WESTINGHOUSE CLASS 3 (NON-PROPRIETARY)

WCAP-13497

CATAWBA UNIT 1
STEAM GENERATOR TUBE
INTERIM PLUGGING CRITERION
PRESENTATION MATERIALS

T. A. PITTERLE
P. J. PRABHU
J. L. HOUTMAN

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Westinghouse Electric Corporation
Nuclear and Advanced Technology Division
P.O. Box 355
Pittsburgh, Pa. 15230

A meeting was held on August 28, 1992 between Duke Power Company, Westinghouse, and the NRC Staff to discuss the application of a voltage-based interim plugging criterion (IPC) for the tube support plate elevation outer diameter initiated stress corrosion cracking occurring on the Catawba Unit 1 steam generator tubes. The presentation materials are included within.

The following topics were discussed by Westinghouse:

1. The development of a bobbin probe voltage-based IPC for Catawba Unit 1 considering:

   - Pulled tube database for 3/4" tubing.
   - NDE Uncertainties
   - Voltage Growth Rates
   - Bounding SLB Leak Rate/Voltage Increments.

2. Steam Generator Tube Burst and Leak Rate Correlations.

Catawba-1 NRC Meeting on IPC (8/28/92)
Westinghouse Presentation

Agenda

	Presentor	Time
Summary of IPC Evaluation	Pitterle	9:00
NDE Uncertainties	Pitterle	
Break		10:45
Voltage Growth Rates	Prabhu	11:00
Bounding SLB Leak Rate/ Voltage Increments	Prabhu	
Lunch		12:00
Pulled Tube Database for 3/4" Tubing	Pitterle	1:00
Burst and Leak Rate Correlations LOCA + SSE Considerations	Houtman	2:00
Discussion	All	3:30

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Summary of IPC Evaluation

Discussion Topics

Interim IPC

Catawba-1 Repair Limit for Full APC Implementation

BOC Indications and EOC Voltage Projections

Margins Against Burst
- Voltage/Burst Correlation
- Margins against 3ΔP and SLB Burst

SLB Leak Rate
- Bounding SLB Leak Rate Incremental with Voltage
- Projected Leak Rates

Conclusions

Catawba-1 Interim Plugging Criteria (IPC)

Tube Repair Basis

- Bobbin coil indications having flaw voltages greater than 1.0 volt and confirmed as a flaw by RPC inspection shall be repaired.
- Bobbin coil indications having flaw voltages greater than 2.5 volts shall be repaired independent of RPC confirmation of a flaw.
- Projected leakage for a postulated SLB event at EOC conditions shall be less than 1.0 gpm for the most limiting S/G. Bobbin coil flaw indications inspected by RPC and found to have no RPC indication do not need to be included in the leakage analyses.
- Tubes identified as subject to significant deformation at a TSP elevation under a postulated LOCA + SSE event shall be excluded from application of the IPC at that TSP location.

Catawba-1 Interim Plugging Criteria (IPC) (Cont'd.)

Inspection Requirements

- The inspection shall include 100% bobbin coil inspection of all hot leg intersections and cold leg intersections down to the lowest TSP for which the IPC is to be applied.
- All bobbin coil flaw indications above 1.0 volt and below 2.5 volts shall be inspected by RPC to evaluate for detectable RPC indications and, for indications, to support ODSCC as the degradation mechanism.
- Eddy current analysis guidelines shall be consistent with guidelines utilized in NRC submittals supporting APC for ODSCC at TSPs.

Operating Leak Rate Limit

- The normal operating leak rate requiring plant shutdown shall be limited to 0.1 gpm (150 gpd) per S/G.

Equivalent Catawba-1 APC Repair Limit

Equivalent Full APC Limit Use in IPC

- Establishes maximum bobbin flaw voltage to be left in service even if not confirmed by RPC
- Utilization based on prior IPC precedent (Farley, Cook Units)

APC Voltage Repair Limit

- Voltage for burst at 3△P (-95%) reduced by allowances for growth and NDE Uncertainty

Burst at 3△P

- Preliminary evaluation of 4.1 volts for 3/4" tubing
  - Pending finalization of Belgian voltage renormalization
- Preliminary considered adequate for conservative repair of bobbin flaw indications without RPC indications

Equivalent Catawba-1 APC Repair Limit

Allowance for Growth

- Growth evaluated for largest 541 indications found in 1992
- Cycle 6 growth (1991 to 1992)
- Growth for all indications is being evaluated
  - Expected to be smaller or approximately equal to largest indications
- Average growth of 25% for Cycle 6 increased to 45% for equivalent APC

Allowance for NDE Uncertainty

- EC Analyst Variability
  - Allowance of 10% of 90% cumulative probability from prior APC submittals and WCAP-13464
- Probe Wear
  - Allowance of 13% estimated for Catawba-1 (without wear standard) at 90% cum. probability
  - Compares to 9% in WCAP-13464 with wear standard
- RMS average of 16% increased to 20% for equivalent APC

Equivalent APC repair limit established at 2.5 volts

Figure 1

Burst Pressure Versus Bobbin Voltage

9

Burst Pressure, ksi

Bobbin Voltage, Volts

BPVLT340.BHB

Table 1

Voltage Growth Per Cycle for Catawba-1 (1991 to 1992, Cycle 6)

	Number of Indications	Average BOC-6 Volts	Voltage Growth		% Voltage Growth	
			Cycle 6	Cycle 7(1)	Cycle 6	Cycle 7(1)
Entire Voltage Range	541(2)	0.71	0.18	0.19	25%	27%
V_{BOC} < 0.75v	318	0.53	0.21	--	40%	--
V_{BOC} ≥ 0.75v	223	0.96	0.14	--	15%	--

Notes:

1. Projected Cycle 7 growth based on ratioing Cycle 6 growth for 0.83 EFPY expected for Cycle 7 compared to 0.80 EFPY for Cycle 6.
2. Represents largest indications found in 1992 and used for growth study. Smaller 1992 indications conservatively not included.

Summary of Catawba-1 EC Uncertainty

	Analyst Variability	Probe Wear	RMS Average
Distribution for Monte Carlo	Cumulative Prob. of Figure 5. Applied as %.	Normal Distr. mean=0, σ=10%	Apply separate distributions
Value at 90% Cum.Prob.	10%	13% (1.28σ)	16%
Value at 99% Cum.Prob.	34%	23% (2.33σ)	41%

Table 3

Equivalent Tube Plugging Limits to Satisfy Structural Requirements

Item	Volts	Basis
Maximum Voltage Limit to Satisfy Tube Burst Structural Requirement	4.1	Burst Pressure vs. Voltage Correlation at -95% confidence level (Fig. 1)
Allowance for NDE Uncertainty	-0.5 (20%)[1]	From Reference 3, 16% uncertainty at 90% cumulative probability. Conservatively increased to 20%.
Allowance for Crack Growth Between Inspections	-1.1 (45%)[1]	Table 1 shows average growth/cycle of 27%. Allowance increased to 45% of Tube Plugging Limit to provide conservative margin for variations in future cycles.
Equivalent Tube Plugging Voltage Limit o Acceptable Limit to Meet Structural Requirement	2.5	

Note:
(1) Voltage percentage allowances for NDE and growth/cycle applied to Equivalent Tube Plugging Voltage Limit of 2.5 volts.

BOC 7 Indications

1992 Inspection

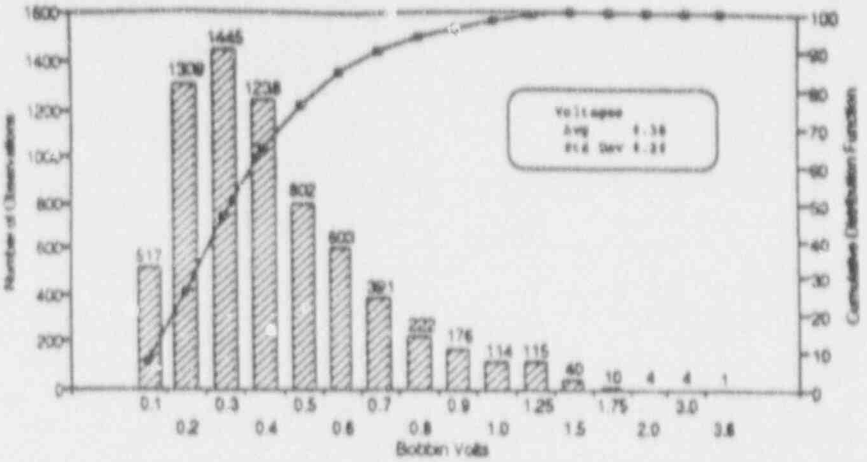
- Indications evaluated at APC voltage normalization
- ASME standards cross calibrated to lab. reference std.
- Cross calibration adjustments included in 1992 voltages

All bobbin indications ≤1.0 volt left in service for IPC evaluation

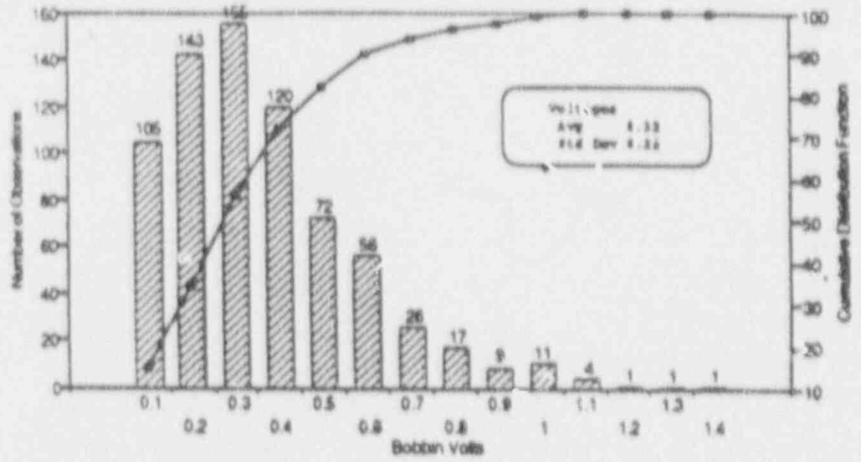
- No reduction for lack of RPC confirmation
- S/G D most limiting for SLB leakage (larger number of ind.)
- S/G C judged most limiting for SLB burst probability

Figure 4

CATAWBA-1: 1992 Indications at TSP's
ALL STEAM GENERATORS



CATAWBA-1: 1992 Indications at TSP's
Steam Generator A



CATAWBA-1: 1992 Indications at TSP's
Steam Generator B

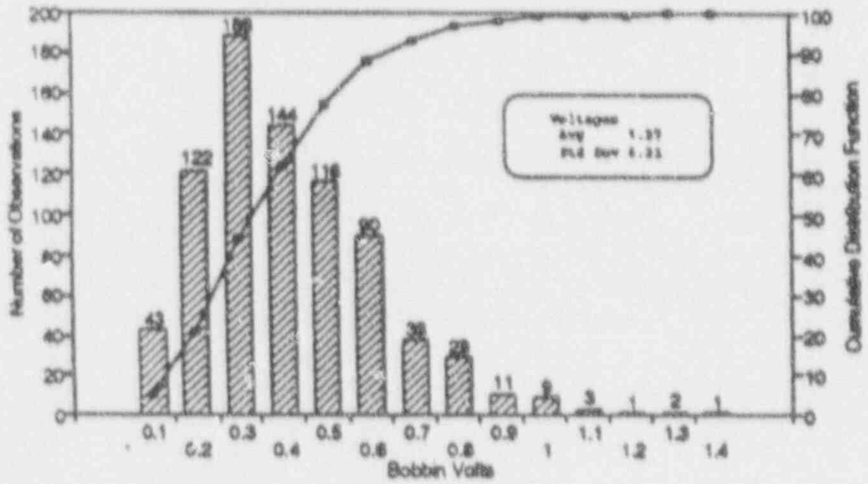
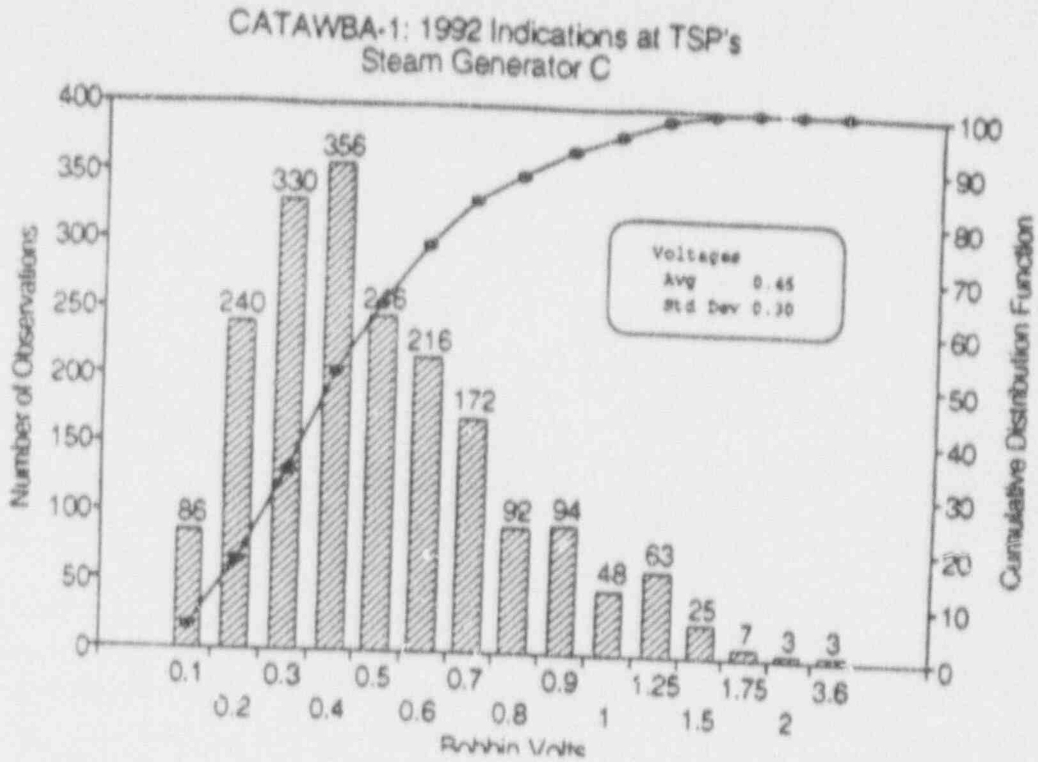
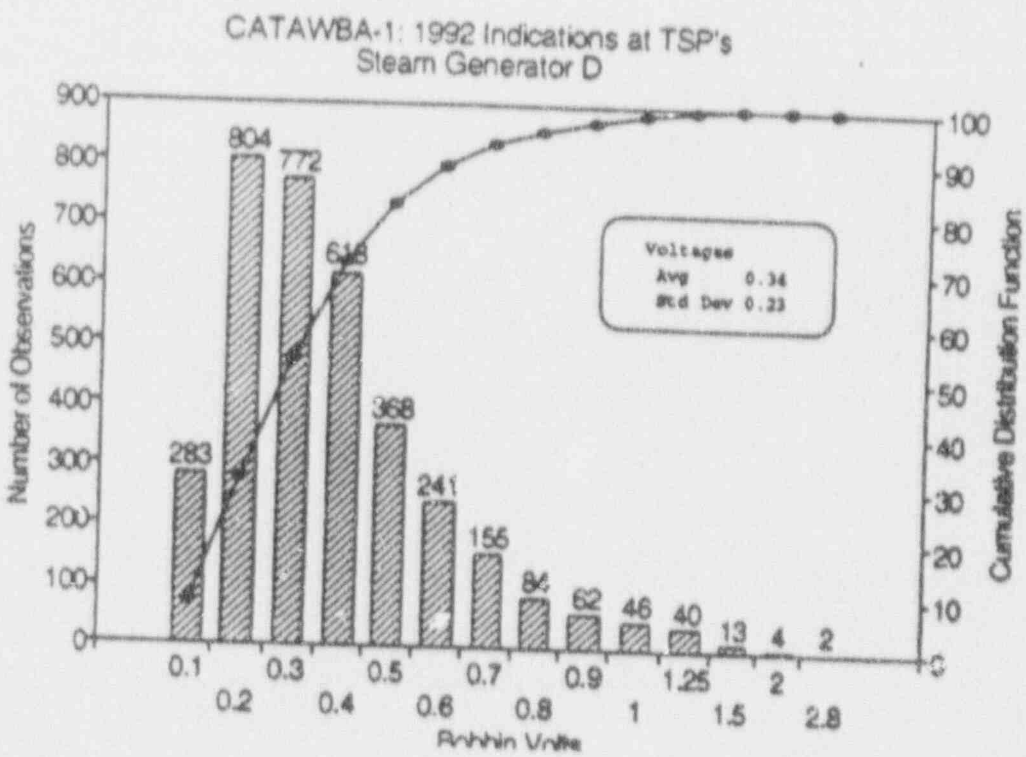


Figure 5



CATAWBA-1: 1992 Indications at TSP's
Steam Generator C
Number of Observations
Cumulative Distribution Function
Voltages
Avg 0.45
Std Dev 0.30
86
240
330
356
246
216
172
92
94
48
63
25
7
3
3
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.25
1.5
1.75
2
3.6
Bobbin Volts



CATAWBA-1: 1992 Indications at TSP's
Steam Generator D
Number of Observations
Cumulative Distribution Function
Voltages
Avg 0.34
Std Dev 0.23
283
804
772
618
368
241
155
84
62
46
40
13
4
2
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.25
1.5
2
2.8
Bobbin Volts

DISTRIBUTION OF VOLTAGES AT EOC 7
BY MONTE CARLO ANALYSES

BOC DISTRIBUTION USED IN 0.05 VOLT INTERVALS

FOR EACH BOC INTERVAL, SAMPLING OF ET ANALYST VARIABILITY, PROBE WEAR AND GROWTH DISTRIBUTIONS YIELD AN EOC SAMPLE

[ ] a,c

TOTAL BOC DISTRIBUTION SAMPLED 100,000 TIMES

RESULTS YIELD EOC DISTRIBUTION/CUMULATIVE PROBABILITY

[ ] a,c

MAXIMUM EOC VOLTAGE OF 3.28 VOLTS FOR S/G D

Figure 6

Distribution of Voltage Differences Between Individual Analysts and Mean Values

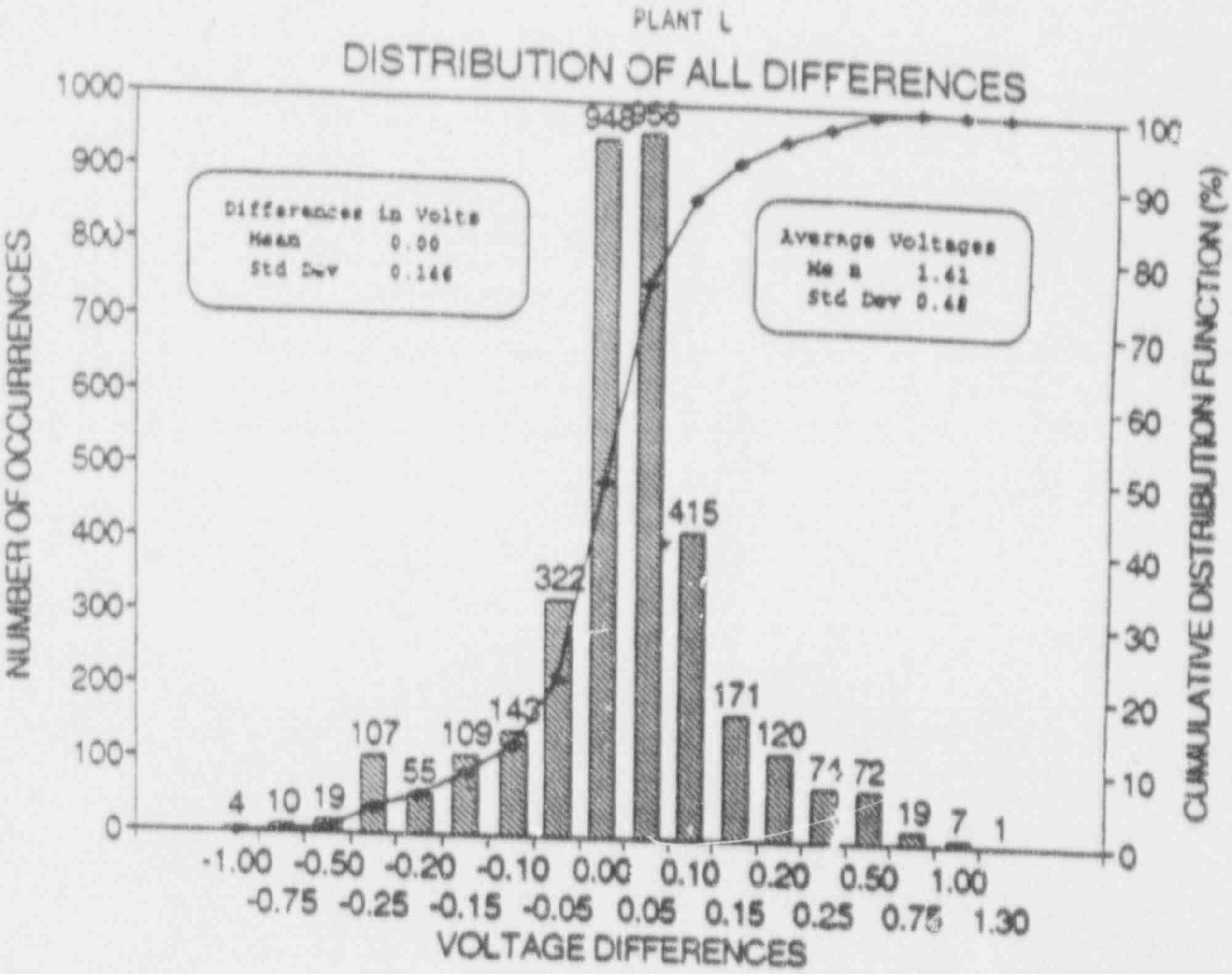
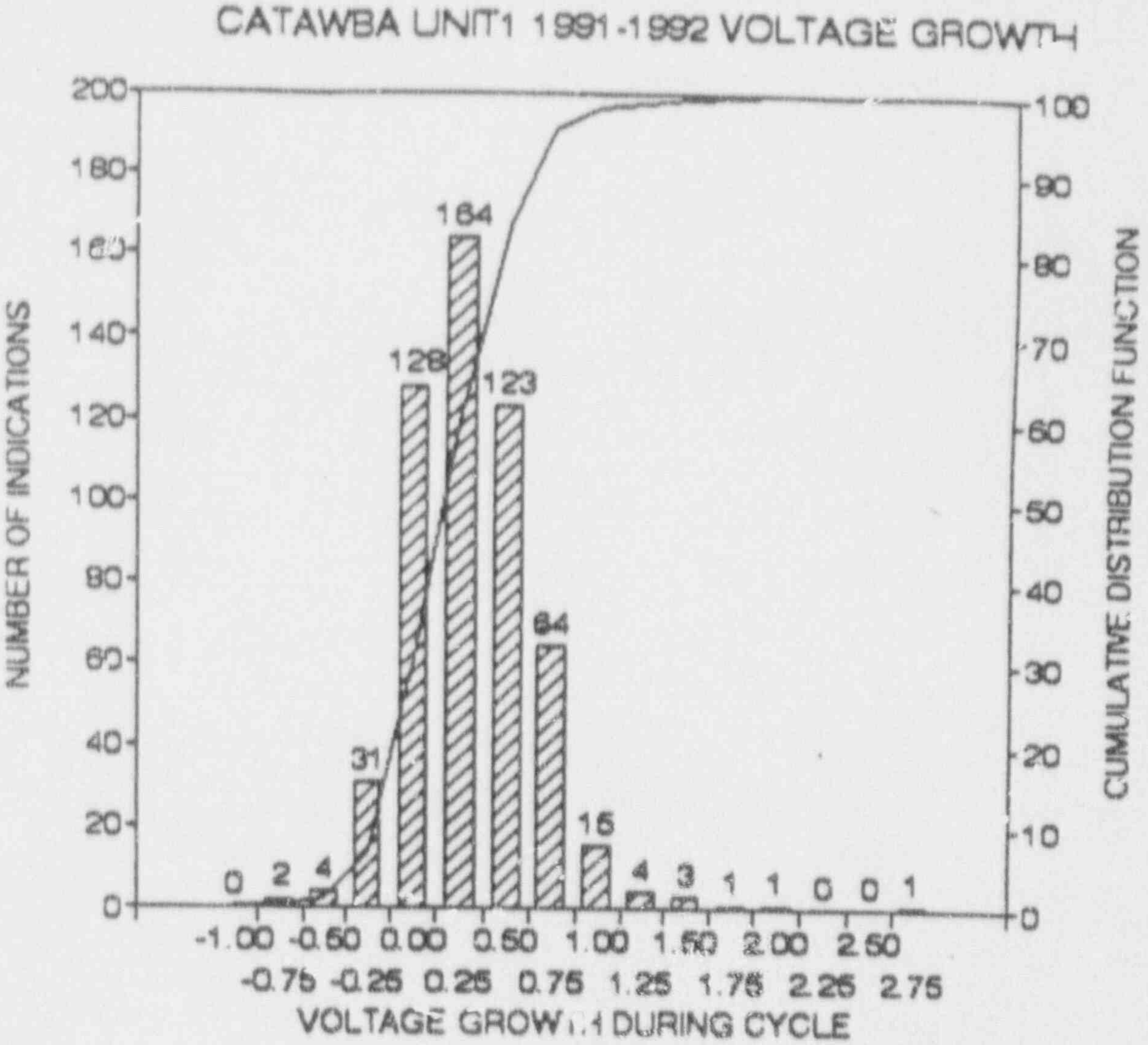


Figure 3

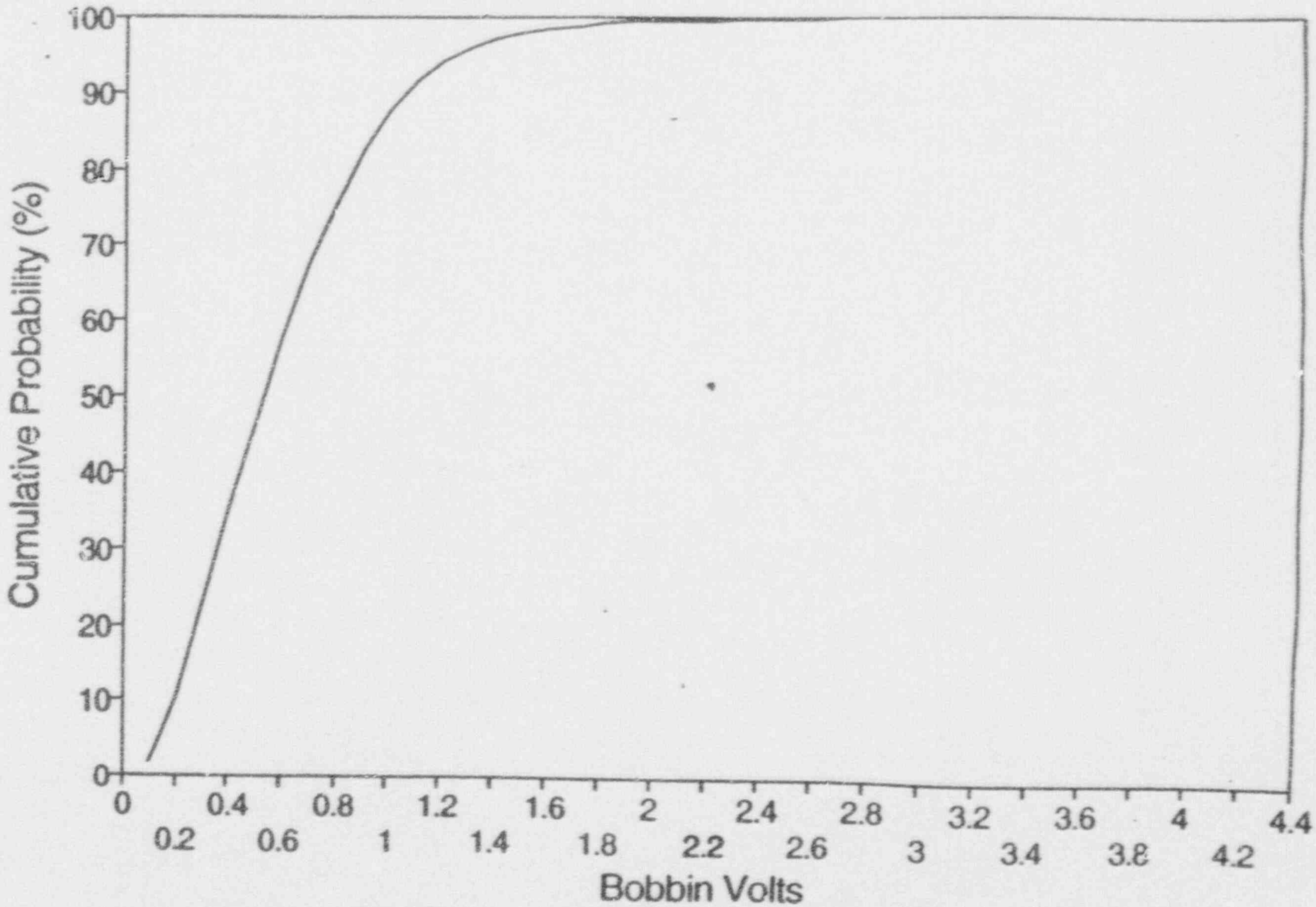


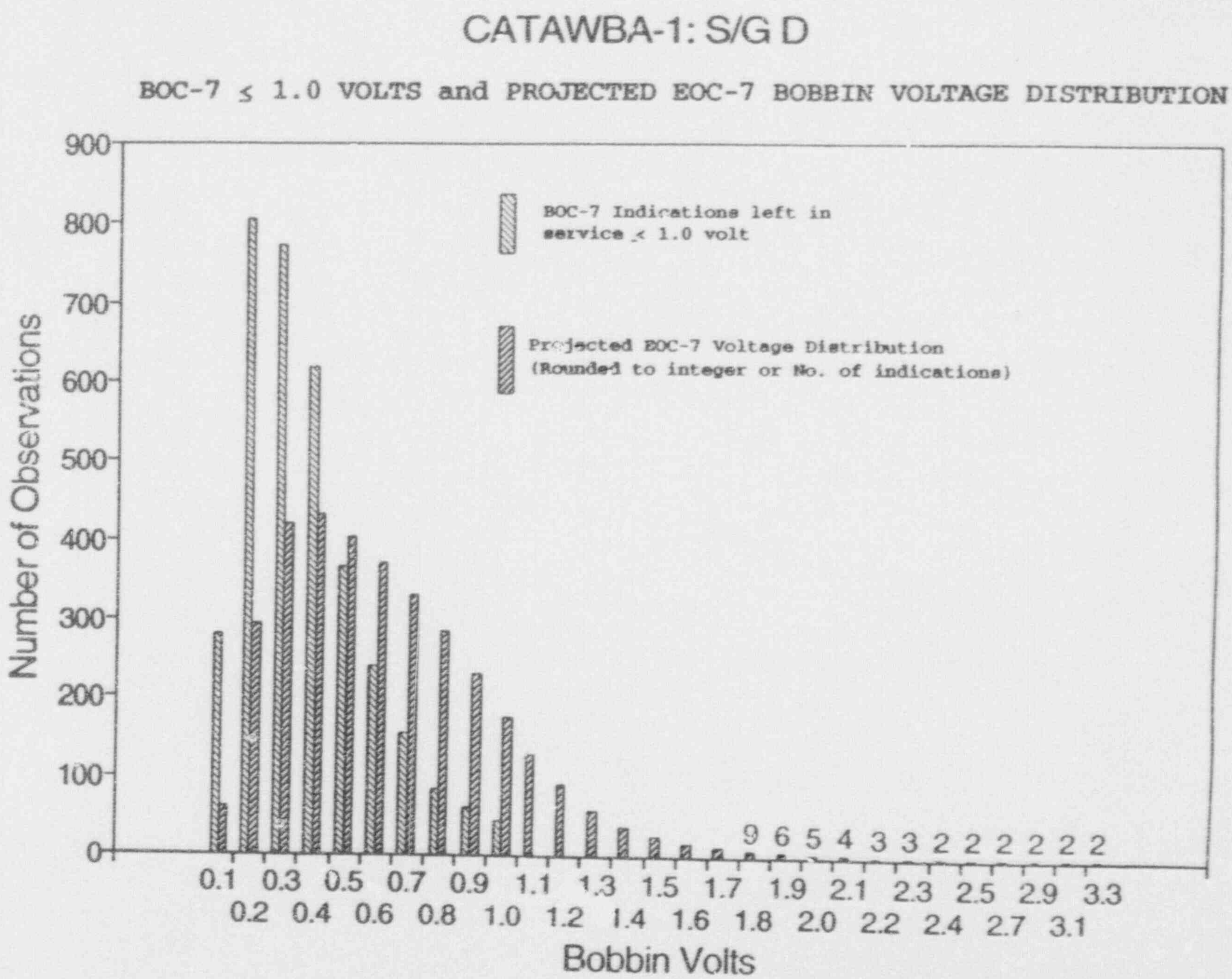
CATAWBA UNIT1 1991-1992 VOLTAGE GROWTH
NUMBER OF INDICATIONS
CUMULATIVE DISTRIBUTION FUNCTION
VOLTAGE GROWTH DURING CYCLE
0
20
40
60
80
100
120
140
160
180
200
10
30
50
70
90
0 2 4 31 128 164 123 64 15 4 3 1 1 0 0 1
-1.00 -0.50 0.00 0.50 1.00 1.50 2.00 2.50
-0.75 -0.25 0.25 0.75 1.25 1.75 2.25 2.75

Figure 8

CATAWBA-1: S/G D

Projected EOC-7 Bobbin Voltage Probability




CATAWBA-1: S/G D
BOC-7 ≤ 1.0 VOLTS and PROJECTED EOC-7 BOBBIN VOLTAGE DISTRIBUTION
BOC-7 Indications left in service ≤ 1.0 volt
Projected EOC-7 Voltage Distribution (Rounded to integer or No. of indications)
Number of Observations
0
100
200
300
400
500
600
700
800
900
9 6 5 4 3 3 2 2 2 2 2 2
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.7 2.9 3.1 3.3
Bobbin Volts

Applications of EOC-7 Voltages

Use of Monte Carlo EOC Voltages

- "Deterministic" SLB leak rates from EOC indications vs voltage interval
- Distribution of SLB leak rates from total distribution of EOC voltages
  - Evaluated at 90% cumulative probability for leak rates
  - May not be most appropriate method for applied step function changes in leak rate correlation
- Probability of burst at SLB from total distribution of EOC voltages

EOC Voltages for Deterministic Burst Margin Assessment

- NDE uncertainty and growth at +90% cum. prob. for comparisons with 3ΔP burst capability (-95%)
  - EOC voltage of 1.78 volts
- NDE unc. and growth at +99% for comparisons with SLB burst capability at -99% prediction interval
  - EOC voltage of 2.81 volts

TUBE BURST MARGINS

3ΔP DETERMINISTIC ANALYSIS

- o EOC VOLTAGE OF 1.78 VOLTS VS 4.10 VOLT 3ΔP CAPABILITY
  - MARGIN OF 2.32 VOLTS EXCEEDS PROJECTED 1.78 VOLT INDICATION

- o EOC VOLTAGE OF 2.81 VOLTS VS 5.87 VOLT SLB CAPABILITY
  - MARGIN OF 3.06 VOLTS EXCEEDS PROJECTED 2.81 VOLT INDICATION

MONTE CARLO ANALYSIS FOR SLB BURST CAPABILITY

- o ESTIMATED AT 3×10^{-5} PROBABILITY OF BURST FOR S/G D BOC DISTRIBUTION
- o NEGLIGIBLE BURST PROBABILITY COMPARED TO NUREG-0844 GUIDELINE OF 2.5×10^{-2}

Table 4

Deterministic Tube Burst Margin Evaluation for IPC

	3ΔP Burst (+90% Unc.)		SLB Burst (+99% Unc.)	
	3/4"(1)	7/8"	3/4"(1)	7/8"(2)
BOC Volts	1.0	1.0	1.0	1.0
Voltage Growth	0.62(1)	0.60(2)	1.4(1)	2.0(2)
NDE Unc.	0.16(1)	0.16(2)	0.41(1)	0.37(3)
EOC Volts	1.78	1.76	2.81	3.37
Tube Burst Capability				
- 95% Prediction Interval	[			]g
- 99% Prediction Interval	---	---	[	]g

Notes:

1) Based on Catabwa-1 evaluation for growth and NDE uncertainty (without probe wear standard.)
2) Growth and NDE uncertainty at 90% cumulative probability for Plant A-2 (WCAP-13464)
3) NDE uncertainty of 37% at 99% cumulative probability based on 34% for analyst variability and 15% for probe wear with implementation of probe wear standard.
4) Burst capability for preliminary 3/4" evaluation and estimated lower bound for final evaluation in parentheses.

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SLB Leak Rates

Step Function Changes Used for SLB Leakage as Function of Voltage

- Consistent evaluation for 3/4" tubing with distribution applied for Cook-2 IPC (WCAP-13464, 7/92 mtg.)
- No leakage [ ][a]
- Leak rate of 1 liter/hr between [ ][a]
- Leak rate of 10 liter/hr [ ][a]

"Deterministic" SLB Leak Rate

- 33 indications (S/G D) projected >1.8 volts up to 3.28 volts
- SLB leak rate = 0.15 gpm
- Leak rate <1.0 gpm allowable limit
- Applying +90% uncertainties yields EOC volts of 1.78 volts or no SLB leakage

Monte Carlo SLB Leak Rate at 90% Cum. Prob.

- Estimated leak rate of 0.54 gpm
  - Differences from 0.15 gpm judged to largely result from step function changes in leak rate distribution
- Estimated 71% probability of zero leakage

Summary of Bounding SLB Leak Rates for 3/4 Inch Tubeing Voltage Ranges

Voltage Range	Bounding SLB Leak Rate	Limiting Indications for Leakage
[ ]^{a}	0.0 l/hr	[ ]^{a}
[ ]^{a}	1.0 l/hr	
[ ]^{a}	10 l/hr	Based on NRC recommendation for IPC implementation (D. C. Cook)
[ ]^{a}		If projected EOC amplitude for indications in 3/4 inch tube exceeds [ ]^{a} additional evaluation on bounding SLB leak rate will be required

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1) Maximum corrosion depth was 97%. Post-pull voltage increased to 5.06 volts. It is judged that throughwall penetration resulting in leakage occurred as a consequence of the tube pull operations (as supported by the post-pull bobbin voltage) rather than opening during the leak test.

2) Utilizes minimum voltage increase in renormalizing Belgian data to APC normalization. Final renormalization factor is expected to significantly increase voltage.

Exclusion of Tubes from IPC for LOCA+SSE Considerations

Combined LOCA+SSE Loads Can Lead to TSP and Tube Deformation

- Significant tube deformation combined with application of APC could result in secondary to primary leakage not accounted for in LOCA analyses

- APC application excludes tubes subject to significant deformation

Conservative Loads Applied to Bound Potential Deformation for Catawba-1

- Catawba-1 specific analyses in process

CATAWBA UNIT 1 IPC ASSESSMENT

CONCLUSIONS

THE CATAWBA UNIT 1 IPC REPAIR LIMIT OF 1.0 VOLTS PROVIDES LARGE MARGINS AGAINST BURST AND SLB LEAK LIMIT OF 1.0 GPM

- o BURST MARGINS OF 2.3 VOLTS @ +90% UNC. FOR 3ΔP AND 3.1 VOLTS @ +99% UNC. FOR SLB EXCEED PREDICTED EOC VOLTAGES
- o SLB LEAK RATE MARGIN A FACTOR OF 2 TO 7 WITH ~ 71% CHANCE OF ZERO LEAKAGE

CATAWBA UNIT 1 IMPACTED FOR IMPROVING EC INSPECTION AND ANALYSIS ("INSPECTION TRANSIENT") PENDING APPROVAL OF MEANINGFUL APC

- o DISCOURAGES FURTHER IMPROVEMENTS IN EC INSPECTIONS

NDE Uncertainty for Catawba-1

EC Analyst Variability

- Distribution of WCAP-13464 (7/92 NRC mtg.)
- NDE uncertainty of 10% at 90% cumulative probability
- Total distribution (no cutoff) used in analyses
  - Inspection practices using independent analyses and a process for resolution of significant differences results in a cutoff (typically <20%) of voltage differences.

Probe Wear Uncertainty

- Probe wear standard not implemented at Catawba-1
- EC Uncertainty estimated for Zetec probe using data of WCAP-13464
  - With wear standard, data for wear up to 5 mils used to define uncertainty (std. dev. of 7%)
  - Without wear standard, data for wear up to 7.5 mils used to define uncertainty (std. dev. of 10%)

PROBE WEAR EVALUATION FOR CATAWBA-1

DATA UTILIZED

- VARIABILITY OF 100% ASME HOLE FROM REPEAT PROBE CALIBRATIONS PRIOR TO PROBE REPLACEMENT

METHOD

- SAME METHOD AS USED WITH WEAR STANDARD
- DATA FOR EACH CALIBRATION RUN NORMALIZED TO 2.75 VOLTS FOR 20% ASME HOLE
- ALL DATA USED TO DEFINE DISTRIBUTION OF VOLTAGES

ESTIMATED PROBE WEAR UNCERTAINTY

- STANDARD DEVIATION OF XX%

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Figure 1

Distribution of Voltage Indications Used for EC Analyst Variability Evaluation

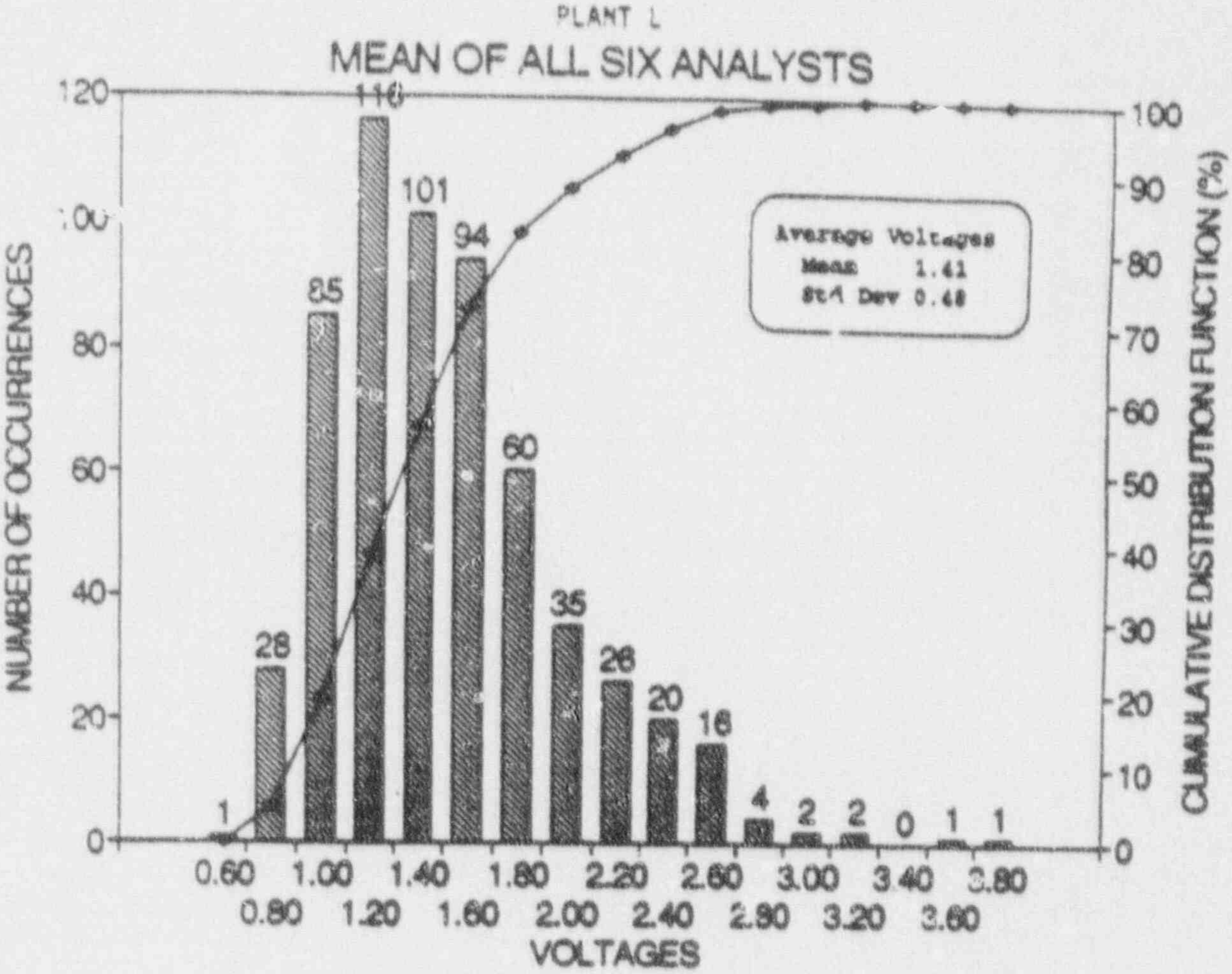


Figure 2

Distribution of Voltage Differences Between Individual Analysts and Mean Values

PLANT L

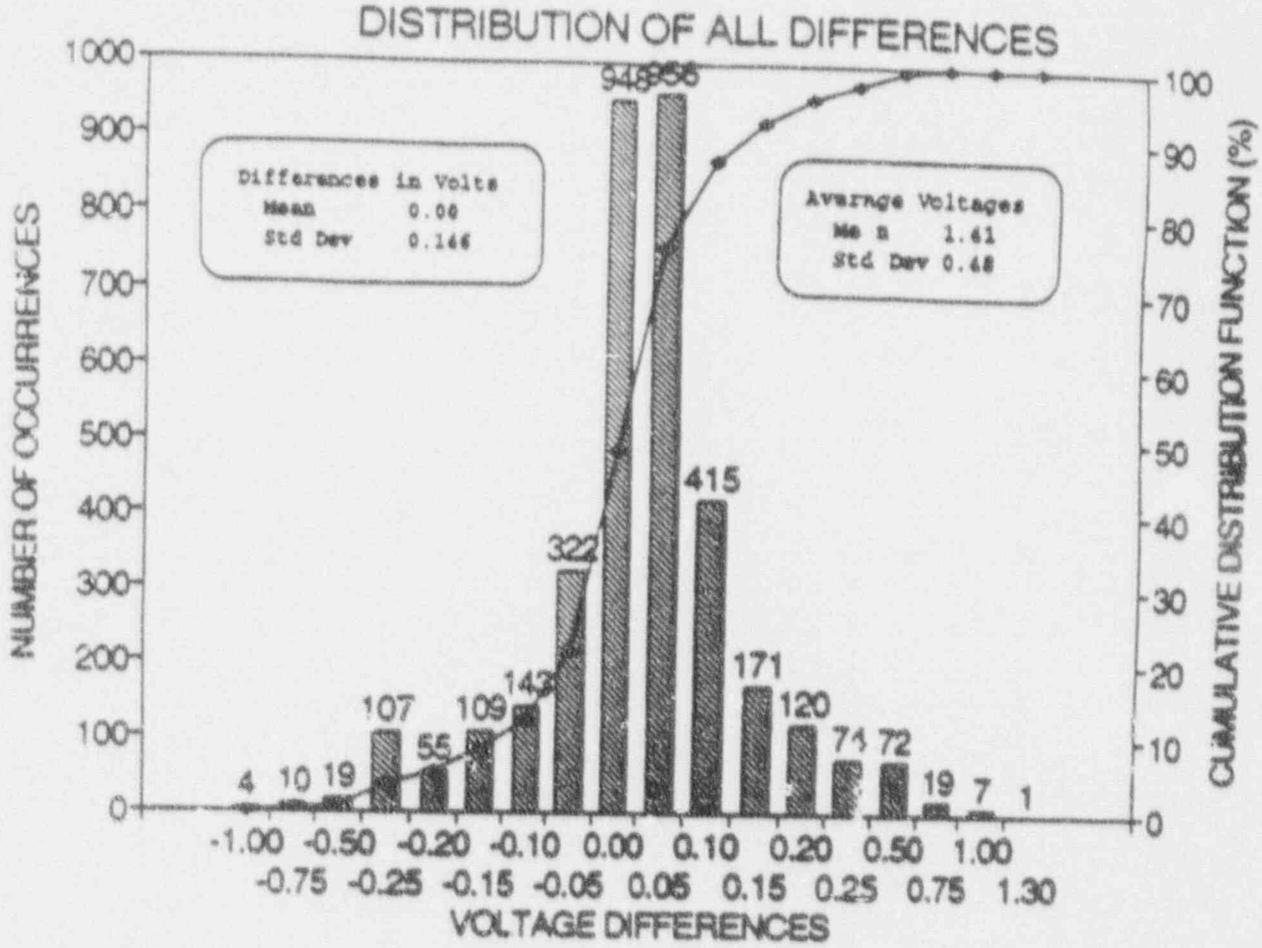


Figure 3

Bobbin Coil Amplitude Dependence on Probe Wear

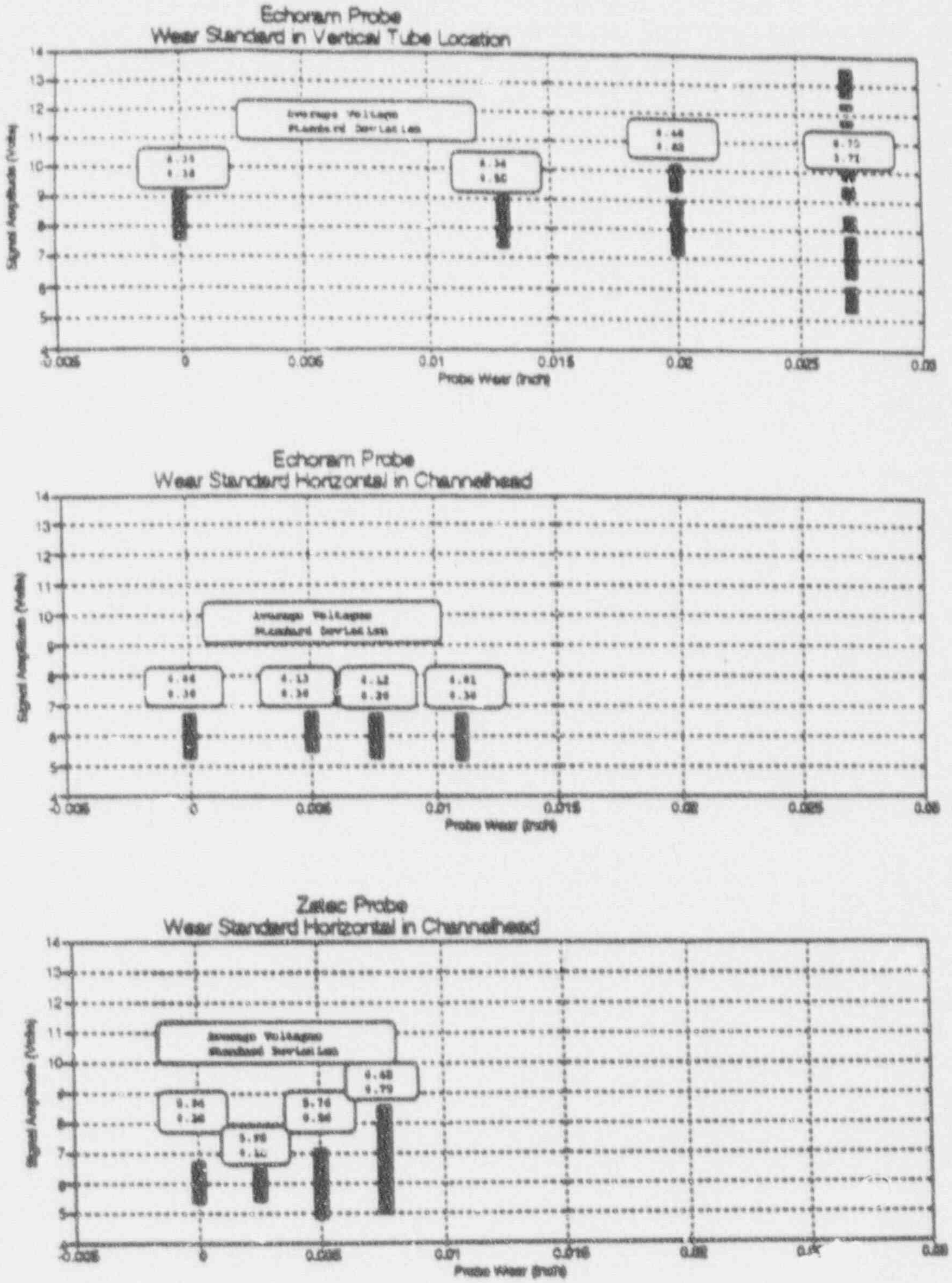


Figure 4

Voltage Variability Due to Bobbin Probe Wear

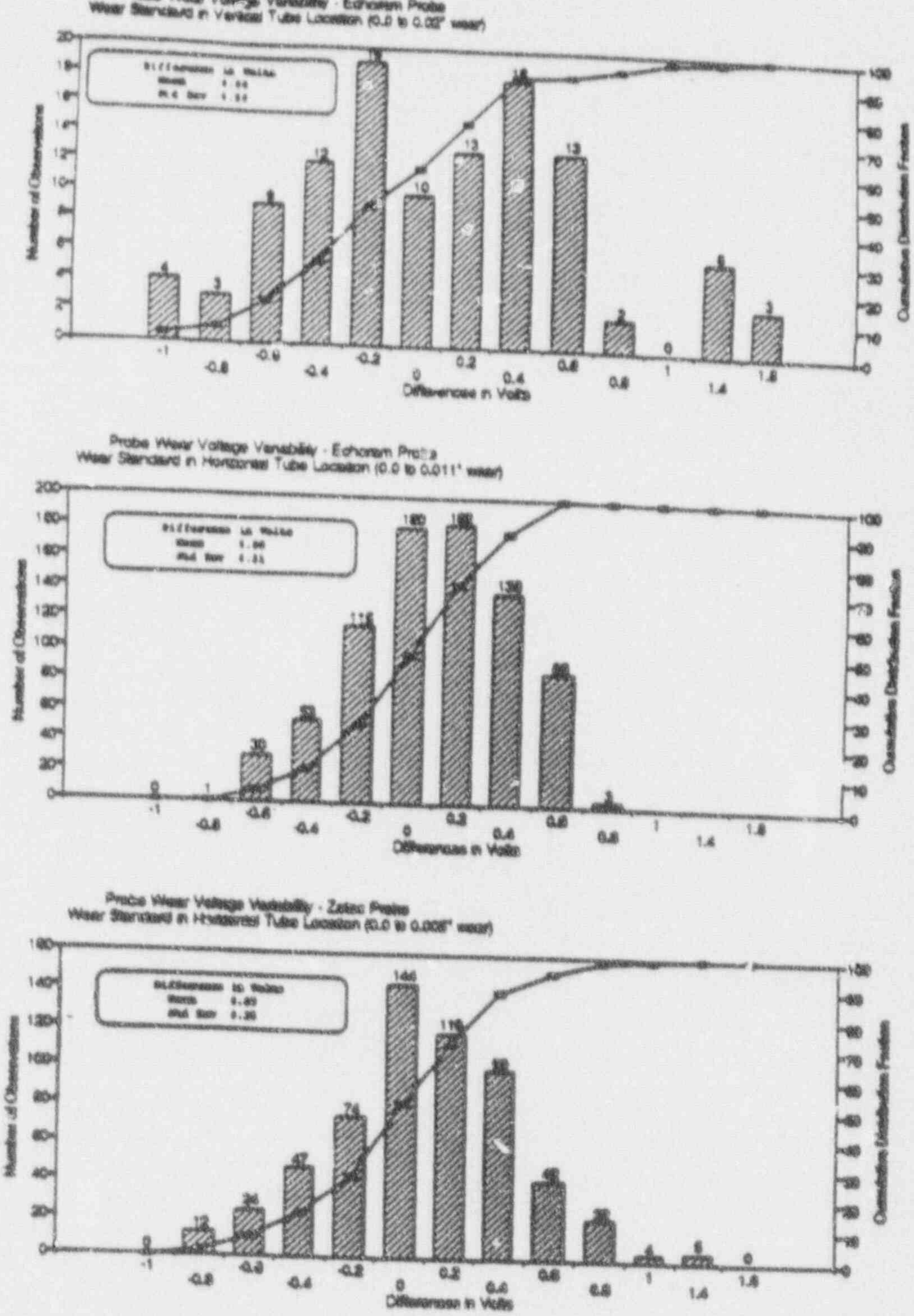
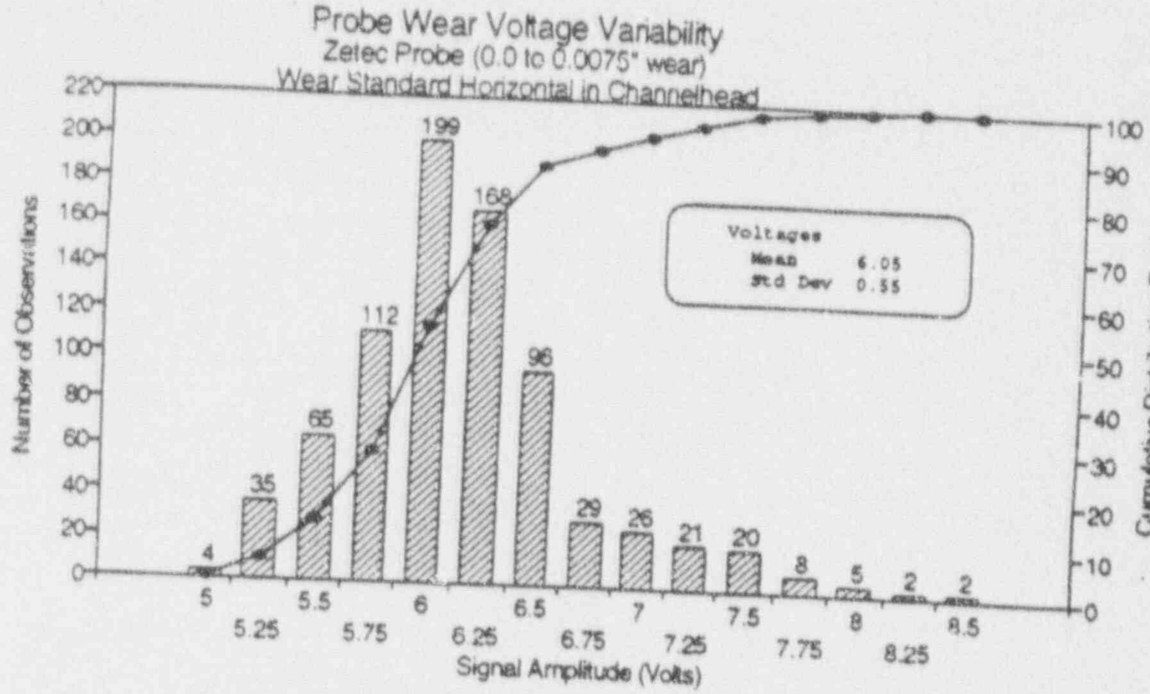


Figure 5


Probe Wear Voltage Variability
Zetec Probe (0.0 to 0.0075" wear)
Wear Standard Horizontal in Channelhead
Voltages
Mean 6.05
Std Dev 0.55
Number of Observations
Cumulative Distribution Fraction
Signal Amplitude (Volts)
4
35
65
112
199
168
96
29
26
21
20
8
5
2
2

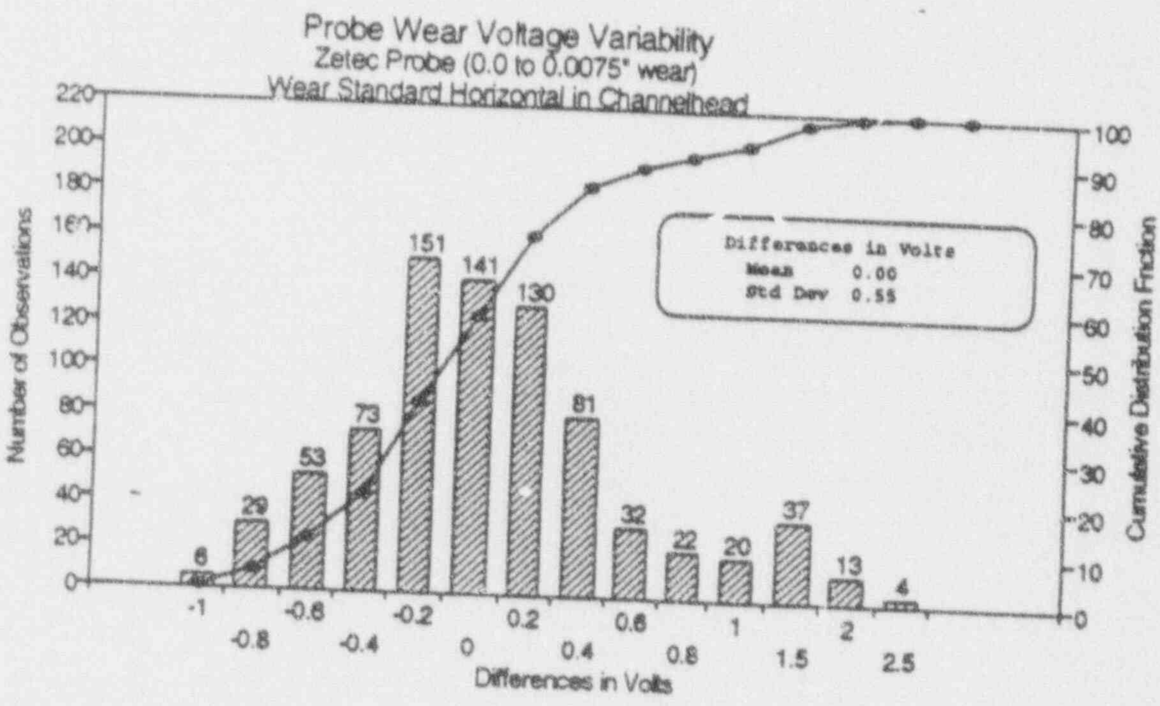

Probe Wear Voltage Variability
Zetec Probe (0.0 to 0.0075" wear)
Wear Standard Horizontal in Channelhead
Differences in Volts
Mean 0.00
Std Dev 0.55
Number of Observations
Cumulative Distribution Fraction
Differences in Volts
6
29
53
73
151
141
130
81
32
22
20
37
13
4

Table 1

Summary of Catawba-1 EC Uncertainty

	Analyst Variability	Probe Wear	RMS Average
Distribution for Monte Carlo	Cum. Prob. in % Columns 2 and 3 of Table 2	Normal Distr. mean=0, σ=10%	Apply separate distributions
Value at 90% Cum.Prob.	10%	13% (1.28σ)	16%
Value at 99% Cum.Prob.	34%	23% (2.33σ)	41%

Table 2 Cumulative Probability for EC Analyst Variability

Voltage Bin	% Uncertainty for Voltage Bin[1]	Percent Cumulative Probability
-1.0	-71	0.11
-1.00 to -.75	-53	0.39
-0.75 to -0.50	-35	0.93
-0.50 to -0.25	-18	3.94
-0.25 to -0.20	-14	5.49
-0.20 to -0.15	-11	8.56
-0.15 to -0.10	-7.1	12.6
-0.10 to -0.05	-3.5	21.6
-0.05 to 0.00	0.0	48.3
0.00 to 0.05	3.5	75.3
0.05 to 0.10	7.1	86.9
0.10 to 0.15	11	91.8
0.15 to 0.20	14	95.1
0.20 to 0.25	18	97.2
0.25 to 0.50	35	99.2
0.50 to 0.75	53	99.8
0.75 to 1.00	71	99.97
1.00 to 1.30	92	100.0

Note 1: % Uncertainty obtained as mid-voltage value for each bin divided by mean voltage of 1.41 volts from Figure 2.

VOLTAGE COMPARISON FOR THE LIFE OF A PROBE

S/G C-INLET

Probe S/N 32493 , same probe from tape 45 to 47.
Probe type 590 ~~[illegible]~~ SF
ASME Std. S/N 50415

Calibration setup IAW RESIZE guidelines. Voltage normalized at 2.75 P/P on 20% FBH's on 550/130 mix [redacted] and not changed for measurements taken for the life of the probe.

Approximate number of tubes examined with this probe: 128

Voltage measurements taken peak-to-peak on 550/130 mix.

TAPE	CAL# INITIAL-01 FINAL-02	ASME FLAT BOTTOM HOLES						ASME 10% OD GROOVE	ASME 20% ID GROOVE
		100%	80%	60%	40%	4 X 20%	4 x 100%		
045	01-1st pull 01-2nd pull 01-3rd pull	4.95 5.02 5.01	5.49	4.62	3.31	2.74 2.75 2.76	4.59 4.71 4.64	4.56	83.74
045	02	5.19	5.58	4.88	3.43	2.77	4.68		
046	01 02	4.87 5.07	5.29 5.54	4.54 4.79	3.21 3.36	2.69 2.78	4.49 4.68		
	01 02								
047	01	4.64	5.03	4.32	3.01	2.76	4.41		
047	02-1st pull 02-2nd pull 02-3rd pull	4.84 5.04 5.00	5.30	4.73	3.26	2.76 2.74 2.80	4.58 4.52 4.59	4.51	82.29
		Circumferentially Assymetrical				Circumferentially Symetrical			

VOLTAGE COMPARISON FOR THE LIFE OF A PROBE

S/G C-INLET

Probe S/N 0144619, same probe from tape001 to 014.
Probe type .510 M/ULC
ASME Std. S/N 050415

Calibration setup IAW RESIZE guidelines. Voltage normalized at 2.75 P/P on 20% FBH's on 550/130 mix at tape001.cal01 and not changed for measurements taken for the life of the probe.

Approximate number of tubes examined with this probe: 1456

Voltage measurements taken peak-to-peak on 550/130 mix.

TAPE	CAL# INITIAL-01 FINAL-02	ASME FLAT BOTTOM HOLES						ASME 10% OD GROOVE	ASME 20% ID GROOVE
		100%	80%	60%	40%	4 X 20%	4 x 100%		
001	01-1st pull	4.68				2.74	4.66		
	01-2nd pull	4.60				2.75	4.69		
	01-3rd pull	4.57	5.13	4.29	3.02	2.75	4.61	4.52	86.02
001	02	4.59	5.04	4.33	3.06	2.79	4.47		
005	01	4.36	4.95	4.04	3.01	2.90	4.77		
	02	4.32	4.84	4.12	2.90	2.87	4.61		
009	01	4.36	4.85	4.23	2.98	2.86	4.72		
	02	4.56	5.14	4.36	3.10	2.87	4.81		
014	01	4.09	4.52	3.83	2.80	2.95	4.90		
014	02-1st pull	3.92	4.50	3.80	2.77	3.05	4.82	4.52	84.07
	02-2nd pull	3.90				3.00	4.86		
	02-3rd pull	3.88				2.90	4.87		
		Circumferentially Assymetrical				Circumferentially Symetrical			

Catawba Unit 1

1991-92 Growth Rate Evaluation

&

Distribution of 1992 TSP Indications

Preliminary Results

8/28/1992

P. J. Prabh[illegible]

Westinghouse Electric Corporation

Catawba Unit 1
Voltage Growth Rate for 1991-92

- 400/130 kHz mix signal used for 1992

- 400/100 kHz mix signal used for 1991

- Both 1991 and 1992 data adjusted up by a factor (determined for 400/100 kHz) to convert to 550/100 kHz equivalent

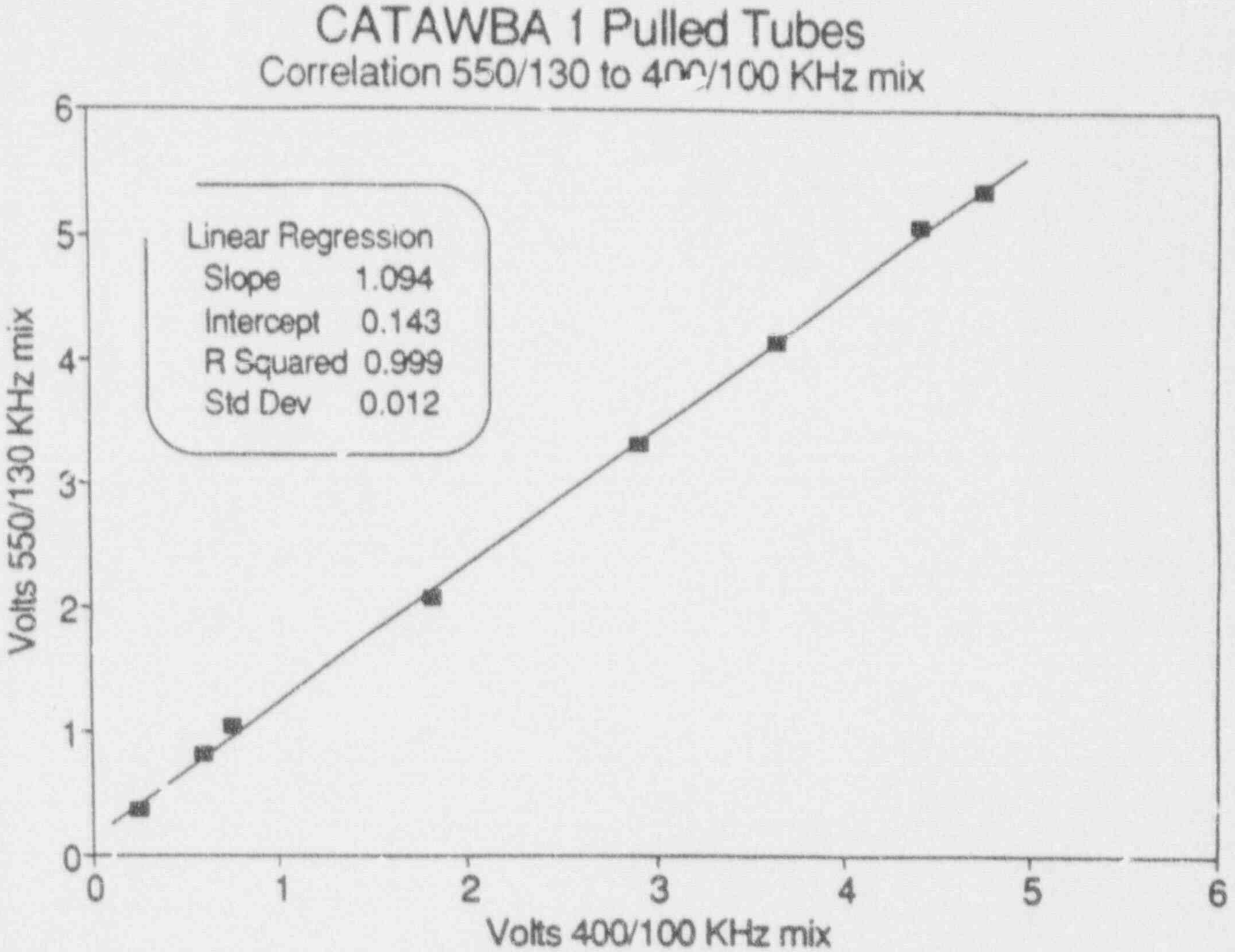
- Resulting growth rates adjusted by a factor of 0.95 to account for the difference in conversion factors for 400/130 and 400/100 kHz

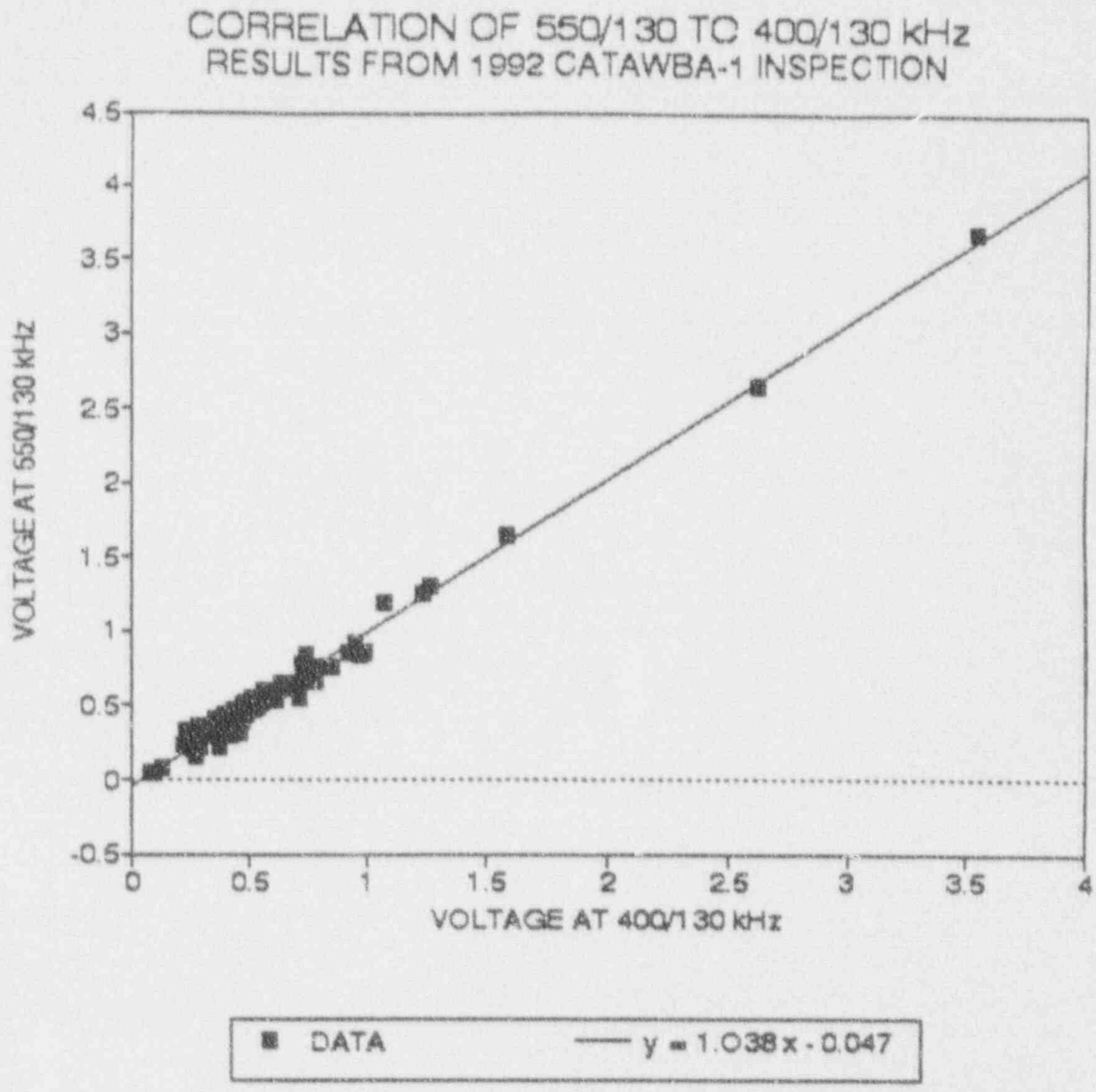
- Projected growth rate for Cycle 7 (1992-93) obtained based on 0.83 EFPY for Cycle 7 versus 0.80 EFPY for Cycle 6 (1991-92)

Catawba Unit 1

Frequencies Used for Bobbin Coil Inspection

1991	1992
100 kHz	130 kHz
300	400
400	550


CATAWBA 1 Pulled Tubes
Correlation 550/130 to 400/100 KHz mix
Linear Regression
Slope 1.094
Intercept 0.143
R Squared 0.999
Std Dev 0.012
Volts 550/130 KHz mix
Volts 400/100 KHz mix
0
1
2
3
4
5
6



CORRELATION OF 550/130 TO 400/130 kHz
RESULTS FROM 1992 CATAWBA-1 INSPECTION
VOLTAGE AT 550/130 kHz
VOLTAGE AT 400/130 kHz
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
DATA
y = 1.038 x - 0.047

Voltage Normalization Trends Between Frequency Mixes [1]

Frequency Mix	Signal Amplitudes for ASME Standard Hole Sizes 20 %	40 %	60 %	80 %	100 %
	Voltages				
550/130 kHz	2.75	3.40	5.12	5.80	5.83
400/130 kHz	2.75	3.30	4.80	5.26	5.15
400/100 kHz	2.75	3.26	4.60	5.01	4.88
	Ratio of Voltages				
550/130 / 400/130	1.00	1.03	1.07	1.10	1.13
550/130 / 400/100	1.[illegible]	1.04	1.11	1.16	1.19

---

1) Adjustments applied for Catawba-1 growth rates at 400/130 and 400/100 kHz to 550/130 kHz are based on voltage ratios for field indications. Evaluation of the ASME standard described in this table independently demonstrates larger renormalization factor for adjusting the 400/100 data of 1991 than for the 400/130 data of 1992.

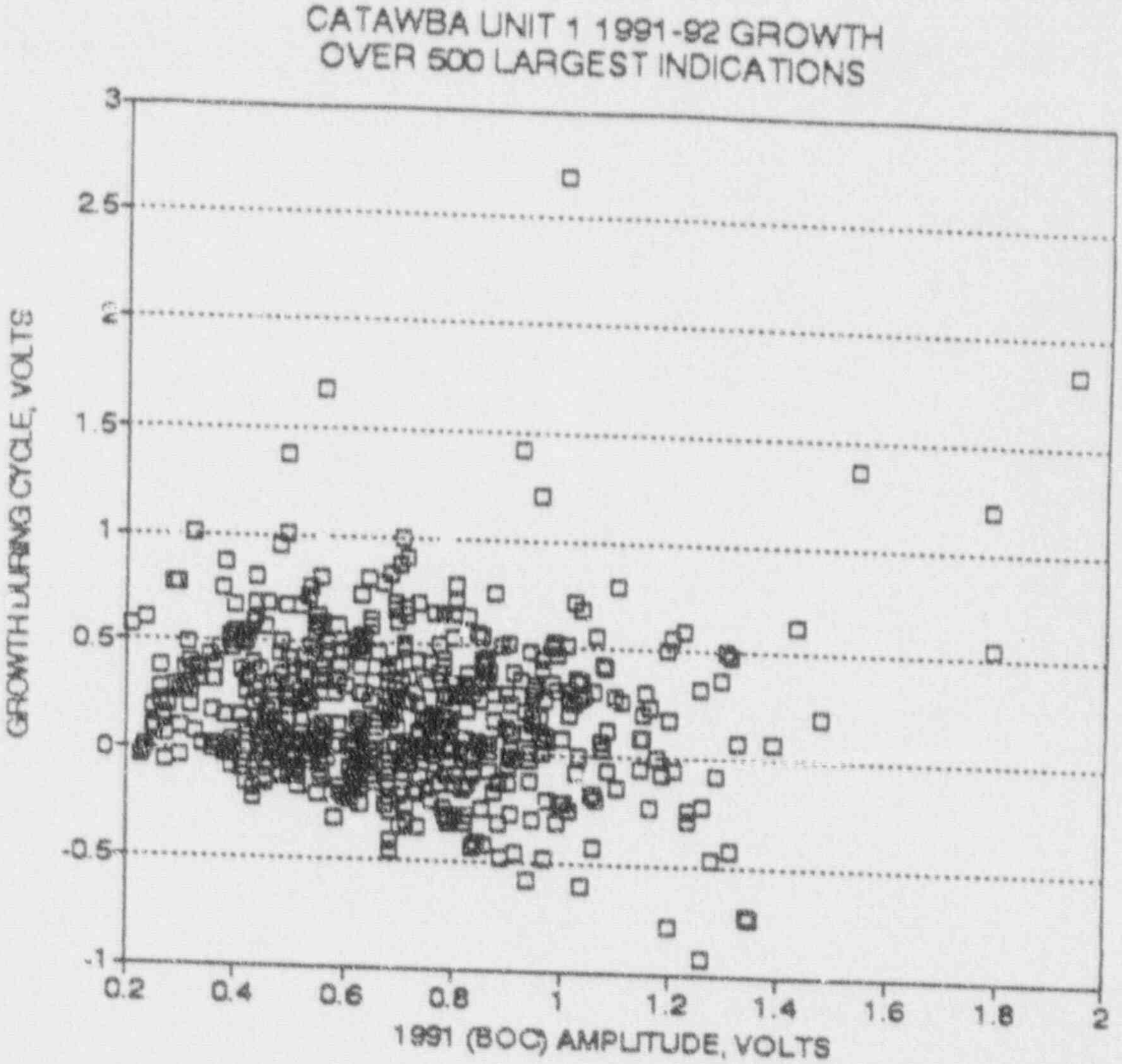


Figure 3. Voltage growth rates of TSP indications versus their BOC amplitude

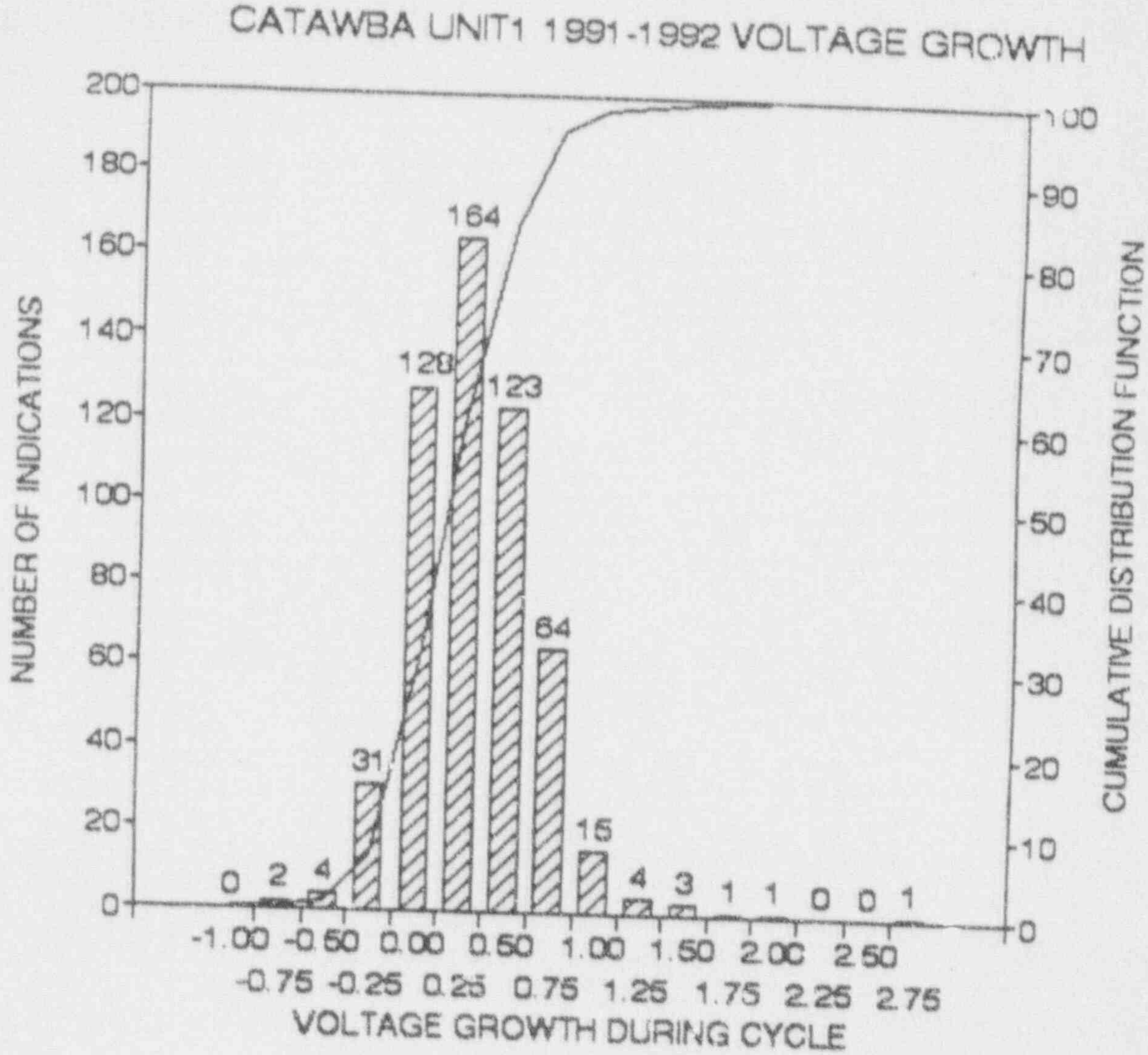


Figure 4. Frequency distribution of voltage growth rates during the 1991-92 cycle at Catawba Unit 1

Catawba Unit 1

1991-92 Growth Rate Statistics

	Number of Indications	1991-92 Growth Rate Average	1991-92 Growth Rate Std. Dev.	Projected 92-93 [1] Growth Rate
Entire Sample	541 [2]	0.18	0.36	0.19
BOC Ranges:				
V < 0.75 volt	318	0.21	0.31	0.21
V ≥ 0.75 volt	223	0.14	0.41	0.15

Notes:

1) Projected from the 1991-92 growth rate based on 0.80 EFPY [illegible] the 1991-92 cycle versus 0.83 EFPY for the next cycle.

2) S/G-A: 90,
S/G-B: 117,
S/G-C: 197,
S/G-D: 137.

Table 4
Results from Cross Calibration of ASME Standards

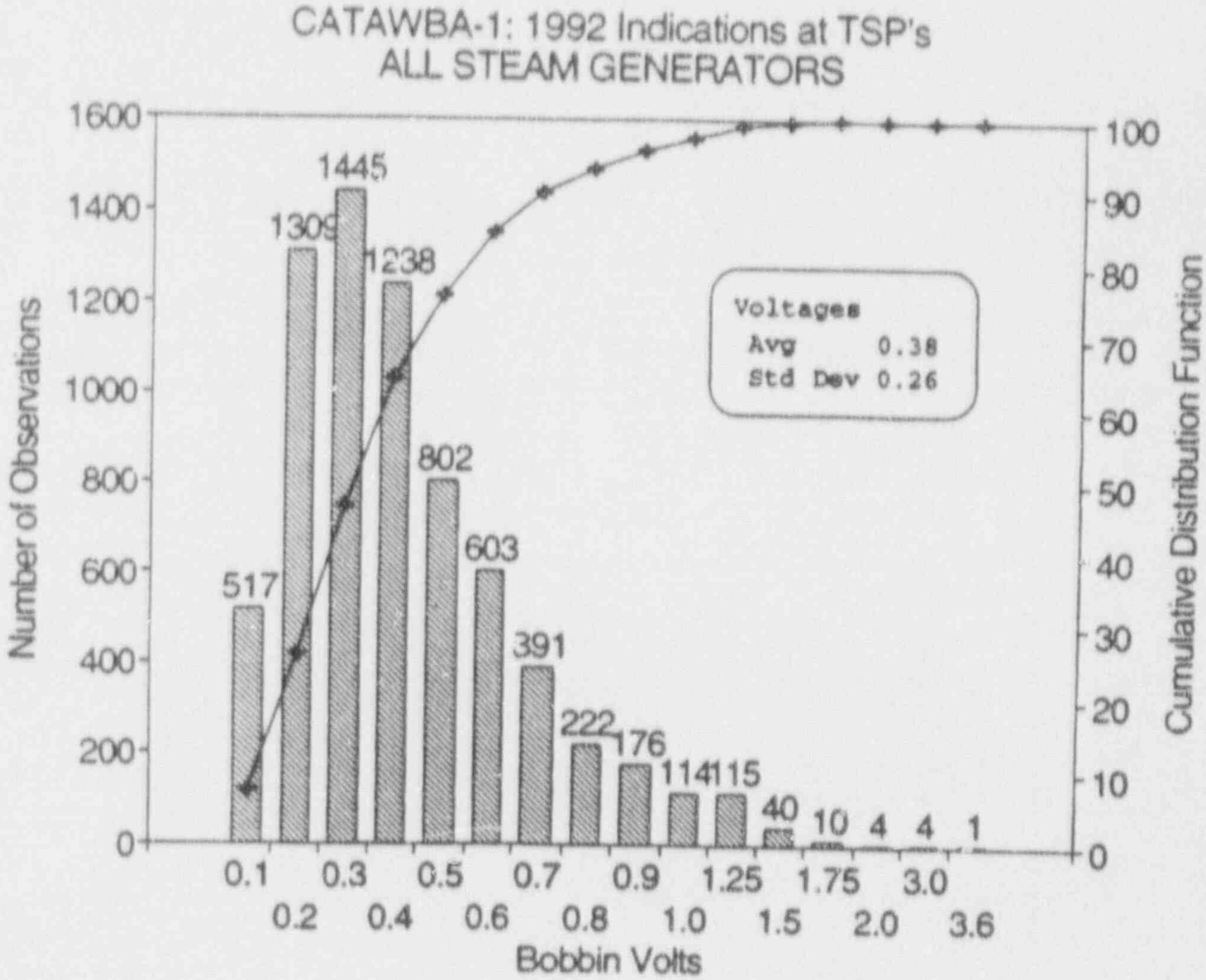
	PROBE	590		610 MULC		610 SFRM		630 MULC	
	Standard	1	P1	1	P1	1	P1	1	P1
TAPE 1	AS-01591	4.560	3.246	4.560	3.236	4.560	3.241	4.560	3.244
	Z-9617	3.316	2.377	3.382	2.389	3.329	2.345	3.374	2.386
TAPE 2	50390	4.287	2.994	3.980	2.783	4.032	2.806	4.112	2.871
	50391	3.954	2.760	3.844	2.710	3.853	2.670	3.786	2.636
	50392	4.408	3.131	4.125	2.939	4.039	2.829	4.055	2.869
	50415	4.229	3.141	3.992	2.841	3.910	2.749	3.971	2.815
	50416	3.985	2.839	3.852	2.736	3.885	2.750	3.797	2.714
	50417	4.469	3.178	4.365	3.134	4.293	3.067	4.199	3.004
	50418	4.180	2.967	3.895	2.746	3.840	2.675	3.831	2.690
	50419	3.823	2.661	3.607	2.546	3.619	2.507	3.617	2.562
	AS-01591	4.561	3.183	4.560	3.224	4.560	3.207	4.560	3.256

1: 550 Hz
P1: 550/130 Hz Mix

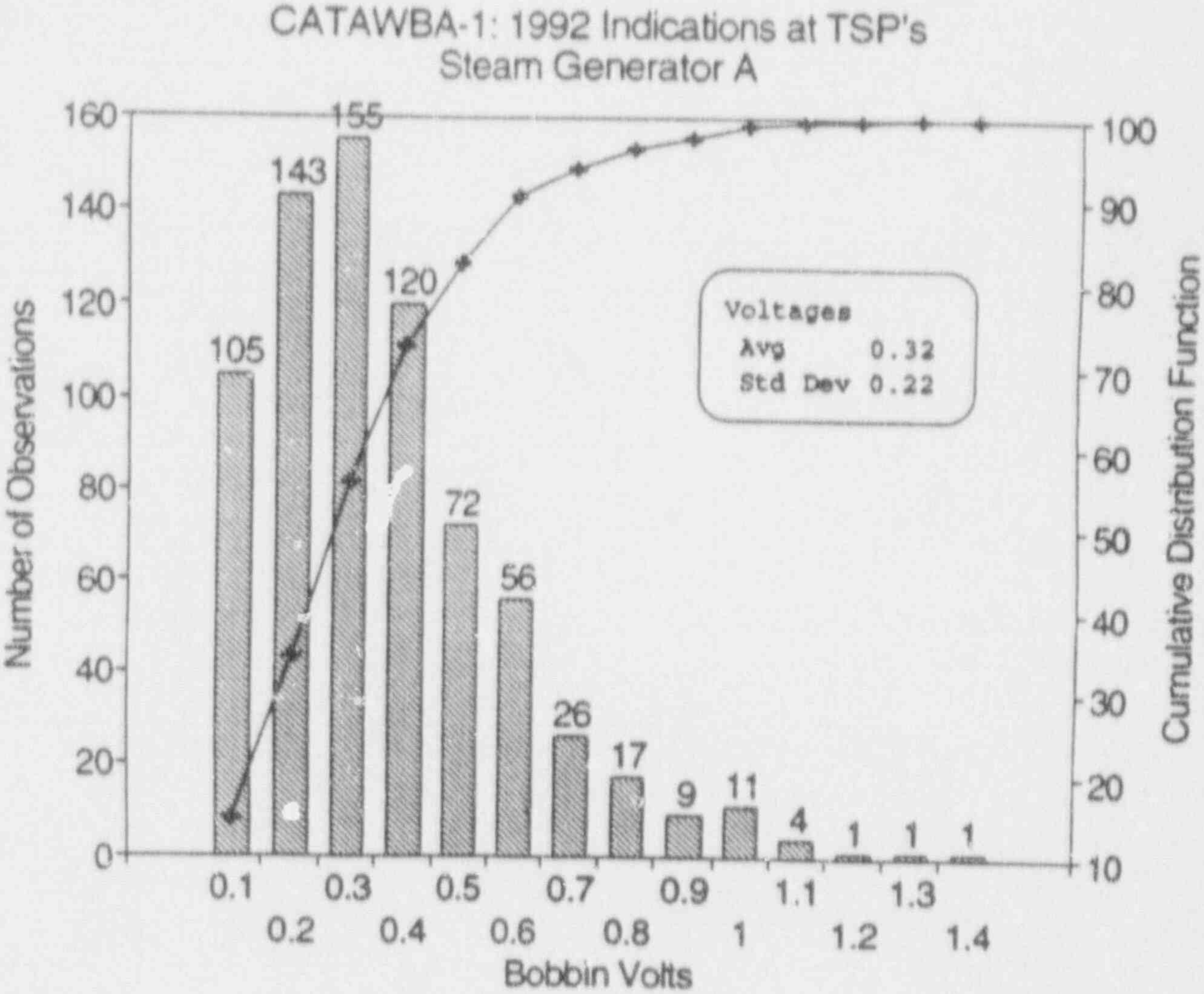
Catawba Unit-1, 1992 Inspection

ASME Standards Used and Corresponding Calibration Corrections

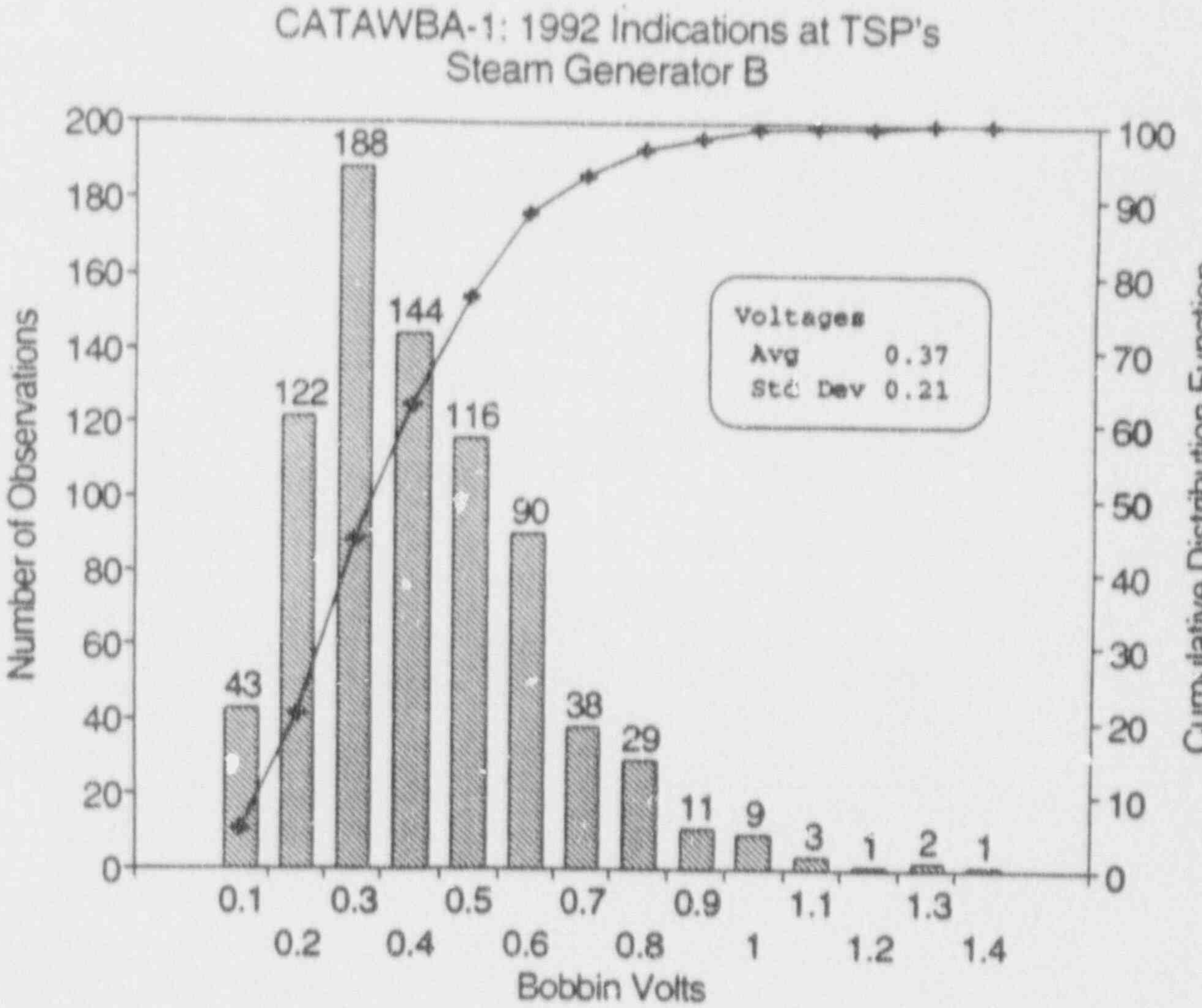
Steam Generator	ASME Standard	Tape Numbers Calibrated Using the ASME Standard	Calibration Correction
A	50391	1 to 37	0.9855
A	50417	39 to 84	1.1396
B	50415	50 to 85	1.0331
B	50417	1 to 49	1.1396
B	50418	86	0.9985
C	50415	1 to 48	1.0331
C	50417	49	1.1396
C	50418	50 to 88	0.9985
D	50391	38, 39, 41	0.9855
D	50416	39, 41 to 50, 52 to 80, 82, 83	0.9949
D	50417	84, 85	1.1396
D	50419	1 to 37, 40, 51, 86, 87	0.9258



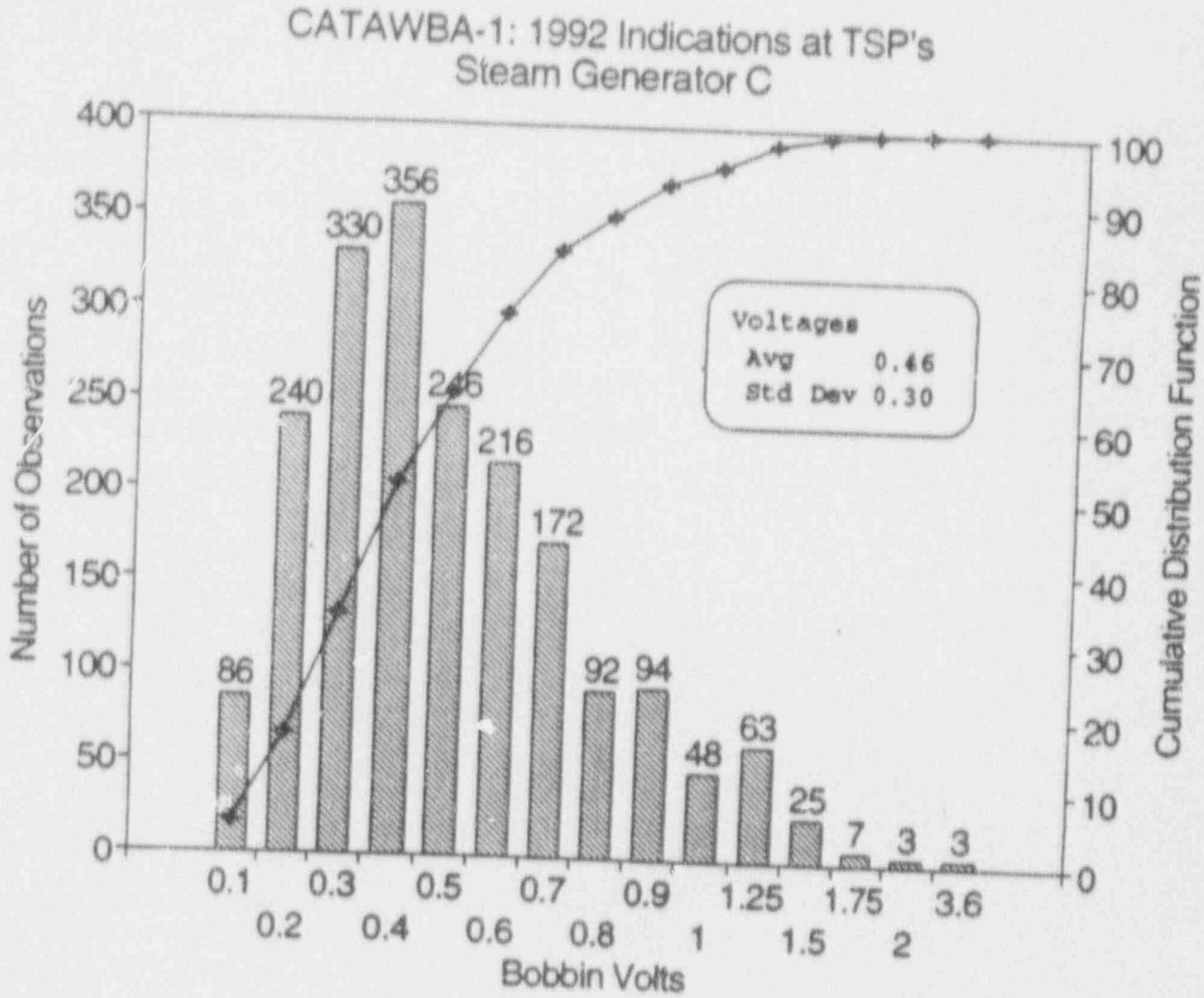
CATAWBA-1: 1992 Indications at TSP's
ALL STEAM GENERATORS
Number of Observations
Cumulative Distribution Function
Bobbin Volts
517
1309
1445
1238
802
603
391
222
176
114
115
40
10
4
4
1
Voltages
Avg 0.38
Std Dev 0.26
0.1 0.3 0.5 0.7 0.9 1.25 1.75 3.0
0.2 0.4 0.6 0.8 1.0 1.5 2.0 3.6

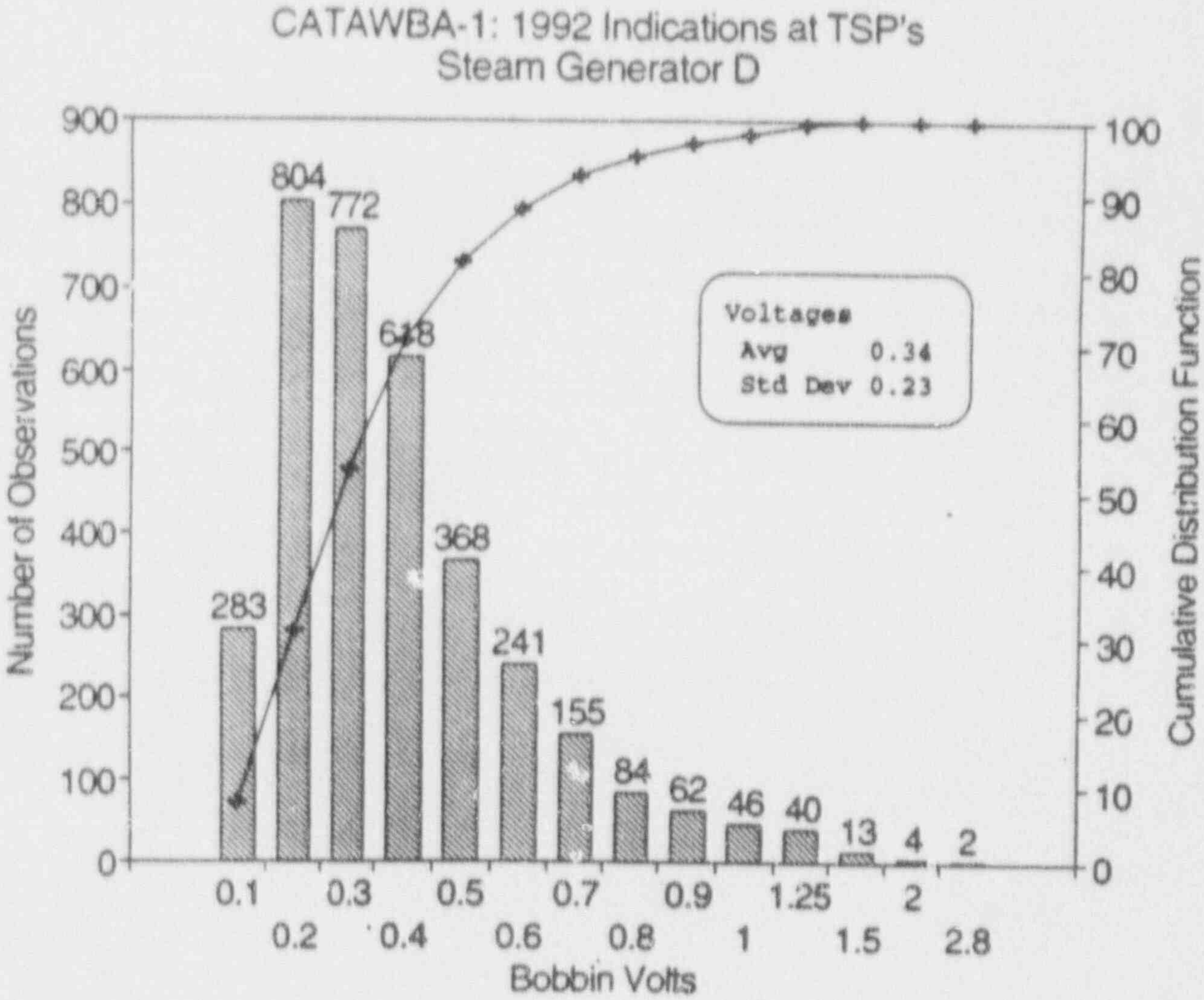


CATAWBA-1: 1992 Indications at TSP's
Steam Generator A
Number of Observations
Cumulative Distribution Function
Bobbin Volts
105
143
155
120
72
56
26
17
9
11
4
1
1
1
Voltages
Avg 0.32
Std Dev 0.22
0
20
40
60
80
100
120
140
160
10
20
30
40
50
60
70
80
90
100
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4



CATAWBA-1: 1992 Indications at TSP's
Steam Generator B
Number of Observations
Cumulative Distribution Function
Bobbin Volts
Voltages
Avg 0.37
Std Dev 0.21
0
20
40
60
80
100
120
140
160
180
200
10
30
50
70
90
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
43
122
188
144
116
90
38
29
11
9
3
1
2
1


CATAWBA-1: 1992 Indications at TSP's
Steam Generator C
Number of Observations
Cumulative Distribution Function
Bobbin Volts
86
240
330
356
246
216
172
92
94
48
63
25
7
3
3
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.25
1.5
1.75
2
3.6
Voltages
Avg 0.46
Std Dev 0.30



CATAWBA-1: 1992 Indications at TSP's
Steam Generator D
Number of Observations
Cumulative Distribution Function
Bobbin Volts
900
800
700
600
500
400
300
200
100
0
100
90
80
70
60
50
40
30
20
10
0
804
772
618
368
283
241
155
84
62
46
40
13
4
2
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.25
1.5
2
2.8
Voltages
Avg 0.34
Std Dev 0.23

Bounding SLB Leak Rates

for 3/4 Inch OD Tubing

8/28/1992

P. J. Prabhu

Westinghouse Electric Corporation

Bounding SLB Leak Rate Development

- Same database as previously presented for 7/8 inch diameter tubing:
  - 93 Pulled tube intersections
  - 74 Model boiler specimens
- 131 Specimens had direct leak rate measurement results. For the remaining 36 samples, leak rate potential could be inferred from crack morphology (destructive examination results)
- Voltage amplitudes of 7/8 inch diameter tubes were reduced by a factor of 1.36 to convert to equivalent 3/4 inch results
- Voltage amplitudes of Belgian pulled tubes could be conservative by about 50% (1.5 factor was not applied)
- SLB Leak rate probability determined for leak rate thresholds of 0 leakage as well as a small leakage (1 l/hr)

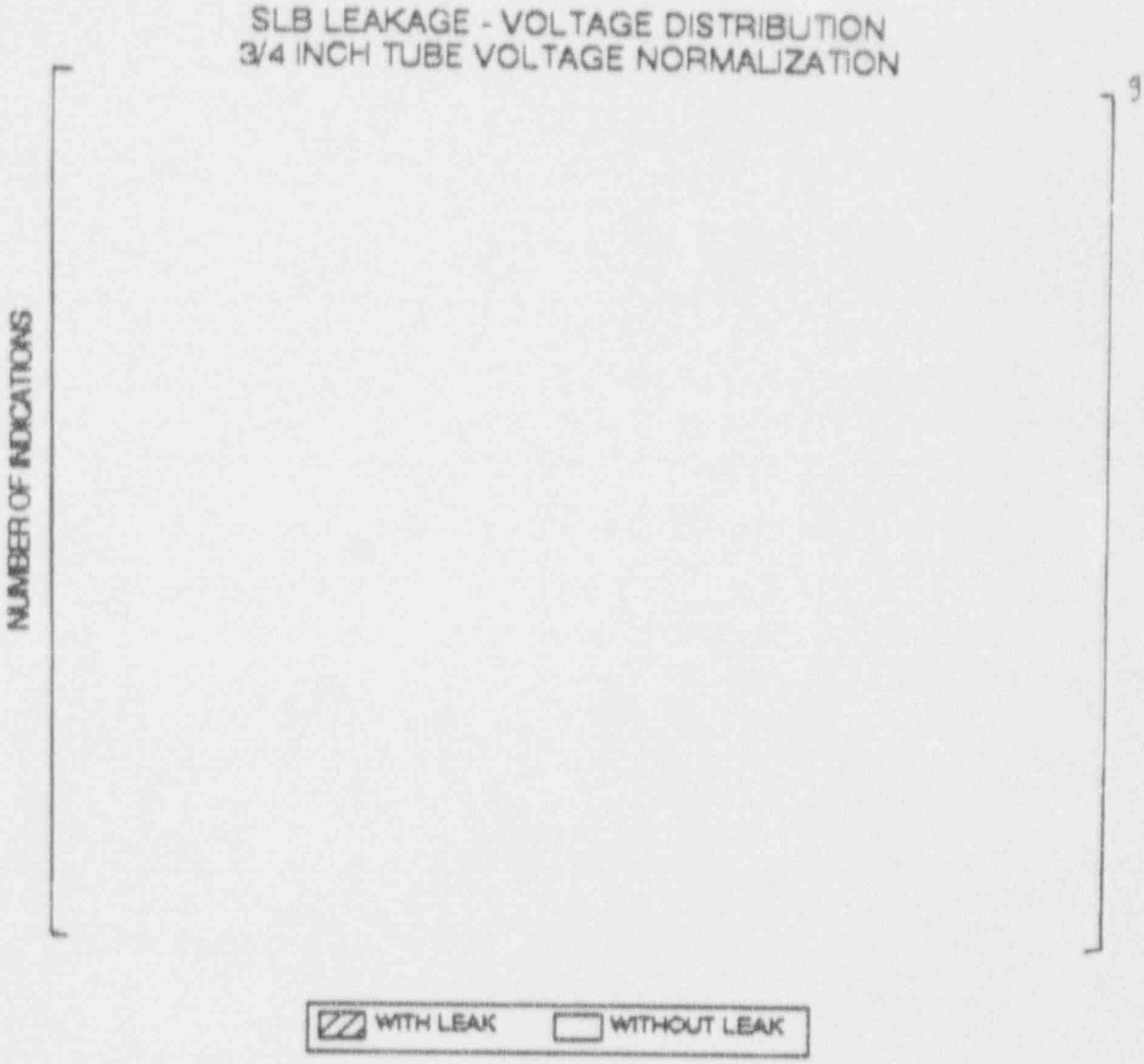


Figure 6. Probability of leakage at various voltage ranges for 3/4 inch tubing

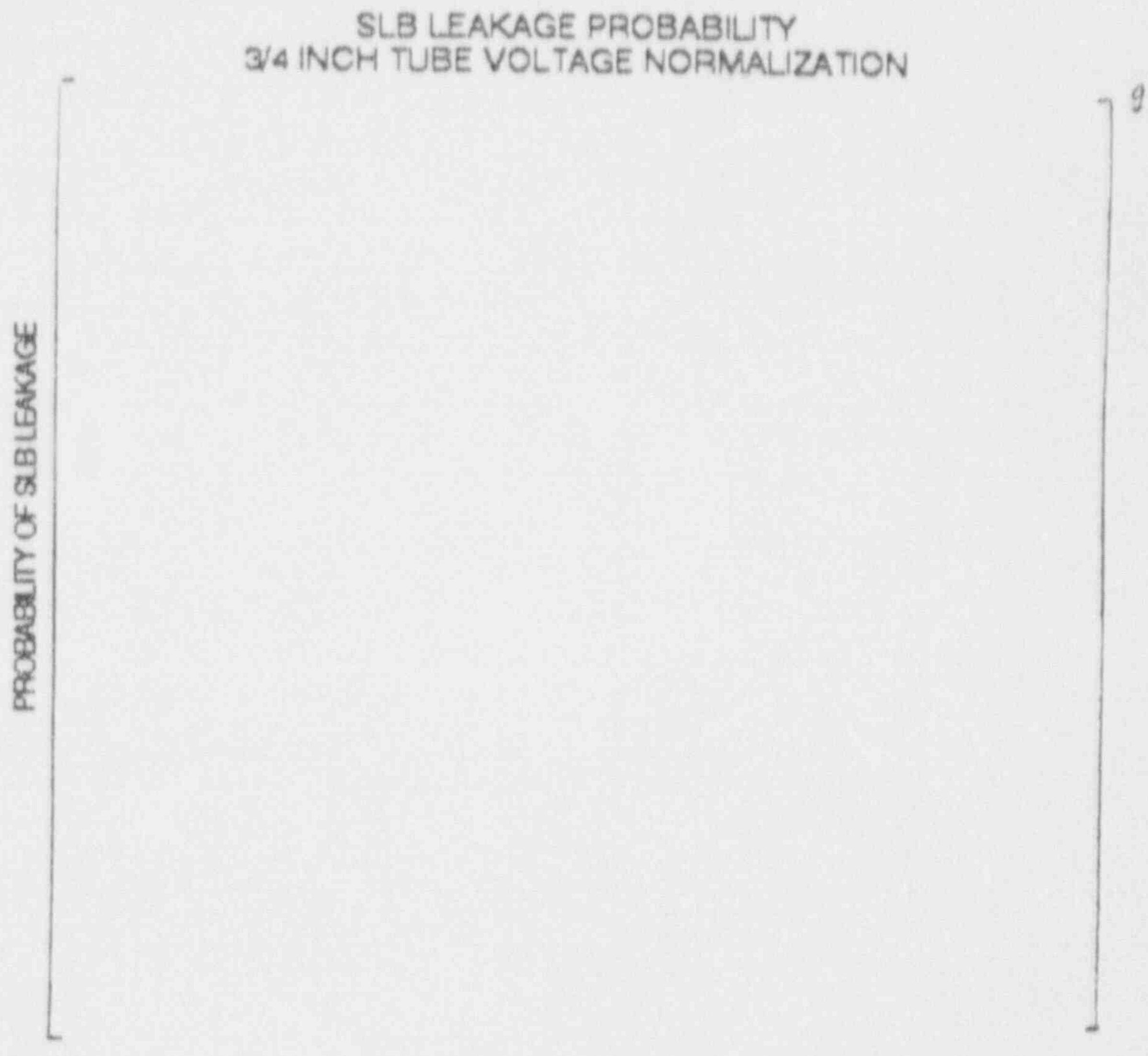


Figure 5. Frequency distribution of voltage for leakers and non-leakers (3/4 inch tubing)

SLB LEAKAGE - VOLTAGE DISTRIBUTION
3/4 INCH TUBE VOLTAGE NORMALIZATION

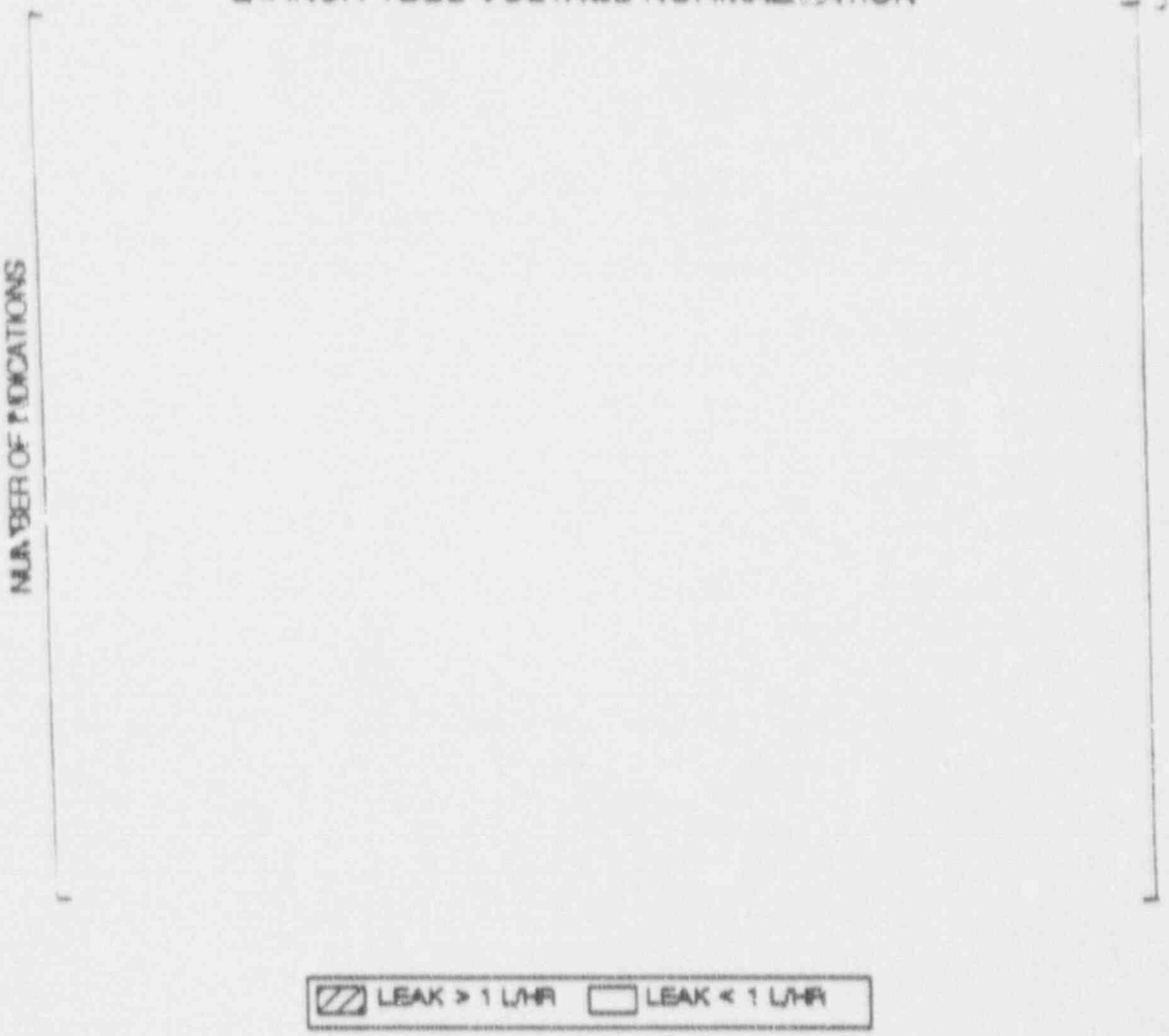


Figure 7. Frequency distribution of voltage for a leakage threshold of 1 l/hr for 3/4 inch tubing

SLB LEAKAGE PROBABILITY
3/4 INCH TUBE VOLTAGE NORMALIZATION

PROBABILITY OF SLB LEAKAGE > 1 L/HR

Figure 8. Probability of exceeding 1 l/hr leakage at various voltage ranges for 3/4 inch tubing

Summary of Bounding SLB Leak Rates for 3/4 Inch Tubeing Voltage Ranges

Voltage Range	Bounding SLB Leak Rate	Limiting Indications for Leakage
[ ] 9	0.0 l/hr	[ ] 9
[ ] 9	1.0 l/hr	
[ ] 9	10 l/hr	Based on NRC recommendation for IPC implementation (D. C. Cook)
[ ] 9	If projected EOC amplitude for indications in 3/4 inch tube exceeds [ ] 9 additional evaluation on bounding SLB leak rate will be required	

---

1) Maximum corrosion depth was 97%. Post-pull voltage increased to 5.06 volts. It is judged that throughwall penetration resulting in leakage occurred as a consequence of the tube pull operations (as supported by the post-pull bobbin voltage) rather than opening during the leak test.

2) Utilizes minimum voltage increase in renormalizing Belgian data to APC normalization. Final renormalization factor is expected to significantly increase voltage.

Pulled Tube Database for 3/4" Tubing

Discussion Topics

Eddy Current Data Renormalization to APC Calibration

Catawba-1 Data Evaluation

- Voltages
- Burst Tests: Adjustments for Incomplete Burst
- Data Summary

Summary of Overall Data

Eddy Current Data Renormalization

APC Normalization
- 2.75 volts at 550/130 kHz for 20% ASME hole

Catawba-1 Pulled Tube Field Normalization
- 5.0 volts at 400 kHz for TSP standard

Belgian Normalization
- 2.0 volts at 300 kHz for 4 TW 0.049" (1.25 mm) holes
- Latest pulled tubes obtained also for APC normalization

Bases for Renormalization
- Correlation of APC to field voltages
- Catawba-1: Lab data on pulled tubes for both normalizations
- Belgian: Field Data for Both Normalizations
  - Further adjustment made based on ASME standard evaluations indicating additional 1.5 to 1.7 factor due to differences in domestic and Belgian probe responses at different frequencies
  - Laborelec to obtain data at APC and Belgian frequencies with domestic probe in upcoming Tihange-3 inspection

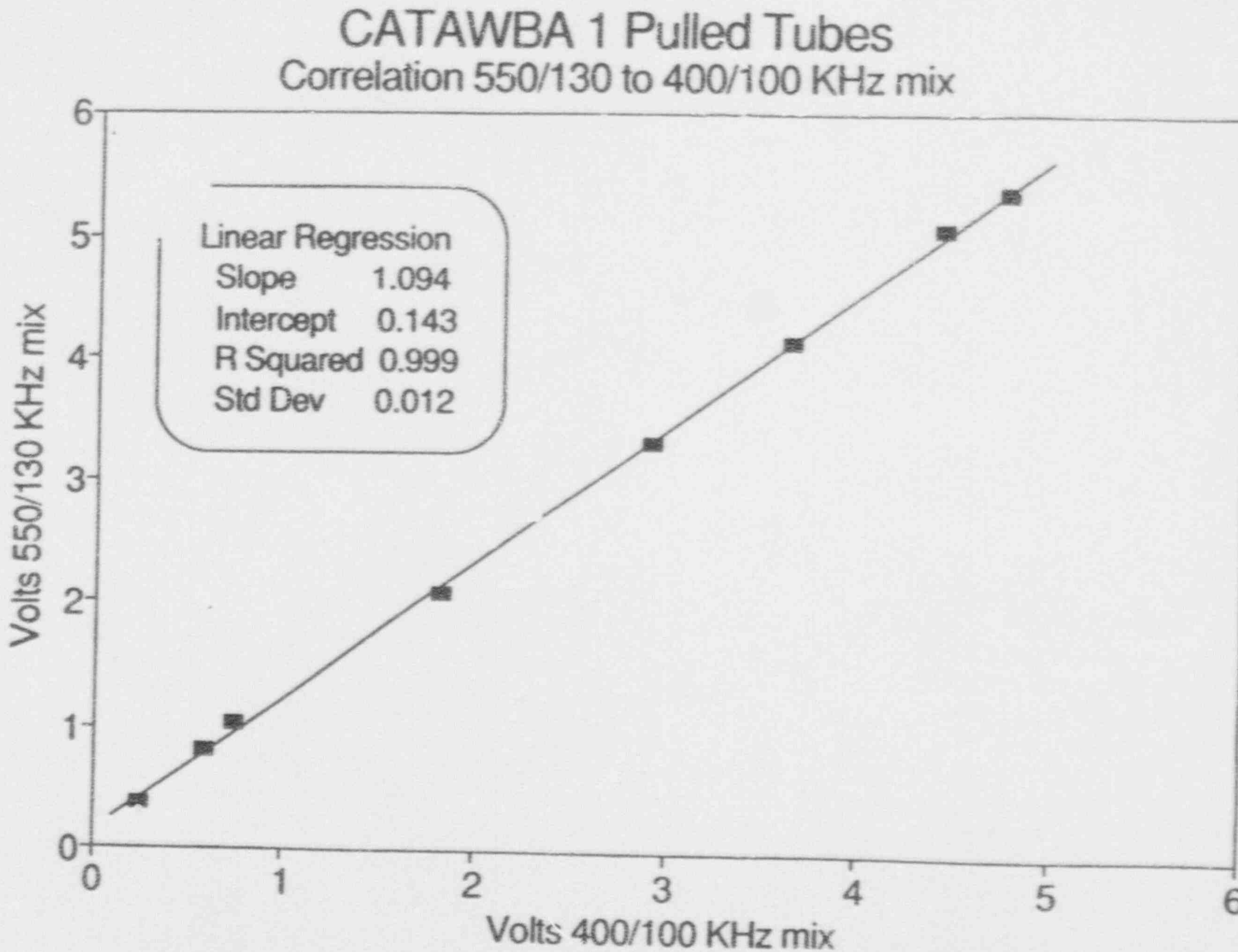
Table A4-1. Voltage Adjustment Factors to Obtain APC Normalization for 550/130 kHz Mix

Tube	TSP	Factor for Adjusting Field TSP Norm. to 20% ASME Norm.		Post-Pull 550/130 kHz and 400/100 kHz Data[4]	
		TSP Volts[1]	Voltage Adjustment Factor[2]	400/100 kHz Volts	550/130 kHz Volts
R5C112	2	6.92	1.38	0.25[5]	0.37
	3			4.44	5.06
R10C6	2	6.4	1.28	1.82	2.07
	3			4.77	5.34
R10C69	2	6.4[3]	1.28	---	NDD
	3			2.92	3.31
R20C46	2	6.04	1.21	0.59	0.92
	3			0.75	1.04
R7C47	2	7.8	1.56	---	---
	3			3.65	4.13

Notes:

1. Westinghouse measure of standard TSP volts when 20% ASME volts set at 2.75 volts.
2. Voltage adjustment to convert voltages normalized to 5.0 volts at standard TSP to normalization of 2.75 volts for 20% ASME hole.
3. Adequate TSP not available on standard. Assumed same as tube R10C6.
4. B&W evaluations of post-pull data.
5. The 400/100 kHz data were renormalized to 2.75 volts for the 20% ASME hole.

FIGURE A2-6


CATAWBA 1 Pulled Tubes
Correlation 550/130 to 400/100 KHz mix
Linear Regression
Slope 1.094
Intercept 0.143
R Squared 0.999
Std Dev 0.012
Volts 550/130 KHz mix
Volts 400/100 KHz mix
0
1
2
3
4
5
6

BELGIAN VOLTAGE RENORMALIZATION

BELGIAN FIELD EVALUATION

- EVALUATION OF 53 INDICATIONS INCLUDING 1992 PULLED TUBES
- MEASUREMENTS AT 300 KHZ WITH BELGIAN PROBE AND EQUIPMENT AND BELGIAN NORMALIZATION
- MEASUREMENTS AT 550/130 KHZ WITH APC NORMALIZATION AS WELL AS 300 KHZ WITH BELGIAN PROBE AND ZETEC EQUIPMENT
- VOLTAGE RENORMALIZATION FOR BELGIAN PROBE DETERMINED BY CORRELATING 550/130 KHZ WITH 300 KHZ
    - SLOPE OF 4.93
- FIELD DATA INDEPENDENTLY REVIEWED BY WESTINGHOUSE WITH EXCELLENT AGREEMENT WITH BELGIAN VOLTAGES CALLS

PRINCIPAL ISSUE OF VOLTAGE RENORMALIZATION

- RATIO OF 550/130 KHZ TO 300 KHZ OBTAINED WITH U.S. PROBES IS FACTOR OF 1.5 TO 1.75 HIGHER THAN OBTAINED WITH BELGIAN PROBE
    - BASED ON ASME STANDARDS
- U.S. PROBE AND LABORATORY TRANSFER STANDARD PROVIDED TO LABORELAC FOR INDEPENDENT EVALUATION

Ratio of U.S. 550/130 KHz to Belgian 300 KHz

Frequency KHz	Probe	Probe Type	100° Ext.	Standard	ASME 20%	40%	60%	80%	100%	ASME 4 TW 0.023	0.027	Belgian 4 TW 1.25mm 0.048	0.049
550/130	Zetec	Non-mag.	No	Lab	2.75	2.62	4.13	4.54		4.17			18.1
550					3.93	3.16	4.17	4.17		3.50			15.7
300					0.89	0.65	0.69	0.66		0.52			2.0
550/130	Echo.	Mag-bias	Yes	Lab	2.75	2.51	4.15	4.81		4.44			
550					3.86	3.01	4.18	4.43		3.72			
300					P.68	0.51	0.62	0.62		0.51		2.0	
550/130	Echo.	Mag-bias	Yes	Transfer	2.68	5.18	4.23	5.63			5.51	18.6	
550					3.82	3.82	4.31	5.22			4.69	16.1	
300					0.62	0.66	0.65	0.72			0.63	2.0	
550/130	Belgian		Yes	Belgian	2.75	2.30	3.17	3.63	3.09			16.32	
550					3.57	2.91	3.31	3.49	2.90			9.58	
300					0.94	0.72	0.79	0.77	0.59			2.0	

Ratio 550/130 (NPC) to 300 (Belgian)

Probe	Probe Type	100° Ext.	Standard	20%	40%	60%	80%	100%	0.023	0.027	0.048	0.049
Zetec	Non-mag	No	Lab	3.09	4.03	5.97	6.88		8.02			9.05
Echo.	Mag-bias	Yes	Lab	4.06	4.92	6.69	7.76		8.71			
Echo.	Mag-bias	Yes	Transfer	4.32	5.30	6.50	7.82			8.75	9.30	
Belgian		Yes	Belgian	2.93	3.47	4.01	4.71	5.24				5.16

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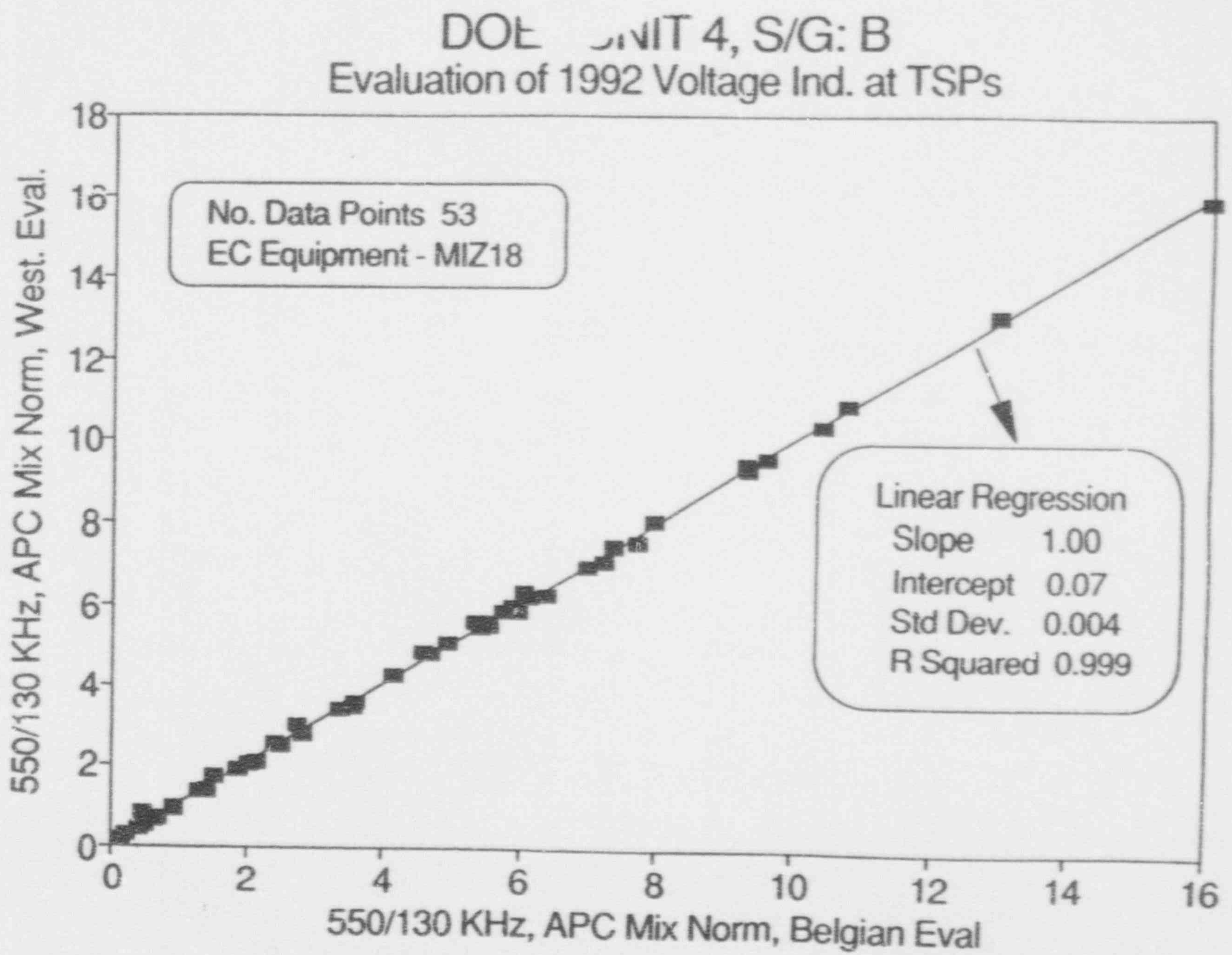

DOE UNIT 4, S/G: B
Evaluation of 1992 Voltage Ind. at TSPs
No. Data Points 53
EC Equipment - MIZ18
Linear Regression
Slope 1.00
Intercept 0.07
Std Dev. 0.004
R Squared 0.999
550/130 KHz, APC Mix Norm, West. Eval.
550/130 KHz, APC Mix Norm, Belgian Eval
0
2
4
6
8
10
12
14
16
18

FIGURE A2-2

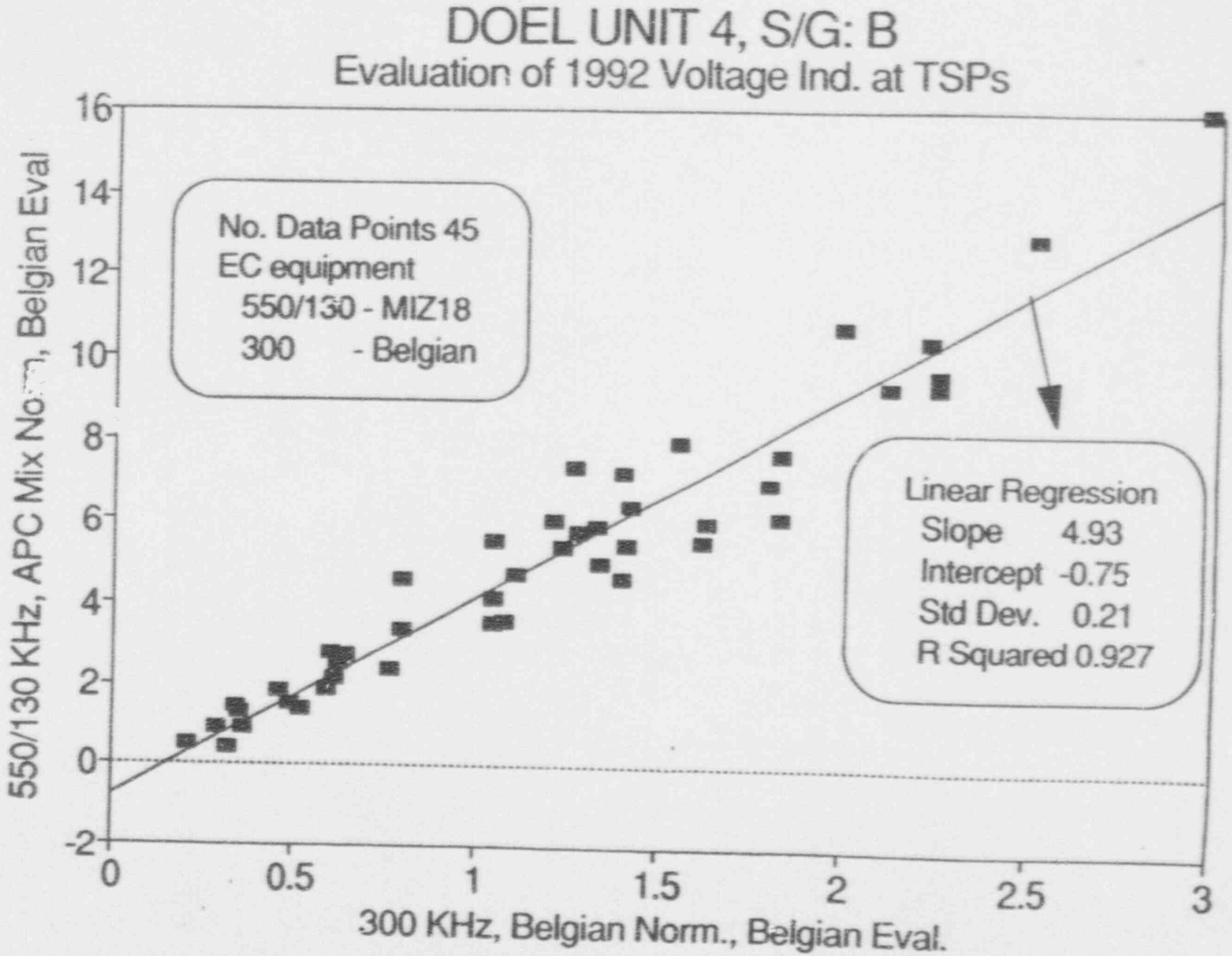
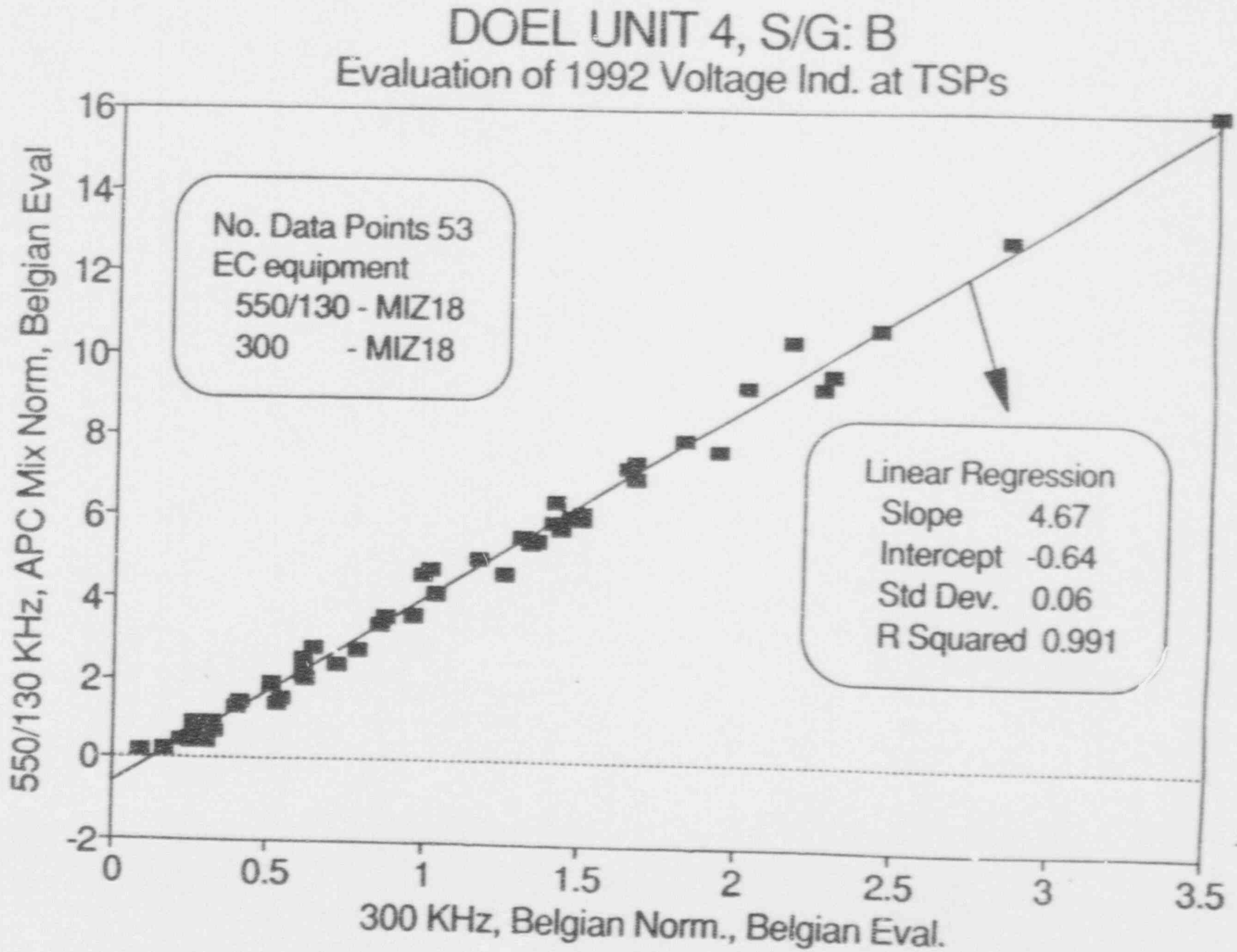

DOEL UNIT 4, S/G: B
Evaluation of 1992 Voltage Ind. at TSPs
No. Data Points 45
EC equipment
550/130 - MIZ18
300 - Belgian
Linear Regression
Slope 4.93
Intercept -0.75
Std Dev. 0.21
R Squared 0.927
300 KHz, Belgian Norm., Belgian Eval.
0
0.5
1
1.5
2
2.5
3
-2
0
2
4
6
8
10
12
14
16

FIGURE A2-3


DOEL UNIT 4, S/G: B
Evaluation of 1992 Voltage Ind. at TSPs
No. Data Points 53
EC equipment
550/130 - MIZ18
300 - MIZ18
Linear Regression
Slope 4.67
Intercept -0.64
Std Dev. 0.06
R Squared 0.991
550/130 KHz, APC Mix Norm, Belgian Eval
300 KHz, Belgian Norm., Belgian Eval.
16
14
12
10
8
6
4
2
0
-2
0
0.5
1
1.5
2
2.5
3
3.5

DOEL UNIT 4, S/G: B

Evaluation of 1992 Voltage Ind. at TSPs

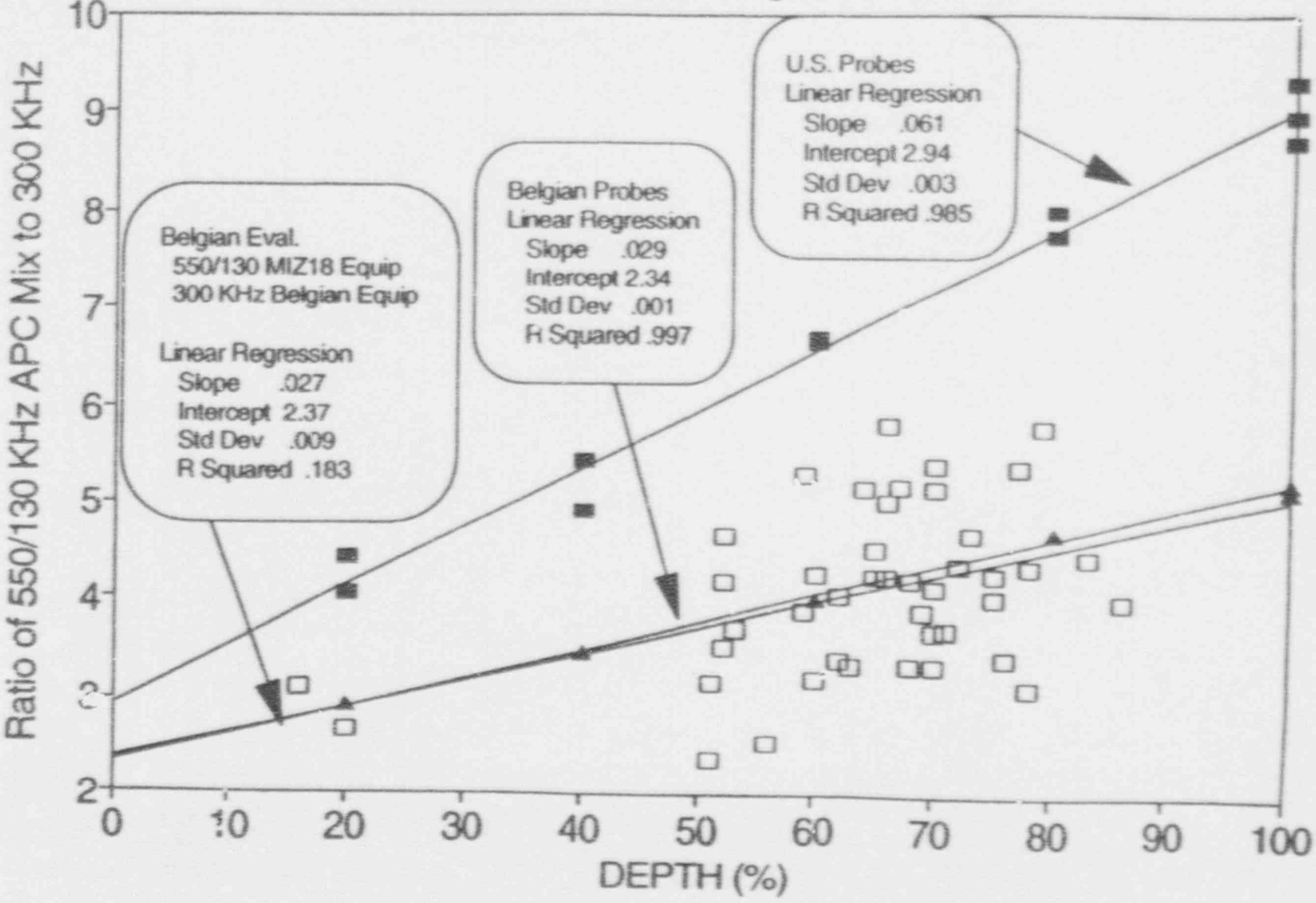


Table A4-2. Field and Westinghouse Evaluations of Catawba-1 Pre-pull Voltages

		Field Evaluation			Westinghouse Evaluation		
		400/100 kHz Mix		550/130 kHz Mix	400/100 kHz	550/130 kHz	RPC
Tube	TSP	TSP Norm.	20% ASME Norm.	20% ASME Norm.	20% ASME Norm.	20% ASME Norm.	Volts[1]
R5C112	2	NDD	--		0.31	0.48[2]	
	3	1.15	1.59	1.88[2]	1.53	1.82	1.30
R10C6	2	0.82	1.05	1.29	1.20	1.46	0.98
	3	0.77	0.99	1.23	1.07	1.31	1.20
R10C69	2	NDD	--	--	NDD	--	
	3	0.93	1.19	1.45	1.22	1.48	0.97
R20C46	2	0.31	0.38	0.56	0.25	0.42	
	3	0.40	0.48	0.67	0.59	0.79	
R7C47	2	0.33	0.40	0.58	0.34	0.51	
	3	0.80	1.25	1.51	1.30	1.57	1.40

Notes:

1. RPC volts at 300 kHz normalized to 20 volts for 0.5" EDM notch.
2. Obtained from 400/100 kHz evaluation using Equation 2-2.

CATAWBA-1 PULLED TUBE BURST TEST EVALUATION

BURST TEST MEASUREMENT ISSUE

- BURST TESTS, IN SOME CASES, RESULTED IN PARTIAL CRACK OPENING AND INCOMPLETE BURST
- ALL BUT ONE INDICATION TESTED WITHOUT BLADDERS
- ONLY R5C112, TSP 3 TESTED WITH BLADDER
  - INCOMPLETE BURST NOT RETESTED AT FASTER PRESSURIZATION RATE
- PRESSURIZATION RATE LEADING TO 2 TO 3 MINUTES TO BURST
  - APC DATABASE RATE ~500-1,000 PSI/SEC
- SIMILAR RESULTS TO MCGUIRE-1 BURST TESTS IN EARLY 1992

EVALUATION PROCESS

- FRACTIONS OF BURST CRACK OPENING EVALUATED
- CRACK OPENING ADJUSTMENT FACTORS ON BURST PRESSURES ESTIMATED
  - COMPARISONS OF EDM NOTCHES & CRACKS FROM MCGUIRE DATA
  - WESTINGHOUSE BURST TEST ON FREE SPAN PIECE OF TUBING FOUND 12% HIGHER THAN DURING DESTRUCTIVE EXAM
- BURST PRESSURES REQUIRING ADJUSTMENT FACTORS OF >1.25 CONSIDERED NOT RELIABLE

FOUR BURST TEST POINTS FOUND ACCEPTABLE FROM 9 MEASUREMENTS

Table A4-3. Comparisons of Burst Test Results

Adjustments to Burst Pressures Based on EDM Notch Simulations

Case	Tube-Section	Estimated Burst Pressure EDM Notches	Actual Burst Pressure	Estimated/Actual Ratio	Description of Actual Burst
		[ ]a,b,c		[ ]a,b,c	
1	5/29-3		4200		Minor crack opening, no bulging or tearing
2	18/5-3		9200		Fishmouth rupture, bulging, tearing
3	18/5-5		4800		Fishmouth rupture, bulging
4	18/5-10		1397		Leak test pressure with minor crack opening. Burst test resulted in a lower burst pressure.
5	18/10-4		2847		Same as Case 4

Adjustment to Burst Pressure Based on Burst Tests of Common Undegraded Tube

	Catawba Tube	Westinghouse Test	Destructive Exam Test	Ratio
6	R5C112	11,100	9900	1.12

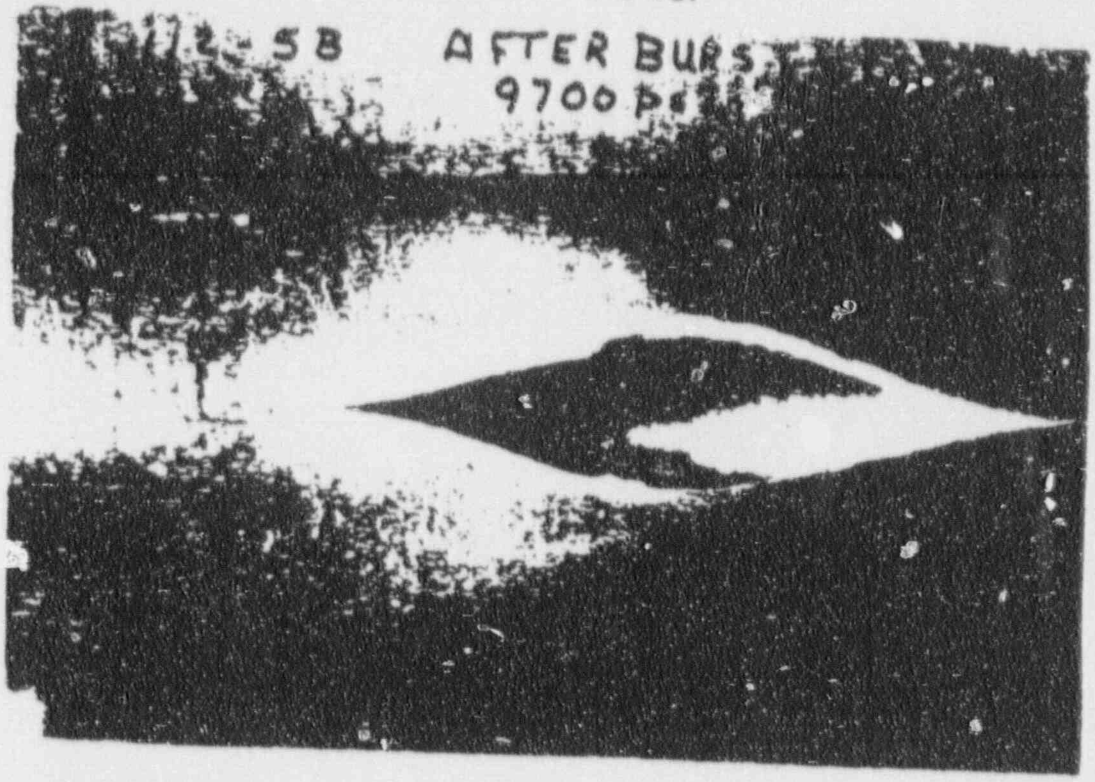
Model Boiler Specimen 601-2

	Retest	Initial Test	Ratio	Comments
7	3405	2935	1.16	Crack opened with no crack tearing in initial test.

Table A4-4 Burst Pressures for Catawba-1 Tubes

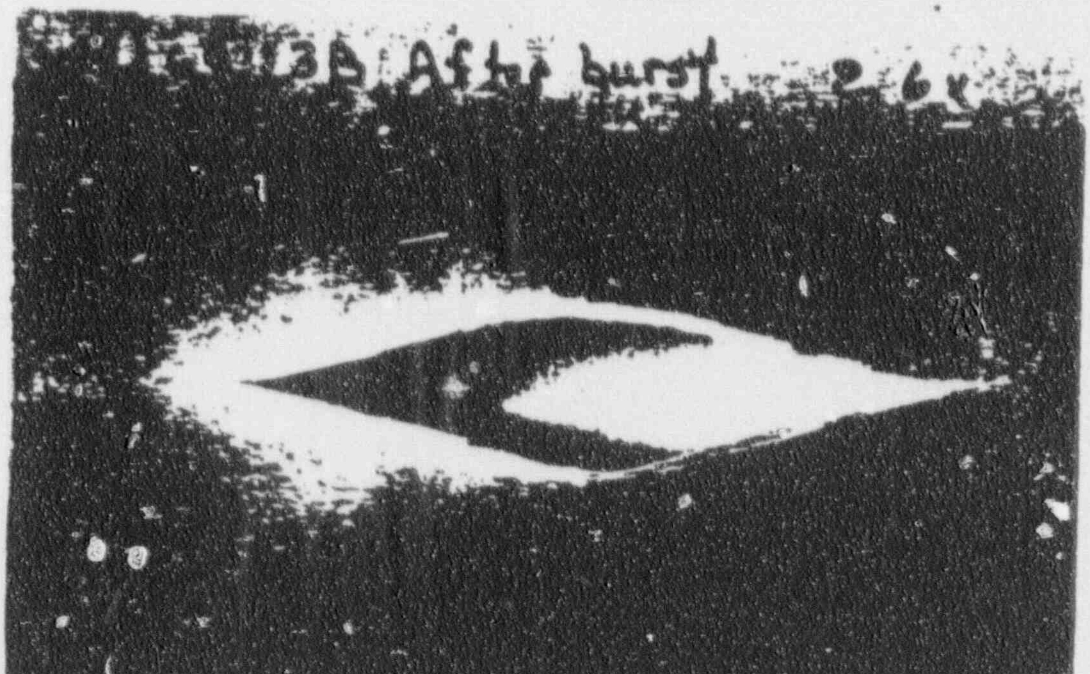
Tube	TSP	Bobbin Volts	Measured Burst-psi	Flow Stress Adjustment Factor	Crack Opening Adjustment Factor	Adjusted Burst-psi	Comments
R5C112	2	0.48	[illegible]	1.02	1.10	10,880	Ductile, fishmouth rupture just outside TSP.
	3	1.82	4,150	1.02	>1.25	Not Reliable	Crack opened (largest ~0.1", others <0.05"), no apparent bulging or tearing. Max. corrosion depth 97%. Max. single macrocrack length ~0.43 (<0.2" TW by burst).
R10C6	2	1.46	6,000	1.03	1.15	7,100	Crack opened, minor bulging or tearing. Maximum corrosion depth ~72%. Burst crack = macrocrack length ~0.33".
	3	1.31	4,850	1.03	1.15	5,740	Crack opened, minor bulging or tearing. Maximum corrosion depth ~85%. Burst crack length ~0.43".
R10C69	2	NDD	9,400	1.0	1.10	10,340	[illegible]tile, fishmouth rupture region.
	3	1.48	5,000	1.0	>1.25	Not Reliable	Minor crack opening, no bulging or tea[illegible] Maximum corrosion depth ~75%. Maximum single macrocrack length ~0.37" (not completely or <.2" opened by burst).
R20C46	2	0.42	8,600	0.98	-	Not Reliable	Both R20C46 intersections burst just above TSP at a hand held grinding tool mark applied for location purposes.
	3	0.79	7,200	0.98	-	Not Reliable	
R7C47	3	1.57	5,800	0.99	>1.25	Not Reliable	Minor crack opening, no apparent bulging or tearing. Maximum corrosion depth ~87%. Maximum single microcrack length (not completely opened by burst) ~0.44".

R5C112 - 2nd TSP

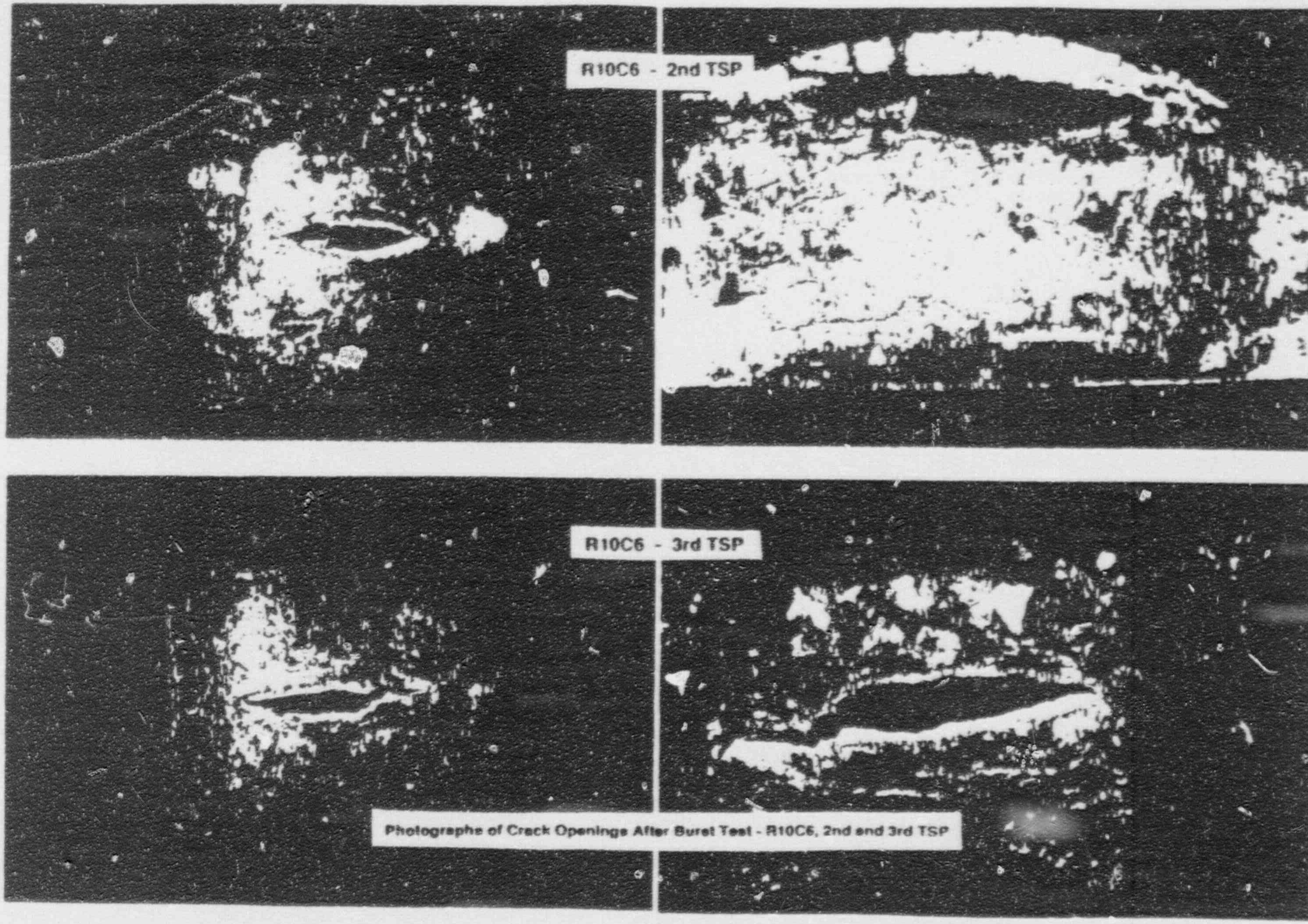


Outside TSP

R10C69 - 2nd TSP



Photographs of Burst Openings for 2nd TSP - R5C112 and R10C69



Photographs of Crack Openings After Burst Test - R10C6, 2nd and 3rd TSP

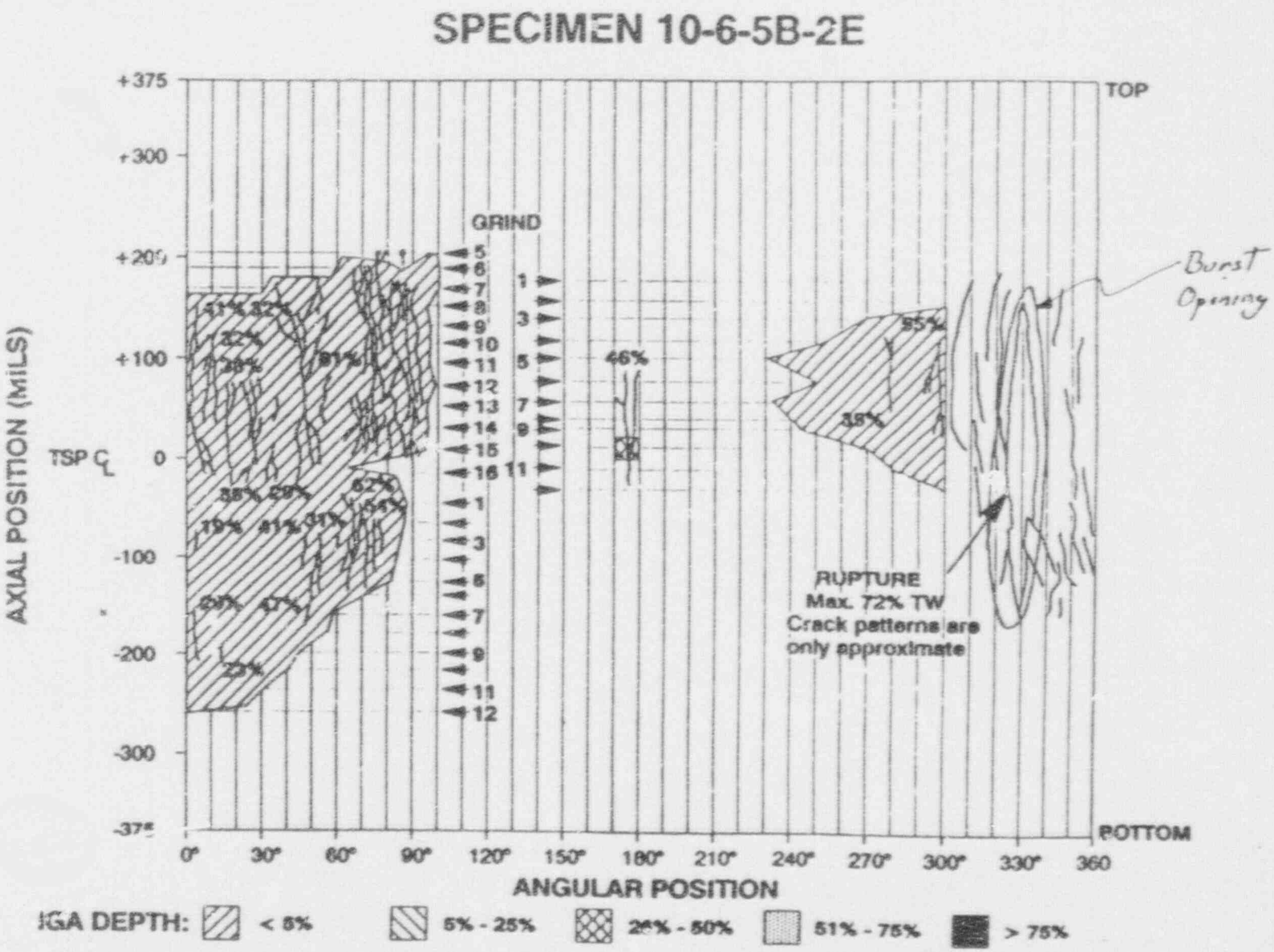
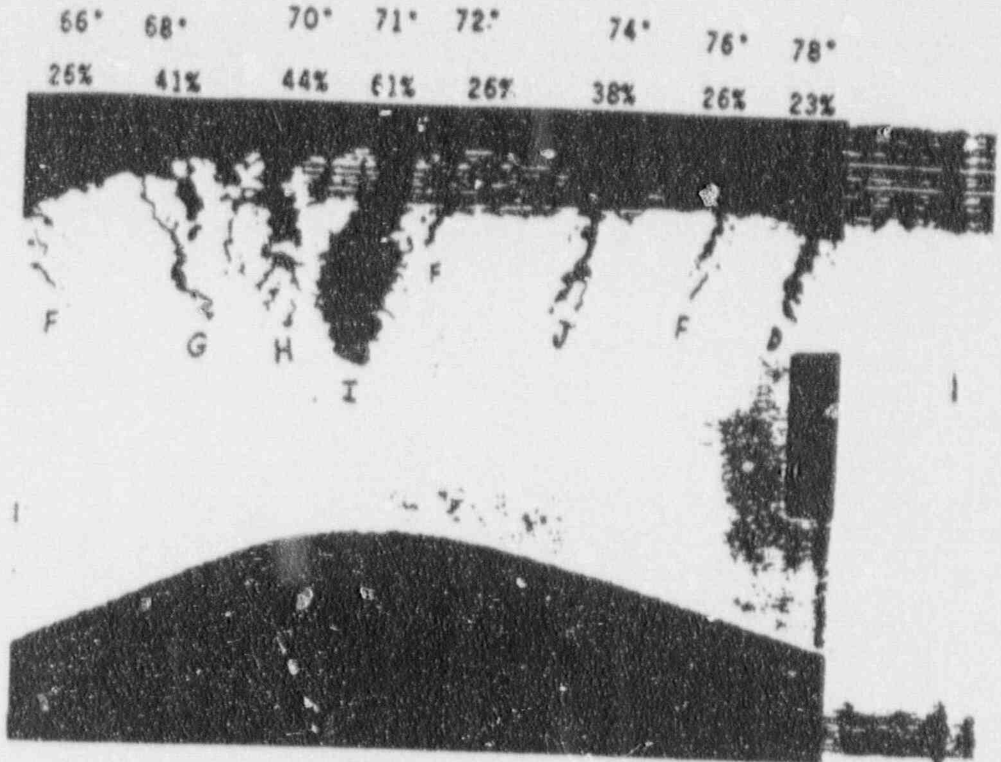
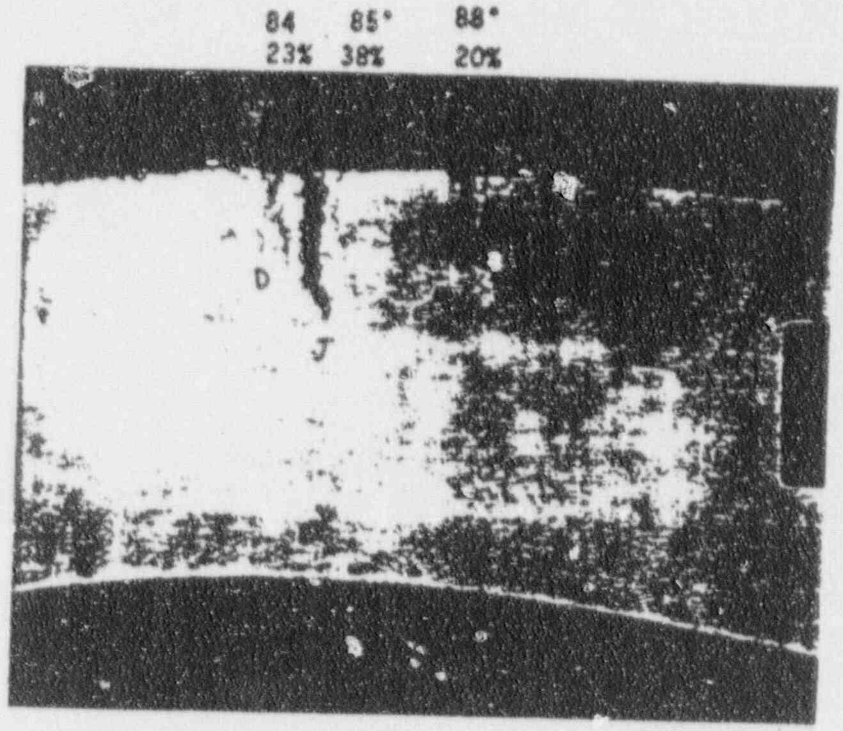


FIGURE 2-60: SUMMARY OF INCREMENTAL GRIND AND POLISH RESULTS ON SPECIMEN 10-6-5B-2E.

2nd TSP

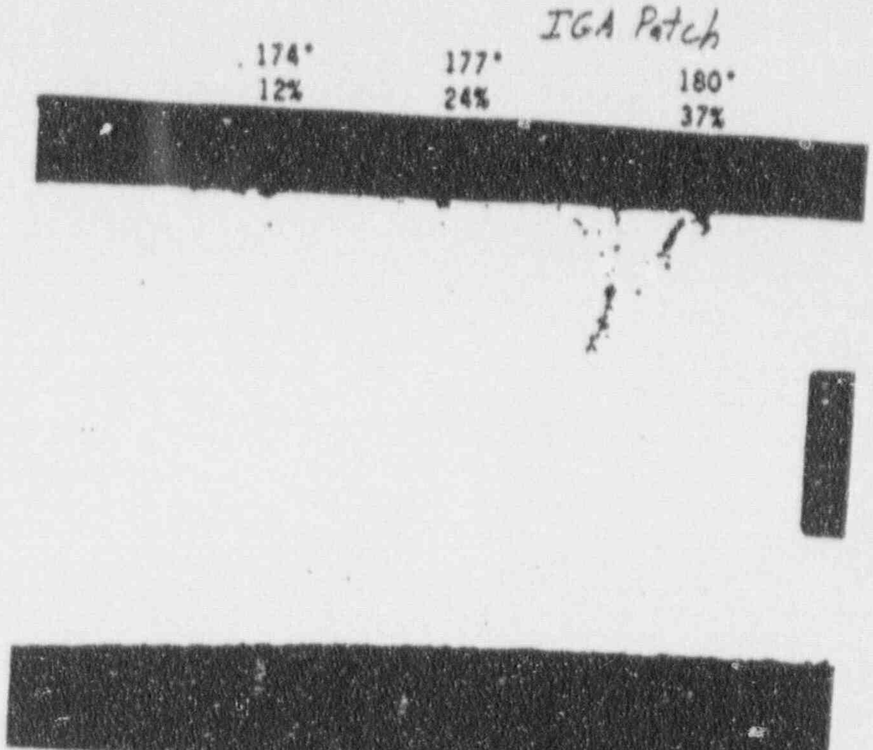


50X Grind #14

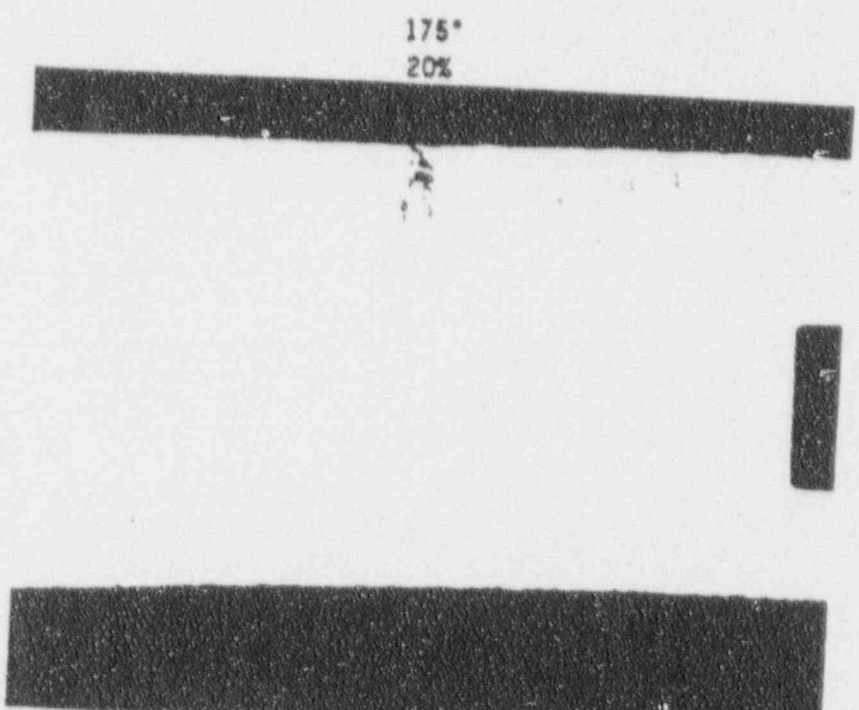


50X Grind #14

10-6-5B-2E, Mount #1, Top Piece

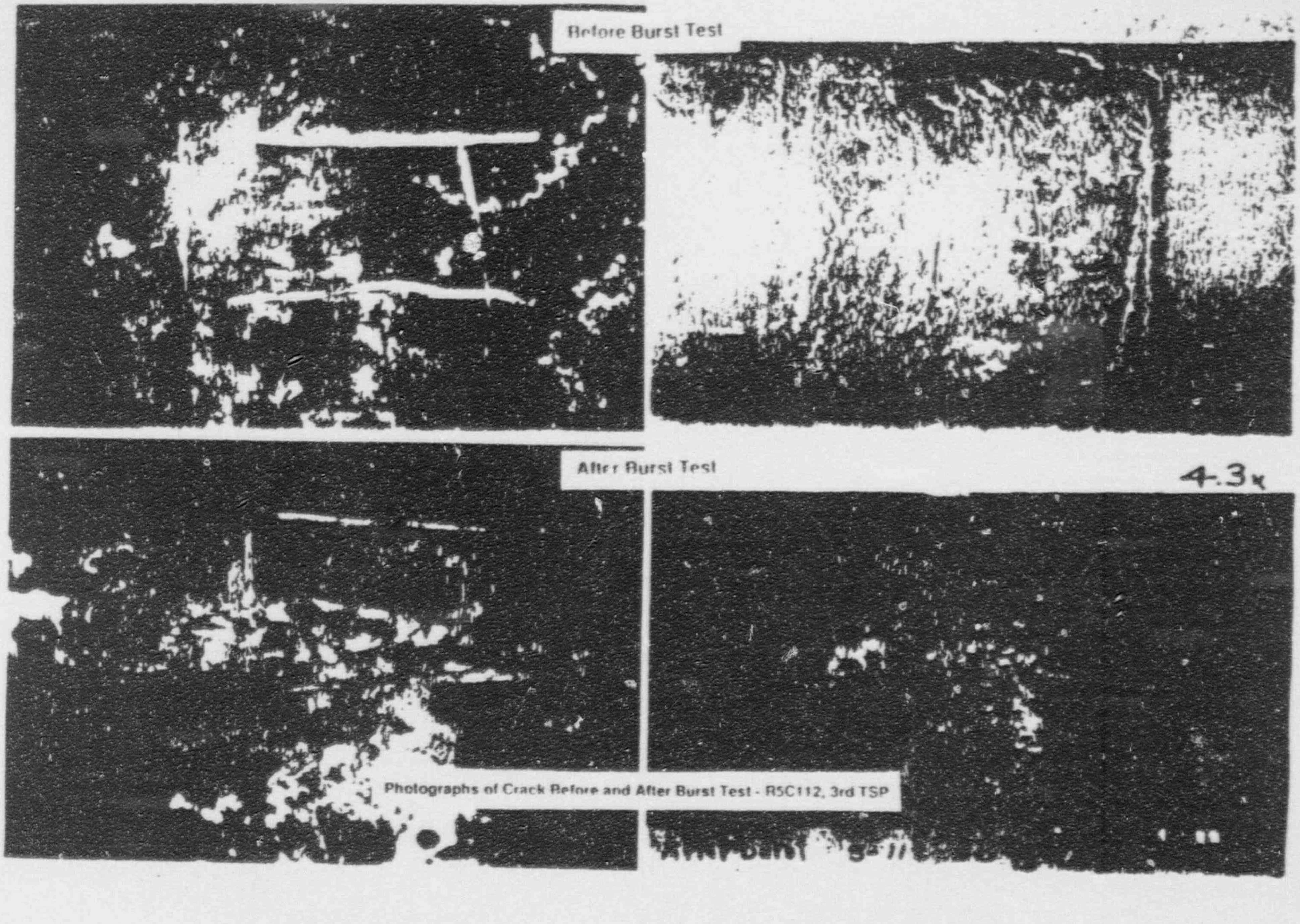


F92-087 50X Grind #10



F92-095 50X Grind #11

10-6-5B-2E, Mount #2



Photographs of Crack Before and After Burst Test - R5C112, 3rd TSP

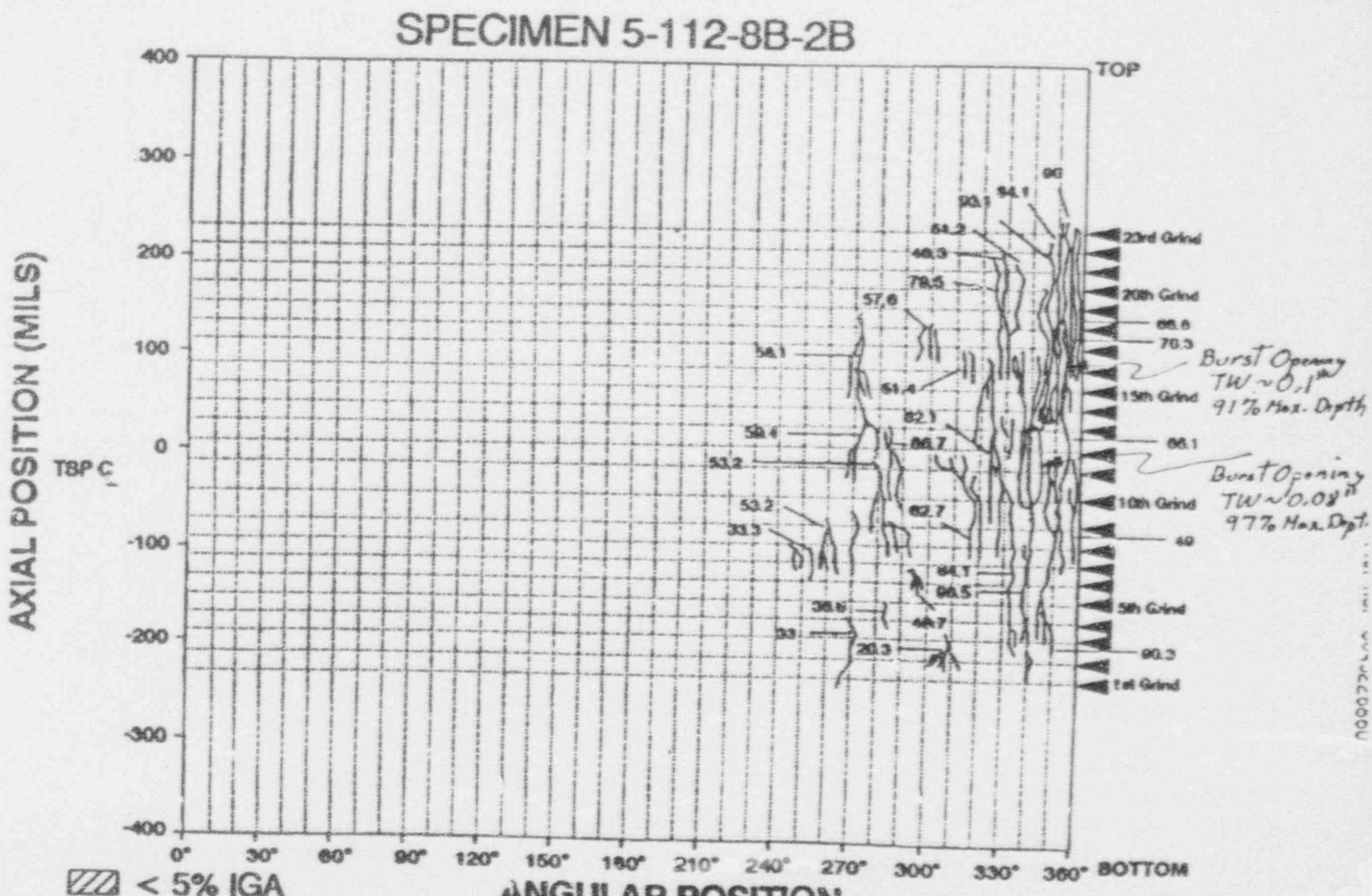
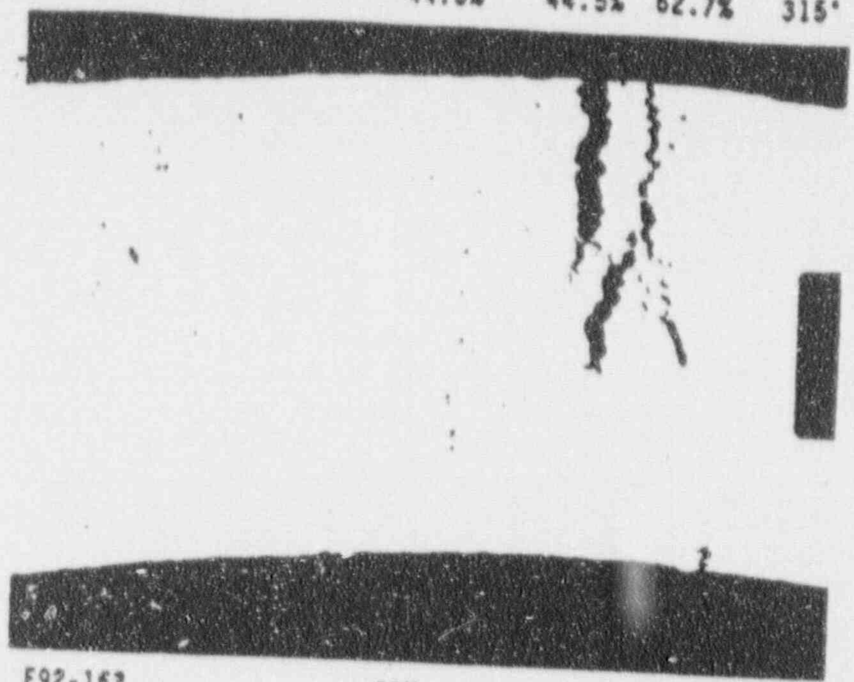
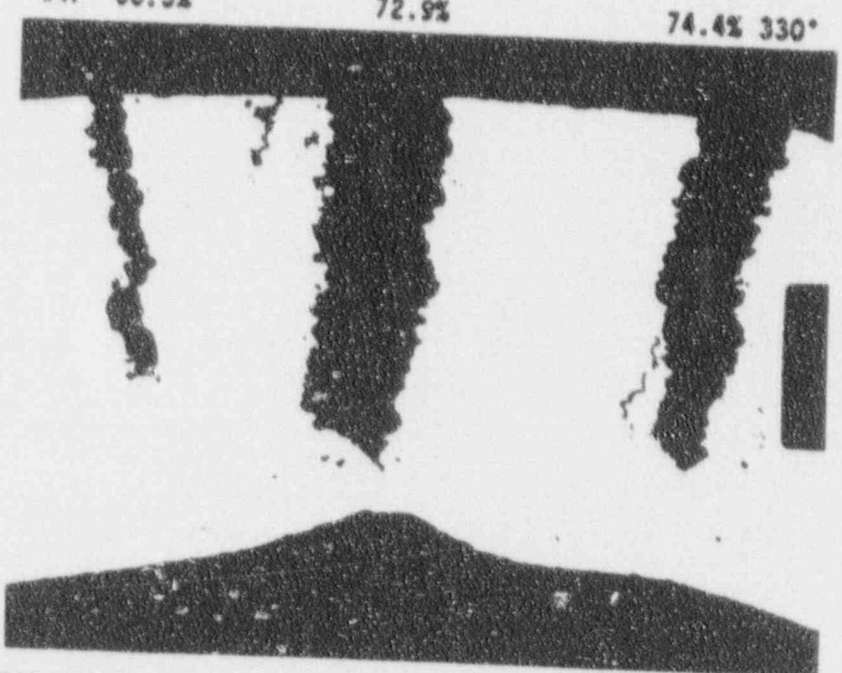


FIGURE 2-63: SUMMARY OF INCREMENTAL GRIND AND POLISH RESULTS ON SPECIMEN 5-112-8B-2B.

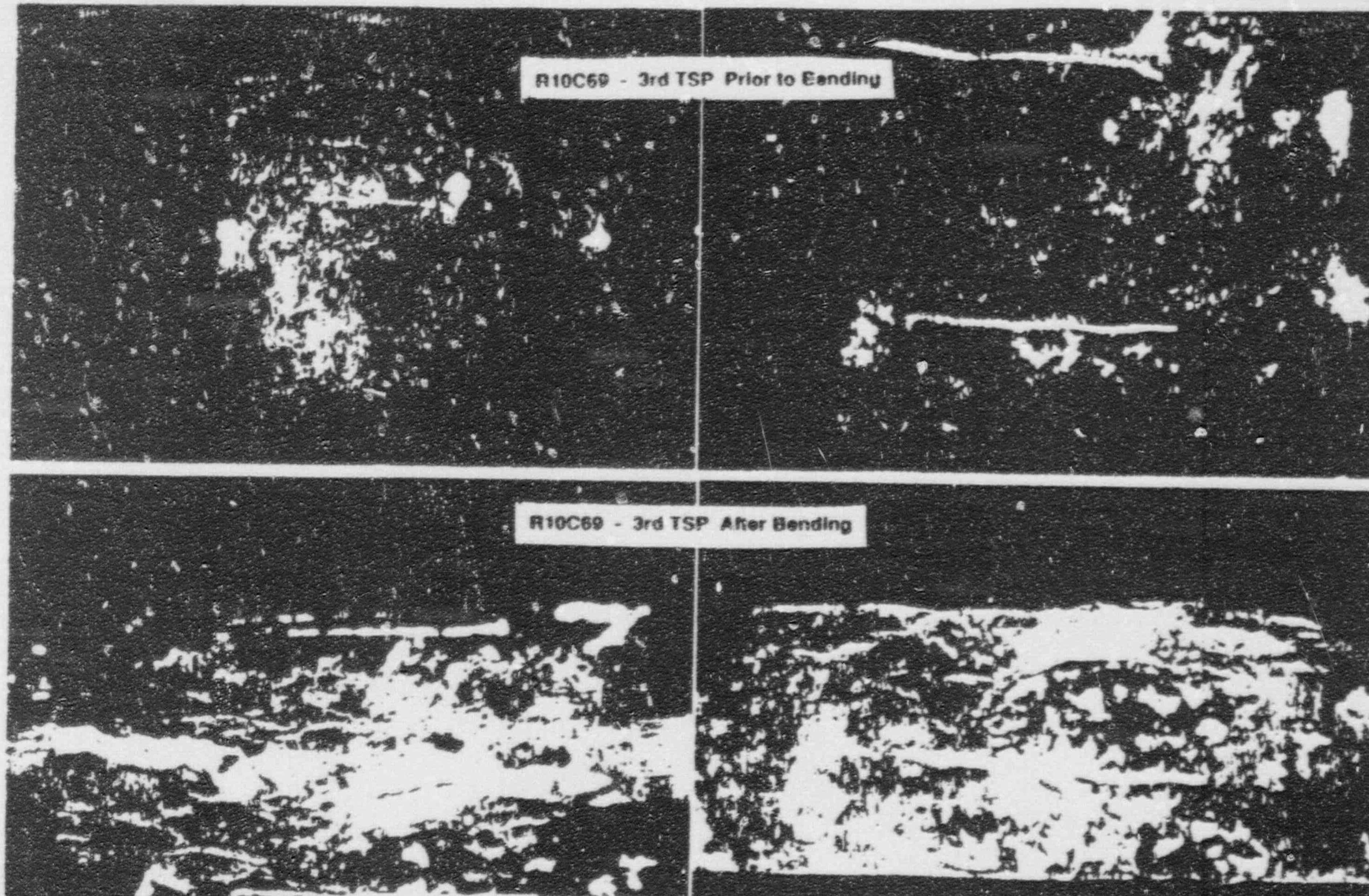


F92-163 60X 9th Grind



F92-164 60X 9th Grind

METALLOGRAPHY RESULTS ON 5-112-8B-2B



Photographs of Crack Opening After Burst Test - R10C69, 3rd TSP

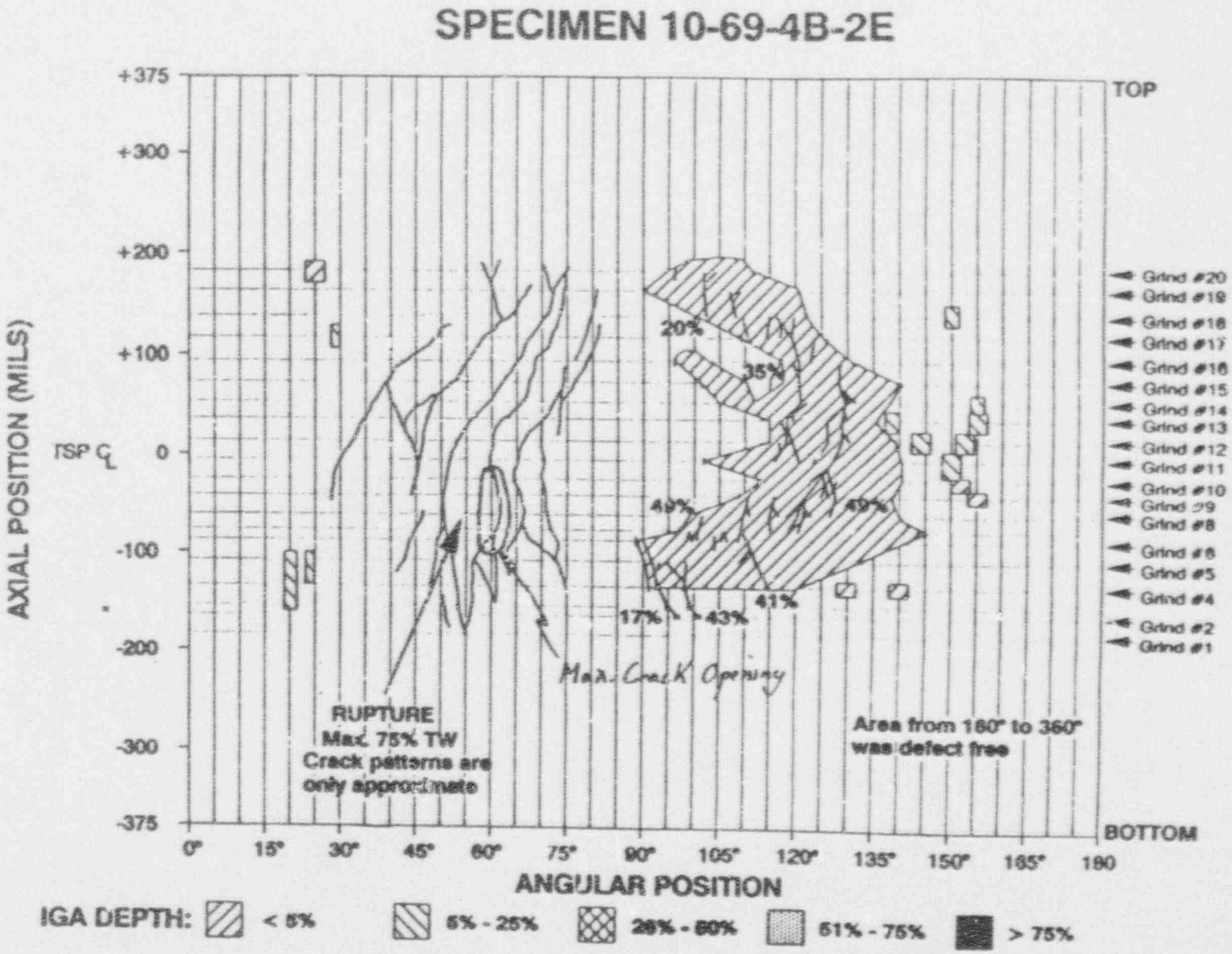
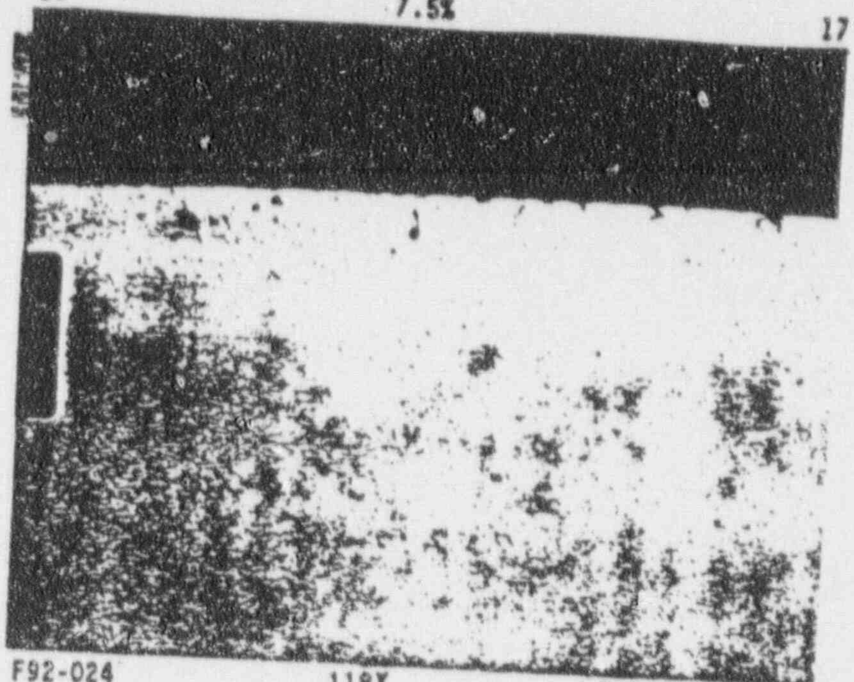
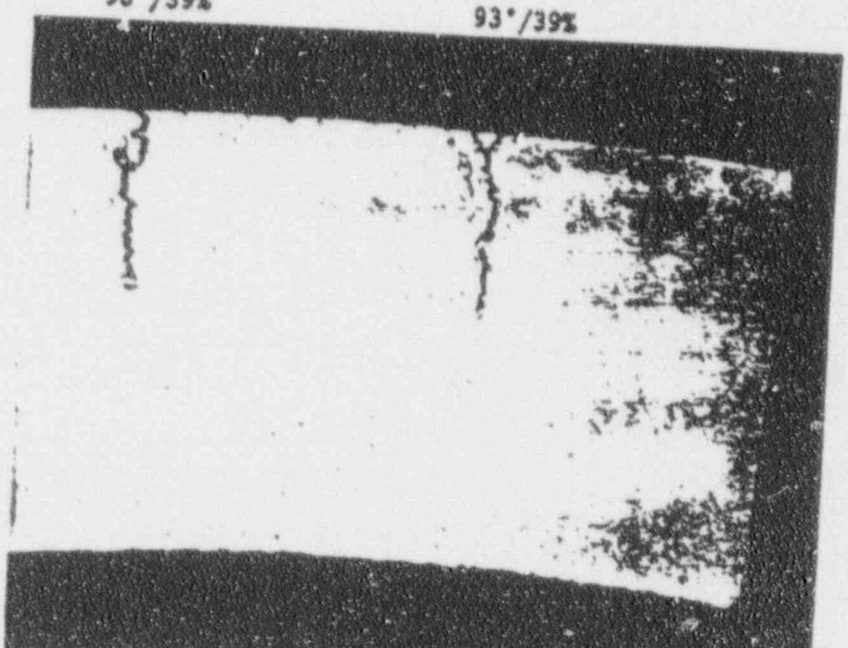


FIGURE 2-61: SUMMARY OF INCREMENTAL GRIND AND POLISH RESULTS ON SPECIMEN 10-69-4B-2E.

IGA Patch



F92-024 118X 3rd Grind, 20°



F92-036 60X 4th Grind, 95°

Specimen 10-69-4B-2E

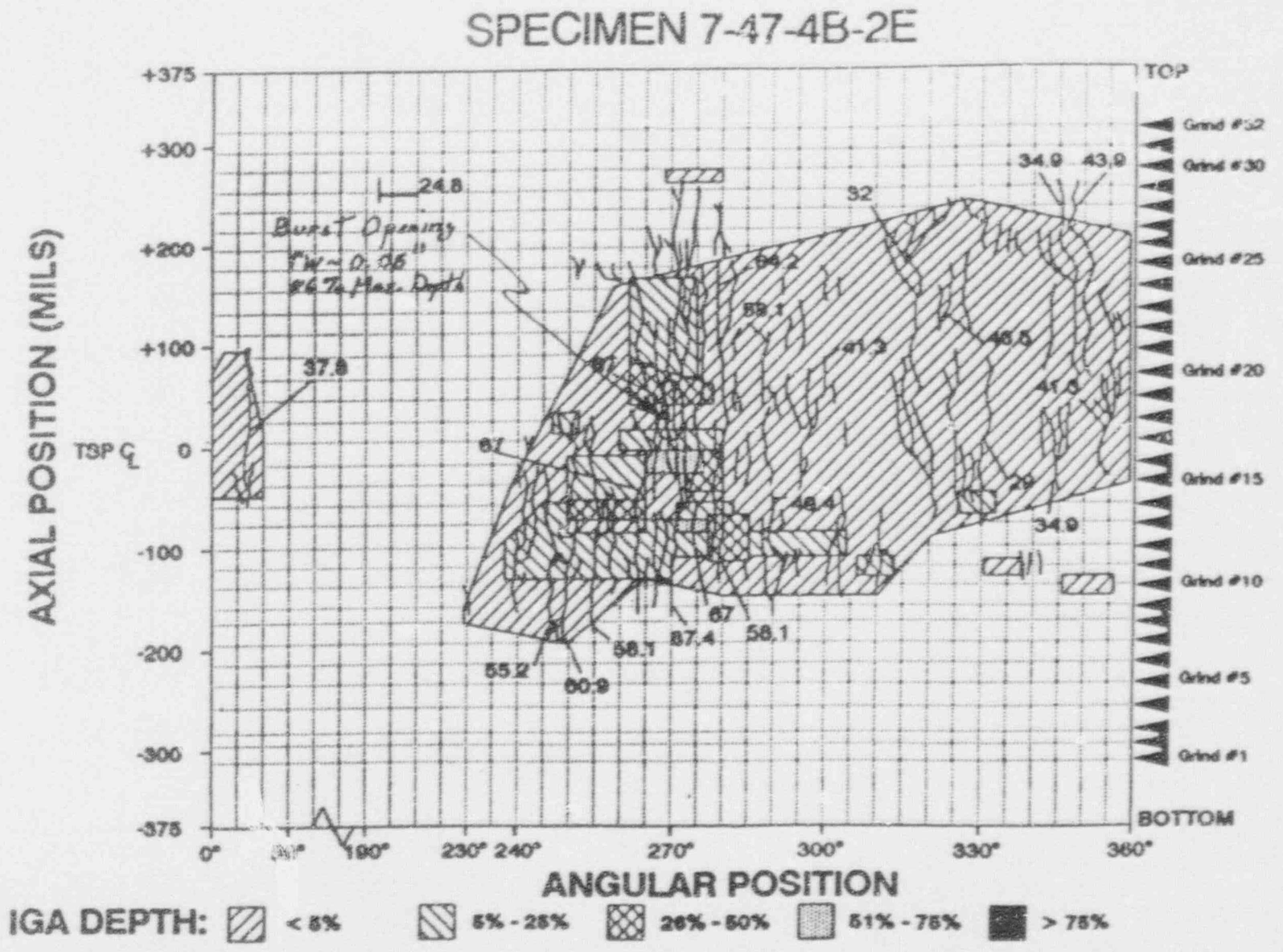
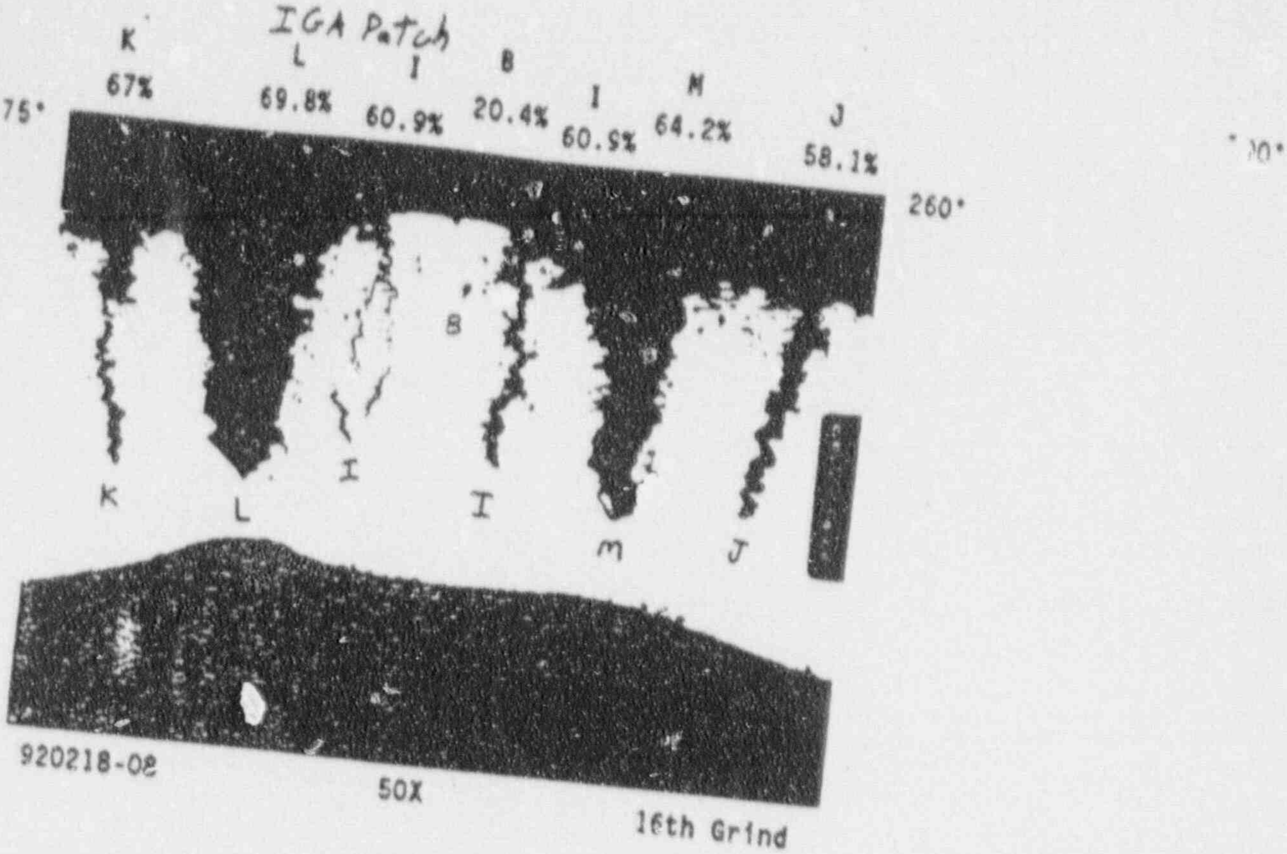
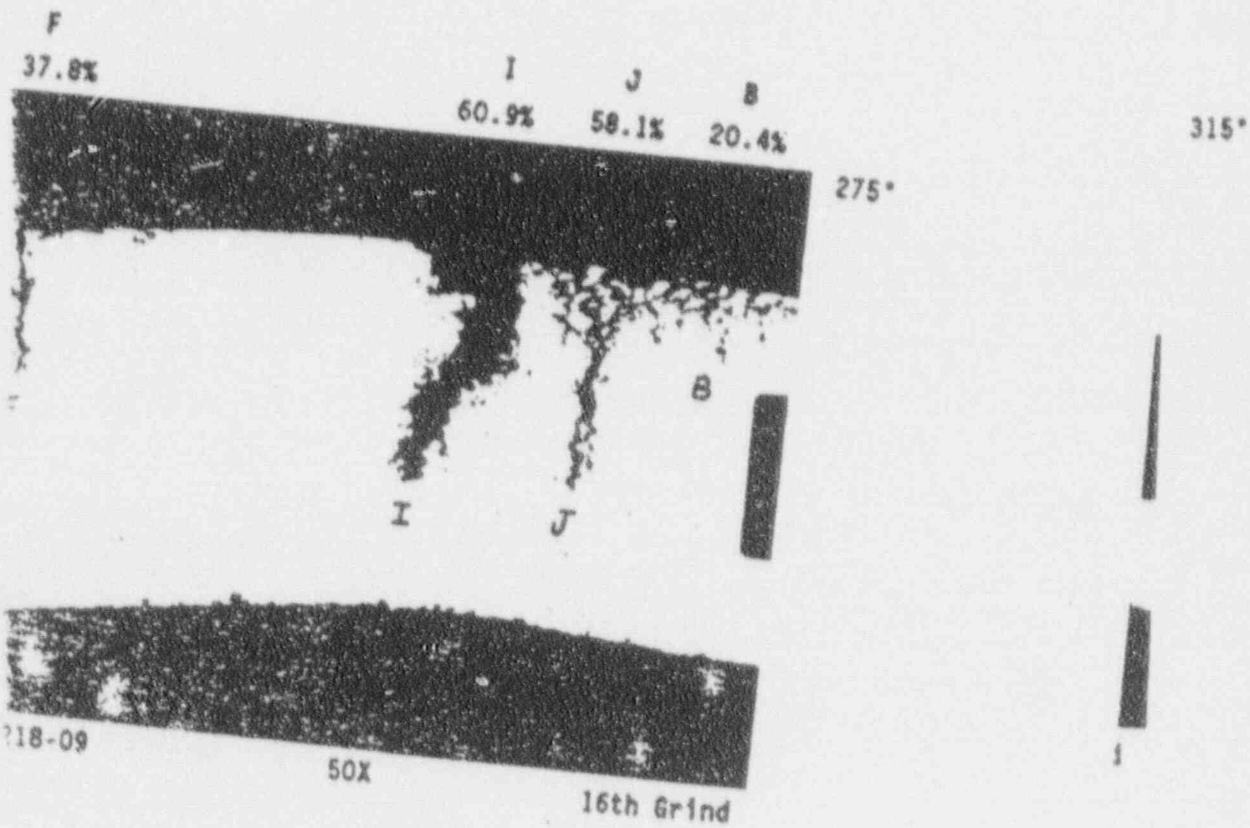


FIGURE 2-62: SUMMARY OF INCREMENTAL GRIND AND POLISH RESULTS ON SPECIMEN 7-47-4B-2B.





SPECIMEN 7-47-4B-2E

Catawba-1 Pulled Tube Crack Morphology

Multiple axial ODSCC

- Ligaments present between microcracks

Minor IGA: Negligible volumetric involvement

Degradation lengths <0.5 inch approximately centered in TSP

Significant parallel axial cracks over ~90° to 150°

Table A.4-5. Summary of Catawba-1 Pulled Tube Results

		West.Field Data Eval.			Lab	Destructive Exam				
		Bobbin		RPC	Post-Pull	Max.		Burst	Leak Rate l/hr	
Tube	TSP	Volts	Depth	Volts	B.C.Volts	Depth	Length	psi	Norm.Op.	SLB
R5C112	2	0.48	-0%		0.37	Superficial		10,880	0.0[3]	0.0[3]
	3	1.82	86%	1.30	5.06	97%[4]	0.50"	N.R.[1]	0.078	0.56
R10C6	2	1.46	83%	0.98	2.07	72%	0.40"	7,100	0.0[3]	0.0[3]
	3	1.31	76%	1.20	5.34	85%	0.43"	5,740	0.0[3]	0.0[3]
R10C69	2	NDD			NDD	None		10,340	0.0[3]	0.0[3]
	3	1.48	72%	0.97%	3.31	75%	0.45"	N.R.	0.0[3]	0.0[3]
R20C46	2	0.42	30%		0.82	12%	0.05"	N.R.	0.0[3]	0.0[3]
	3	0.79	28%		1.04	-0%		N.R.	0.0[3]	0.0[3]
R7C47	3	1.57	78%	1.40	4.13	85%	0.42"	N.R.	0.0[3]	0.0[3]

Notes:
1. N.R. = Not Reliable, See Table A4-4.
2. N.D. = Not determined.
3. No leak identified during room temperature pressurization tests.
4. Crack opening for leakage may have resulted during tube pull.

3/4" Pulled Tube Data Base Summary

Plant	No. Tubes	Intersections: Burst Tested	Intersections: Leak Tested	Intersections: Destructive Exam
Catawba-1	5	4(5)[(1)]	1(8)[(2)]	9
E-4	9	7	9	13
B-1	1	1	0(1)[(2)]	5
B-2	3	0	0	11
C-2	2	0	0	42

Notes:

1) Number in parentheses represents number of additional pressurization tests performed without complete burst. Data not included in data base.
2) Number in parentheses represents room temperature pressure tests performed with no identified leakage at pressure differentials exceeding SLB conditions.

Table A.7-1. Pulled Tube Leak Rate and Burst Test Measurements
3/4 Inch Diameter Tubing

Plant	Row/Col	TSP	Bobbin Coil Volts[1]	Bobbin Coil Depth	RPC Volts	Destructive Exam Max.Depth	Destructive Exam Length[2]	Leak Rate l/hr Norm.Oper.	Leak Rate l/hr SLB	Burst Pressure
Catawba-1	R5C112	2	0.48	~0%		Superficial		---	--	10,880
		3	1.82	86%	1.30	100%	0.50	0.078	0.56	---
	R10C6	2	1.46	83%	0.98	72%	0.40	0.0[3]	0.0[3]	7,100
		3	1.31	76%	1.20	85%	0.43	0.0	0.0	5,740

Notes:
1. Voltage normalization for 550/130KHz to 2.75 volts on 20% ASME holes.
2. Maximum burst crack corrosion length in inches with throughwall length in parentheses.
3. Tested at room temperature.
4. Not measured at 550/130 KHz. Voltage renormalized from 300 KHz data.
5. Leak rates measured at room temperature conditions and analytically adjusted to operating conditions.

TAP2081A:082192

3/4" Pulled Tube Data: Bobbin Coil Voltage Vs. Maximum Depth from Destructive Exam

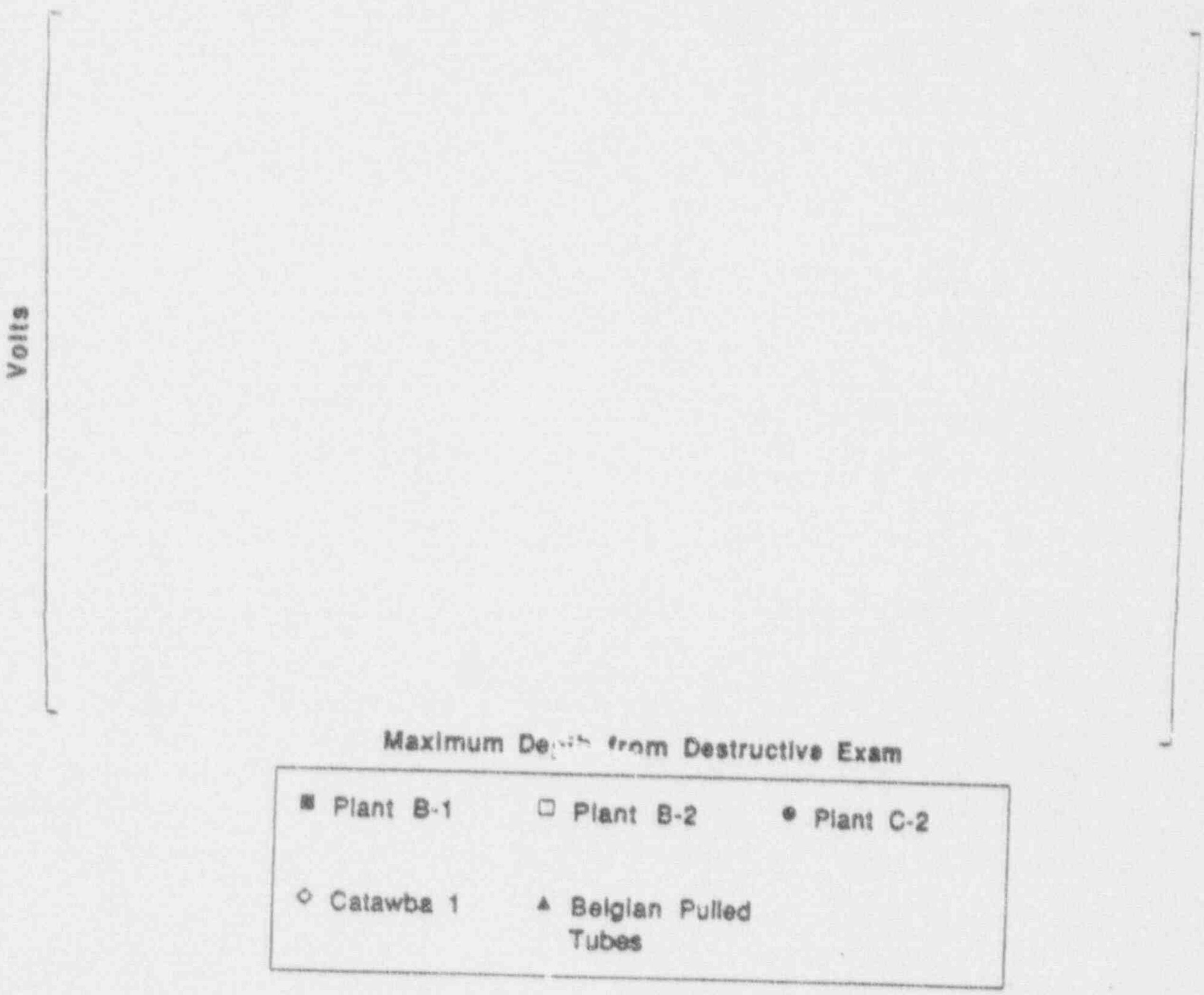


Chart 3/4" PT Volts vs. Depth 8/27/92

7/8" Pulled Tube Data: Bobbin Coil Voltage and Depth from Destructive Exam

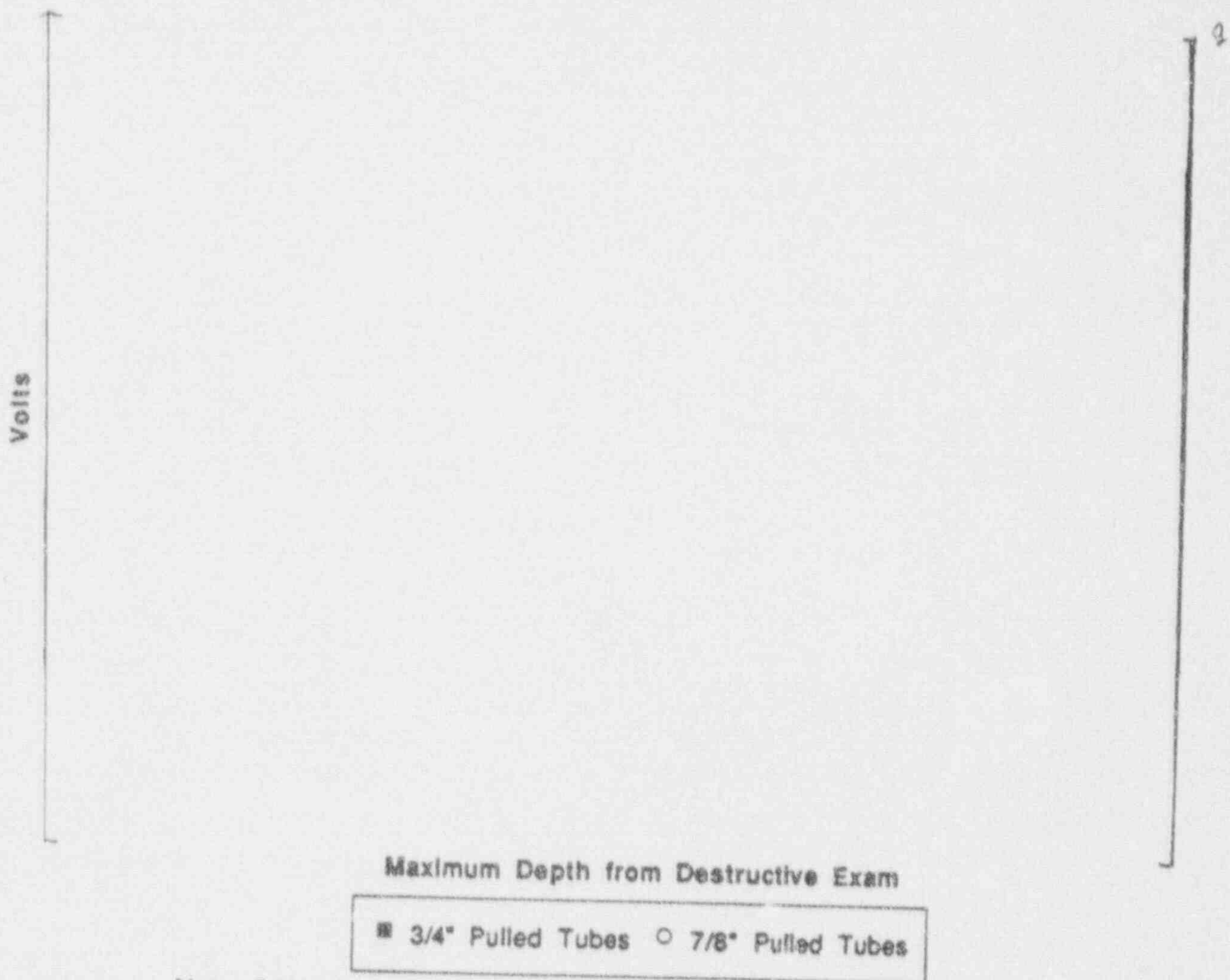
Volts

Maximum Depth From Destructive Exam

□ Plant A	△ Plant D	○ Plant L	● Plant M
▲ Plant N	+ Plant P	■ French Pulled Tubes	

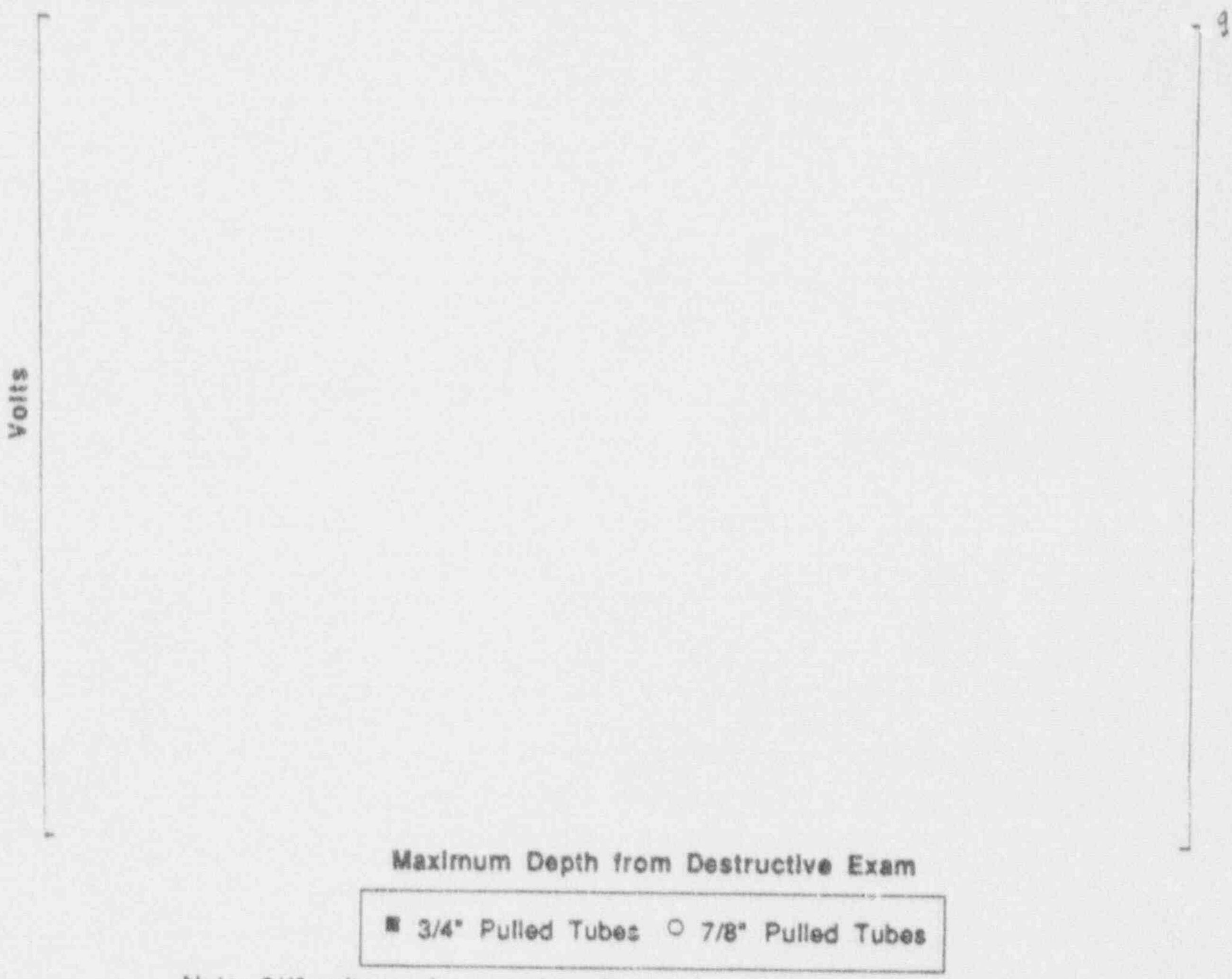
7/8" PT Volts vs. Depth 8/27/92

3/4" and 7/8" Pulled Tube Data: Bobbin Coil Voltage Vs. Maximum Depth from Destructive Exam



Note: 7/8" voltages decreased by factor of 1.36 to correspond to 3/4" tubing.

3/4" and 7/8" Pulled Tube Data: Bobbin Coil Voltage Vs. Maximum Depth from Destructive Exam



Note: 3/4" voltages increased by factor of 1.36 to correspond to 7/8" tubing.

Preliminary Umbrella LOCA + SSE Accident Analysis for Catawba Unit 1 to Determine Excluded Tubes at Wedge Group Locations

Prepared by:

R. E. Smith

8/27/92

Combined LOCA + SSE Accident Condition Analysis

Issues Relative to Interim Plugging Criterion

- Potential Exists for Permanent Deformation of Tube Support Plates (TSP) Adjacent to Wedge Groups Under Combined LOCA + SSE Loads

- Deformation of TSP Results in Corresponding Tube Ovalization in TSP Deformation Zone

- Tube Deformation can Potentially Lead to Opening of Existing Through-Wall Cracks and In-Leakage Under Post-LOCA Secondary to Primary Pressure Drop

- In-leakage is Unacceptable, as it may Cause Increase in Peak Clad Temperature

Combined LOCA + SSE Accident Condition Analysis

Analysis Objectives

- Calculate Combined LOCA + SSE TSP loads

- Determine Number of Deformed Tubes at Wedge Group Locations

- Prepare Summary Tables / Tube Maps to Identify Tubes to be Excluded from IPC

- Preliminary Evaluation Utilizes Specific SSE Analyses of Two Other Model D3 Plants that Envelope Catawba 1

Combined LOCA + SSE Accident Condition Analysis

Analysis Method

- SSE Analysis

[ ] a,c

- LOCA Analysis

[ ] a,c

- Resulting TSP Load

[ ] a,c

- Tube Deformation

[ ] a,c

a,c

MODEL D SEISMIC FINITE ELEMENT MODEL GEOMETRY

DISK 119-DCP26-8/27/95

a,c

FINITE ELEMENT MODEL FOR
LOCA TIME HISTORY ANALYSIS

DISK 119-DCP26-8/27/95

Number of Deformed Tubes as a Function of Load
Model D Steam Generator

a,b

Combined LOCA + SSE Accident Condition Analysis

Analysis Results

- SSE Analysis

[ ]a,c

- LOCA Analysis

[ ]a,c

- Number of Deformed Tubes

[ ]a,c

- Selection of Tubes to be Excluded from IPC

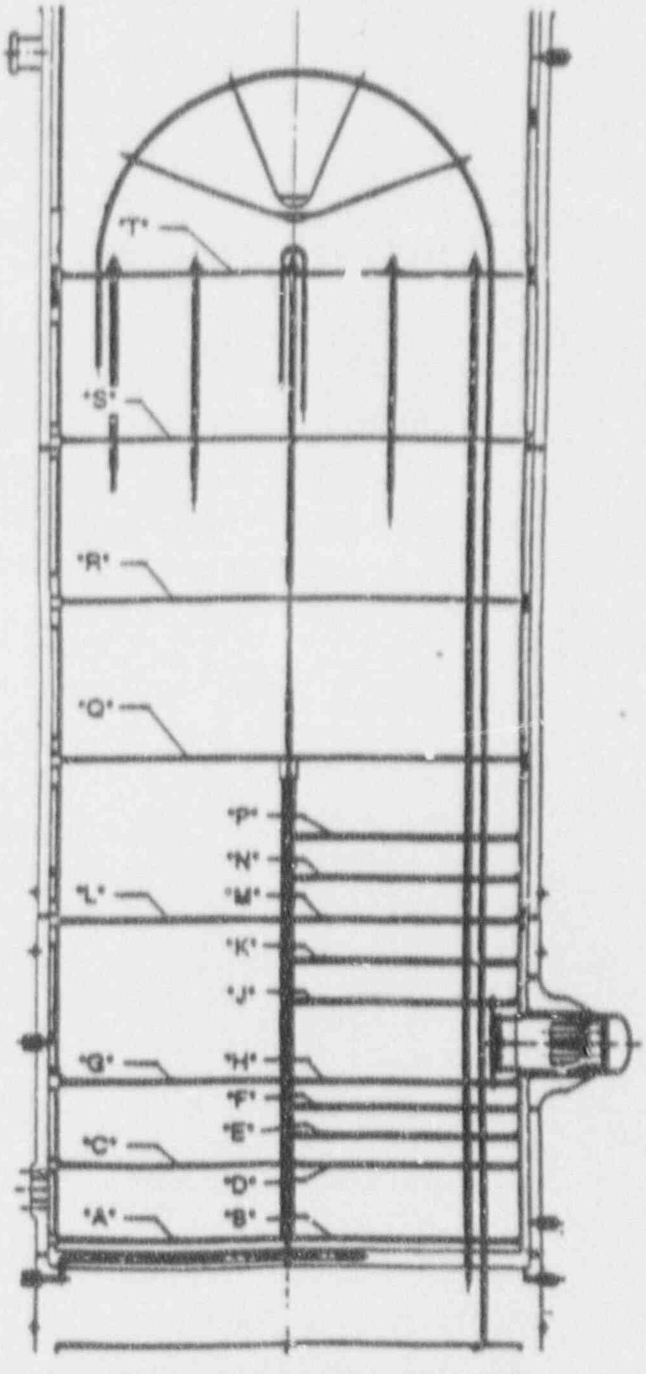
[ ]a,c

Summary of Wedge Loads
Combined LOCA + SSE Loadings

[ ] a,b

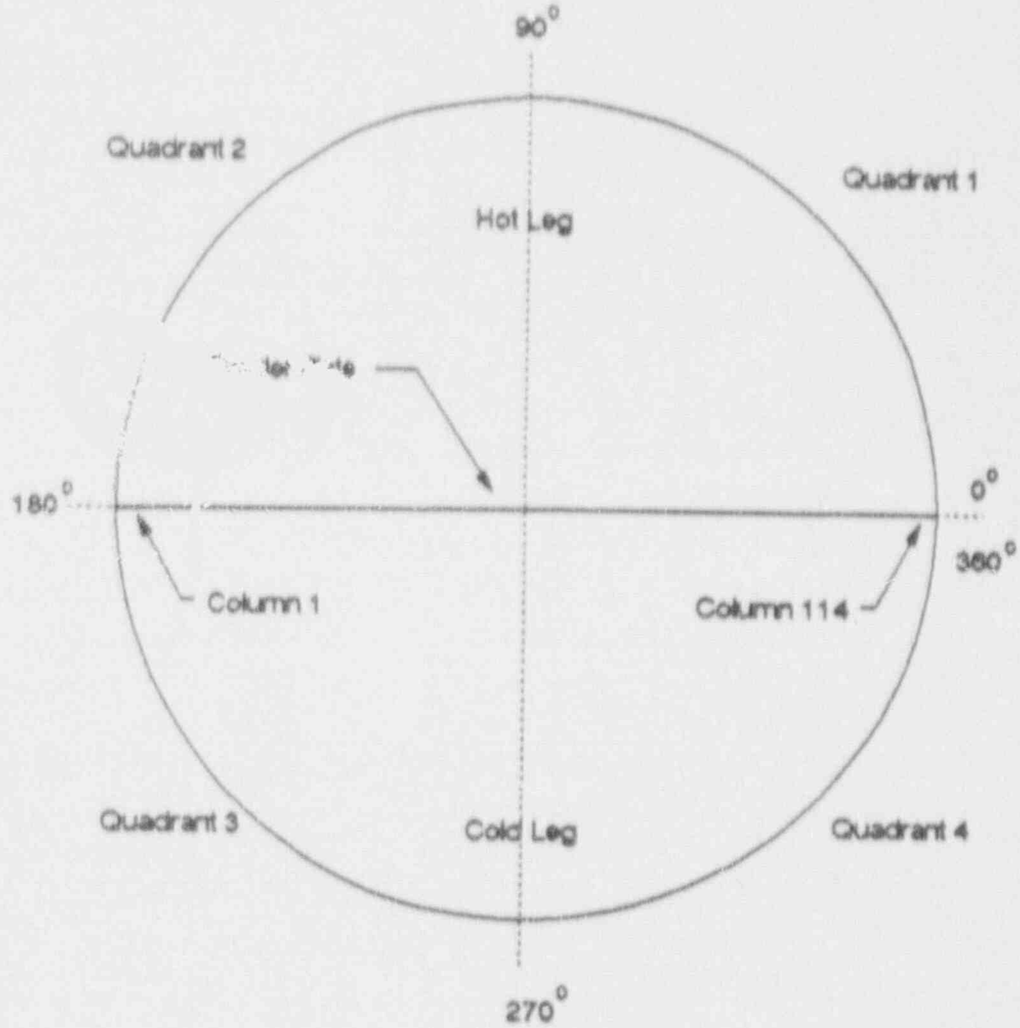
NUMBER OF DEFORMED TUBES

[ ]a



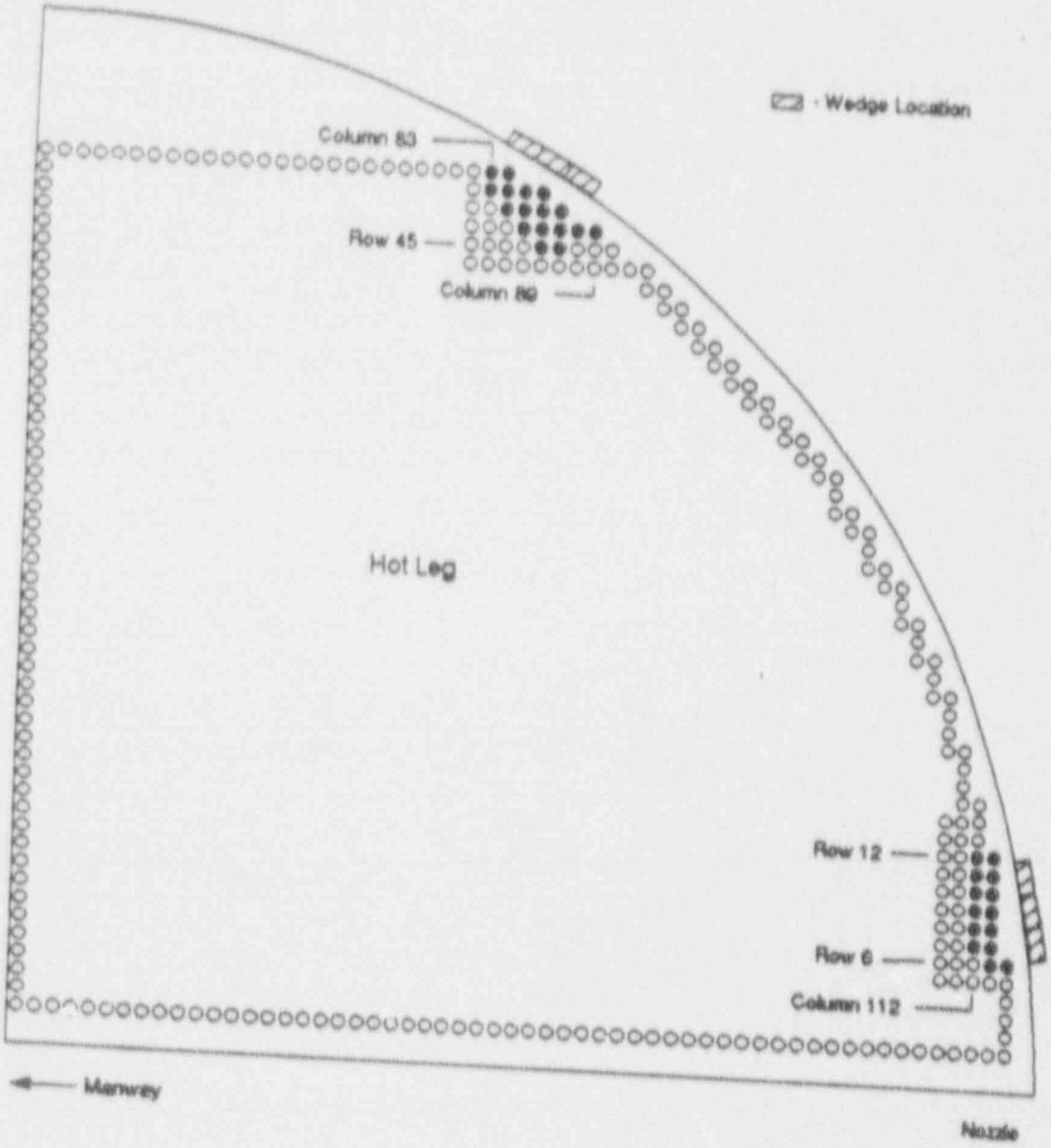
NOTE: PREHEATER MODIFICATION NOT SHOWN

TUBE BUNDLE GEOMETRY



Reference Configuration for Locating Tubes
Looking Down on Steam Generator
Catawba Site Specific Convention

DISK 119-DCP26-8/27/95

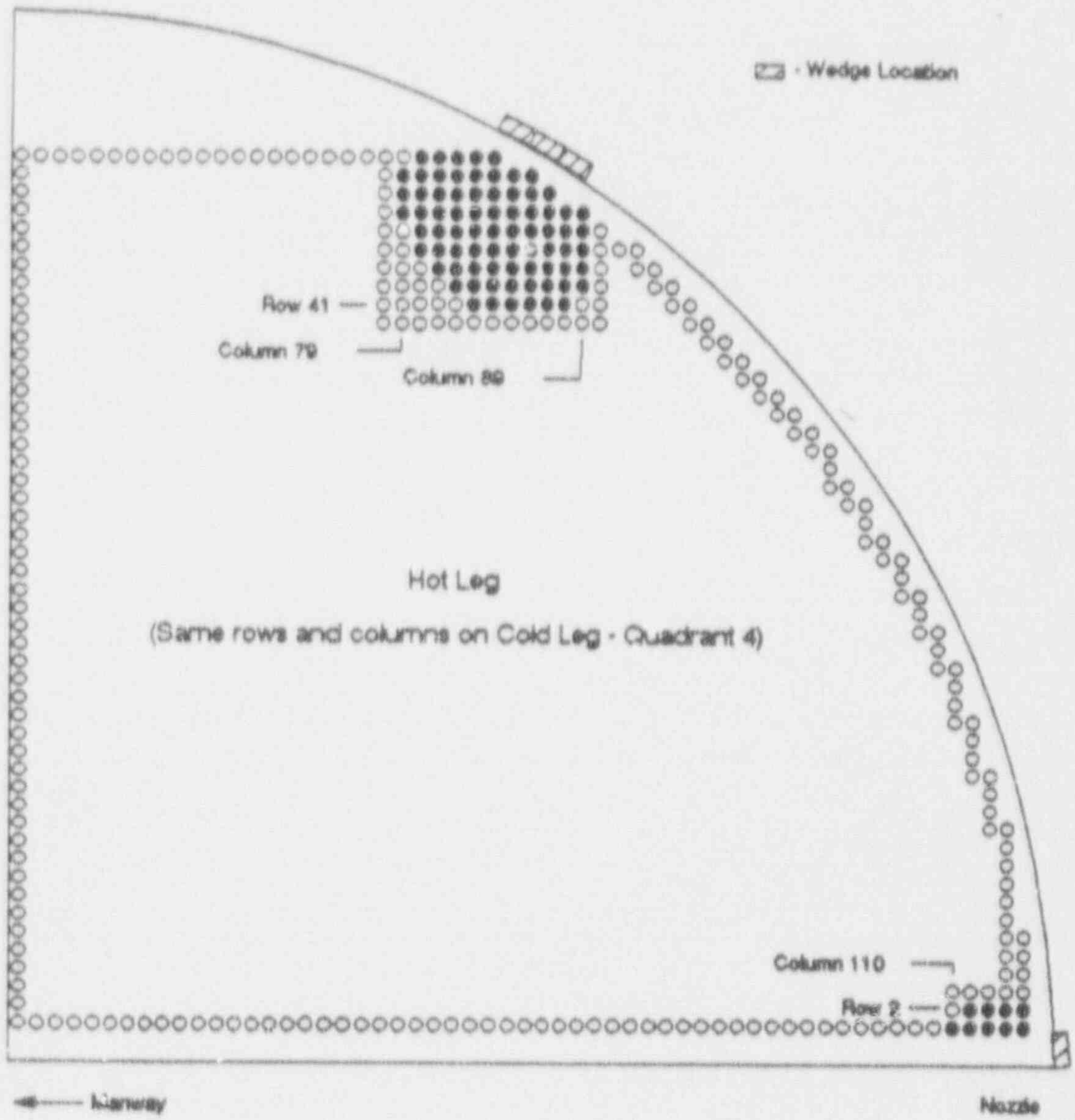


TUBES EXCLUDED FROM IPC
PLATE C - QUADRANT 1

DISK 119-DCP26-8/27/95

Summary of Tubes Excluded from IPC
Plates C/D

Hot Leg			Cold Leg		
Wedge Location	Row	Column	Wedge Location	Row	Column
[ ]a	6	113-114	[ ]a	6	113-114
	7	112-113		7	112-113
	8	112-113		8	112-113
	9	112-113		9	112-113
	10	112-113		10	112-113
	11	112-113		11	112-113
	12	112-113		12	112-113
	45	86-87		43	90-91
	46	85-89		44	89-92
	47	84-87		45	87-90
	48	83-86		46	86-89
	49	83-84		47	86-87
				48	86
	45	28-29		43	24-25
	46	26-30		44	23-26
	47	28-31		45	25-28
	48	29-32		46	26-29
	49	31-32		47	28-29
				48	29
	6	1-2		6	1-2
	7	2-3		7	2-3
	8	2-3		8	2-3
	9	2-3		9	2-3
	10	2-3		10	2-3
	11	2-3		11	2-3
	12	2-3		12	2-3



TUBES EXCLUDED FROM IPC
PLATE T - QUADRANT 1

DISK 119-DCP26-8/27/95

Summary of Tubes Excluded from IPC
Plate T

Hot Leg			Cold Leg		
Wedge Location	Row	Column	Wedge Location	Row	Column
[ ]a	1	110-114	[ ]a	1	110-114
	2	111-114		2	111-114
	41	83-88		41	83-88
	42	82-89		42	82-89
	43	81-89		43	81-89
	44	80-89		44	80-89
	45	80-89		45	80-89
	46	79-89		46	79-89
	47	79-87		47	79-87
	48	79-86		48	79-86
	49	80-84		49	80-84
	40	30-32		40	30-32
	41	29-34		41	29-34
	42	28-35		42	28-35
	43	27-36		43	27-36
	44	27-36		44	27-36
	45	27-35		45	27-35
	46	27-35		46	27-35
	47	28-34		47	28-34
	48	29-34		48	29-34
	49	31-33		49	31-33
	1	1-4		1	1-4
	2	1-4		2	1-4
	3	2-3		3	2-3

CATAWBA 1
TUBE ODSCC AT TSP'S

PRELIMINARY BURST AND LEAK RATE CONSIDERATIONS 3/4 x 0.043 INCH TUBING

- Burst Strength Vs Bobbin Voltage
- Single Crack Leak Before Break
- SLB Leak Rate Vs Bobbin Voltage

3/4" TUBING
BURST PRESSURE- BOBBIN VOLTAGE
REGRESSION ANALYSIS

SECOND ORDER REGRESSION

- BURST PRESSURE VERSUS LOG (VOLTS)
- 57 DATA POINTS FROM PULLED TUBES AND MODEL BOILER SAMPLES - ROOM TEMPERATURE TESTS
- THE MEAN CORRELATION:

  [ ]a

- THE -95% PROBABILITY PREDICTION INTERVAL:

  [ ]a

  WHERE

  [ ]a

- THE -95% PROBABILITY CURVE WITH LOWER TOLERANCE LIMIT (LTL) STRENGTH PROPERTIES AT OPERATING TEMPERATURE IS OBTAINED BY SCALING 0.848

Burst Pressure Versus Bobbin Voltage

Burst Pressure, ksi

Bobbin Voltage, Volts

SPW.T340.848

Burst Pressure Versus Bobbin Voltage

a

Burst Pressure, ksi

Bobbin Voltage, Volts

BPVLT34C.DWG

7/8" AND 3/4" (SCALED) TUBING BURST PRESSURE- BOBBIN VOLTAGE REGRESSION ANALYSIS

SECOND ORDER REGRESSION

- BURST PRESSURE VERSUS LOG (VOLTS)

- 119 DATA POINTS FROM PULLED TUBES AND MODEL BOILER SAMPLES - ROOM TEMPERATURE TESTS (3/4" DATA SCALED)

- THE MEAN CORRELATION:

  [ ][a]

- THE -95% PROBABILITY PREDICTION INTERVAL:

  [ ][a]

  WHERE

  [ ][a]

- THE -95% PROBABILITY CURVE WITH LOWER TOLERANCE LIMIT (LTL) STRENGTH PROPERTIES AT OPERATING TEMPERATURE IS OBTAINED BY SCALING BY 0.857.

Burst Pressure Versus Bobbin Voltage

Burst Pressure, ksi

Bobbin Voltage, Volts

8PVL173H.BNB

Leakage Rate Calculation

Axial Crack Flow Model
(CRACKFLO)

Assumptions

[ ]a,c

Leakage Rate Calculation

Axial Crack Flow Model
(CRACKFLO)

Fluid and Pressure Drop Characteristics

a,c

LEAKAGE RATE CALCULATION

AXIAL CRACK FLOW MODEL
(CRACKFLO)

AXIAL CRACK OPENING AREA MODEL

a,c

Leakage Rate Calculation

Axial Crack Flow Model
(CRACKFLO)

Solution Procedure

a,c

LEAKAGE RATE CALCULATION

COMPARISON WITH EXPERIMENTAL RESULTS

NORMAL PLANT OPERATION

- IN GENERAL, MODEL YIELDS A GOOD PREDICTION FOR THE TREND OF LEAK RATE WITH CRACK LENGTH.

- EXCELLENT AGREEMENT BETWEEN PREDICTED AND MEASURED LEAK RATES IS SHOWN FOR FATIGUE CRACKS.

- FOR STRESS CORROSION CRACKS, GREATER DATA SCATTER IS SHOWN.

  - SCC CRACKS ARE CHARACTERISTICALLY SMALL ~ 0.1" LONG
  - DIFFICULT TO DEFINE GEOMETRICALLY
  - SUSCEPTIBLE TO PLUGGING

COMPARISON BETWEEN PREDICTED & MEASURED LEAK RATES

[a,b,c]

PREDICTED LEAK RATE (GPM)

NORMAL OPERATING CONDITIONS
LEAK RATE VS AXIAL CRACK LENGTH
3/4" TUBING AT 600F AND 1250 PSI

a,c

LEAK RATE, GPM

AXIAL CRACK LENGTH, INCH

BURST PRESSURE VERSUS CRACK LENGTH

BURST PRESSURE, KSI

]g

highpCRT.wng

AXIAL CRACK LENGTH, INCH

Operating Leakage Rate Limit

Leak Before Break

Assuming 0.1 GPM Leak Rate Limit and Belgian Burst Capability

Normal Leakage Vs Crack Length

- o 3ΔP Burst Capability is Satisfied; [ ]a,c, Burst Vs Leak

-95% Leakage Vs Crack Length

- o SLB Burst Capability is Satisfied; [ ]a,c, Burst Vs Leak

3/4" Tubing
SLB Leak Rate - Bobbin Voltage
Regression Analysis

First Order Regression

- Log(Q) versus Log(V)
- Thirty-Two Data Points from
  Model Boiler Samples - SLB Conditions
- Zero Leakers Included at [ ]9
  (90% Thru Wall Penetration)
- The Mean Correlation:

  [ ]9

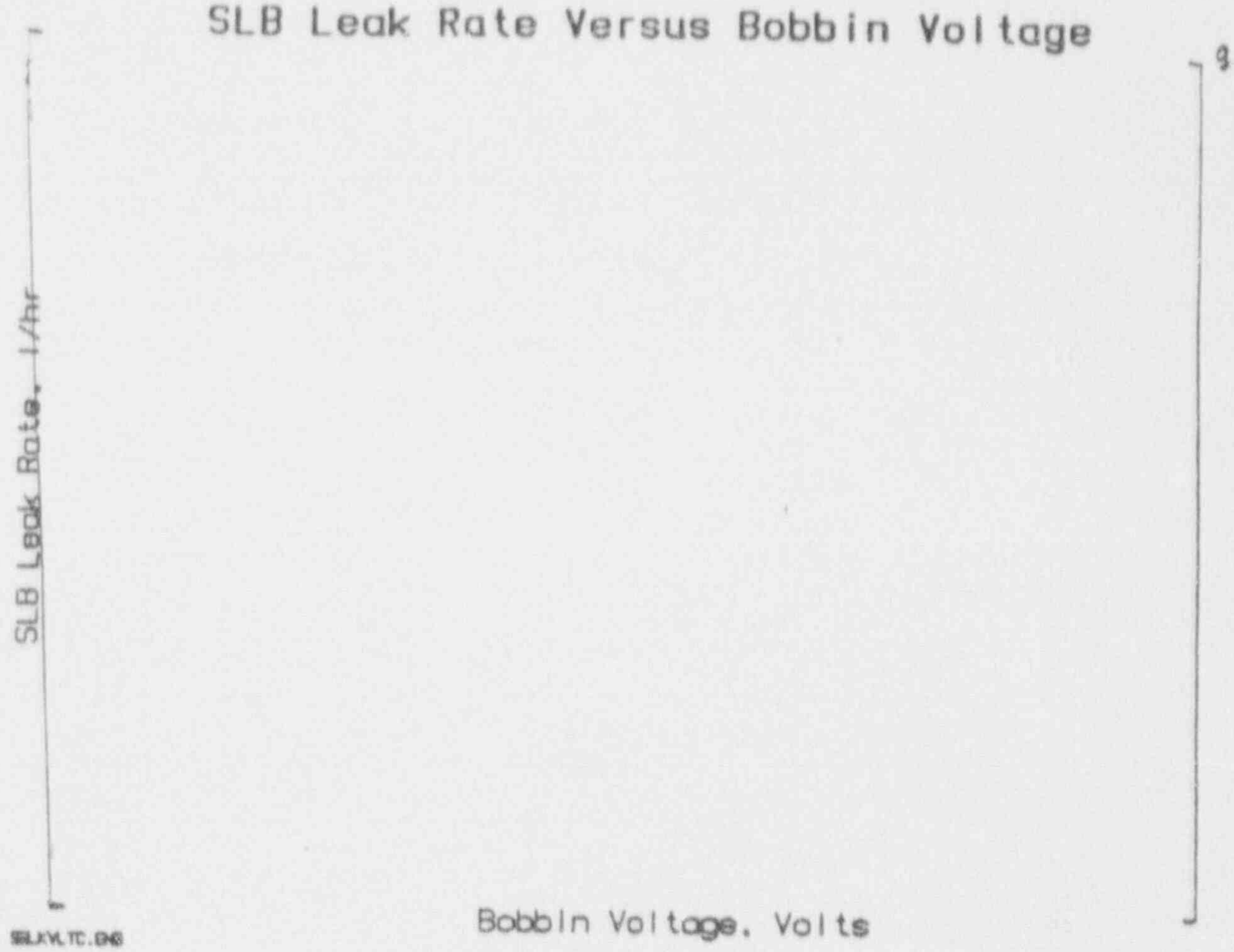
- Prediction Intervals Established using:

  [ ]9

  where $T_{X\%}$ = Students T Value

  [ ]9

SLB Leak Rate Versus Bobbin Voltage



SLB Leak Rate Vs Bobbin Voltage-3/4"

r^2=0.210475354 FitStdErr=0.83623173 Fstat=6.66462267

[ ]a

[ ]a

Log(Leak Rate, lph)

Log(Bobbin Voltage)

ALTERNATIVE LEAK RATE CORRELATIONS UNDER CONSIDERATION

- o USE A "ROBUST" REGRESSION ESTIMATOR TO IDENTIFY AND PROPERLY WEIGHT "OUTLIERS" IN THE REGRESSION ANALYSIS (LEAKERS ONLY).

  - LEAST MEDIAN OF SQUARES (LMS) APPROACH

- o ESTABLISH LEAK RATE VERSUS VOLTAGE CORRELATION FROM:

[ ] a,c

Crack Length Vs Bobbin Voltage–3/4"

r^2=0.774782077 FitStdErr=0.066331946 Fstat=41.2817274

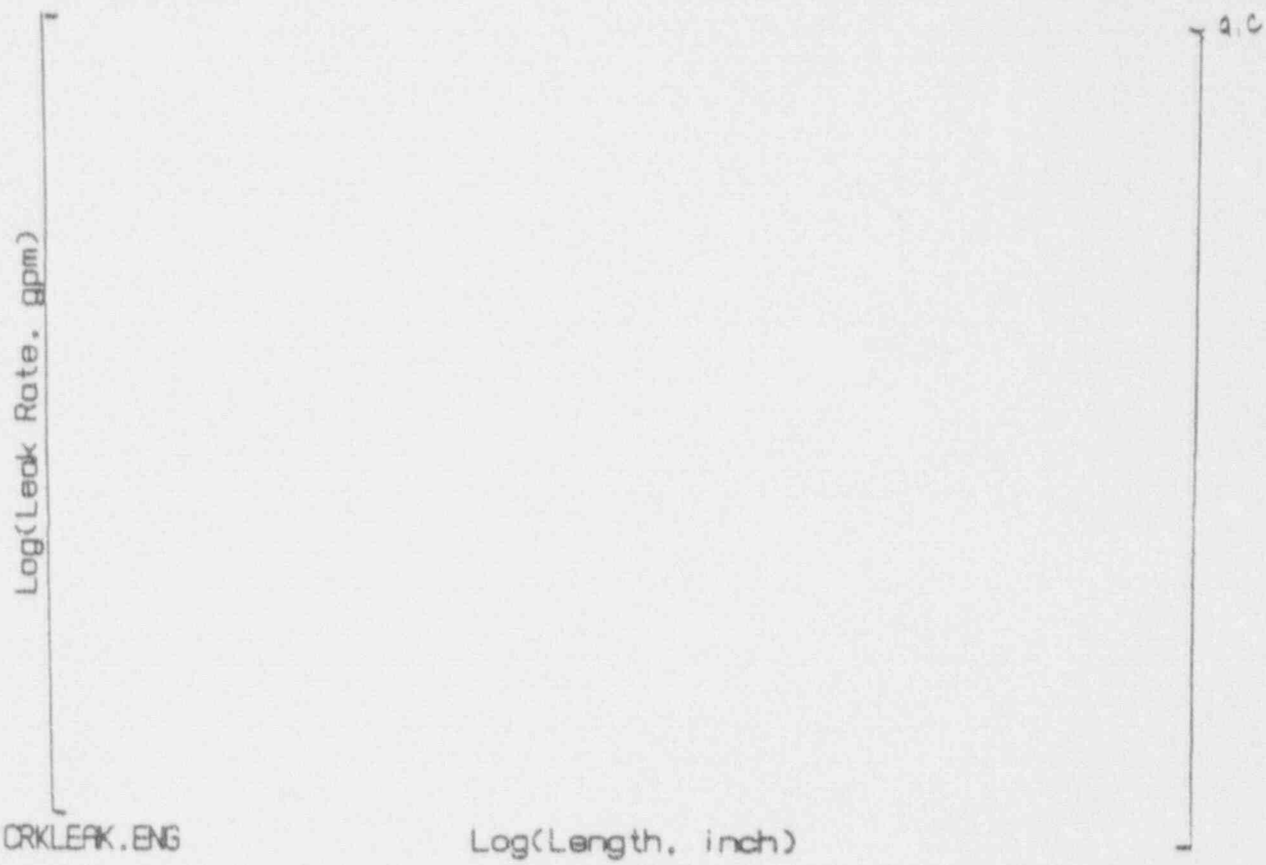
[ ]a,c

[ ]a,c

Crack Length, Inch

Bobbin Voltage

SLB Leak Rate Vs Crack Length



Leakage Rate Calculation

COMPARISON WITH EXPERIMENTAL RESULTS

STEAM-LINE BREAK CONDITIONS

- In general, the model over predicts leak rates for SLB.
- In order to improve prediction capability, empirically based adjustments are made to the model.

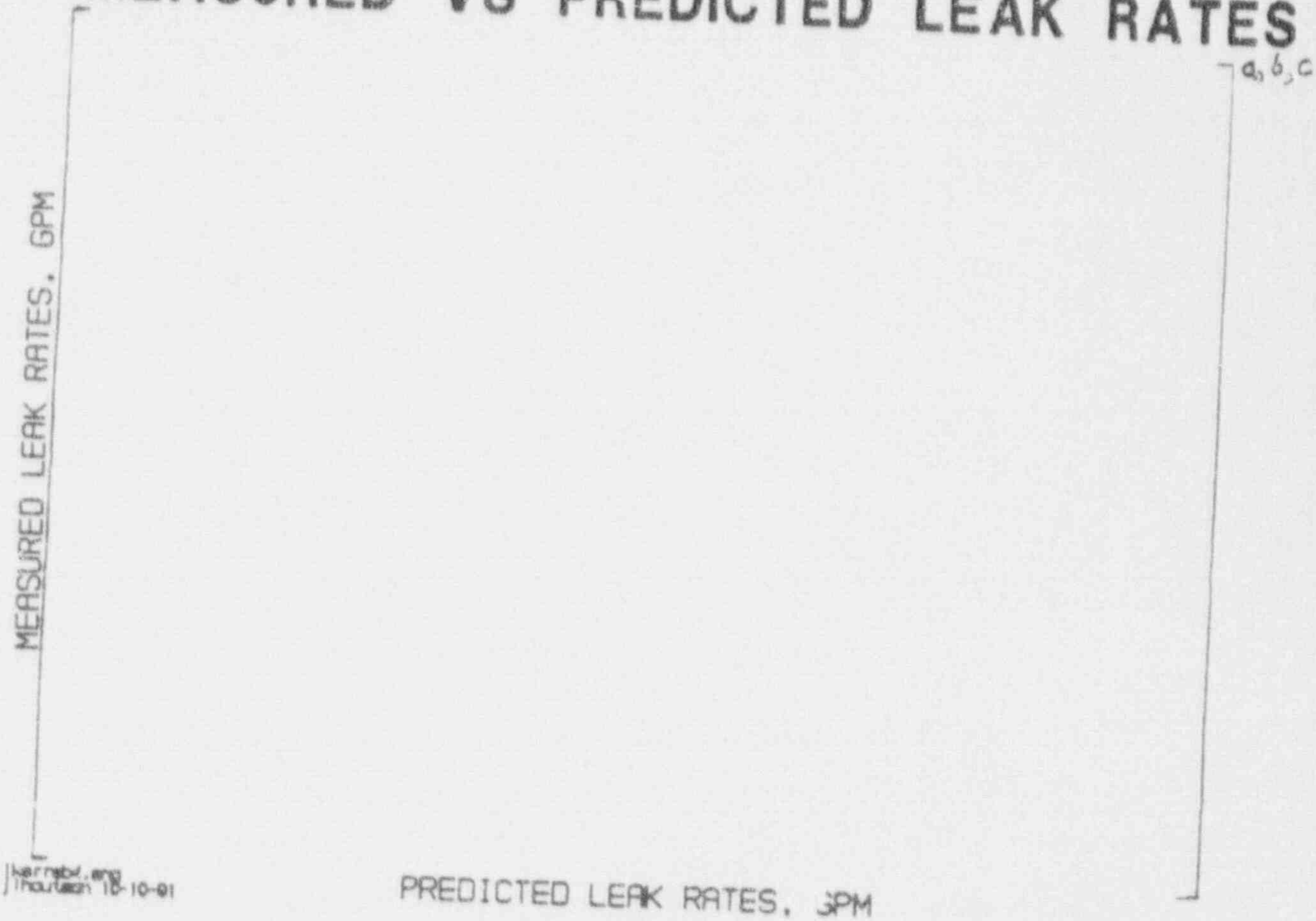
[ ] a,c

COMPARISON BETWEEN PREDICTED & MEASURED LEAK RATES

a,b,c

PREDICTED LEAK RATE (GPM)

MEASURED VS PREDICTED LEAK RATES



MEASURED VS PREDICTED LEAK RATES

a,b,c

MEASURED LEAK RATES, GPM

kerrab5.erg
lhoutman 10-10-91

PREDICTED LEAK RATES, GPM

Calculation Of SLB Q vs Voltage

[ ] a,c

Voltage (V)	Crack Length (In)	SLB Leak Rate (gpm)	SLB Leak Rate (lph)
0.1			
0.25			
0.5			
0.7			
1			
2			
3			
3.5			
5			
7			
10			
15			

a,c

SLB Leak Rate Vs Bobbin Voltage

3/4X0.043" Tubing

a,b,c

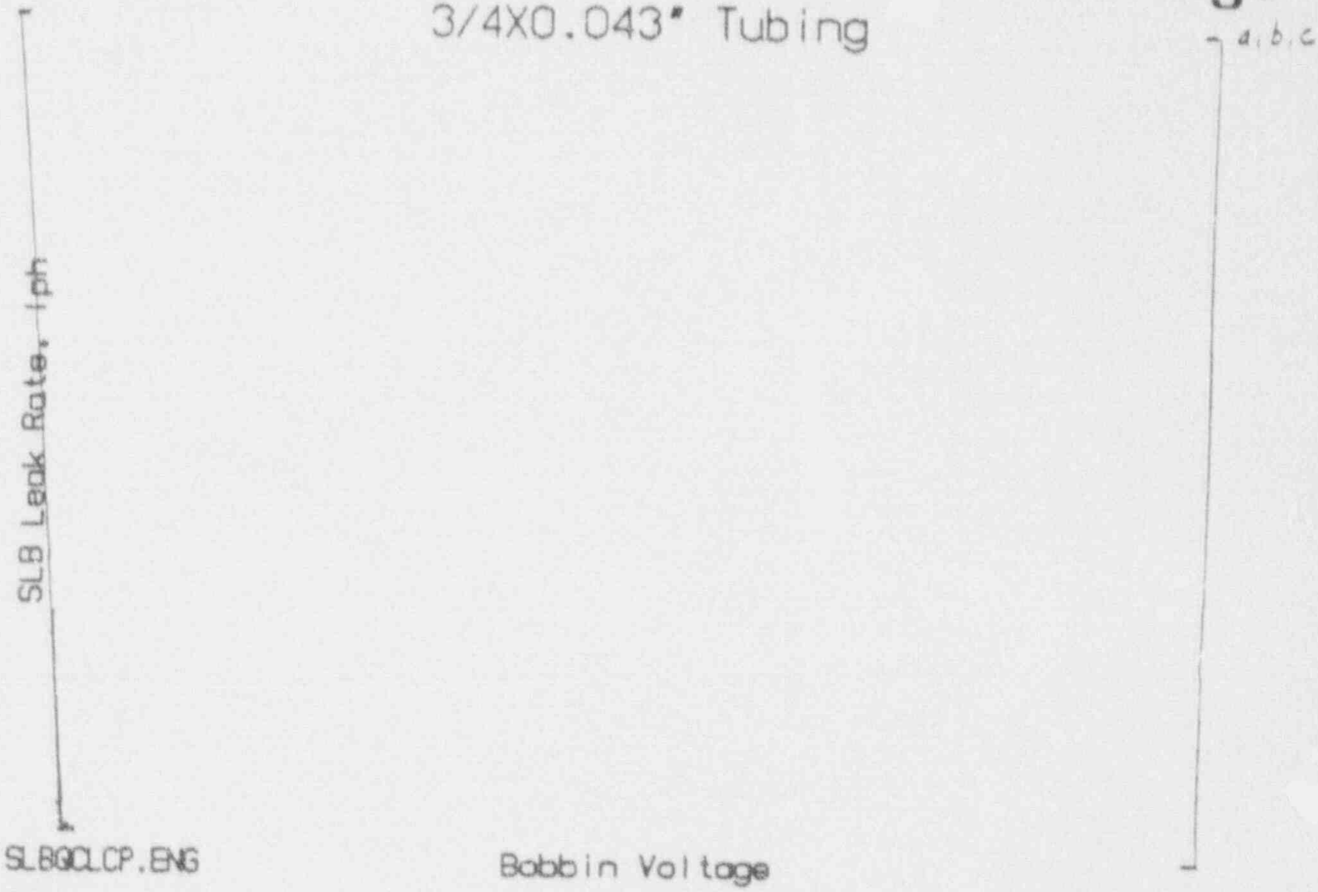
SLB Leak Rate, lph

SLBGCALC.ENG

Bobbin Voltage

SLB Leak Rate Vs Bobbin Voltage

3/4X0.043" Tubing



SLB Leak Rate Vs Bobbin Voltage

3/4X0.043" Tubing

a,b,c

SLB Leak Rate, lph

SLBGCLC1.ENG

Bobbin Voltage

SLB Leak Rate Vs Bobbin Voltage

3/4X0.043" Tubing

a,b,c

SLB Leak Rate, lph

SLBGCLC4.ENG

Bobbin Voltage

SLB Leak Rate Vs Bobbin Voltage

3/4X0.043" Tubing

a,b,c

SLB Leak Rate, lph

SLBQCLC2.ENG

Bobbin Voltage

SLB Leak Rate Vs Bobbin Voltage

3/4X0.043" Tubing

a,b,c

SLBQCLC3.ENG

Bobbin Voltage