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WCAP-13702

SG-93-04-017

CATAWBA UNIT 1 STEAM GENERATOR TUBE INTERIM PLUGGING CRITERIA

MID-CYCLE OUTAGE ASSESSMENT PRESENTATION MATERIALS

April, 1993

WESTINGHOUSE ELECTRIC CORPORATION
Nuclear & Advanced Technology Division
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355

A meeting was held on April 1, 1993 between Duke Power Company, Westinghouse, and the NRC staff to present information pertaining to the Catawba Unit 1 steam generator tube interim plugging criterion mid-cycle outage assessment.

The following topics were discussed by Westinghouse at the meeting:

1) New information since NRC SER.

2) Steam Line Break (SLB) tube support plate displacement analyses.

3) Catawba Unit 1 pulled tube data.

4) Tube burst and leak rate correlations.

5) Summary of the interim plugging criterion margin assessment.

The presentation material provided to the NRC in support of this meeting via Westinghouse Letter Number ET-NRC-93-3851 (dated March 31, 1993) has been marked for proprietary information and is contained herein.

Westinghouse Electric Corporation
Energy Systems
Box 355
Pittsburgh Pennsylvania 15230-0355

March 31, 1993
ET-NRC-93-3851

Document Control Desk
US Nuclear Regulatory Commission
Washington, DC 20555

Attention: Mr. James E. Richardson, Director
Division of Engineering Technology

Subject: Catawba Unit 1 Steam Generator Tube Interim Plugging Criterion
Mid-Cycle Outage Assessment

Dear Mr. Richardson:

Attached is a single copy of presentation materials entitled "Catawba Unit 1 Steam Generator Tube Interim Plugging Criterion Mid-Cycle Outage Assessment" (Proprietary), which will be used at the April 1, 1993 NRC meeting.

This presentation material contains information which is proprietary to Westinghouse Electric Corporation. Accordingly, we request that this information be withheld from public disclosure.

We will comply with the requirements of 10 CFR 2.790 to provide proprietary and non-proprietary versions of the above material together with an affidavit as soon as the proprietary and non-proprietary versions have been prepared. We will submit the total required number of copies of the proprietary and non-proprietary versions of the information and the required affidavit at that time.

In the meantime, we have provided sufficient copies for your information and use. M. P. Siemien, Esq. of the NRC Office of the General Counsel, has advised Westinghouse that she concurs with this procedure.

We expect to be able to fully comply with the requirements for the proprietary and non-proprietary versions of the information and an accompanying affidavit within four weeks.

Very truly yours,

Nicholas J. Liparulo, Manager
Nuclear Safety and Regulatory Activities

DLC/cld
Enclosure

CLD262:DLC/033193

Catawba-1 IPC Evaluation
Discussion Topics

New Information Since NRC SER

Overall Conclusions

SLB TSP Displacement Analyses

- Analysis and Results
- Probability of Rupture for Potentially Exposed Crack Lengths

Pulled Tube Data

- 1992 Catawba-1 Pulled Tubes
- Final Belgian Data

Burst and Leak Rate Correlations

Summary of IPC Margin Assessment

Catawba-1 IPC Evaluation
New Information Since NRC SER

Pulled Tube Data

- 3 Tubes, Six Intersections from Catawba-1 (1992)
- Belgian Voltages Finalized by Laborelec
  - Voltages higher than assumed in 1992 IPC evaluation
  - SER assumed lower voltages than 1992 submittal

Updated Burst and Leak Rate Correlations

- Burst updated for new pulled tube data
  - $3\Delta P_{NO}$ voltage increased to 4.6 volts compared to 4.1 volts in prior submittal
- Revised SLB Leak Rate Methodology
  - New probability of leakage correlation
  - SLB leak rate correlation does not include non-leakers
- ΔP_{SLB} = 2335 psid based on risk considerations
- Refined methodology and correlations approved by EPRI ARC Committee
- Same correlations as recent V. C. Summer submittal

Catawba-1 IPC Evaluation
New Information Since NRC SER

Analyses Performed for TSP Displacements in an SLB Event for Catawba-1 Model D3 S/Gs

- Thermal-hydraulic analyses for TSP loads
- Nonlinear finite element analyses of S/G for displacements of each TSP
- Maximum displacements evaluated for probability of tube burst assuming displacement exposes a thruwall crack

Catawba-1 IPC Evaluation
Conclusions

Overall Conclusion

- Continued operation of Catawba-1 until the next scheduled refueling outage is strongly supported by the updated assessment

- RG 1.121 guidelines for tube integrity conservatively satisfied at EOC-7 for implemented IPC repair limit of 1.0 volt

- Updated margins exceed those reported in WCAP-13494, Rev. 0 supporting implementation of the IPC for Cycle 7 in 1992

CATAWBA-1 IPC EVALUATION
CONCLUSIONS

SLB TSP DISPLACEMENT ANALYSES

- MAXIMUM DISPLACEMENTS ARE <0.53 INCH EVEN UNDER CONSERVATIVE ASSUMPTIONS OF ZERO FRICTION AND NOMINAL TUBE GAPS
  - CRITICAL THRUWALL CRACK LENGTHS AT 1.4 ΔP_{SLB} = 0.57 INCH AND AT ΔP_{SLB} = 0.84 INCH

- LIMITED SLB TUBE BURST PROBABILITY OF $<7\times10^{-5}$/SG FOR CYCLE 7 AND $<8.2\times10^{-4}$ INDEPENDENT OF NUMBER OF HOT LEG INDICATIONS

- TUBE REPAIR CRITERIA FOR CATAWBA-1 SHOULD BE BASED ON LIMITING SLB LEAKAGE DUE TO NEGLIGIBLE BURST PROBABILITY FOR ODSCC INDICATIONS AT TSPS

Catawba-1 IPC Evaluation
Conclusions

Maximum EOC-7 Voltages

- EOC-7 voltages projected to be less than about 2.5 volts for indications <1.0 volt left in service
- Maximum EOC voltages comparable to or less than values following implementation of 40% depth repair limit

Catawba-1 1992 Pulled Tubes

- Voltages up to 3.5 volts span range expected at EOC-7
- Burst pressure of 5400 psi for 3.54 volt indication and higher for smaller indications
- Two indications had SLB leakage of 0.015 gpm for 3.54 volt indication and 10^{-4} gpm for 1.13 volt indication
- Crack morphology of multiple axial ODSCC with localized cellular patches is typical of that found in other pulled tubes in APC database

Catawba-1 IPC Evaluation
Conclusions

Free Span Tube Burst Considerations

- Updated burst correlations lead to equivalent APC repair limit of 3.0 volts compared to 2.5 volts for prior correlation
- EOC-7 burst capability at +90% uncertainties of about 4825 psi compared to 3750 psi for $3\Delta P_{NO}$; at +99% uncertainties of about 3830 psi compared to 2335 psi for ΔP_{SLB}

SLB Leakage

- Projected EOC-7 SLB leak rate of about 0.1 gpm compared to allowable limit of 1.0 gpm

Catawba-1 TSP Displacement Evaluation
Conservatisms in Analysis

Thermal-Hydraulic Analyses for TSP Loads

- Hot standby conditions to maximize loads
- Water level 30 inches below expected value to increase loads

Structural Analyses for TSP Displacement

- Zero friction at TSP supports and tube to TSP intersections
- Nominal tube to TSP gaps without reduction for crevice deposits
- Maximum TSP displacements at <1 second assumed to remain for typical ~20 minutes to reach maximum ΔP across tubes

TSP Loads During an SLB Event for Catawba Unit 1 SG

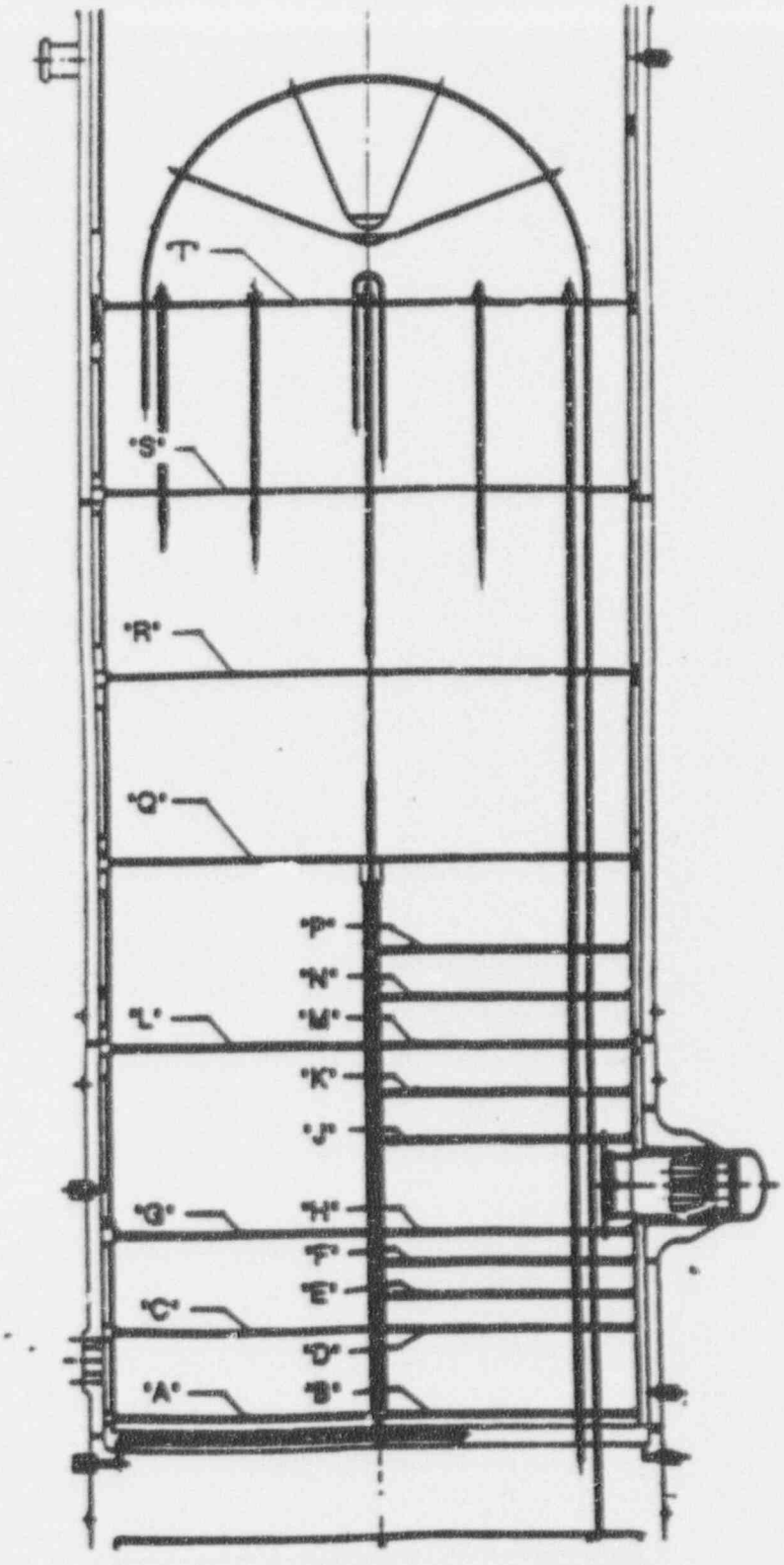
Analysis Methods

a,c

TSP Loads During an SLB Event for Catawba Unit 1 SG

Results of TSP Loads

- Blowdown flow peaks within milliseconds
- Flow through tube bundle peaks or becomes quasi-steady state within one second
- Pressure drops through TSPs (i.e., TSP loads) peaks and becomes quasi-steady state within one second



NOTE: PREHEATER MODIFICATION NOT SHOWN

Figure 8 - 1. Tube Bundle Geometry

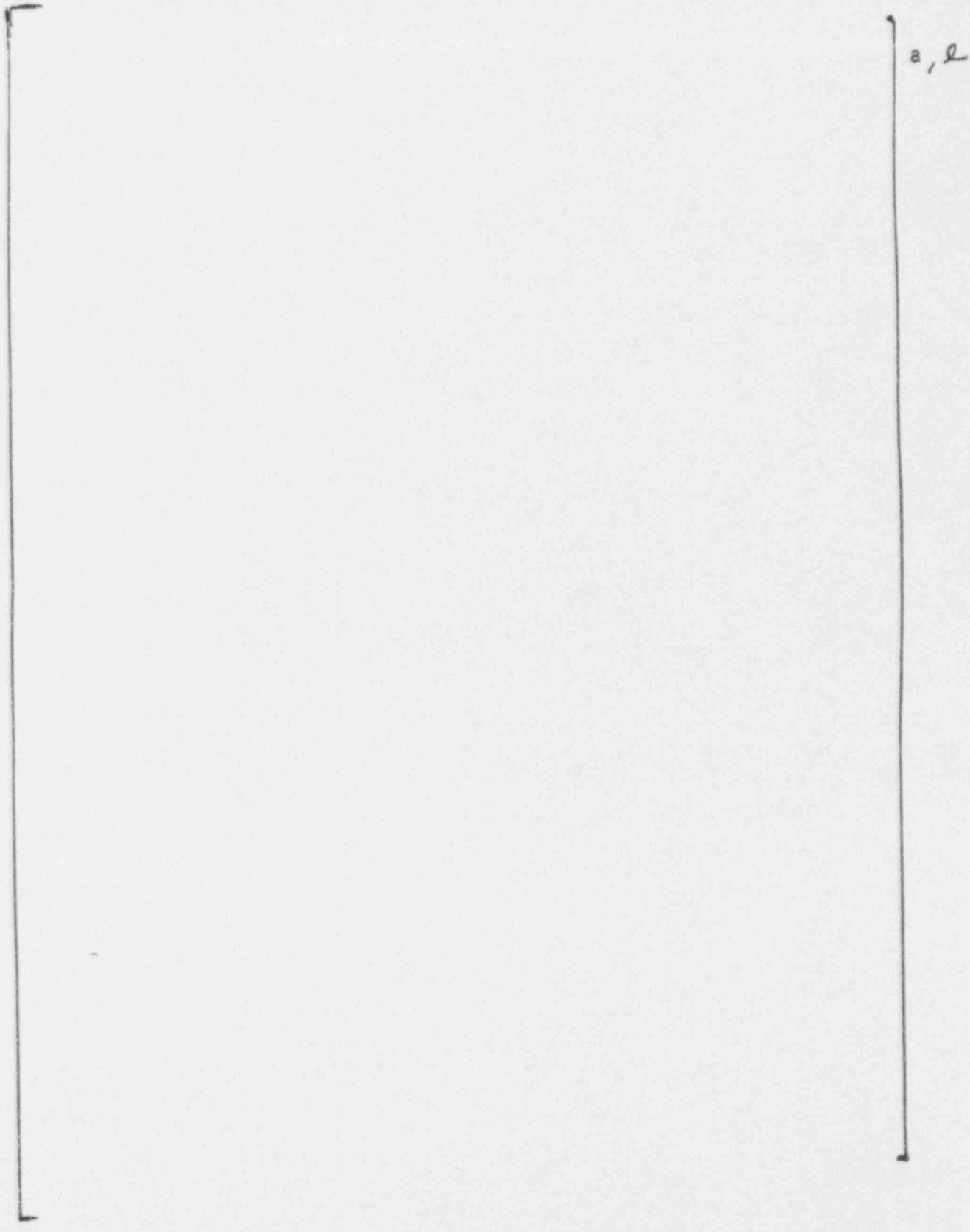


Figure 8 - 7. Pressure Drops Across Tube Support Plates C, G, and L During SLB

SLB TUBE / TSP RELATIVE DISPLACEMENTS UNDER

ANALYSIS METHODOLOGY

[a,c

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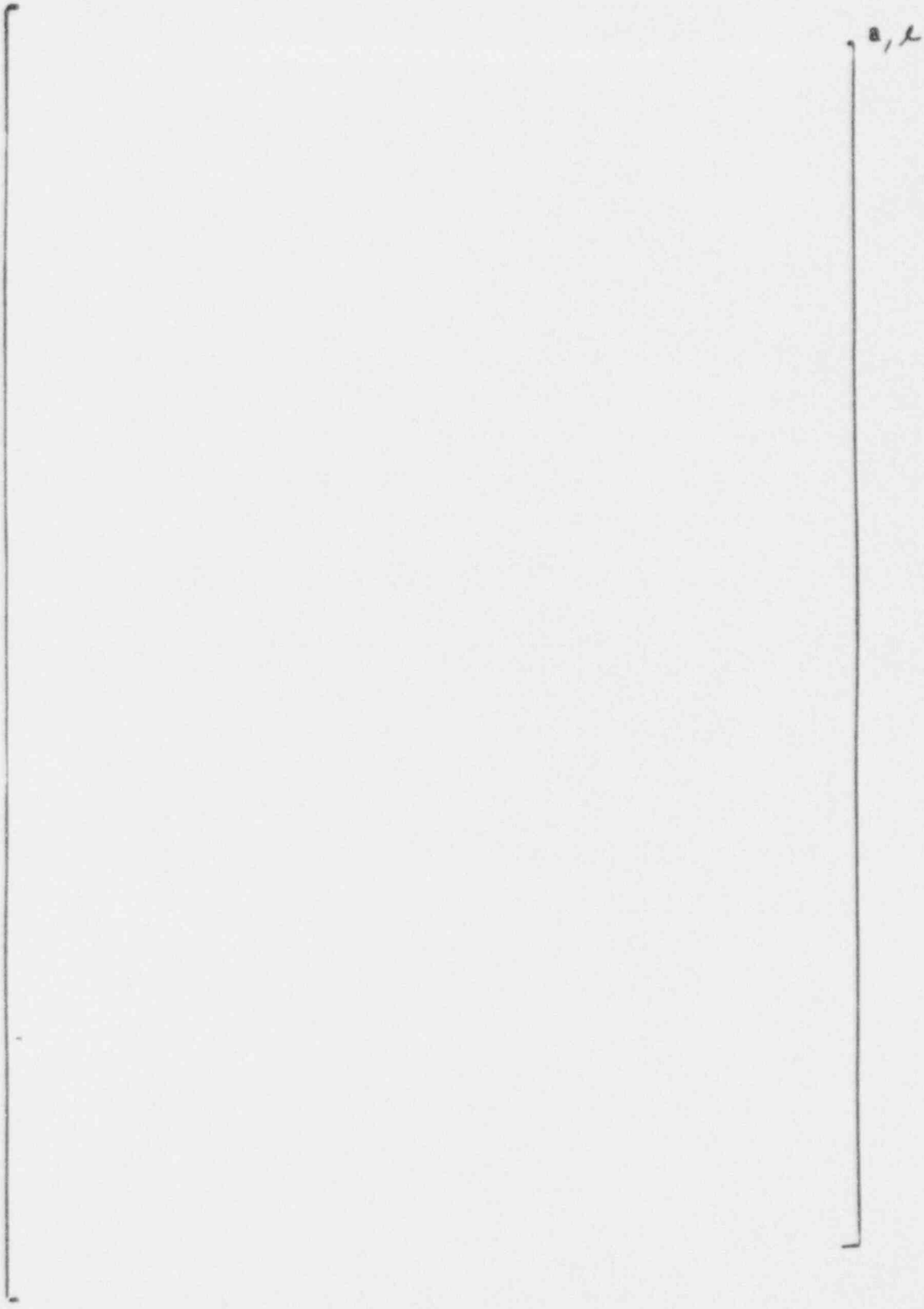
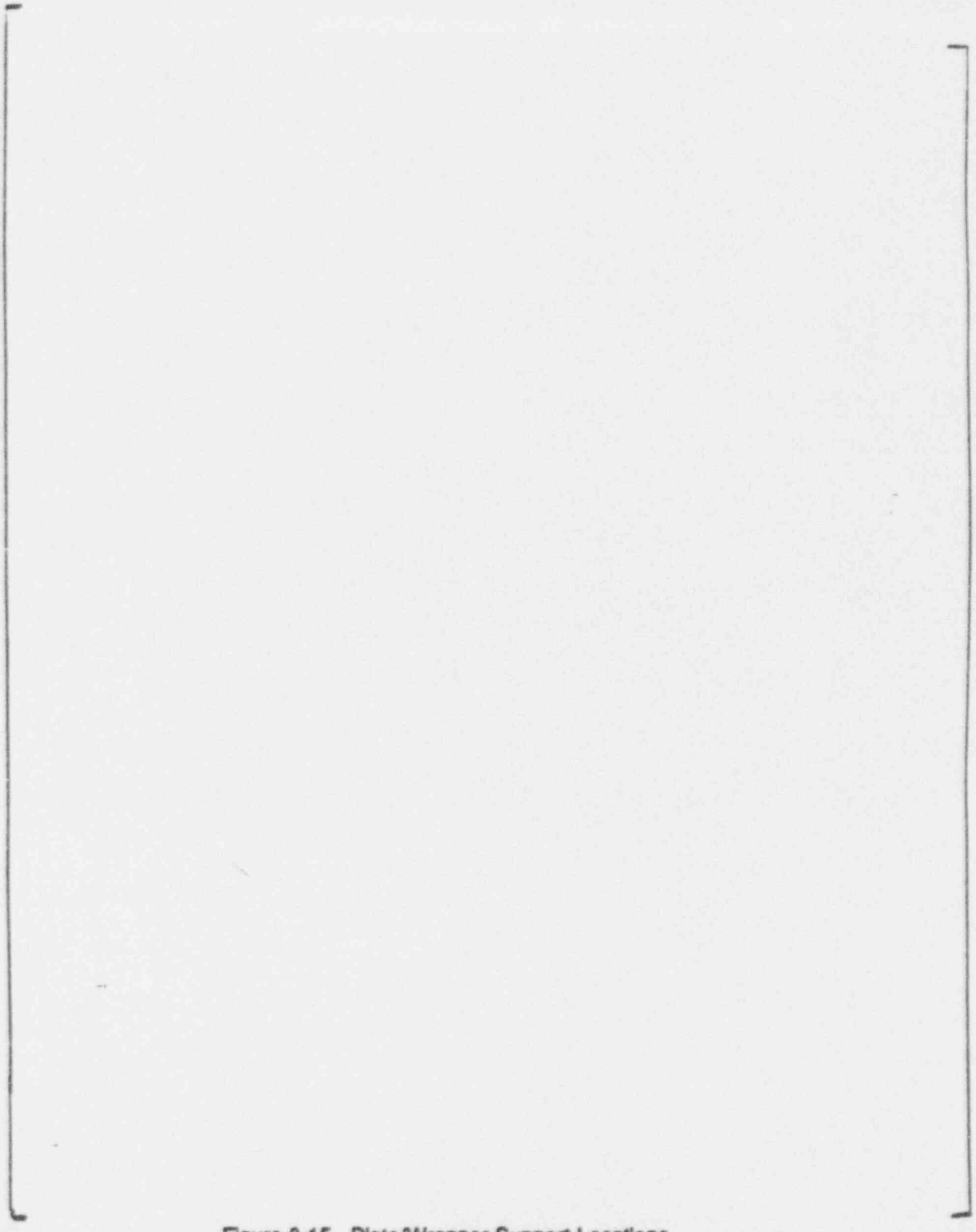


Figure 8-14. Tierod/Spacer Locations



a,c

Figure 8-15. Plate/Wrapper Support Locations
Hot Leg Plates A, C, L
Cold Leg Plates B, D, E, F, J, K, M, N, P

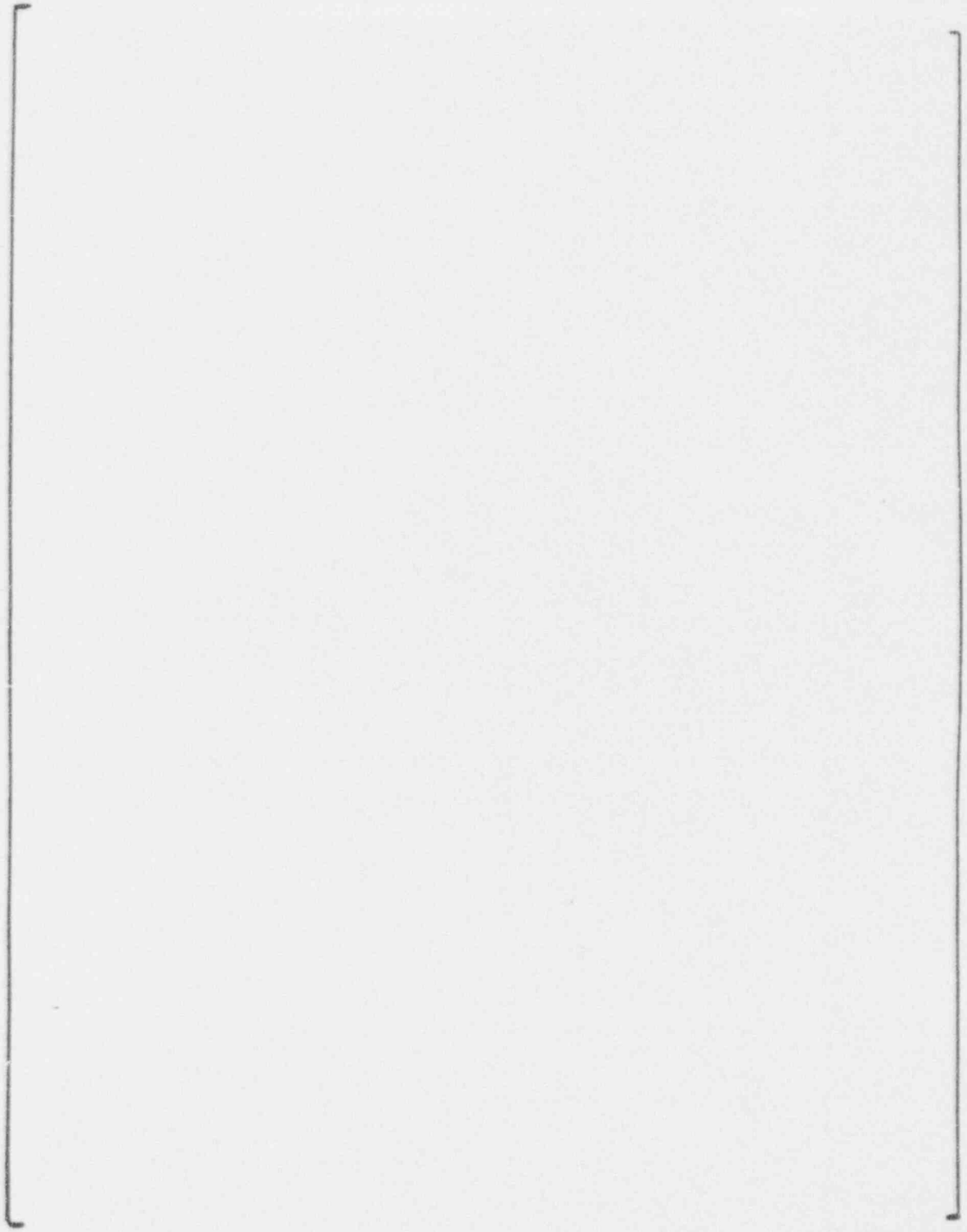


Figure 8-19. Partition Plate Support Locations for Plates C, D, G

Figure 3-9 Overall Finite Element Model Geometry

SLB Tube / TSP Relative Displacements Under

Analysis Results

Tierods Strains are Elastic

Plate Stresses are Predominantly Elastic, Local Regions Where Stresses Exceed Yield / Maximum Displacements not Significantly Affected

Displacement Categorization Shown Below

Plate	Displacement Amplitude
C R S T	a, c

DISK 205 - D3SLBREP\NRCPRES - 3/31/93

Table 8-1

Summary of TSP-Tube Relative Displacements for
Postulated SLB Event for Catawba Model D3 S/Gs

[ ] 2,c

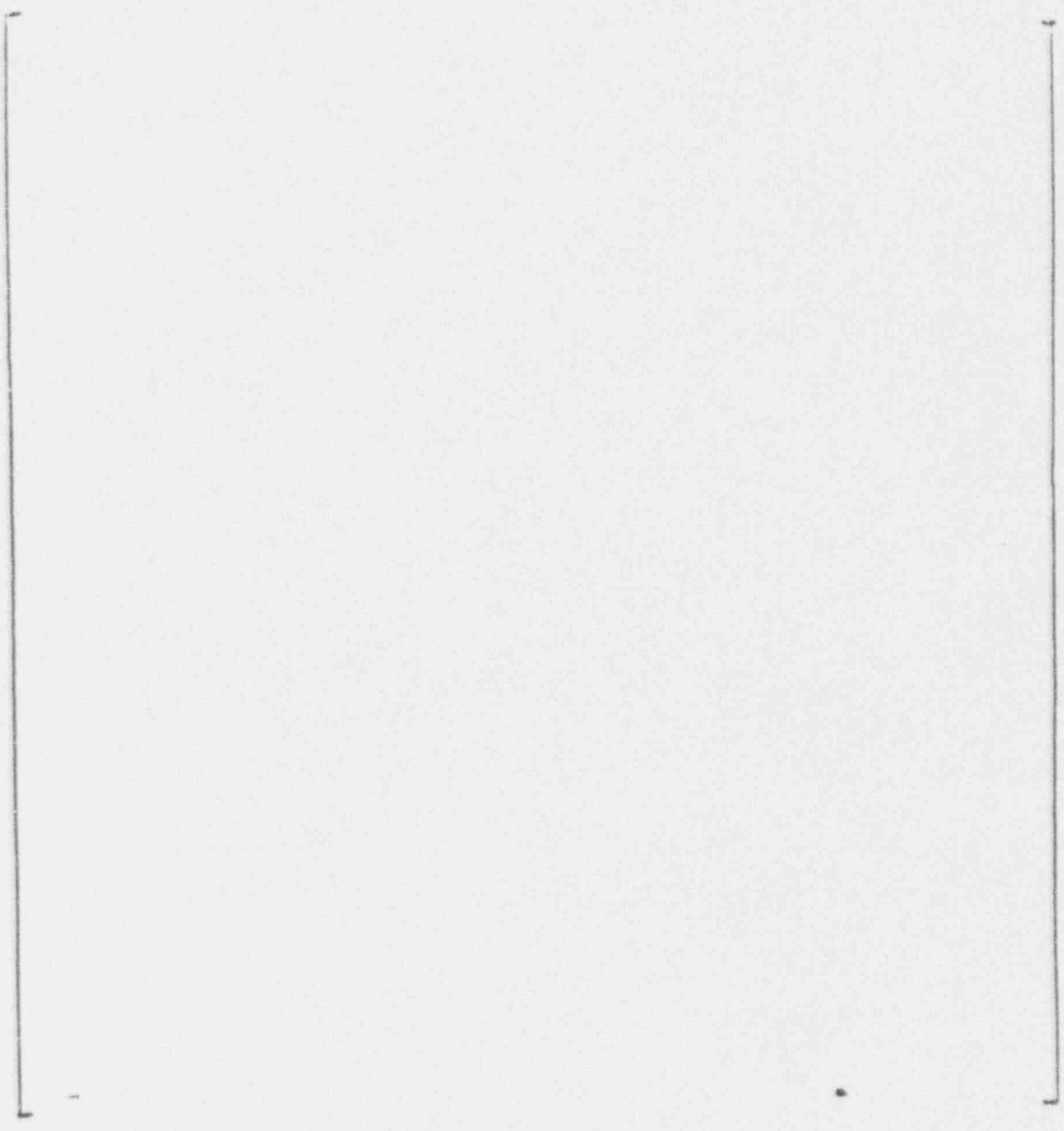


Figure 6-16 Plate Q (Hot Leg) SLB Displacement Time-History

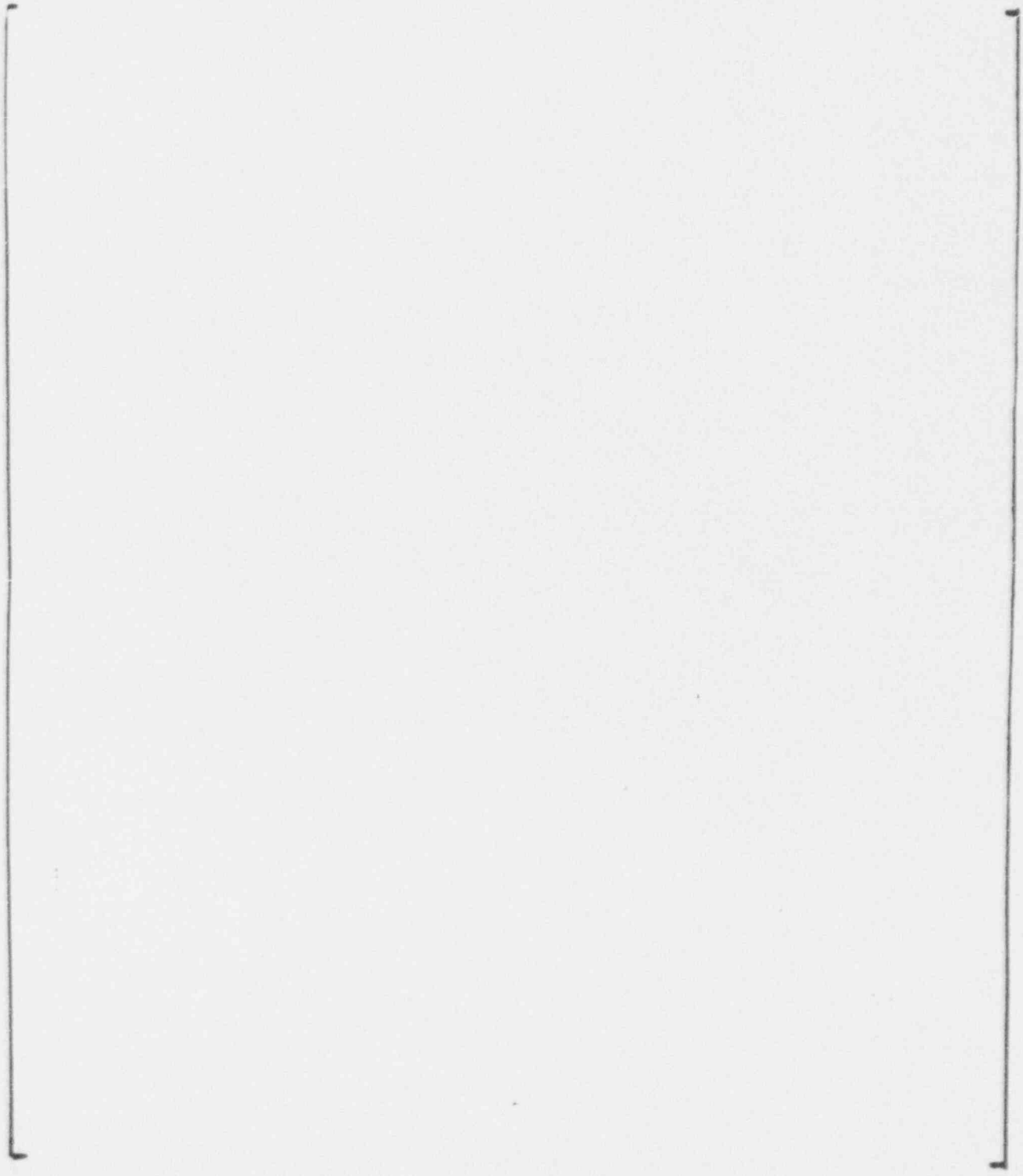


Figure 8-25. Distorted Geometry - Plate C

Assessment of SLB TSP Displacements

Maximum TSP Displacement of 0.525" is Less than Critical Crack Length

- Critical thruwall length of 0.57 inch at 1.4 ΔP_{SLB}
- Critical length of 0.84 inch at ΔP_{SLB}

Maximum TSP Displacements Affect Small Fraction of TSP Intersections

- Number of intersections defined for 3 ranges of TSP displacements to support burst probability analyses

Burst Pressure vs Thruwall Crack Length Correlation Developed for Statistical Analyses

- Define burst probability as function of crack length

Figure 12-6. Burst Pressure versus Crack Length for 3/4 Inch Tubing

Figure D.5

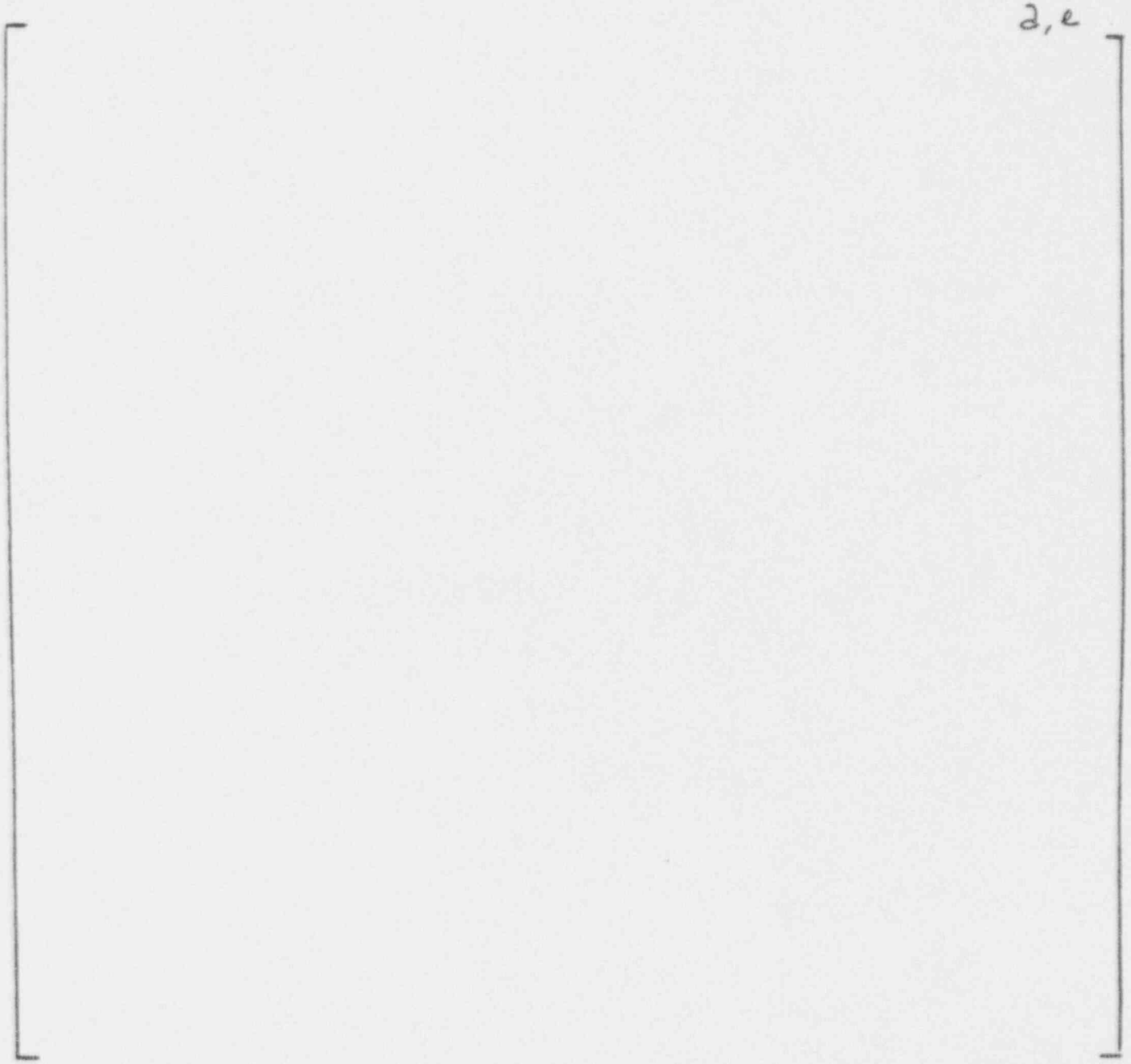
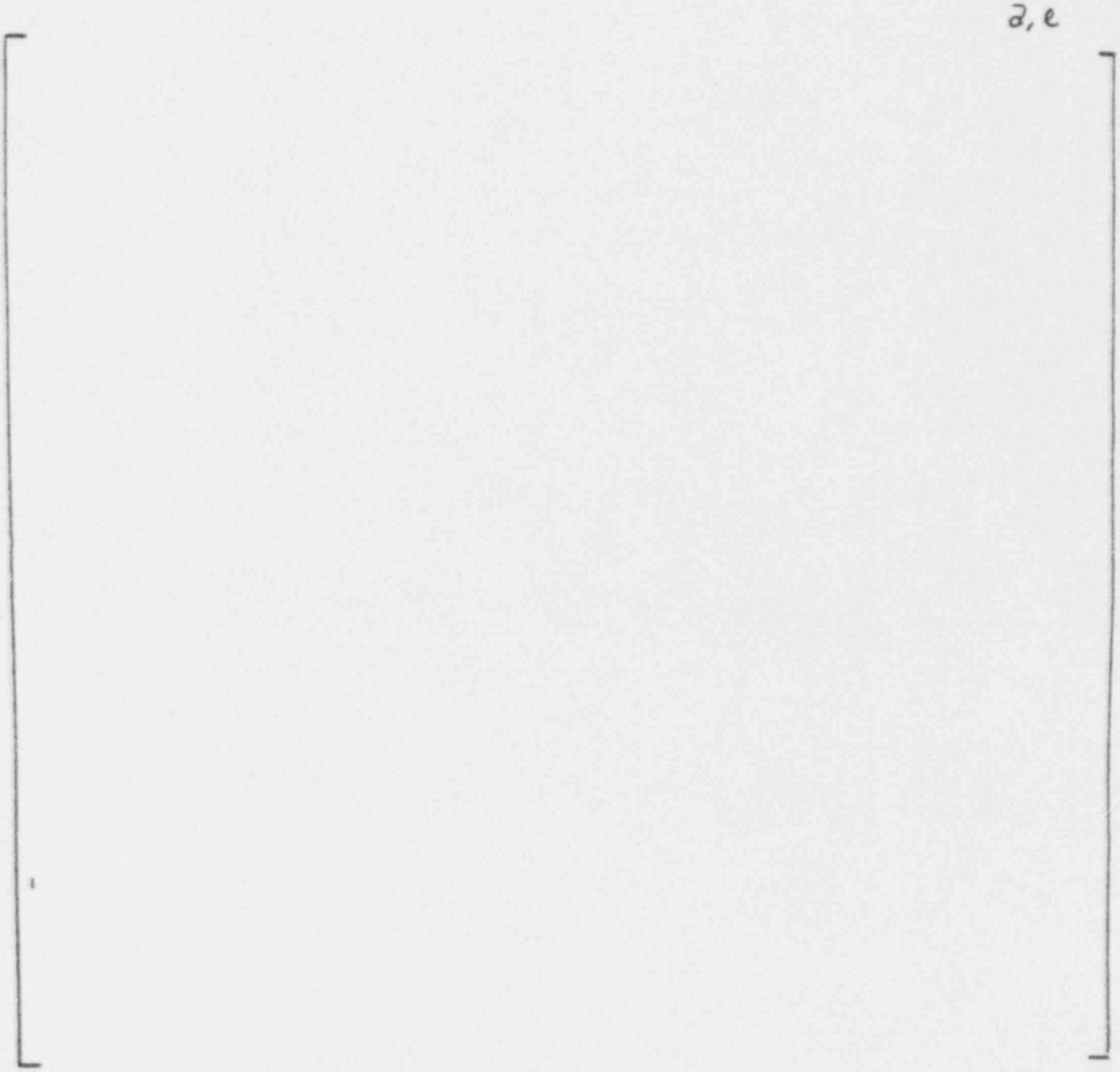


Figure D.8



Assessment of SLB TSP Displacements

Assumptions for Burst Probability Analyses

- TSP displacements assumed to expose a thruwall crack length equal to TSP displacement
- For Cycle 7 assessment, all indications left in service are assumed to be thruwall
- For bounding assessment, all hot leg TSP intersections assumed to have thruwall crack equal to TSP displacement

Results for Burst Probabilities

- Cycle 7 S/G Burst Prob. $<7X10^{-5}$
- Upper bound probability of $<8.1X10^{-4}$ independent of number of intersections

Table 12-2

Maximum SLB TSP Displacements and Associated Burst Probabilities
(Assuming Free Span Throughwall Crack Length Equals TSP Displacement)

a,c

Catawba-1 Pulled Tubes

1991 Pulled Tubes (5 tubes, 9 intersections)

- Used as adjusted (incomplete burst) burst pressure data in prior IPC submittal
- EPRI ARC Committee recommended not include data due to unresolvable uncertainty in burst pressures
- SLB Leak Tests

[ ] a, e

- Crack morphology typical of APC database

Table 6-1

Number of Pulled Tubes with NDE and Destructive Exam Data

Plant	Number of Tubes	Number of Intersections: Burst Tested	Leak Tested: Leak	Leak Tested: No Leak	Destructive Exam
3/4 Inch Pulled Tube Data Base Summary					
Catawba-1	8				
E-4	9				
B-1	1				
B-2	3				
C-2	2				
Totals	23				
7/8 Inch Pulled Tube Data Base Summary					
A-1	3				
A-2	4				
D-1	3				
D-2	4				
J-1	9				
L	8				
M-1	1				
P-1	2				
Totals	34				

Notes:

1. Number in parentheses represents number of additional pressurization tests performed without complete burst or successful burst test. Data not included in data base.

2. Number in parentheses represents room temperature pressure tests performedwith no identified leakage at pressure differentials exceeding SLB conditions. One additional Catawba-1 tube was leak tested, but throughwall penetration is likely the result of tube pulling and results are not included in data base.

CATAWBA-1 PULLED TUBES

1992 PULLED TUBES (3 TUBES, 6 INTERSECTIONS)

[a,c

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- CRACK MORPHOLOGY TYPICAL OF APC DATABASE-AXIAL ODSCC PLUS SOME LOCAL PATCHES OF CELLULAR CORROSION

Table 6-4

Catawba-1 1992 Pulled Tube Burst Pressures and Leak Rates

Row/Col	TSP	Bobbin Coil Volts	Bobbin Coil Depth	RPC Volts	Destructive Exam Max. Depth	Destructive Exam Length (in.)	Leak Rate (l/hr) Norm. Op.	Leak Rate (l/hr) SLB	Burst Pressure (psi)
R7C71	2								
SG C	3								
R9C76	2								
SG C	3								
R9C91	2								
SG C	3								

2, 2

Notes:

1) Average depth given in parentheses.
2) Throughwall depth for ~0.08" in burst crack and also in a second crack.
3) Burst crack depth and length.
4) Throughwall length of 0.016" found in a crack away from burst crack.
5) Burst test not reliable due to pressure recorder malfunction.

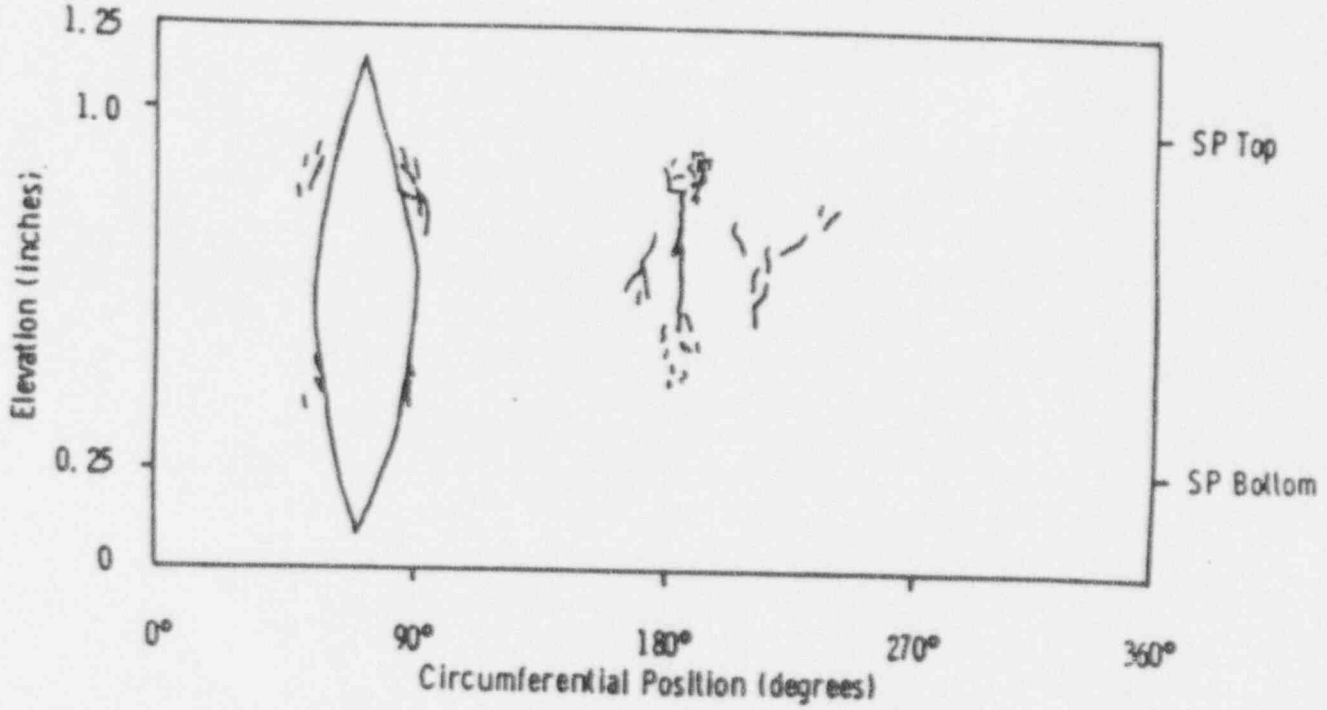


Figure 3-11. Sketch of the crack distribution found at the third support plate crevice region of tube R9-C91 from Catawba-1. Included is the location of the burst test fracture opening. The OD origin intergranular corrosion was confined to the support plate crevice region, including that found on the burst fracture face.

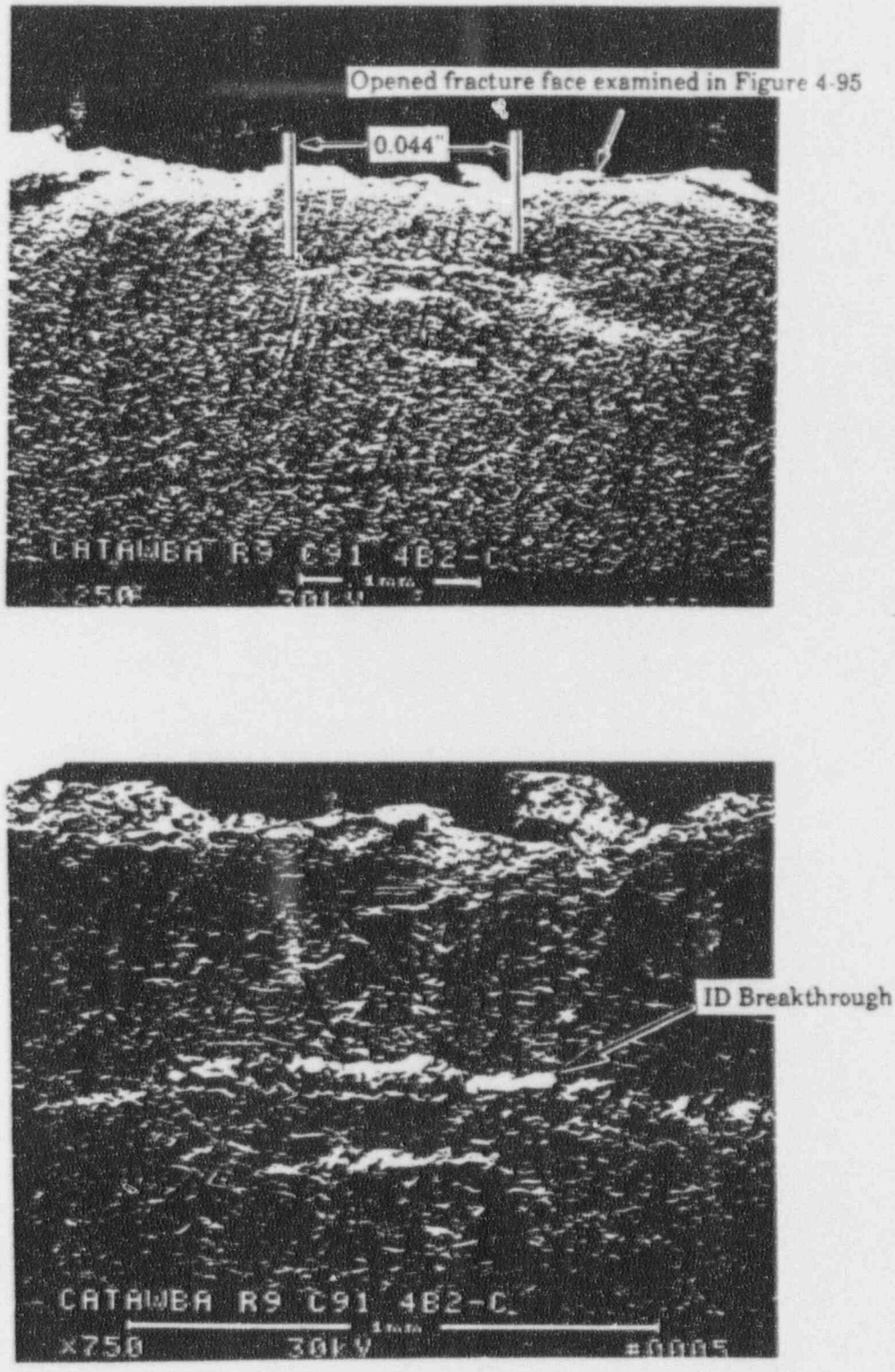
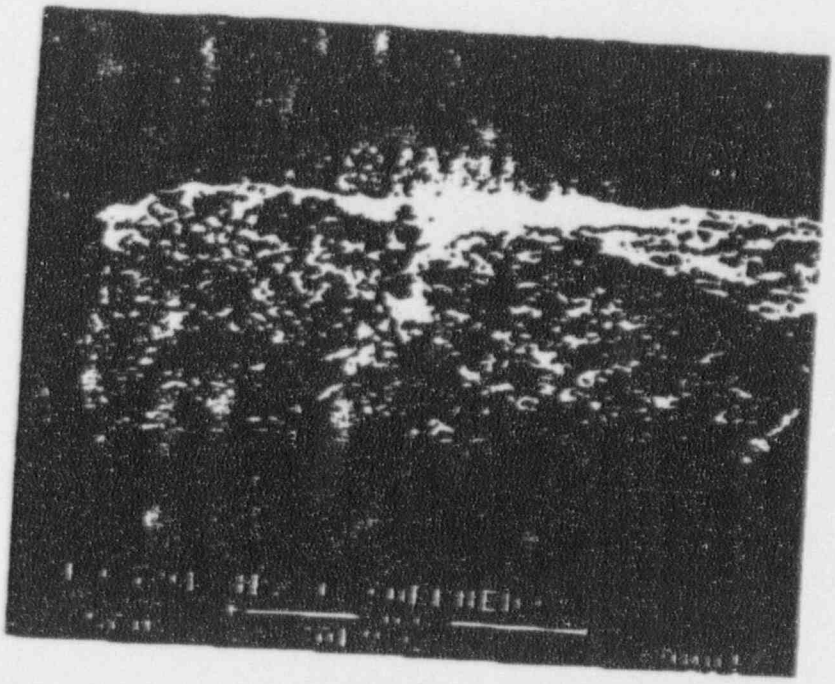


Figure 4-97 SEM micrographs showing the ID wall penetration where leakage occurred, Tube R9-C91, SP3.



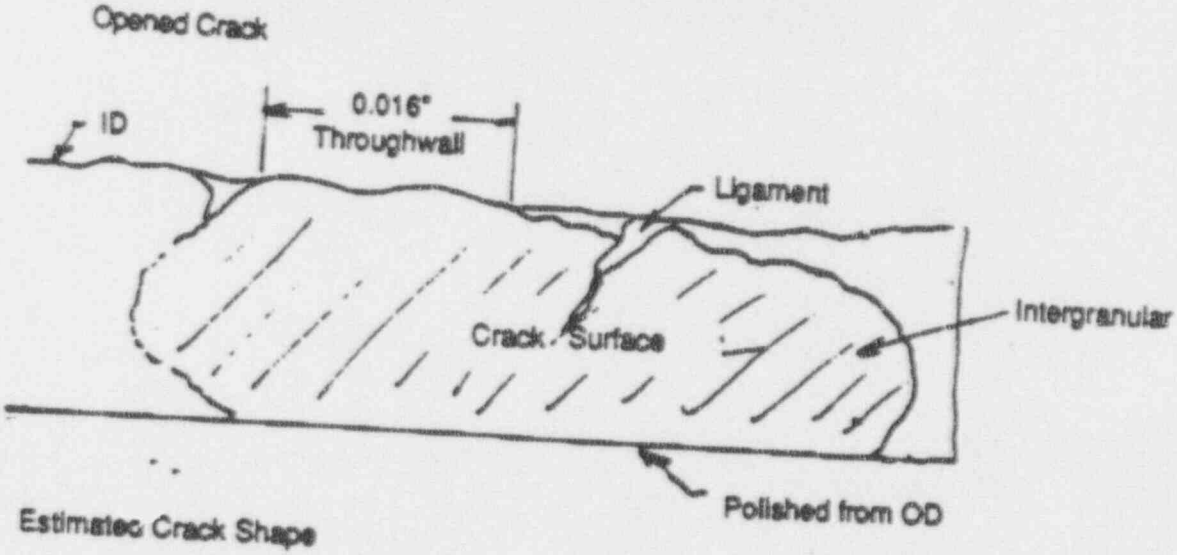


Figure 3-14. Through Wall Corrosion for SP3 of R9-C91 from Catawba-1.

Belgian Pulled Tubes

Resolution of Cross-Calibration of ASME standards (Belgian vs U.S.) was in-process at time of prior submittal

- Belgium EDM holes vs U.S. drilled holes
- Preliminary cross calibration correction of 1.7-1.8 was being further evaluated by Laborelec at time of prior submittal
  - Submittal conservatively assumed would be >1.5
  - SER assumed 1.0
- Final factor of 1.7

Resolution Separately Confirmed by Laborelec on 7/8" Tubing

- Field measurements
- U.S. standard and probe for APC voltage normalization
- Belgian standard and probe for Belgian normalization
- Ratio of Belgian (French) to APC volts, like 3/4" tubing, consistent with magnitude expected from ASME standard evaluation
- Ratio consistent with that previously developed from model boiler specimens

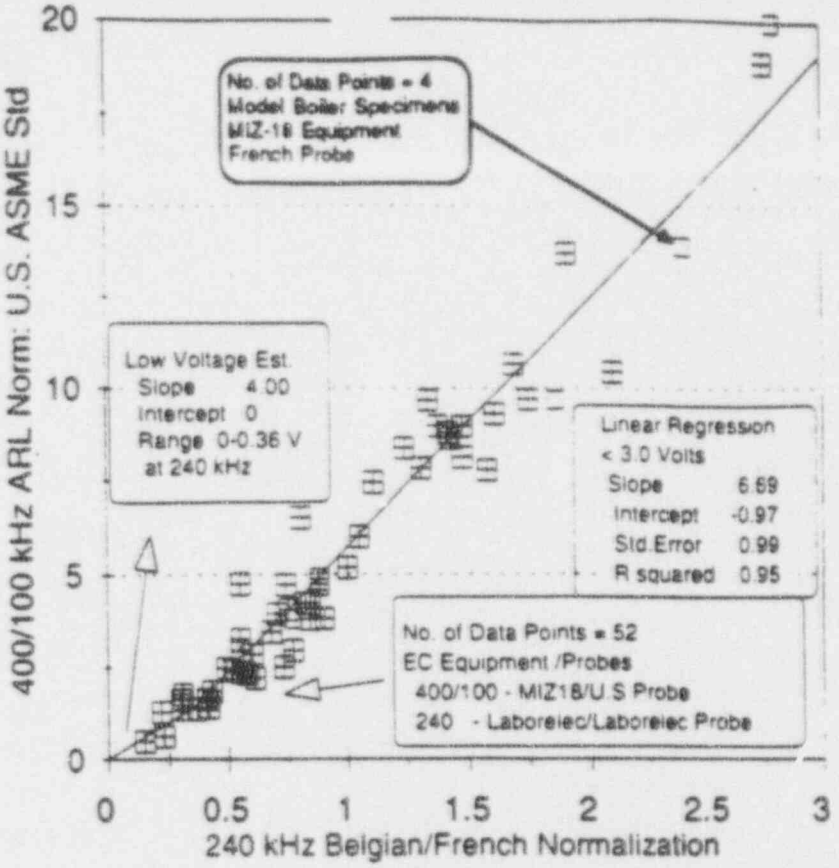


Figure 6-3(a) Belgian/French Voltage (3/8" Tubing) Renormalization to U.S. APC Calibration for Belgian Plant K-1 (1992 Data) and Model Boiler Data Below 3.0 Volts

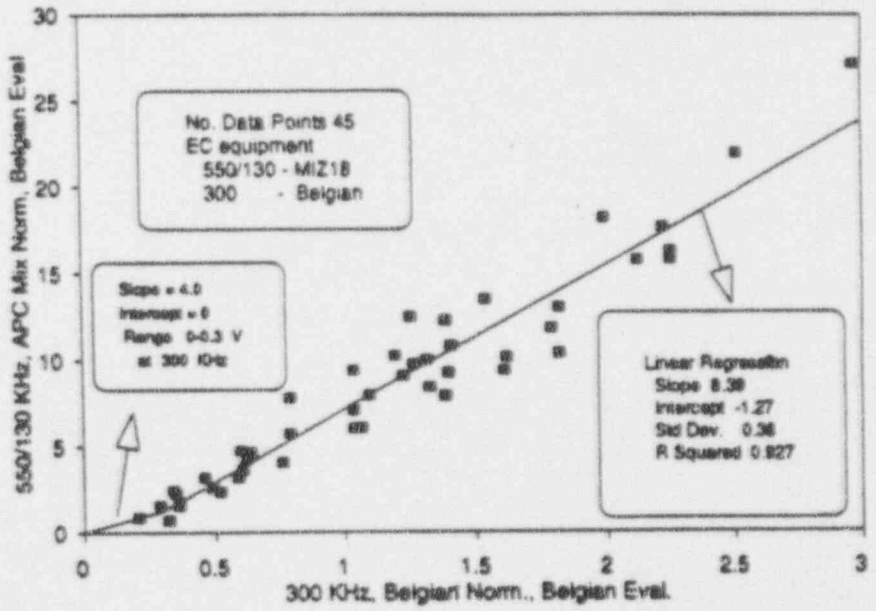


Figure 6-3(b) Belgian (3/4" Tubing) Voltage Renormalization to U.S. APC Calibration for Plant E-4 1992 Voltage Indications at Tube Support Plates

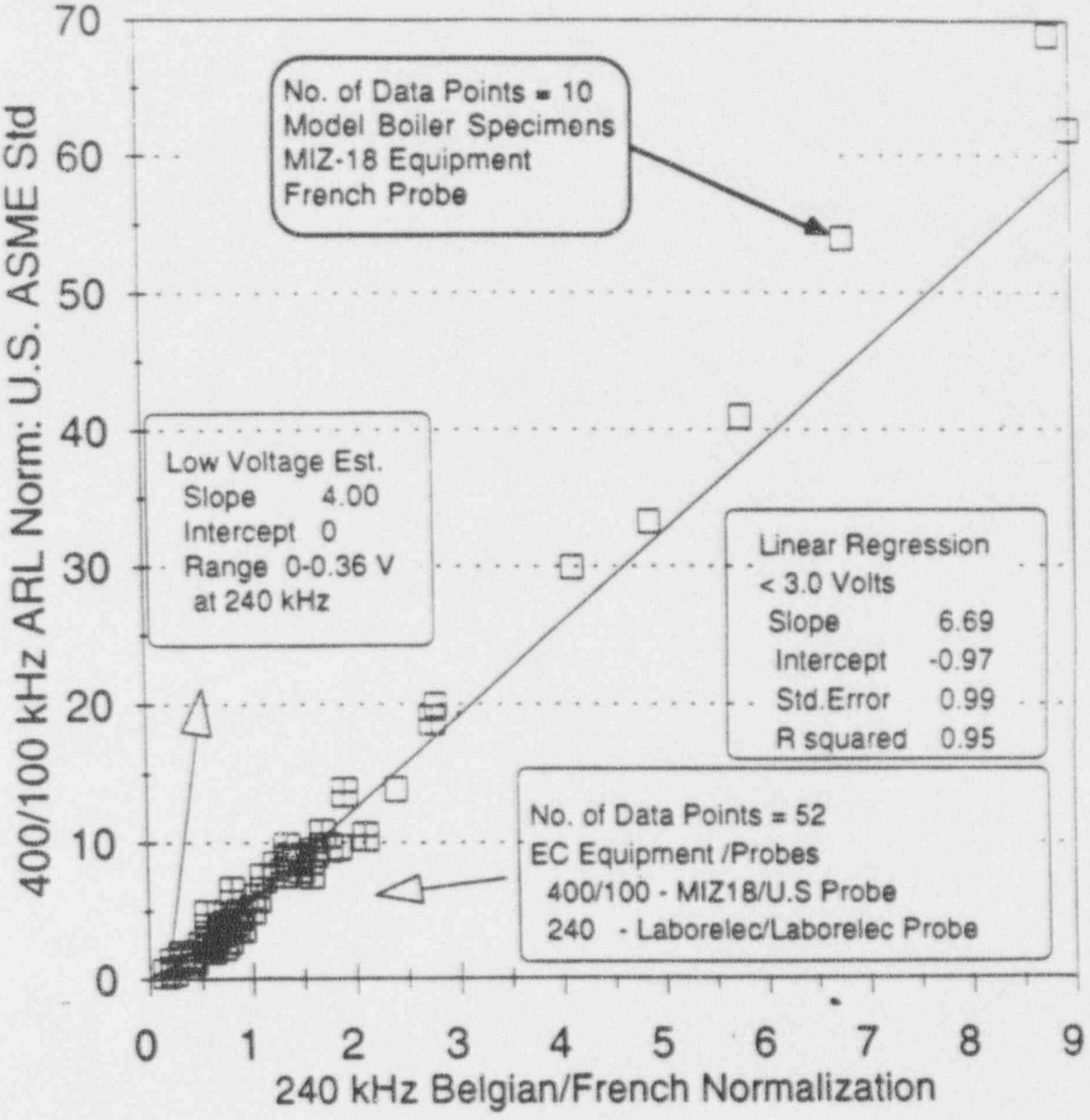


Figure 6-4 Belgian/French Voltage Renormalization (7/8" Tubing) to U.S. APC Calibration - Comparison of Correlation with Model Boiler Data above 3.0 Volts

Belgian Pulled Tube Data

7 Tubes, 11 Intersections

Generally good agreement with model boiler burst and leak rate data

Provides pulled tube support to high voltage database not obtainable in domestic plants

Table 6-7

3/4-Inch Diameter Pulled Tube Leak Rate and Burst Pressure Measurements

Plant	Row/Col.	TSP	Bobbin Coil Volts[3]	Bobbin Coil Depth	RPC Volts	Destructive Exam Max.Depth	Destructive Exam Length[4] (in.)	Leak Rate(l/hr)[1] Normal Oper.	Leak Rate(l/hr)[1] SLB	Burst Pressure[2] Meas. (psi)	Burst Pressure[2] Adj. (psi)
B-1	R4C61	5									
E-4	R26C34	3									
	R16C31	2									
		3									
	R45C54	2									
		3									
	R47C66	2									
		3									
		4									
	R33C96	2									
	R19C35	2									
	R26C47	2									
Catawba Unit 1	R7C71	2									
		3									
	R9C76	2									
		3									
	R9C91	2									
		3									

Notes:

1. Leak rates at operating temperature and pressure differentials of 1300 psi for normal operation and 2650 psi for SLB conditions based on adjustments given in Appendix C.
2. Measured (Meas.) burst pressure and burst pressure adjusted (Adj.) to 150 ksi for Sy+Su at room temperature.
3. Voltage normalization for 550/130KHz to 2.75 volts on 20% ASME holes.
4. Crack network length for burst crack with through wall crack length given in parentheses.
5. Measurement no reliable (N.R.).
6. Leak rates measured at room temperature conditions and analytically adjusted to operating conditions.
7. Not measured at 550/130 KHz. Voltage renormalized from 300 KHz data.
8. Leak rate at SLB conditions associated with 0.016 inch throughwall penetration at a crack location separated from the burst crack.
9. Minimum burst pressure, as no ductile tearing extension of burst crack was found after burst test.
10. OD corrosion extended additional 0.16" above the top of the TSP as microcracks separated by ligaments with individual microcrack depths in range of 3% (farthest above TSP) to 27% (nearest TSP).

Burst and Leak Rate Correlations

Free Span Burst Correlation

- Structural limit ($3\Delta P_{NO}$) of 4.6 volts compared to 4.1 volts in prior submittal

Addition of SLB Probability of Leakage Correlation

- Negligible prob. of leakage <1.0 volt
- 0-40% chance of leakage up to EOC 3.5 volts
- Average prob. of leakage of 2.6% for 1.0 volt BOC indication

More Conservative SLB Leak Rate Correlation

- Form of correlation selected for conservatism in low voltage region
- Semi-independent development supports correlation
  - Combines volts vs thruwall crack length correlation with leak rate vs crack length from CRACKFLO analytical model

Analysis methods selected to obtain $\geq$90% cumulative probability on leak rate

Correlations developed and approved by EPRI ARC Committee

Figure 10-3

3,c

Burst Pressure vs. Bobbin Volts, Final LS

Figure 11-7: Probability of Leak vs. Bobbin Amplitude

[a, c

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Figure 11-17

2335 psi SLB Leak Rate vs. Bobbin Ampiltude

3/4" Tubes. Model Boiler & Field Data

2, e

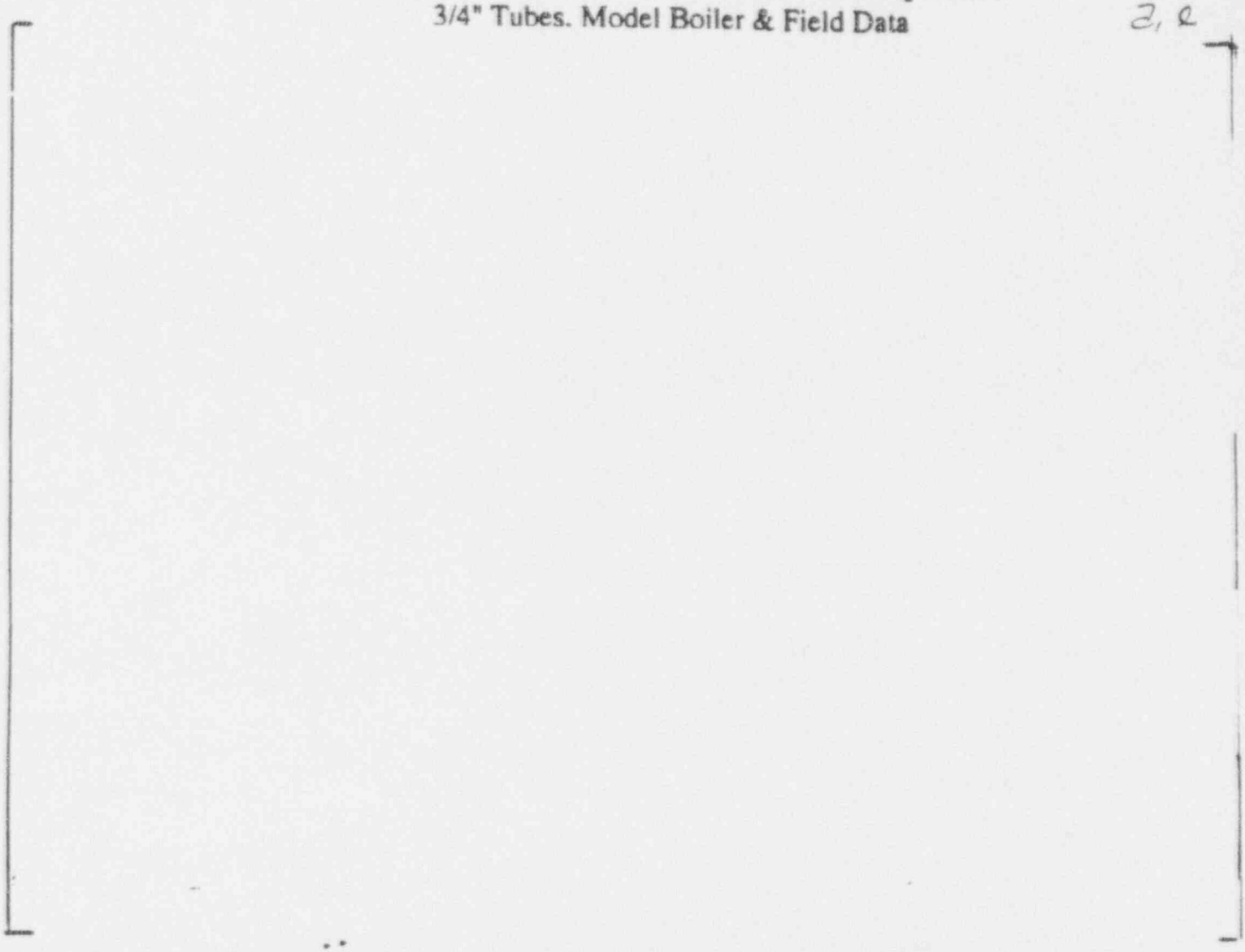

Figure 11-18

2335 psi SLB Leak Rate vs. Bobbin Amplitude

3/4" Tubes, Model Boiler & Field Data

a, c

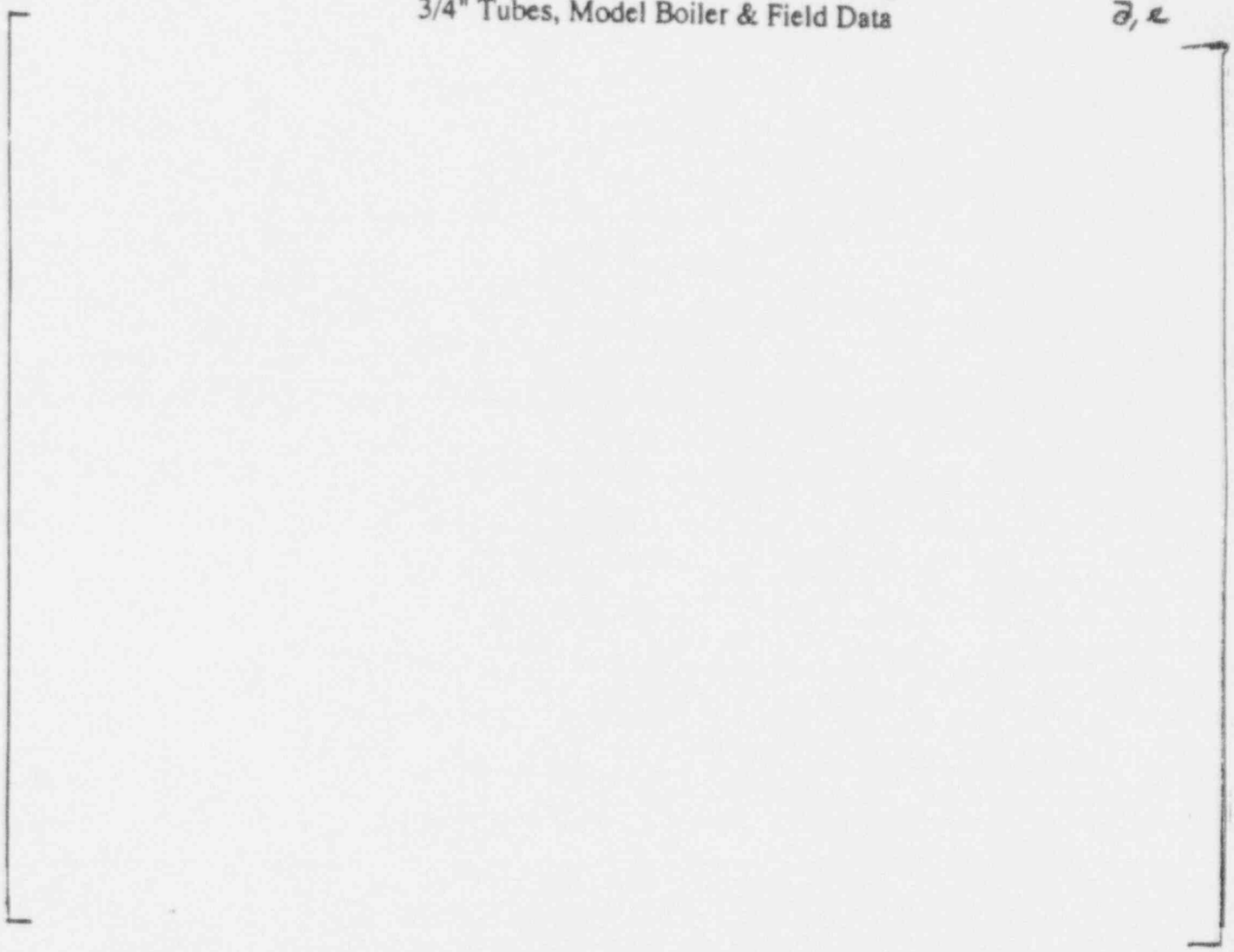

Table 12-3

APC Repair Limit to Satisfy Free Span Burst Requirements

Item	Volts	Basis
Maximum Voltage Limit to Satisfy Tube Burst Structural Requirement	[a, e]	Burst Pressure vs. Voltage Correlation at ~95% confidence level (Section 8.3)
Allowance for NDE Uncertainty		NDE uncertainty at 90% cumulative probability with implementation of NDE analysis guidelines and probe wear std.
Allowance for Crack Growth Between Inspections		Tables 9-7 and 9-8 show average growth/cycle of 32%. Allowance conservatively increased to 40% of Tube Repair Limit.
APC Repair Limit o Acceptable Limit to Meet Free Span Burst Requirement		

Note:

1. Voltage percentage allowances for NDE and growth rate/cycle applied to Equivalent APC Repair Voltage Limit of 3.0 volts.

Summary of IPC Margin Assessment

EOC Voltages

- EOC voltages expected <2.5 volt (99.9% cum.prob.) for BOC <1.0 volt
- Maximum EOC volts less than or equal to that found for 40% depth repair criteria

Free Span Burst Margins

- Expect EOC capability at 90% cum. prob. of 4825 psi compared to $3\Delta P_{NO}$ = 3750 psi
- EOC capability at 99% cum. prob. of 3830 psi compared to ΔP_{SLB} = 2335 psi

SLB Leakage

- Single BOC = 1.0 volt indication
  - 97.4% chance of no leakage at EOC
  - Leak rate per indication ~0.0002 gpm at ~98.6% cum. prob.
- Limiting S/G C expected ~0.02 gpm or well less than 1 gpm allowable limit

Table 12-6

Typical Maximum Bobbin Voltages for ODSCC at TSPs

Plant	Year of Inspection	Maximum Voltage Following 40% Depth Repair Limit	Maximum Bobbin Voltages Following 1.0v IPC	
			Prior Inspection Bobbin >1.0v(RPC NDD)	Prior Inspection Bobbin <1.0v
Catawba-1	1992	3.54	---	---
S	1991	2.80	---	---
A-1	1992	3.30	---	---
A-2	1992	3.84	---	---
D-1	1992	2.02	---	---
F	1992	4.00	---	---
L	1991	3.80	---	---
	1992	---	2.51(1)	1.36(1)
P-1	1991	3.91	---	---

Note:

1. Results of mid-cycle inspection projected to EOC value. Indications confirmed by RPC at mid-cycle inspection.

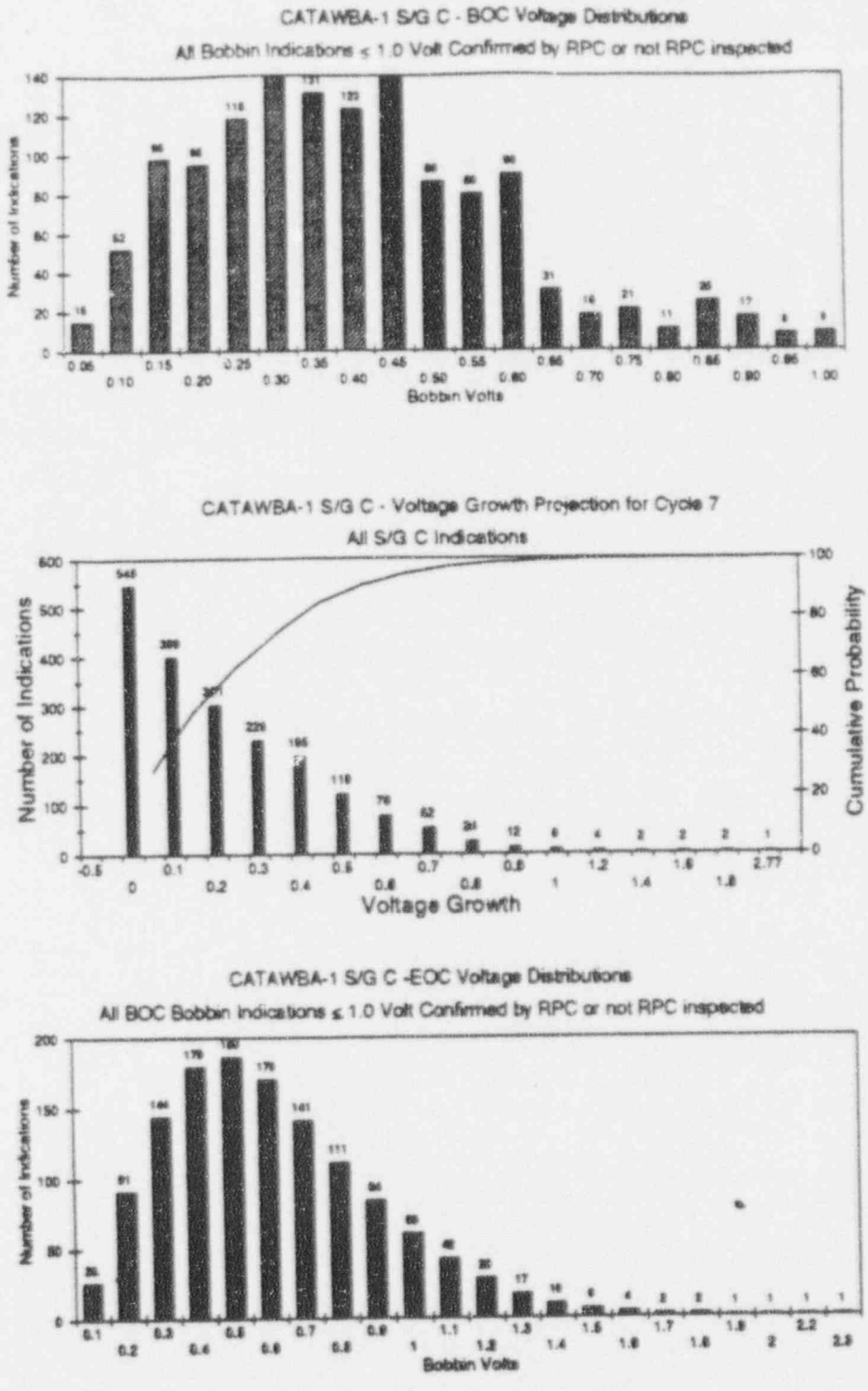

Figure 12-2. Steam Generator C BOC and EOC Voltage Distributions for BOC Bobbin Indications ≤1.0 Volt Confirmed by RPC or Not RPC Inspected

Table 12-9

Catawba-1 SLB Leak Rate per Indication

BOC Volts	1.0	2.0	3.0
Allowances (+90% Cum. Probability)			
o NDE Uncertainty	0.22	0.44	0.66
o Growth	0.49	0.49	0.49
EOC Volts	1.71	2.93	4.15
o Monte Carlo Cum.Prob.	92%	93%	94%
Expected Value Model			
o SLB Leak Rate (gpm)(1)	0.00018	0.0031	0.013
o No. Ind. per gpm	5,550	325	77
o Monte Carlo Cum.Prob.	98.6%	96.8%	95.2%
Monte Carlo Leak Rates (gpm)			
o 90% Cumulative Prob.	~0	0.00011	0.0058
o No. Ind. per gpm	--	9000	172
o Monte Carlo Prob. of No Leakage	97.4%	86.2%	64.3%

Note:

1. Expected value model combines probability of leak with numerical average of leak rate for +90% confidence on leak rate correlation.

Table 12-10

Deterministic EOC 7 SLB Leak Rate Analysis for S/G-C(1)

B.O.C. Volts	ΔV-NDE Uncertainty	ΔV Growth	E.O.C. Volts	Expected SLB Leakage-l/hr	Number of Indications	Total SLB Leakage-l/hr
0.425	0.094	0.49	1.009	0.0020	139	0.28
0.475	0.105	0.49	1.060	0.0028	86	0.24
0.525	0.116	0.49	1.131	0.0028	80	0.30
0.575	0.127	0.49	1.192	0.0051	90	0.45
0.625	0.138	0.49	1.253	0.0069	31	0.21
0.675	0.149	0.49	1.314	0.0090	18	0.16
0.725	0.160	0.49	1.375	0.0117	21	0.25
0.775	0.171	0.49	1.436	0.0150	11	0.17
0.825	0.182	0.49	1.497	0.0187	25	0.47
0.875	0.193	0.49	1.558	0.0238	17	0.40
0.925	0.204	0.49	1.619	0.0295	8	0.24
0.975	0.215	0.49	1.680	0.0349	9	0.31

Total S/G C Leak Rate:		
	o liters/hr	3.48
	o gpm	0.015
Monte Carlo Cum.Prob.		95%

Note:

1. Reference S/G C Analysis: BOC distribution of Figure 12-2. NDE Uncertainties and Growth at +90% cumulative probability. Expected value leakage model of Section 11.6.