66		0.50	0.45	-0.06	0.90
S/G A	88	53	009 + 0.75	0.60	0.52		-0.08	0.87
S/G B	86	6	009 + 0.78	0.60	0.55	0.50	-0.10	0.83
S/G B	54	124	009 - 0.68		0.33	0.23	-0.10	0.70
S/G B	82	6	009 - 0.72		0.58	0.62	0.04	1.07
S/G B	82	38	009 - 0.72		0.69	0.42	-0.27	0.61
S/G B	6	49	009 - 0.76	1.26	1.22	0.46	-0.80	0.37
S/G B	14	7	009 - 0.78		0.91	0.40	-0.51	0.44
S/G B	4	24	009 - 0.81	1.27	1.10	0.46	-0.81	0.36
S/G B	10	12	009 - 0.83	0.86	1.10	0.44	-0.42	0.51
S/G B	146	26	009 - 0.85		0.59	0.09	-0.50	0.15
S/G A	22	59	010 + 0.66		0.46	0.31	-0.15	0.67
S/G B	149	30	010 + 0.66		0.53	0.40	-0.13	0.75
S/G A	56	3	010 + 0.73		0.44	0.60	0.16	1.36
S/G B	151	3	010 - 0.68		0.42	0.28	-0.14	0.67
S/G B	127	96	010 - 0.73	0.49		0.56	0.07	1.14
S/G B	151	13	010 - 0.75		0.76	0.63	-0.13	0.83
S/G A	149	20	010 - 0.77		0.44	0.50	0.06	1.14
S/G A	148	36	010 - 0.78		0.42	0.47	0.05	1.12
S/G A	146	50	010 - 0.79		0.54	0.51	-0.03	0.94
	AVG. DEV.						-0.19	0.79
	STD. DEV.						0.30	0.31

7.0 EDDY CURRENT CORRELATIONS

Metallographic data from indications found on sections of four tubes removed from the CR#3 steam generators were used to evaluate the ability of eddy current examination to detect and size degradation. Indications on the subject tubes were physically characterized as pit-like intergranular attack (IGA) with wall metal in place. IGA occurs as the result of grain boundary degradation. Physically, there is no metal loss. As a result, IGA causes only a slight decrease in conductivity over an area and is more difficult to detect and size than other damage mechanisms where wall metal loss occurs. Per Reference 7, experience at recirculating units confirms that detection and sizing of IGA using conventional eddy current techniques is less reliable than for other volumetric forms of degradation where metal loss occurs. Therefore, detection rates and sizing techniques based on correlation of eddy current data to actual metallographic data for CR#3 IGA indications are considered conservative when applied to other volumetric type indications.

7.1 EPRI CORRELATION OF CR#3 PULLED TUBE DATA

Following destructive examination of CR#3 pulled tubes, the EPRI NDE center was requested to perform an evaluation to determine the accuracy of detectability and sizing for CR#3 pit-like IGA. Reference 3 (included as part of Appendix A) provided the results of this evaluation.

CR#3 pit-like IGA was found by EPRI to be detectable 80% of the time for 45% and greater through wall penetration with eddy current bobbin coils. This detection rate is consistent with industry experience.

To evaluate the accuracy of bobbin coils to size IGA patches, eddy current depth estimates were compared with metallurgical test results. Sizing accuracy was evaluated using a linear regression analysis by comparing eddy current estimates made using bobbin coil phase angle to metallurgical test results.

In general, flaw sizing accuracy increases as the value of best-fit slope and correlation coefficient increases. However, sizing precision decreases with increasing RMS error values. For optimal flaw sizing, a correlation coefficient of greater than 80% with RMS error of less than 20% is desirable. Under this condition, the slope of the best-fit line generally falls between 0.8 and 1.2.

For CR#3 pulled tube data, a high degree of scatter was observed in comparing eddy current estimates made using bobbin coil phase angle to metallurgical test results. The best statistical values obtained were a 25% correlation coefficient and 27% RMS error with a slope of 0.646. As a result, it was determined that the bobbin coil phase angle method of sizing could not be used for CR#3 small volume pit-like IGA. This condition is not unique to CR#3 but generally applicable to the whole industry.

Since bobbin coil phase angle methodology was found by EPRI to be unreliable for use in estimating IGA through wall depths, EPRI was asked to evaluate sizing accuracy using signal amplitude (voltage) in lieu of bobbin coil phase angle. The report of this work is included as Appendix D.

EPRI reevaluated the CR#3 pulled tube eddy current data to determine if a correlation could be developed using signal amplitude. As a result of this evaluation, correlation curves were developed for 200, 400, and 600 kHz frequencies which could be used to estimate through wall size of pit-like IGA using signal amplitude. The curves were then used by EPRI to estimate IGA depths for comparison to actual metallurgical data. Best results were obtained using a 600 kHz differential VMax amplitude curve. A correlation coefficient of 74% with an RMS error of 8% and slope of 0.83 was achieved. These values represent significant improvements over the statistical values obtained using bobbin coil phase angle to estimate IGA size.

Although useful, the correlation curves developed for the various frequencies could not be used in their original form by Eddynet analysis software. Figure 18 shows a calibration curve that was subsequently developed by EPRI from the 400 kHz differential correlation curve for use with analysis software.[5] Figure 18 has a built in conservatism in that the voltages shown on the horizontal access are based on the Vmax voltage response and not the peak to peak response. Vmax readings represent only the vertical component of the eddy current signal whereas voltages reported during field eddy current are typically reported as peak to peak voltages. Peak to Peak voltages are always greater than Vmax voltages unless the phase angle is exactly 90°. Therefore, higher voltages would have been shown on the horizontal axis for each corresponding percent through wall if the peak to peak voltages had been used to develop the curve.

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[5] Use of the 400 kHz differential data to develop the calibration curve does not prohibit application of the calibration curve to data obtained from the 600 kHz differential frequency. The correlation coefficients, RMS errors, and Slopes obtained when comparing 400 kHz and 600 kHz data were essentially the same. Therefore, a calibration curve developed using either data set would be essentially the same as that shown on Figure 18.

The conservatism of Figure 18 is demonstrated by plotting the ACTUAL percent through wall depth versus the peak to peak 600 kHz voltage along with the estimated percent through wall depth for eleven indications from pulled tubes. Estimated percent through wall depths are shown plotted on the calibration curve in Figure 19. Arrows represent the relationship between each estimated percent through wall depth and the ACTUAL percent through wall depth of that indication. As shown on Figure 19, the calibration curve significantly overestimated the through wall depth of eight of the eleven indications. Two of the eleven indications had almost a one to one relationship between estimated and actual percent throughwall and only one indication was underestimated by the calibration curve.

From Figure 18, CR#3 freespan IGA patches are projected to be 100% through-wall at a bobbin coil voltage of approximately 3.4 volts. Appendix F provides information on how a linear regression model was used to establish the 95% confidence level voltage value for 100% through wall penetration based on 400 kHz data used by EPRI to develop Figure 18. As shown on Figure 20, the 95% confidence level line reaches a predicted 100% through wall penetration at 2.73 volts. The same prediction is shown on Figure 21 using a simplified approach. In Figure 21, upper and lower bound curves are provided which illustrate application of a factor of one and a factor of two to the standard deviation calculated from the 400 kHz data used to develop the curve. Based on two times the standard deviation, predicted 100% through wall penetration would occur at 2.8 volts.

Tube support plate indications are typically examined using a 600-200 mix frequency as the prime analysis frequency to suppress signal contribution due to the presence of the tube support plate. Since Figure 18 was developed using data from freespan indications, it cannot be directly applied to indications located at tube support plates without adjustment. The effect of mix frequency on signal amplitude will be discussed further in section 8.0.

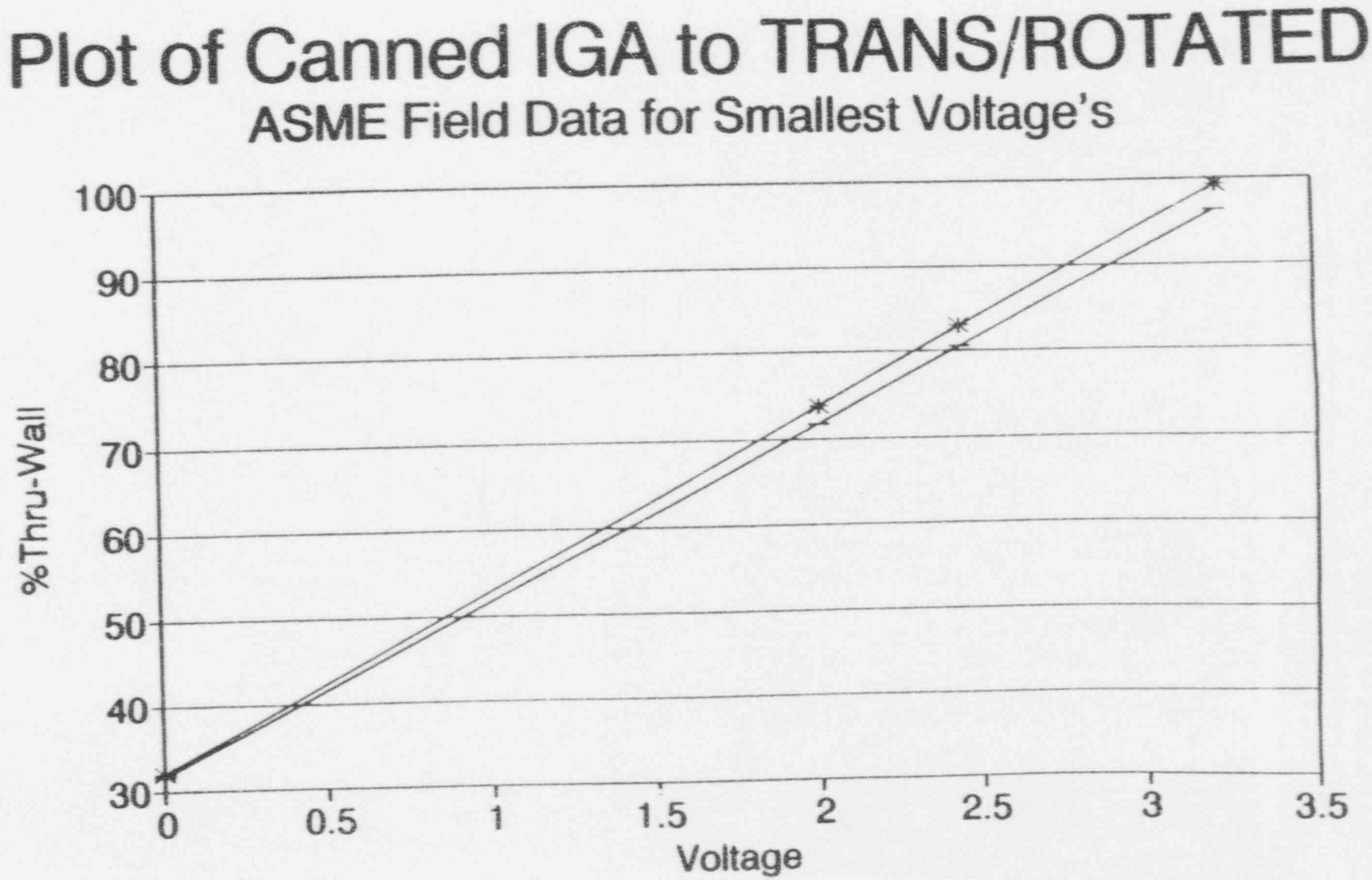

FIGURE 18: EPRI IGA CALIBRATION CURVE

Plot of Canned IGA to TRANS/ROTATED

ASME Field Data for Smallest Voltage's

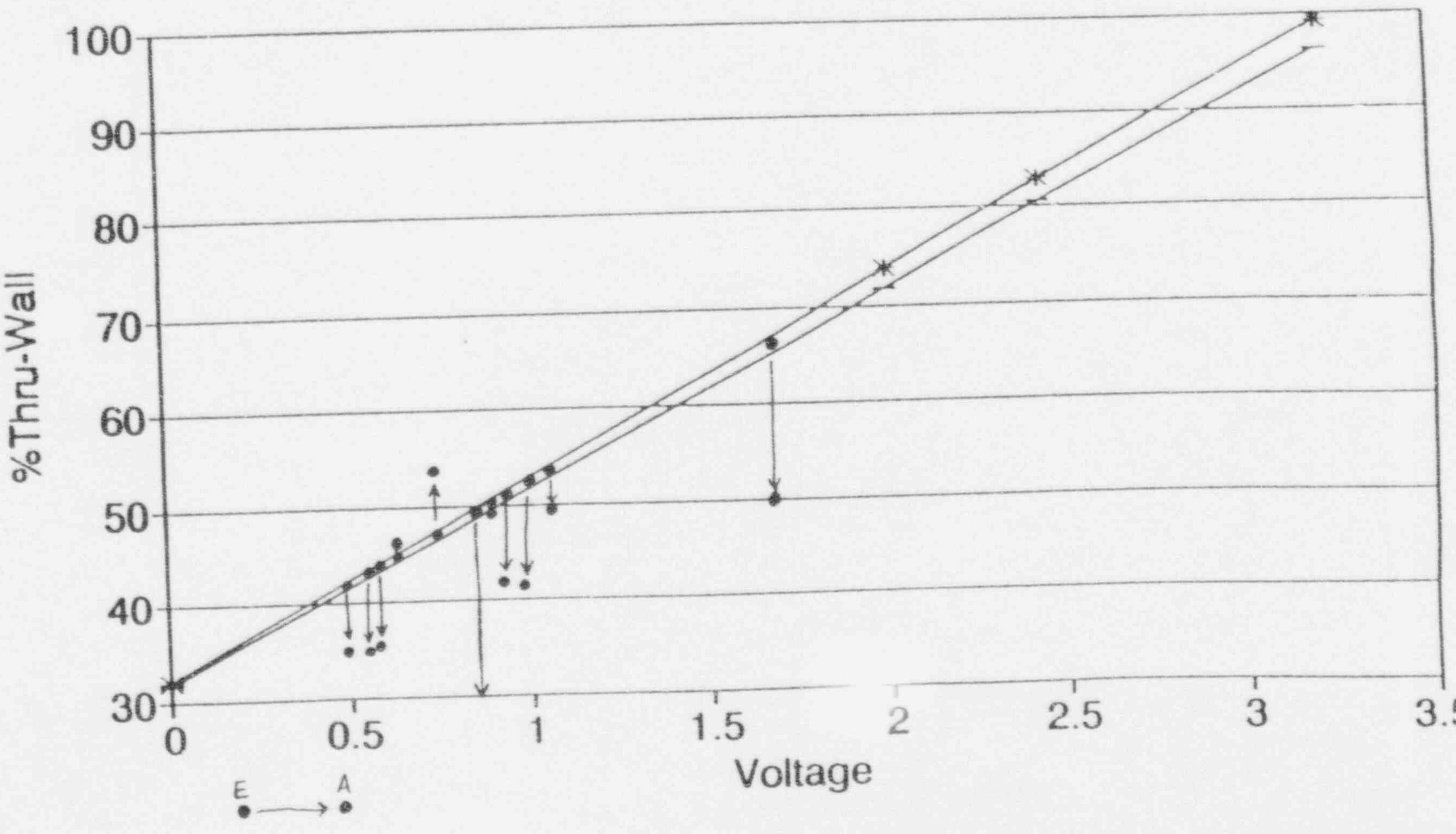

FIGURE 19: Comparison of CR#3 Pulled Tube Data to EPRI Calibration Curve

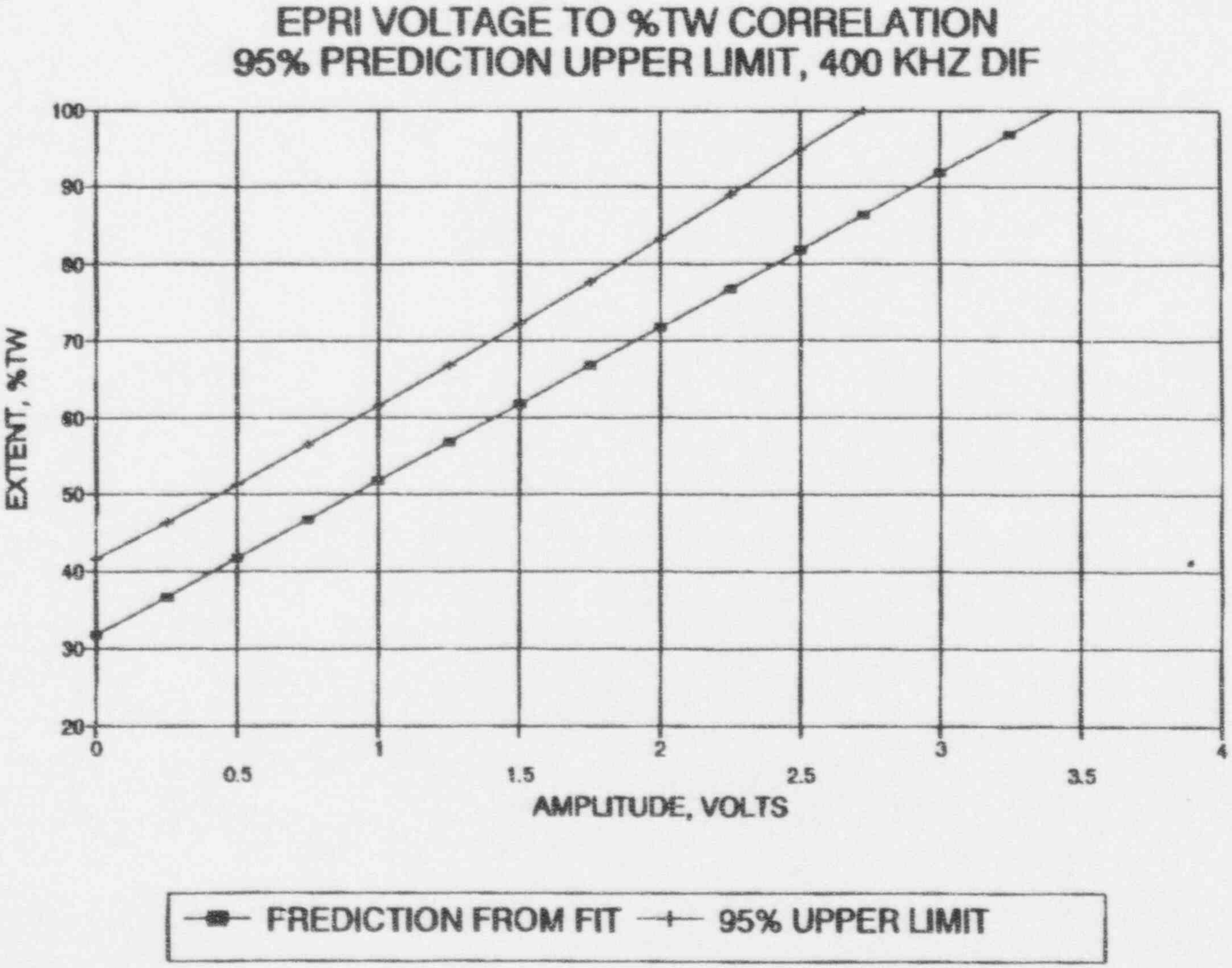

FIGURE 20: Confidence Level fo: EPRI Calibration Curve

FIGURE C2

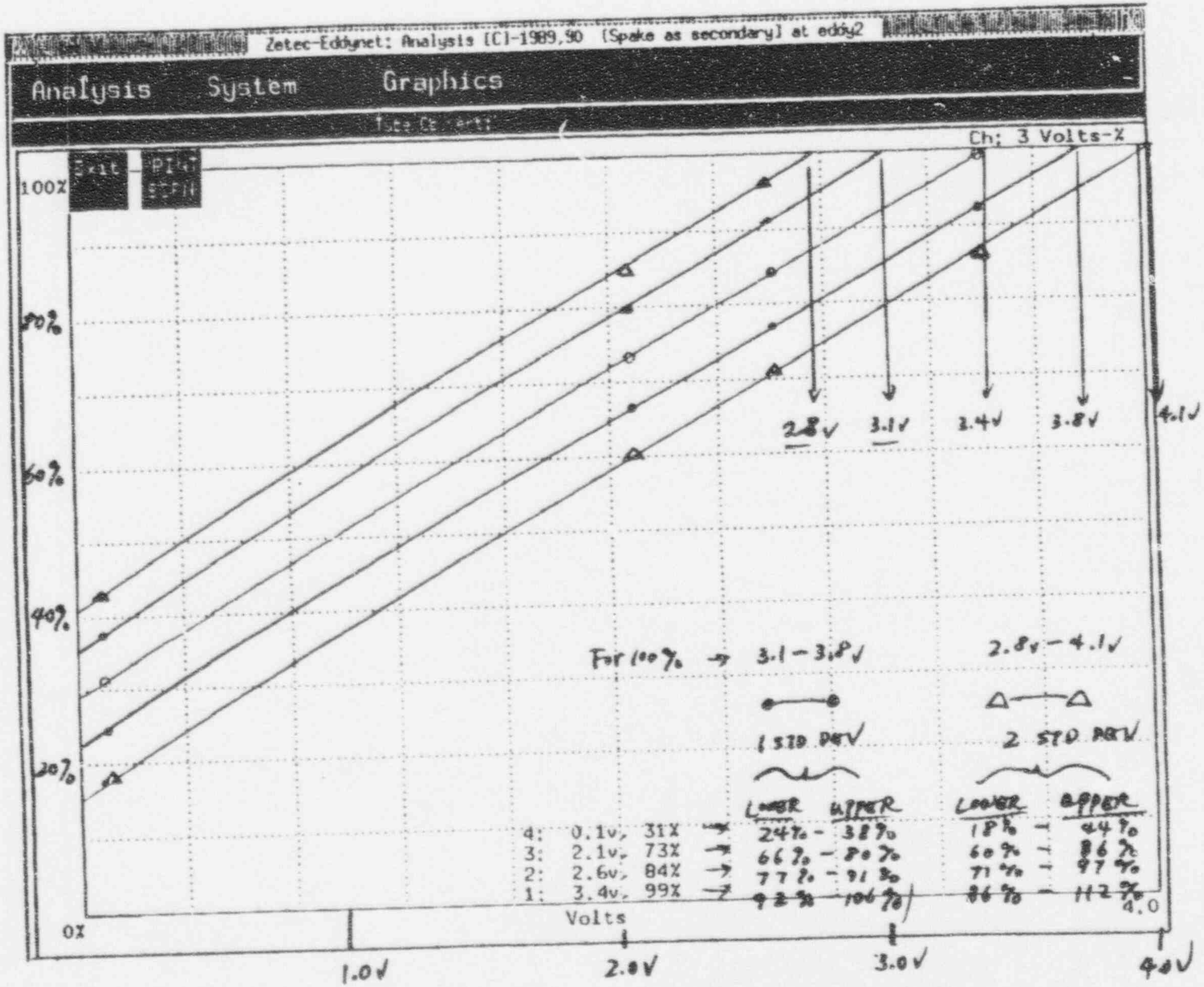

FIGURE 21: Confidence Level for EPRI Calibration Curve

7.2 B&W OWNERS GROUP NON-DESTRUCTIVE EXAMINATION COMMITTEE IGA WORK

The data in Reference 4 were used to correlate a known defect size with an ECT voltage parameter. In the Reference 4 study, IGA samples were fabricated in the laboratory[6] and inspected with various eddy current techniques to compare sizing and detection capabilities. Bobbin coil eddy current data were acquired with three different probes: a 0.51^ M/ULC, a 0.510 M/ULC/HF, and a 0.510 ULC. Six of the samples were then dest. -tively examined to determine the actual flaw depth of the IGA patches. All of the . tructively examined flaws were approximately 0.75" long and extended approximately 45 degrees around the tube circumference.

The 0.510 M/ULC/HF (high frequency) probe is the identical probe design used at CR#3, so the results from this probe were used in the evaluation. An ASME calibration standard was acquired with the bobbin data, and was used to normalize the signal amplitudes from the IGA study to eddy current data from CR#3. The data from the IGA study was re-analyzed using the same setup, and all calls were made off the 600 kHz channel to be consistent with current practice at CR#3.

The through-wall extent and corresponding bobbin coil voltage from re-analysis of the eddy current data are tabulated below.

TABLE 5: BWOG NDE Committee IGA Samples

Sample #	Maximum % Through-Wall	Bobbin Coil Signal Amplitude, Volts	Approximate Volume
1217423-A	55	2.7	.0034 in^3
1217423-E	55	2.9	.0034 in^3
1217424-A	56	3.4	.0035 in^3
1217424-E	71	7.7	.0044 in^3
1217425-A	22	0.5	.0013 in^3
1217425-E	41	1.1	.0025 in^3

The 7.7 volt signal is associated with an unacceptable flaw per the MPR analysis

[6] IGA was grown by immersing Inconel 600 tubing samples in a sodium tetrathionate solution. This method produces IGA due to acidic attack comparable to the sulfur related IGA found on CR#3 pulled tubes.

(71% through wall and 0.75 inches axial length). The 3.4 volt signal, however, is associated with an acceptable flaw size (56% through wall and 0.75 inches axial length). Figure 22 provides a graphic representation of the percent through wall depth to voltage. As shown in Table 3, the largest percent through wall depth corresponding to a 0.75 inch axial and 45 degree circumferential indication which could be considered acceptable relative to RG 1.121 limits is 62%. From Figure 22, it can be observed that the voltage corresponding to a 62% through wall indication would be approximately 6 volts.

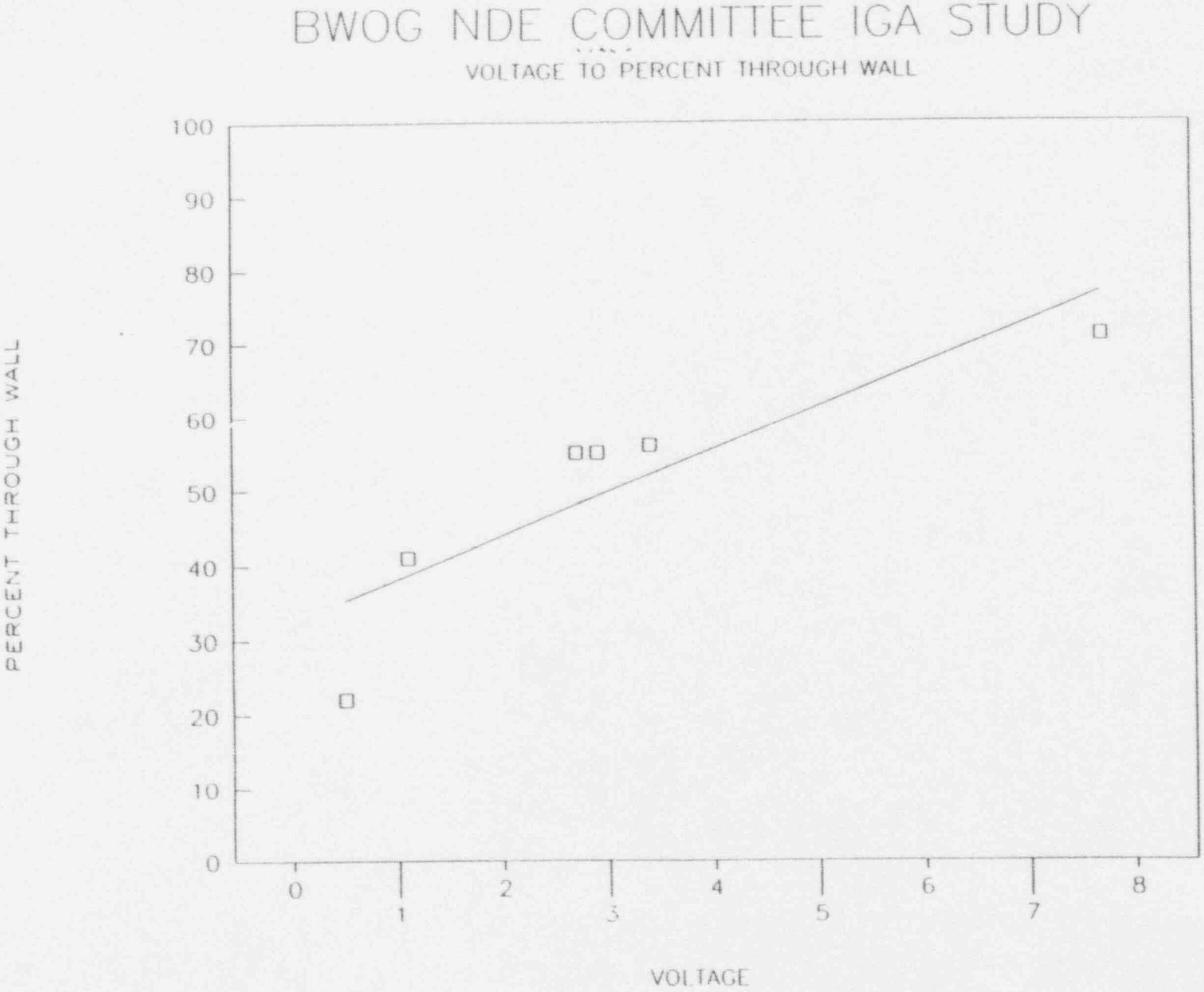

FIGURE 22: BWOG NDE Committee Voltage to Indication Through Wall Correlation

7.3 PALISADES MIZ-18 QUALIFICATION PROGRAM

Reference 5 presents data generated during an eddy current qualification program for IGA performed by the Consumers Power Palisades Plant. The samples used in this study had IGA patches of 0.2 inch axial length and 0.588 inch circumferential extent (equivalent to 90 degrees on the tube OD) with varying through wall depths.[7]

Per Reference 5 the Palisades data was obtained using a 0.580 high frequency probe, using 400 kHz as the prime reporting frequency. The Palisades tubing is 0.750 inch OD by 0.048 inch wall, which yields a fill factor of 79% using the .580 probe. CR#3 uses a .510 probe in the 0.625 OD tubing, which has a fill factor of 83%. The lower fill factor in the Palisades tubing would tend to depress the signal amplitude for the same size flaw. The Palisades data was not corrected for the fill factor difference for purposes of this evaluation since it is in the conservative direction for this evaluation. In addition, the calibration for the Palisades data established the voltage setting at 5.0 volts on the ASME 20% calibration standard. CR#3 calibrates at 4.0 volts on the ASME 20% calibration standard. The Palisades data was therefore normalized by multiplying the reported voltages by 4/5 to arrive at an equivalent voltage for the CR#3 setup.

Since the Palisades tubing is thicker than OTSG tubing (0.048 wall vs 0.034 wall), the volume of the ASME 20% holes is larger. Assuming that bobbin coil voltage is proportional to flaw volume, the Palisades data was further normalized by multiplying by the ratio of wall thicknesses, so that a given percent through wall flaw would produce the same voltage in both size tubes.

Results from the Palisades IGA correlation with bobbin coil voltage normalized to CR#3 are presented in Figure 23 for those samples which did not have dents associated with the flaw. Data from a total of twelve samples are included, each having two (2) patches of IGA. In the qualification, each sample was run four times with four different probes, which gives eight (16) data points for each IGA patch.

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7 IGA examined as part of the Palisades study was grown on sensitized Inconel 600 tubing by immersing tubing samples in a sulfurous acid bath.

The following tabulation is representative of information shown graphically on Figure 23, with the addition of approximate defect volumes.

Table 6: Palisades IGA Samples

Average % Through Wall	Bobbin Coil Signal Amplitude, Volts	Approximate Volume
18%	0 to 2	.0007 in^3
25%	.5 to 3	.0009 in^3
35%	2 to 4	.0013 in^3
45%	4 to 7	.0017 in^3
55%	6 to 8	.0021 in^3
79%	22 to 27	.0031 in^3

7.4 ECT VOLTAGE TO DEFECT VOLUME CORRELATION

Both the BWOG NDE committee work and the Palisades IGA work demonstrate a relationship between voltage and defect volume. Both studies used standardized axial and circumferential size IGA patches. As such, the volume of each IGA patch studied was entirely dependent upon its percent through wall depth. As shown on Figures 22 and 23, as percent through wall (i.e. volume) increased, voltage also increased.

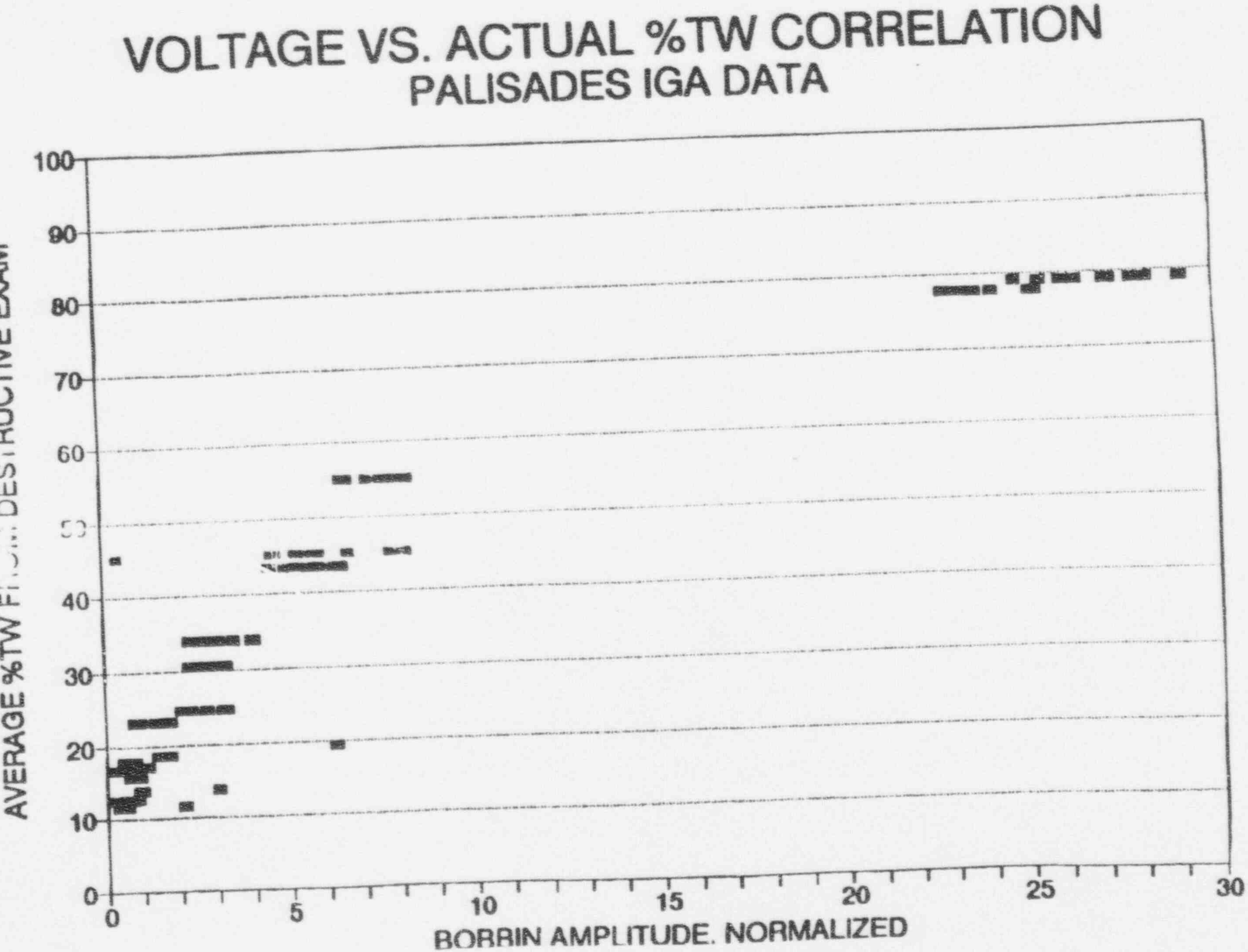

FIGURE 23: Palisades Voltage to Indication Through Wall Correlation

7.5 CORRELATION OF RPC CLIP PLOTS TO DEFECT AXIAL AND CIRCUMFERENTIAL SIZE

A review of CR#3 pulled tube data has been performed to assess the accuracy of using clip plots generated from RPC examinations to estimate the axial and circumferential size of an eddy current indication. This method is discussed in reference 10. In general, the method allows the defect to be sized based on when the RPC probe first detects the indication and when the indication is no longer detected after the probe passes. Sizing is based on known axial pull and rotational speeds.

In order to assess the accuracy of this technique, clip plots were produced from the RPC examination conducted on the first span indications pulled during the May 1992 Refuel 8 outage. The eddy current measurements were then compared to the actual flaw sizes reported from metallographic examination of indications.

The results of this comparison are provided in Table 7 and Figures 24 and 25. The clip plot technique over-estimated the actual flaw size for every case examined. From table 7, the average ratio of measured to actual flaw size for axial extent is 3.2, with a minimum of 1.5. Measurement of circumferential extent was even more conservative, with an average measured to actual ratio of 5.6 and a minimum of 2.3. in general the amount of conservatism decreases with increasing flaw size for both axial and circumferential flaws.

The last two columns of table 7 show the error in the clip plot measurements as the difference between the actual dimension and the clip plot estimation. The errors reported in this way are more consistent than the errors reported as a ratio, which leads to the conclusion that the clip plot method consistently overestimates by the same amount. Once again, the circumferential measurement is shown to be more conservative than the axial measurement. For axial measurements the average difference is 0.09 inches, compared to 0.14 inches for the circumferential dimension.

To verify that the same conservatism would be present when estimating the axial and circumferential size of indications resulting from a damage mechanism other than pit-like IGA, a similar comparison was made using RPC data from an ASME calibration standard 40% through wall flat bottom hole. The RPC clip plot estimated an axial size of 0.19 inch and a circumferential size of 0.25 inch. The actual diameter of the hole was 0.094 inch. Therefore, the RPC clip plot axial estimate was conservative with a difference of 0.096 inch and the clip plot circumferential estimate was even more conservative with a difference of 0.156 inch, which closely matches the results achieved for pit-like IGA.

These results indicate that the RPC probe does not have to be directly over the indication to detect it. Therefore this technique will tend to overestimate the actual flaw size since the probe will detect the indication before it actually reaches it, and will still detect it for some distance after it has passed. It is therefore concluded that no additional adjustment for RPC measurement needs to be made. Using sizing estimates direct from clip plots without further adjustment for NDE uncertainty is appropriate and conservative.

Table 7: COMPARISON OF DESTRUCTIVE EXAM RESULTS TO RPC CLIP PLOT MEASUREMENTS

TUBE SECTION NO	AXIAL POSITION	FLAW ID NUMBER	STEROVISUAL RESULTS AXIAL EXTENT (IN.)	STEROVISUAL RESULTS CIRC. EXTENT (DEG)	STEROVISUAL RESULTS CIRC. EXTENT (IN.)	RPC SIZING AXIAL EXTENT (IN.)	RPC SIZING CIRC. EXTENT (IN.)	RATIO, MEAS/ACTUAL AXIAL	RATIO, MEAS/ACTUAL CIRC	ERROR, ACT - MEAS AXIAL	ERROR, ACT - MEAS CIRC
52-51-2	LTSF + 9.25"	D	0.061	8.4	0.041	0.15	0.20	2.5	4.9	0.09	0.16
	LTSF + 12.75"	I2	0.048	7.6	0.037	0.19	0.17	4.0	4.6	0.14	0.13
		I1	0.053	7.6	0.037	0.19	0.17	3.6	4.6	0.14	0.13
90-28-2	LTSF + 13.60"	C	0.053	2.0	0.010	0.14	0.19	2.6	19.5	0.09	0.18
		B	0.063	4.1	0.020	0.11	0.14	1.7	7.0	0.05	0.12
	LTSF + 15.30"	E	0.071	7.9	0.038	0.16	0.20	2.3	5.2	0.09	0.16
	LTSF + 17.70	I	0.063	4.7	0.023	0.19	0.19	3.0	8.3	0.13	0.17
		H	0.059	4.5	0.022	0.15	0.19	2.5	8.7	0.09	0.17
		G	0.079	8.1	0.039	0.15	0.19	1.9	4.8	0.07	0.15
97-91-2	LTSF + 15.30"	P	0.073	15.2	0.074	0.15	0.17	2.1	2.3	0.08	0.10
		O	0.078	12.8	0.062	0.15	0.19	2.0	3.1	0.07	0.13
	LTSF + 19.00"	U	0.054	9.6	0.047	0.16	0.25	2.8	5.4	0.10	0.20
		T	0.061	13.6	0.066	0.19	0.18	3.1	2.7	0.13	0.11
		S	0.011	0.1	0.0005	0.08	0.10	7.3	205.7	0.07	0.10
	LTSF + 21.60"	W	0.061	9.6	0.047	0.16	0.18	2.6	3.9	0.10	0.13
108-32-2	LTSF + 13.80"	X2	0.071	11.0	0.053	0.11	0.14	1.6	2.6	0.04	0.09
		Y	0.015	1.6	0.008	0.13	0.11	8.7	14.1	0.12	0.10
		X	0.016	7.8	0.038	0.11	0.19	6.9	5.0	0.09	0.15
	LTSF + 16.30"	AG2	0.062	7.3	0.035	0.11	0.13	1.8	3.7	0.05	0.09
		AH	0.056	5.7	0.028	0.12	0.15	2.1	5.4	0.06	0.12
	LTSF + 21.00"	AT	0.060	10.3	0.050	0.15	0.19	2.5	3.8	0.09	0.14
		AU	0.047	11.2	0.054	0.11	0.25	2.3	4.6	0.06	0.20
		AV	0.040	9.6	0.047						
							AVG =	3.2	5.6	0.09	0.14
							STD =	1.9	4.1	0.03	0.03
							MIN =	1.5	2.3	0.04	0.09

NOTE: STATISTICS FOR CIRC. FACTOR DO NOT INCLUDE DATA FOR SAMPLE 97-91-2-S.

AXIAL EXTENT MEASUREMENT ACCURACY DESTRUCTIVE EXAM VS. RPC CLIP PLOT

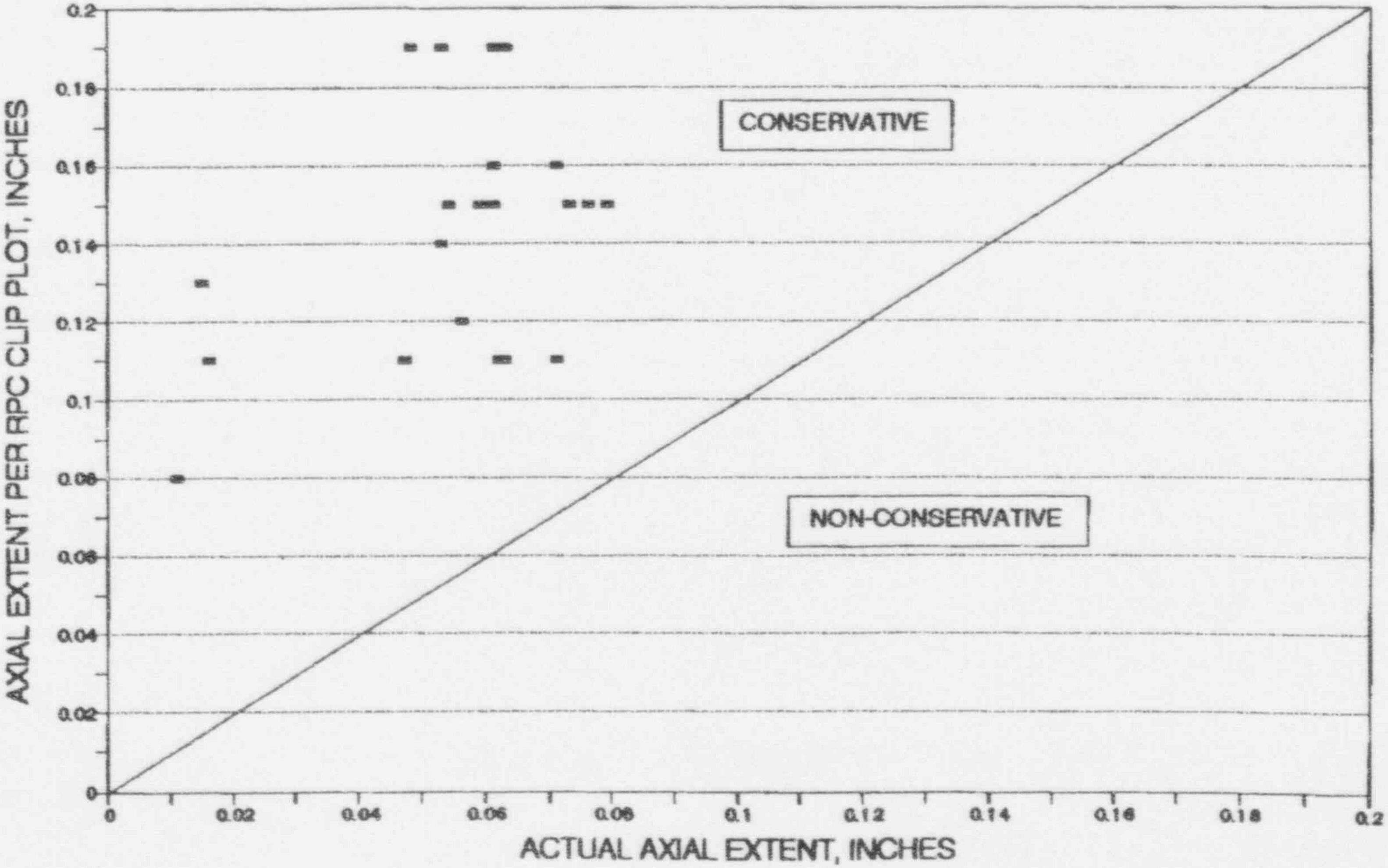

FIGURE 24: Accuracy of Axial Sizing Using RPC

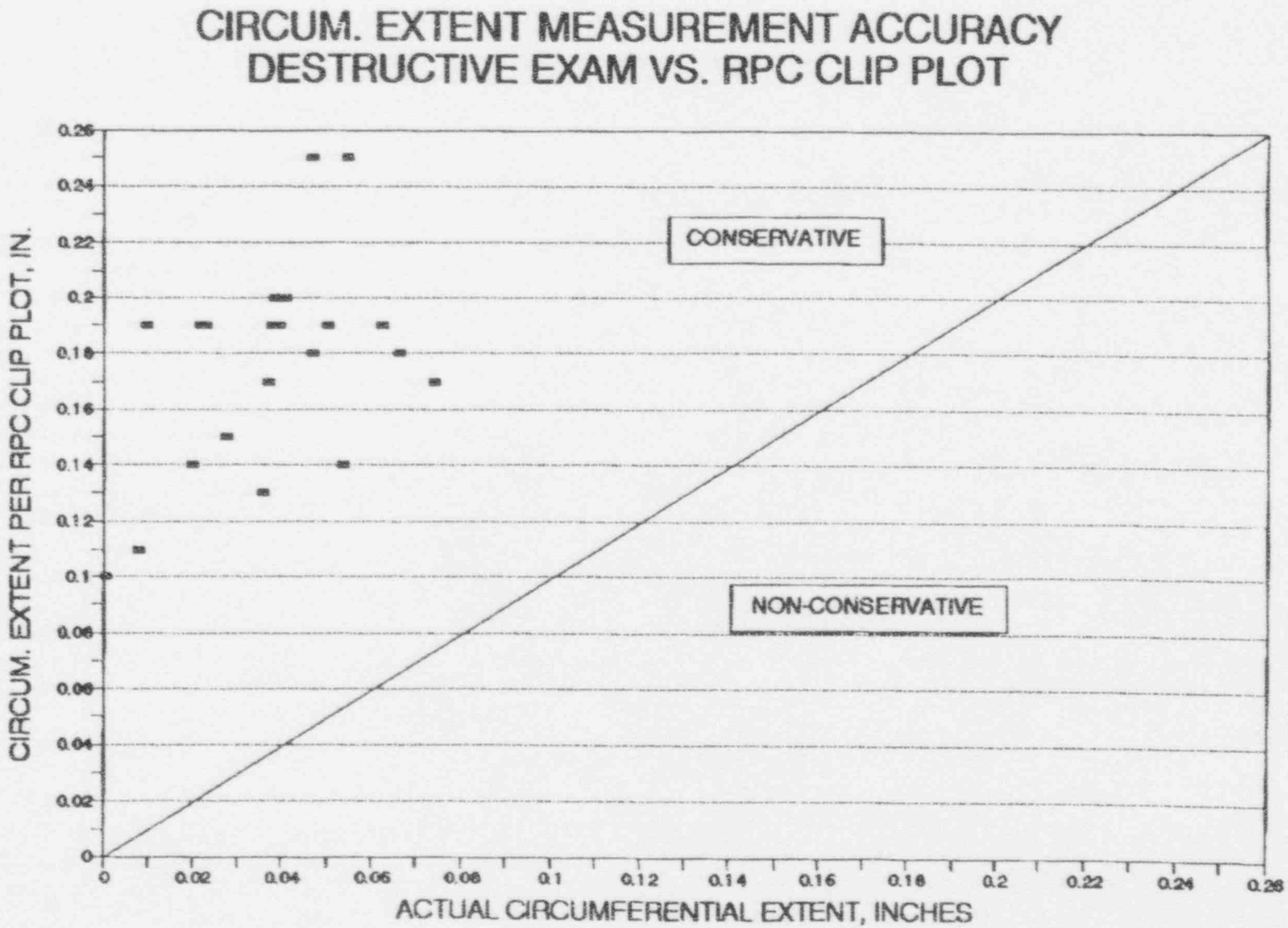

FIGURE 25: Accuracy of Circumferential Sizing Using RPC

8.0 REVISED REPAIR LIMITS

8.1 EXISTING REPAIR LIMITS

The CR#3 Technical Specifications currently define the steam generator tube repair limit as "the imperfection depth at or beyond which the tube shall be restored to serviceability by the installation of a sleeve or removed from service because it may become unserviceable prior to the next inspection." The existing repair limit is equal to 40% of the nominal tube wall thickness. The basis for the 40% through wall "depth-based" repair limit is:

(1) to conservatively account for all potential flaw types which include uniform thinning of the tube wall; and

(2) to satisfy the criteria of regulatory guide 1.121 which includes:
- margin of safety consistent with NB-3225 of ASME Code, Section III under postulated accident conditions (i.e.; LOCA, MSLB),
- assure no burst at 3 times normal operating pressure,
- an allowance for NDE measurement error, and
- an allowance for incremental flaw growth between inspections.

8.2 DIMENSIONAL BASED REPAIR LIMIT

Figures 26 and 27 provide the results of the MPR structural analysis. These Figures can be used to select dimensional parameters which provide a conservative limit for defects which may remain in service on once through steam generator tubes.

As stated in section 7.1, the bobbin coil phase angle method of percent through wall estimation has been determined to be inaccurate for the very small volume pit-like IGA found on CR#3 steam generator tubes. Although a voltage to percent through wall correlation was found to be more accurate than phase angle, it cannot be directly applied to indications located at tube support plates where mix frequencies must be used to suppress interference. Therefore, there is no existing methodology which can be used to estimate percent through wall for the very small indications observed at CR#3 with an acceptable degree of accuracy.

Since accurate percent through wall estimates cannot be made, the conservative approach to establishing a dimensional based repair limit is to select the allowable axial and circumferential dimensional limits which correspond to 100% through wall depth. Axial and circumferential defect size can be conservatively estimated using RPC clip plots as discussed in section 7.0.

As shown on Figures 26 and 27 and discussed in section 5.1, the calculated allowable axial and circumferential dimensions for a 100% through wall indication are 0.25 inch axial and 122 degrees circumferential (0.6 inch). Projected burst pressure for a 0.25 inch axial and 100% through wall indication is 4,940 psi. This burst pressure is above the regulatory guide 1.121 limit of three times the operating differential pressure (4050 psi).

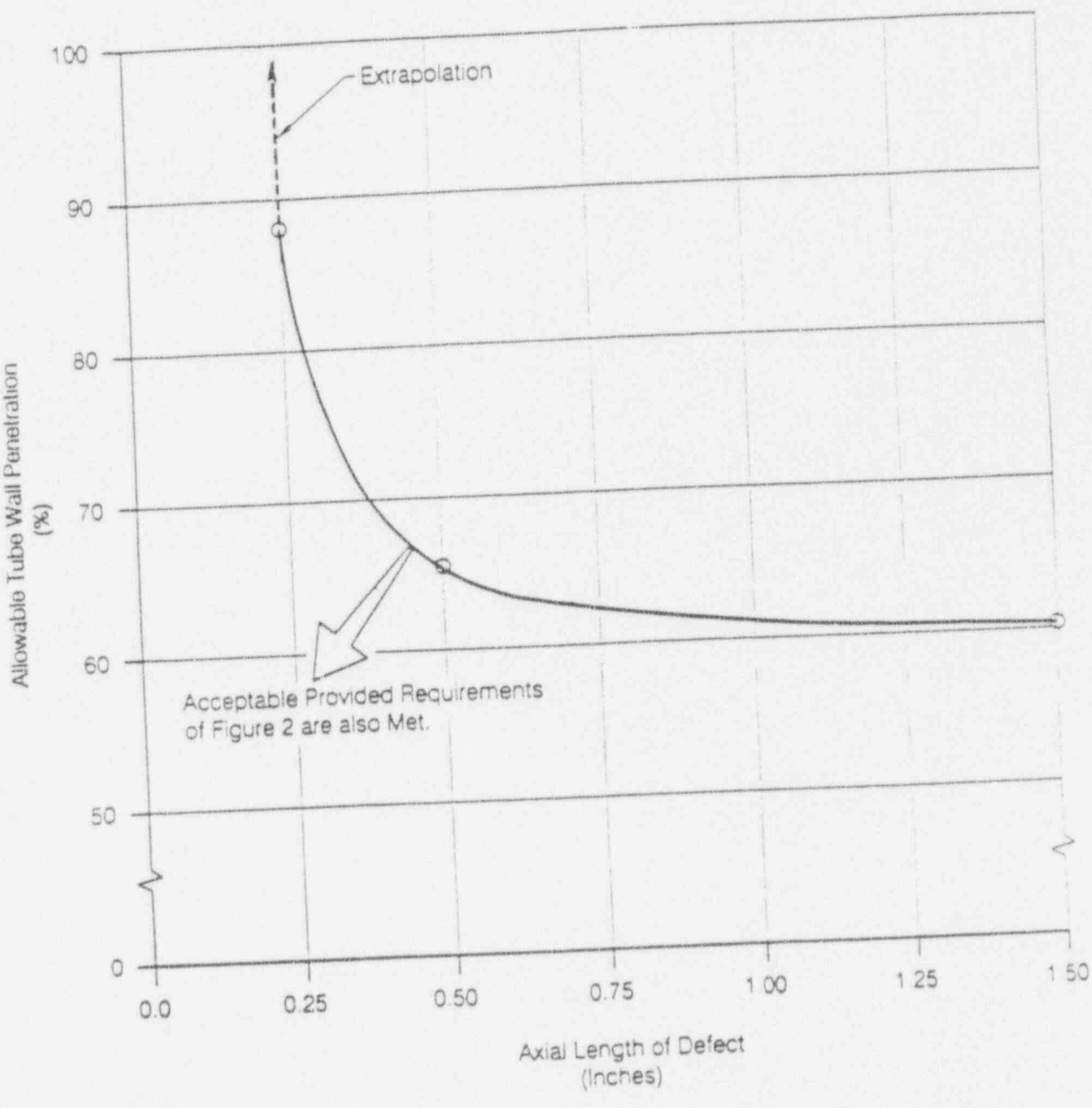

FIGURE 26: Allowable Tube Wall Penetration For Axial Slot Type Defects (Axial Cracks)

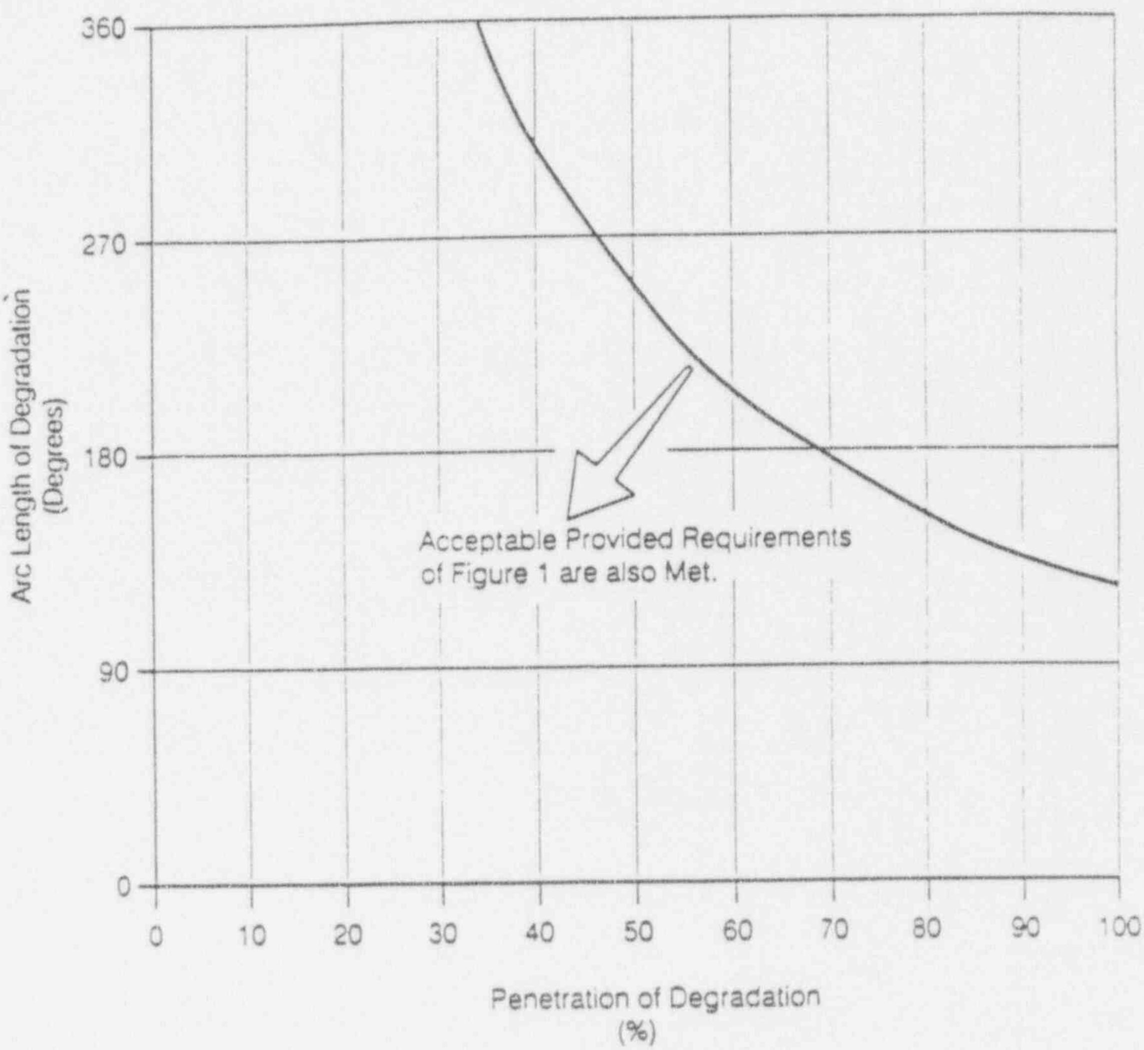

FIGURE 27: Maximum Allowable Penetration Versus Arc Length for 34.1 % Maximum Allowable Area of Degradation

8.2 VOLTAGE BASED REPAIR LIMIT

Examination of indications using the motorized rotating pancake coil requires a significant amount of outage time due to the very low pull speed of the RPC probe. From Table 7, review of RPC data for indications on pulled tubes indicates that if the dimensional based repair criteria discussed in section 8.1 had been applied, none of the indications would have been considered unacceptable. Therefore, it is desirable to establish a repair criteria which may be applied to S/N indications without requiring 100% RPC examination of the smallest indications which have the highest confidence level of passing the dimensional based repair criteria.

As discussed in section 7.2, the estimated voltage for an indication with dimensions corresponding to the maximum allowable size for OTSG tubing is 6 volts. In order to account for data scatter, uncertainty, and the limited amount of data available, a more conservative approach should be taken in establishing a voltage based criteria for OTSG tubing.

In comparing the voltage correlation performed by EPRI using CR#3 pulled tube data to the voltage correlations based on BWOG NDE committee work and Palisades Miz-18 qualification program information, it is apparent that in addition to defect volume, defect geometry must also be considered. The IGA patches on CR#3 pulled tubes were pit-like in geometry, with a relatively high penetration for their axial and circumferential sizes as compared to the IGA patches grown by the B&W Owners Group and Palisades. CR#3 pit-like IGA yielded relatively low voltages in comparison to the BWOG NDE committee and Palisades IGA patches which had significantly larger axial and circumferential extent, covering more surface area of the tube and resulting in greater volume for a given penetration. The larger volumes result in a larger bobbin signal response. Although the volumes of CR#3 pit-like IGA are as much as 100 times smaller than MPRs calculated maximum allowable defect dimensions, it is desirable to establish a conservative limit. This limit should not only ensure that potentially significant defects are examined using RPC, but should also ensure that structurally insignificant defects with 100% through wall penetrations which have the potential for leakage are identified.

Correlations based on low signal amplitudes from CR#3 pit-like IGA, shown on Figure 18, result in the projection that 100% through wall penetration may be present in indications with voltages as low as 3.4 volts. The 95% confidence level for Figure 18 conservatively reduces the predicted 100% through wall voltage to approximately 2.8 volts. Additionally, since tube support plate indications are typically examined using a mix frequency as the prime frequency in order to suppress the tube support plate signal, voltages from Figure 18 must be adjusted to account for potential differences in signal amplitude.

A comparison was performed between the signal amplitudes obtained using a 600 kHz prime frequency on the four 20% through wall holes of an ASME calibration standard and the signal amplitudes obtained by examination of the same calibration standard holes with a 600-200 mix frequency. Based on nine runs, the average 600 kHz signal amplitude was 4.16 volts. The average mix frequency signal amplitude was 3.17 volts, or 76% (.76) of the 600 kHz voltage. Reduction of the 2.8 volt repair limit by a factor of 0.76 to account for use of mix frequencies at tube support plates further reduces the voltage based repair limit to 2.13 volts. For ease in application, the proposed voltage based repair limit will be rounded down to 2.0 volts.

Growth studies performed for CR#3 S/N type indications and discussed in section 6.0 of this report, determined that neither the freespan or tube support plate indications have significant growth rates in the CR#3 steam generators. Therefore, due to the extreme conservatism used in establishment of the 2 volt repair limit (i.e. Figure 18 was developed based on Vmax voltage readings AND a 95% confidence level has been applied, which is shown by Figure 19 to be very conservative.) no further reductions in the proposed voltage based repair limit will be made. However, any S/N type indication, with voltage greater than 1 but less than 2, which exhibits a positive voltage change in excess of 0.5 volts since its previous inspection will be included as a degraded tube in calculations performed to determine required Technical Specification examination bobbin expansion.

Existing RPC data for 97 S/N indications examined during the Refuel 8 outage has been reviewed to evaluate the acceptability of the proposed 2 volt repair limit as compared to the dimensional based repair limit. Figure 28 provides the results of this review. 96 out of 97 indications reviewed would be considered acceptable to remain in service based on the 2 volt repair limit. Ninety-three out of the 96 indications which passed the 2 volt repair limit were also considered acceptable to remain in service based on the dimensional based repair limit. The three indications which did not pass the dimensional based repair limit exceeded the axial limit by no more than 0.06 inches. Since error in RPC sizing has been shown to be conservative, with an average error of 0.09 inch between the actual and measured axial size, there is a high probability that the ACTUAL axial sizes of the two indications are less than 0.25 inch.

To provide further confidence in the established 2 volt repair limit, RPC inspection will be performed on a sample of S/Ns. This sample will include all existing S/Ns which were RPC'd during Refuel 8 and were determined to have axial and/or circumferential sizes in excess of 1/2 the dimensional based repair criteria (0.13" axial and 0.30" circumferential). The balance of the sample to be inspected will include S/Ns with the highest 600 kHz bobbin voltages.

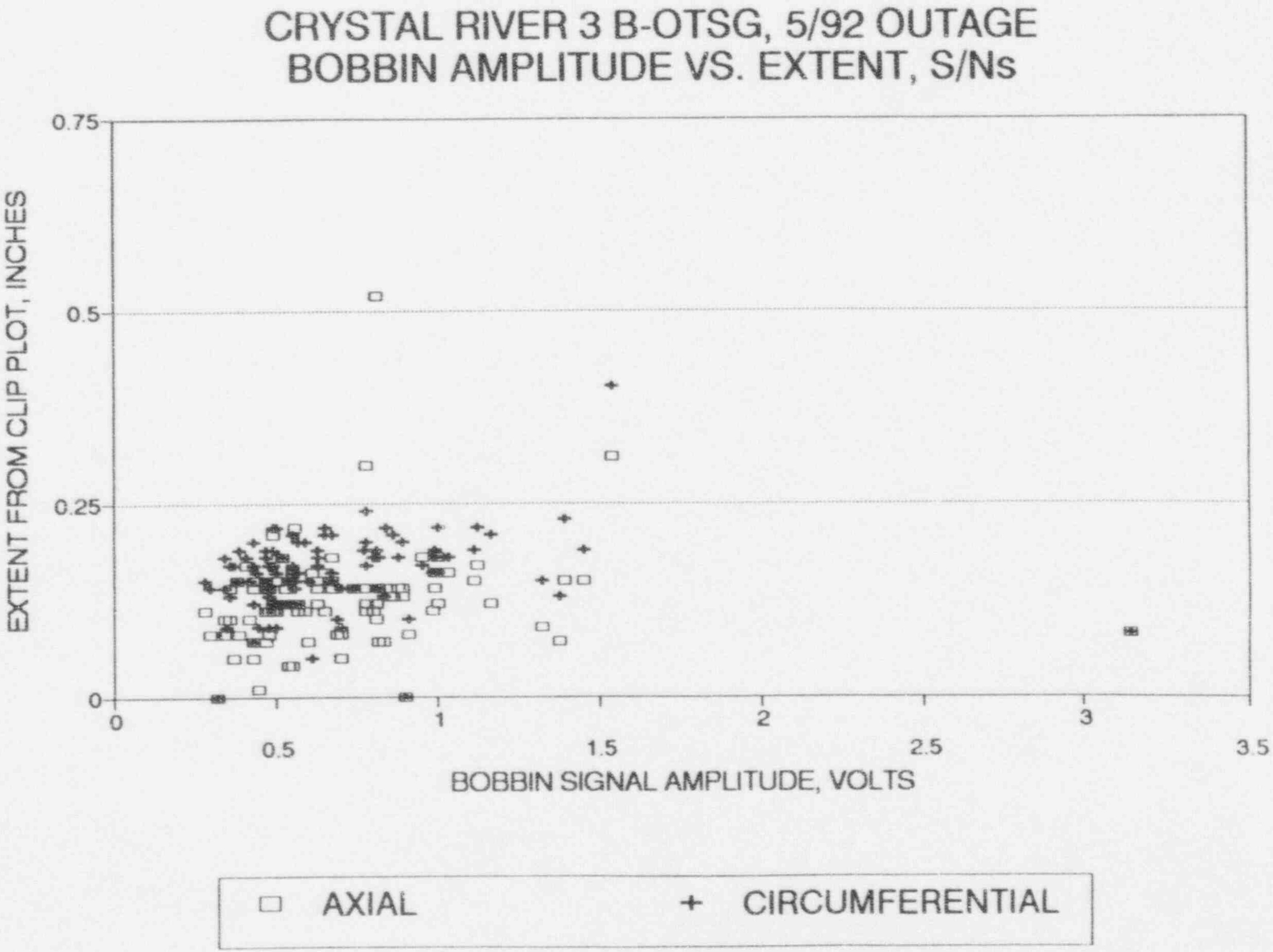

FIGURE 28: Estimated Sizes of Sample Inservice S/N Indications

8.3 BASIS FOR REVISED REPAIR LIMITS

The bases for the proposed signal amplitude based Repair limit of 2 Volts and for the Dimensional based Repair limit are summarized below:

Criteria (1) **to conservatively account for all potential flaw types which include uniform thinning of the tube wall**

The proposed repair limit of 2 volts was derived from information obtained during various eddy current studies of intergranular attack. Basing the voltage correlation on IGA flaw types is conservative compared to other volumetric flaws. Since the material is still present in an IGA flaw, the bobbin coil signal will be depressed when compared with a wear or wastage type flaw of the same size where more material is missing. The structural strength of the two flaws is comparable, therefore, basing the structural limit on smaller IGA signal amplitudes is conservative. This voltage based structural limit will not be applied to indications in the lane/wedge region which are observed to be crack-like by RPC. The dimensional based structural limit is based on a calculation performed by MPR which conservatively determined the maximum allowable flaw size on OTSG tubing for ANY TYPE of damage mechanism.

Criteria (2) **to satisfy the criteria of regulatory guide 1.121 which includes:**

- **margin of safety consistent with NB-3225 of ASME Code, Section III under postulated accident conditions (i.e.; LOCA, MSLB)**

Postulated accident conditions have been addressed in the calculations performed by MPR Associates, Inc, and provided as attachment A to this report. The maximum allowable defect sizes calculated by MPR take into account the requirement that tube burst pressure must be greater than the pressure difference across the tube wall for accident conditions and the tube stress intensity should be less than the lesser of 2.4 times the design stress intensity (Sm) or 0.7 times the Ultimate Stress. The proposed dimensional repair limits of 0.25 inch axial and 122 degrees circumferential are based on these calculations. The proposed 2 volt voltage based limit was arrived at by conservatively reducing the upper voltages observed to correspond with defect volumes and dimensions found to be smaller than the maximum allowable defect sizes calculated by MPR Associates, Inc. A 2 volt limit is believed to be adequate to ensure defects are removed from service well before they approach such size that they would be subject to failure or leakage under postulated accident conditions.

- **assure no burst at 3 times normal operating pressure**

Burst tests performed on two tube sections removed from the CR#3 "B" steam generator, containing over 80 S/N indications, resulted in a burst pressure margin of more than 2.5 times the Regulatory Guide 1.121 limit of 3 times operating differential pressure. Based on review of RPC data for similar indications located in various regions of the "B" steam generator, it can be determined that the majority of inservice S/Ns are similar in size to the indications present on burst tubes. Additionally, historical burst test data discussed in section 5.3 can be used to project burst pressure for a 0.25 inch axial, 100% through wall indication. As stated in section 5.3, projected burst would occur above the regulatory guide 1.121 limit. Both the voltage based and dimensional based plugging limits proposed contain adequate margin to ensure the Regulatory Guide 1.121 burst pressure requirement can be met by defects which will remain in service under the revised limits.

- **includes an allowance for NDE measurement error**

The proposed 2 volt repair limit was arrived at following conservative reduction to account for NDE measurement error. Operating experience with no primary to secondary leakage over several cycles since first detecting S/Ns indicates a low probability of inservice 100% through wall indications. The maximum penetration observed on pulled tubes removed from the "B" steam generator during Refuel 8 was 62%. The axial and circumferential dimensional based plugging limit was conservatively selected to account for potential 100% through wall indications due to identified inaccuracies in depth estimation. Since the allowable axial size increases as the percent through wall of an indication decreases and the maximum penetration observed on pulled tubes has not exceeded 62%, application of a 0.25 inch axial and 122 degree circumferential repair limit is conservative. Additionally, as discussed in section 7.5, there is a built in conservatism in estimation of axial and circumferential size of indications using RPC clip plots. Therefore, there is no need to further reduce the axial and circumferential limits selected to account for NDE uncertainty.

- **includes an allowance for incremental flaw growth between inspections.**

Review of eddy current historical data indicates an insignificant growth rate for S/N type indications in the CR#3 steam generators. Additionally, per the structural analysis performed by MPR Associates, Inc., even a postulated axial crack would grow only about 0.006% due to fatigue from cyclic loads per startup/shutdown cycle. Since the number of startup/shutdown cycles between eddy current inspections is not large, growth due to fatigue between inspections would not be significant. Conservatisms incorporated during establishment of the voltage and dimensional based repair criterias are sufficient to ensure that indications left in service will be very small such that any incremental flaw growth between inspections will not result in structurally significant indications.

9.0 LEAKAGE CONSIDERATIONS

9.1 POTENTIAL FOR LEAKAGE RELATIVE TO NEW REPAIR CRITERIA

MPR Associates, Inc., has performed a calculation to determine the minimum ligament width which must be available during a main steam line break to ensure that existing outside diameter tube imperfections will not result in primary to secondary leakage. This calculation is provided as Appendix E. For a differential pressure equivalent to normal operating reactor coolant system pressure, the minimum ligament required is 0.0029 inches, which equates to a degradation of about 91.5% of the tube wall. For primary to secondary differential pressures up to 2600 psid, the minimum ligament required is 0.0043 inches, which equates to a degradation of about 87% of the tube wall.

From Figures 20 and 21, it can be observed that the proposed voltage based repair criteria of 2 volts provides a 95% confidence level that indications of greater than 85% through wall penetration will not be left in service.

Based on comparison of RPC data obtained from examination of pit-like IGA on pulled tubes to RPC data obtained from inservice S/N type indications, the majority of inservice S/N indications appear to exhibit a similar geometric shape. This shape can be best characterized as a pit-like appearance. Figures 6 through 15 of section 5.4 illustrate this physical similarity.

NDE examination of IGA samples as part of Palisade's Miz-18 qualification program and through the BWOG NDE Committee work has demonstrated a definite relationship between voltage and the volume of an indication (i.e. voltage increases if the volume increases.) Thus, it logically follows that if two data sets of indications have approximately the same voltages, their volumes are also going to be approximately the same.

Figures 29 and 30 illustrate the similarity in voltages and axial and circumferential sizes of indications on pulled tubes and a representative sample of inservice S/Ns. Since eddy current signal amplitude or voltage has been shown to be a function of indication volume, it can be reasoned that if the axial and circumferential sizes of inservice S/Ns are approximately the same as the axial and circumferential sizes of indications on pulled tubes AND the average voltages of inservice S/Ns are approximately the same as indications on pulled tubes, there is a high probability that the depths of the inservice S/Ns are the same as the depths of the indications on pulled tubes. The geometric similarities in the two data sets further supports this logic. Figure 31 provides information concerning the actual depth distribution of indications on pulled tubes.

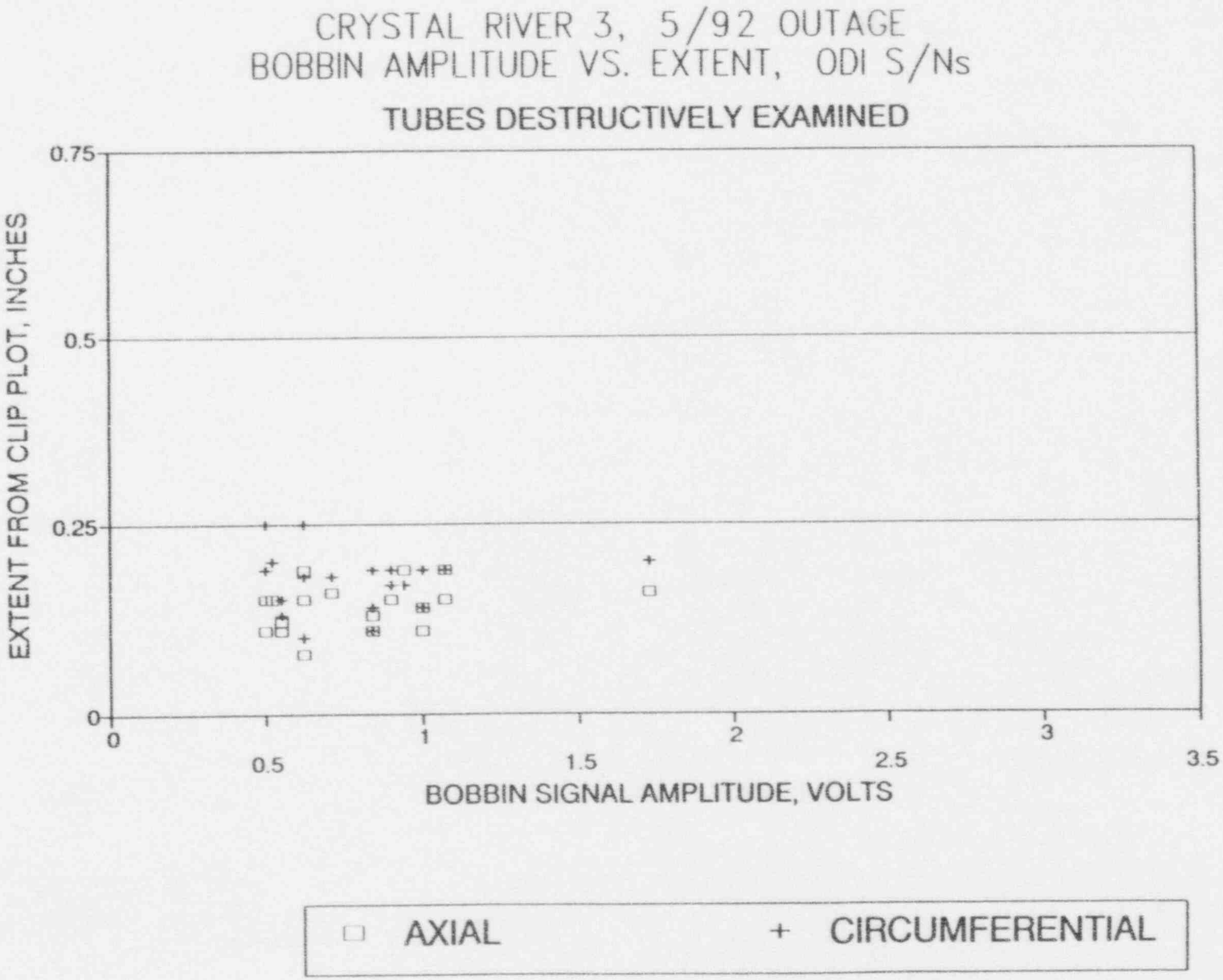

FIGURE 29: Size and Voltages of indications on pulled tubes

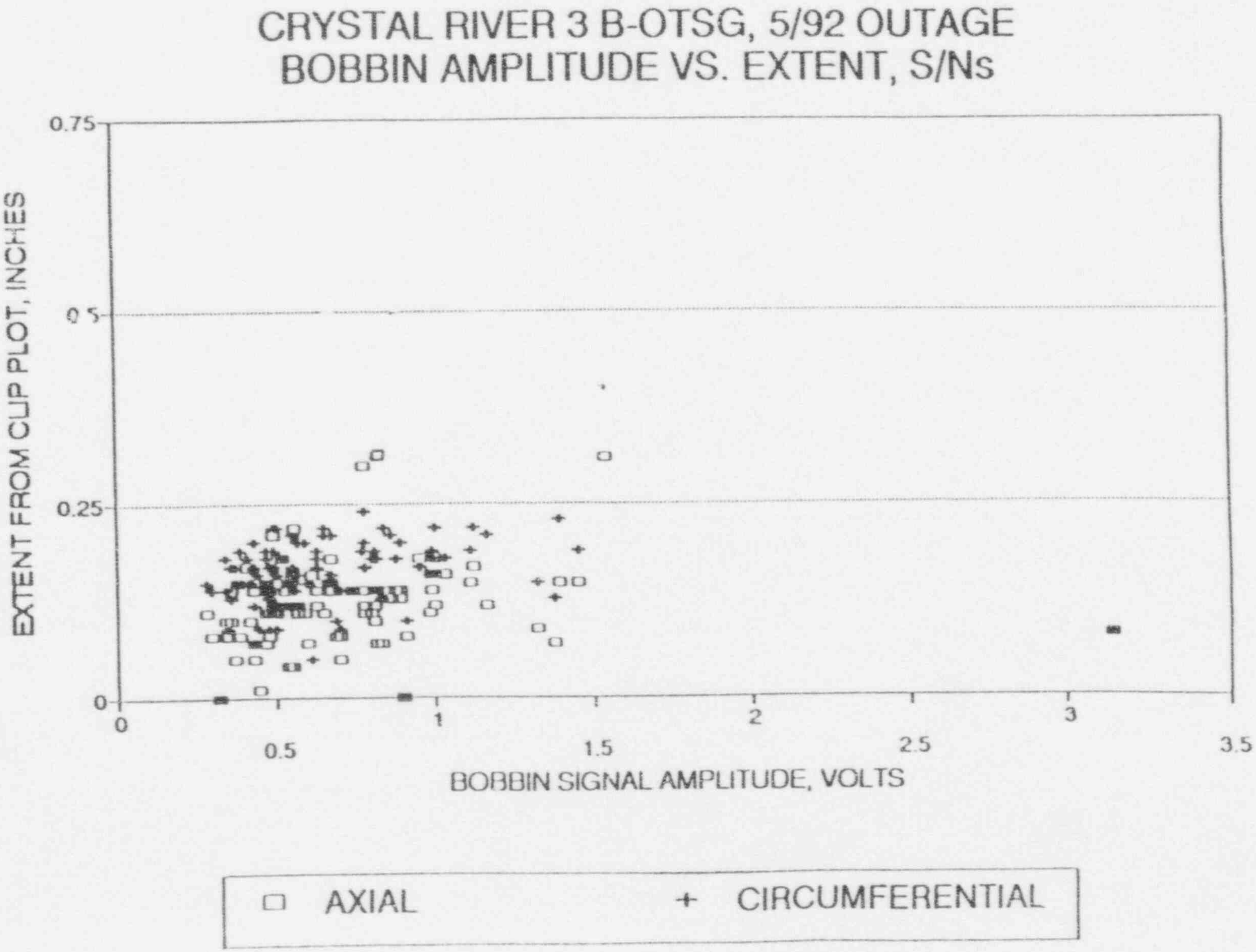

FIGURE 30: Size and Voltages of Inservice S/Ns

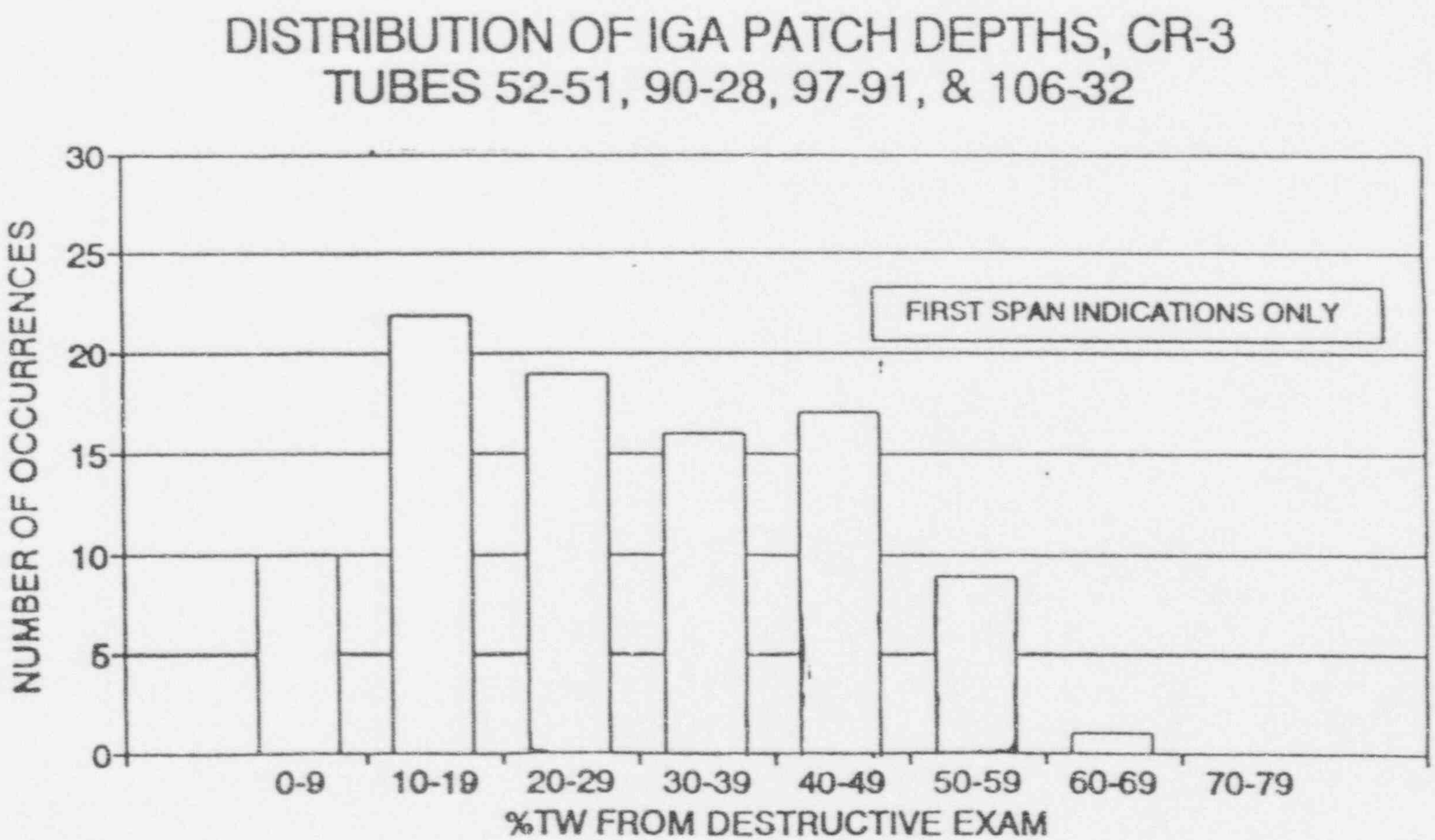

FIGURE 31: Depth Distribution of Indications on Pulled Tubes

To project the depth distribution of inservice S/Ns, a width to depth (W/D) ratio correlation for the pit-like IGA found on pulled tubes was developed. The estimated axial and circumferential sizes of pit-like IGA from RPC was used in development of the W/D ratio in lieu of the actual sizes to facilitate comparison, since only the RPC estimated axial and circumferential sizes of inservice S/Ns are available. The numerator of the ratio, or width, was taken from the major axis of the pit-like IGA whether it was oriented in the axial or circumferential direction. The denominator of the ratio, or depth, was the actual maximum through wall penetration of the indication determined by metallography. Ratios were calculated for a sample of 18 pit-like IGA indications. In general, the W/D ratio of the pit-like IGA increased as the estimated width increased. Table 8 presents the results of the W/D correlation for pit-like IGA on pulled tubes.

Table 8: Width to Depth Ratios for Pit-Like IGA on Pulled Tubes

Estimated Indication Width from RPC (inches)	Average Width to Depth Ratio
0.0 to 0.05	2 [8]
0.05 to 0.10	4.5 [8]
0.1 to 0.15	9.5
0.15 to 0.20	14
0.20 to 0.25	18
0.25 to 0.30	21 [8]
0.30 to 0.35	24 [8]

W/D ratios shown on Table 8 were used to project the depths of inservice S/Ns for which RPC axial and circumferential sizing has been performed. Figure 32 provides the results of this projection. Based on comparison of the width to depth ratios of indications on pulled tubes to the RPC estimated width of inservice S/Ns which were examined by RPC during Refuel 8, it can be projected that there are no inservice S/Ns with depths which exceed 66%.

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[8] Projected from linear regression best fit line for the data.

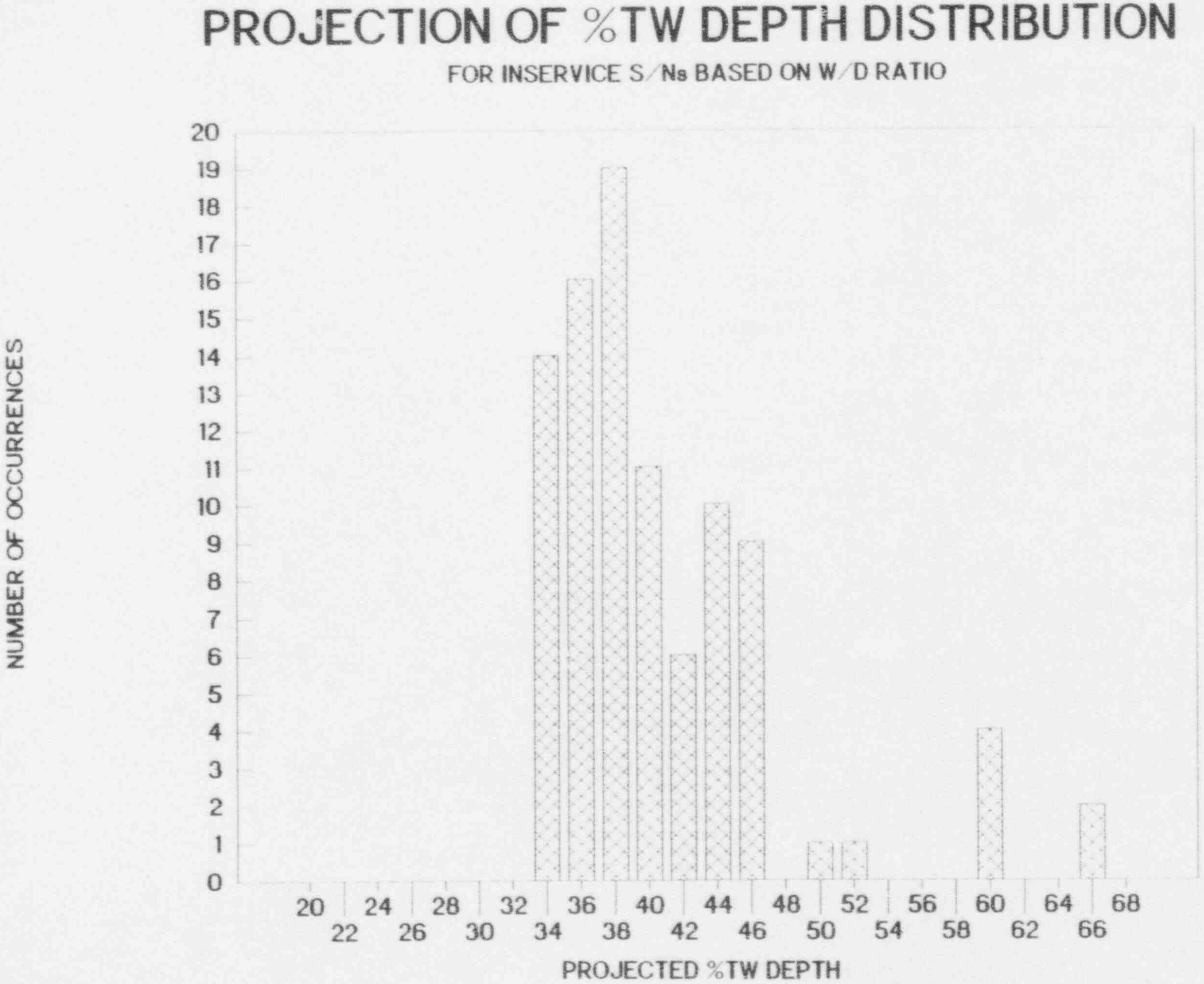

FIGURE 32: Projected Depth Distribution of Inservice S/Ns

A statistical analysis has been performed by MPR Associates, Inc. and is included in this report as attachment C. Statistical techniques outlined in the National Bureau of Standards Handbook 91, "Experimental Statistics", were used to project the through wall depth distribution of the entire population of S/Ns which are potentially present in the CR#3 steam generators, but have not all been detected. The results of MPR's analysis provide a 95% confidence level that 95% of all the inservice S/N type indications have percent through wall depths less than 57.1% and that 100% of all the S/N type indications have percent through wall depths less than 81%. Figures 33 and 34 present the results of the MPR analysis.

Based on two independent approaches (FPC's projection based on the width to depth ratio of indications on pulled tubes versus MPR's standard statistical approach using the depth distribution of indications on pulled tubes) there is a very low probability that S/N type indications in the CR#3 steam generator will exceed the maximum percent through wall depth (91.5% for normal operating pressure, 87% for 2600 psi) required to ensure no leakage will be present following a main steam line break. Additionally, since no significant growth of S/N type indications has been observed, sufficient margin exists between the largest projected percent through wall depths (66% and 57.1%) and the maximum allowable through wall depth to ensure that any potential growth will not reduce the remaining wall thickness to less than the minimum ligament required.

9.2 LEAKAGE LIMITS

Crystal River Unit 3 has a primary to secondary administrative leakage limit of 0.3 gpm. This leakage limit provides reasonable assurance of tubing structural adequacy as well as being practical in terms of detectability.

Defect opening displacements and resulting leakages have been analyzed in a number of cases, including for OTSGs (Reference 11). However, industry operating experience has shown that sometimes even substantial tube defects do not exhibit much leakage. (This is apparently due to tight cracks and the presence of deposits on the tube.) Accordingly, CR#3 uses an administrative leakage acceptance criteria based on engineering judgment and satisfactory past operating experience.

Operating experience at another OTSG plant where several tube leaks have occurred due to corrosion assisted high cycle fatigue in the lane/wedge region has shown that the leakage pattern exhibited by this type of damage mechanism can be easily distinguished by its characteristic step increases in leakage. Should this type of leakage pattern be observed at CR#3, consideration would be given to beginning Unit shutdown at a leakage level lower than the current 0.3 gpm administrative limit.

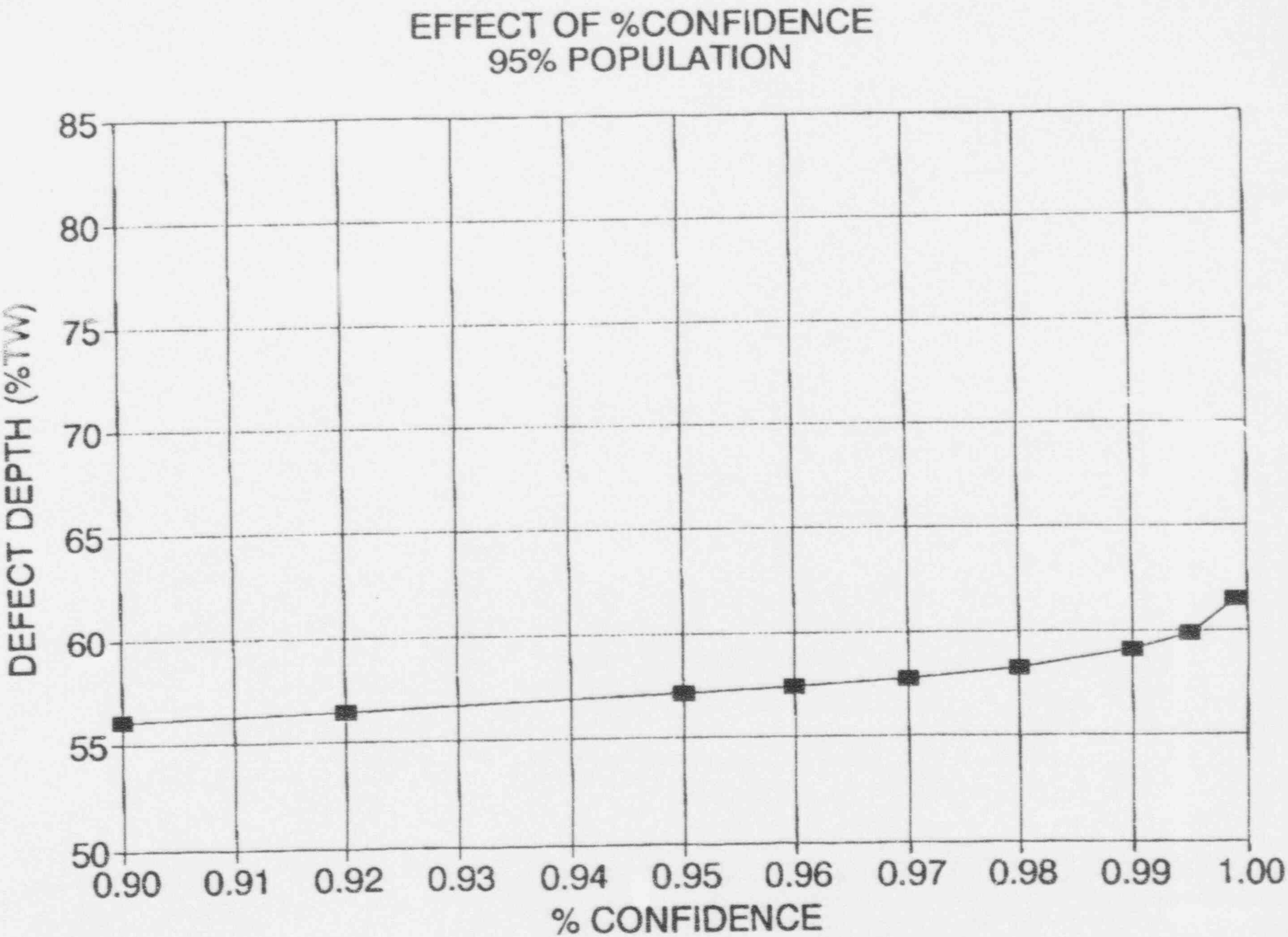

FIGURE 33: Effect of Confidence Level on Projected Depth Distribution

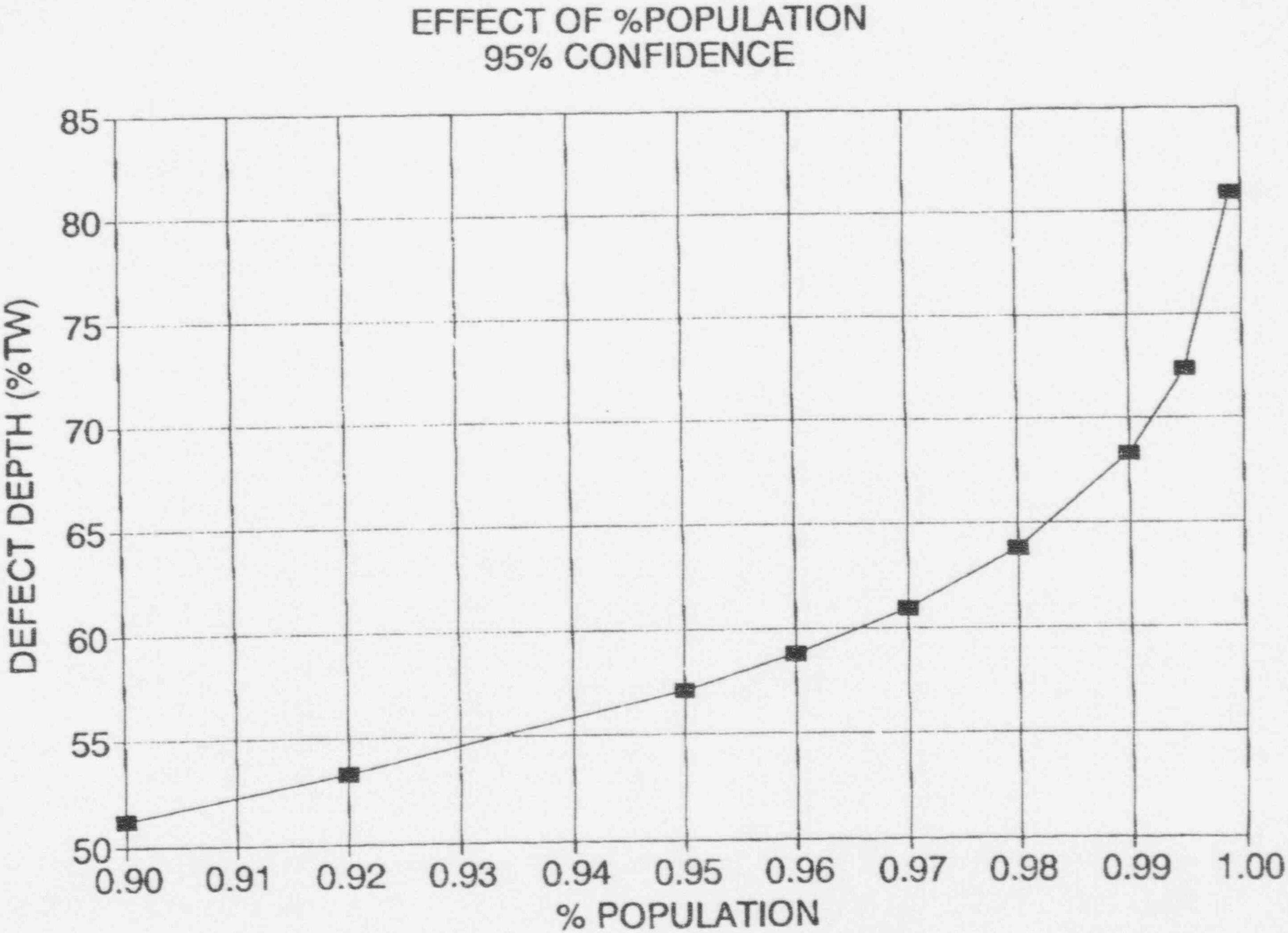

FIGURE 34: Effect of Sample Population on Projected Depth Distribution

10.0 Refuel 9 PLANS

10.1 EDDY CURRENT INSPECTION SCOPE

During Refuel 8, 54% of the tubes in the "A" steam generator and 73% of the tubes in the "B" steam generator were inspected using bobbin coil probes. [Note: 100% of the tubes in the "A" steam generator have been inspected since 1987 and 100% of the tubes in the "B" steam generator have been inspected since 1989.] RPC was performed on lane/wedge region tubes at the 15th tube support plate and upper tube sheet secondary face. RPC was also performed on 47 S/N indications in the "A" steam generator and 123 S/N indications in the "B" steam generator.

The 1994 Refuel 9 bobbin coil inspection total will include 23% of the tubes in each steam generator. 100% of inservice tubes with any previous recorded indication, including S/Ns, will be examined as part of the 3rd sample of the inspection. The new BWNT rotating field eddy current (RFEC) probe will be used to inspect lane/wedge region tubes outside the preventive sleeving zone at the 15th tube support plate and upper tube sheet secondary face.[9] The RFEC probe will also be used to examine S/N indications on eight tubes which have been chosen as tube pull candidates. RPC will be used to confirm any lane/wedge region indication identified by RFEC. RPC will also be performed on the eight tube pull candidates and a sample of S/Ns.

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9 The RFEC probe has been shown in trials to have better sensitivity than bobbin coil probes for most defect orientations/types, with equal sensitivity to RPC for most types of defects. Field experience with this probe may subsequently lead to complete replacement of the RPC probe.

10.2 EDDY CURRENT ANALYSIS GUIDELINES

The CR#3 specific analyst guidelines prepared prior to Refuel 8 have been revised in preparation for use during Refuel 9. The guidelines have been developed to establish consistency in the analysis process. Requirements in the guideline are in addition to those specified by BWNT technical procedure ISI-460, which governs the evaluation and reporting of eddy current data. A draft copy of revision 1 to the CR#3 analyst guidelines is included in this report as Appendix G.

Revision 1 of the guidelines incorporates new sections on "Noisy Data" and use of RPC clip plots to assess axial and circumferential size of an indication. For consistency, guidelines for determining the amplitude of a signal and its signal to noise ratio have not been changed since the guidelines were used during Refuel 8.

In addition to site specific analyst guidelines, all data analysts are required to pass a CR#3 specific performance demonstration test which documents accepTable measurement of CR#3 damage mechanisms. During the course of the examination, resolution analysts provide corrective feedback to individual analysts as required based on primary and secondary analysis results.

10.3 EDDY CURRENT REPEATABILITY

There are several factors which can affect the repeatability of eddy current inspections. Examples of these factors are: probe selection and fill factor, examination frequencies, cable lengths, and probe wear. Efforts to ensure repeatability and consistency during eddy current inspection planning are important to facilitate data comparison with historical eddy current data.

The first step taken by CR#3 to ensure repeatability of eddy current inspections is the use of the same qualified eddy current vendor, BWNT for all CR#3 eddy current inspections. BWNT has performed all the previous eddy current inspections at CR#3 and will continue to do so under a Long Term Maintenance Contract which is in place through Refuel 12.

Fill factor is a function of the outside diameter of the inspection probe to the inside diameter of the tube. Fill factor provides a measure of how much the probe could potentially move inside the tube, subsequently affecting the eddy current signal. When inspecting steam generator tubing, a fill factor of greater than 0.80 is desirable. The Refuel 8 bobbin coil examination was performed using a 0.510"

M/ULC/HF bobbin probe. The same probe will be used during Refuel 9 for consistency. Use of the 0.510" probe produces a nominal fill factor of 0.85, which is currently the best fill factor that can reasonably be achieved in 0.625" OD OTSG tubing. Therefore, quality of eddy current data obtained during Refuel 9 should be consistent with that obtained during Refuel 8 with respect to probe selection.

In RSGs, probe wear and its resulting decrease in fill factor have created a problem with consistently obtaining signal amplitudes for eddy current indications. Probe wear in RSGs is likely increased due to the path the probe must take around the U-bend of the tube. Probe wear has not been previously identified as a problem in OTSGs. However, the CR#3 analyst guidelines instruct analysts to continuously verify probe acceptability for each tube by reviewing the overall quality of data and determining if the probe is causing undesirable signal responses. If problems due to probes are identified, all tubes with questionable data are rerun with an alternate probe.

Examination frequencies can also affect repeatability of inspections. Although the 600 kHz frequency channel has been determined to be the best frequency for use in sizing of indications, the 400 kHz differential frequency is best suited for detection of indications during analysis because it is less influenced by noise. Therefore, use of the 400 kHz frequency for detection and the 600 kHz frequency for sizing will be continued during Refuel 9.

Eddy current equipment (Miz 18/18A) and data cable lengths have been maintained consistent from outage to outage. To minimize noise and ensure quality of data, data cable length has been consistently kept at 60 feet. (50 feet of extension cable plus 10 feet of sacrificial cable from the ECT probe to the data acquisition unit). The short cable length used at CR#3 minimizes loss of signal amplitude due to extension cable length.

11.0 BWOG TUBE INTEGRITY PROGRAM

11.1 TUBE PULLS

The BWOG Steam Generator Committee has recently initiated a tube pull program to identify and characterize degradation currently affecting steam generator tubing. As part of this program, co-funded tube pulls are planned at both Crystal River Unit 3 and the Oconee Nuclear Station during 1994.

The CR#3 tube pull will focus on the 7th to 9th tube support plate regions of the "B" steam generator. Four tubes will be removed for chemical and metallurgical analysis. Burst testing will also be performed as part of the analysis plan. Analysis of tube samples from both Crystal River and Oconee should be completed in 1995. Information obtained from the Refuel 9 tube pull analysis will be compared with the results of the Refuel 8 tube pull analysis and the information contained within this document. Should any of the conclusions reached within this document change as a result of the Refuel 9 tube pull analysis or the Oconee Tube Pull Analysis, it will be revised and resubmitted as appropriate.

11.2 BURST TESTING

Burst testing will be performed as part of the BWOG tube integrity program to determine the structural significance of various defect types. The testing will include tube samples with various types of indications that will be manufactured and/or laboratory grown. The samples will be non destructively examined prior to burst testing in order to correlate a measured NDE parameter with burst pressure for various flaw sizes. Leak testing of specific flaws will also be performed as part of this program. This work will begin in 1994 and is scheduled for completion prior to Crystal River's next scheduled Refueling Outage (RFO 10) in 1996. Information obtained from the BWOG burst test program will be used to verify the conclusions reached within this document. Should any of the conclusions reached within this document change as a result of the BWOG burst test program, it will be revised and resubmitted as appropriate.

12.0 CONCLUSIONS

Based on evaluations which have been performed it can be concluded that application of a revised repair criteria to pit-like IGA, volumetric indications with signal to noise ratios less than or equal to 5:1 is acceptable. Following discussions with NRC staff, it has been determined that insufficient information and time is available to finalize a formal change to the Technical Specification repair limit prior to Refuel 9 eddy current inspections. For this reason, CR#3 has proposed a means by which to address the S/N issue outside the Technical Specifications. Following analysis of tubes removed during Refuel 9, additional discussion will be held on proposed Technical Specification changes.

The following discussion summarizes the approach which will be used to disposition S/Ns during Refuel 9:

1. S/Ns which are dispositioned as wear will be through wall sized following RPC examination using ASME wear standards, with 40% through wall as the allowable limit.

2. S/Ns which are dispositioned as manufacturer's burnish marks must have a historical data review to confirm the presence of the indication during past inspections with no change in signal characteristics.

3. S/Ns which are dispositioned as IGA/pit-like will be considered unacceptable if their primary frequency voltage is greater than 2 volts. (600 kHz freespan, 600-200 kHz mix frequency for tube support plates)

4. S/Ns confirmed by RPC examination with an RPC clip plot estimated axial dimension greater than 0.25 inch or an estimated circumferential dimension greater than 0.60 inch will be repaired.

5. A sample of 20% of the population of S/N type indications with voltages less than 2 volts will be examined using RPC. This sample will consist of any indication RPC examined during Refuel 8 with RPC clip plot estimated dimension(s) greater than 1/2 the limits established in item 4 above. The balance of the sample will be selected from the remaining S/Ns with the highest bobbin coil voltages. Based on the number of S/Ns identified in the CR#3 steam generators during Refuel 8, approximately 147 indications will be examined during the 20% sample inspection..

NOTE: If an S/N indication on a tube causes a tube to be removed from service, then the remaining S/N indications on the same tube would be excluded from any RPC examination.

6. RPC sample expansion shall be performed if the failure rate exceeds 5% of the total number of S/N type indications with voltages below the median voltage of the 20% sample.

7. RPC sample expansion will be dependent upon the voltage distribution of indications which fail the dimensional based criteria. If all indications which fail have voltages greater than 1.0 volt, then a minimum 10% sample of the remaining population of S/Ns with voltages greater than 1.0 volt must be inspected. If any indications which fail have voltages less than 1.0 volt, then a 10% sample of the remaining population of S/Ns in each voltage range where a failed tube is identified must be inspected. Examples of sample expansion would be as follows:

EXAMPLE A: IF >5% of the 20% sample fails and all indications which fail have bobbin voltages greater than 1.0 volt, an expanded RPC examination must be performed by examining a minimum of 10% of all the remaining indications with voltages greater than 1.0 volt.

EXAMPLE B: IF >5% of the 20% sample fails and some of the indications which fail have voltages of 0.95 volts, some have voltages greater than 1.0 volt, then an expanded RPC examination must be performed by examining 10% of the remaining indications with voltages greater than 1.0 volt <u>AND</u> 10% of the remaining population of S/Ns with bobbin voltages between 0.9 and 1.0 volt.

EXAMPLE C: IF >5% of the 20% sample fails and some of the indications which fail have bobbin voltages of 0.75 volts, some have bobbin voltages of 0.85 volts, some have bobbin voltages of 0.95 volts, and the rest have voltages greater than 1.0 volt, then an expanded RPC examination must be performed by examining 10% of the remaining population of S/Ns with voltages greater than 1.0 volt AND 10% of the remaining population of S/Ns with voltages between 0.9 and 1.0 volts AND 10% of the remaining population of S/Ns between 0.8 and 0.9 volts AND 10% of the remaining population of S/Ns between 0.7 and 0.8 volts.

8. If one tube fails as a result of the expanded sample described in item 7, then an additional 10% of the remaining population of S/Ns in the same voltage range as the failed indications should be inspected. For example:

EXAMPLE A: If an indication with a bobbin voltage of 0.95 volts fails the dimensional criteria then a 10% sample of the remaining population of indications in the 0.9 to 1.0 volt range must be inspected.

EXAMPLE B: If indications with bobbin voltages of 0.95 AND 0.85 volts fail the dimensional criteria then a 10% sample of the remaining population of indications in the 0.9 to 1.0 volt range must be inspected AND a 10% sample of the remaining population of indications in the 0.8 to 0.9 volt range must be inspected.

Sample expansion would continue in the same fashion until no failures are found or until all the indications in a particular voltage range have been inspected.

9. Identification of "new" S/N type indications will be monitored and considered with respect to bobbin coil inspection sample expansion. "New" S/Ns (NSN) will be defined as any signal to noise indication greater than 0.75 volts which has not been identified in any eddy current inspection since 1987. S/N type indications documented for the first time as a result of eliminating the use of "multi" designators for areas where more than one S/N indication is present will not be considered NSNs.

10. Identification of significant growth rates for S/Ns documented during the 1992 inspection will also be considered with respect to bobbin coil inspection sample expansion. Significant growth, for S/N type indications with bobbin coil voltages greater than 0.75 volts, will be defined as any positive voltage increase greater than 0.5 volts. S/Ns which exhibit growth, but do not exceed the 2 volt repair limit, will be documented using the characterization code SNG.

NOTE: A bobbin voltage threshold of 0.75 volts has been established for investigation of "new" S/Ns and growth. Establishment of a lower voltage threshold is intended to screen out very low voltage indications which are just above the noise level of the tubes and tend to fade in and out from inspection to inspection.

11. If more than 10% of the total tubes inspected in the 1s, 2s, and 4s Technical Specification bobbin inspection contain indications which are characterized as NSNs or SNGs, bobbin sample expansion should be performed by inspecting all tubes adjacent to any tube characterized as an NSN or SNG.

Implementation of this plan during Refuel 9 will provide a reasonable methodology by which to disposition S/N type indications while maintaining the margin of safety established by Regulatory Guide 1.121.

13.0 REFERENCES

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2. R.J. Kurtz, et al, "Steam Generator Tube Integrity Program/Steam Generator Group Project - Final Project Summary Report", NUREG/CR-5117, 5/90.

3. Letter from K. Krzywosz (EPRI) to P. Sherburne (BWNS), "Review of Successive Eddy Current Data on Pulled Steam Generator Tubes from Crystal River Unit 3", 3/24/93.

4. The B&W Owners Group NDE Committee Report on Intergranular Attack (IGA) Detection and Sizing Capabilities of Various ECT and UT NDE Examination Methods in OTSG Tubing, Document #47-1228838-00, 11/11/93.

5. Palisades Nuclear Plant 1989 Miz-18 Eddy Current System Qualification, Project Number 248815222024, Consumers Power Company NDT Services, Volume 1 of 9, 8/24/89.

6. OTSG Outage Summary Report for Crystal River Unit 3, B&W Nuclear Service Company, 5/92.

7. PWR Steam Generator Examination Guidelines, Electric Power Research Institute, EPRI NP-6201, 12/88.

8. Crystal River Unit 3 Eddy Current Data Analysis Guidelines, B&W Nuclear Service Company, 5/1/92.

9. BWNT Document 51-1218868-00, Draft "Crystal River Unit-3 Refuel 8 Pulled Tube Data Evaluation".

10. BWNT Document 51-1229575-00.

11. GPU Topical Report 008 R2, "Assessment of TMI-1 Plant Safety For Return to Service after Steam Generator Repair", March 1983.

12. BWNT Document 51-1229189-00, Criteria for Determining Structurally Significant Steam Generator Tube Flaws.

13. BWNT Document 1217317A, Crystal River Unit #3 Eddy Current Data Analysis Guidelines

APPENDIX A

DRAFT EPRI TUBE PULL REPORT

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February 4, 1994
CE-94-015

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Subject: Transmittal of Final Report for RPS 413-06

Dear Peter:

Submitted herewith is the final manuscript for Research Project S413-05, "Crystal River Unit #3 Steam Generator Tube Sections." One complete copy of the final report and diskettes for the report text, graphics, and Appendix C are also included with the manuscript.

If you have any comments or questions regarding this submittal, please contact me at (804)832-3324.

Very truly yours,

Paul A. Sherburne

Paul A. Sherburne
Chemical Engineering, SPIS

Enclosures

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