

Westinghouse Non-Proprietary Class 3

WCAP-14796

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**NRC/UTILITY MEETING ON  
MODEL 51 SG TUBE INTEGRITY  
AND ARC METHODOLOGY**

Westinghouse Energy Systems



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WCAP-14796

NRC/UTILITY MEETING ON MODEL 51 SG TUBE INTEGRITY  
AND ARC METHODOLOGY

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WESTINGHOUSE ELECTRIC CORPORATION  
NUCLEAR SERVICES DIVISION  
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**NRC/Utility Meeting on  
Model 51 SG Tube Integrity and ARC Methodology**

**November 20, 1996**

**AGENDA**

<b>Topic</b>	<b>Presenter</b>	<b>Time</b>
Meeting Purpose and Objective	PG&E/TVA	10
W* ARC		
• W* Criteria and Overview	Pitterle	35
• W* Length Basis	Wepfer	20
• SLB Leak Rate Methodology	Lilly	30
Limited SLB TSP Displacement with Packed Crevices		
• Summary of Submitted WCAP-14707	Pitterle	10
• Local TSP Structural Analyses - Hot to Cold Condition	Smith	30
NDE Uncertainty for Sizing Axial PWSCC at Dented TSPs	Pitterle	40
• Pulled Tube and Laboratory Specimen Data		
• NDE and Destructive Exam Depth Profiles		
• Edge Effects and Adjustment Procedure		
• NDE Uncertainty - length, avg. depth, max. depth		
ARC Concept - Axial Cracks at Dented TSPs	Pitterle	15
• Negligible TSP Displacement		
• ARC Concept		
• SLB Leakage Analysis Basis		
Discussion	All	15



W\* ARC and Overview

NRC/Utility Meeting

November 20, 1996

Presented By:

T. A. Pitterle

Nuclear Services Division

Westinghouse Electric Corp.

## Discussion Topics

### General Approach

### W\* Tube Repair Criteria

- Repair basis
- Inspection requirements

### W\* SLB Leak Rate Evaluation

### WEXTEx Inspection Results and Growth Rates

### NDE Uncertainties

### Conservatisms in W\* Criteria



## Elements of ARC for Tubesheet Region

### W\* Builds Upon Fundamental Basis for L\* ARC

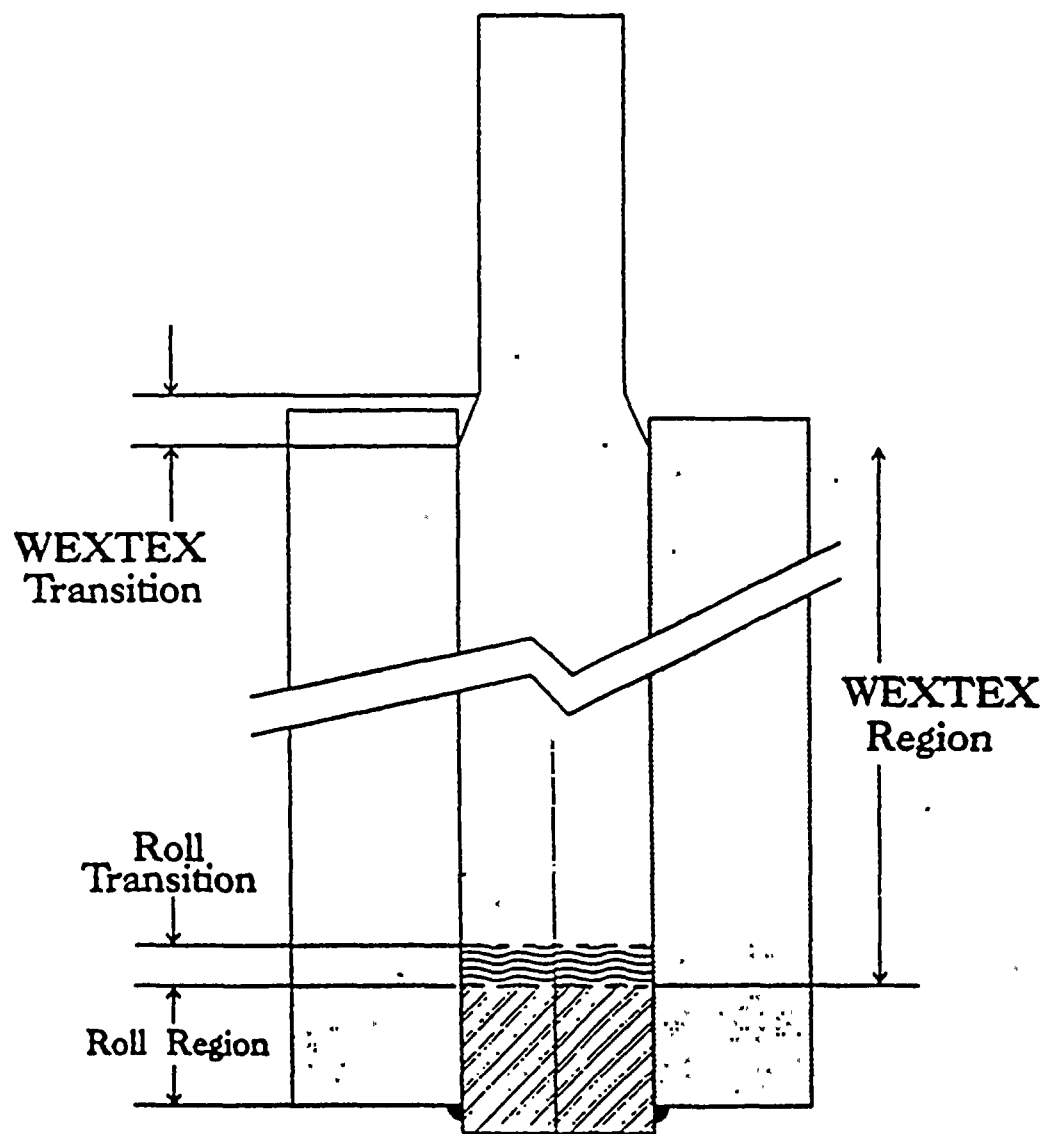
- Basic principles of L\* applied, differing primarily in method of leak rate evaluation
- Pullout load reaction lengths (W\* lengths) are dependent upon the type of tubesheet joint

### Elements of Repair Criteria

- Pullout load reaction length
  - Flexible W\* distance dependent upon length of degradation
  - Undegraded lengths below BWT must sum to W\* distance
- Allowable tube degradation
- SLB leak rate evaluation

### Principle Differences Between L\* and W\*

- W\* lengths > hardroll lengths due to lower WEXTEx contact pressure
- L\* undegraded length of about 0.5" below BRT not applied to W\* as not applicable to limit leakage to negligible levels
- Allowable degradation within W\* distance simplified compared to L\*
  - Closely spaced, multiple cracks not found in WEXTEx expansions



Regions in the WEXTEx Full Depth Tube-to-Tubesheet Expansion

## General Approach to ARC Within Tubesheet Region

Provide for Disposition of Indications Found by Bobbin or RPC Inspections

Tube Must be Capable of Withstanding Axial Pullout Forces

- RG 1.121 criterion for  $3\Delta P_{NO}$  is generally limiting
- Pullout force resistance is sum of: WEXTEx expansion + thermal expansion + pressure differential + tubesheet bow

W\* Distance of Undegraded Tubing Below BWT

- Flexible distance such that tube to tubesheet contact forces prevent pullout of a postulated severed tube below this distance

Cracks Within Tubesheet Cannot Burst Due to Tubesheet Constraint

- Axial crack length limits not required for W\*

Pullout Distance and Leakage Restriction Models Supported by Tests for Prototypic Expansions

## **W\* Tube Repair Criteria**

### **Any Tube Degradation Acceptable Below Flexible W\* Distance**

- Minimum W\* distances below BWT ( $3\Delta P_{NO}$  R.G. 1.121 Guideline)
  - Zone B: 6.4" hot leg
  - Zone A: 5.0" hot leg
- Minimum W\* lengths increased by:
  - Uncertainty in W\* NDE length measurement relative to BWT
  - Sum of overall axial crack length within flexible W\* distance
    - Crack lengths increased by uncertainty in NDE length measurement and crack growth

### **Axial Indications Within W\***

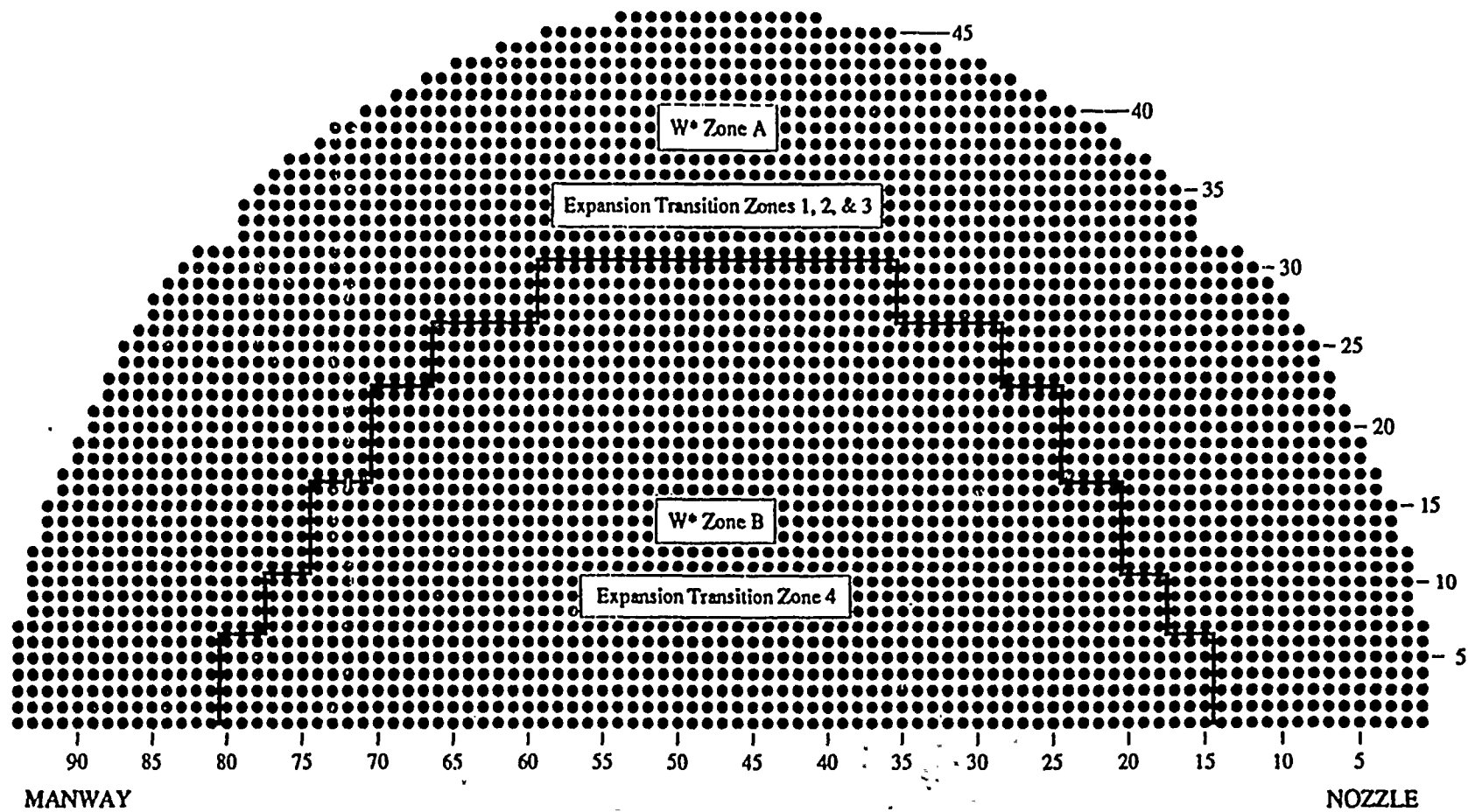
- Crack tip must be below BWT by allowances for:
  - NDE uncertainty on distance between BWT and crack tip
- Multiple axial cracks must be circumferentially separated such that the RPC amplitude returns to null between indications
  - Bands of unresolved axial ind. require repair unless confirmed to be separate axials with no circumferential involvement by UT inspection
- Axial cracks must be inclined  $< (45^\circ - \text{NDE unc.})$  from tube axis where NDE uncertainty applies to measurement of the crack angle

### **Circumferential Indications Within W\* Distance are Repaired**

### **SLB Leakage Must be Within Site Specific Allowable Leakage Limits**

- Total leakage from all indications within W\* distance as adjusted for percent inspection
  - Total leak rate from all indications within W\* region divided by the fraction of tubes inspected (RPC or bobbin which is frequently 100%)
- W\* leakage added to SLB leakage for other applied ARCs (i.e., GL 95-0)

# W\* Zone A and Zone B Boundaries



## W\* Tube Repair Criteria Inspection Requirements

### Extent of Inspection

- Extent of inspection determined by plant Tech Specs as supplemented by plant specific guidelines
- Application of W\* ARC does not mandate extent of inspection

### Indications Within Flexible W\* Length

- Bobbin indications must be RPC (or equivalent coil) inspected to measure crack lengths and elevations

### RPC (or equivalent) Inspection

- When RPC inspection of WEXTEx region is performed, the inspection shall include the full length of the flexible W\* region
  - Confirm absence of circumferential indications
- Measurements required
  - Bottom of BWT relative to TTS
  - Distance of crack tip within W\* length relative to BWT or TTS
  - Crack length of axial indications within W\* distance
  - Crack angle relative to tube axis when crack is clearly inclined to the tube axis
    - Crack angles clearly  $< 30^\circ$  to tube axis do not require angle measurement

## W\* SLB Leak Rate Evaluation

### SLB Leak Rate Summed Over Individual Ind. Within W\*

- Deterministic analysis methodology
- Total leak rate based on leakage from sum of indications divided by fraction inspected (RPC or bobbin)

### Leak Rate for Each Indication is Function of Distance of Crack Tip Below BWT and W\* Zone

- Leak rates are independent of crack length due to tubesheet constraint
  - Constraint results in an effective crack length as a function of tube to tubesheet contact pressure
- Leak rate variation with tubesheet radius results from change in contact pressure with varying tubesheet bow
- Radial dependence simplified by defining only two W\* zones

### Crack Distance Below BWT Adjusted for NDE Uncertainties and Crack Growth

- Reduced by NDE uncertainty on measurement of length from BWT to upper tip of crack
- Reduced by crack growth allowance for projected EOC leak rate (Operational Assessment)
  - Growth allowance not required for current EOC analysis (Condition Monitoring)

## Leak Rate Model

### Test Basis for Leak Rate Model

- Constrained crack leak rate tests
  - Leak rates for fatigue cracks with varying contact pressure and zero contact pressure (gaps < 1 mil)
  - Leak rates measured at tip of crack
- WEXTEx crevice leak rates
  - Leak rates from large openings through varying lengths of WEXTEx expansion

### Leak Rate Model

- Effective throughwall crack length as function of tubesheet contact pressure
  - Freespan, throughwall crack length (from CRACKFLO code) that gives measured leak rate at tip of crack
  - Throughwall cracks 0.3" to 0.6" throughwall reduced to effective throughwall lengths of 0.05" to 0.2" by restricted crack opening due to tubesheet constraint
  - Effective length is independent of actual crack length
- Crevice loss coefficient as function of tubesheet contact pressure
  - Developed from WEXTEx crevice leak tests
- Effective length and loss coefficient applied at 95% confidence on mean regression fit to test data
- Leak rate is a series model of leakage from effective crack length through crevice based on crevice loss coefficient
- Leak rates are a function of distance between upper crack tip and BWT



## Leakage Model is a Generic Approach

### Generic Leak Rate Model for Constrained (contact pressure to small gaps) Cracks

- Effective crack length approach applicable from expected contact pressure to gaps  $< 1$  mil
- Loss coefficient varied to specific crevice conditions (expansion or packed crevices)

### Potential Applications

- Applicable to cracks within fully expanded tubesheet for hardroll and hydraulic expansions as well as WEXTEx expansions
  - Different loss coefficient correlations for hardroll and hydraulic expansions
- Packed TSP crevices
  - Constrained crack opening model with zero contact pressure and different loss coefficient correlation

## WEXTEx Inspection Results

### Types of Indications Below TTS

- Field data reviewed from four plants
- Axial indications are dominantly SAIs (227 of 231 axials)
  - 2 MAIs reach null point between ind. and 2 do not reach null point
- Four circumferential and one volumetric (by + Point call)
  - Small circumferential involvement
- Two inclined indications within 30° of tube axis

### Location of Indications Below TTS

- Distributed across tubesheet with a bias toward center
- Circumferential indications within or at bottom of expansion transition
- Axial indications principally within first few inches below TTS
  - Need for flexible W\* length to permit indications to remain in service

### Bobbin Detection of Indications Below BWT

- Data review indicates bobbin detection of 30 to 40% of RPC indications below BWT
- Larger voltage (> 5 volts) appear to be detectable by bobbin inspection
  - Recent in situ testing of 32 TTS hardroll transition, axial PWSCC indications found no leakage
    - Consistent with French integrated SG leak tests
    - Tubesheet constraint apparently increases tightness of cracks
- Bobbin inspection judged adequate to detect indications which could be potential axial leakers or could reduce tube to tubesheet contact pressure

Table 7.1-1

SAI	MAI		SVI	Circ. (SCI or MCI)
Single Axial Indication	RPC Null Point Reached Between Cracks	RPC Null Point Not Reached Between Cracks or Indeterminate*	Single Volumetric Indication*	Single or Multiple Circumferential Indication*

Depths Measured  
Relative to TTS

<-0.4"	180	2	2	1	4
-0.4" to <-0.2"	24	0	0	0	23
-0.2" to <-0.1"	9	0	0	0	52
-0.1" to < 0.0"	14	0	0	1	52
Totals	227	2	2	2	131
					364

Depth Measured  
Relative to BWT\*\*

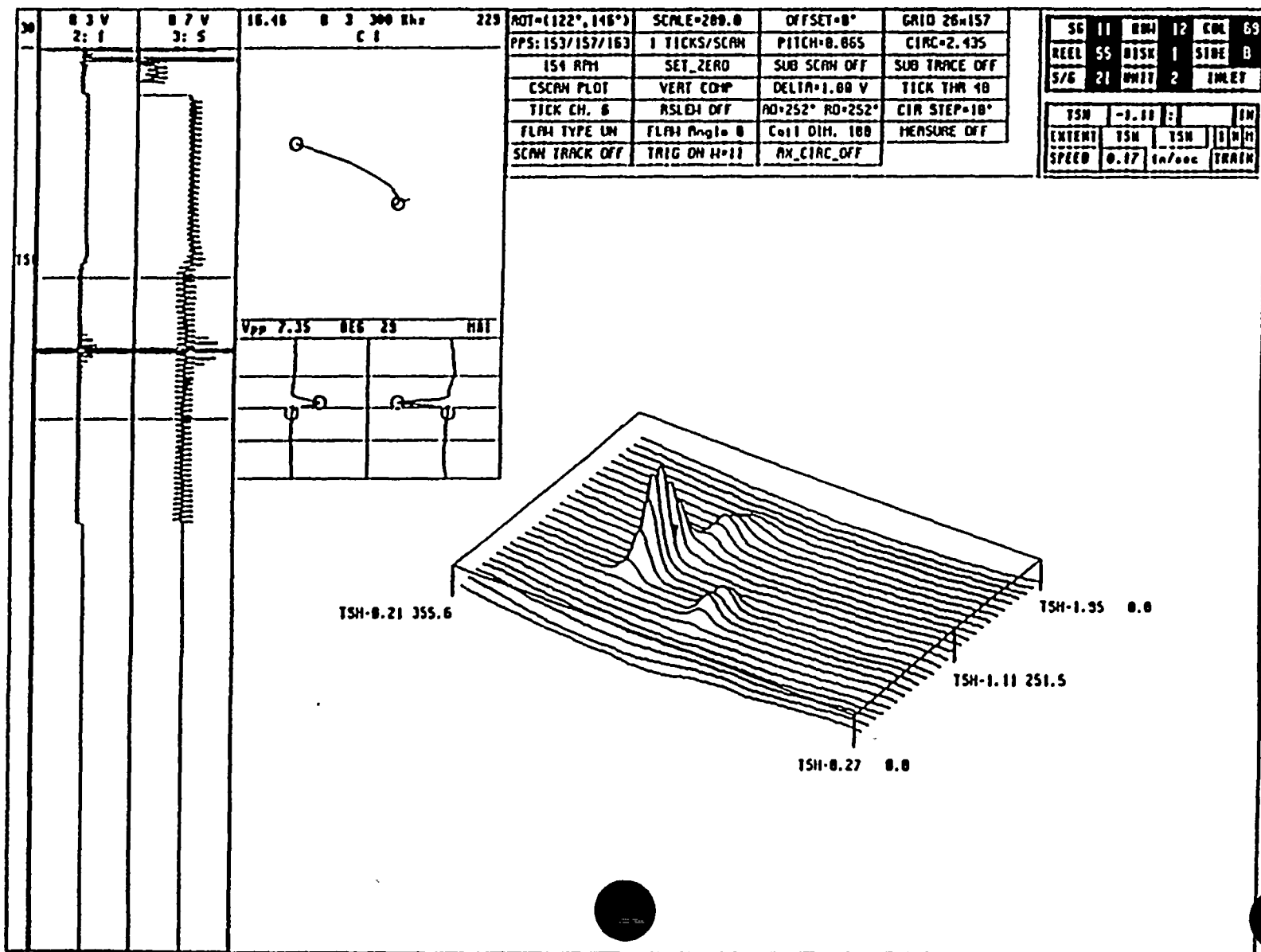
<-0.4"	13	0	0	0	0
-0.4" to <-0.2"	3	0	0	0	0
-0.2" to <-0.1"	1	0	0	0	0
-0.1" to < 0.0"	1	0	0	0	0
Totals	18	0	0	0	0

\* Criteria Not Applicable

\*\* Circ. Cracks not included in BWT study

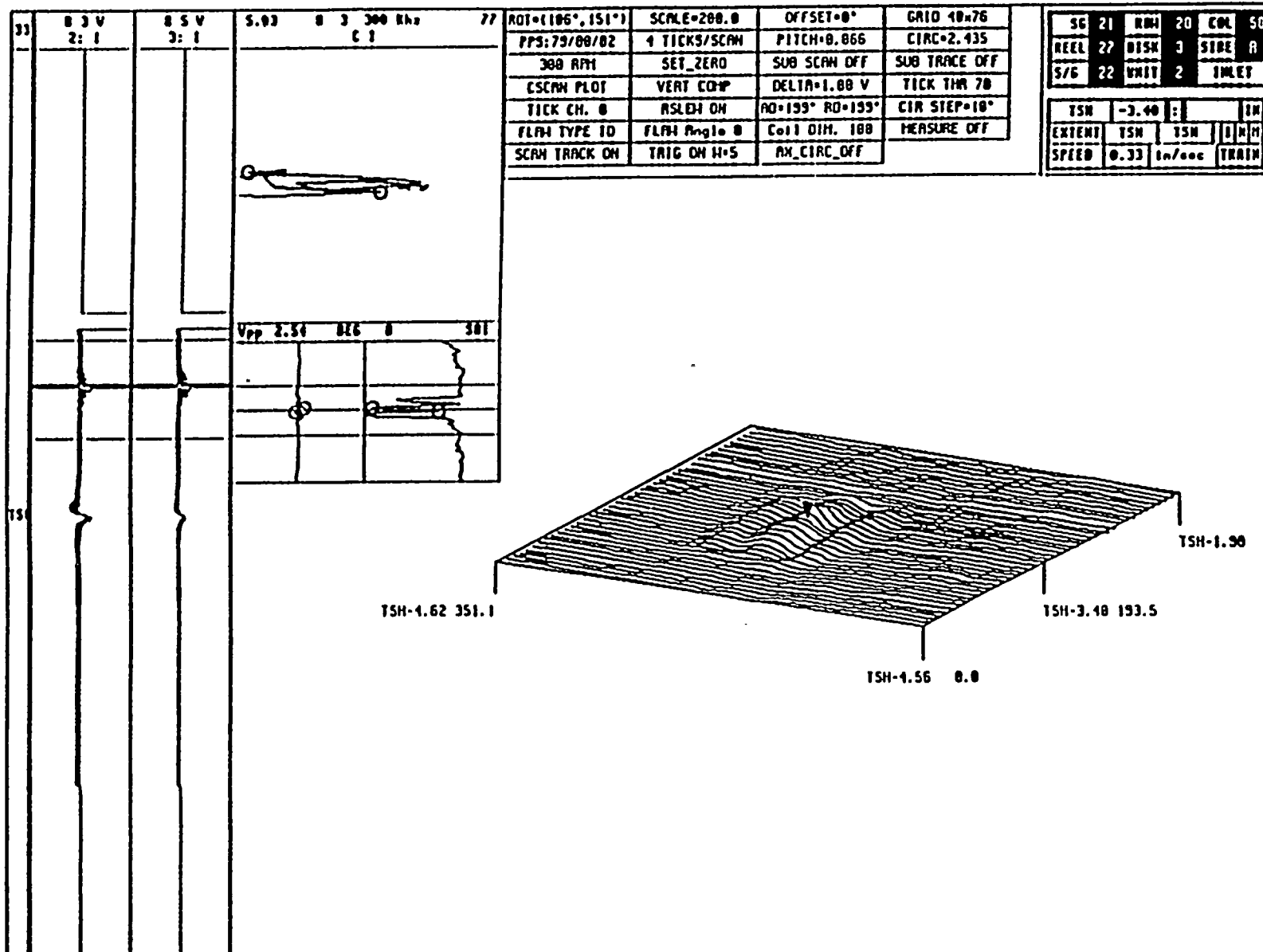
# Plant Z2 SG-1

## November 1994 R12C69

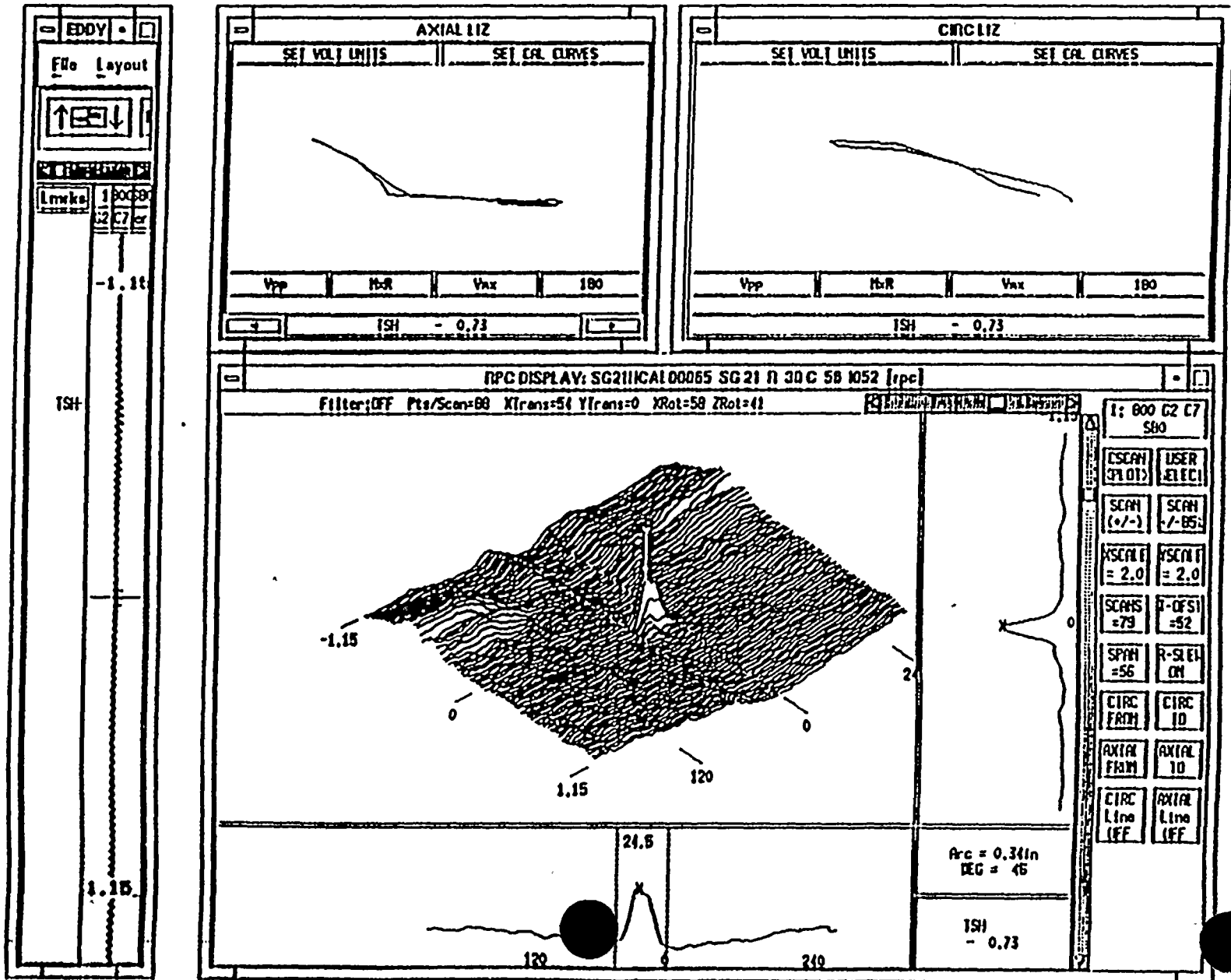


# Plant Z2 SG-2

## March 1993 R20C58

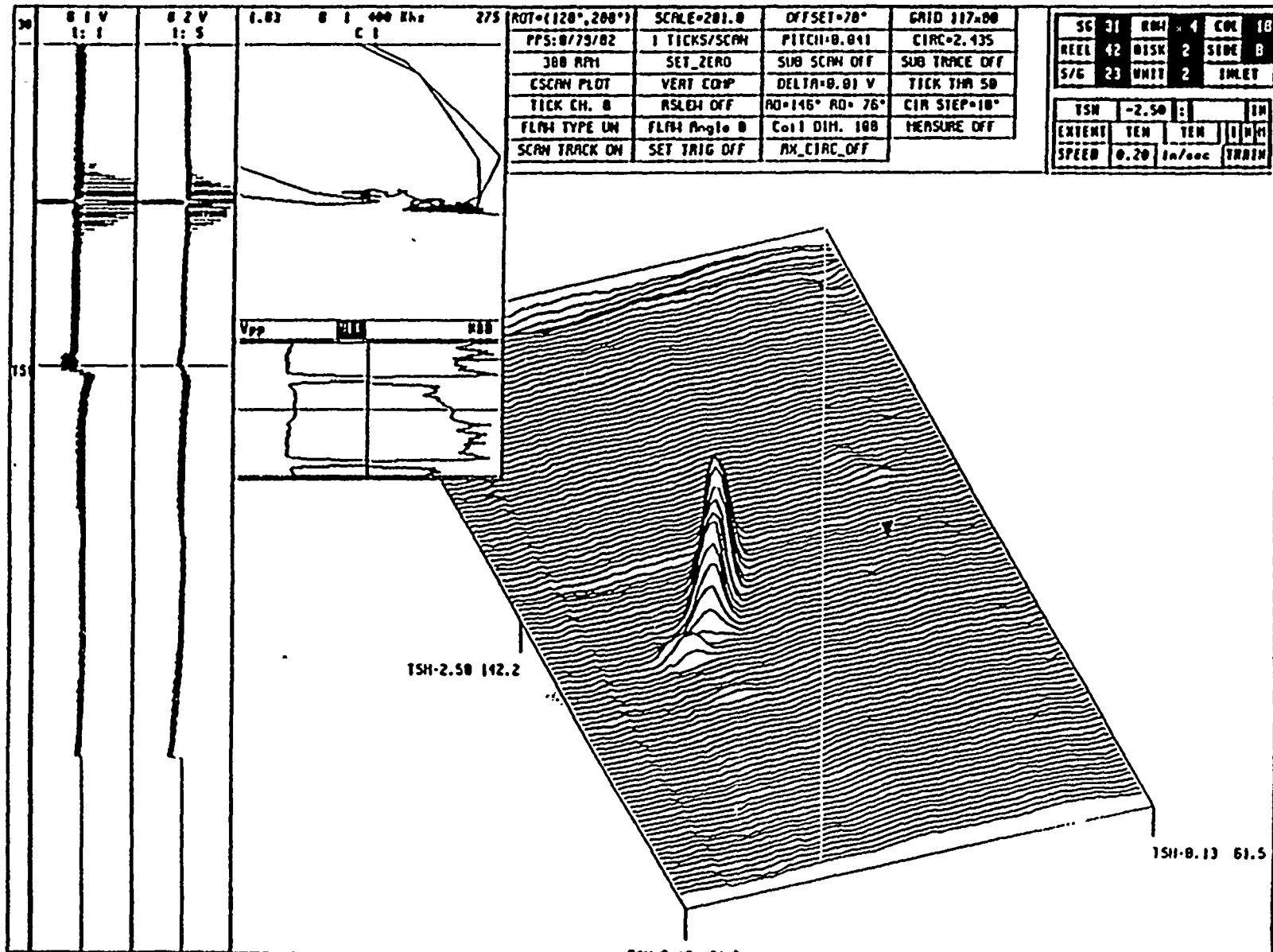


Plant Y2 SG-1  
April 1994 R30C56



# Plant Y2 SG-3

## March 1993 R4C18



**Figure 7.1.2-1**  
**WEXTEX Single and Spaced Multiple Axial Indications Below TTS**

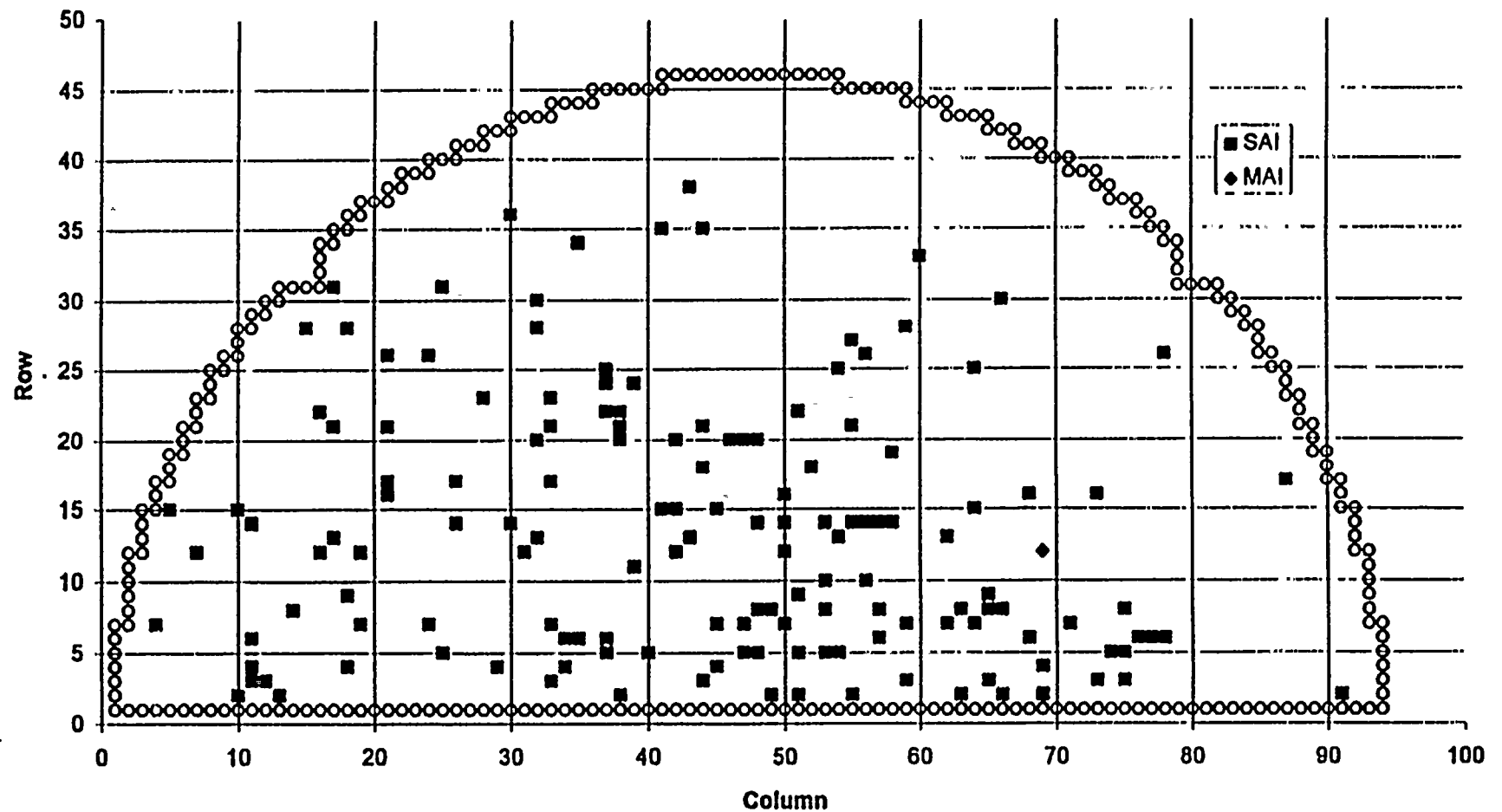




Figure 7.1.3a - Number of WEXTEx Circumferential and Volumetric Indications vs. Depth Below Top of Tubesheet

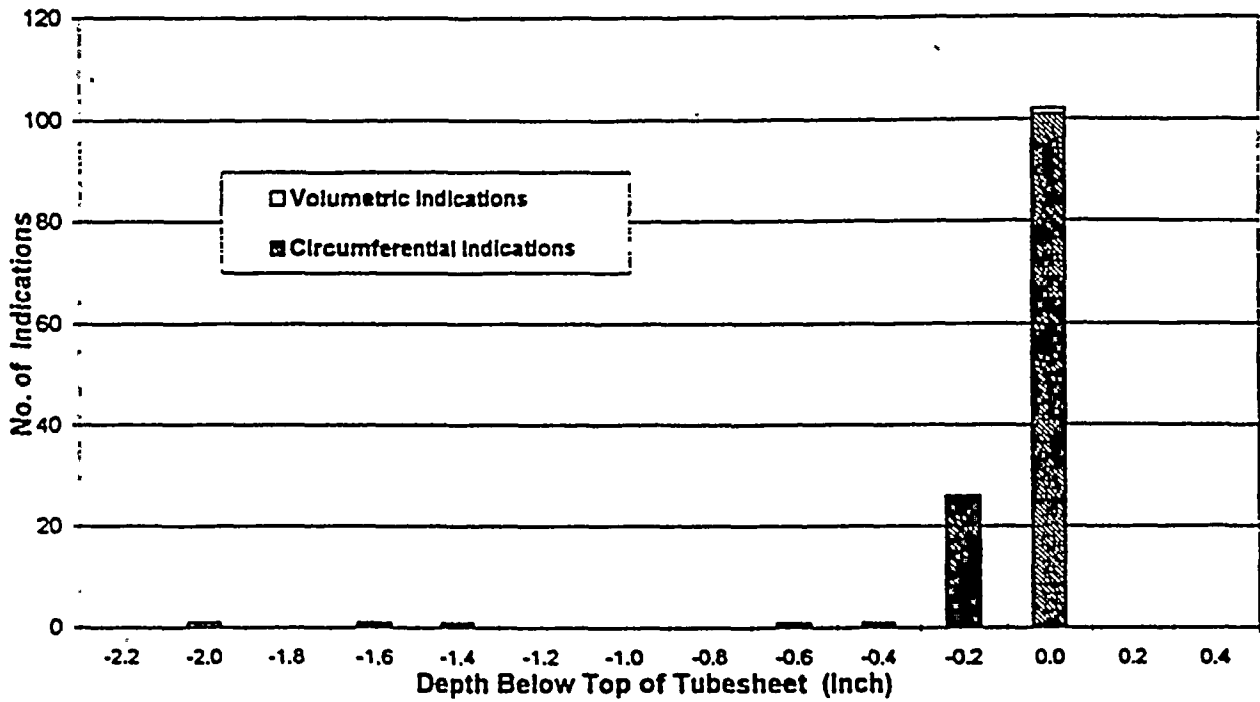


Figure 7.1.3b - Number of Single and Multiple Axial Indications vs. Depth Below Top of Tubesheet or BWT

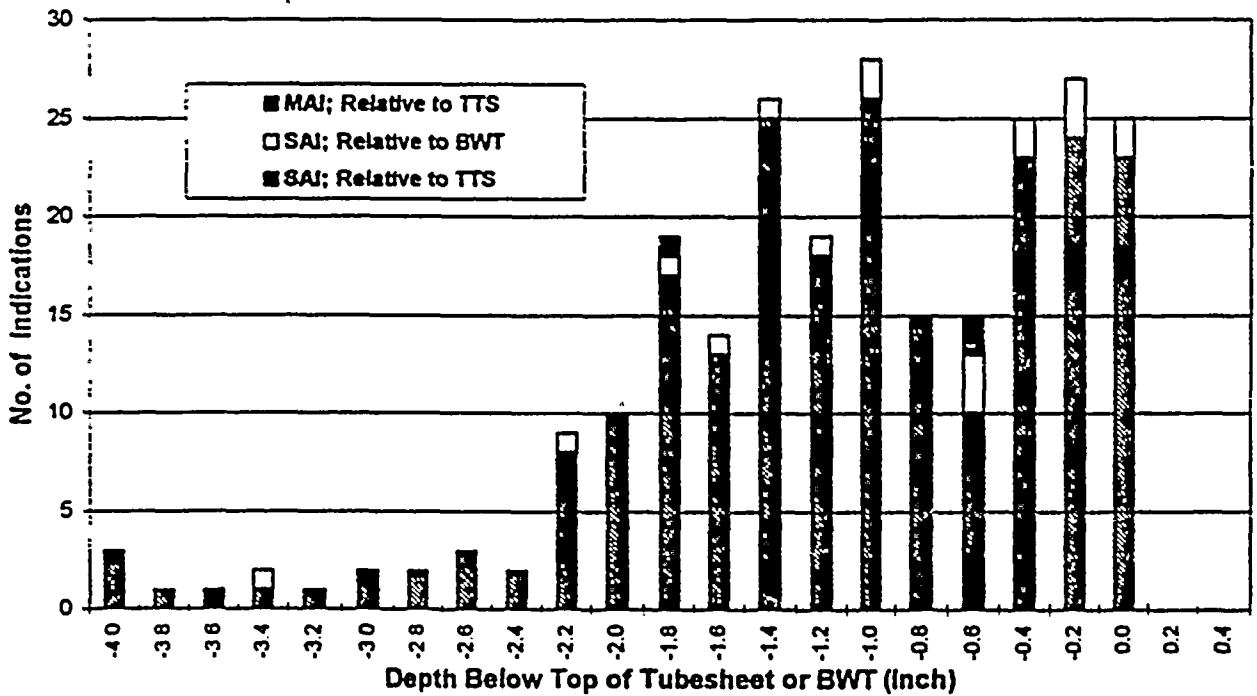
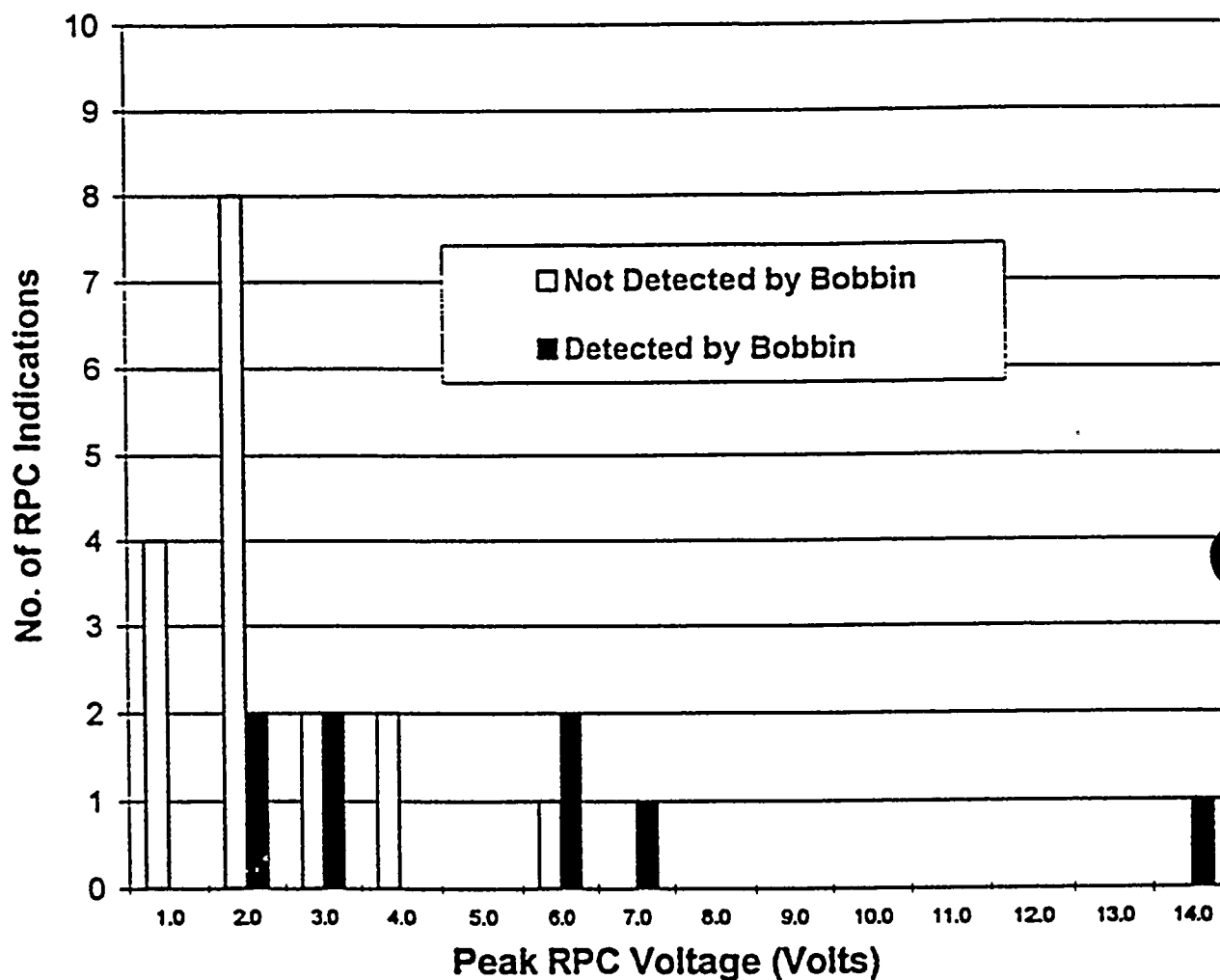


Figure 7.2-1  
Bobbin Detection of RPC-Confirmed SAls vs. Peak RPC Voltage



## Growth Rates of Axial Indications Below BWT

### Growth Rates Evaluated for Two Plants

- 30 indications evaluated for growth in length

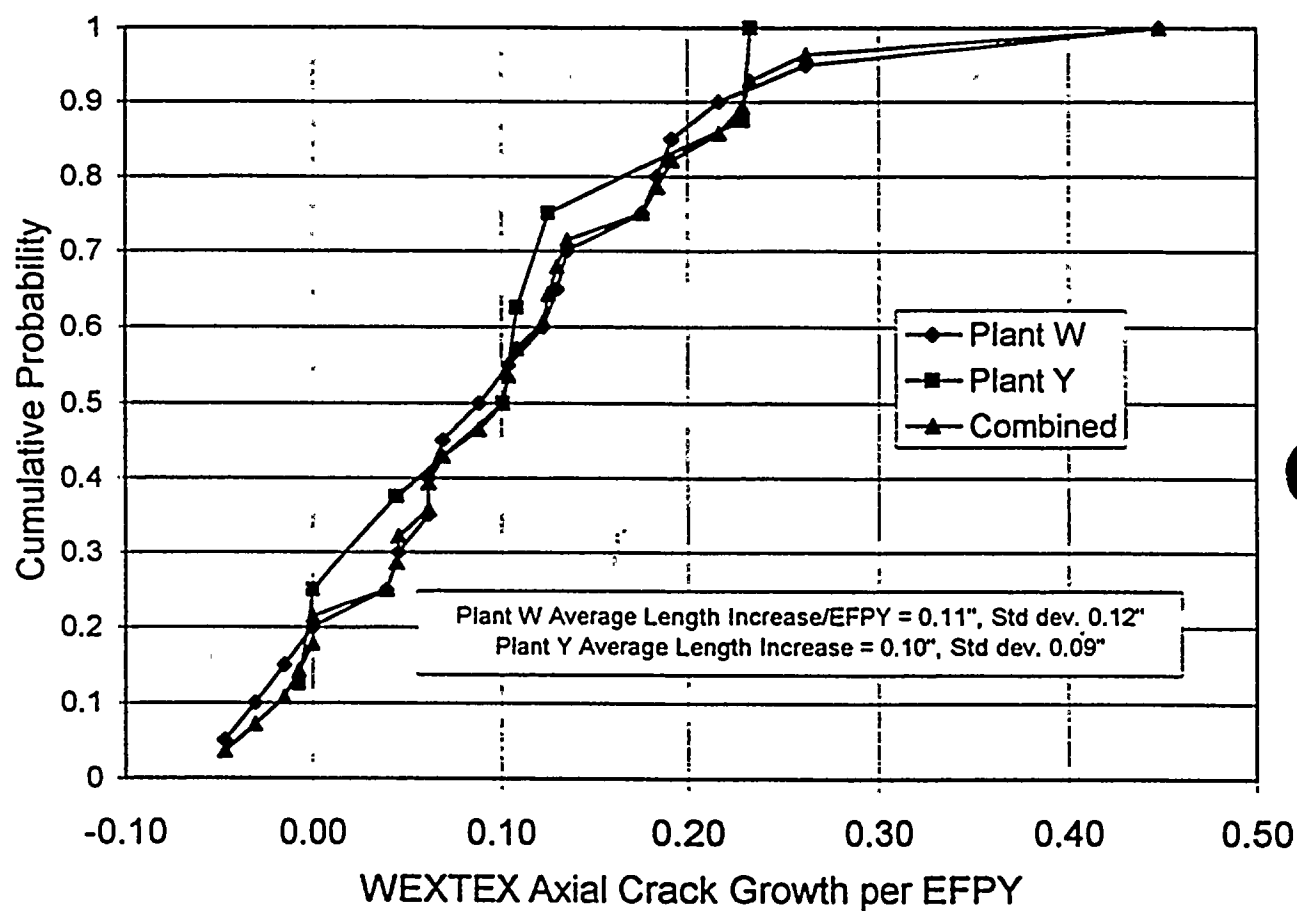
### Crack Length Growth Rate of 0.236" per EFPY at 95% Cumulative Probability

- Judged conservative due to difficulties in sizing initial crack lengths

### Growth Rate Options for W\* Applications

- Apply generic growth value of 0.24" per EFPY or develop plant specific values
- Not considered mandatory to develop plant specific growth rates for W\* applications due to overall conservatism in W\* criteria

# Cumulative Probability Distribution for Growth of W\* Region Axial Indications



## NDE Uncertainties

### Test Specimens

- Tube and tubesheet collar with WEXTEx expansions
- Full length tubesheet mockup with multiple, WEXTEx expanded tubes
- EDM notches
  - Judged conservative for applicable  $W^*$  length measurements since coil lead-in and lead-out effects, which increase crack length measurements, are larger for EDM notches than for tapered cracks

### NDE Data Collection

- Robotic inspection in SG mockup to simulate field conditions
- Probes for which data collected
  - Bobbin
  - + Point
  - Pancake coils - 80, 115 mil

### NDE Data Analysis by Field Resolution Analysts

Analyses of Test Data to Obtain NDE Uncertainties is in Process

## **Summary of Conservatisms in W\* ARC**

**Length of crack assumed to provide no contribution to pullout force**

- **Likely only that WEXTEx expansion pullout resistance affected and thermal expansion, pressure differential and tubesheet bow not affected**

**W\* lengths are most limiting tube in each of two zones and bound all other tubes in the zone**

**Axial cracks assumed throughwall for SLB leakage analyses**

**SLB leak rates are most limiting tube in each of two zones**

**All expansions assumed to have a small gap over upper 0.7" of distance below BWT**

**All growth is assumed toward the BWT for leakage analysis**

# W\* Pullout Load Evaluation

Robert M. Wepfer

Senior Engineer

Westinghouse Electric Corporation  
Nuclear Services Division

## Elements in the W\* Pullout Load Evaluation

- Analysis Conditions and Criteria
- Pull Force Testing
- Analysis of Contact Pressure
- Calculation of Pullout Load Reaction Length (W\* Length)
- Analysis results subject to completion of final checking process



## Analysis Conditions and Criteria

### W\* Analysis Conditions

<u>Parameter</u>	<u>Value</u>	<u>Basis</u>
$T_{hot}$	590°F	Lower bound hot leg temperature estimate
$T_{cold}$	535°F	Lower bound cold leg temperature estimate
$P_{pri}$	2250 psia 2650 psia	Operating primary pressure Feed Line Break pressure conservatively used instead of 2560 SLB value
$P_{sec}$	900 psia 760 psia	Upper bound steam pressure - for tubesheet interaction pressure analysis Lower limit steam pressure - for $3\Delta P$ burst pressure analysis selected from review of plant operating data

### W\* Design Parameters

<u>Parameter</u>	<u>Value</u>
Tube O.D.	0.875 inch
Tube I.D.	0.775 inch
Tubesheet Hole Diameter	0.890 inch

## Analysis Conditions and Criteria

### Tube Burst - Normal Operating Conditions

- RG 1.121 Criteria for Tube Burst of  $3\Delta P_{n.o.}$
- Load Developed from Pressure Acting on Area of Expanded Tube OD (0.890" dia)
- Bounding Min. Steam Pressure of 760 psia Selected from Review of Plant Operating Data
- Normal Condition Axial Pullout Load Criterion:

$$\begin{aligned} F &= 3 * (P_{Pri} - P_{Sec}) * (\pi/4) * (\text{Tube OD})^2 \\ &= 3 * (2250 - 760) * (\pi/4) * (0.890)^2 = 2781 \text{ lbs.} \end{aligned}$$

## Analysis Conditions and Criteria

### Tube Burst - Faulted Conditions

- Feedline Break (FLB)  $\Delta P$  of 2650 psia used as compared to Steam Line Break (SLB) of  $\Delta P$  of 2560 psia
- Load Developed from Pressure Acting on Area of Expanded Tube OD (0.890" dia)
- ASME factor of safety of  $1.0/0.7 = 1.43$  applied
- Faulted Condition Axial Pullout Load Criterion:

$$F = 1.43 * (P_{Pri} - P_{Sec}) * (\pi/4) * (\text{Tube OD})^2$$

$$= 1.43 * (2650 - 0) * (\pi/4) * (0.890)^2 = 2358 \text{ lbs.}$$

## Pull Force Testing

### Test Objectives and Description

#### Objective:

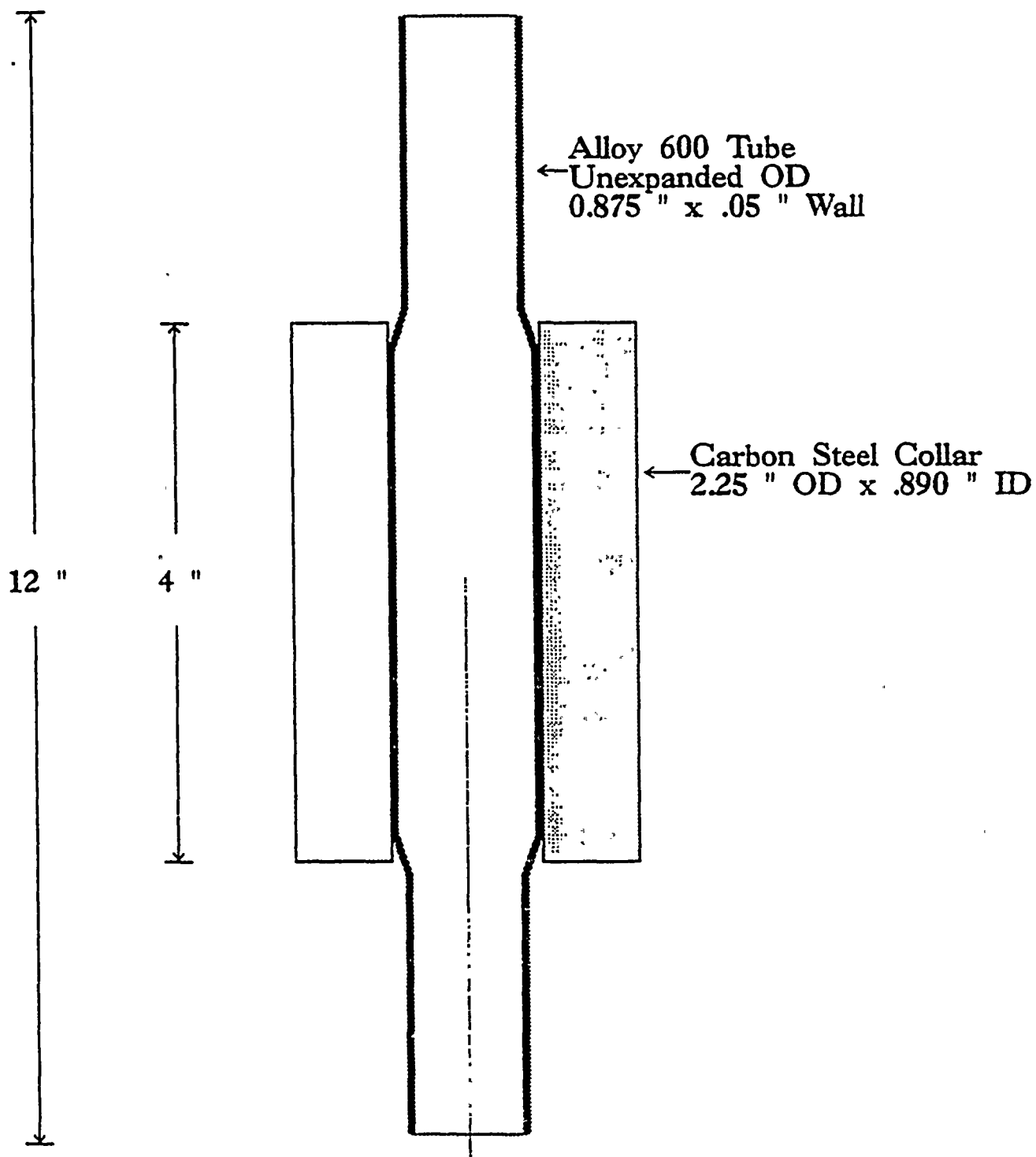
To determine the coefficient of friction between the tube and tubesheet collar and the nominal radial interference pressure due to WEXTEx expansion

#### Specimen Preparation:

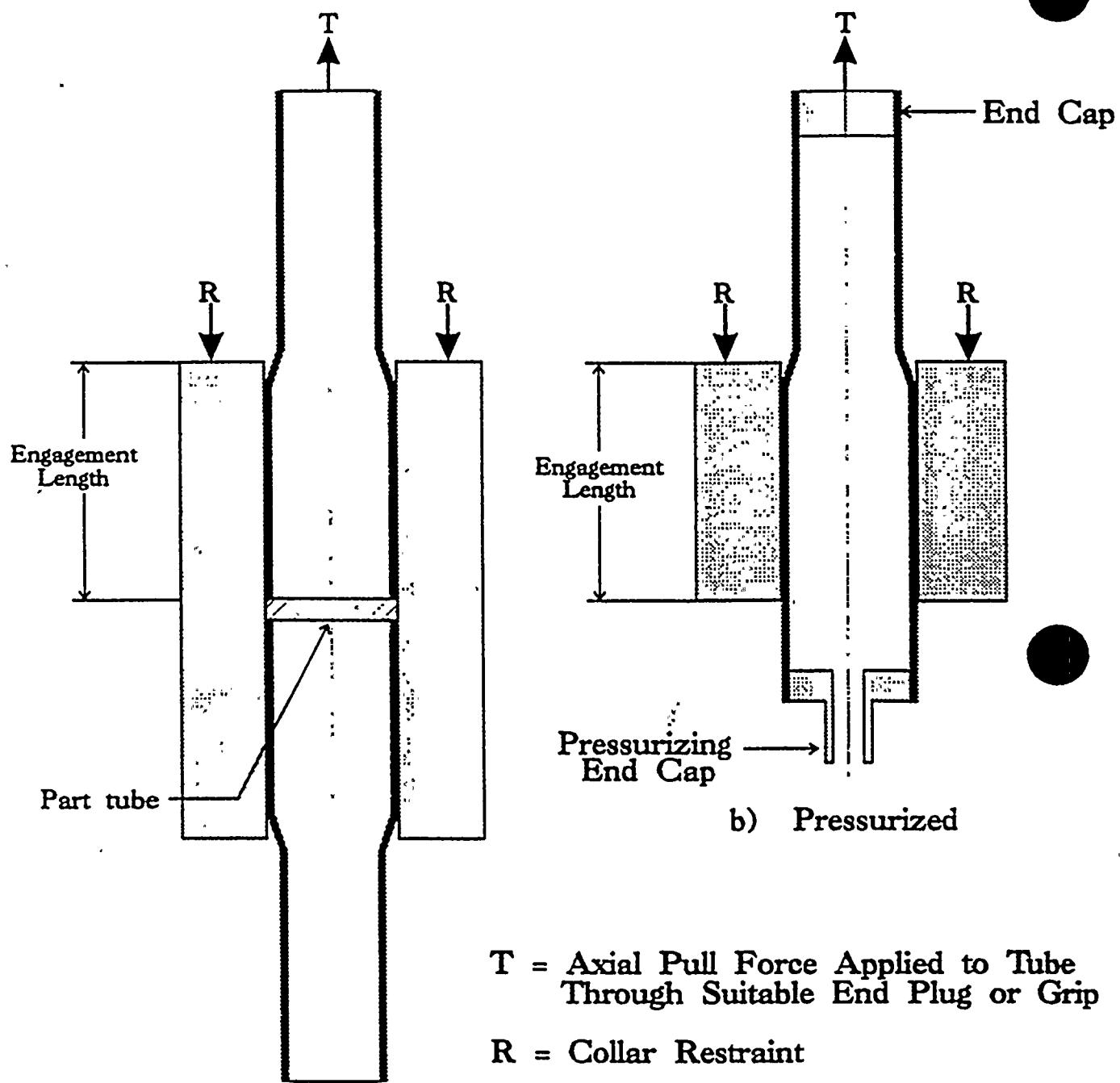
- Tubes expanded with nominal WEXTEx conditions
- Average sample length approx. 4"
- 0.875" x 0.050" Alloy 600 tubes
- Expanded into 1018 CR collars sized to simulate the radial stiffness of the tubesheet
- Typical collar ID surface finish of 100 to 250 rms

#### Testing:

- Each specimen tested at four conditions:
  - Room temperature
  - 400°F, Zero ID pressure
  - 600°F, Zero ID pressure
  - 600°F, 1635 ID pressure
- Pull forces obtained for each test condition



As-Fabricated WEXTEx Samples for Pull Tests



a) Unpressurized

b) Pressurized

Pull Force Sample Configurations Tested

## Pull

b, c, e

## Pull Force Testing

### Test Results

Linear Regression Fit of 4 Data Points for Each Sample:

Sample No.	$\mu$ , Friction Coefficient	SrW, WEXTEx Radial Contact Pressure

Limiting Condition:

- WEXTEx average friction coefficient =  $\left[ \begin{array}{c} \phantom{0} \\ \phantom{0} \end{array} \right]^{b,c,e}$
- WEXTEx average expansion pressure =  $\left[ \begin{array}{c} \phantom{0} \\ \phantom{0} \end{array} \right]^{b,c,e}$



## Pull Force Testing

### Pullout Load Reaction Length Calculation

- Pullout Load Reaction Length (PLRL)

$$\text{PLRL} = \frac{\text{Applied Axial Load}}{(\text{Integrated Contact Pressure} * \pi * D * \mu)}$$

where,

$\mu$  = average tube-to-tubesheet friction coefficient

D = expanded tube outside diameter

and Contact Pressure = Operating Contact Pressure  
+ WEXTEx Contact Pressure

# Tubesheet Structural Analysis

## Overview

### Purpose of Analysis:

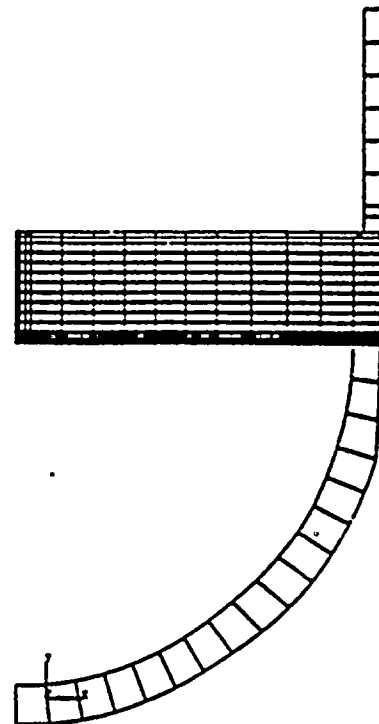
Provide a model to represent changes in tube/tubesheet contact pressure for variations in:

- Operating conditions (temperature, pressure)
- Radius from tubesheet centerline axis
- Depth below secondary face of tubesheet

Results used in conjunction with test to determine radial contact pressure at each location of tubesheet.

### Model Configuration:

- Model 51 FEM
- 2-D, Axisymmetric
- Unit Loadings
- Results for analysis conditions determined by scaling

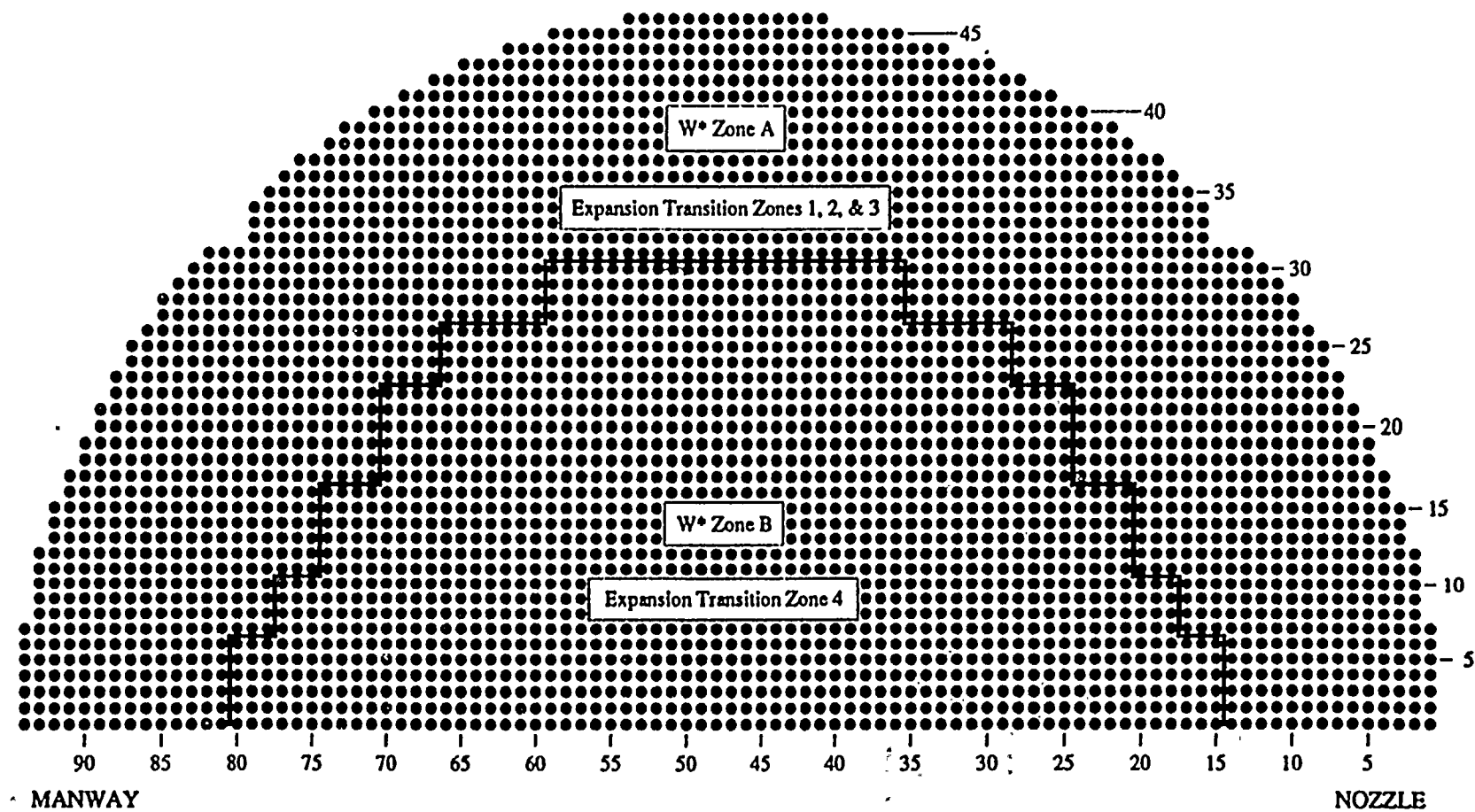


## Tubesheet Structural Analysis

### Observations for $W^*$ Conditions

- Radial contact pressure increases with distance (depth) from top of tubesheet
- Radial contact pressure is lower near tubesheet centerline axis, higher at periphery
- Radial contact pressures are lower on cold leg than on hot leg

# W\* Zone A and Zone B Boundaries



### W\* Length Calculation for Normal Conditions - Hot Leg

Depth	Total Contact Pressure		Incremental Load		Cumulative Load	
from TTS	R=2.28" (Zone B)	R=37.7" (Zone A)	R=2.28" (Zone B)	R=37.7" (Zone A)	R=2.28" (Zone B)	R=37.7" (Zone A)

c, e

**W\* Length**

c,e

## W\* Length Summary

Condition	Location	Radial Distance from Tubesheet Centerline	
		R= 2.28" (W* Zone B)	R= 37.7" (W* Zone A)
Normal	HL	6.4	5.0
Normal	CL	6.9	5.2
Faulted	HL	5.0	3.0
Faulted	CL	5.2	3.1

## Conservatism in W\* Length Calculations

- Lower value of  $\mu$  and WEXTEx radial pressure used
- "Clean" crevice conditions used in test; significantly higher pullout loads observed in samples exposed to doped steam
- Crevice deposits expected to increase radial contact pressures
- No pullout load resistance assumed over entire axial extent of an axial crack

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- The potential for burst-type leakage is essentially eliminated by the presence of adjacent U-bends (interior tubes) and lockup at tube support plates





**W\* ARC**  
**SLB Leak Rate Methodology**

**Meeting with NRC**  
**November 20, 1996**

**Presented by**  
**G. P. Lilly**  
**Westinghouse, NSD**

## **W\* Leak Rate Modeling**

### **Purpose**

**Develop and Apply Model for Calculating Leakage from Cracks within a WEXTEx Crevice**

### **Summary**

- **Background - Previous Modeling**
- **Model Changes, Leak Tests with Constrained Crack Opening**
- **Model Test Data Bases and Results**

## **W\* Leak Rate Modeling**

### **Background - Previous Modeling**

- Developed Leak Rates for Cracks in Series with WEXTX Crevices
- Basis
  - Free Span Crack Opening Assumed
  - Crevice Loss Coefficient Based on Crevice Leak Tests, Correlated with Contact Pressure
  - Calculated Contact Pressure for Field Application
- Results: Leak Rates vs Geometry and Operating Condition Factors
  - Normal / Faulted Operating Conditions
  - Tube Position on Tubesheet
  - Crack Length and Depth

### **Model Changes**

**Integrate New Data Base for Constrained Crack Opening Leak Tests into Leak Rate Model**

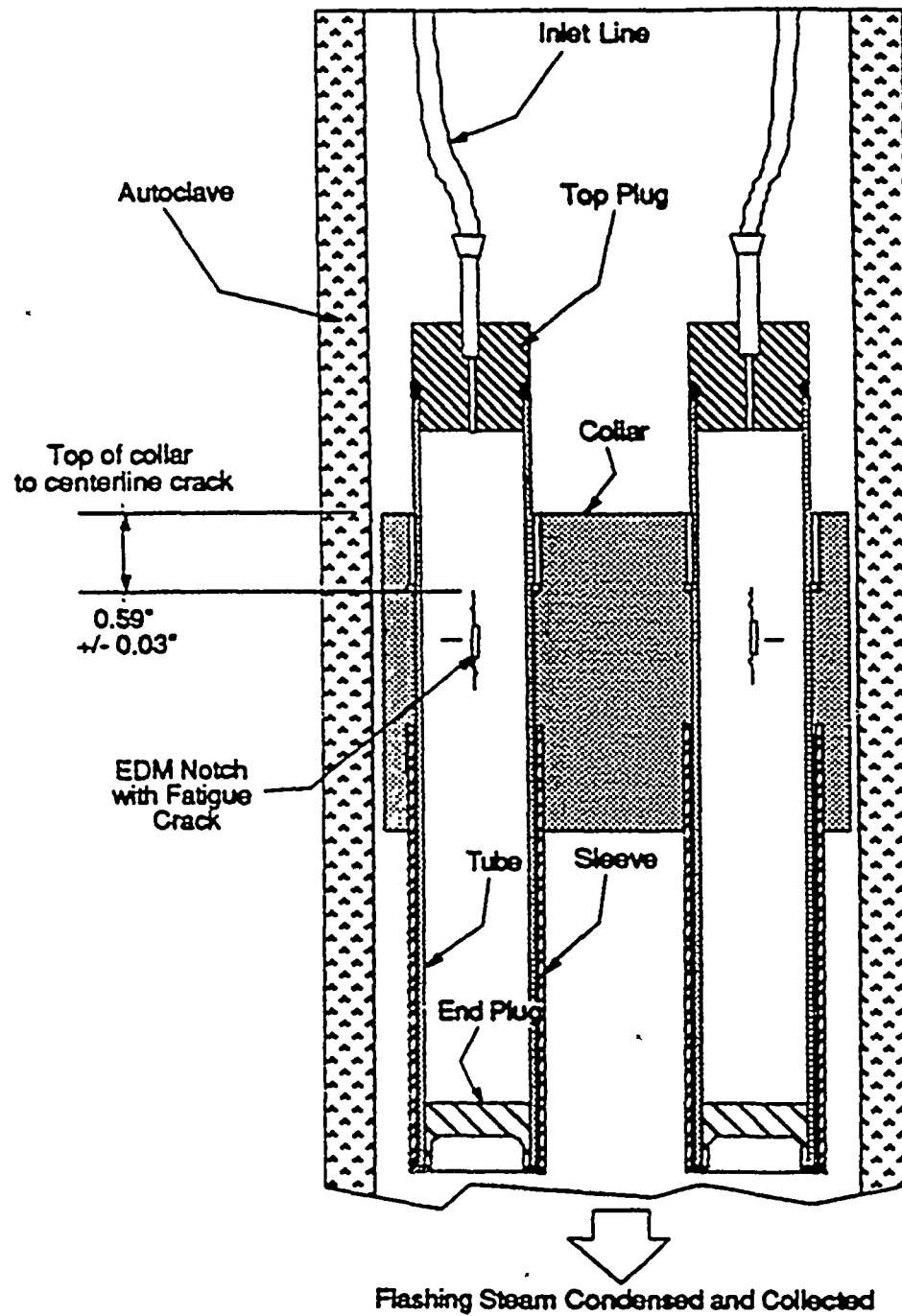
## **Leak Tests with Constrained Crack Opening**

- Cracks Leak Tested at Free Span and in Constraining Collar with Controlled Gap/ Interference Fit
- Tests Designed to Eliminate Crevice Resistance Effect

## **Constrained Crack Leak Test Results**

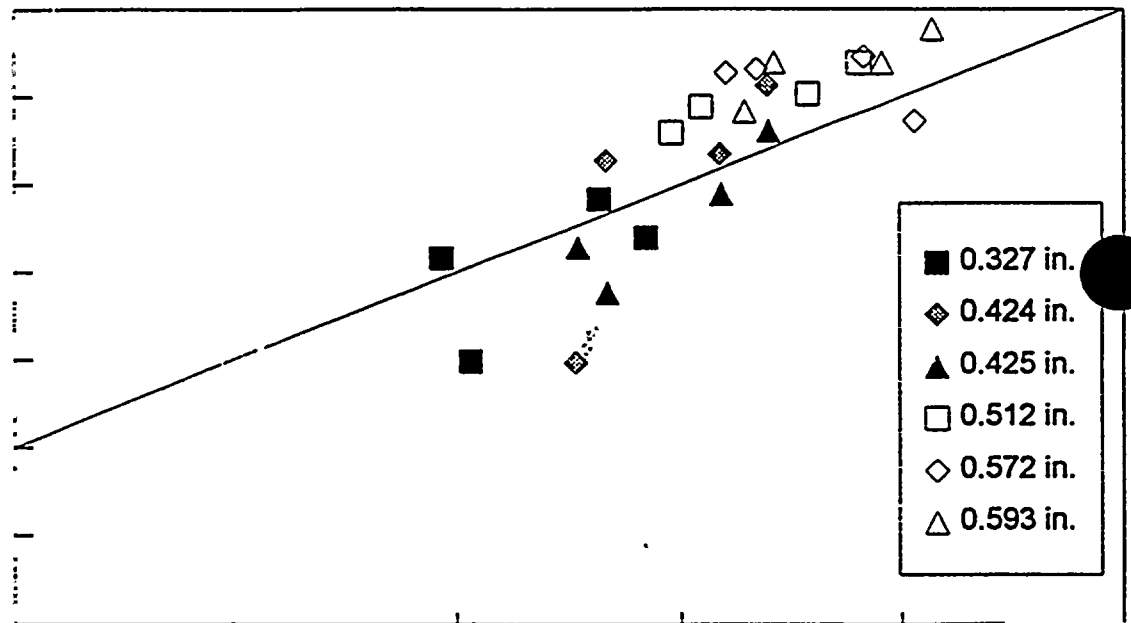
- Comparison with CRACKFLO, Code for Calculating Free Span Crack Leak Rates
  - Free Span Tests
  - "Closed Gap" Collar Tests
  - "Tight Gap" Collar Tests
- Determination of an "Effective Crack Length"
  - Effective length of a crack is the length of a free span crack which leaks at the measured rate
  - The correlating parameter is tube/tubesheet contact pressure

## W\* Leak Rate Modeling



# Free Span Results Predicted vs. Measured

Test Leak Rate - GPM

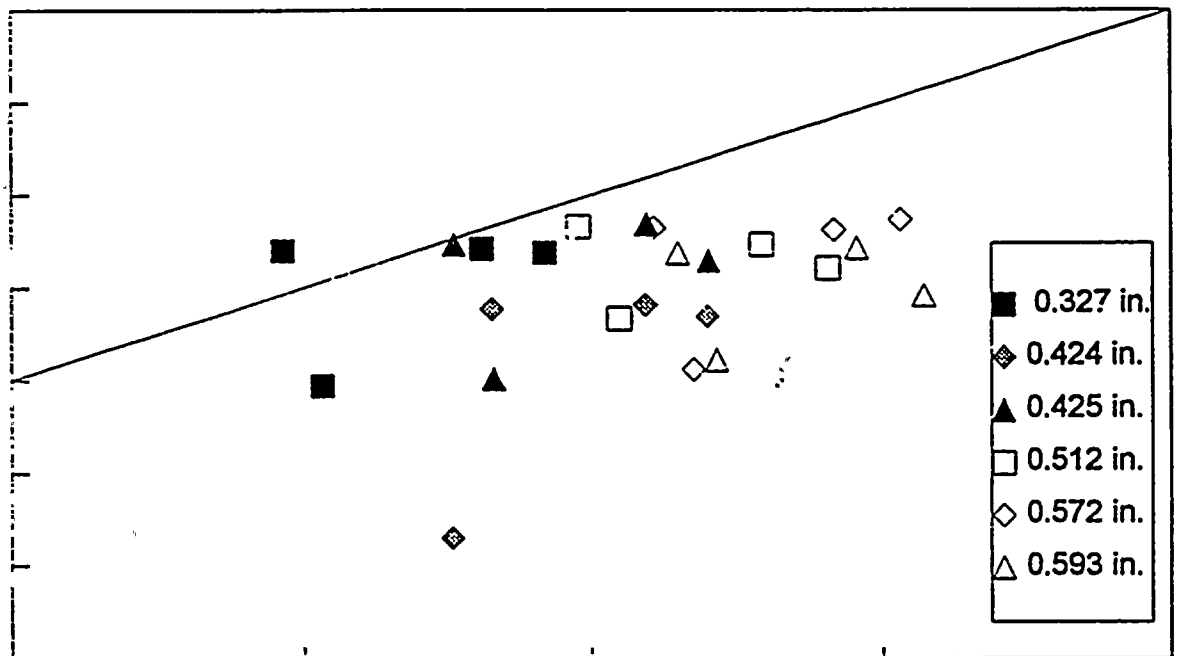


CRACKFLO Leak Rate - GPM

# Constrained Crack Results Closed Gap - Collar B

Test Leak Rate - GPM

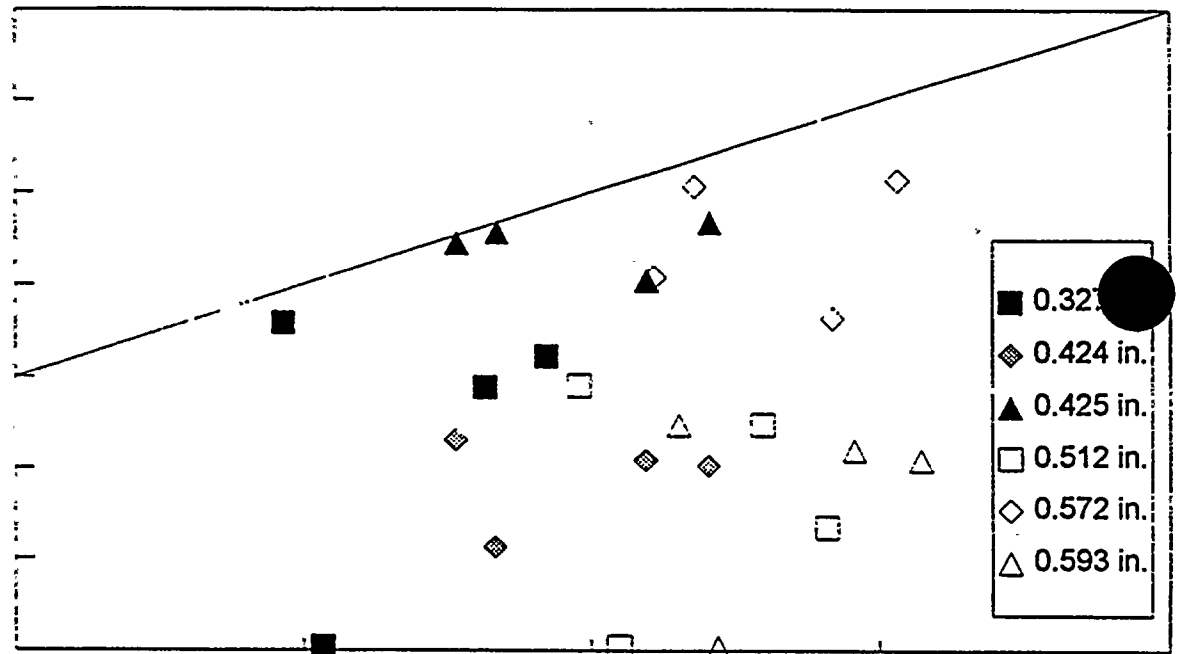
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CRACKFLO Leak Rate - GPM

# Constrained Crack Results Tight Gap - Collar A

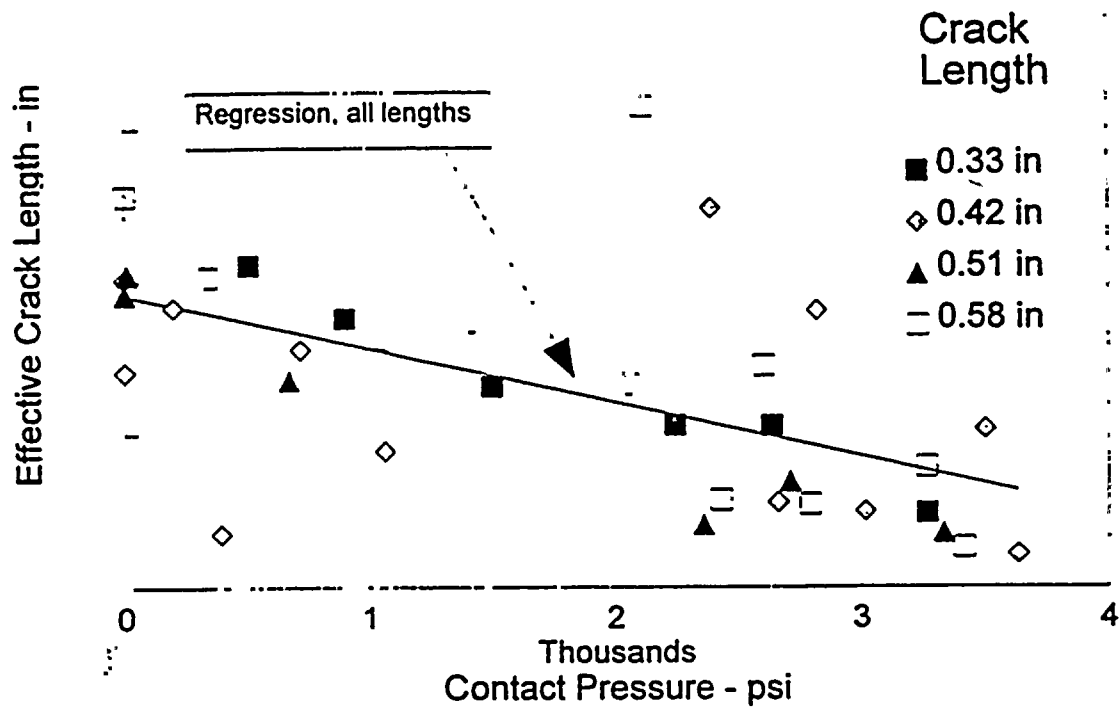
Test Leak Rate - GPM



CRACKFLO Leak Rate - GPM



## Effective Crack Length vs Contact Pressure



## W\* Leak Rate Modeling

### Leak Rate Model

- Uses the DENTFLO Code which solves for leakage of a tube crack in series with a crevice resistance.
- The crack element of the leakage path assumes an effective length derived from the constrained crack data. Effective length is a function of contact pressure and independent of crack length.
- The crevice element of the leakage path uses a crevice loss coefficient derived from leak rate tests through WEXTEx crevices. Loss coefficient is a function of contact pressure.

### Leak Rate Calculations

Parameters which determine leak rate are:

- Primary and secondary side fluid conditions - SLB assumed
- Crack depth and tubesheet radial position. These two parameters define contact pressure:
  - At the crack depth  $\Rightarrow$  Effective crack length
  - Along the crevice  $\Rightarrow$  Crevice loss coefficient

Analysis results are subject to completion of final checking process

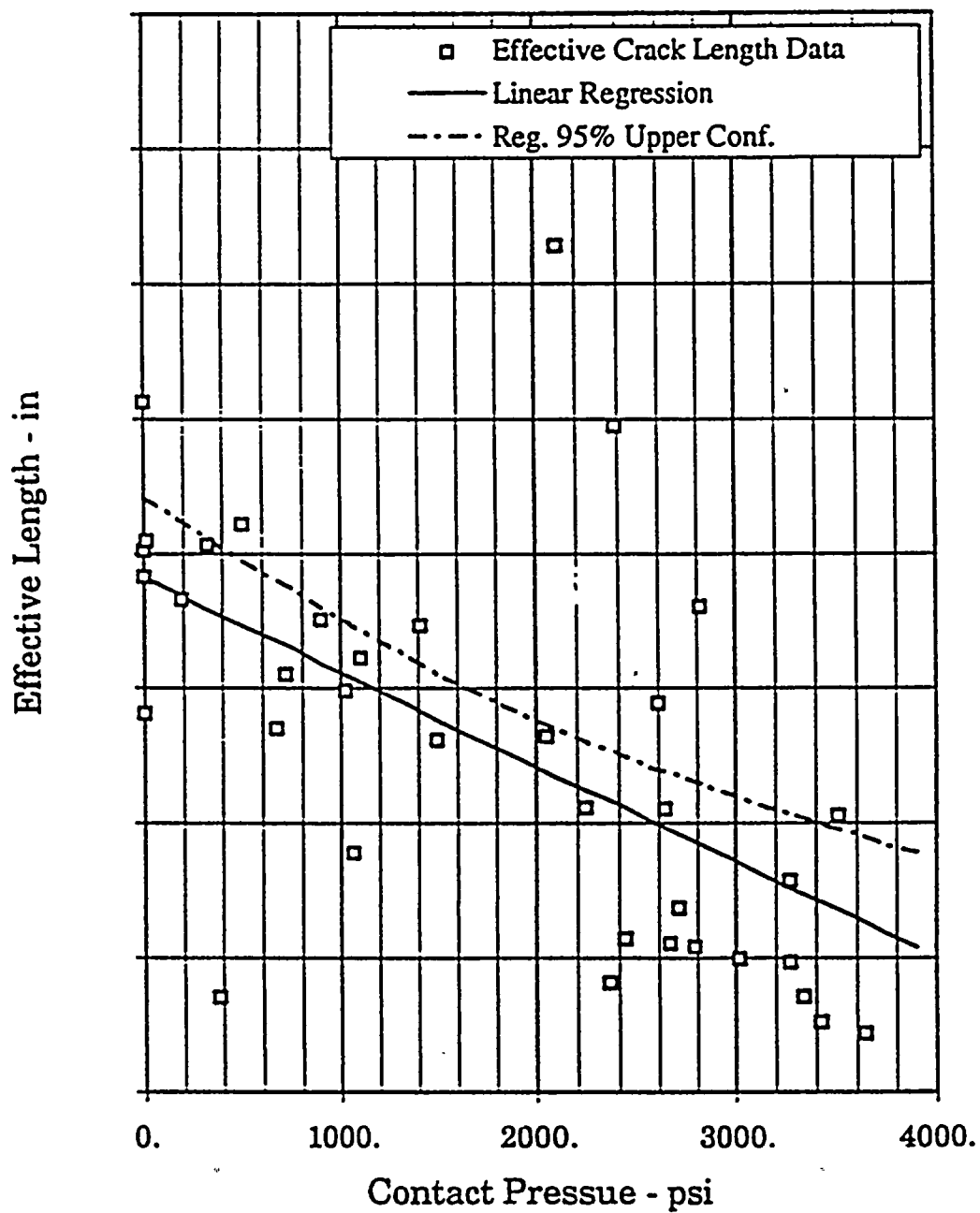
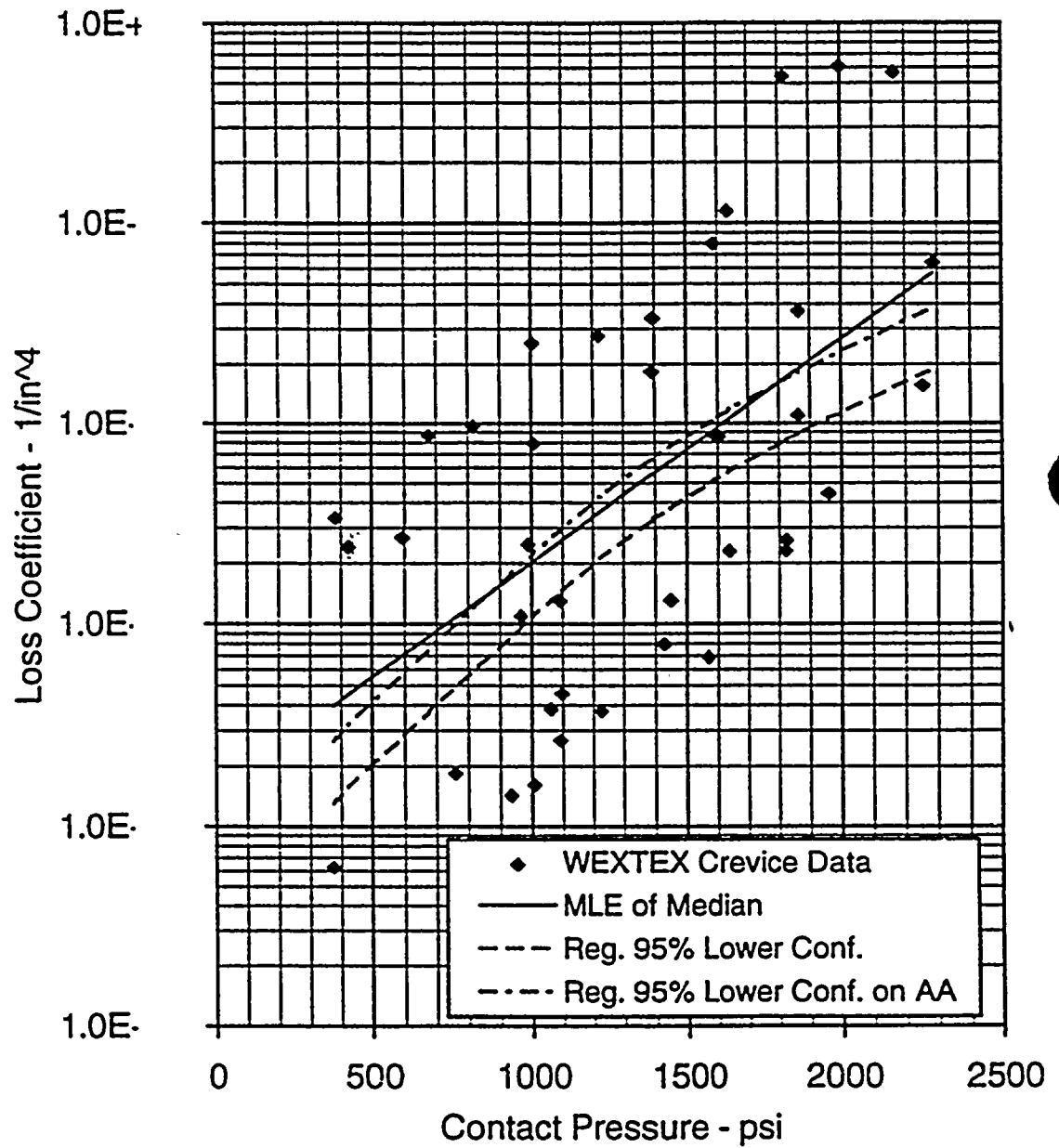
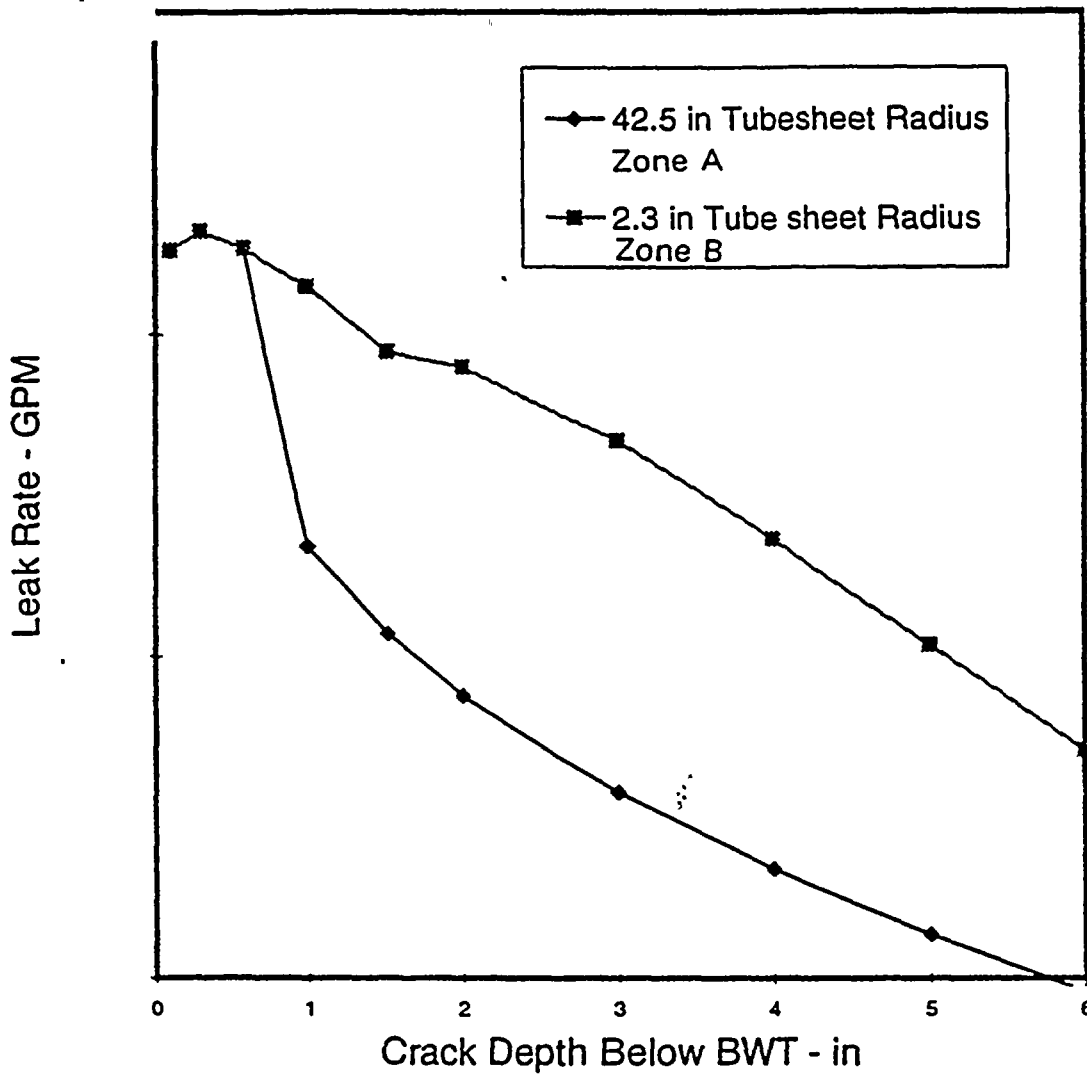


Figure 6.4-1 Effective Crack Length Versus Tube-to-Tubesheet Contact Pressure

# WEXTEx Crevice Loss Coefficients vs Contact Pressure



## WEXTEx Crack/ Crevice Leak Rate Hot Leg





Model 51 SG Limited SLB TSP Displacement  
Summary of WCAP-14707

NRC/Utility Meeting

November 20, 1996

Presented By:

T. A. Pitterle

Nuclear Services Division

Westinghouse Electric Corp.

# **WCAP-14707: Model 51 SG Limited TSP Displacement Analyses for Dented or Packed Tube to TSP Crevices**

**Axial Pull Forces to Determine Loads Required to Displace TSPs Relative to  
Tube for Packed or Dented Intersections**

**Leakage Tests with Packed or Dented Intersections**

**Hydraulic SLB Loads on TSPs (RELAP5, TRANFLO)**

**Dynamic Structural Analyses for TSP Displacements**

**Assessment for SLB TSP Displacements with Dented or Packed Crevices**

**Revision to WCAP-14707 in Process**

- Local TSP structural analyses for Hot to Cold Condition



## Tube/TSP Displacement Force Tests

### Laboratory Pull Force Tests

- TSP displacement forces of 80 to 4200 lbs for laboratory induced dented specimens

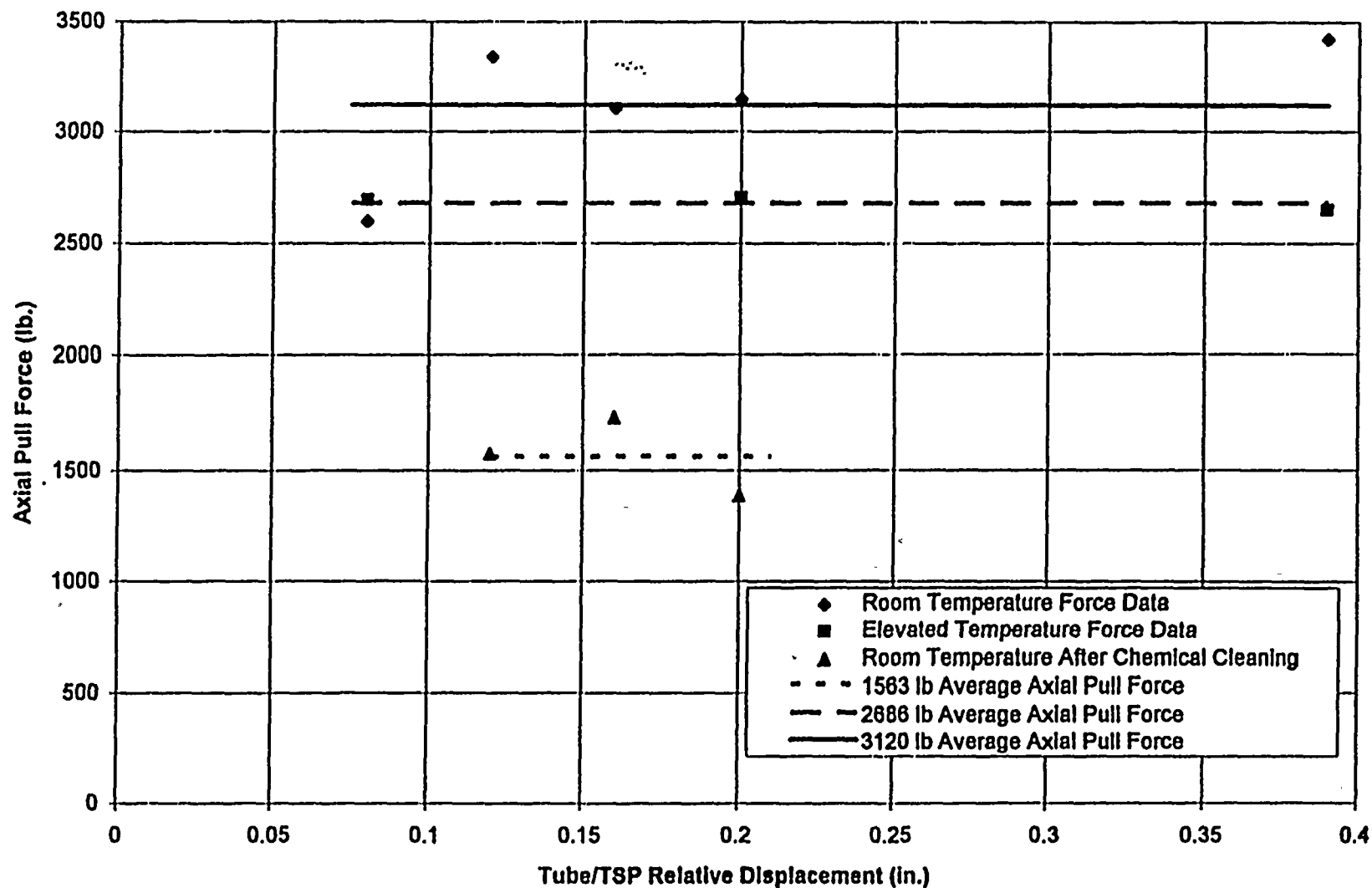
### Pulled Tubes

- Tube breakaway forces of 925 to 2650 lbs

### French Dampierre-1 Tubes Removed from SG with TSP

- Non-dented tube/TSP intersections
- Average of 23 measurements yields 3120 lbs to move tube at room temperature and 2686 lbs at operating temperatures
  - Forces at lower 90% confidence are 2106 at room temperature and 1635 at operating temperature
- Forces approximately independent of TSP displacements up to 0.4"

**Tube/Tsp Axial Pull Force vs. Displacement**  
**Dampierre-1 Removed Tubes and TSP with Crevice Deposits**



## Leakage for Indications at Packed and Dented TSPs

### Laboratory Leak Rate Tests

- Essentially no leakage for throughwall cracks up to 0.7" at SLB conditions

### Dampierre-1 Leak Rate Tests for Tubes/TSP Removed from SG

- Crevice deposits limit leakage to negligible levels ( $< 0.004$  gpm for TW hole in tube)
- Leakage essentially independent of TSP displacements up to about 0.16"

### Conclusion

- Leakage from indications within packed or dented TSPs result in negligible leakage

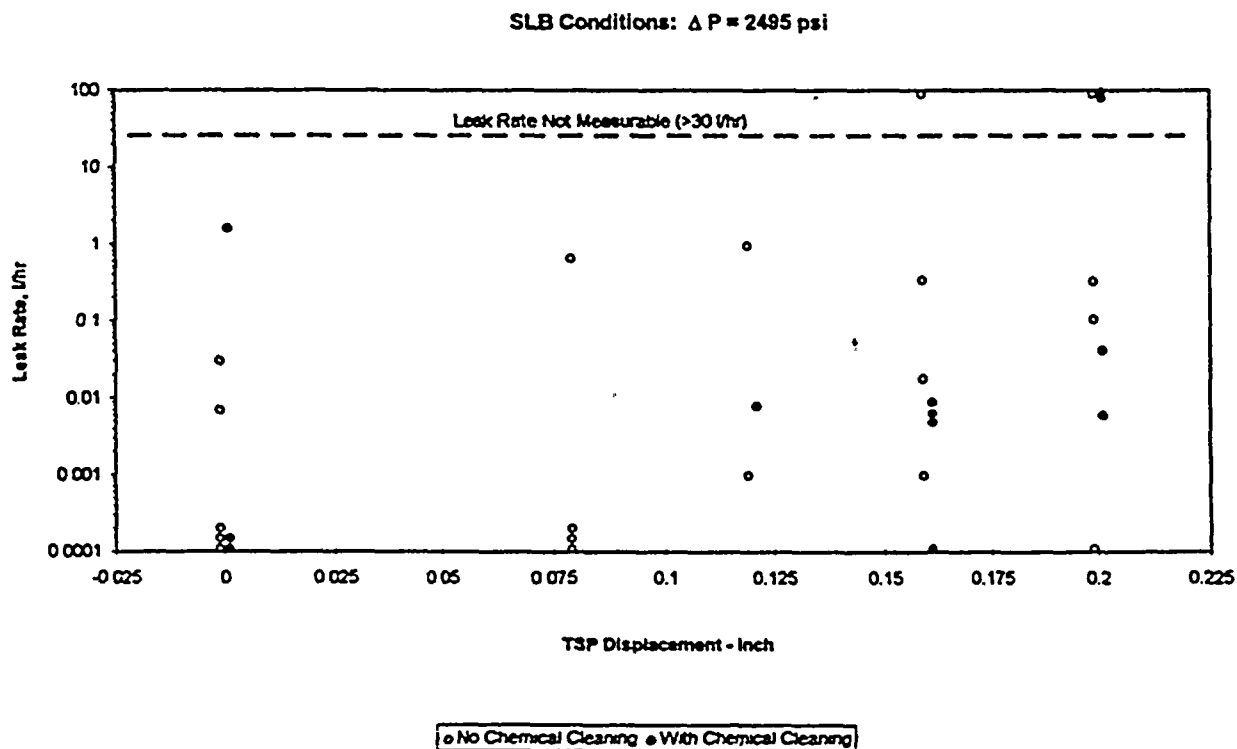
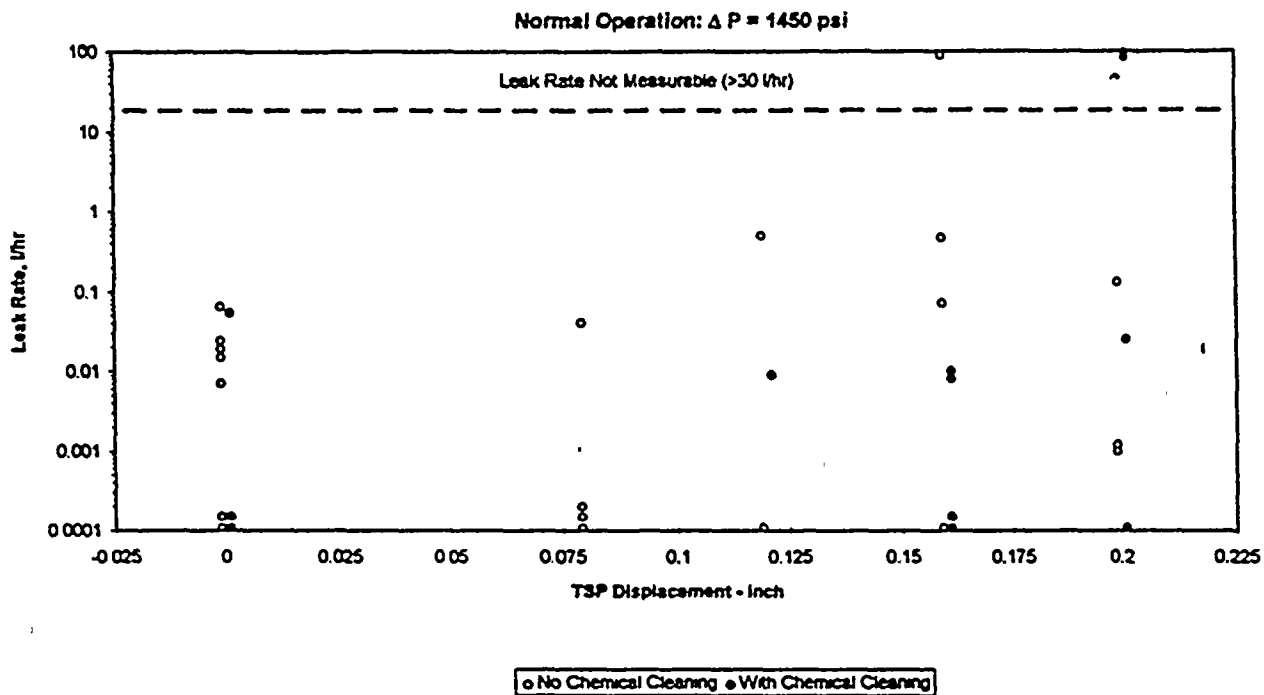
# **Summary of Laboratory Leak Rate and Pull Force Test Results for Dented TSP Intersections**

<b>Specimen</b>	<b>Dent Volts</b>	<b>TW Crack Length, in.</b>	<b>SLB Leak Rate, gpm</b>	<b>TSP Pull Force, lbs</b>
FAT-1	7.4	0.500	0.0	-
FAT-2	6.1	0.299	0.0	4,200
FAT-3	12.1	0.300	0.0	3,220
FAT-4	12.0	0.697	0.0	-
FAT-5	4.6	0.300	-	475
FAT-6	0.0	0.302	-	700
FAT-7	9.4	0.509	0.0	-
FAT-8	17.4	0.707	0.0	-
FAT-9	3.4	0.513	-	85
FAT-10	2.5	0.701	-	85
FAT-11	2.8	0.499	0.0002	80
BW-3	6.3	0.78 <sup>(1)</sup>	0.0	-
BW-9	6.4	0.65 <sup>(1)</sup>	0.0	-

**Notes:**

- Corrosion crack specimens. Lengths given are total corrosion crack length of known TW cracks. TW lengths were not measured.

# Leak Rates (Dampierre-1 Data) from 20 mil Diameter Hole with Packed Crevice



## **SLB TSP Displacement Analysis Results**

### **SLB Forces on TSP to Cause Displacement**

- Maximum force on TSP < 60 lbs even for SLB upstream of flow restrictor

### **Conclusions**

- SLB forces acting on TSPs are much smaller than the forces required to displace the TSP with packed crevices
- 0.1 to 1.3 tubes with packed crevices within tube groups of 13 to 60 tubes are adequate to prevent SLB TSP displacement
- 0.2 to 2.5 tubes per tube group are adequate to prevent TSP displacement even following chemical cleaning

## Overall Conclusions

### **TSPs With Packed Crevices Will Not Displace Relative to the Tube in a SLB Event**

#### **Tube Integrity Analyses Should be Based Upon:**

- Only crack length outside TSP contributes to the potential for tube burst
- Only the throughwall crack length outside the TSP or near the edge of the TSP contributes to potential SLB leakage
  - Even with crack extending outside the TSP, crack opening is restricted by the packed crevice, particularly for dented TSP intersections
- Adequate TSP integrity is retained to prevent tube rupture as long as there is not a loss of a section of TSP at an indication
  - Limited cracking of the TSP ligament at an indication is acceptable provided there is not a loss of a TSP section
  - Acceptable TSP integrity would include one crack at a tube indication or two or more cracks if the adjacent tube intersection has only one crack
- Some denting presence in a SG provides a basis for the TSP corrosion and packed crevices to develop high forces resisting SLB TSP displacement and resulting in negligible leakage for indications within the TSP

## Overall Conclusions

### Alternate Repair Criteria for Indications at Dented TSP Intersections

- Based on TSP preventing tube burst even at SLB conditions for indications within the TSP or negligible (about  $< 0.2$ " ) extension outside of the TSP
- Limiting SLB leakage within acceptable limits would be the basis for tube repair for indications at dented TSP intersections within or negligibly outside the TSP
- ARCs for cracks (PWSCC) extending significantly outside the TSP would be based upon the length of crack outside the TSP relative to achieving structural and leakage integrity



**TSP DISPLACEMENT ANALYSIS FOR  
SERIES 51 STEAM GENERATORS WITH PACKED CREVICES  
LOCAL TSP STRUCTURAL ANALYSES  
HOT - TO - COLD CONDITION**

**RICHARD E. SMITH**

**NOVEMBER 20, 1996**

# **TSP DISPLACEMENT ANALYSIS PRESENTATION OUTLINE**

- INTRODUCTION
- TSP SUPPORT CONFIGURATION
- REVIEW OF GLOBAL (DYNAMIC) MODEL / RESULTS FOR HOT-TO-COLD CONDITION
- GENERAL METHODOLOGY FOR DETAILED EVALUATION
- DEVELOPMENT OF TUBE / PLATE EQUIVALENT PROPERTIES
- FINITE ELEMENT MODEL
- INITIAL MATRIX OF BOUNDARY CONDITIONS TO BE CONSIDERED
- ANALYSIS STATUS
- TUBE / TSP INTERACTION: TUBES EXCEEDING BREAKAWAY FORCE
- TSP STRESS RESULTS
- REMAINING WORK
- ANALYSIS CONCLUSIONS

## INTRODUCTION

- ANALYSIS PURPOSE - EVALUATE LOCKED TUBE CONDITION FOR SERIES 51 STEAM GENERATORS SUBJECT TO DIFFERENTIAL THERMAL EXPANSION FROM FULL POWER TO COLD SHUTDOWN
  
- ANALYSIS OBJECTIVES
  - DETERMINE NUMBER AND LOCATION OF TUBES THAT EXCEED BREAKAWAY FORCE
  
  - CALCULATE PLATE STRESSES FOR THE PRESCRIBED LOADING
  
  - CALCULATE STRESSES FOR WELDS JOINING WEDGES AND SUPPORT BARS TO TSP AND WRAPPER

## **TSP SUPPORT CONFIGURATION**

- **TSP SUPPORTED BY WEDGES, SUPPORT BARS, AND TIERODS / SPACERS**
- **SIX WEDGES SPACED EVERY 60° AROUND PLATE CIRCUMFERENCE**
- **WEDGE WIDTH OF 6" FOR TSP 1 - 6, 10" FOR TSP 7**
- **TWO VERTICAL BAR SUPPORTS LOCATED 180° APART**
- **ONE CENTRAL TIEROD / SPACER, 4 PERIPHERAL TIERODS / SPACERS**
- **WEDGES AND VERTICAL BARS WELDED TO BOTH TSP AND WRAPPER**
- **TIERODS THREADED INTO TUBESHEET, WITH NUT ON TOP OF UPPERMOST TSP**
- **SPACERS LOCATED BETWEEN TSP - NON-LINEAR INTERACTION**

a.c

Figure 8-2. Wrapper / TSP / Wedge Interface



a.c



**Figure 8-4. TSP Support Locations  
TSP 2 - 7**

## **REVIEW OF GLOBAL (DYNAMIC) MODEL / RESULTS FOR HOT-TO-COLD LOAD CONDITION**

- DYNAMIC MODEL LUMPED TUBES INTO 30 GROUPS
- NUMBER OF TUBES / GROUP BASED ON PLATE AREA RATIO
- FINITE ELEMENT MODEL CONSIDERED 7 TSP, CHANNEL HEAD, TUBESHEET, SHELL, TIERODS / SPACERS, AND TUBE GROUPS
- ANALYSIS SHOWED TUBE / PLATE INTERACTION FORCES THAT RANGED FROM 56 LBS. TO 419 LBS.
- MAX FORCES ISOLATED TO AREAS ADJACENT TO WEDGES
- DISPLACEMENT PLOTS SHOW HIGH LOCALIZED DISPLACEMENTS
- DUE TO TUBE GROUPING, DYNAMIC MODEL DID NOT GIVE SUFFICIENT DETAIL IN WEDGE REGIONS
- DETAILED MODELS OF WEDGE REGIONS NEEDED TO CALCULATE TUBE / PLATE INTERACTION FORCES, AND PLATE AND WELD STRESSES



a,c



Figure 8-5. Overall Finite Element Model





a.c

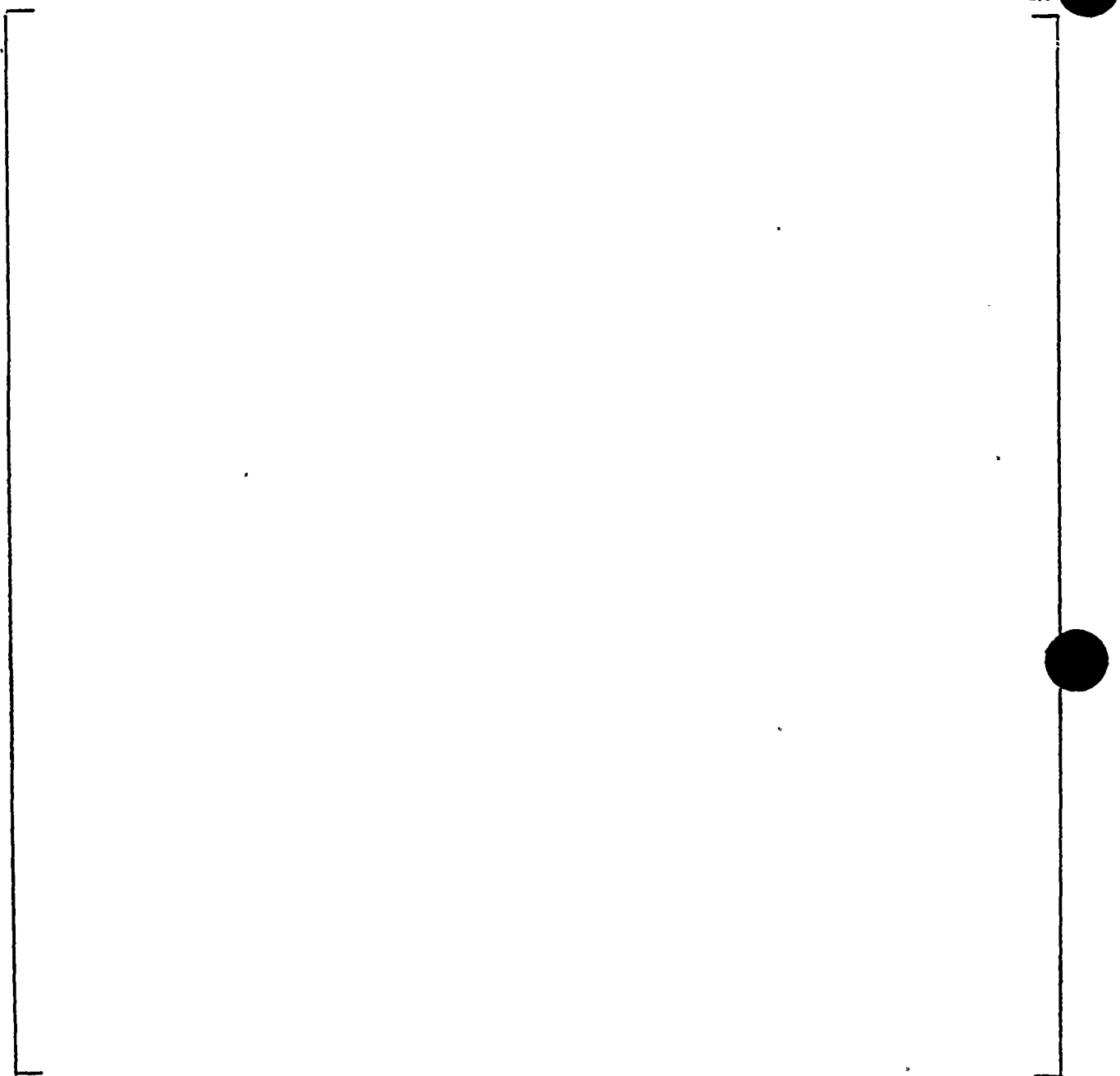
Figure 8-7. Location of Tube Groups  
and Number of Tubes Per Group

### Summary of Maximum Tube / Plate Interface Forces Full Power to Cold Shutdown Conditions

[REDACTED]

a.c

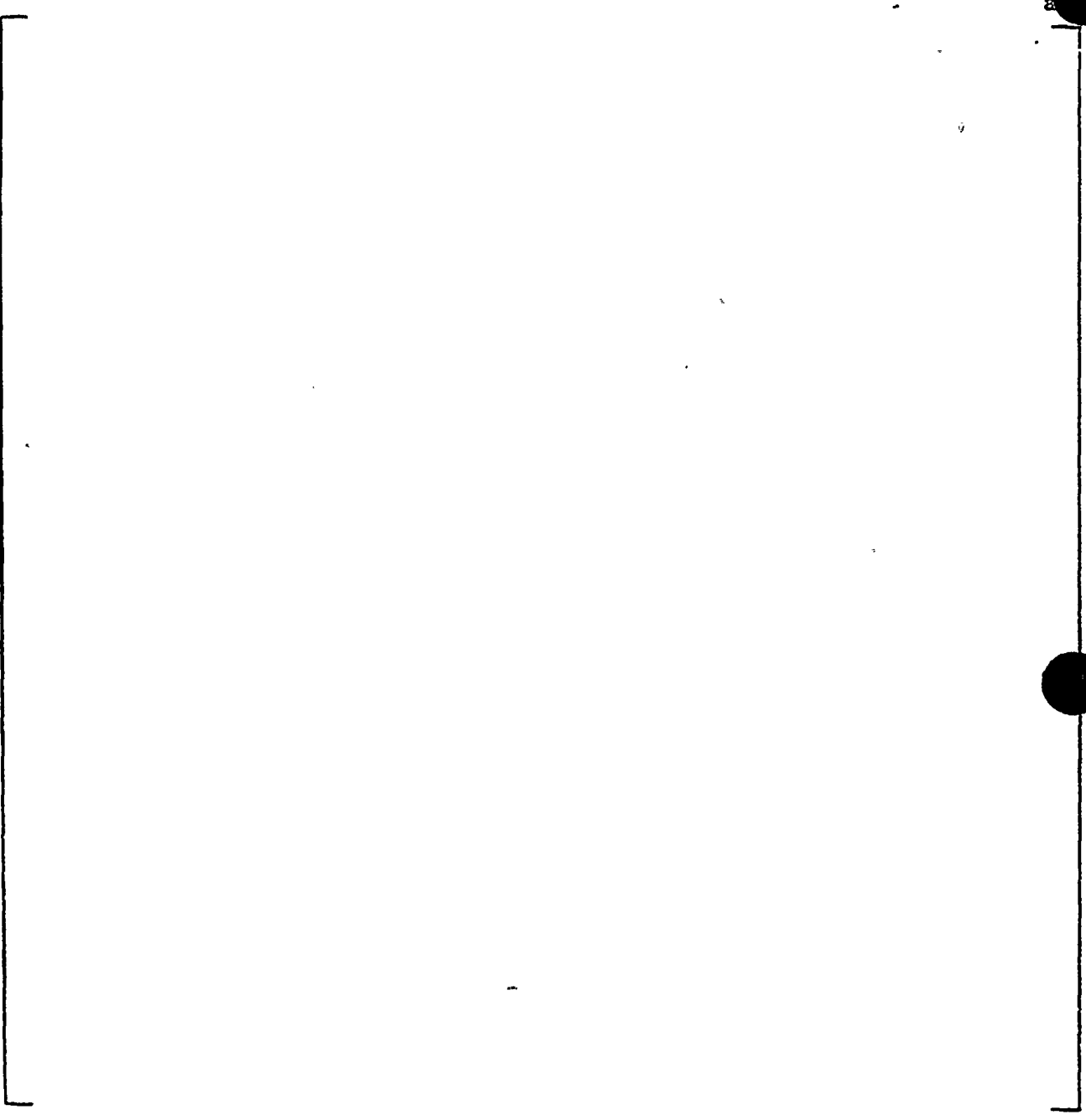
**Figure 10-6. Distribution of Tube / Plate Forces  
Full Power to Cold Shutdown - Plate 6  
Quadrant 1,3 Support Locations**



**Figure 10-7. Distribution of Tube / Plate Forces  
Full Power to Cold Shutdown - Plate 7  
Quadrant 1,3 Support Locations**

a.c

**Figure 10-13. Distribution of Tube / Plate Forces  
Full Power to Cold Shutdown - Plate 6  
Quadrant 2,4 Support Locations**



**Figure 10-14. Distribution of Tube / Plate Forces  
Full Power to Cold Shutdown - Plate 7  
Quadrant 2,4 Support Locations**

a,c

**Figure 10-15. Displaced Geometry Plot  
Full Power to Cold Shutdown  
Quadrant 1,3 Support Locations**

**Figure 10-16. Displaced Geometry Plot  
Full Power to Cold Shutdown  
Quadrant 2,4 Support Locations**

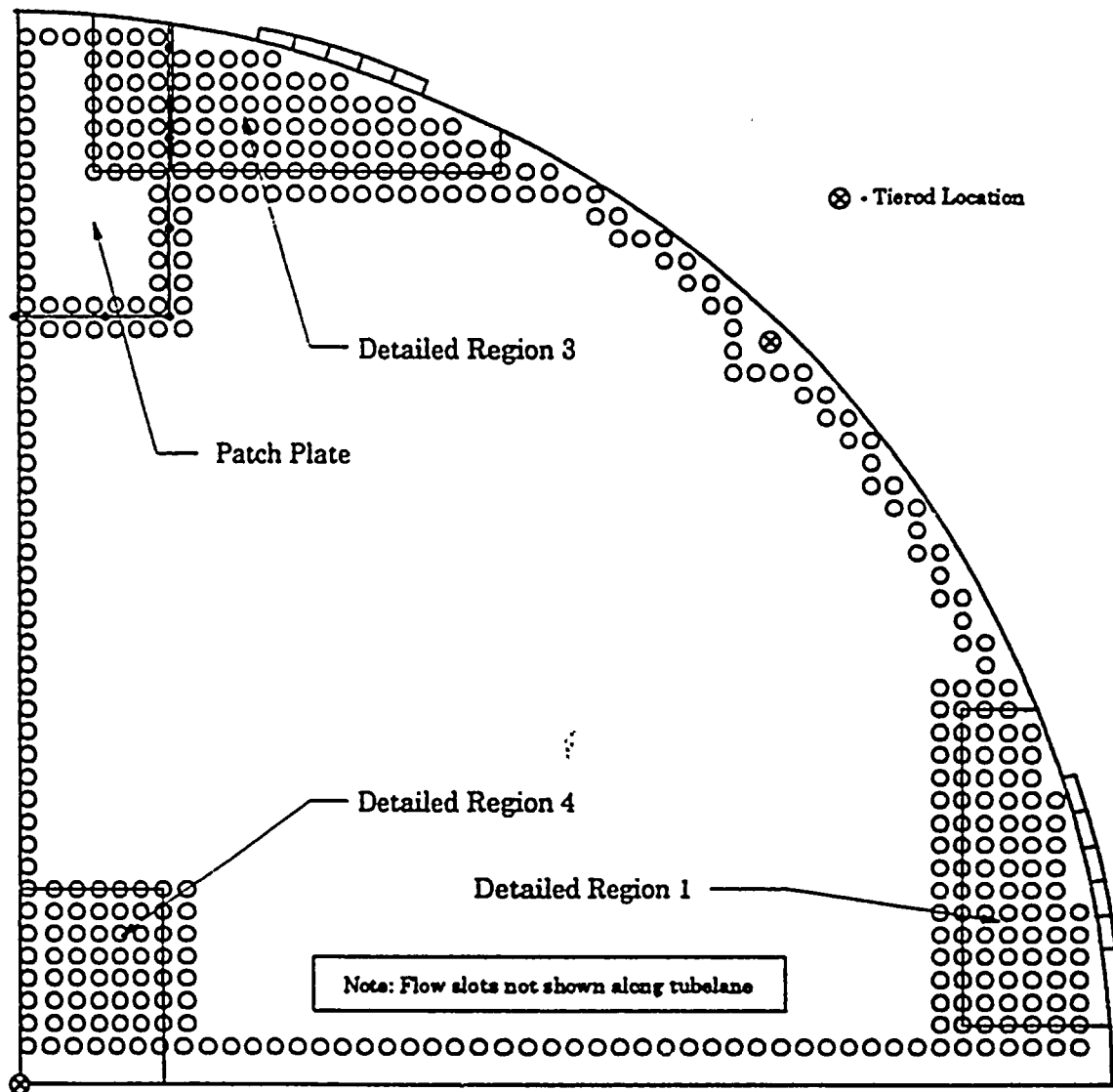


## **GENERAL METHODOLOGY FOR DETAILED EVALUATION**

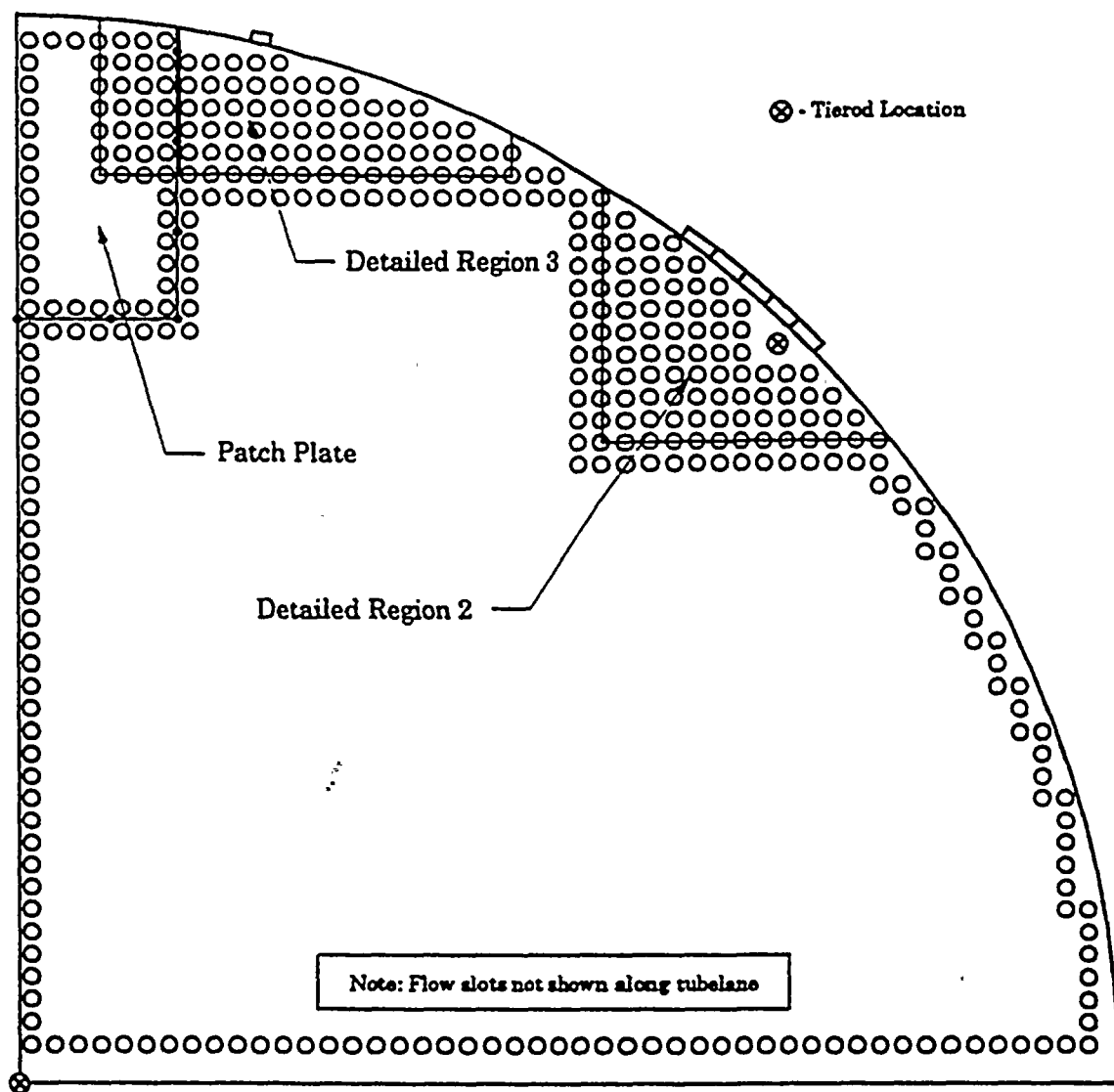
- **DEVELOP DETAILED MODELS OF THREE WEDGE REGIONS AND CENTRAL REGION ADJACENT TO TIEROD**
- **DEVELOP PLATE EQUIVALENT PLATE PROPERTIES FOR LOCAL WEDGE REGIONS USING DETAILED MODELS**
- **MODIFY DYNAMIC MODEL TO INCLUDE MORE DETAILED MODELING OF WEDGE REGIONS AND CENTRAL TIEROD AREA**
- **APPLY TEMPERATURE GRADIENTS TO MODEL**
- **CALCULATE TUBE / PLATE INTERACTION FORCES**
- **FOR ANY TUBE WHERE BREAKAWAY FORCE IS EXCEEDED, DECOUPLE TUBE / PLATE INTERFACE, AND RERUN THERMAL SOLUTION UNTIL CONVERGED SOLUTION RESULTS**
- **ONCE CONVERGED SOLUTION IS OBTAINED, CALCULATE WELD STRESSES**
- **CONSIDER VARIOUS BOUNDARY CONDITIONS TO ACCOUNT FOR TSP SUPPORT ARRANGEMENT, FIXED / PINNED TSP / WRAPPER INTERFACE, AND MIN / MAX BREAKAWAY FORCE**

## **DEVELOPMENT OF TUBE / PLATE EQUIVALENT PROPERTIES**

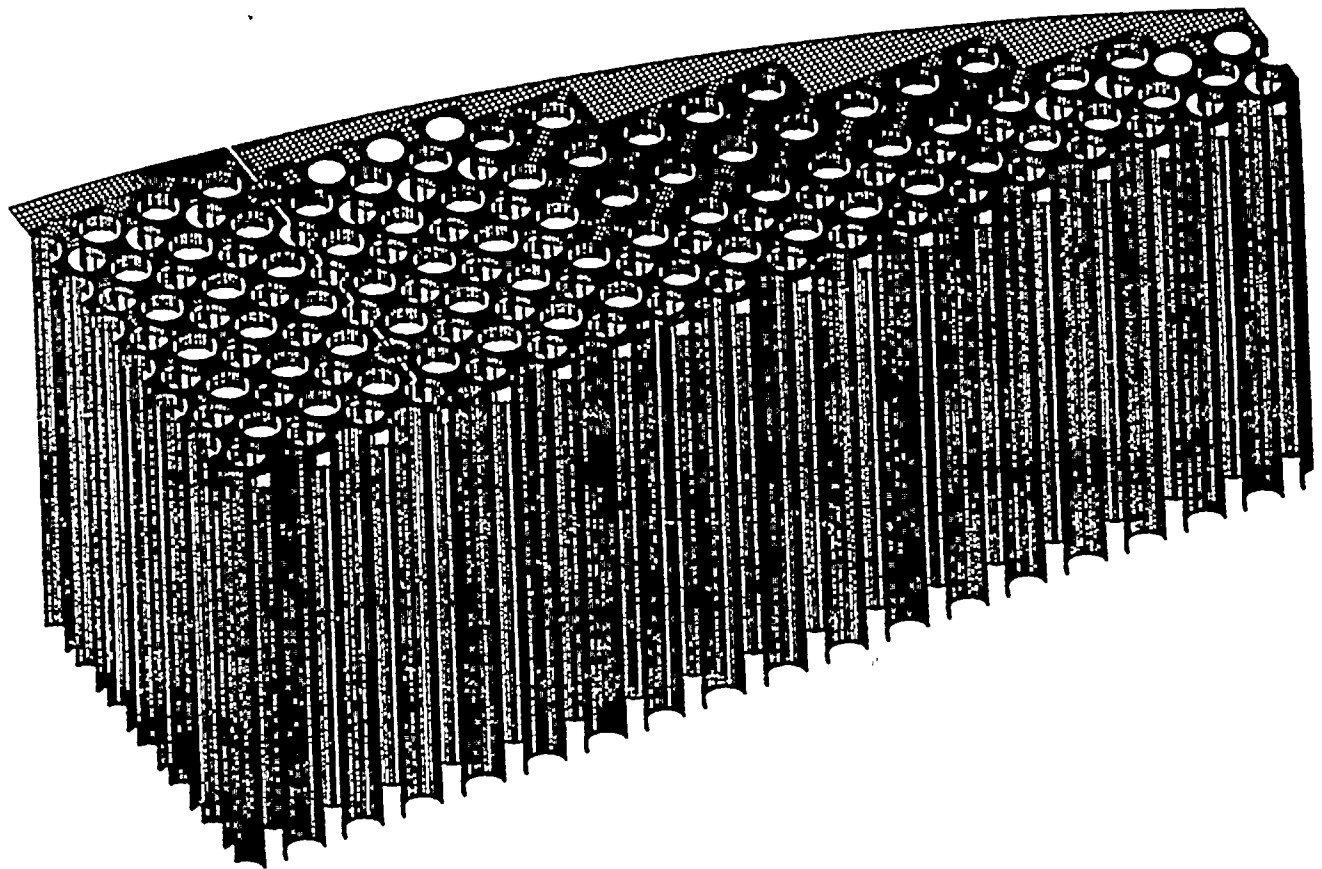
- **DEVELOP DETAILED MODELS OF THREE WEDGE REGIONS AND CENTRAL REGION ADJACENT TO TIEROD**
- **DEVELOP CORRESPONDING EQUIVALENT PLATE MODEL OF EACH REGION**
- **INCLUDE TUBES WITH PACKED INTERSECTIONS IN EACH MODEL**
- **APPLY DIFFERENTIAL TEMPERATURE TO TUBES**
- **ADJUST TUBE / PLATE PROPERTIES TO ACHIEVE SAME (OR AS CLOSE AS POSSIBLE) AXIAL STRESS DISTRIBUTION IN TUBES**



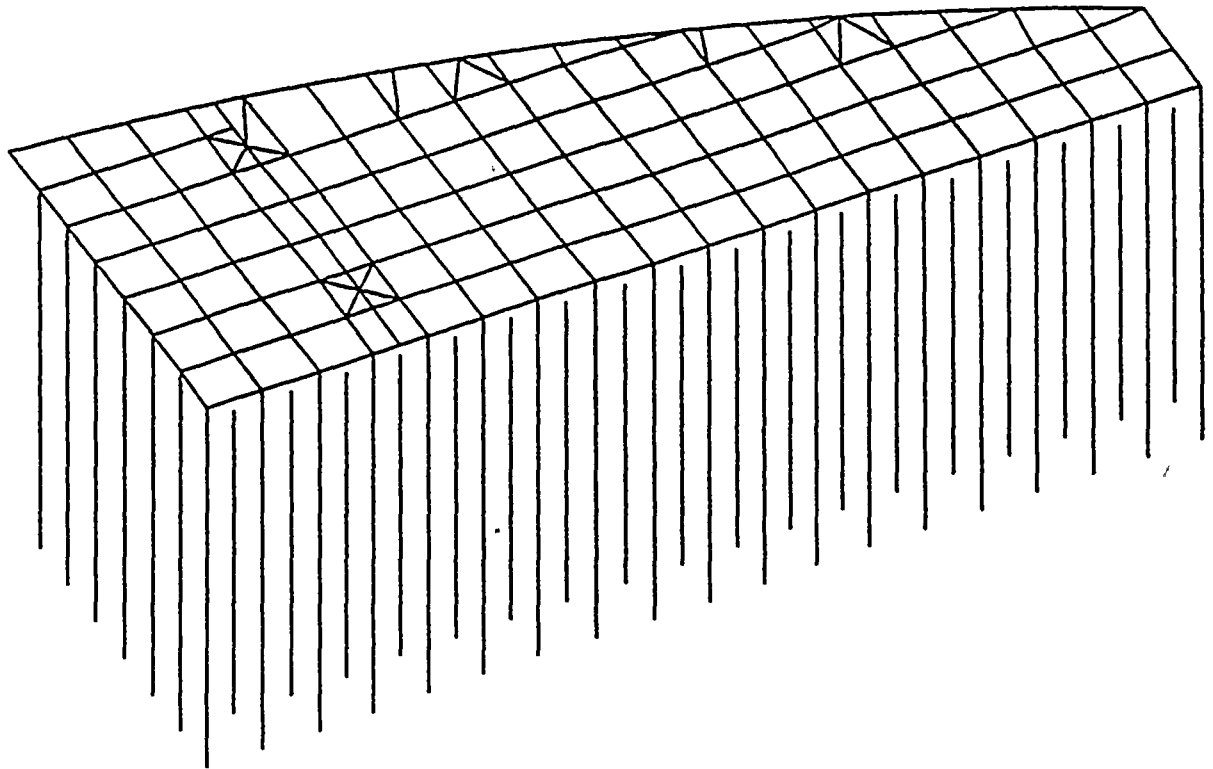
**Model 51 Tube Support Plate  
Location and Size of Detailed Plate Regions**



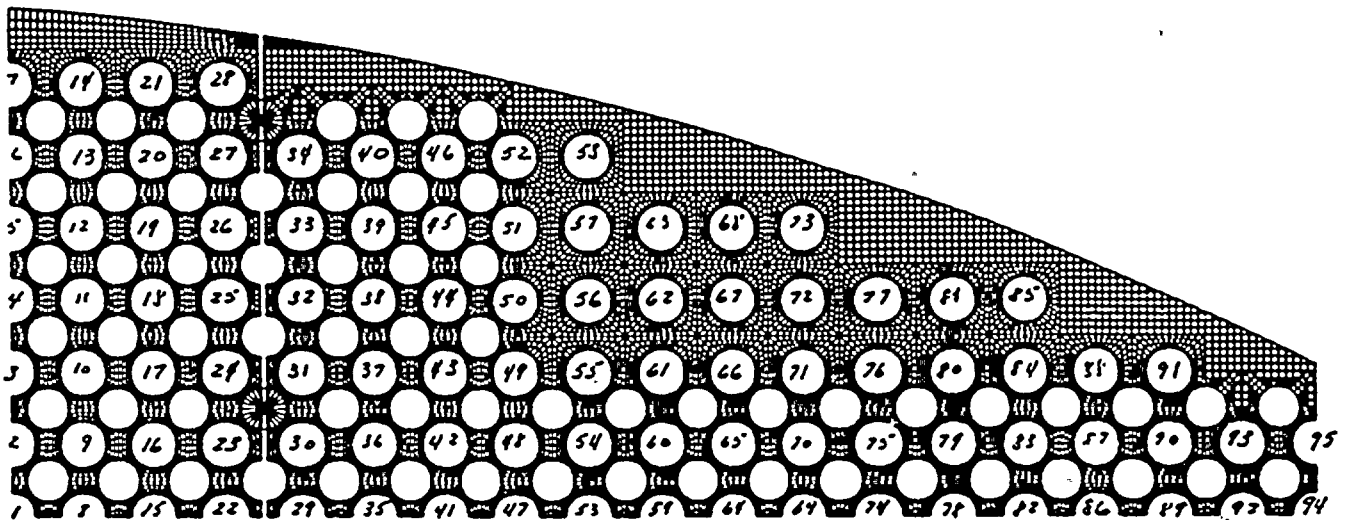
**Model 51 Tube Support Plate  
Location and Size of Detailed Plate Regions**



DETAILED REGION 3 / PATCH PLATE  
FINITE ELEMENT MODEL

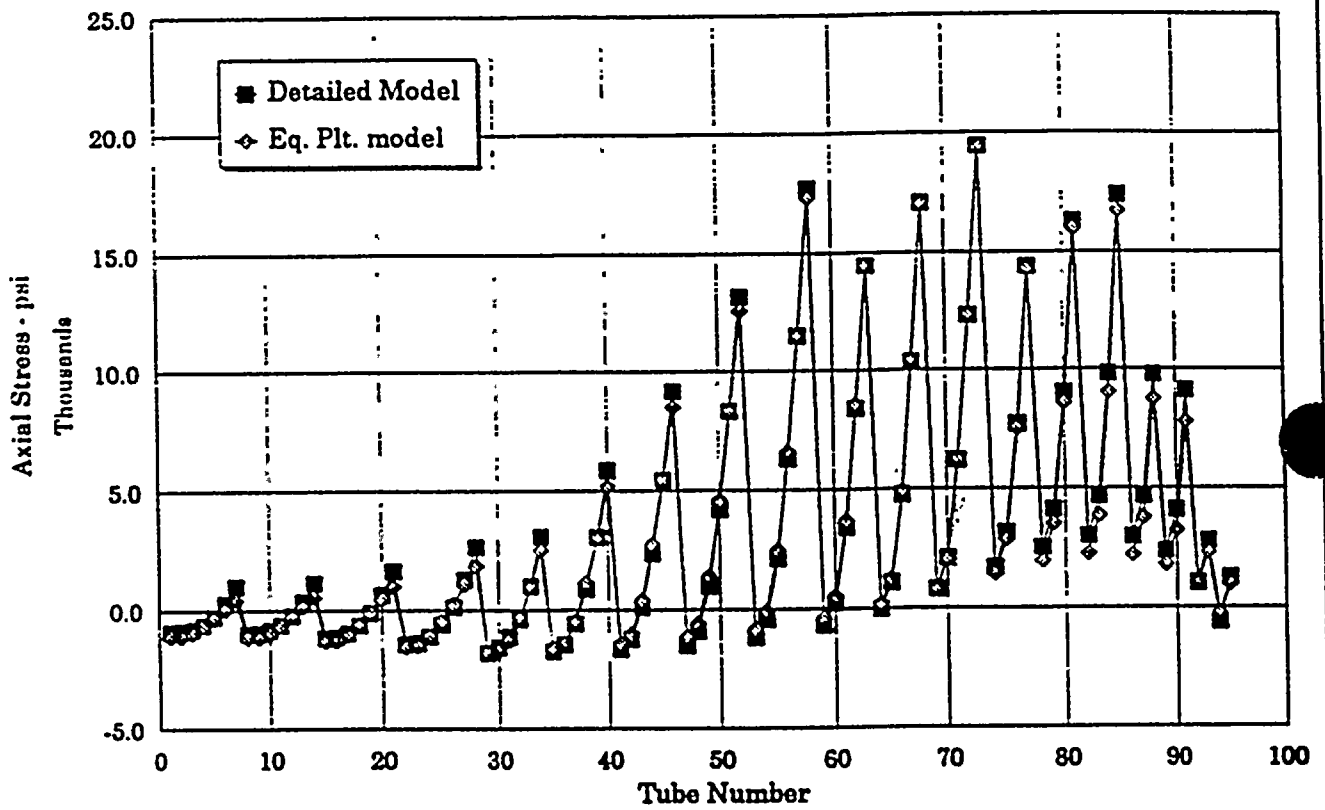


DETAILED REGION 3 / PATCH PLATE  
EQUIVALENT PLATE MODEL



DETAILED REGION 3 / PATCH PLATE  
TUBE NUMBERING SCHEME

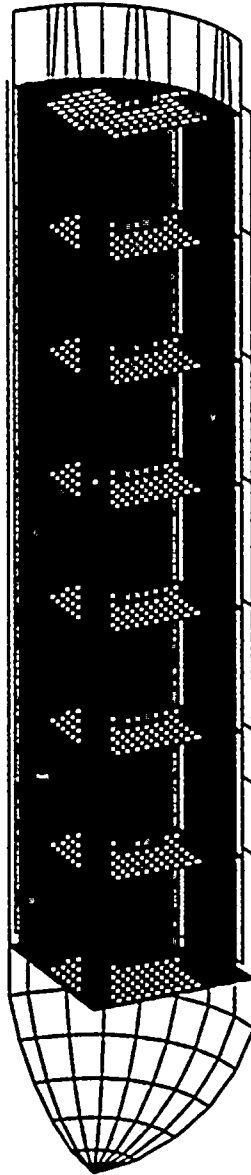
# Comparison of Tube Axial Stress Detailed Region 3 Six Inch Wedge Width



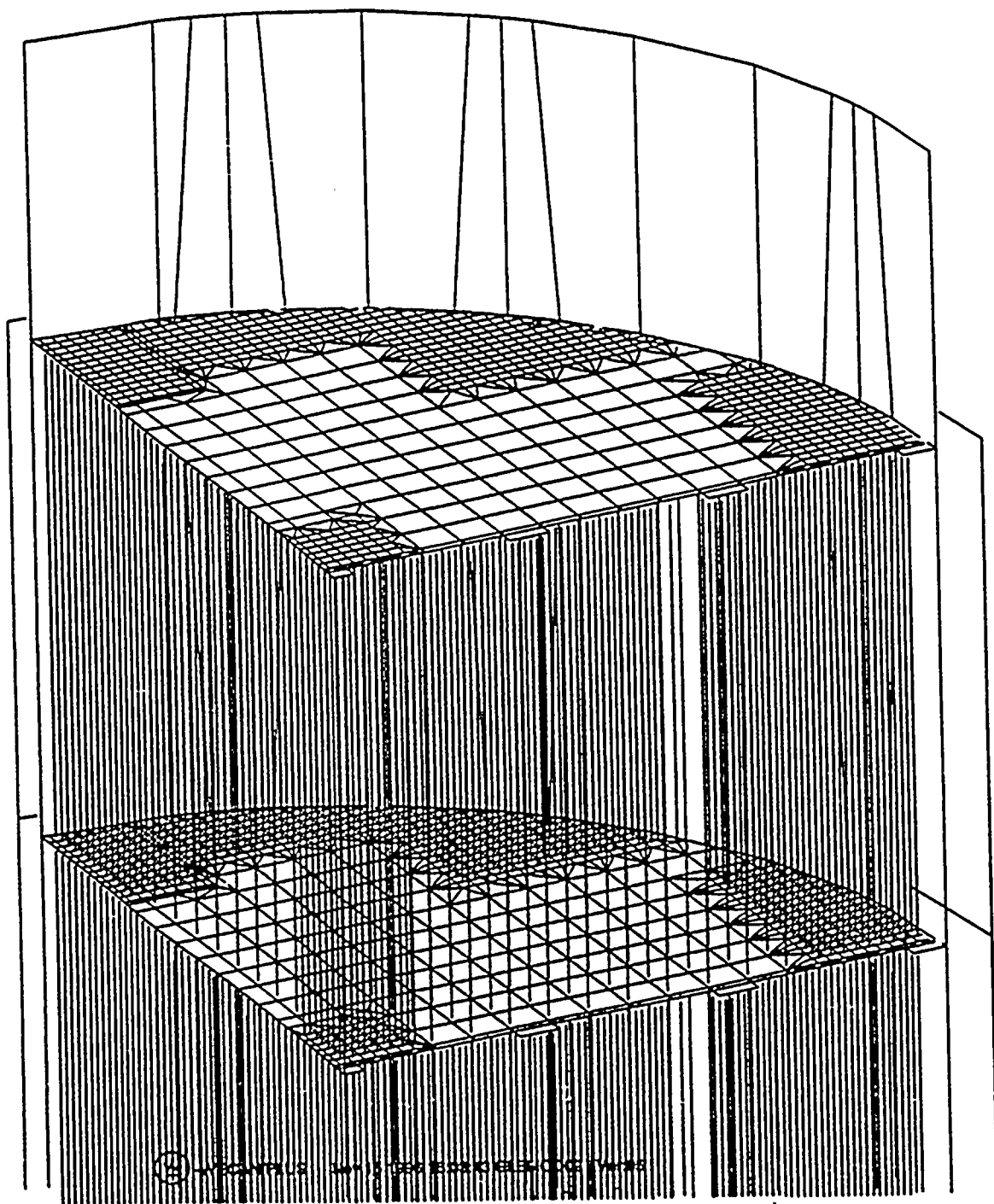


## **FINITE ELEMENT MODEL**

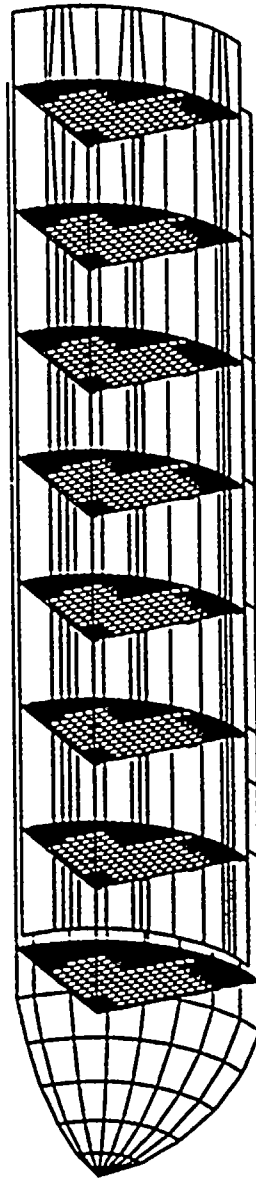
- **FINITE ELEMENT MODEL SAME AS DYNAMIC MODEL WITH MODIFIED PLATE REPRESENTATION AND SHELL EXTENDED TO TOP TSP**
- **SINGLE TUBES MODELED - 567**
- **TUBE GROUPS MODELED - 119**
- **TOTAL NUMBER OF ELEMENTS IN MODEL EXCEEDS 31,000**



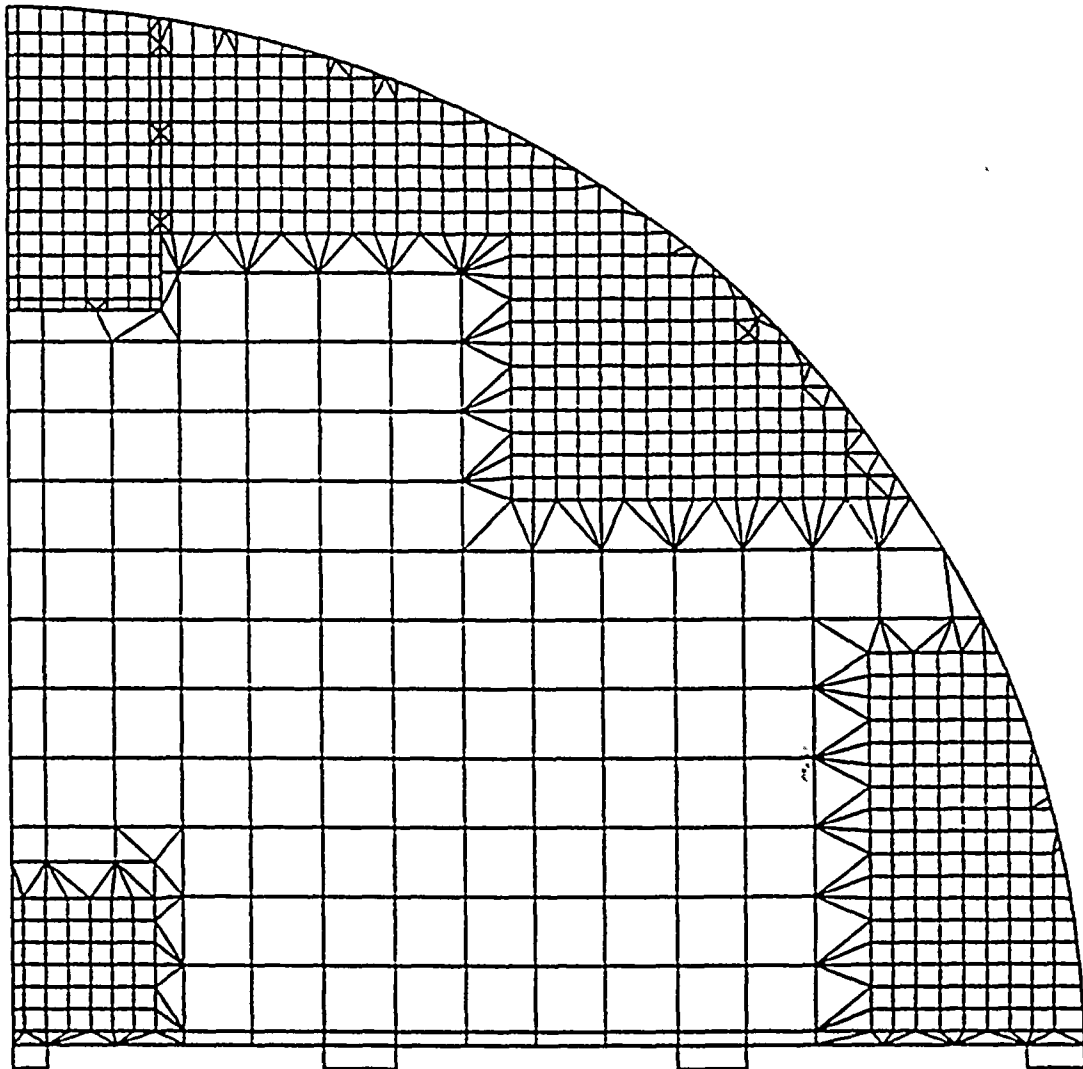
**FINITE ELEMENT MODEL**



**FINITE ELEMENT MODEL  
ENLARGED VIEWS OF PLATES 6 AND 7**

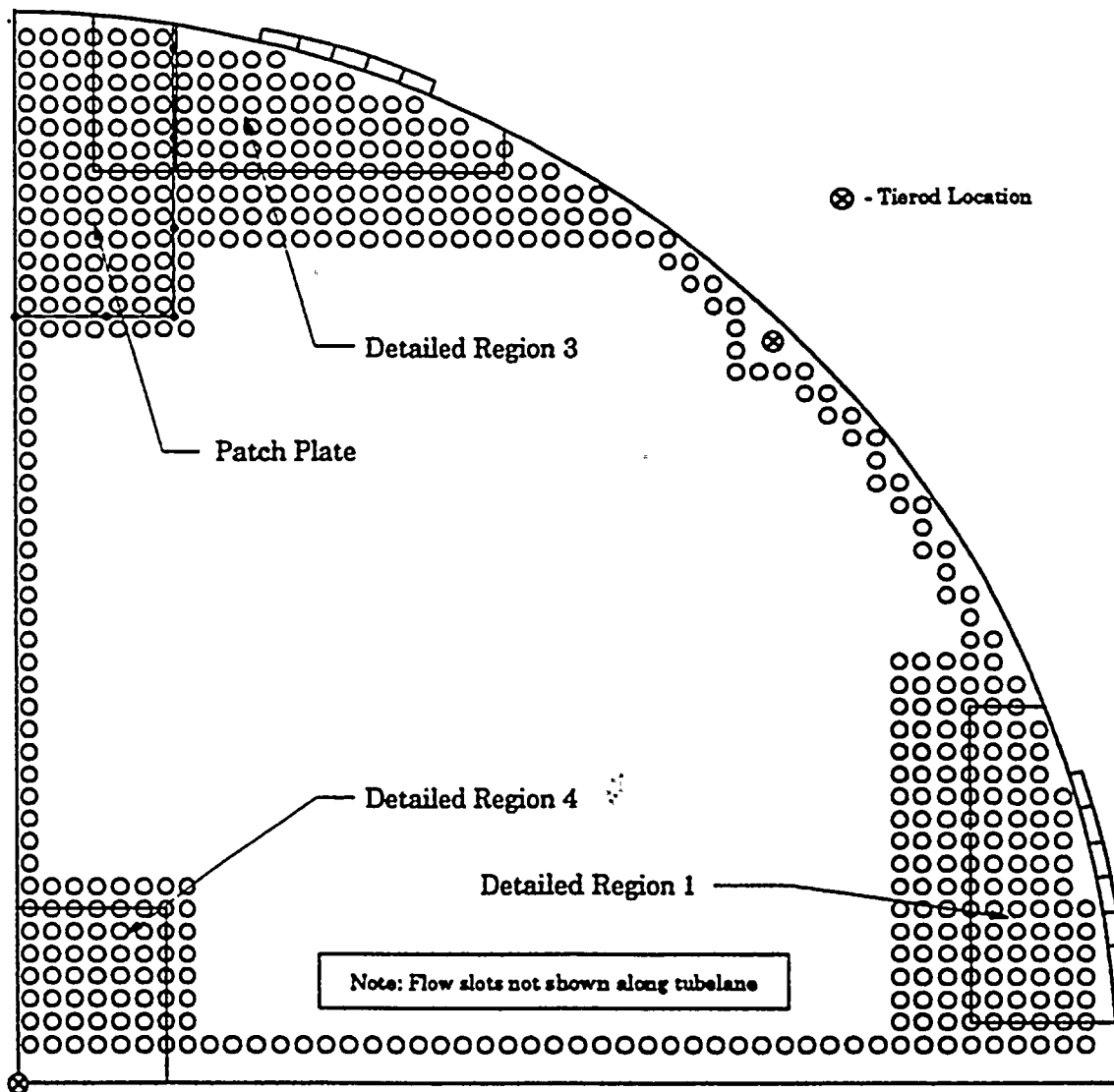


**FINITE ELEMENT MODEL  
TUBE ELEMENTS NOT SHOWN**

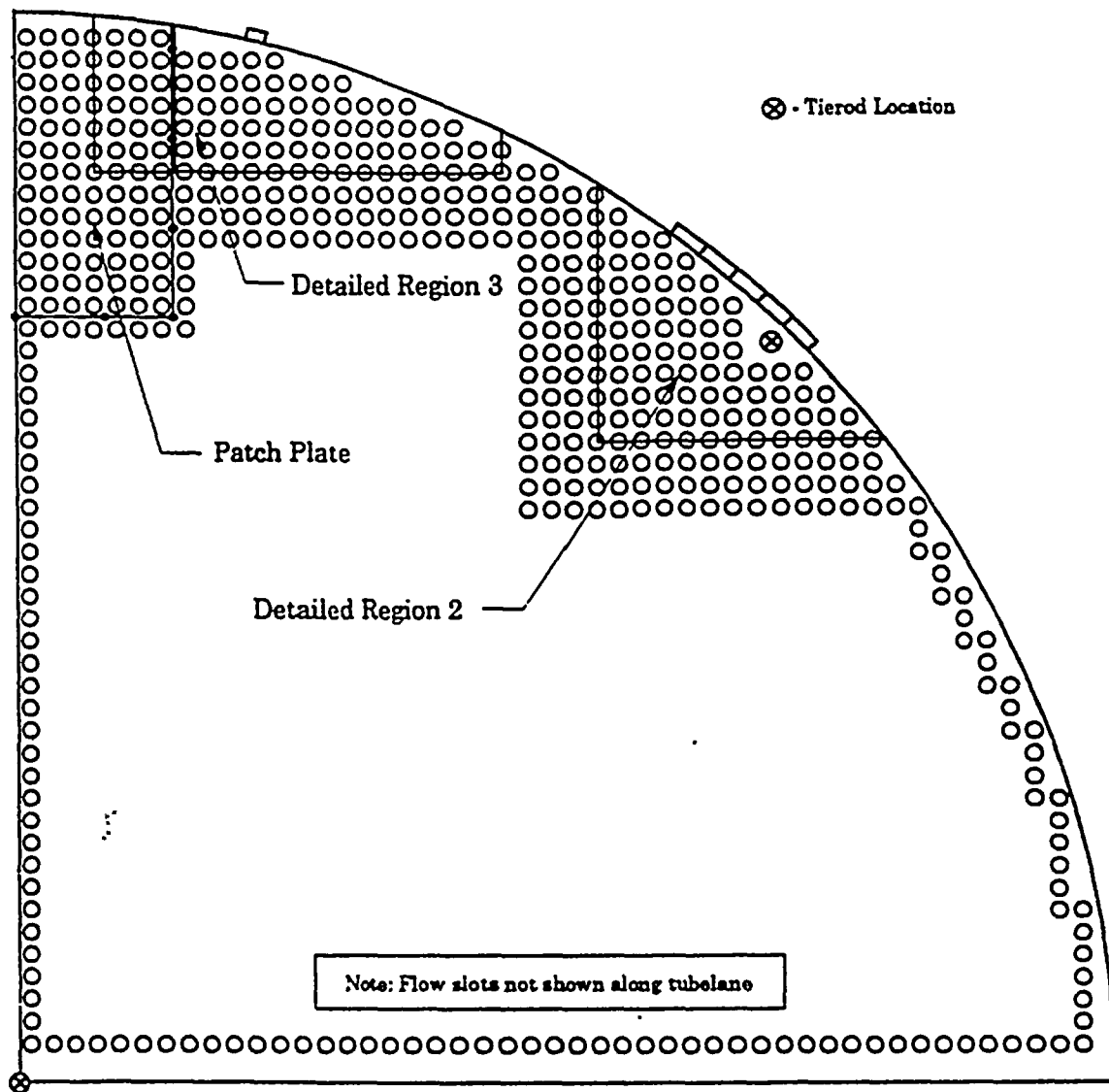


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TOP PLATE ELEMENTS  
PLAN VIEW



**Model 51 Tube Support Plate  
Location and Size of Detailed Plate Regions  
Global Model**



**Model 51 Tube Support Plate  
Location and Size of Detailed Plate Regions  
Global Model**

## INITIAL MATRIX OF BOUNDARY CONDITIONS CONSIDERED

- NUMBER OF TSP SUPPORT CONFIGURATIONS: 2
  - QUADRANT 1, 3
  - QUADRANT 2, 4
- NUMBER OF PLATE / WRAPPER SUPPORT CONDITIONS: 2
  - FIXED AND PINNED
- NUMBER OF BREAKAWAY FORCES CONSIDERED: 2
  - MINIMUM ( $-\sigma$ ) : 1630 LBS.
  - MAXIMUM ( $+\sigma$ ) : 3740 LBS.
- TOTAL NUMBER OF CASES TO BE CONSIDERED: 8



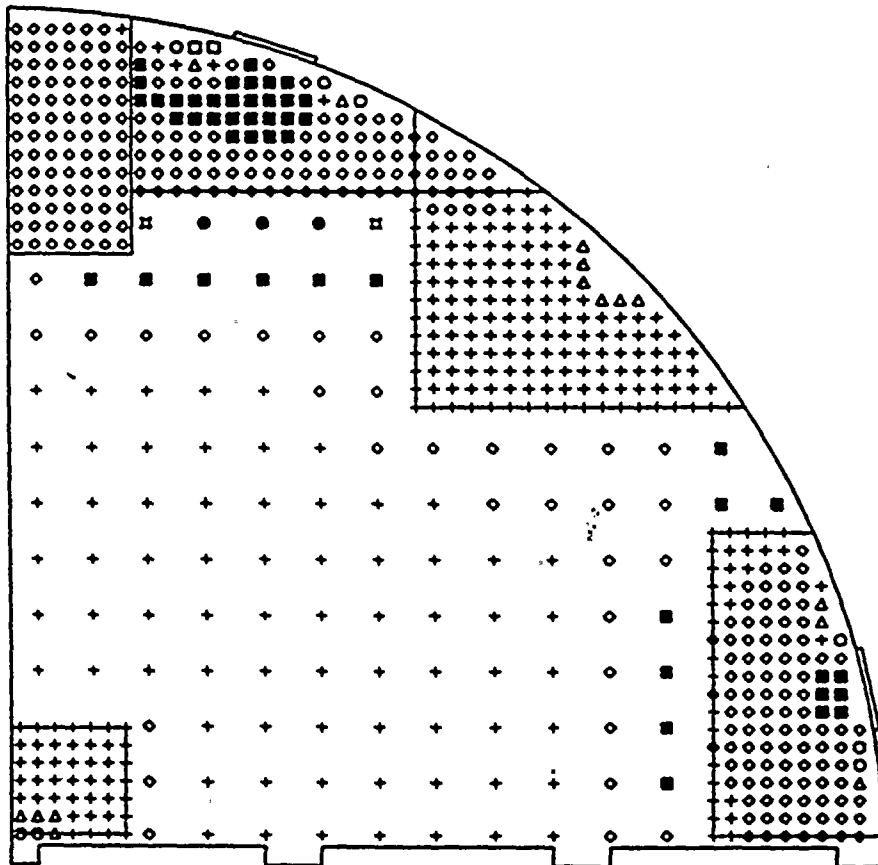
## ANALYSIS STATUS

- FOUR CASES CURRENTLY IN PROGRESS
  - QUADRANT 1,3; FIXED TSP / WRAPPER; MIN FORCE
  - QUADRANT 1,3; PINNED TSP / WRAPPER; MIN FORCE
  - QUADRANT 2,4; FIXED TSP / WRAPPER; MIN FORCE
  - QUADRANT 2,4; PINNED TSP / WRAPPER; MIN FORCE

**Distribution of Interface Forces  
Quadrant 1, 3 Boundary Conditions  
Plate / Wrapper - All DOF Coupled  
All Elements Active**

Plate	Region	Min / Max Force Values For Each Range										
		-1078	-1000	-500	-100	100	400	800	1200	1630	2543	Inactive
		-1000	-500	-100	100	400	800	1200	1630	2543	Inactive	
1	Interior	0	0	0	994	133	0	0	0	0	0	0
	Detail 1	0	0	7	134	0	0	0	0	0	0	0
	Detail 2	0	0	0	115	38	10	5	3	3	0	0
	Detail 3	0	3	29	80	0	0	0	0	0	0	0
	Patch Plate	0	0	1	89	1	0	0	0	0	0	0
	Detail 4	0	0	0	49	0	0	0	0	0	0	0
	TOTAL	0	3	37	1461	172	10	5	3	3	0	0
2	Interior	0	0	0	881	246	0	0	0	0	0	0
	Detail 1	0	0	13	128	0	0	0	0	0	0	0
	Detail 2	0	3	7	137	27	0	0	0	0	0	0
	Detail 3	0	0	0	109	3	0	0	0	0	0	0
	Patch Plate	0	0	0	85	6	0	0	0	0	0	0
	Detail 4	0	0	0	49	0	0	0	0	0	0	0
	TOTAL	0	3	20	1389	282	0	0	0	0	0	0
3	Interior	0	0	0	748	331	47	0	0	0	0	0
	Detail 1	0	0	4	137	0	0	0	0	0	0	0
	Detail 2	0	0	0	174	0	0	0	0	0	0	0
	Detail 3	0	0	6	106	0	0	0	0	0	0	0
	Patch Plate	0	0	0	91	0	0	0	0	0	0	0
	Detail 4	0	0	0	49	0	0	0	0	0	0	0
	TOTAL	0	0	10	1305	331	47	0	0	0	0	0
4	Interior	0	0	0	720	313	95	0	0	0	0	0
	Detail 1	0	0	0	136	5	0	0	0	0	0	0
	Detail 2	0	0	0	174	0	0	0	0	0	0	0
	Detail 3	0	0	0	112	0	0	0	0	0	0	0
	Patch Plate	0	0	0	86	5	0	0	0	0	0	0
	Detail 4	0	0	0	49	0	0	0	0	0	0	0
	TOTAL	0	0	0	1277	323	95	0	0	0	0	0
5	Interior	0	0	0	691	303	85	47	0	0	0	0
	Detail 1	0	0	5	94	42	0	0	0	0	0	0
	Detail 2	0	0	0	174	0	0	0	0	0	0	0
	Detail 3	0	0	8	41	63	0	0	0	0	0	0
	Patch Plate	0	0	0	17	74	0	0	0	0	0	0
	Detail 4	0	0	0	49	0	0	0	0	0	0	0
	TOTAL	0	0	13	1066	482	85	47	0	0	0	0
6	Interior	0	0	0	663	284	133	19	28	0	0	0
	Detail 1	0	3	3	31	98	6	0	0	0	0	0
	Detail 2	0	0	6	146	22	0	0	0	0	0	0
	Detail 3	2	3	2	4	72	29	0	0	0	0	0
	Patch Plate	0	0	0	1	90	0	0	0	0	0	0
	Detail 4	0	2	4	43	0	0	0	0	0	0	0
	TOTAL	2	8	15	888	566	168	19	28	0	0	0
7	Interior	0	0	0	786	218	76	19	28	0	0	0
	Detail 1	0	0	0	31	81	19	5	2	3	0	0
	Detail 2	0	0	0	118	50	6	0	0	0	0	0
	Detail 3	0	0	0	0	68	23	8	10	3	0	0
	Patch Plate	0	0	0	36	55	0	0	0	0	0	0
	Detail 4	0	0	0	36	9	3	1	0	0	0	0
	TOTAL	0	0	0	1007	481	127	33	40	6	0	0

DISTRIBUTION OF INTERFACE FORCES  
 QUADRANT 1 & 3 SUPPORT LOCATIONS  
 PLATE / WRAPPER - ALL DOF COUPLED  
 PLATE 6 - ALL ELEMENTS ACTIVE

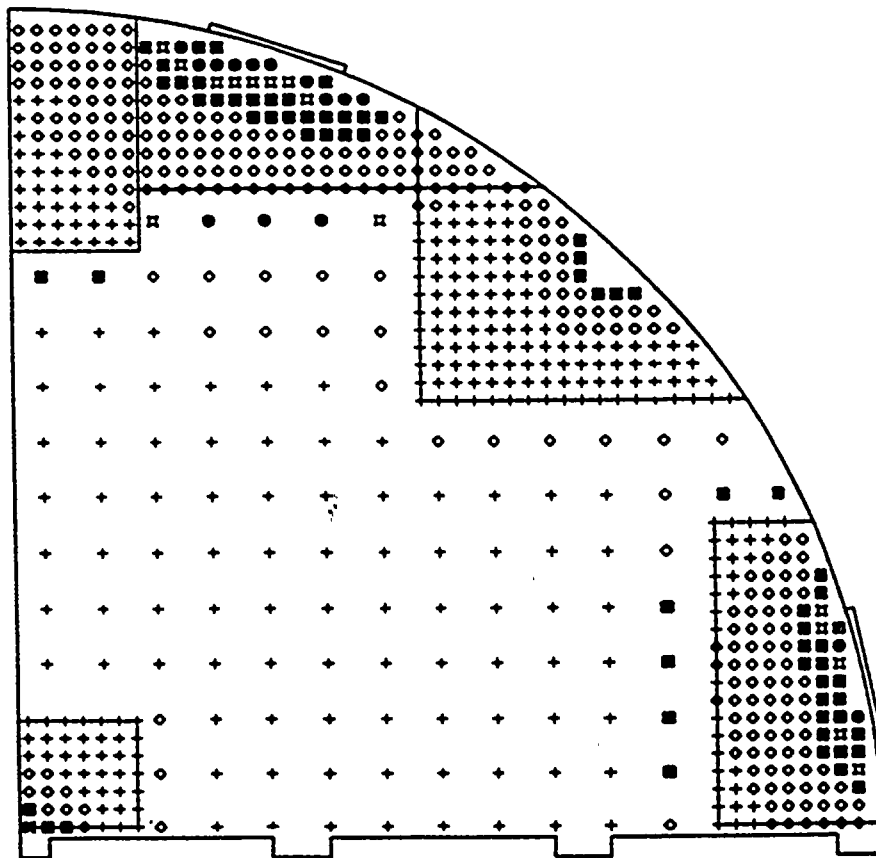


FORCE LEGEND

- -1078. < F < -1000.
- -1000. < F < -500.
- △ -500. < F < -100.
- + -100. < F < 100.
- ◇ 100. < F < 400.
- 400. < F < 800.
- ⊠ 800. < F < 1200.
- 1200. < F < 1630.
- ⊞ 1630. < F < 2543.

● INTERFACE ELEMENT  
 DEACTIVATED

DISTRIBUTION OF INTERFACE FORCES  
 QUADRANT 1 & 3 SUPPORT LOCATIONS  
 PLATE / WRAPPER - ALL DOF COUPLED  
 PLATE 7 - ALL ELEMENTS ACTIVE



FORCE LEGEND

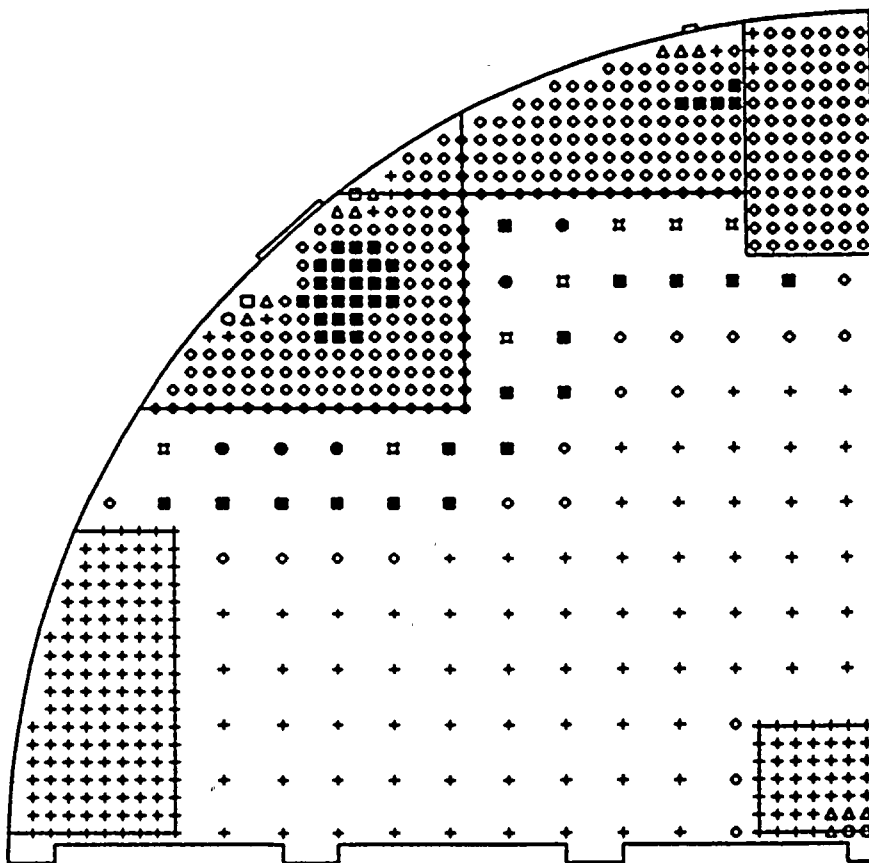
◻	-1078. < F < -1000.
○	-1000. < F < -500.
△	-500. < F < -100.
+	-100. < F < 100.
◇	100. < F < 400.
■	400. < F < 800.
⊠	800. < F < 1200.
●	1200. < F < 1630.
⊞	1630. < F < 2543.

● INTERFACE ELEMENT  
 DEACTIVATED

**Distribution of Interface Forces**  
**Quadrant 2, 4 Boundary Conditions**  
**Plate / Wrapper - All DOF Coupled**  
**All Elements Active**

Plate	Region	Min / Max Force Values For Each Range									
		-1410	-1000	-500	-100	100	400	800	1200	1630	Inactive
		-1000	-500	-100	100	400	800	1200	1630	2657	
1	Interior	0	0	0	938	189	0	0	0	0	0
	Detail 1	0	0	0	116	13	6	2	2	2	0
	Detail 2	0	0	16	158	0	0	0	0	0	0
	Detail 3	0	0	2	60	31	10	4	3	2	0
	Patch Plate	0	0	0	90	1	0	0	0	0	0
	Detail 4	0	0	0	49	0	0	0	0	0	0
	TOTAL	0	0	18	1411	234	16	6	5	4	0
2	Interior	0	0	0	833	265	28	0	0	0	0
	Detail 1	0	1	4	135	1	0	0	0	0	0
	Detail 2	0	0	0	156	18	0	0	0	0	0
	Detail 3	0	1	7	77	25	2	0	0	0	0
	Patch Plate	0	0	0	80	11	0	0	0	0	0
	Detail 4	0	0	0	49	0	0	0	0	0	0
	TOTAL	0	2	11	1330	320	30	0	0	0	0
3	Interior	0	0	0	739	256	133	0	0	0	0
	Detail 1	0	0	1	140	0	0	0	0	0	0
	Detail 2	0	0	0	174	0	0	0	0	0	0
	Detail 3	0	0	0	110	2	0	0	0	0	0
	Patch Plate	0	0	0	91	0	0	0	0	0	0
	Detail 4	0	0	0	49	0	0	0	0	0	0
	TOTAL	0	0	1	1303	258	133	0	0	0	0
4	Interior	0	0	0	729	208	133	57	0	0	0
	Detail 1	0	0	0	141	0	0	0	0	0	0
	Detail 2	0	0	1	59	114	0	0	0	0	0
	Detail 3	0	0	0	60	52	0	0	0	0	0
	Patch Plate	0	0	0	83	8	0	0	0	0	0
	Detail 4	0	0	0	49	0	0	0	0	0	0
	TOTAL	0	0	1	1121	382	133	57	0	0	0
5	Interior	0	0	0	720	161	133	104	9	0	0
	Detail 1	0	0	0	141	0	0	0	0	0	0
	Detail 2	0	0	3	28	143	0	0	0	0	0
	Detail 3	0	0	2	21	89	0	0	0	0	0
	Patch Plate	0	0	0	29	62	0	0	0	0	0
	Detail 4	0	0	0	49	0	0	0	0	0	0
	TOTAL	0	0	5	988	455	133	104	9	0	0
6	Interior	0	0	0	682	180	142	66	47	9	0
	Detail 1	0	0	0	141	0	0	0	0	0	0
	Detail 2	2	1	5	6	134	26	0	0	0	0
	Detail 3	0	0	3	1	103	5	0	0	0	0
	Patch Plate	0	0	0	3	88	0	0	0	0	0
	Detail 4	0	2	4	43	0	0	0	0	0	0
	TOTAL	2	3	12	876	505	173	66	47	9	0
7	Interior	0	0	0	748	218	28	76	57	0	0
	Detail 1	0	0	0	141	0	0	0	0	0	0
	Detail 2	0	0	0	4	122	27	11	7	3	0
	Detail 3	0	0	0	5	92	11	2	2	0	0
	Patch Plate	0	0	0	42	48	1	0	0	0	0
	Detail 4	0	0	0	36	9	3	1	0	0	0
	TOTAL	0	0	0	976	489	70	90	66	3	0

DISTRIBUTION OF INTERFACE FORCES  
 QUADRANT 2 & 4 SUPPORT LOCATIONS  
 PLATE / WRAPPER - ALL DOF COUPLED  
 PLATE 6 - ALL ELEMENTS ACTIVE

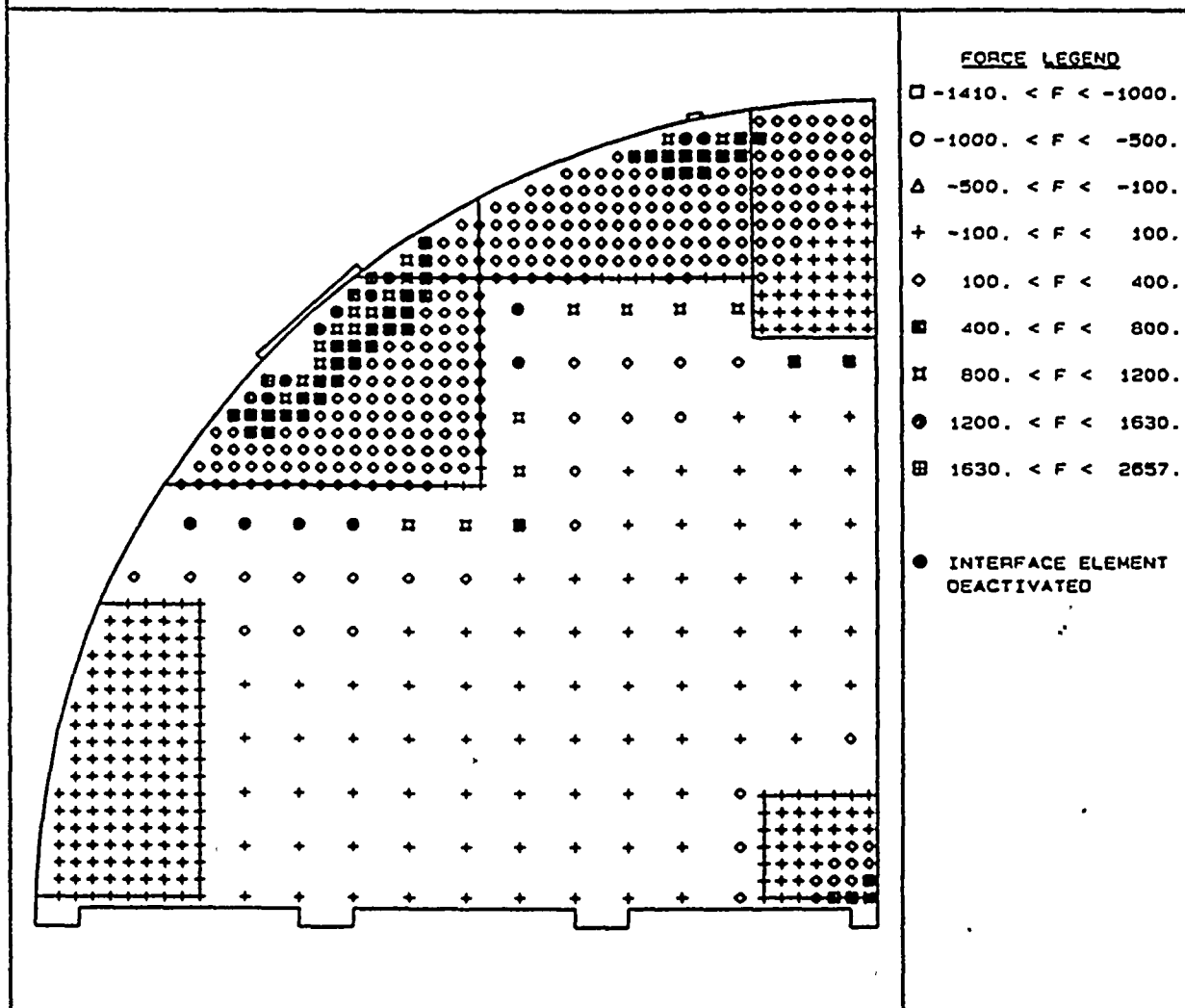


FORCE LEGEND

□	-1410. < F < -1000.
○	-1000. < F < -500.
△	-500. < F < -100.
+	-100. < F < 100.
◊	100. < F < 400.
■	400. < F < 800.
⌘	800. < F < 1200.
●	1200. < F < 1630.
⊞	1630. < F < 2657.

● INTERFACE ELEMENT  
 DEACTIVATED

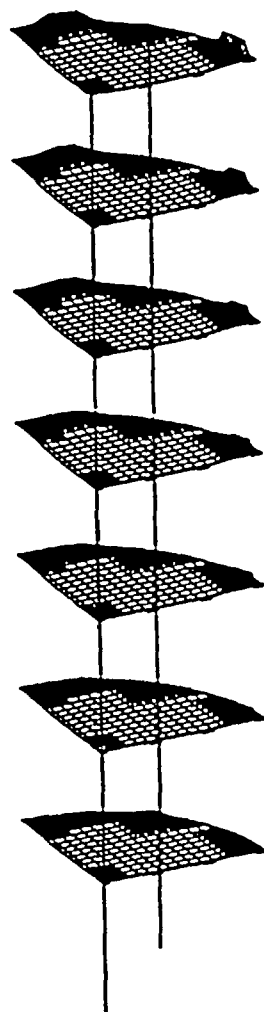
DISTRIBUTION OF INTERFACE FORCES  
 QUADRANT 2 & 4 SUPPORT LOCATIONS  
 PLATE / WRAPPER - ALL DOF COUPLED  
 PLATE 7 - ALL ELEMENTS ACTIVE



## TSP STRESS RESULTS

- MAXIMUM STRESSES CONCENTRATED AT WEDGES NEAR THE PLATE EDGE
- GENERAL PLATE STRESSES LESS THAN YIELD TWO TO THREE TUBE PITCHES AWAY FROM SUPPORT LOCATION
- PEAK STRESSES LESS THAN YIELD FOUR TO FIVE TUBE PITCHES AWAY FROM SUPPORT LOCATION

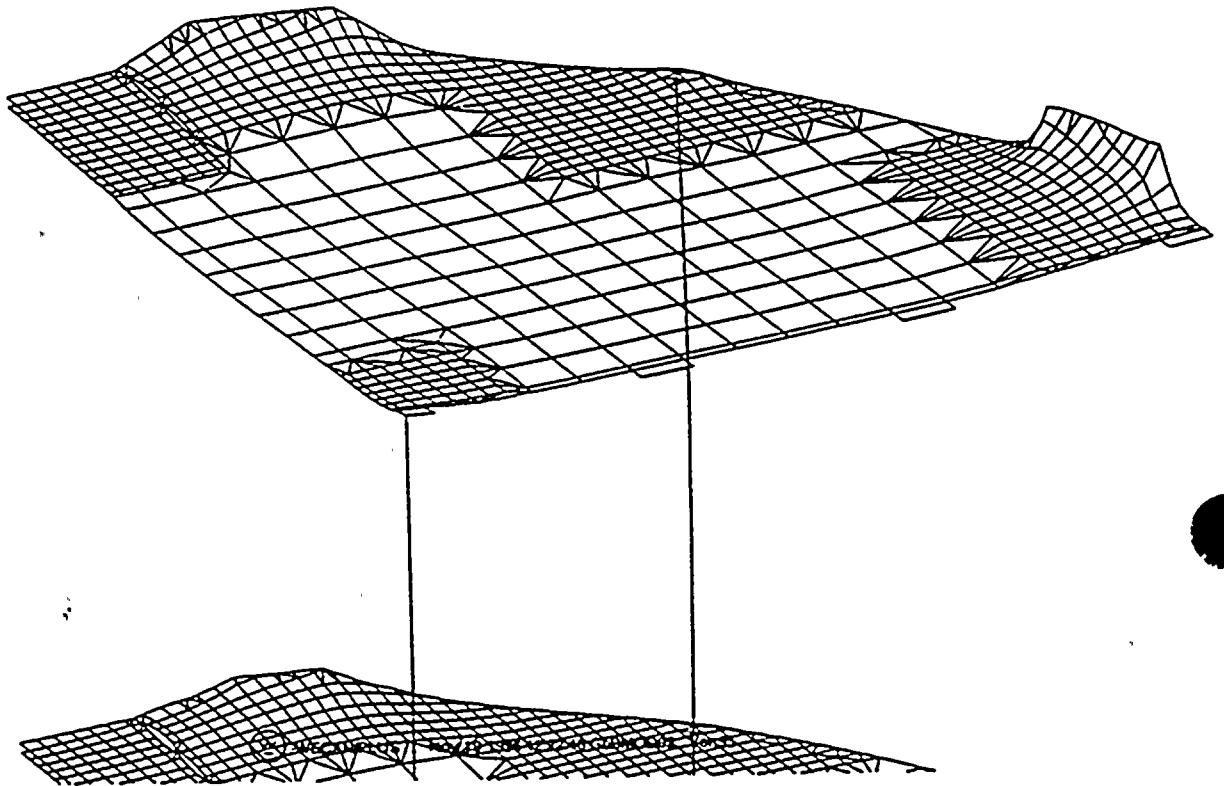




W-WECAVPLUS Nov 19 1996 12:22:28 GLBMOO02 Ver:95

DISPLACED GEOMETRY  
QUADRANT 1,3 SUPPORT CONDITION  
PLATE / WRAPPER - ALL DOF COUPLED

DISK 250 - DIABLO\NRC01 - 11/19/96



DISPLACED GEOMETRY - PLATE 7  
QUADRANT 1,3 SUPPORT CONDITION  
PLATE / WRAPPER - ALL DOF COUPLED

Load step = 1 Iteration = 1  
Neutral file = STRS201.RES

Variable = SINT

Max. = 67002.8

Min. = 10.9391

20 = 65520.

19 = 62160.

18 = 58800.

17 = 55440.

16 = 52080.

15 = 48720.

14 = 45360.

13 = 42000.

12 = 38640.

11 = 35280.

10 = 31920.

9 = 28560.

8 = 25200.

7 = 21840.

6 = 18480.

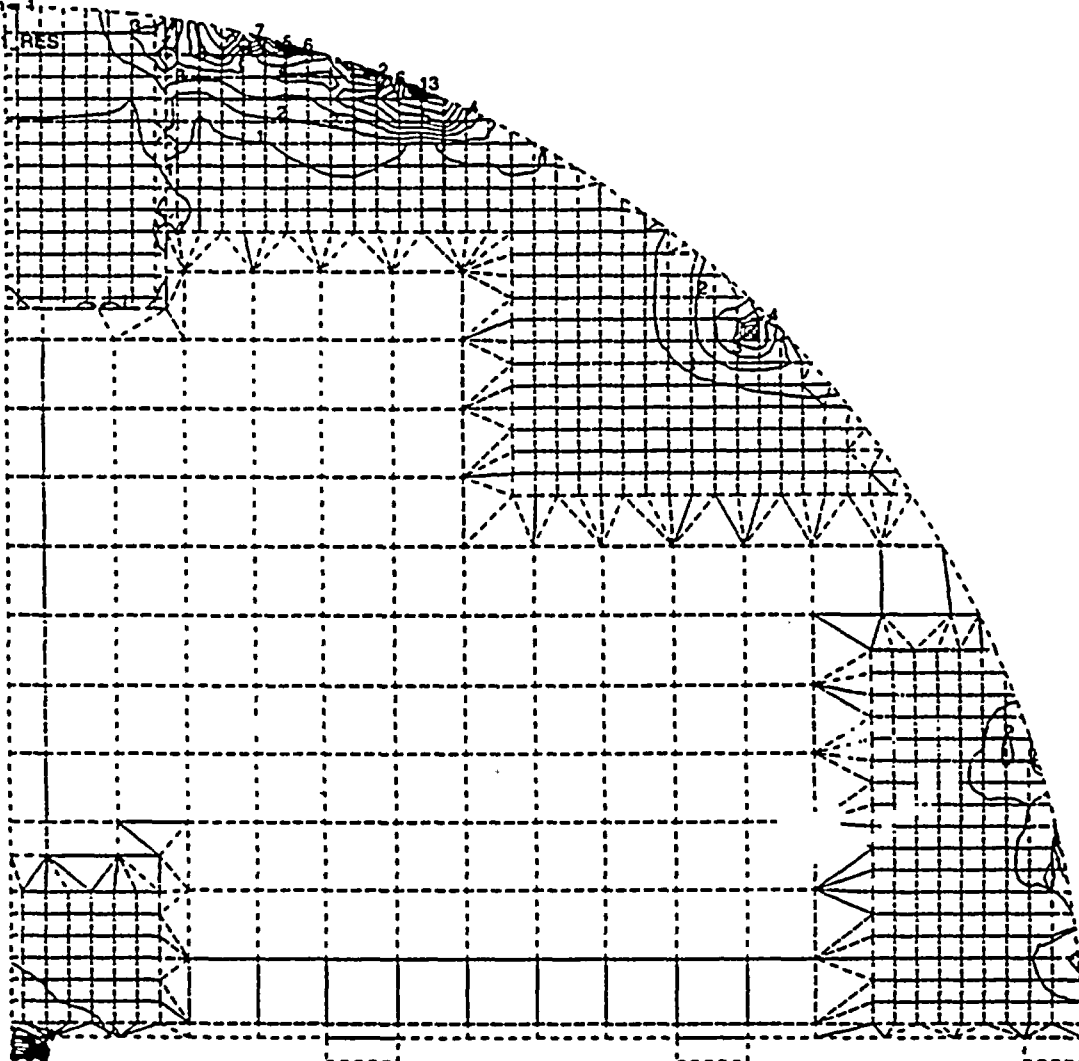
5 = 15120.

4 = 11760.

3 = 8400.

2 = 5040.

1 = 1680.



WECAN/PLUS Nov 19 1996 12:20:00 GLBMOD02 Ver:85

STRESS CONTOUR PLOT - PLATE 7  
QUADRANT 1,3 SUPPORT CONDITION  
PLATE / WRAPPER - ALL DOF COUPLED

Load step = 1 iteration = 4, --  
Neutral file = STRS201.RES

Variable = SINT

Max. = 67002.8

Min. = 10.9391

20 = 65520.

19 = 62160.

18 = 58800.

17 = 55440.

16 = 52080.

15 = 48720.

14 = 45360.

13 = 42000.

12 = 38640.

11 = 35280.

10 = 31920.

9 = 28560.

8 = 25200.

7 = 21840.

6 = 18480.

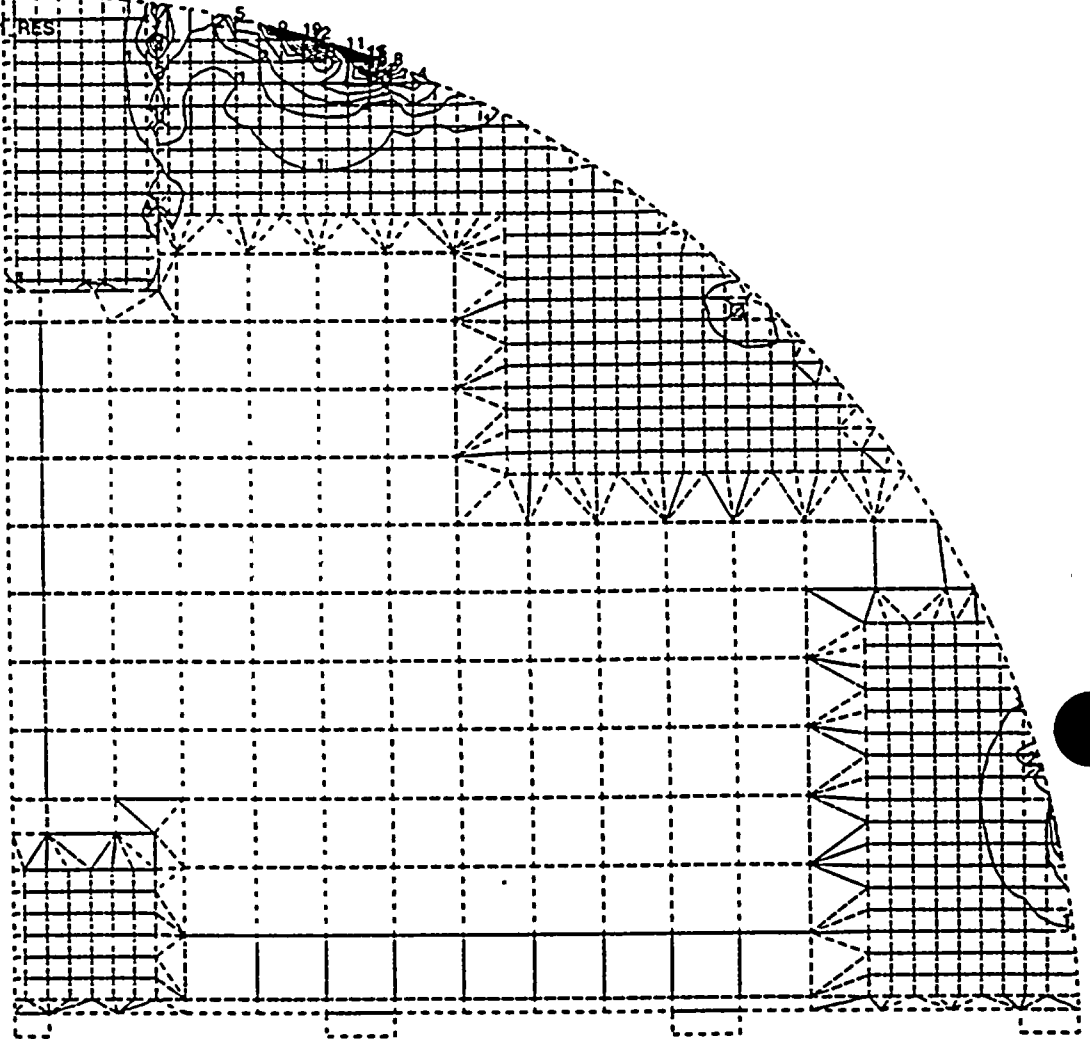
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2 = 5040.

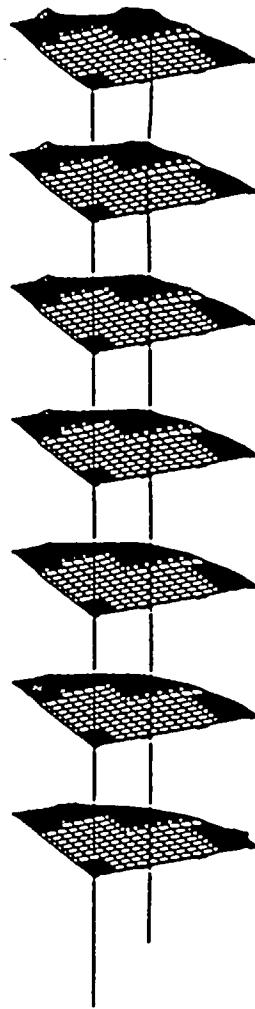
1 = 1680.



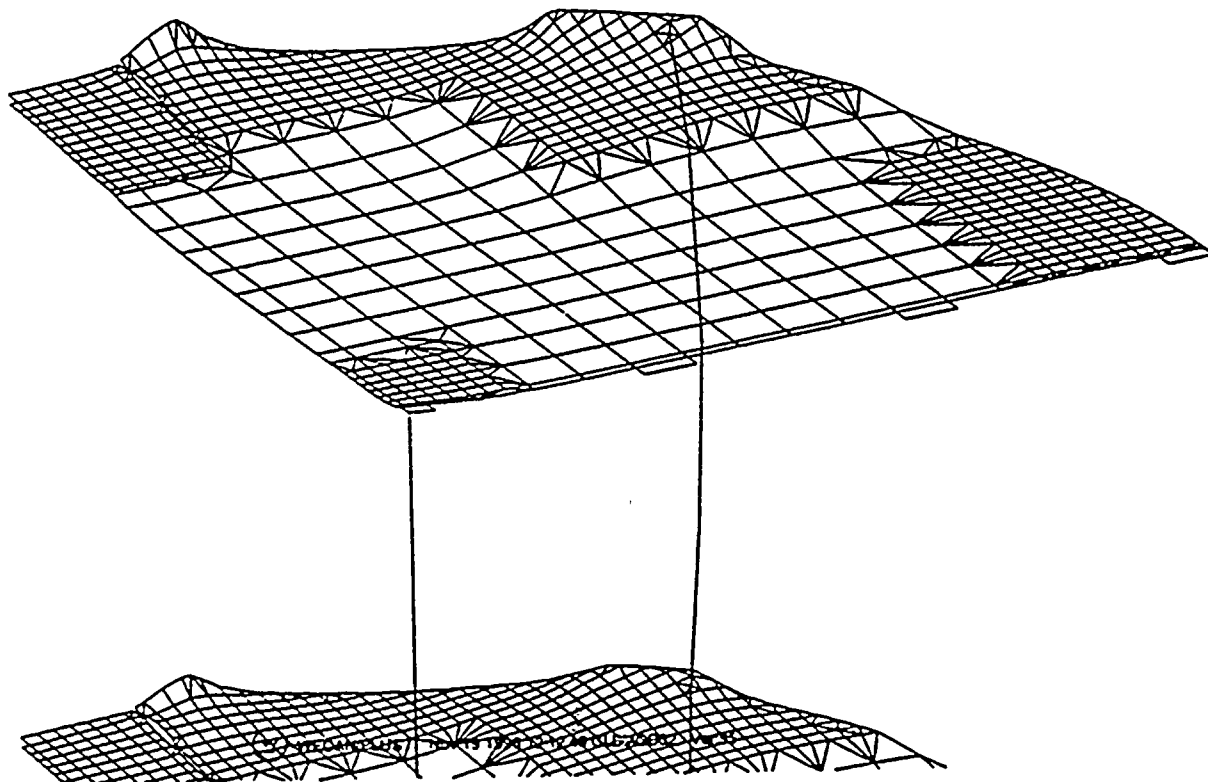
W -WECANPLUS Nov 19 1996 12:20:16 GLBMOO02 Ver:25

STRESS CONTOUR PLOT - PLATE 6  
QUADRANT 1,3 SUPPORT CONDITION  
PLATE / WRAPPER - ALL DOF COUPLED

DISK 250 - DIABLO\NRC01 - 11/19/96



DISPLACED GEOMETRY  
QUADRANT 2,4 SUPPORT CONDITION  
PLATE / WRAPPER - ALL DOF COUPLED



DISPLACED GEOMETRY - PLATE 7  
QUADRANT 2,4 SUPPORT CONDITION  
PLATE / WRAPPER - ALL DOF COUPLED

Load step = 1 Iteration = 1

Neutral file = STRS401.RES

Variable = SINT

Max. = 83502.9

Min. = 1.81866

20 = 81120.

19 = 76960.

18 = 72800.

17 = 68640.

16 = 64480.

15 = 60320.

14 = 56160.

13 = 52000.

12 = 47840.

11 = 43680.

10 = 39520.

9 = 35360.

8 = 31200.

7 = 27040.

6 = 22880.

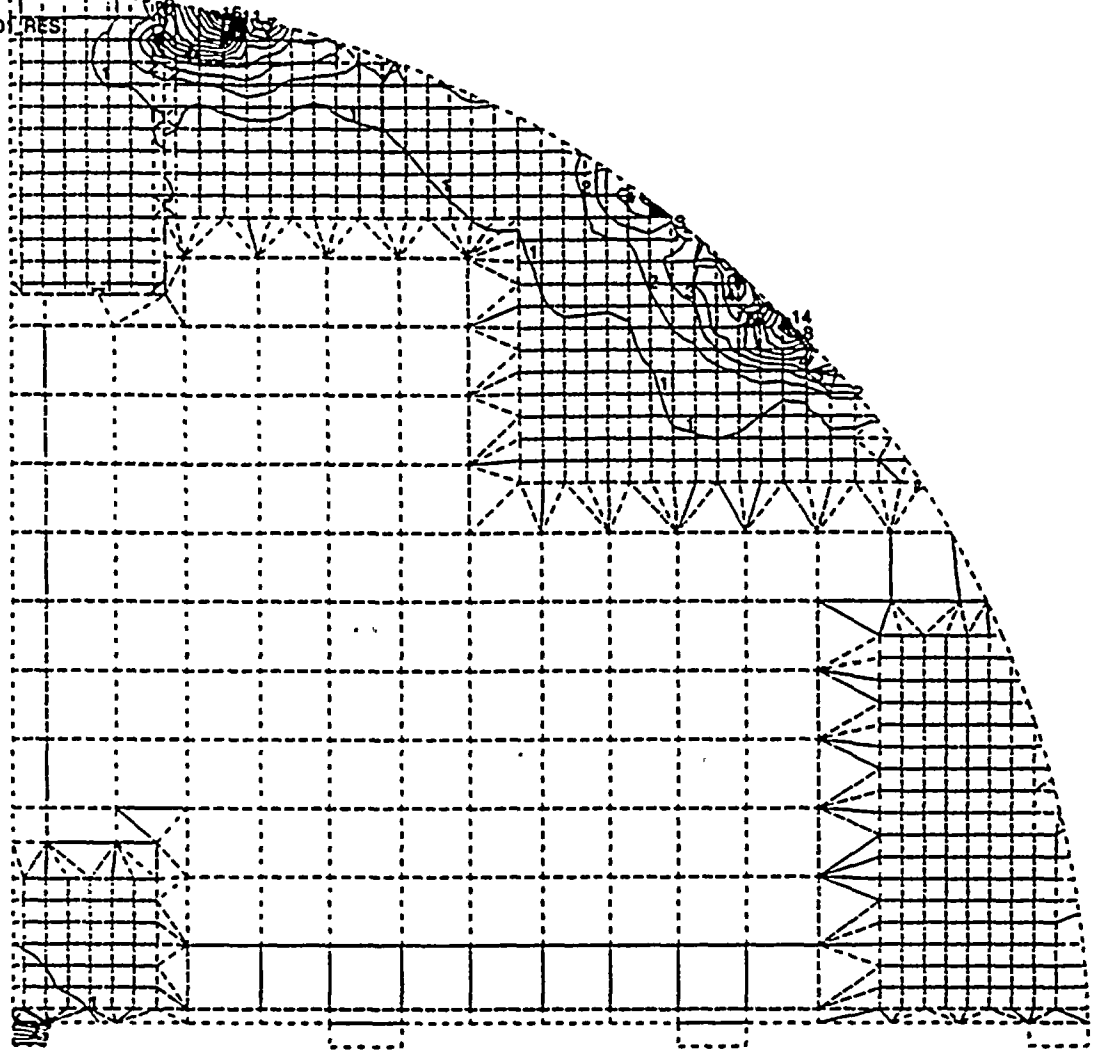
5 = 18720.

4 = 14560.

3 = 10400.

2 = 6240.

1 = 2080.



STRESS CONTOUR PLOT - PLATE 7  
QUADRANT 2,4 SUPPORT CONDITION  
PLATE / WRAPPER - ALL DOF COUPLED

Load step = 1 Iteration = 4

Neutral file = STRS401.RES

Variable = SINT

Max. = 83502.9

Min. = 1.81866

20 = 81120.

19 = 76960.

18 = 72800.

17 = 68640.

16 = 64480.

15 = 60320.

14 = 56160.

13 = 52000.

12 = 47840.

11 = 43680.

10 = 39520.

9 = 35360.

8 = 31200.

7 = 27040.

6 = 22880.

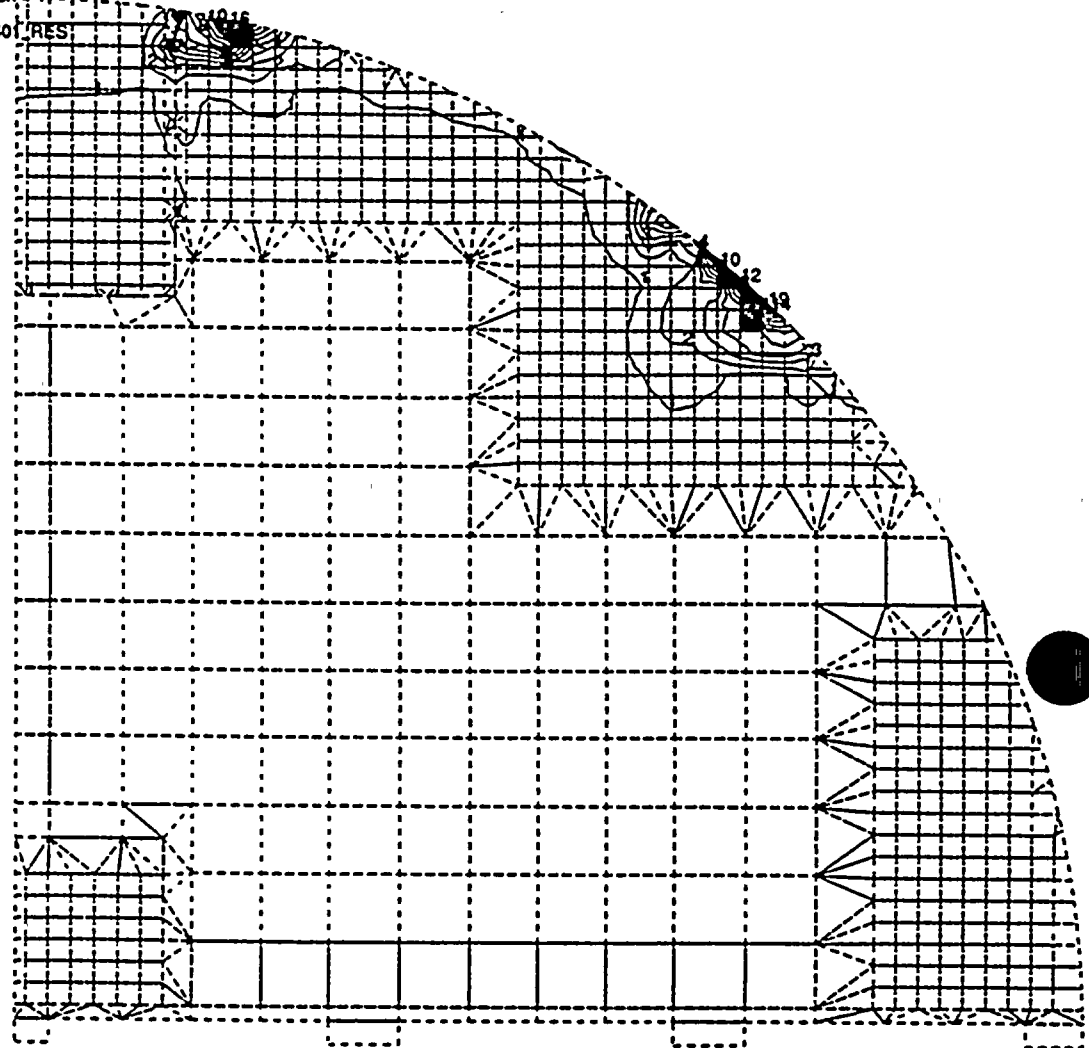
5 = 18720.

4 = 14560.

3 = 10400.

2 = 6240.

1 = 2080.



STRESS CONTOUR PLOT - PLATE 6  
QUADRANT 2,4 SUPPORT CONDITION  
PLATE / WRAPPER - ALL DOF COUPLED



## REMAINING WORK

- COMPLETE MATRIX OF CASES TO CONVERGENCE
- CALCULATE WELD STRESSES
- PREPARE REPORT
- COMPLETE DOCUMENTATION

## ANALYSIS CONCLUSIONS

- LIMITED NUMBER OF TUBES WILL EXCEED MINIMUM BREAKAWAY FORCE
- HOT-TO-COLD DISPLACEMENT AT TOP TSP IS 0.1 INCH. TUBE BREAKAWAY WILL NOT RESULT IN SIGNIFICANT DISPLACEMENT
- BREAKAWAY OF LIMITED NUMBER OF TUBES ADJACENT TO WEDGES WILL NOT RESULT IN SIGNIFICANT INCREASE IN PLATE DISPLACEMENT UNDER SLB
- PLATE STRESSES ARE LOCALIZED AT PLATE WEDGE REGION
- PLATES SUPPORTED BY BOTH WEDGES AND TUBES:  
LOSS OF WEDGE SUPPORT WOULD NOT RESULT IN PLATE MOTION
- AXIAL STRESS IN TUBES FOR HOT-TO-COLD CONDITION LESS THAN YIELD

**NDE Sizing for Axial PWSCC at Dented TSPs**

**NRC/Utility Meeting**

**November 20, 1996**

**Presented By:**

**T. A. Pitterle**

**Nuclear Services Division**

**Westinghouse Electric Corp.**

## Discussion Topics

Pulled Tube and Laboratory Specimen Database

Coil Lead-in and Lead-out Crack Edge Effects

- Length adjustment guidelines

Depth Adjustments for Uncorroded Ligaments

General Comparisons of NDE and Destructive Exam

NDE Uncertainties

Conclusions

## NDE Sizing for Axial PWSCC

### Objective

- Qualify + Point sizing for PWSCC axial cracks at dented TSPs
  - Average depth
  - Maximum depth
  - Length

### Database

- 4 pulled tube axial PWSCC indications from dented TSP intersections
  - Lengths = 0.12" to 0.99"
  - 4 cracks in 3 intersections
- 14 laboratory cracks in dented specimens
  - Lengths = 0.13" to 2.56"
  - 14 cracks in 6 specimens
  - Additional specimen with 2 cracks being processed

### NDE Analyses are "Blind"

- Completed prior to destructive examination
- Only 1 pulled tube has NDE following tube exam

### Coils Evaluated

- + Point mid-range - principal emphasis
- Also + Point high frequency, mag bias and gimbaled

## Laboratory Specimen Preparation

Mechanically dented

Cracked in doped steam

TSP with packed magnetite crevice placed on tube

NDE data collected

Specimens burst

- 3 with TSP and 3 freespan

Specimens destructively examined

Fractography to obtain depth vs length profiles

- Uncorroded ligaments identified and sized

## **Crack Morphology of Pulled Tubes and Lab Specimens**

### **Pulled Tube PWSCC Shows Relatively Simple Morphology**

- Generally single cracks
  - May be two cracks about 180° apart
- Typical initiation as microcracks
- Only a few remaining uncorroded ligaments
- Cracks nearly linear with small (typically < 10 mil) ligaments joining microcracks

### **Laboratory PWSCC Morphology**

- No identifiable differences from pulled tubes

### **No Identifiable Difference in Sizing Lab Specimens vs Pulled Tubes**

- Shallower lab and pulled tube ind. show comparable NDE
- Deeper lab ind. easier to size as would pulled tubes if available

### **Lab Specimen Preparation Emphasized Deeper Indications**

- Desire to demonstrate capability to size indications challenging structural integrity
- Smaller indications also obtained with larger indications

## Coil Lead-in, Lead-out Crack Edge Effects

### Edge Effects

- Demonstrated on EDM notches
- Effects somewhat larger for + Point coil than for pancake coils
  - Larger + point field of  $> 0.2"$

### Effects Found on EDM Notch and Laboratory Specimens

- Lengths overestimated within coil field of end of crack
- Phase angles increase within coil field of edge of crack
  - Causes ID depths to be overestimated
  - OD phase angles frequently occur at edges of crack
- Increased phase angles occur with low voltage response
  - Typically depths  $> 85\%$  with  $< 1$  volt

### Edge Effects Significantly Reduce Detection of Large (.1-0.3") Ligaments Within Macrocrack

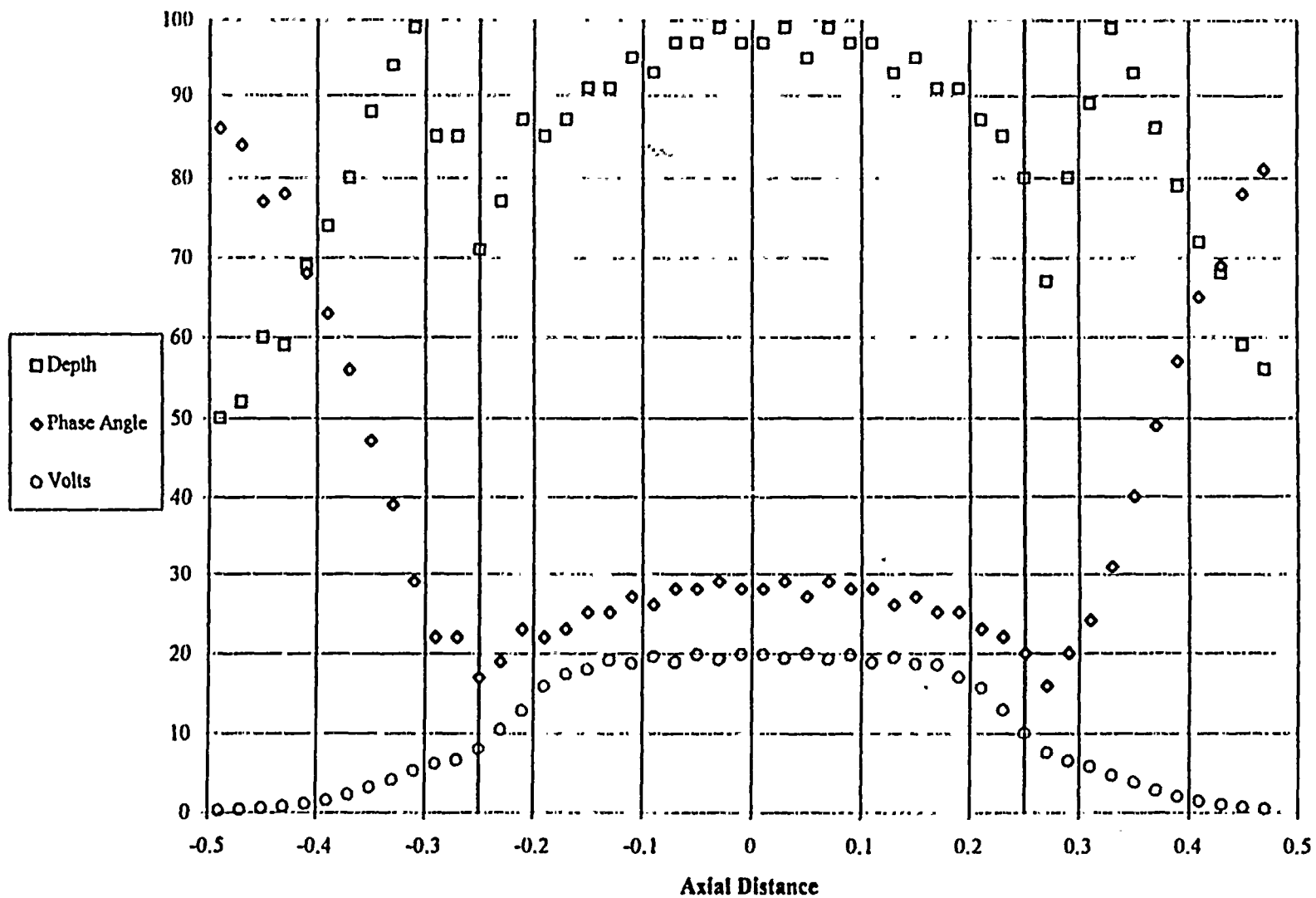
- Effects tend to result in deep NDE calls at ligaments

### Length Adjustment Guideline Defined

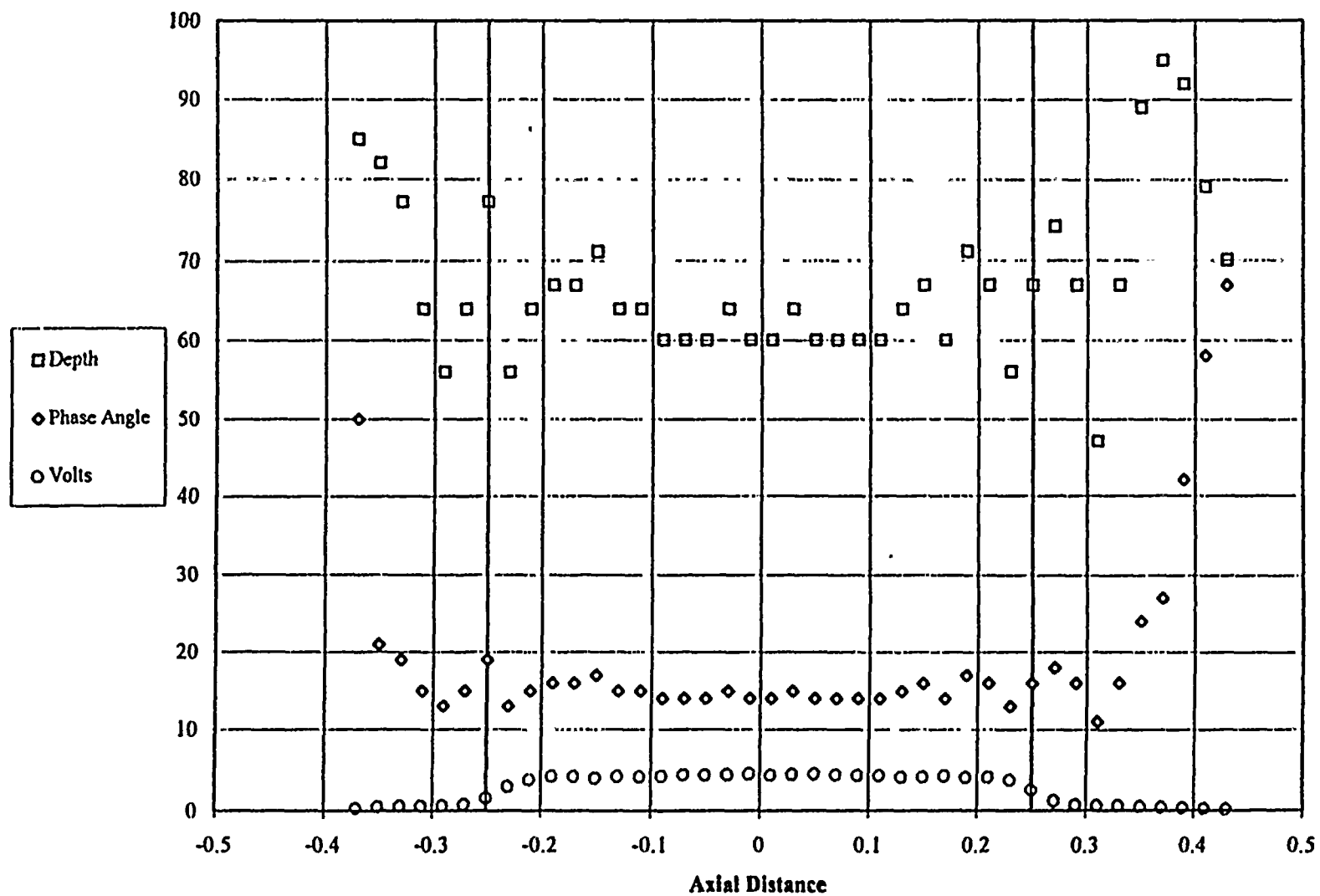
- Length adjustment applied to NDE for development of NDE uncertainties



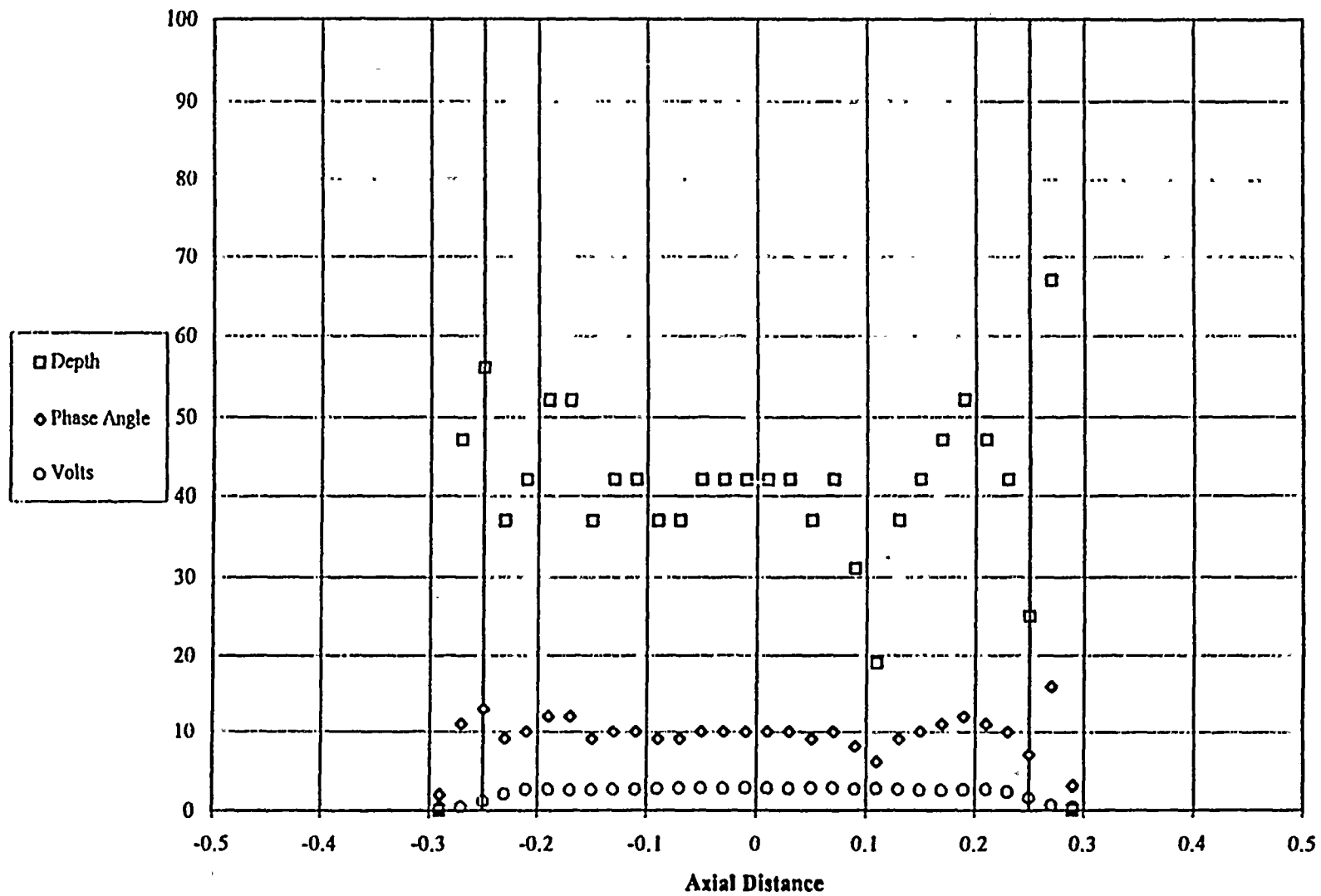
# 100% TW Slot - Eddynet, + Point



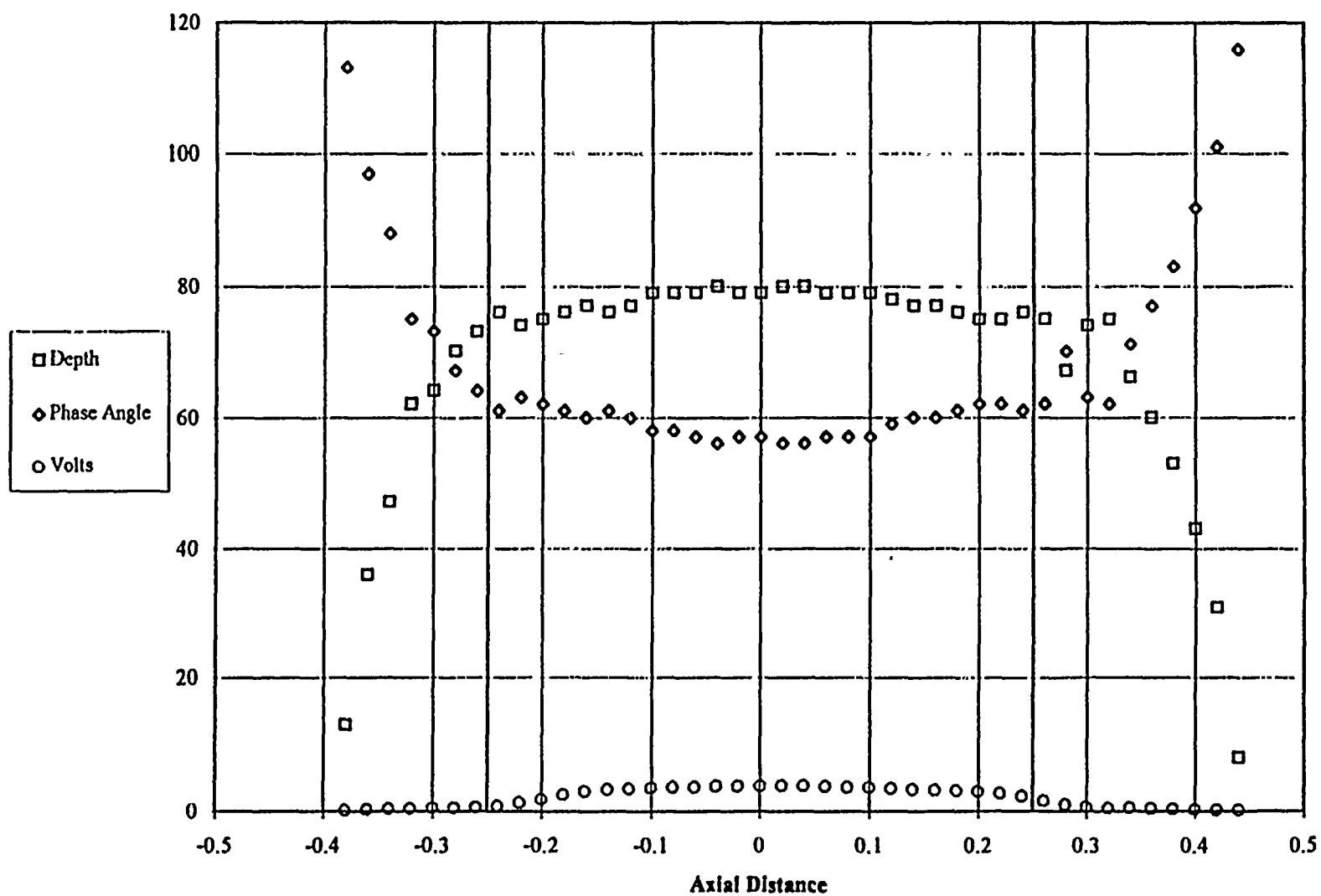
# 60% TW ID Slot - Eddytest + Point



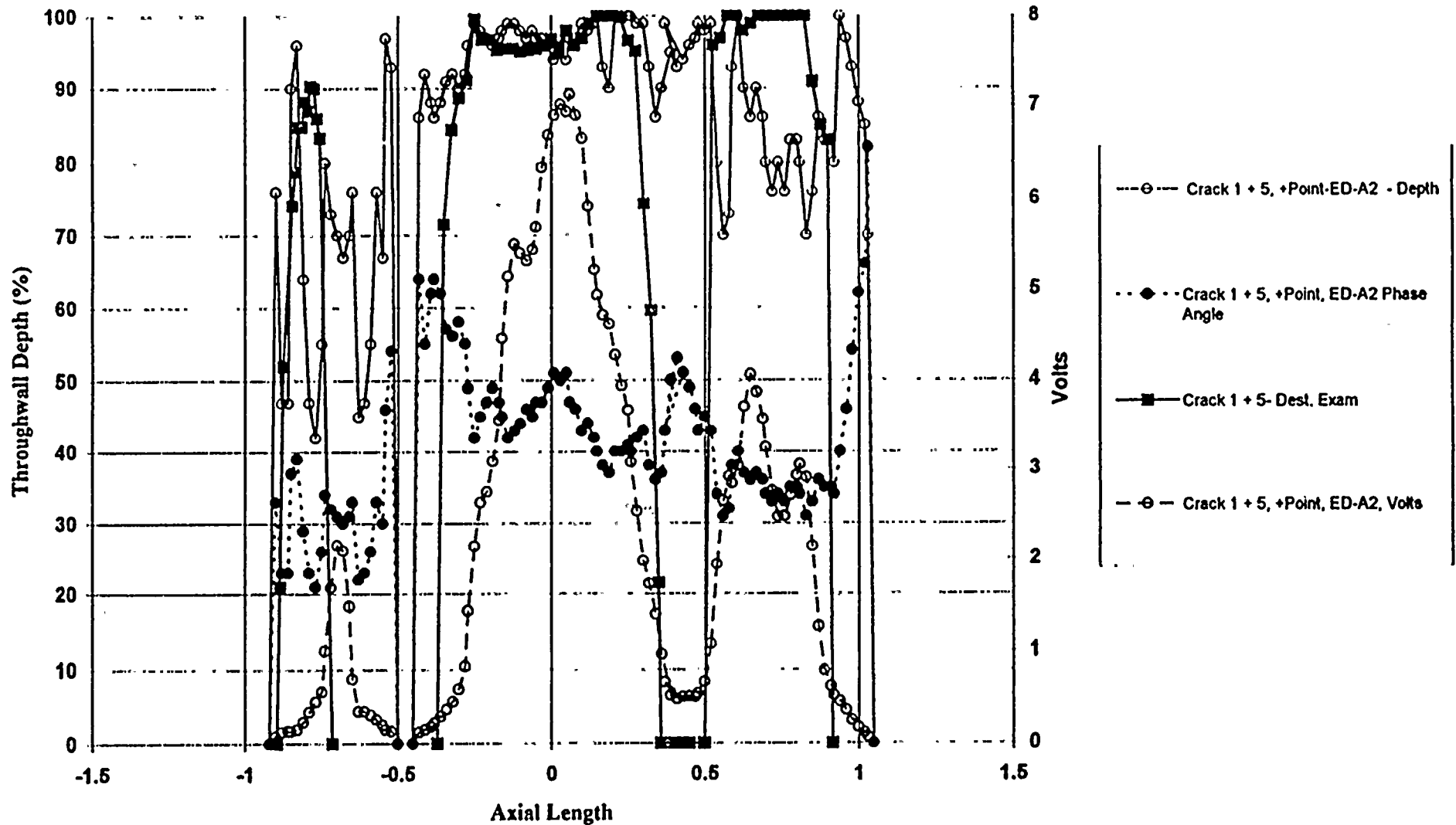
# 40% TW ID Slot - Eddynet, + Point



# 80% TW OD Slot - Eddynet, + Point



# Sample 12 - Cracks 1 and 5 Destructive Exam Depth vs. NDE +Pt Depth, Volts and Phase Angle



## **Adjustment Guidelines for PWSCC Crack Lengths**

### **OD Phase Angles Near Ends of Crack**

- Data points with OD phase angles from the start of OD to the end of the crack are ignored in defining the crack length as long as within 0.2" of the indicated end of the crack. The end of the crack shall be defined as  $\leq 0.03$ " beyond the last accepted (without points with OD phase) data point if points are deleted at the end of the crack.

### **Near Throughwall ID Phase Angles Near Ends of Crack**

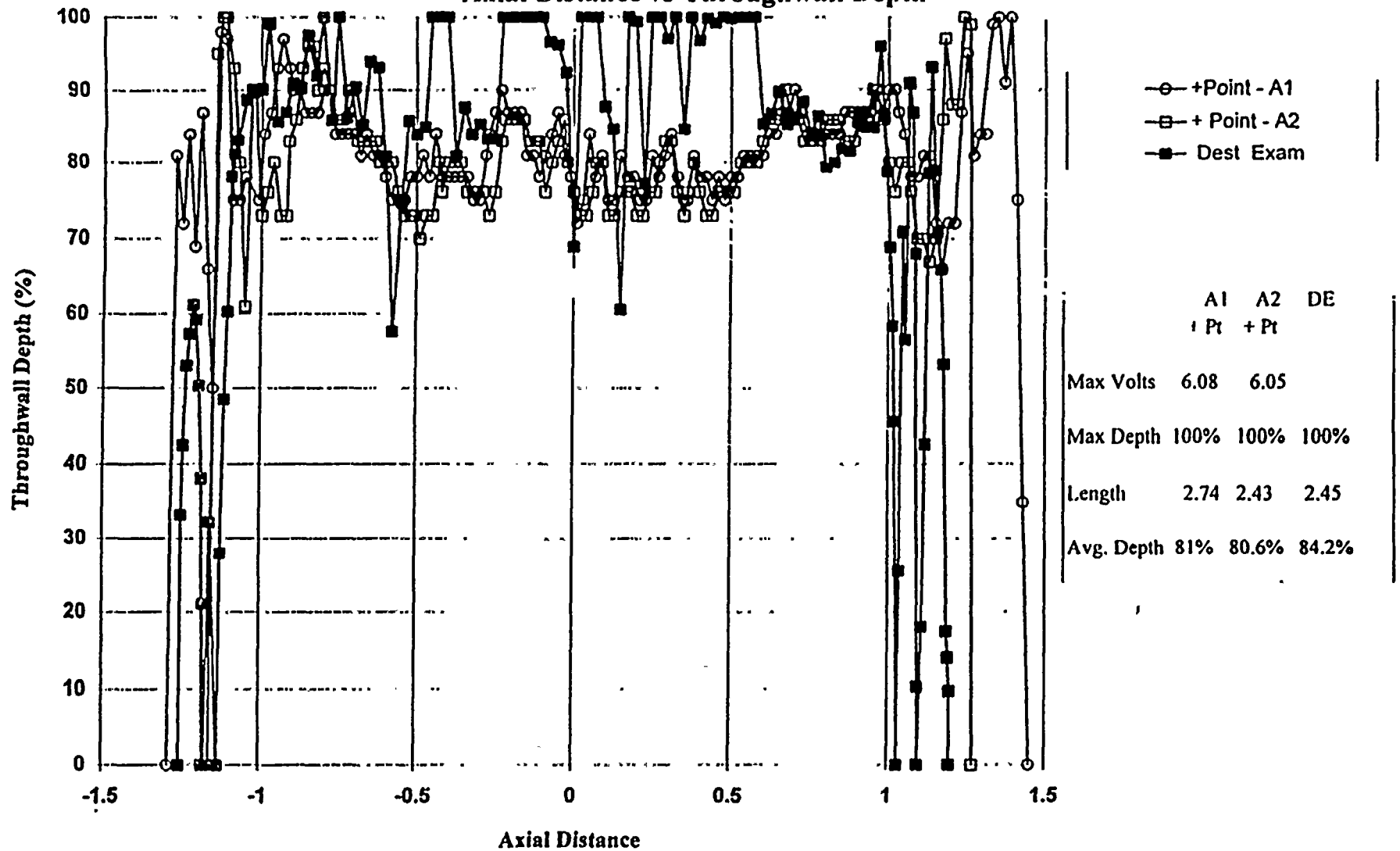
- Near throughwall ID phase depths ( $\geq 85\%$ ) with voltages  $< 1$  volt are ignored in defining the crack length as long as within 0.2" of the indicated end of the crack. The end of the crack shall be defined as  $\leq 0.03$ " beyond the last accepted data point if points are deleted at the end of the crack.

### **ID Depths Increase Near Ends of Crack**

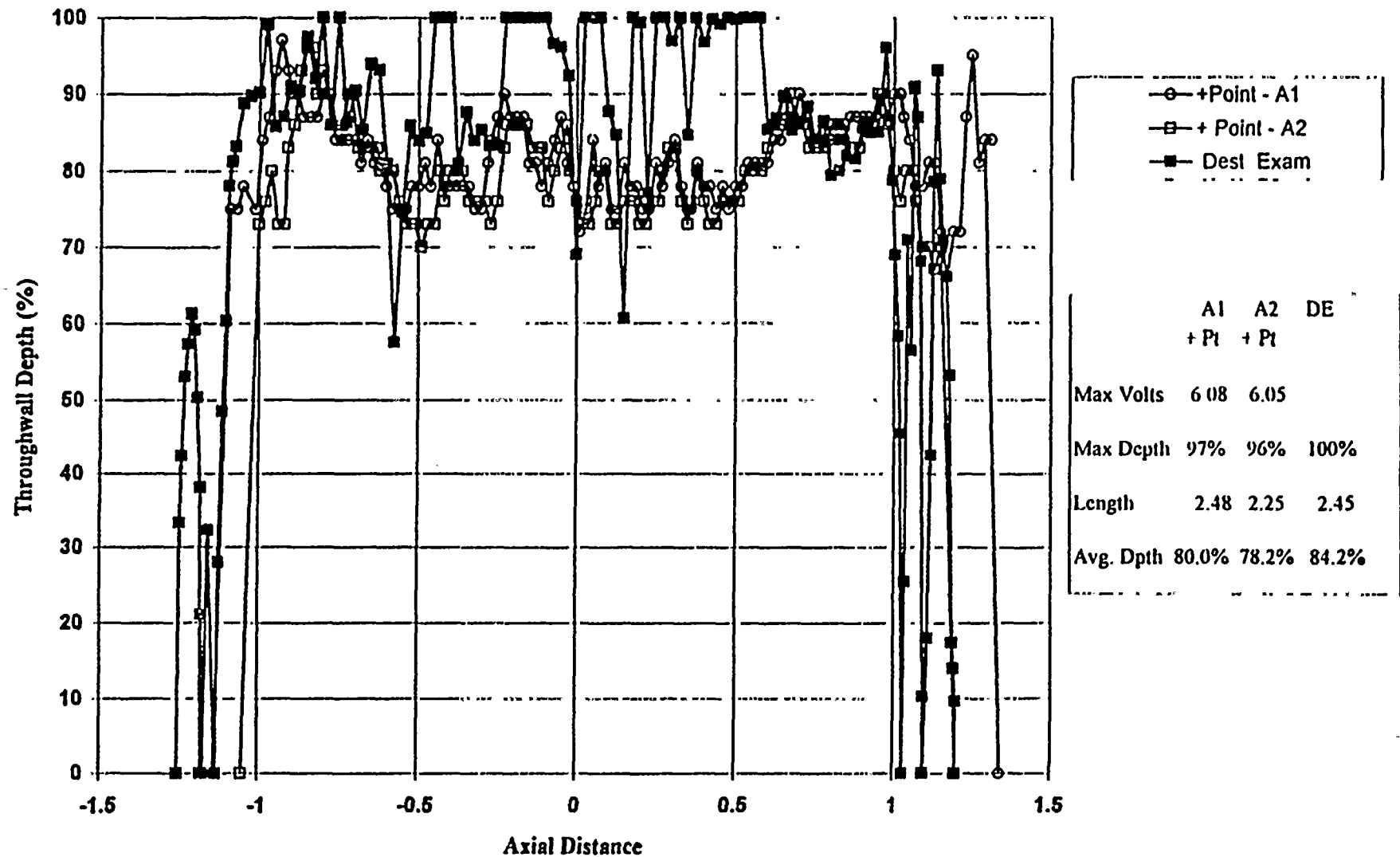
- If ID depths at points near the end of the crack show depth increases of  $> 10\%$  over about 0.05" spans and voltages  $< 1$  volt, the data points shall be ignored in defining the crack length as long as within 0.2" of the indicated end of the crack. The end of the crack shall be defined as  $\leq 0.03$ " beyond the last accepted data point if points are deleted at the end of the crack.

# Sample 8 - Crack 2

## Axial Distance vs Throughwall Depth



Sample 8 - Crack 2 (MOD 3)  
Axial Distance vs Throughwall Depth





## Depth Adjustments for Uncorroded Ligaments

### General Considerations

- Uncorroded ligaments between microcracks much smaller for PWSCC at dents than for ODSCC indications
- Smaller ligaments result in less influence on NDE sizing accuracy

### Ligament Area of Uncorroded Ligaments Measured in Destructive Exams

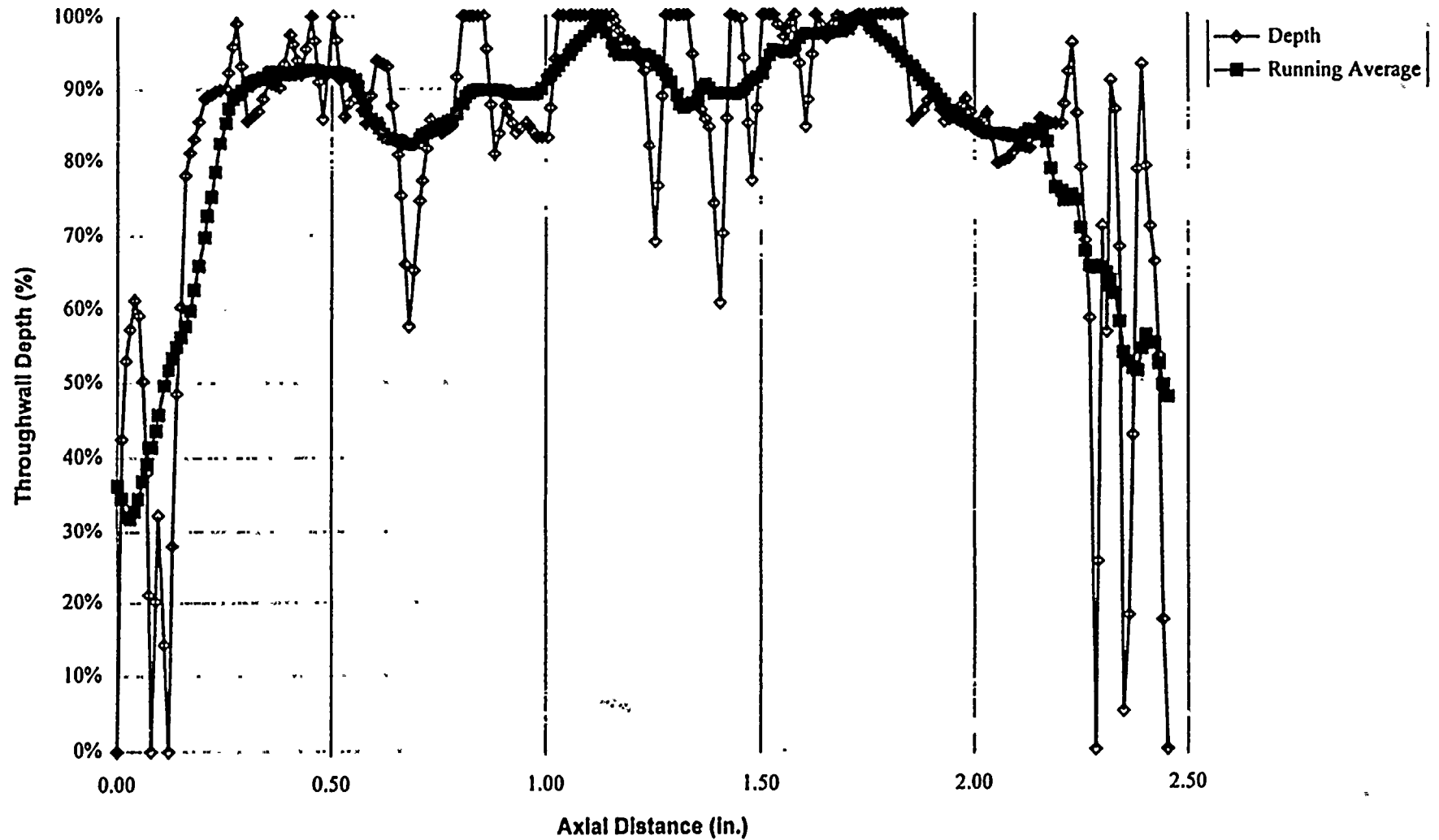
#### Crack Depths Can be Adjusted for Ligament Area

- Crack depths are reduced by effective ligament area
- Effective ligament area for burst considerations is 60% of total area
  - Ligaments perpendicular to plane of crack are in shear
- Application to depth profiling requires length averaging
  - Destructive exam depth profiles and ligament areas developed as running average over 0.2" coil field spread

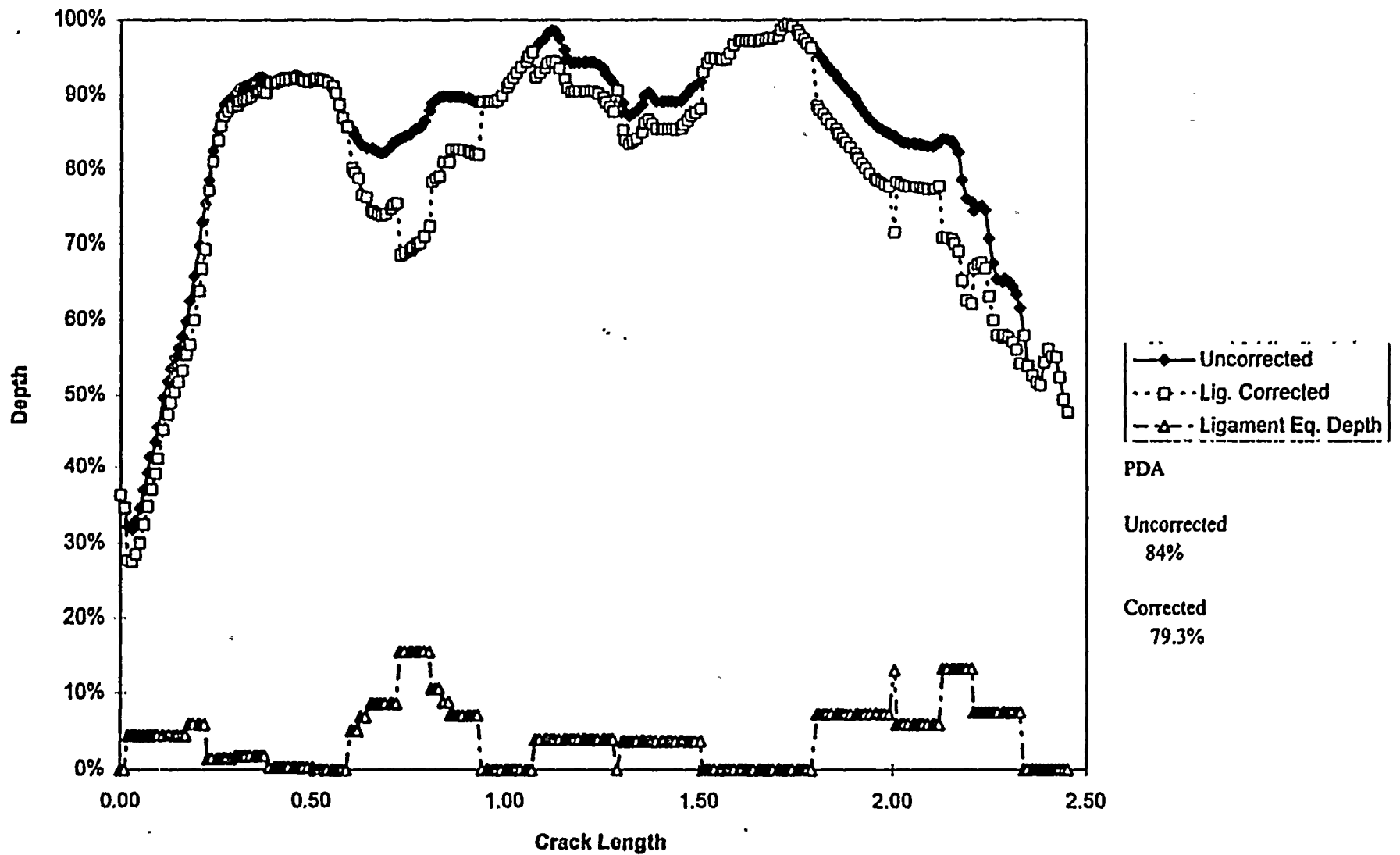
#### Corrections for Ligaments

- Adjustments range from 1% to 5% on average depth
- Ligament corrections improve agreement with NDE

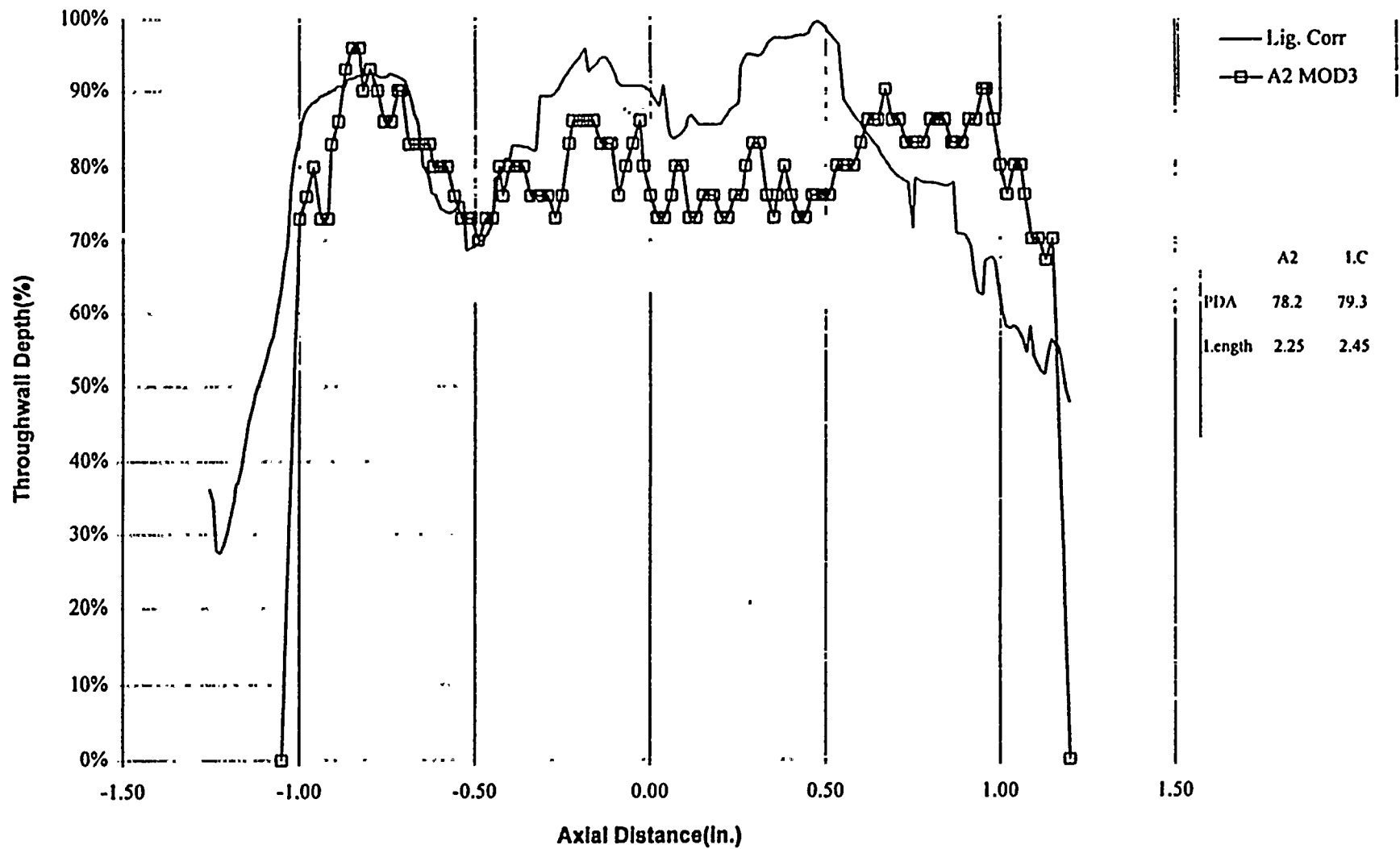
Comparison of Length vs Depth to Length  
vs Running Average of Depth



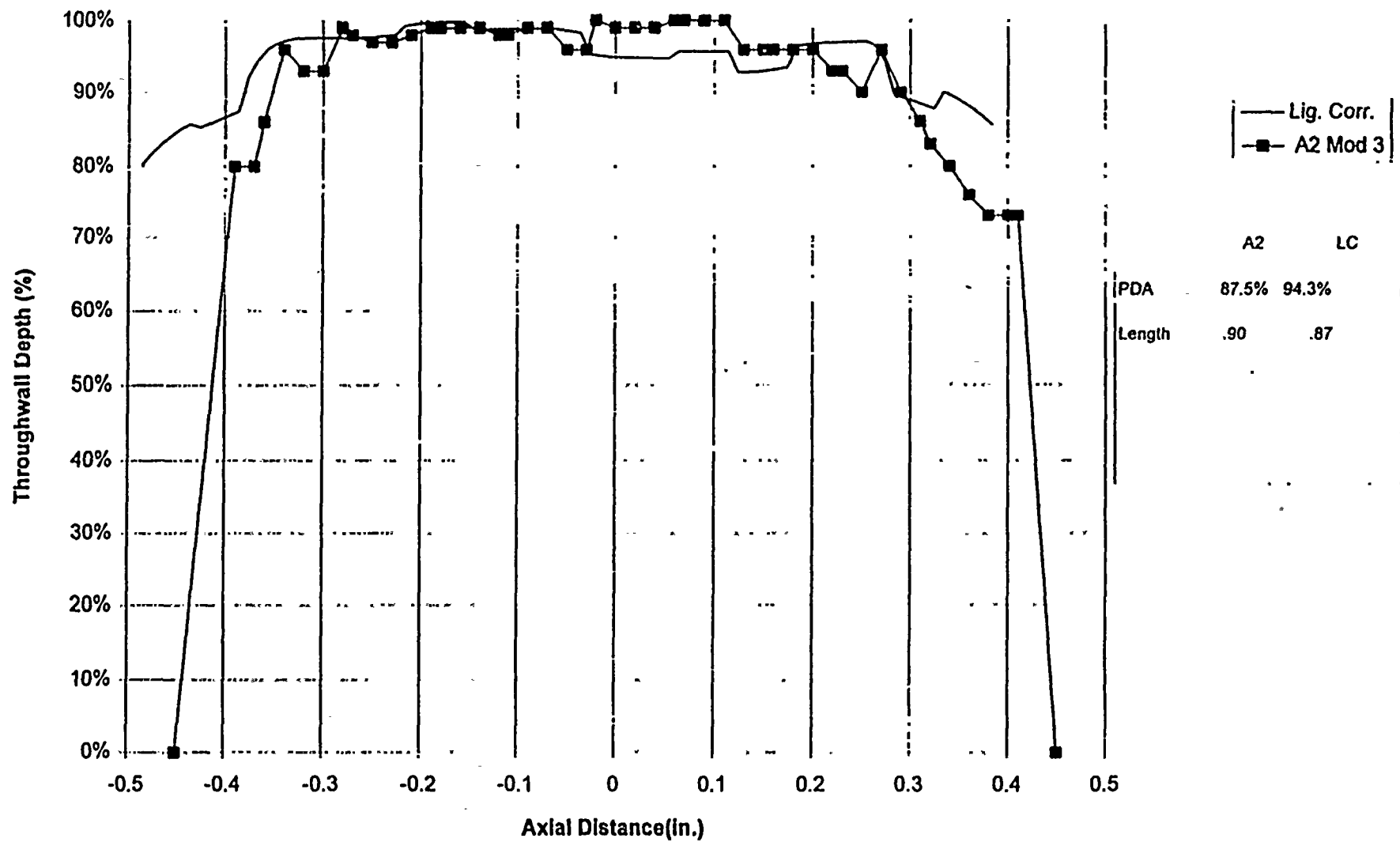
## Sample 8 Crack 2, Ligament Correction



### Sample 8 Lig Correction Compared to NDE Crack 2



## Sample 7 Lig Correction Compared to NDE Crack 1



# **General Comparisons of NDE and Destructive Exam**

## **Comparisons Between Analysts**

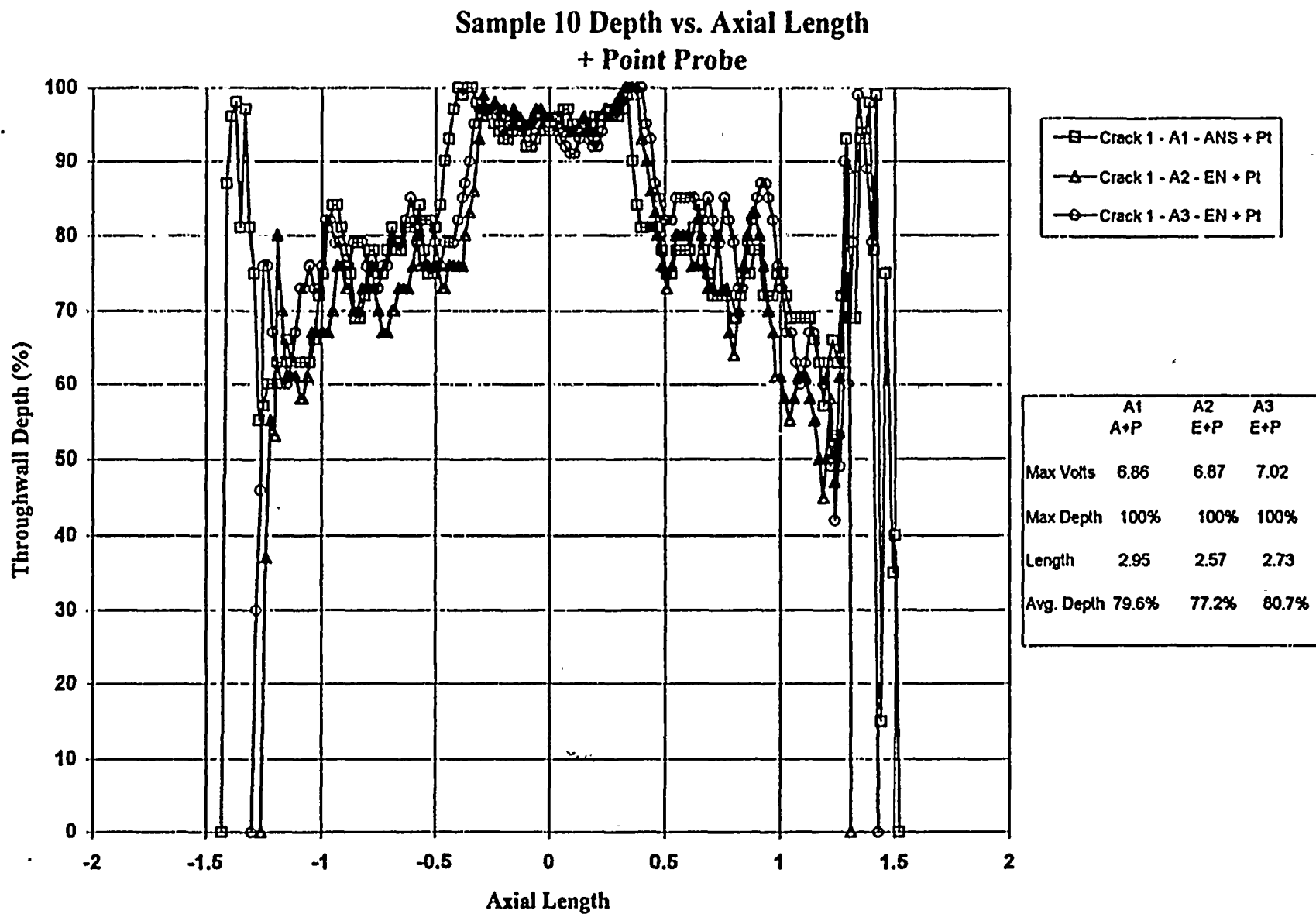
- Very good agreement between NDE analysts for significant indications
- Differences between analysts primarily in unadjusted length calls with some analysts terminating length at significant OD phase angles
- As would be expected, differences between analysts are more significant for small indications and in separating closely spaced, small indications

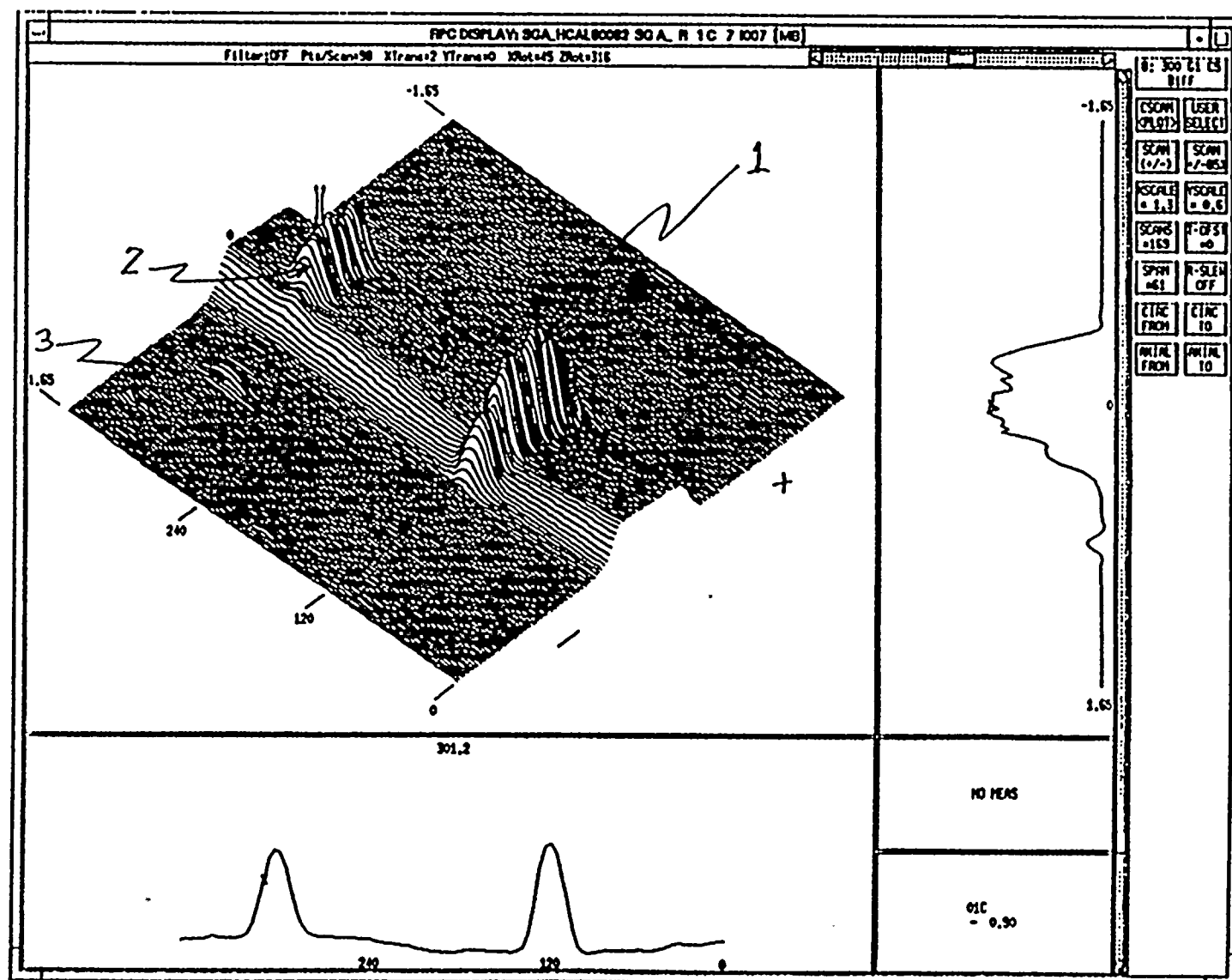
## **Length**

- Unadjusted lengths consistently and significantly overestimate actual lengths
- Adjusted lengths remain slightly biased to overestimates of length but show generally good agreement with actual lengths

## **Average Depth**

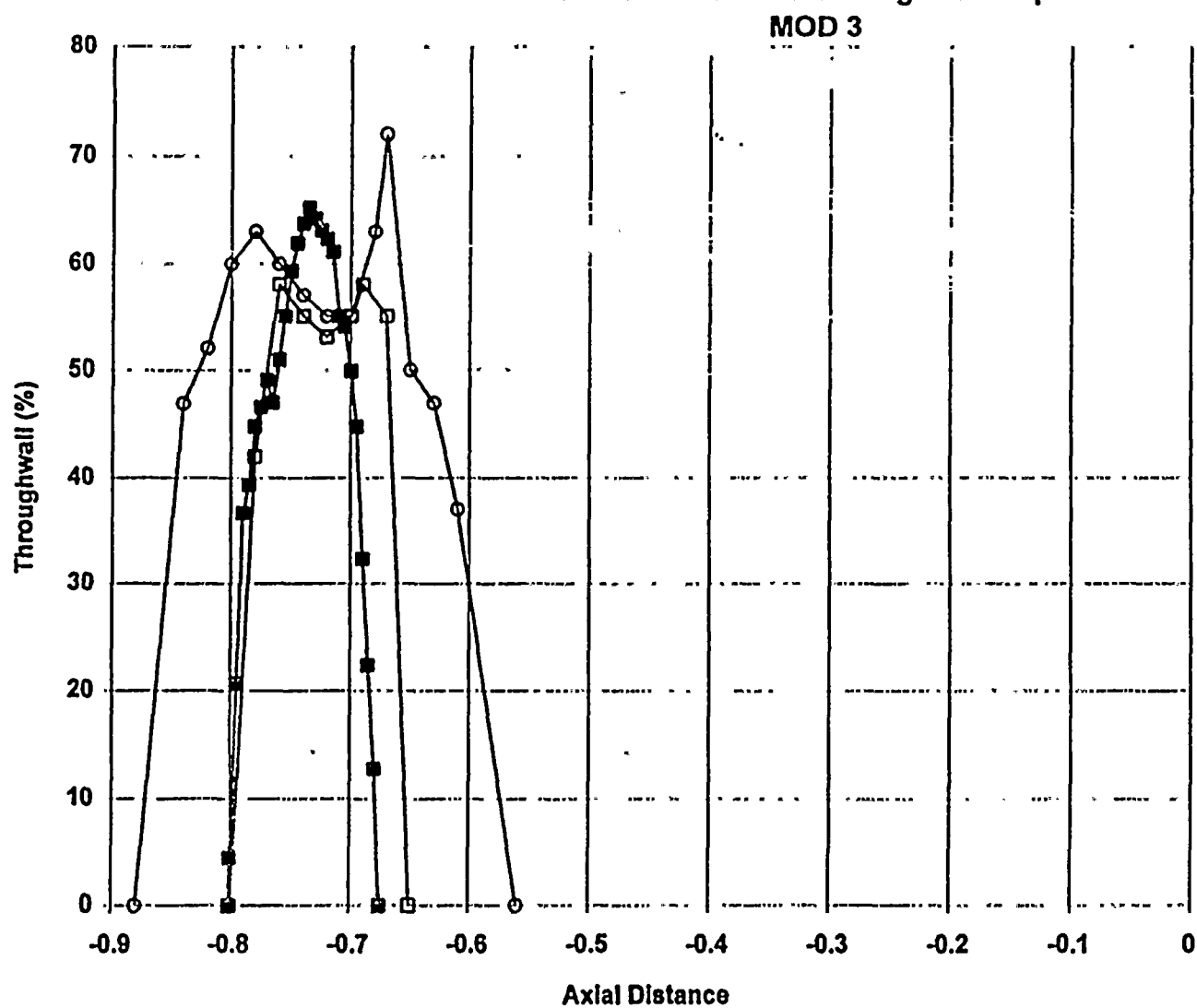
- General trend to overestimate average depths below about 80% depth and slightly underestimate above 80%
- Overall agreement of NDE with actuals is good
- Length adjustment leads to a modest improvement in average depth





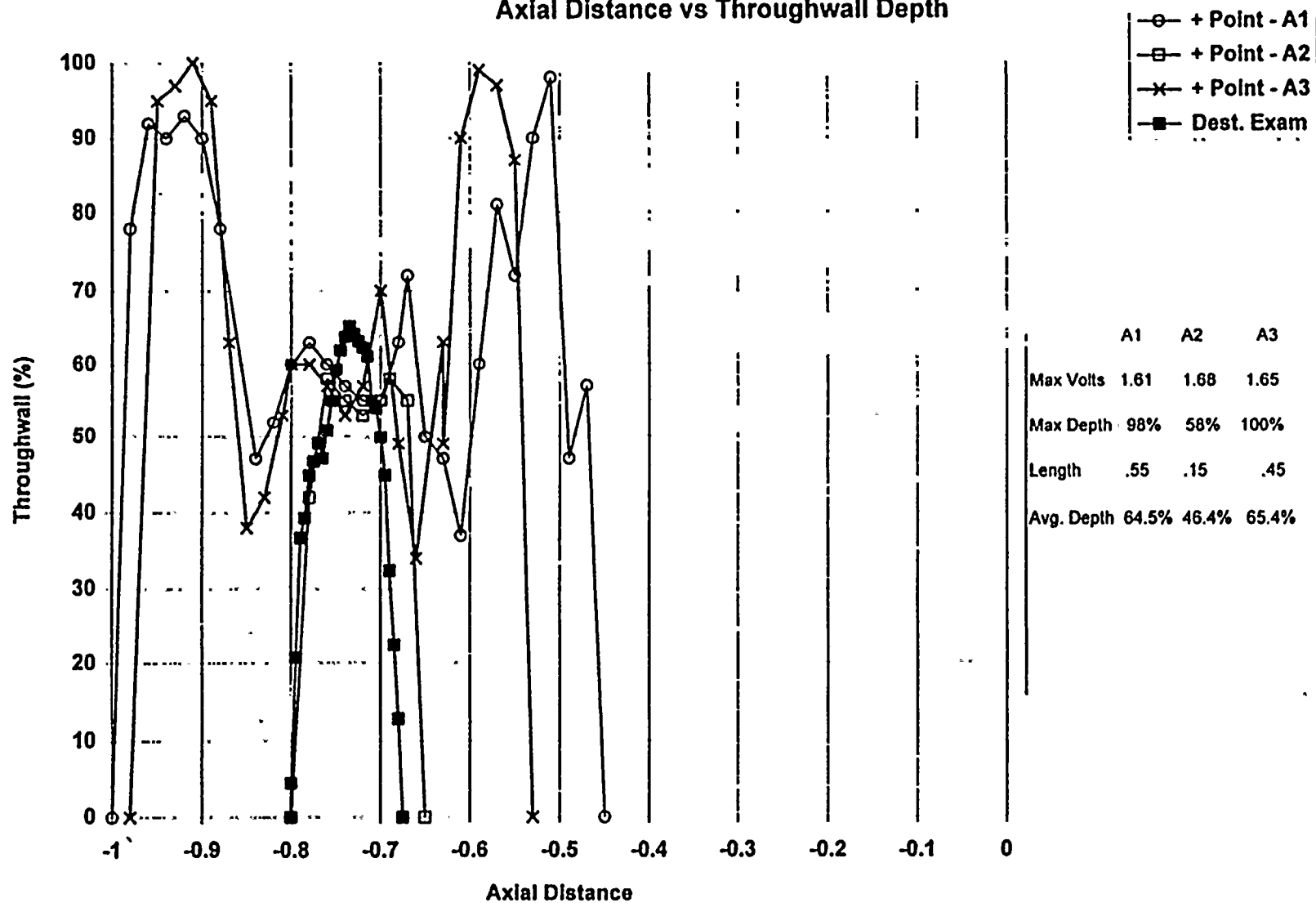


**Sample 7 - Crack 3**  
**Axial Distance vs Throughwall Depth**  
**MOD 3**



	A1	A2	DE
Max Volts	1.61	1.68	
Max Depth	72%	58%	65.2%
Length	.32	.15	.13
Avg. Depth	45.9%	46.4%	46.2%

**Sample 7 - Crack 3**  
**Axial Distance vs Throughwall Depth**



	A1	A2	A3	DE
Max Volts	1.61	1.68	1.65	
Max Depth	98%	58%	100%	65.2%
Length	.55	.15	.45	.13
Avg. Depth	64.5%	46.4%	65.4%	46.2%

## General Comparisons of NDE and Destructive Exam

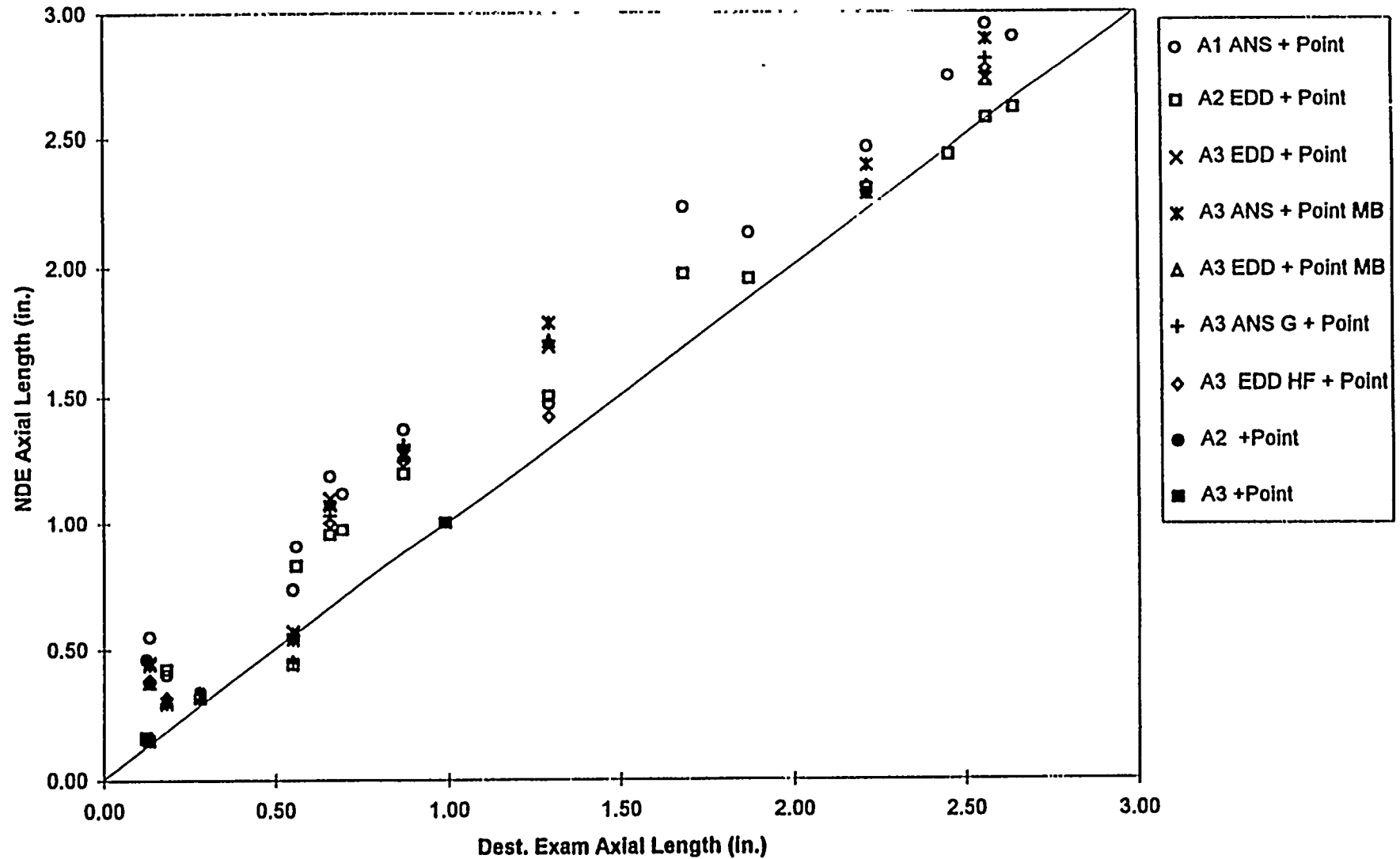
### Maximum Depth

- As generally expected, agreement of NDE with actuals is not as good as for average depth and length
- Generally acceptable for predicting throughwall or near throughwall depths

### Differences Between Coils

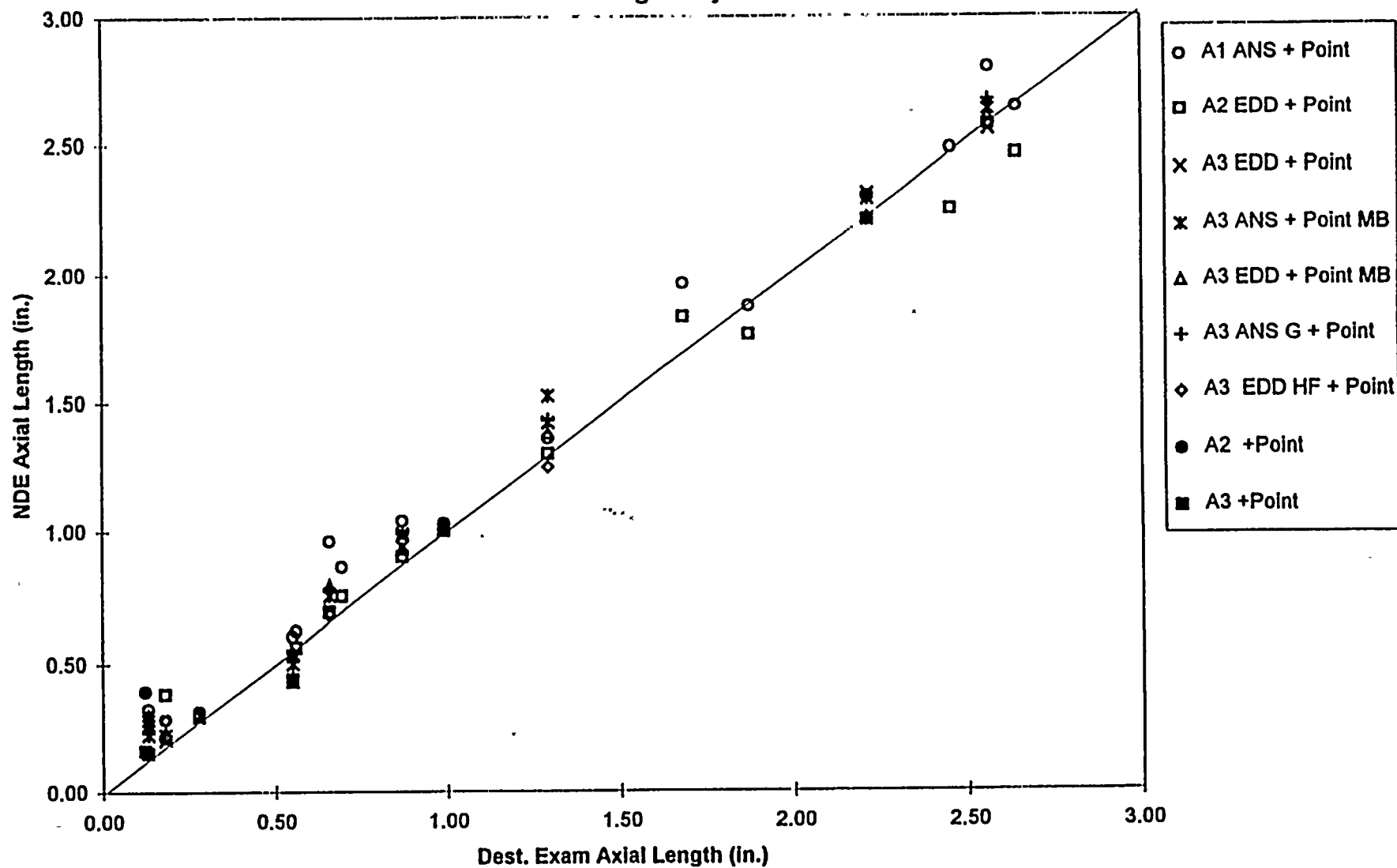
- Mid-range + Point coil yields an acceptable and consistent agreement with actuals
- Mag bias and high frequency + Point tend to overpredict average depths
- Mid-range + Point is preferred coil and used as basis to develop NDE uncertainties

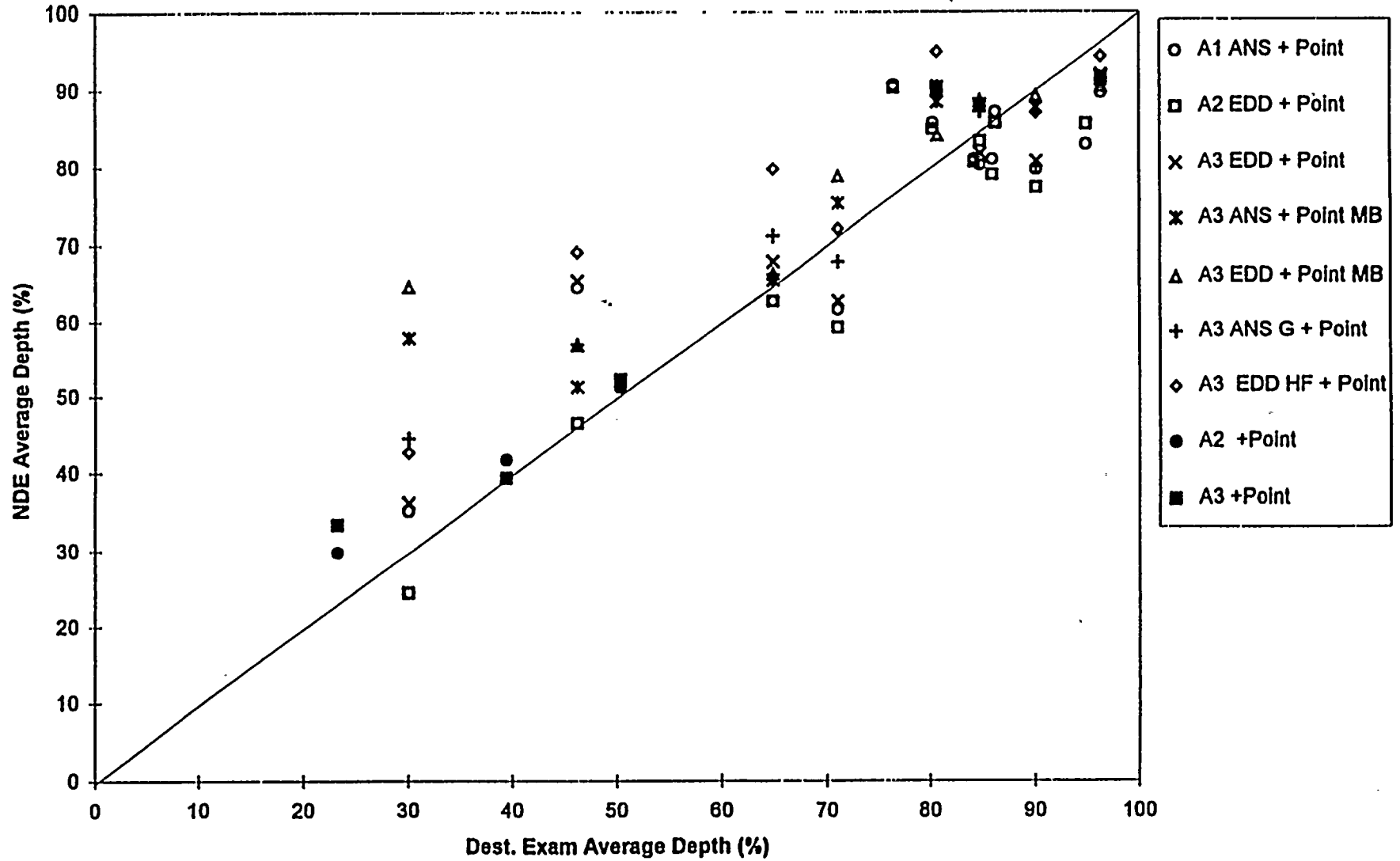
NDE vs DE Axial Length (in.)



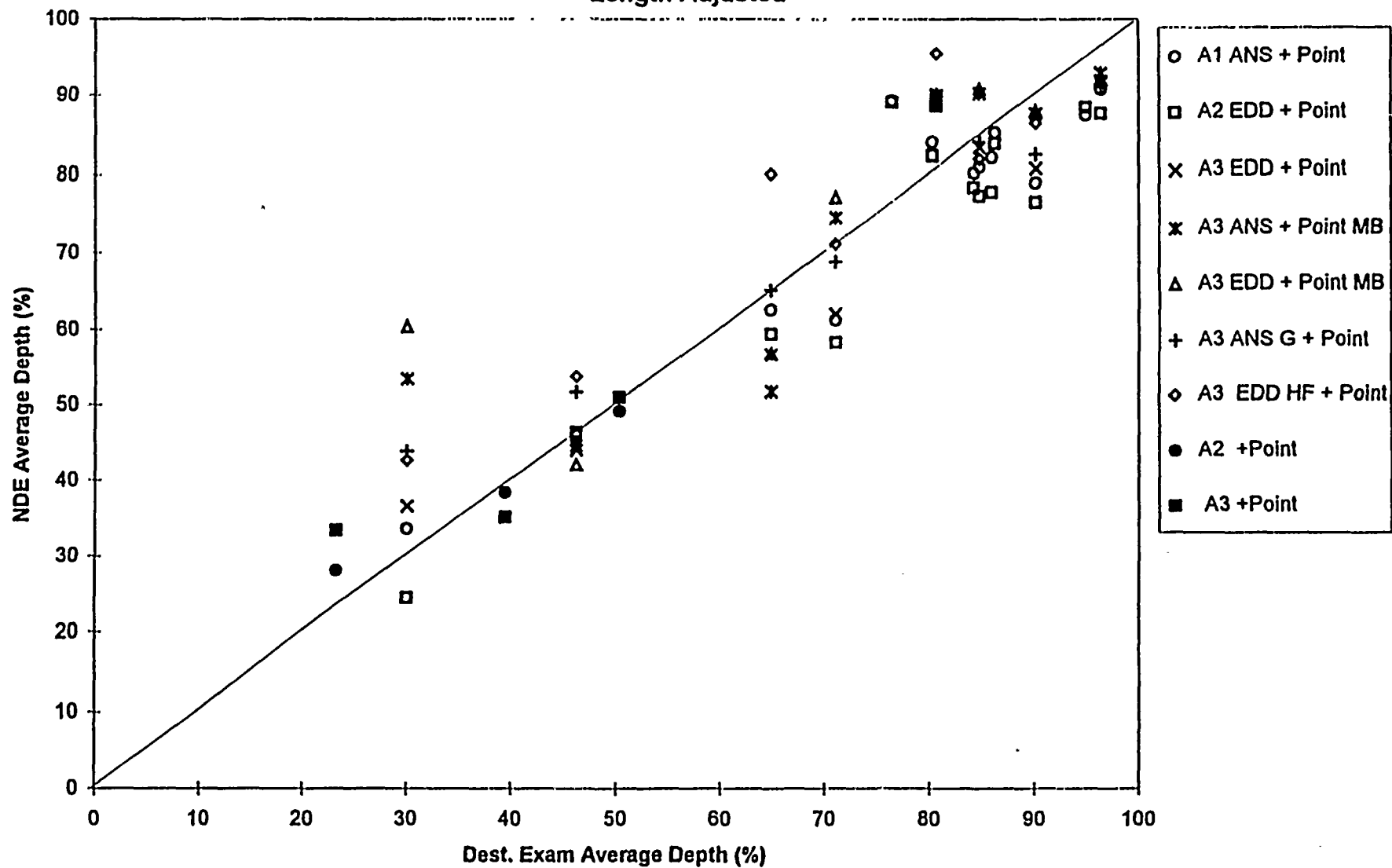


NDE vs DE Axial Length (in.)  
Length Adjusted



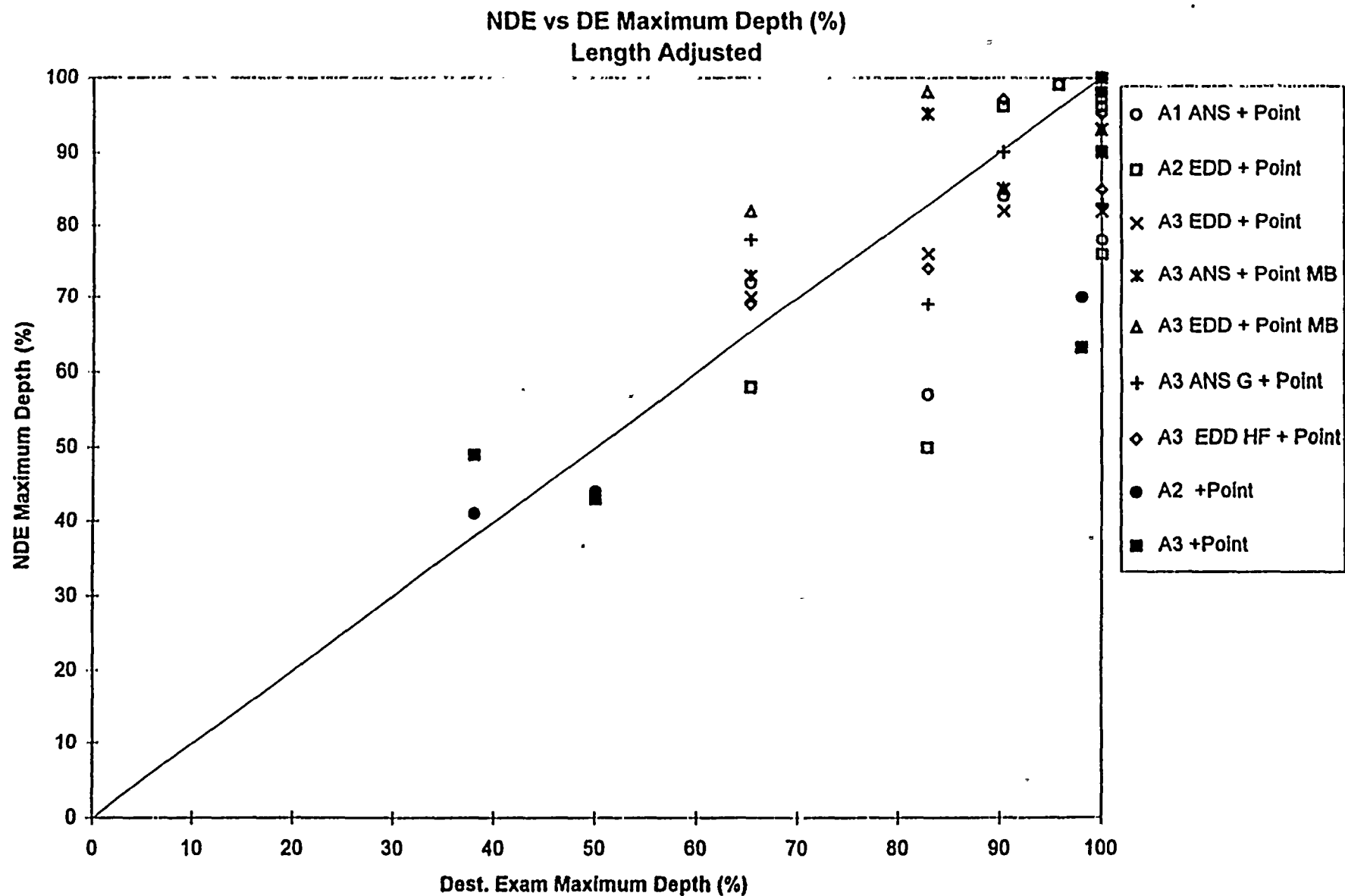


NDE vs DE Average Depth (%)  
Length Adjusted



**Dest. Exam Maximum Depth (%)**





## **NDE Uncertainties**

### **Data for Three Analysts Utilized**

- Some indications only analyzed by two analysts
- One pulled tube with only one analyst
  - Data is 80 mil coil but included for completeness and conservatism

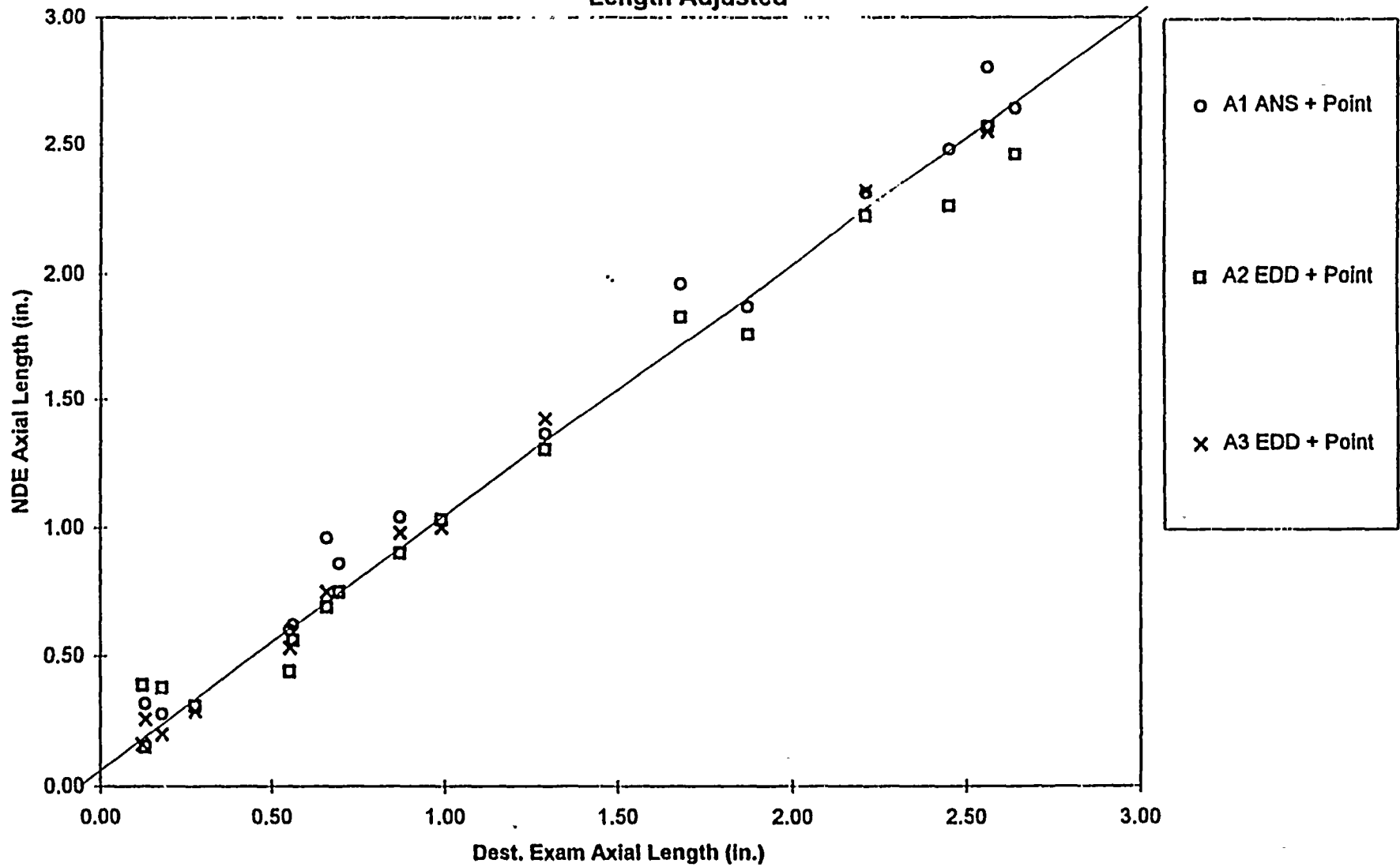
### **NDE Uncertainty Analysis Limited to Mid-range + Point Coil with Length Adjusted Data**

### **Analyses for NDE Uncertainties**

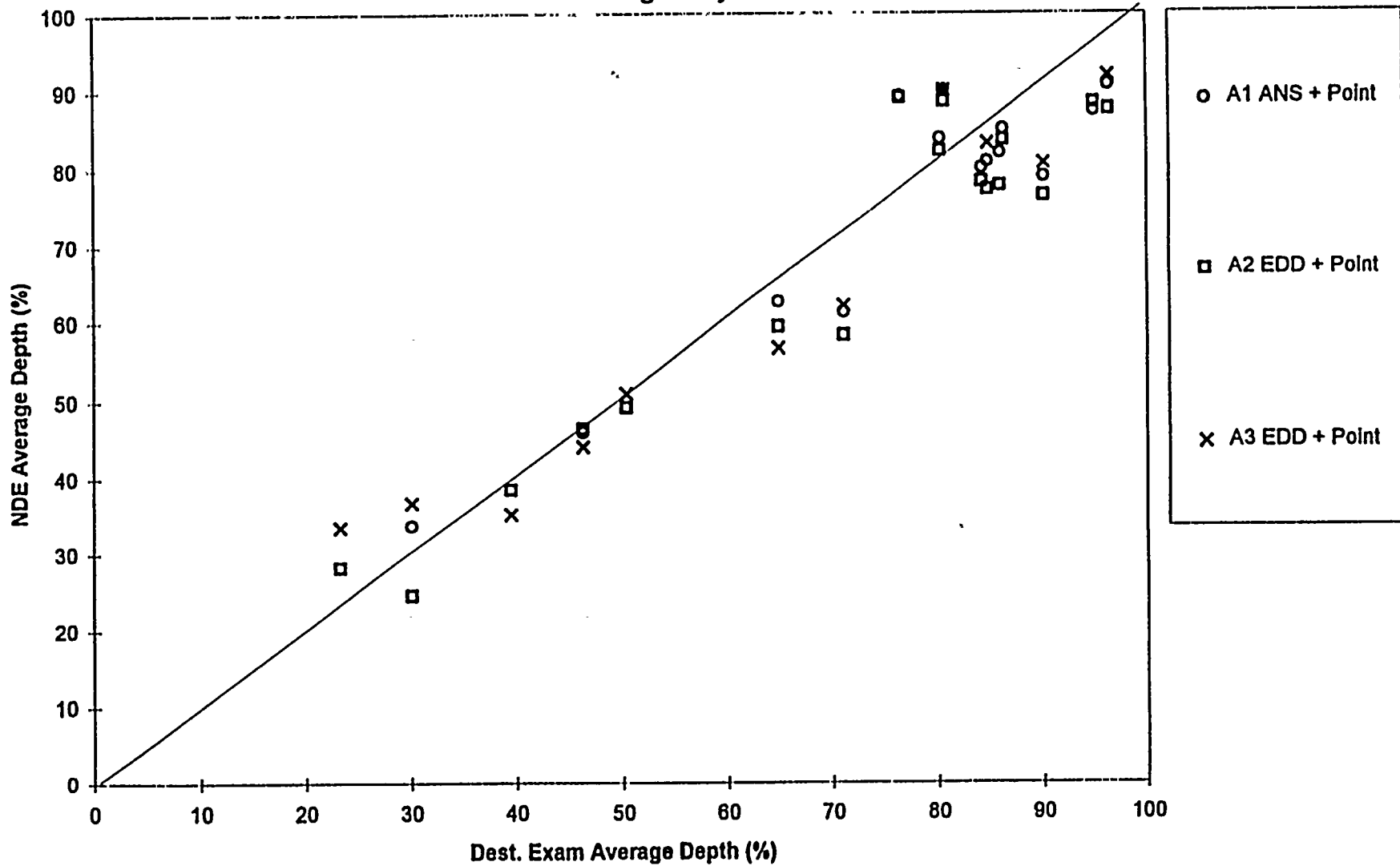
- Comparisons of NDE with Destructive Exam
- Regression analyses to compare slope to theoretical one-to-one slope
- Mean and standard deviation of differences between NDE and Destructive Exam
- Preliminary NDE uncertainty analyses given herein will be updated to include two additional indications and ligament corrections to the destructive exam average depths



+Point Coil  
NDE vs DE Axial Length (in.)  
Length Adjusted

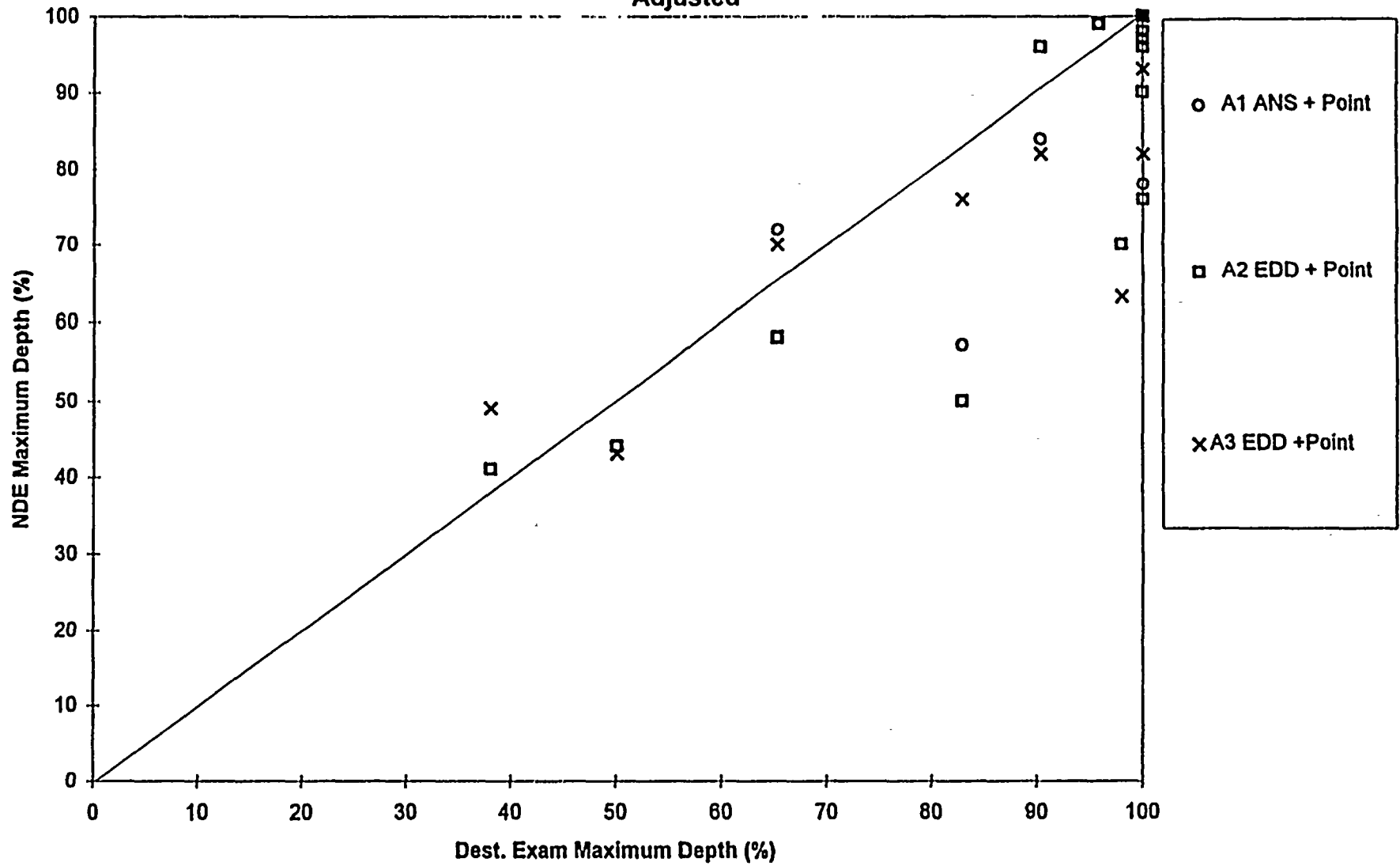


**+Point Coll**  
**NDE vs DE Average Depth (%)**  
**Length Adjusted**





**+Point Coil**  
**NDE vs DE Maximum Depth (%)**  
**Adjusted**



**DENTED TUBE SUPPORT PLATE**  
**Adjusted NDE & DESTRUCTIVE EXAM EVALUATIONS**  
**Comparison of Analysis Techniques, Software and Probes**

Sample Number	Crack Number	Probe Type	Software	Analyst	Adjusted NDE			Destructive Exam			NDE-Destructive Exam		
					Length (inches)	Max Depth (%)	Avg Depth (%)	Length (inches)	Max Depth (%)	Avg Depth (%)	Length (inches)	Max Depth (%)	Avg Depth (%)
7	1	+point	ANS	1	1.04	100	90.8	0.87	100	96.3	0.17	0.0	-5.7
7	2	+point	ANS	1	0.96	100	80.8	0.66	100	84.7	0.30	0.0	-3.9
7	3	+point	ANS	1	0.32	72	45.9	0.13	65.2	46.2	0.19	6.8	-0.3
8	1	+point	ANS	1	2.64	100	85.0	2.64	100	86.2	0.00	0.0	-1.2
8	2	+point	ANS	1	2.48	97	80.0	2.45	100	84.2	0.03	-3.0	-4.2
9	1	+point	ANS	1	1.87	100	83.8	1.87	100	80.2	0.00	0.0	-3.6
9	2	+point	ANS	1	1.96	100	81.9	1.68	100	85.9	0.28	0.0	-4.0
10	1	+point	ANS	1	2.80	100	78.8	2.56	100	90.1	0.24	0.0	-11.3
10	2	+point	ANS	1	2.30	78	61.1	2.21	100	71.0	0.09	-22.0	-9.9
11	1	+point	ANS	1	0.86	97	87.3	0.694	100	94.9	0.17	-3.0	-7.6
11	2	+point	ANS	1	0.62	99	89.2	0.56	95.8	76.4	0.06	3.2	12.8
12	1	+point	ANS	1	1.36	100	89.9	1.29	100	80.6	0.07	0.0	9.3
12	2	+point	ANS	1	0.60	57	33.6	0.55	82.8	30.0	0.05	-25.8	3.6
12	5	+point	ANS	1	0.28	84	62.4	0.18	90.3	64.8	0.10	-6.3	-2.4
7	1	+point	EDD	2	0.90	100	87.5	0.87	100	96.3	0.03	0.0	-8.8
7	2	+point	EDD	2	0.69	90	77.2	0.66	100	84.7	0.03	-10.0	-7.5
7	3	+point	EDD	2	0.15	58	46.4	0.13	65.2	46.2	0.02	-7.2	0.2
8	1	+point	EDD	2	2.46	100	83.6	2.64	100	86.2	-0.18	0.0	-2.6
8	2	+point	EDD	2	2.25	96	78.2	2.45	100	84.2	-0.20	-4.0	-6.0
9	1	+point	EDD	2	1.76	100	82.2	1.87	100	80.2	-0.11	0.0	2.0
9	2	+point	EDD	2	1.83	100	77.7	1.68	100	85.9	0.15	0.0	-8.2
10	1	+point	EDD	2	2.57	100	76.4	2.56	100	90.1	0.01	-13.7	-13.7
10	2	+point	EDD	2	2.21	76	58.2	2.21	100	71.0	0.00	-24.5	-12.8
11	1	+point	EDD	2	0.75	98	88.3	0.694	100	94.9	0.06	-2.0	-6.6
11	2	+point	EDD	2	0.56	99	89.0	0.56	95.8	76.4	0.00	3.2	12.8
12	1	+point	EDD	2	1.30	100	88.5	1.29	100	80.6	0.01	0.0	7.9
12	2 (3+4)	+point	EDD	2	0.44	50	24.4	0.55	82.8	30.0	-0.11	-32.8	-5.6
12	5	+point	EDD	2	0.38	96	59.3	0.18	90.3	64.8	0.20	5.7	-5.5
21/43	1	+point		2	1.03	70	49.1	0.991	98	50.3	0.04	-28.0	-1.2
21/43	2	+point		2	0.31	44	38.4	0.277	50	39.4	0.03	-6.0	-1.0
10/22	1	+point		2	0.39	41	28.0	0.122	38	23.2	0.27	3.0	4.8
7	1	+point	EDD	3	0.98	100	91.8	0.87	100	96.3	0.11	0.0	-4.5
7	2	+point	EDD	3	0.75	93	83.2	0.66	100	84.7	0.09	-7.0	-1.5
7	3	+point	EDD	3	0.26	70	44.0	0.13	65.2	46.2	0.13	4.8	-2.2
10	1	+point	EDD	3	2.55	100	80.6	2.56	100	90.1	-0.01	0.0	-9.5
10	2	+point	EDD	3	2.31	82	61.9	2.21	100	71.0	0.10	-18.0	-9.1
12	1	+point	EDD	3	1.42	100	89.9	1.29	100	80.6	0.13	0.0	9.3
12	2 (3+4)	+point	EDD	3	0.53	76	36.6	0.55	82.8	30.0	-0.02	-6.8	6.6
12	5	+point	EDD	3	0.20	82	56.6	0.18	90.3	64.8	0.02	-8.3	-8.2
21/43	1	+point		3	1.00	63	50.9	0.991	98	50.3	0.01	-35.0	0.6
21/43	2	+point		3	0.29	43	35.1	0.277	50	39.4	0.01	-7.0	-4.3
10/22	1	+point		3	0.16	49	33.4	0.122	38	23.2	0.04	11.0	10.2
Mean											0.06	-5.2	-2.0
Standard Deviation											0.11	10.61	6.80

## Preliminary NDE Uncertainties

### Length

- Mean = 0.06", Std. Dev. = 0.11"

### Average Depth

- Mean = -2.0%, Std. Dev. = 6.8%

### Maximum Depth

- Mean = -5.2%, Std. Dev. = 10.6%

# **NDE Sizing for Axial PWSCC at Dented Tube, TSP Intersections**

## **Conclusions**

### **+ Point Coil Provides Acceptable Crack Sizing for Tube Integrity and Potential Future ARC Applications**

- Uncertainty on length  $< 0.1$ " and average depth about 7 %:

### **+ Point Coil Meets EPRI Appendix H Requirements for Sizing**

- Formal Appendix H qualification to be performed with final report of sizing qualification efforts.



ARC Concepts for Indications at Dented TSPs

NRC/Utility Meeting

November 20, 1996

Presented By:

T. A. Pitterle

Nuclear Services Division

Westinghouse Electric Corp.

## **ARCs to be Developed**

### **ARCs Based on Negligible SLB TSP Displacement**

- **WCAP-14707**
  - Packed crevices prevent SLB TSP Displacement
  - Presence of denting demonstrates packed tube to TSP crevices

### **ARC for Axial Indications at Dented TSP Intersections**

- **Near term ARC**
  - Axial ID or OD cracks within dented tube TSP intersection
- **Longer term ARC**
  - Axial cracks extending outside TSP

### **Longer Term ARC for Circumferential Indications at Dented TSP Intersections**

- **Small ID or OD circumferential cracks detected by + Point but not confirmed by second coil**
- **Confirmed circumferential cracks left in service**

## **ARC for Axial Cracks Within Dented TSPs**

### **Tube Burst Prevented by TSP for Crack Length Within TSP**

- Normal operation and SLB conditions (WCAP-14707)

### **Potential for Tube Burst Negligible and Limited to Crack Growth Outside TSP for PWSCC Indications**

- Current growth data would indicate growth outside TSP limited to about 0.2"
- Further growth studies to be performed
  - Sizing qualified for PWSCC axial indications
- Freespan burst probability for about 0.2" outside TSP is negligible
  - Estimated at  $< 10^{-8}$  for a very large number of indications

### **Tube Repair Based on Limiting SLB Leakage to Within Allowable Limits**

- Low leakage rates for cracks within TSP
- More significant leakage for crack tips near edge of TSP and outside of TSP
- Leakage must be combined with that from other ARCs when comparing to allowable limit

### **Indications Extending Outside the TSP Would be Repaired**

## SLB Leakage Model for Axial Cracks at Dented TSPs

### Utilization of W\* Leakage Model

- Effective crack length for length within TSP
  - Crack opening limited by hard magnetite resulting from denting
  - Contact pressure is high enough to deform tube
    - Analyses required to develop lower bound of contact pressure
- Crevice loss coefficient
  - Develop from leak tests performed on tubes/TSP removed from retired Dampierre-1 SG and EPRI tests for throughwall cracks at dented TSPs
  - Dampierre-1 tests show very low leak rates for throughwall hole in packed crevices
  - EPRI tests show essentially no leakage for throughwall cracks within dented tube at TSP intersection

### Free Span Leakage Expected to be Applied for Length of Crack Outside TSP

- Short lengths due to limited crack growth rates

### Anticipate Monte Carlo Analyses for Projected EOC Leak Rate

- Operational Assessment
- Statistically account for crack growth in length and depth as well as NDE uncertainties

## Longer Term ARC Including Axial Cracks Extending Outside TSP

Implementation of ARC for cracks within TSP permits development of more accurate growth rates for crack length and depth

- Principle need to develop ARC including lengths outside TSP

### Repair Basis

- Allowable length outside TSP as required to limit tube burst probability to acceptance limit
  - Burst probability must be combined with other implemented ARCs such as GL 95-05 ARC for ODS CC at non-dented TSP intersections
- As required to limit leakage to acceptable limit

### Tube Burst Considerations

- Burst potential limited to length outside TSP
- Based on length and depth of crack outside TSP
- Monte Carlo analyses for operational assessment burst probability

### SLB Leakage

- Modeling similar to ARC for cracks within TSP
- Plan to assess leakage for cracks outside TSP based on projected throughwall crack lengths
  - Requires growth rates for maximum depth and associated length as well as growth rates on total length and average depth
  - Could use number of length of deep crack sections in a model similar to that developed for circumferential indications
    - Number and length of deep sections developed from pulled tubes and NDE sizing analyses of field indications
    - Growth rate in depth applied first to deep sections until throughwall

## ARC Concepts for Circumferential Indications

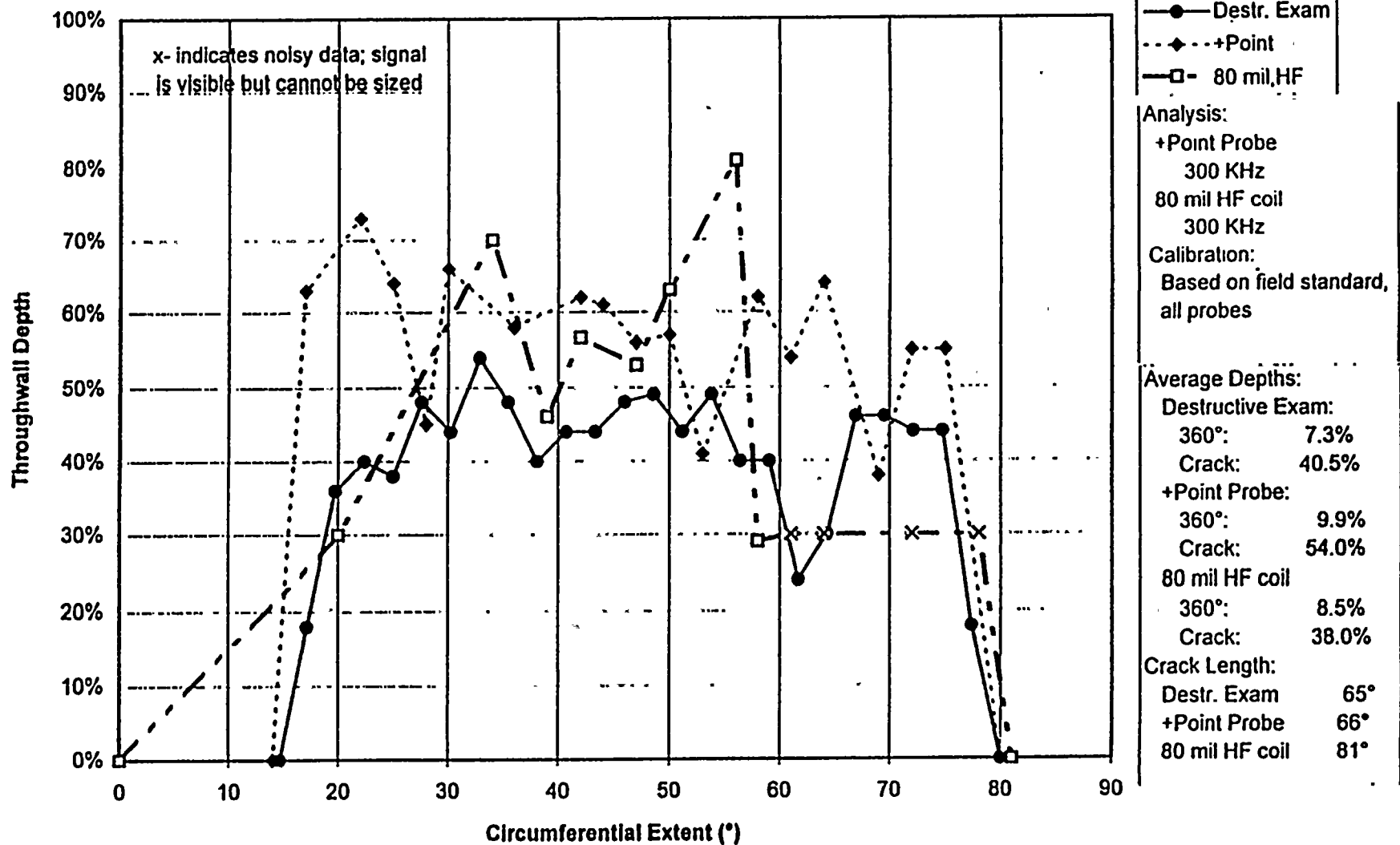
### Option Based on + Point and UT Inspections

- Detection and sizing by + Point inspection
  - Sizing in angle and depth
  - Adequate sizing supported by two pulled tube exam results
- Confirm crack associated with local dent or major axis of ovality by UT examination
- In situ test largest indications to confirm structural and leakage integrity at EOC
- Repair largest indications in situ tested
  - For example, indications  $> 90^\circ$  (TBD) or  $< 90^\circ$  with PDA  $> 50\%$  (TBD)
- Support next operating cycle using approximate growth rates (angle, PDA, volts) developed from current and prior cycle data
- Tube pull for largest indication

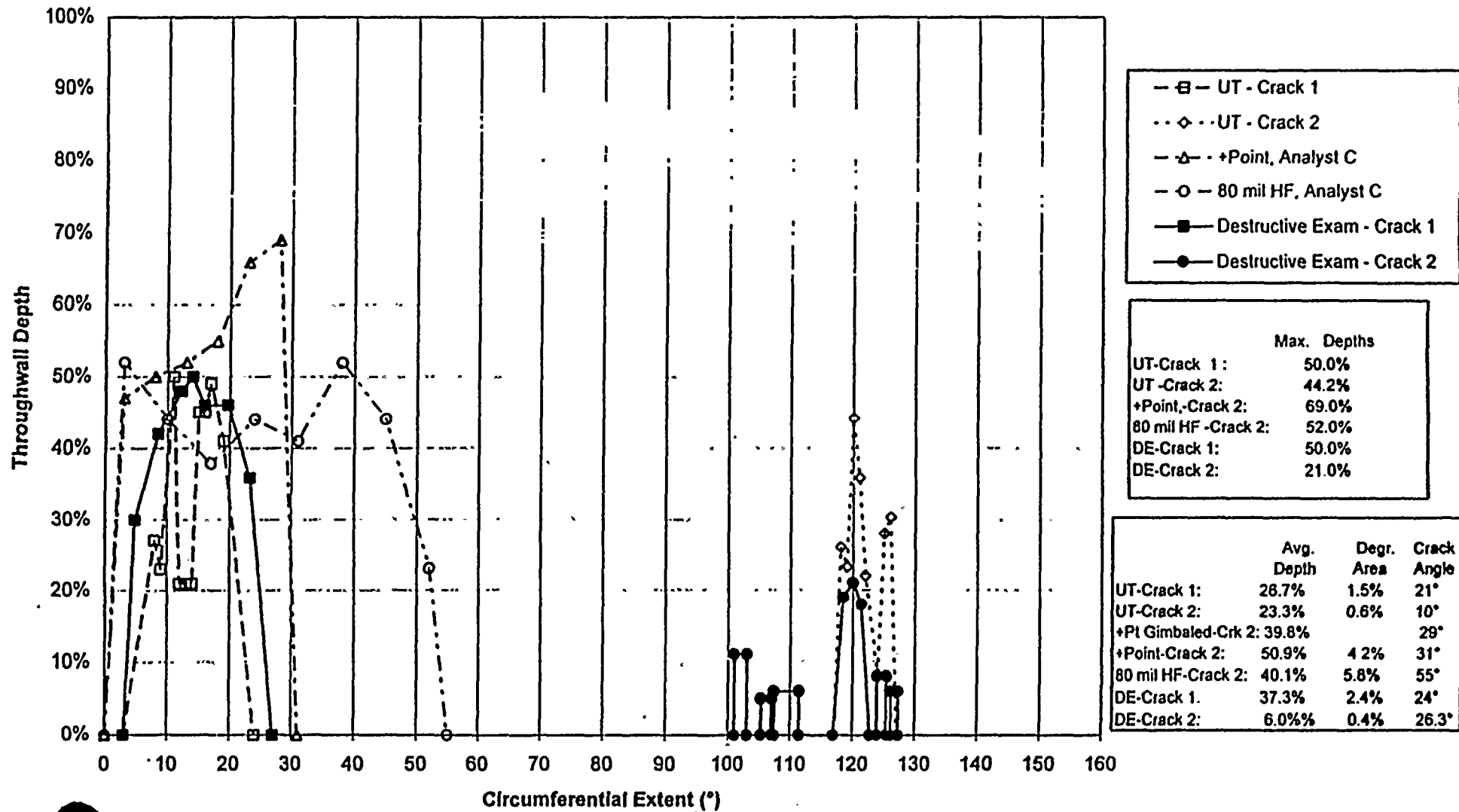
### Second Option Based on + Point and Pancake Coil Inspection

- NDD by pancake coil as basis for defining short and shallow indications
  - Lack of flaw behavior as basis for NDD call
    - None or negligible C-scan indication with negligible implied depth from phase response and lack of phase rotation with frequency
- Pancake coil NDD replaces + Point sizing and UT inspection of Option 1
- Repair indications confirmed by pancake coil
- In situ testing of largest pancake coil confirmed indications, growth analyses and tube pull same as Option 1

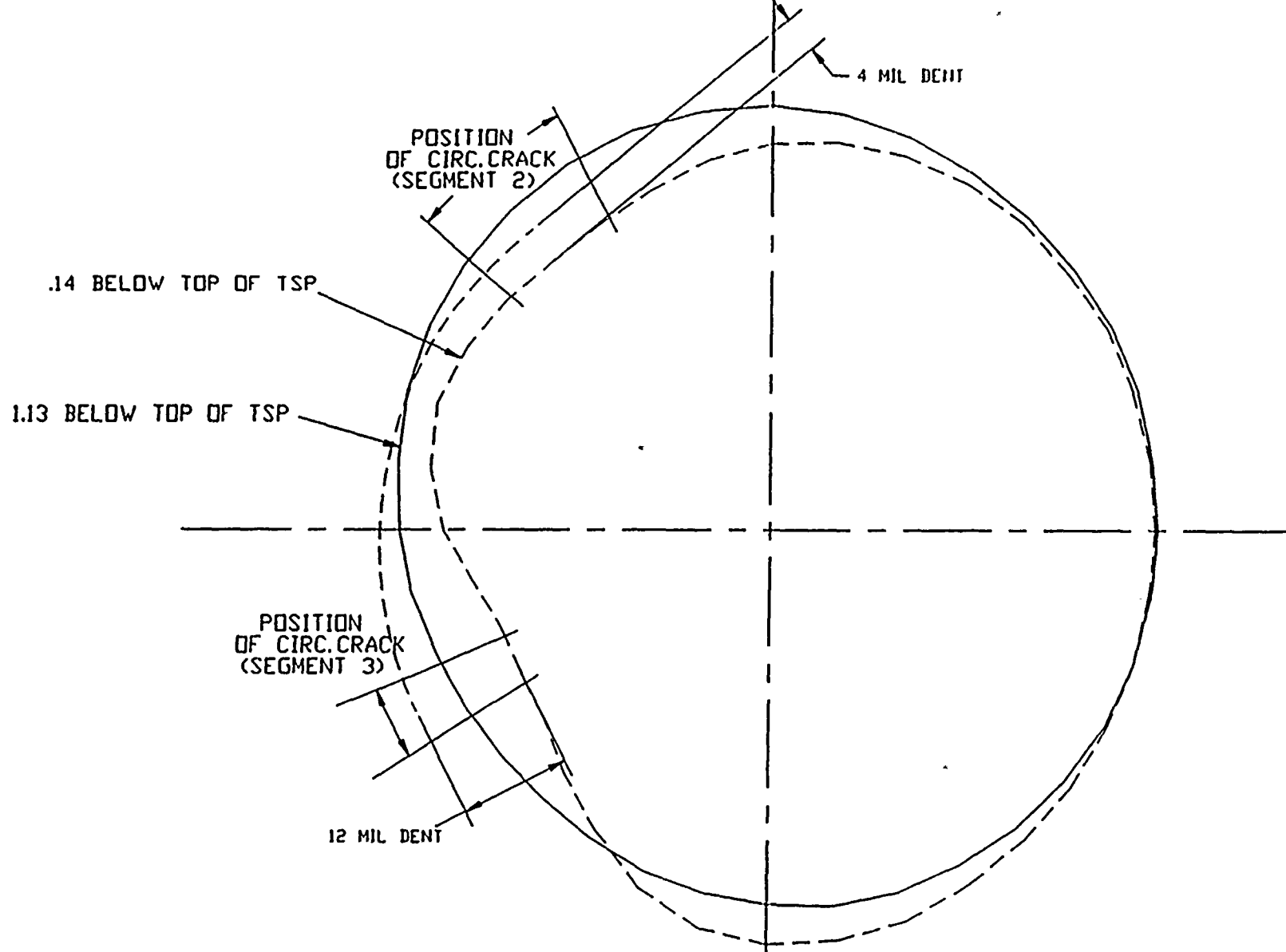
# Plant W, R11C61 - 1H; Circumferential Crack Profile Evaluation



# Plant Y-1 - Tube R14C69, TSP 1H







ROW 14 COL 69 1ST SUPPORT  
PGE - S/G 12  
OVALITY PLOT

