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Title Repair Criteria for Small Volume Indications, CR-3

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Remarks:

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This document develops and supports a criteria which can be used to determine which tubes should be repaired in the CR-3 steam generators. The criteria will be used to address small volume indications that cannot be accurately sized by conventional eddy current examination techniques.

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1.0 Introduction

During the most recent steam generator tube eddy current inspections performed at Crystal River 3, a significant number of small volume indications have been identified. Due to the small signal amplitude associated with these indications, they can not be sized accurately by conventional bobbin coil phase angle. During the 4/92 CR-3 outage, six (6) tubes with small volume indications were pulled from the first span and examined in the laboratory [8.5]. In addition, an engineering evaluation of the first span indications was performed which concluded that the indications were not structurally limiting and did not show evidence of growth [8.7].

The purpose of this document is to develop a criteria for assessing the structural integrity of all small volume indications in the CR-3 steam generators. The criteria has been developed in accordance with the requirements of USNRC Reg. Guide 1.121 [8.1], and is based on tube burst tests, structural analysis, flaw growth studies, and correlation of NDE examination techniques to flaw size. It is shown that the resulting criteria can be conservatively applied to any volumetric (non-crack) indication in the CR-3 steam generator and assure that the plant can be operated safely until the next scheduled inspection.

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2.0 Methodology

The criteria proposed by Florida Power for disposition of small volume indications is given in the flow chart in Figure 1. A graphical representation of the proposed criteria is presented in Figure 2. All indications with an associated bobbin coil signal to noise ratio greater than 5:1 would be sized by bobbin coil phase angle and dispositioned by the current 40% TW plugging criteria. The remaining indications which are too small to size by bobbin coil phase angle would be dispositioned as described in the following paragraphs.

If the signal to noise ratio is less than 5:1, the indication will be dispositioned based on application of the criteria shown in Figure 1. If the indication is in the existing ECT database and can be determined from previous data to be volumetric, the flaw will be dispositioned based on its signal amplitude. For this filter, a conservative bobbin coil voltage threshold (designated "x" on Figure 1) will be determined to represent a limiting flaw size. It will be shown that all volumetric flaw types represented by this signal amplitude are structurally insignificant per the

FIGURE 1
PROPOSED FLOW CHART FOR DISPOSITIONING
SMALL AMPLITUDE INDICATIONS, CR-3

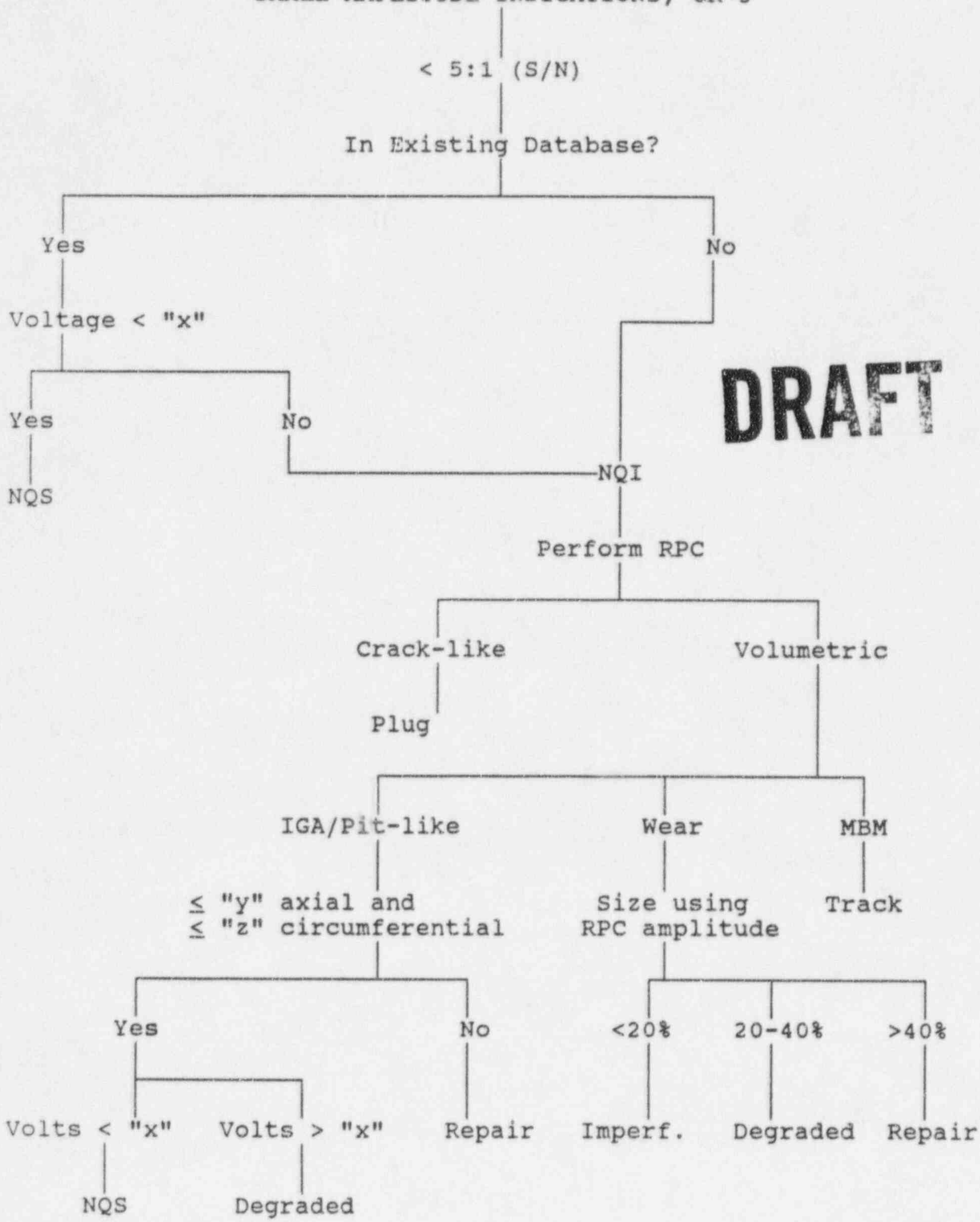

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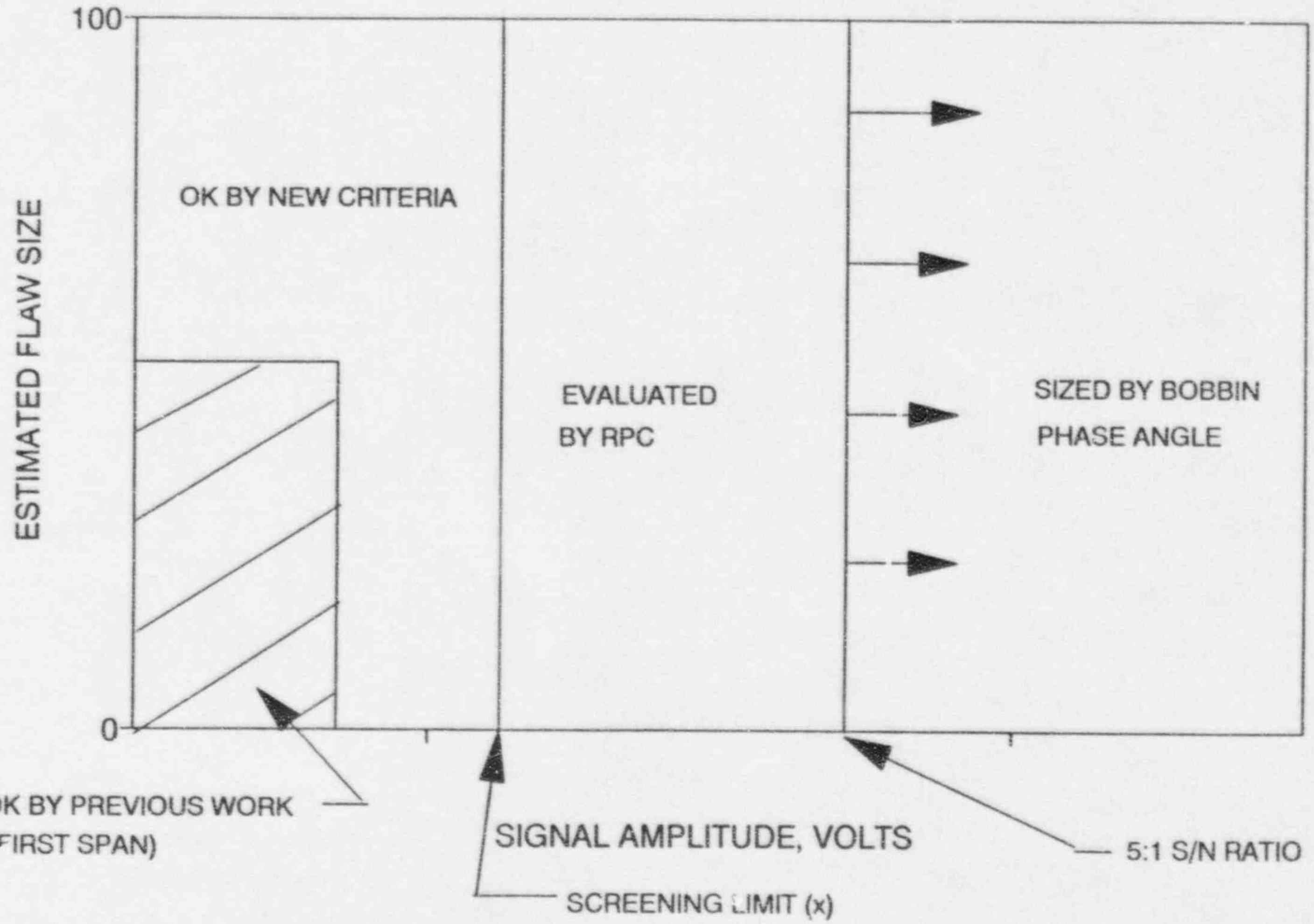
FIGURE 2
PROPOSED CR-3 REPAIR CRITERIA



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Reg. Guide 1.121 [8.1] criteria. All indications producing a signal amplitude below this voltage would be designated as a non-quantifiable signal (NQS) and be allowed to remain in service. These indications would be re-inspected during the next scheduled outage.

If the signal amplitude is greater than the screening limit, or if the indication has not been previously detected, it will be designated as a non-quantifiable indication (NQI) and further characterized by RPC inspection. If the indication is shown to be crack-like it would be repaired. If the indication is volumetric, it will be assigned to one of three categories by degradation type, including IGA/pit-like, Wear, and manufacturing burnish mark (MBM). Wear indications can be accurately sized by RPC signal amplitude, and will be dispositioned based on %TW. Any indication designated as an MBM will be allowed to remain in service and will be monitored in future inspections.

For IGA and pit-like indications which are too small to size by conventional methods, a criteria based on axial and circumferential extent will be used to determine whether these indications must be repaired. These parameters are designated as "y" and "z" on Figure 1. Since the %TW penetration of these indications can not be accurately determined, these dimensions must represent a structural limit for potentially 100% TW flaws.

Application of the above methodology requires determination of the following parameters.

1. The limiting flaw size for the various types of volumetric tube degradation found in the CR-3 steam generators.

2. The bobbin coil voltage that conservatively represents the limiting flaw size for all expected types of volumetric degradation.

3. An acceptable eddy current technique for determining the limiting flaw dimensions of small volume indications in item 1.

4. A conservative estimation of flaw growth over one inspection cycle.

Each of these items is addressed in the subsequent sections.

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3.0 Limiting FLAW SIZE

MPR Associates performed an analysis per the requirements of NRC Regulatory Guide 1.121 [8.1] to determine the geometry of a structurally limiting flaw in OTSG tubing. This analysis [8.2] determines the allowable thru-wall penetration as well as axial and circumferential extent for flaw geometries that envelope the tube degradation mechanisms previously observed in operating OTSGs. All applicable OTSG tube loads are considered, including normal operation and accident conditions as required by the Reg. Guide. The analysis also accounts for margin against tube rupture by reference to burst testing performed on OTSG tubing with simulated flaws that envelope all known OTSG damage mechanisms.

Limiting flaw sizes for OTSG tubes can be determined from Figures 1 and 2 of Reference 8.2, which are reproduced in this report as Figures 3 and 4. From these figures, the following observations are made.

1. The limiting flaw size for an assumed 100% TW flaw is 0.25 inch in the axial direction and 120 degrees in the circumferential direction. The combination of these two figures defines the boundary for an acceptable 100% TW flaw.

2. For defects where the %TW can be estimated, the figures provide a means of determining the allowable axial and circumferential extent as a function of %TW.

Figure 3. Allowable Tube Wall Penetration
For Axial Slot Type Defects (Axial Cracks)
(From Reference 8.2)

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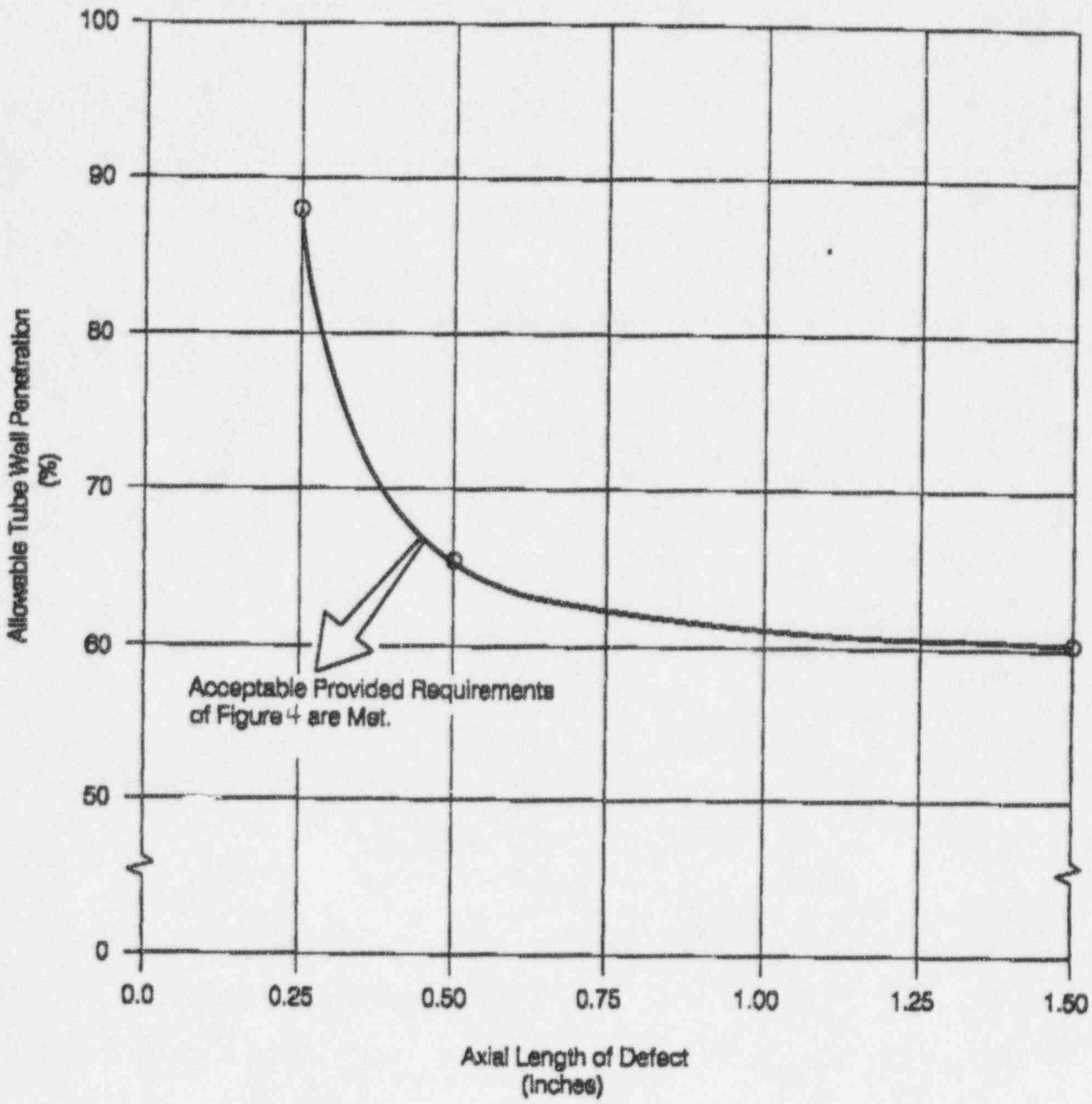

Figure 4. Maximum Allowable Penetration Versus Arc Length For 34.1 % Maximum Allowable Area of (From Reference 8.2)

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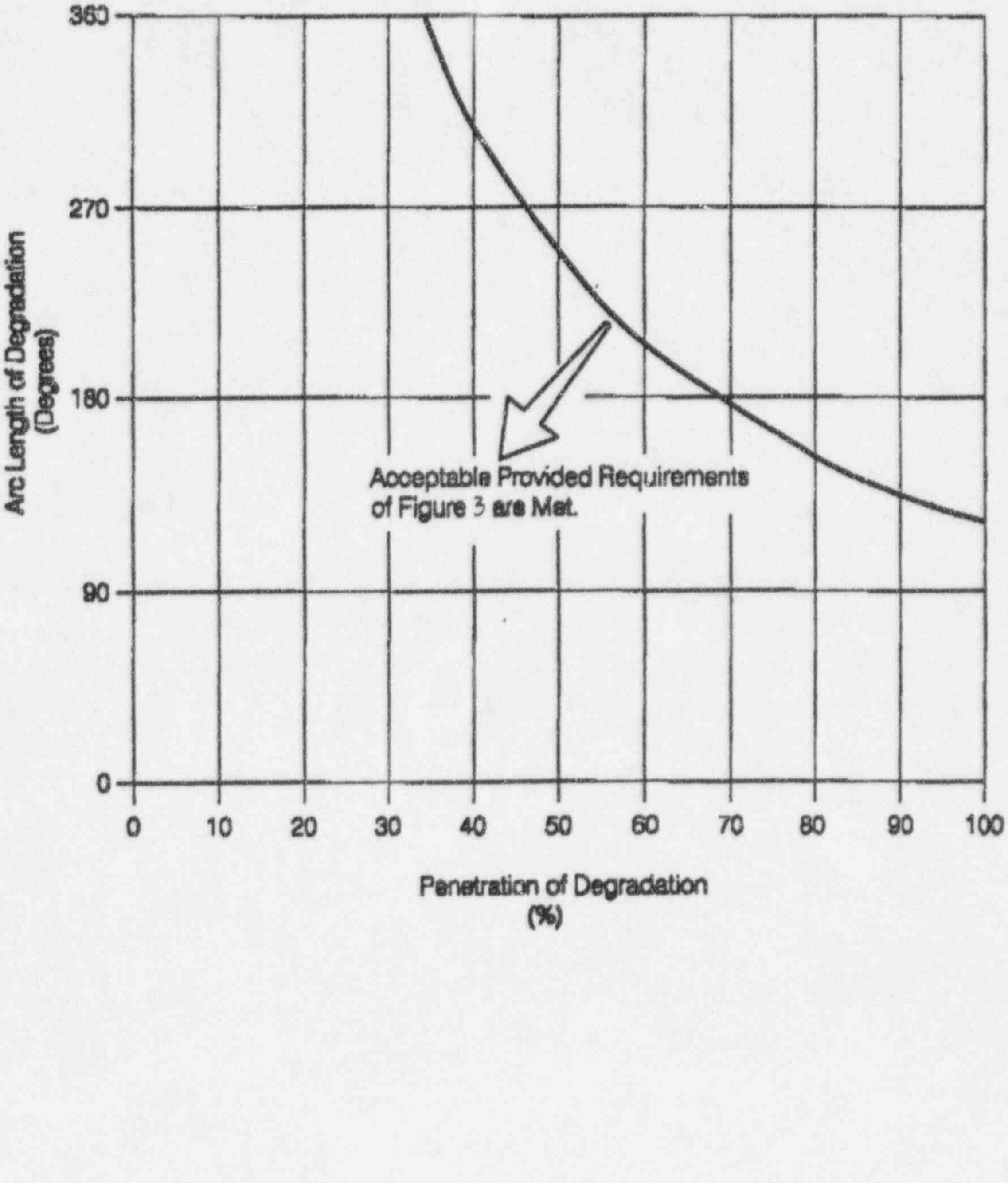

4.0 ECT CORRELATION TO FLAW SIZE

The correlation of ECT signal response to flaw size is dependant on existing data from previously completed work. In order to develop a conservative criteria, several different approaches are used. These are discussed in detail in the following sub-sections.

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4.1 IGA Correlation on OTSG Tubes

The data in Reference 8.3 were used to correlate a known defect size with an ECT voltage parameter. In the Reference 8.3 study, IGA samples were fabricated in the laboratory and inspected with various eddy current techniques to compare sizing and detection capabilities. Bobbin coil ECT data were acquired with three (3) different probes: a 0.510 M/ULC, a 0.510 M/ULC/HF, and a 0.510 ULC. Six of the samples were destructively examined to determine the actual flaw depth of the IGA patches. All of the destructively 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 the ECT data from CR-3. CR-3 establishes the bobbin coil signal amplitude at 4.0 volts on the four 20%TW holes using the 600 Khz channel. The data from the IGA study was re-analyzed using the same setup, and all calls were made off of the 600 kHz channel to be consistent with current practices at CR-3.

The actual through-wall extent from the destructive exam reported in Reference 8.3 and the corresponding bobbin coil voltage from the re-analysis of the eddy current data are tabulated below.

Sample #	Destructive Exam Max %TW	600 kHz Differential Bobbin Coil Signal Amplitude, Volts
1217423-A	55	2.7
1217423-E	55	1.9
1217424-A	56	3.4
1217424-E	71	7.7
1217425-A	22	0.5
1217425-E	41	1.1

Superposition of these voltage amplitudes on Figures 3 and 4 for the applicable defect size shows the resulting relationship between structural integrity and bobbin coil voltage for these IGA samples. This is done on Figures 5 and 6. As can be seen from Figure 5, the 7.7 volt signal is associated with an unacceptable flaw per the analysis (71% TW and .75 inches axial length). The 3.4 volt signal, however, is associated with an acceptable flaw size. A bobbin coil amplitude structural integrity limit based on this set of data would appear to be on the order of 5 volts.

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4.2 IGA Correlation on Palisades Tubing

Reference 8.4 presents data generated during an eddy current qualification program for IGA performed for the Consumers Power Palisades plant. The samples used in this study had IGA patches of 0.2" axial length and 0.588" in circumferential extent (equivalent to 90° on the tube OD).

Per Reference 8.4 the Palisades data was obtained using a 0.580" dia. high frequency probe, using 400 kHz as the prime reporting frequency. The Palisades tubing is 0.750 OD x .048 wall, which yields a "fill factor" of 79% using the .580 probe. CR-3 uses a 0.510" dia. probe in the 0.625 OD tubing, which has a fill factor of 83%. (Fill factor is the ratio of probe cross-sectional area to the tube inside cross-sectional area). The lower fill factor in the Palisades tubing would tend to depress the signal amplitude for the same size flaw. The data was not corrected for this difference 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 the OTSG tubing (.048 wall vs .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 %TW flaw would produce the same voltage in both size tubes.

Results from the Palisades IGA correlation are presented in Figure 7 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 (8) data points for each IGA patch.

The Palisades data is also displayed on Figures 5 and 6. Since none of these flaws are limiting per the Reference 8.2 analysis, a threshold of structural significance can not be established using this data. However, it is apparent that the OTSG IGA study produced conservative results compared to the Palisades data.

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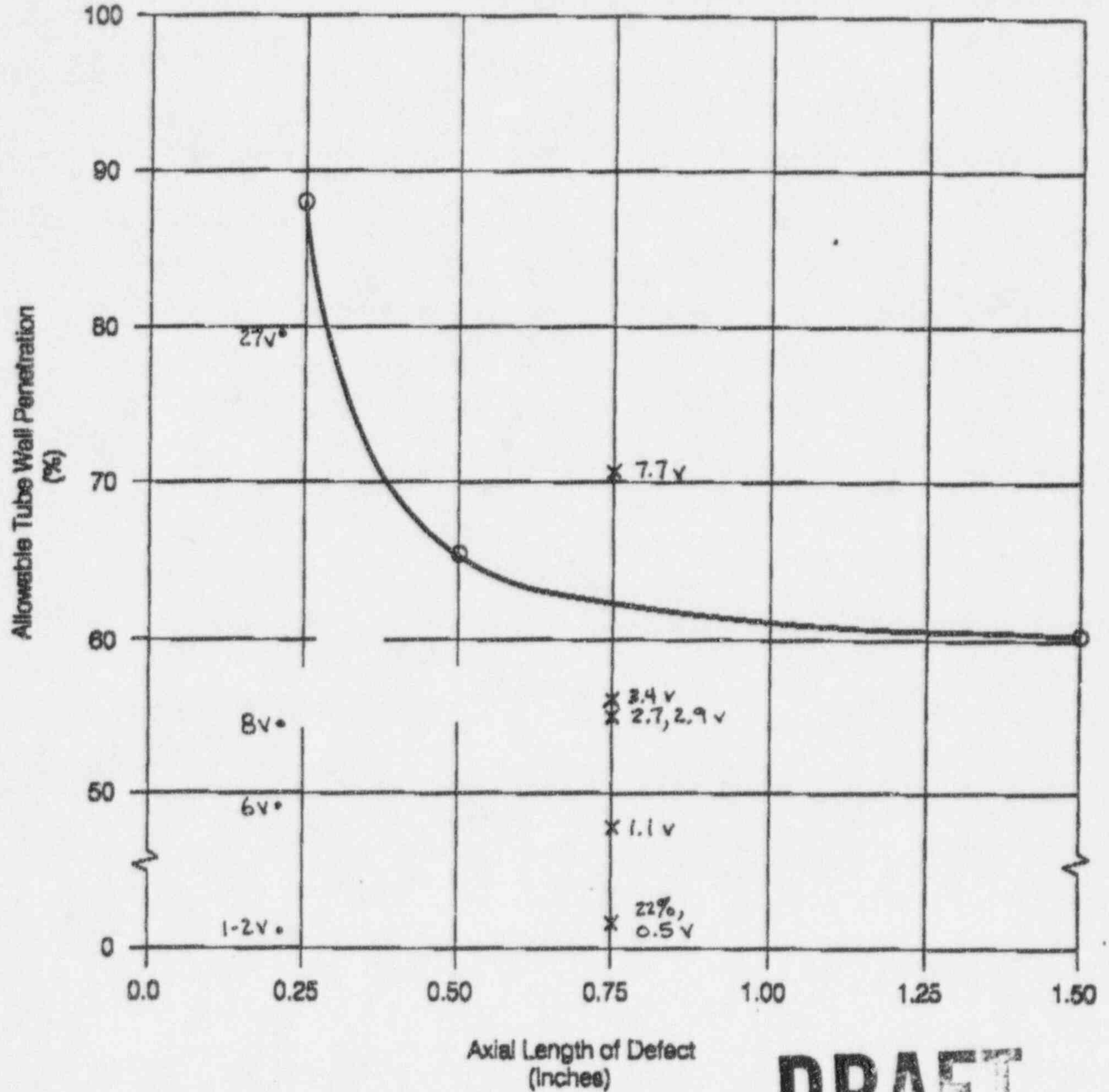
Figure 5. Relationship Between Bobbin Signal Amplitude and Allowable Axial Length, IGA Correlation Data



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Legend: X - NDE Committee IGA Samples (Ref 8.3).
• - Palisades IGA Data (Ref 8.4)

Figure 6. Relationship Between Bobbin Signal Amplitude and Allowable Circumferential Length, IGA Correlation Data

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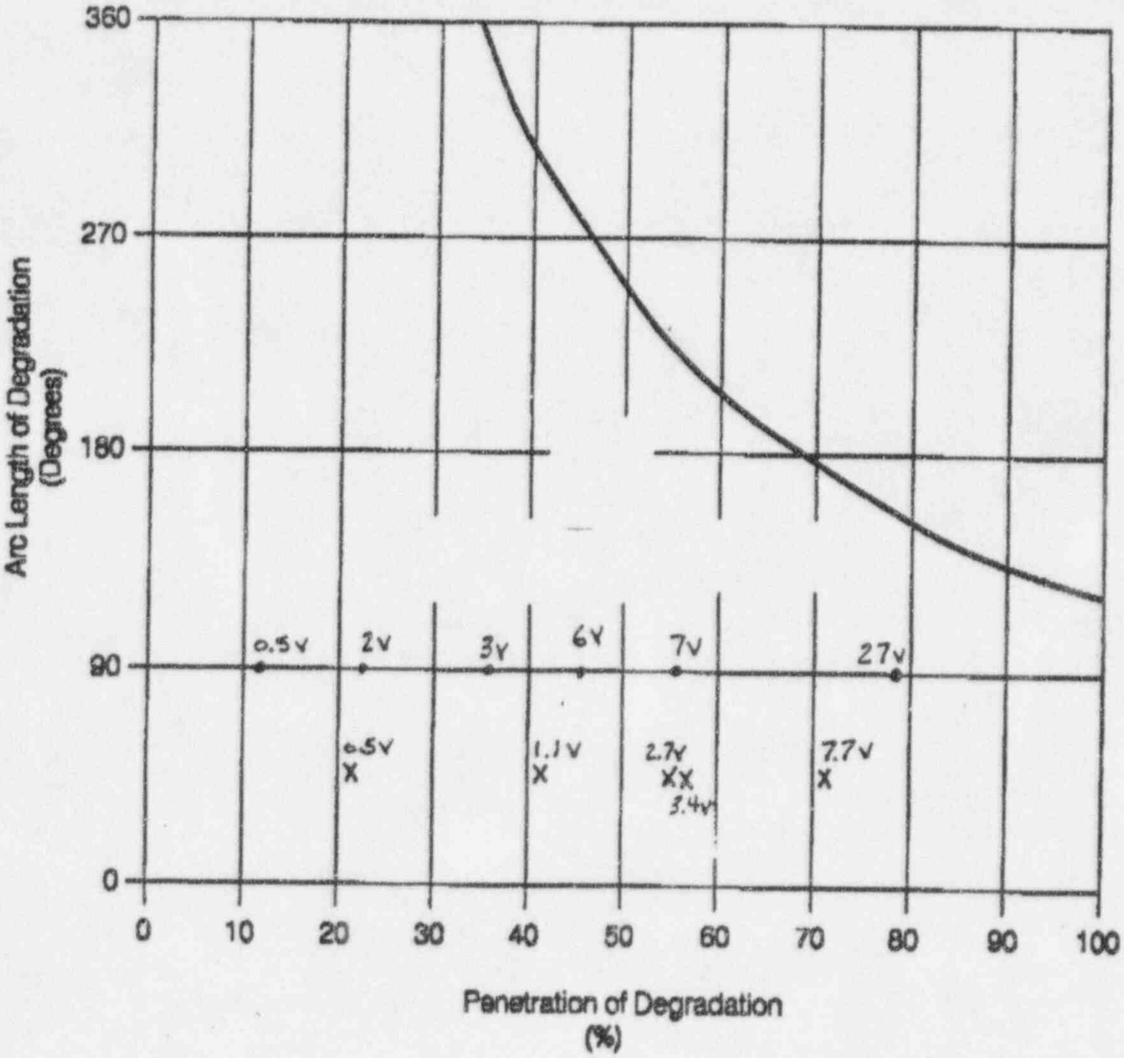
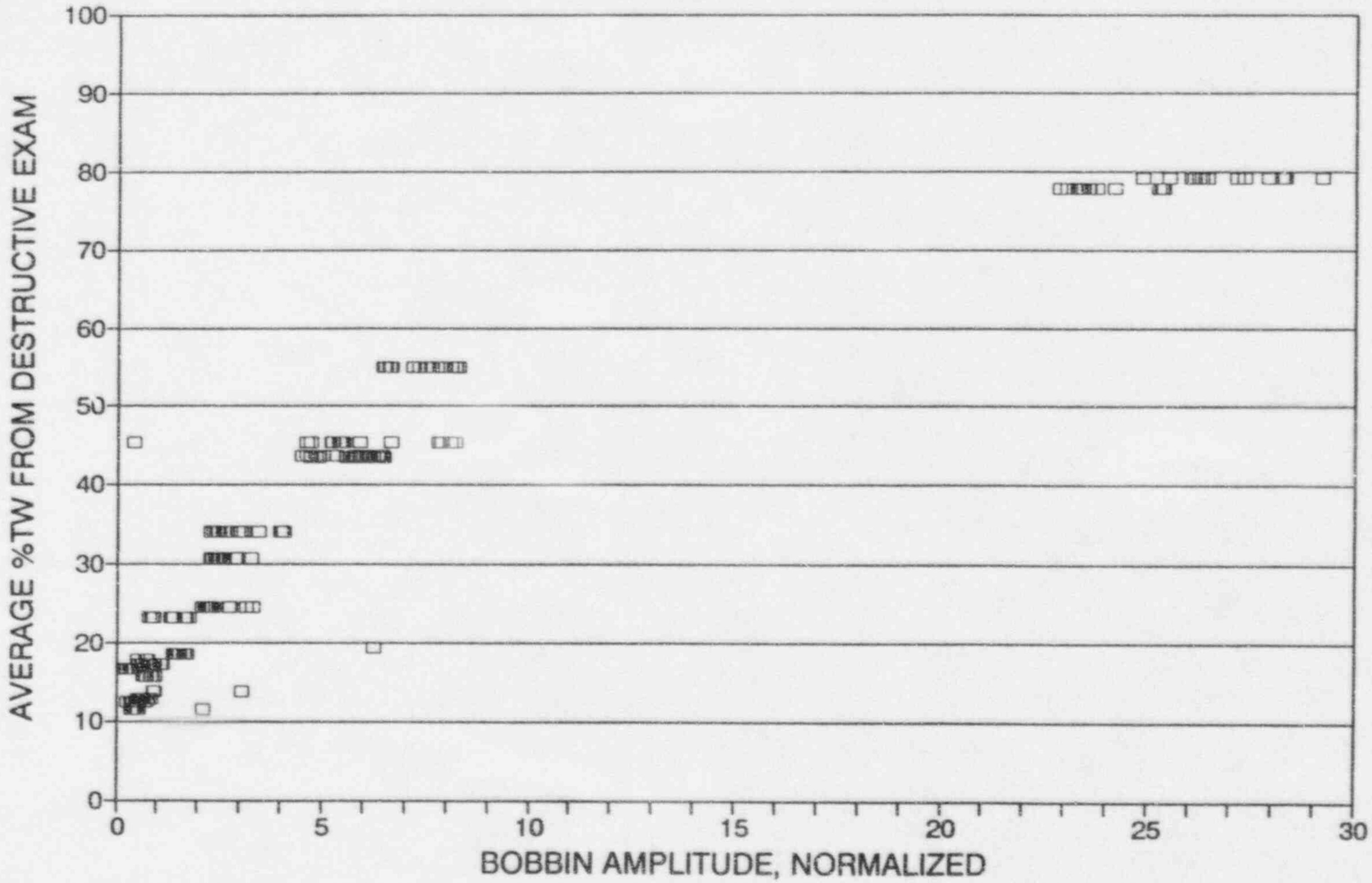


Legend: X - NDE Committee IGA Samples (Ref 8.3).
• - Palisades IGA Data (Ref 8.4)

FIGURE 7
VOLTAGE VS. ACTUAL %TW CORRELATION
PALISADES IGA DATA



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4.3 CR-3 Pulled Tube ECT Correlation

During the 5/92 refueling outage CR-3 pulled six tubes from the B-OTSG that had first span indications. Four of these tubes were examined in the laboratory [8.5] to determine the degradation mechanism present in the tubing. As identified in Reference 8.5, the degradation was identified as small patches of IGA, the largest being less than 0.1 inches in axial length. The maximum penetration was determined to be 62% TW. By comparing the actual thru-wall penetration with the eddy current %TW estimation, it was determined that the depth of these indications was not accurately quantified by bobbin coil phase angle due to their extremely small size.

EPRI [8.6] evaluated the laboratory data on these pulled tubes with the eddy current data to determine if a correlation could be developed to accurately size these indications. As a result of this evaluation, a calibration curve was developed which can be used to estimate the size of the IGA patches using bobbin coil voltage instead of phase angle. Figure 8 shows the resulting relationship. Application of this relationship would conclude that the IGA patches are 100% through-wall at a bobbin coil voltage of approximately 3.4 volts.

Comparing the voltage correlations from the previous two sections with this correlation shows that the EPRI correlation is the most conservative in relating voltage to through-wall penetration. This is due to the different shapes of degradation examined. The IGA patches on the pulled tube samples were pit-like in geometry, with a relatively high penetration for their size. In comparison, the IGA samples discussed in the previous sections were spread over a much larger tube surface area, resulting in a much greater volume for a given penetration. This results in a larger bobbin signal response for the larger flaws.

FIGURE 8
CR-3 IGA AMPLITUDE ANALYSIS/FIELD DATA
ACTUAL PENETRATION VS. SIGNAL AMPLITUDE
(from Reference 8.6)

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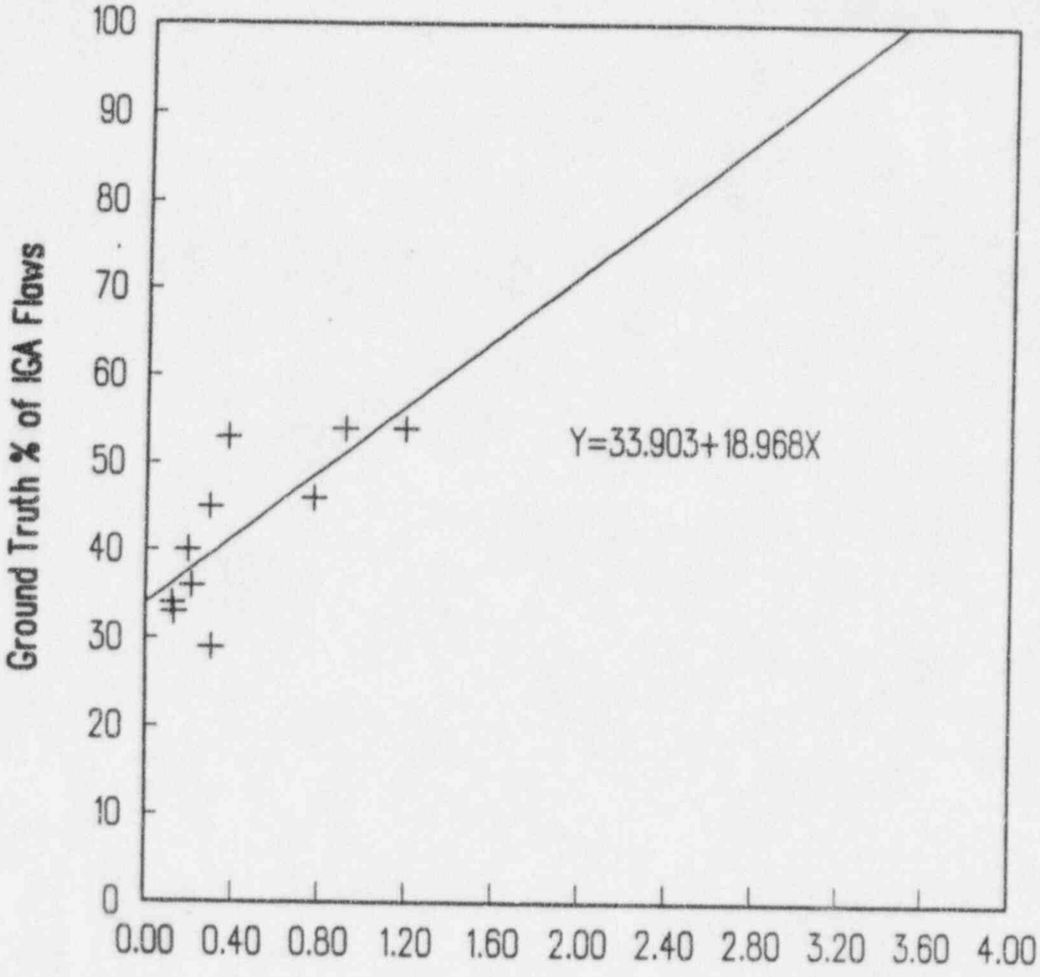

Curve based on 10 seleted data points.

4.4 Recommended Voltage Structural Limit

It is recognized that this voltage based criteria is being based on a limited amount of data compared to that which has been used to develop similar tube repair criteria. Accordingly, it was deemed prudent to apply an extra measure of conservatism to allow for the resulting uncertainty. It is therefore recommended that the voltage structural limit be based on the EPRI calibration curve discussed in Section 4.3, and displayed in Figure 8. The point at which it crosses the 100% TW line (approximately 3.4 volts) is considered to be a conservative structural limit for flaws of this type. This is further supported by burst testing performed in the laboratory [8.5] on two of the pulled tube samples, which resulted in a burst pressure margin of more than 2.5 times the Reg. Guide 1.121 limit of 3 times operating ΔP.

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 the smaller IGA signal amplitude is conservative.

5.0 FLAW GROWTH

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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 inspections. This study is documented in Reference 8.8. A side-by-side comparison of eddy current signals was performed using the data from the 1989, 1990, and 1992 inspections.

For the comparison, all data was normalized to 4 volts on the four 20%TW flat bottom holes in the ASME calibration standard, using the 400 kHz frequency channel. The results are reproduced in Tables 1 and 2 of this report for freespan and support plate indications, respectively. From Table 1 it can be seen that when all freespan indications are considered together, the average change in signal amplitude is +0.01 volts. The freespan indications therefore do not show evidence of growth, which is consistent with the conclusion reached on the first span indications documented in Reference 8.7.

The results from the growth study performed on support plate indications is shown in Table 2. The average change in amplitude for these indications is -0.19 volts, which also suggests that these indications have not grown significantly over the period of evaluation.

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TABLE 1.
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 + 31.45		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	0.95	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

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TABLE 1.
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	0.05	1.09
S/G B	63	29	LTS + 8.29		0.50	0.59	0.09	1.18
S/G B	46	46	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	-0.05	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 + 12.35		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	98	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

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TABLE 2.
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	126	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	0.65	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	128	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

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TABLE 2.

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	146	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	-0.05	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

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However, the standard deviation associated with these growth studies are relatively significant (0.11 volts for freespan indications and 0.30 volts for TSP indications). It is therefore recommended that an allowance for growth be considered in the development of the voltage based screening critieria. Using statistical rules, a 99% confidence level can be assumed when a factor of three is applied to the standard deviation. Using the larger TSP standard deviation, the recommended growth allowance for these CR-3 indications is 3 x 0.30, or 0.90 volts.

6.0 ECT ASSESSMENT OF FLAW GEOMETRY

The measurement of flaw axial and circumferential extent will be performed by using clip plots generated from the RPC examination. This method is explained in Reference 8.8. 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 5/92 outage. The ECT measurements were then compared to the actual flaw sizes reported in Reference 8.5 to determine the amount of conservatism or non-conservatism in the measurement method.

The results of this comparison are reported in Reference 8.8, and reproduced here in Table 3 and Figures 9 and 10. The clip plot technique over-estimated the actual flaw size for every case examined. From Table 3, 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 more conservative, with an average ratio of 5.6 and a minimum of 2.3. In general the amount of conser atism decreases with increasing flaw size for both axial and circumferential flaws.

The last two columns of Table 3 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 about 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.

TABLE 3.
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	0.076	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	0.15	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
106-32-2	LTSF + 13.80"	X2	0.071	11.0	0.053	0.11	0.14	1.5	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.

TABLE 3.
COMPARISON OF DESTRUCTIVE EXAM RESULTS TO RPC CLIP PLOT MEASUREMENTS

TUBE SECTION NO.	AXIAL POSITION	FLAW ID NUMBER	STEREOVISUAL RESULTS AXIAL EXTENT (IN.)	STEREOVISUAL RESULTS CIRC. EXTENT (DEG)	STEREOVISUAL 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	0.076	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	0.15	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
106-32-2	LTSF + 13.80"	X2	0.071	11.0	0.053	0.11	0.14	1.5	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						

	AXIAL	CIRC	AXIAL	CIRC
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.

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FIGURE 9
AXIAL EXTENT MEASUREMENT ACCURACY
DESTRUCTIVE EXAM VS. RPC CLIP PLOT

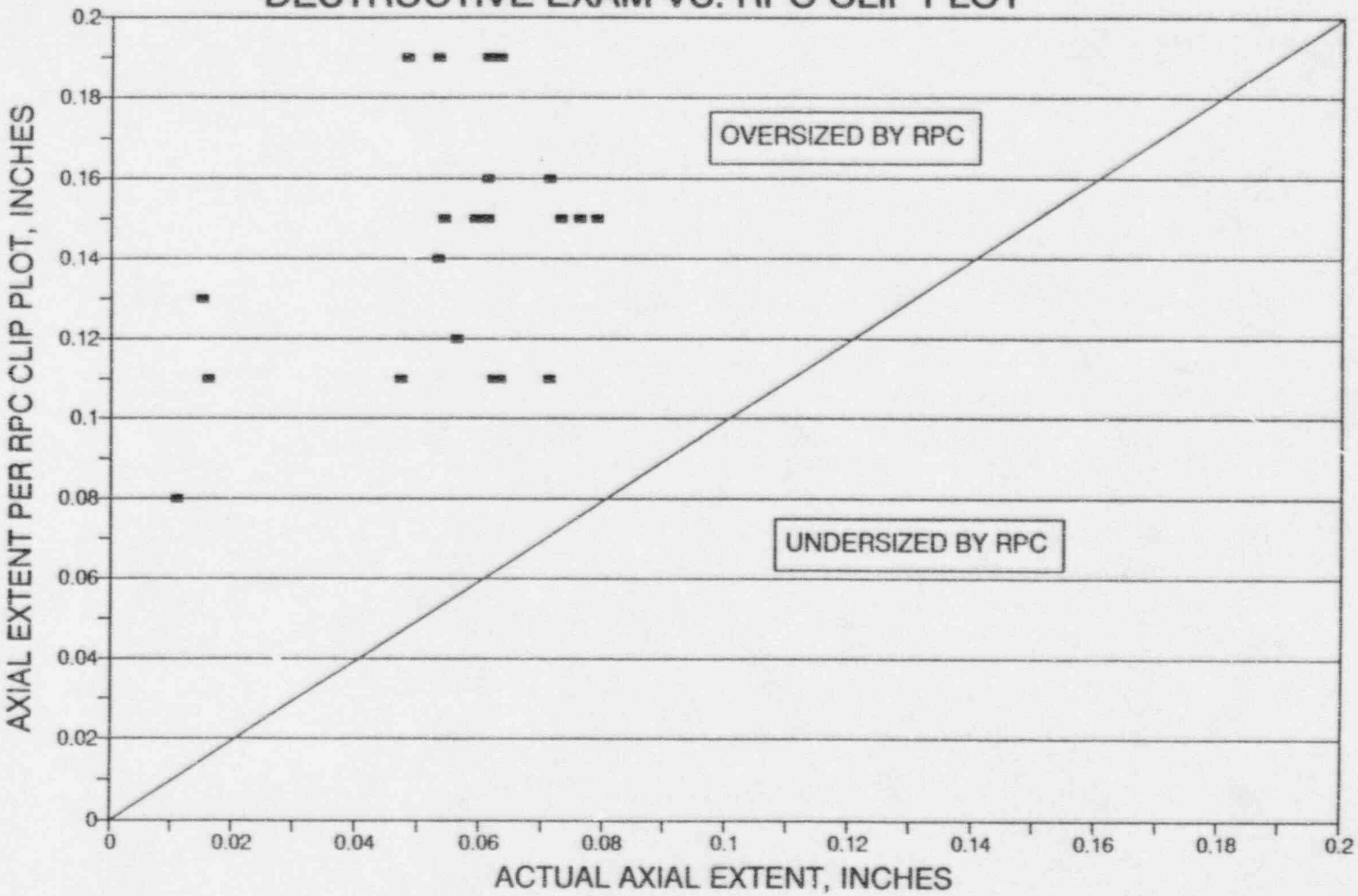
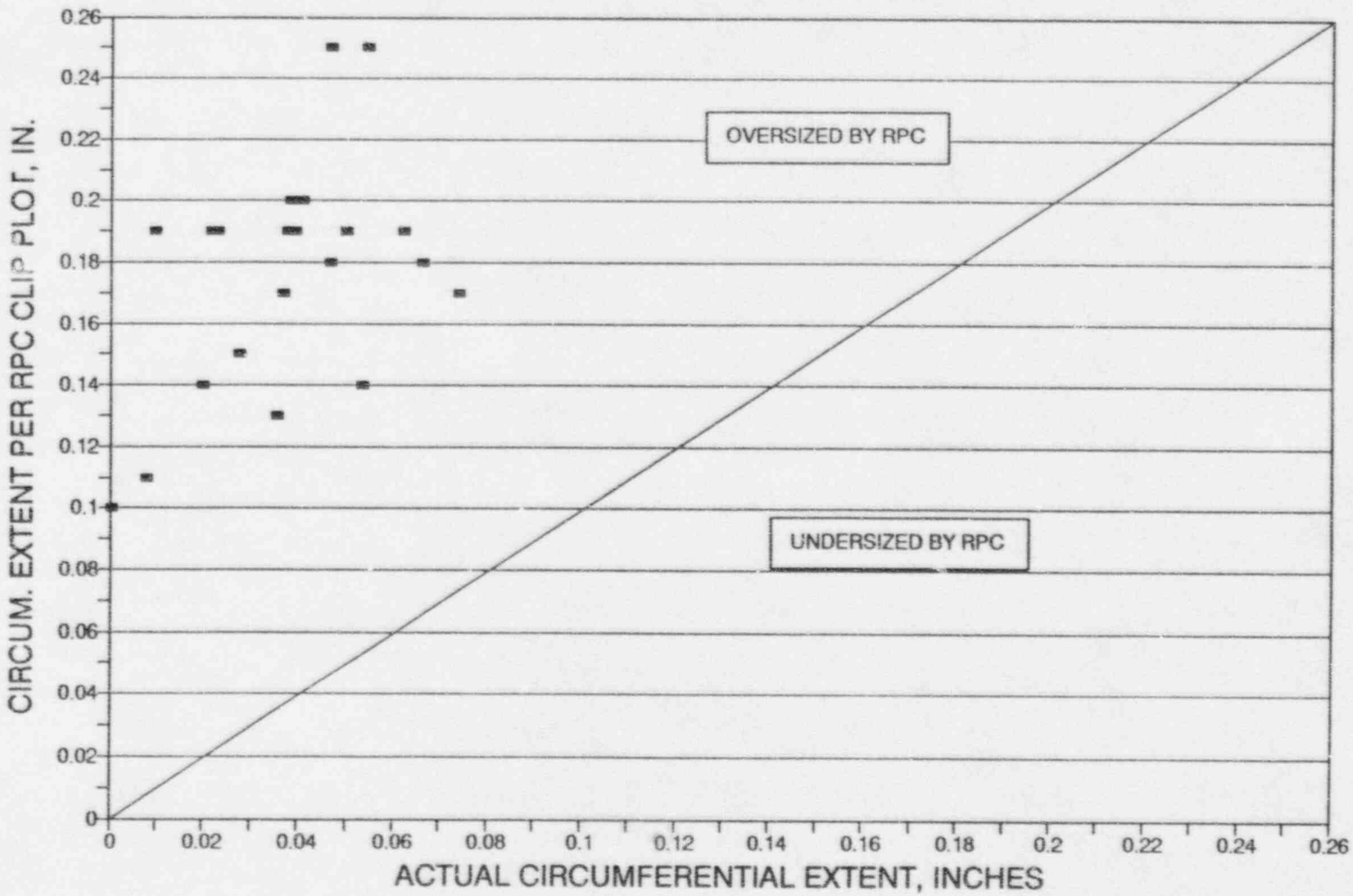


FIGURE 10
CIRCUM. EXTENT MEASUREMENT ACCURACY
DESTRUCTIVE EXAM VS. RPC CLIP PLOT



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These results indicate that the RPC probe does not have to be directly over the indication to detect it. Therefore this technique will always 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 the clip plot results without adjustment for estimation of flaw axial and circumferential extent is appropriate and conservative.

7.0 REPAIR CRITERIA

The goal of this task has been to support development of two separate repair criteria that will be used to disposition small amplitude eddy current indications at CR-3. The first is a voltage based screening limit that can be conservatively applied to any volumetric flaw. The second is a length and width criteria that can be applied to any indication that exceeds the first criteria. To this end the following has been accomplished.

- Determination of Structurally Limiting Flaw

  The analysis discussed in Section 3.0 determined that a potentially 100% TW flaw can be up to 0.25 inches in axial extent and 120° in circumference and still meet the requirements of USNRC Reg Guide 1.121.

- Correlation of ECT Bobbin Voltage with Flaw Size

  The investigations in Section 4.0 resulted in a conservative bobbin signal amplitude of 3.4 volts to represent the structurally significant flaw.

- Flaw Growth

  From the growth study in Section 5.0 it was recommended that a growth rate of 0.9 volts per inspection cycle be assumed in a voltage based plugging criteria for volumetric flaws at CR-3. The 3.4 volt structural limit should therefore be reduced by this amount to account for growth. This reduces the allowable voltage limit to 2.5 volts.

- RPC Clip Plot Measurement Accuracy

  In Section 6.0 it was determined that measurements of flaw length and width made by RPC clip plots always

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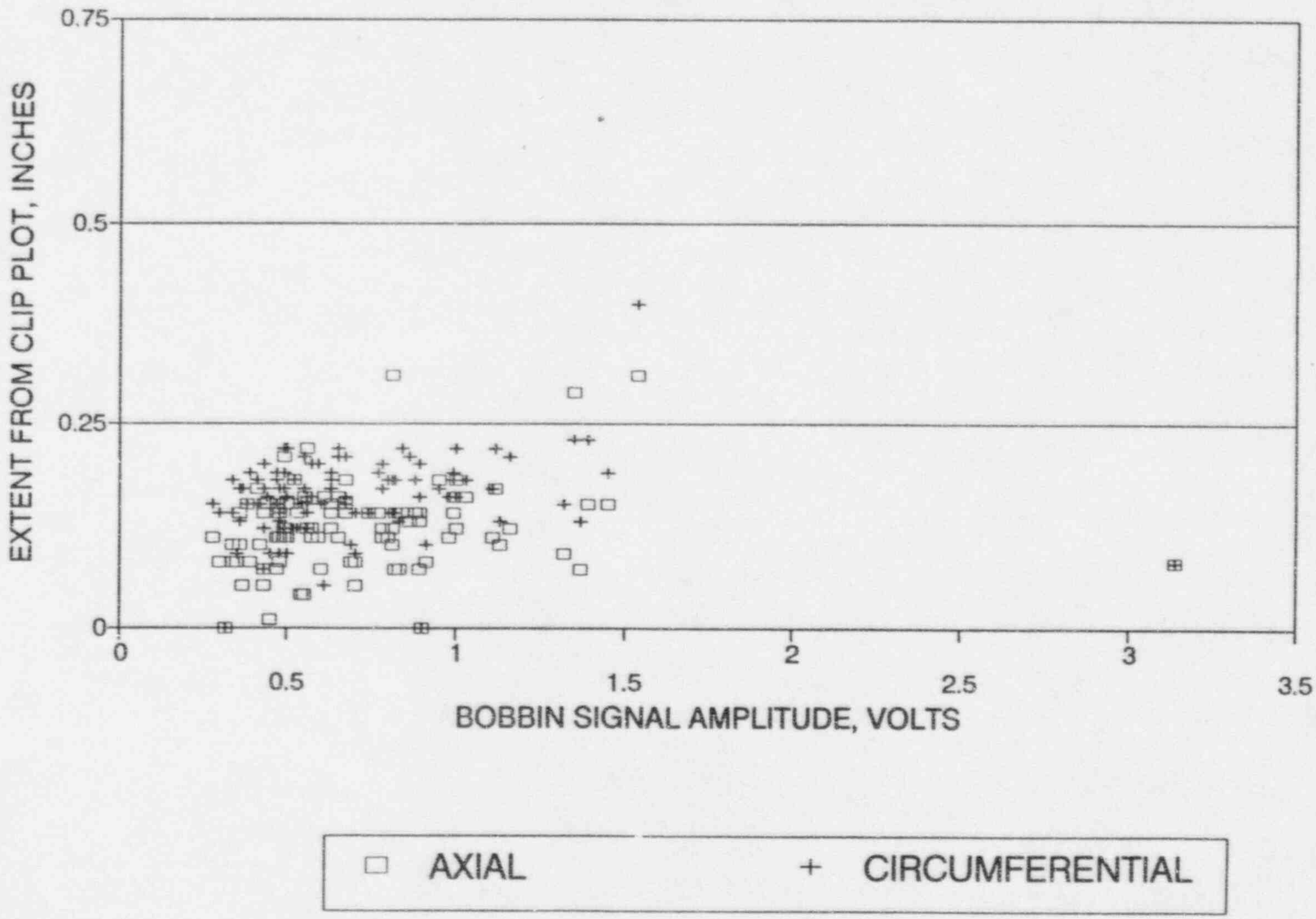
over-estimate the actual flaw dimensions. No reduction in allowable flaw size is required to account for uncertainty in this measurement technique. The dimensions calculated in the Ref. 8.2 analysis may therefore be used directly as a plugging criteria based on axial and circumferential extent.

As a final check of the voltage screening limit, clip plots were produced from all ODI S/N indications which were run with MRPC during the 5/92 outage. These clip plots were evaluated to determine which of the indications would fail the axial/circumferential extent based repair criteria recommended in this document. The results of this evaluation are shown in Figure 11. Out of the 97 total ODI S/N indications evaluated, three (3) indications failed the recommended 0.25 inch axial limit by a small margin and would be recommended for repair under this criteria. The smallest of this indications that exceeded the axial limit had an associated signal amplitude of 0.78 volts. No indications failed the 0.5 inch recommended circumferential limit.

Most of the previous ODI S/N indications were 1.5 volts or less in bobbin signal amplitude. Therefore, the initial screening criteria (to determine if RPC must be performed) can be set as high as 1.5 volts and provide a high degree of confidence that very few indications are being left in service that would fail the RPC clip plot criteria if it was applied. If a more conservatism is desired, a screening limit of 0.75 volts would ensure that all of the known ODI S/N indications that do not exceed the screening criteria would pass the RPC criteria if applied. Either of these two limits provides an adequate margin for flaw growth below the 3.4 volt structrual limit as discussed in Section 5.0.

FIGURE 11
CRYSTAL RIVER 3, 5/92 OUTAGE
BOBBIN AMPLITUDE VS. EXTENT, ODI S/Ns



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8.0 REFERENCES

8.1 USNRC Regulatory Guide 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes", 8/76.

8.2 MPR Analysis

8.3 BWNT Doc. 47-1228838-00, "Report on Intergranular Attack (IGA) Detection and Sizing Capabilities of Various ECT and UT NDE Examination Methods in OTSG Tubing", 11/93.

8.4 Palisades IGA Correlation

8.5 EPRI Report TR-103756, "Examination of Crystal River Unit 3 Steam Generator Tube Sections", Research Project S413-06.

8.6 Letter Report from Kenji Krzywosz (EPRI) to J. Brown (BWNT), "P.O. 83-786323: Eddy Current Voltage to Volume Wall Loss Evaluation", 12/93.

8.7 BWNT Doc. 51-1218868-00, "Crystal River-3 Refuel 8 Pulled Tube Data Evaluation".

8.8 BWNT Doc. 1232075A-0, "Eddy Current Evaluations for Crystal River Unit 3, Task 103".