

WEC PROPRIETARY CLASS 3



Westinghouse Energy Systems



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WCAP-12951

STEAM GENERATOR PLUGGED TUBE
PRESENTATION MATERIAL

May 1991

G. W. Whiteman

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A meeting was held on April 23, 1991 between Westinghouse and the NRC staff to discuss the potential for the rupture of plugged steam generator tubes.

The following topics were discussed by Westinghouse during the meeting:

1. Discussion of the Postulated Mechanism for Bulged and Fishmouthed Plugged Tubes.
2. Potential for Flow Diode Effect in SG Tubes Plugged Due to Circumferential Cracks.
3. Summary and Westinghouse Actions.

NRC PLUGGED TUBE
MEETING AGENDA

1. INTRODUCTION (M.J. WOOTTEN)
2. DISCUSSION OF POSTULATED MECHANISM FOR BULGED AND FISHMOUTHED PLUGGED TUBES (R.F. KEATING)
3. POTENTIAL FOR FLOW DIODE EFFECT IN SG TUBES PLUGGED DUE TO CIRCUMFERENTIAL CRACKS (A.R. VAIA)
 - WELDED PLUGS
 - ROLLED PLUGS
 - EXPLOSIVE PLUGS
 - MECHANICAL PLUGS
4. SUMMARY AND WESTINGHOUSE ACTIONS (M.J. WOOTTEN)

PLUGGED TUBE
MEETING OBJECTIVE

TO ADDRESS THE FOLLOWING QUESTIONS:

1. WHAT IS THE FLOW DIODE EFFECT IN EXPLOSIVELY PLUGGED TUBES?
2. CAN MECHANICAL PLUGS BE SIMILARLY AFFECTED?
3. SHOULD THE POTENTIAL FOR FLOW DIODE EFFECT BE CONSIDERED IN THE DEVELOPMENT OF STABILIZATION CRITERIA WHEN TUBES ARE PLUGGED DUE TO CIRCUMFERENTIAL CRACKS USING ALLOY 600 PLUGS?

MECHANISM FOR BULGED
AND FISHMOUTHED
PLUGGED TUBES

R. F. KEATING

INTRODUCTION

● *Summarize Known Information*

- Ringhals 2
 - Geometry
 - ECT Results
- Salem 1
 - Geometry

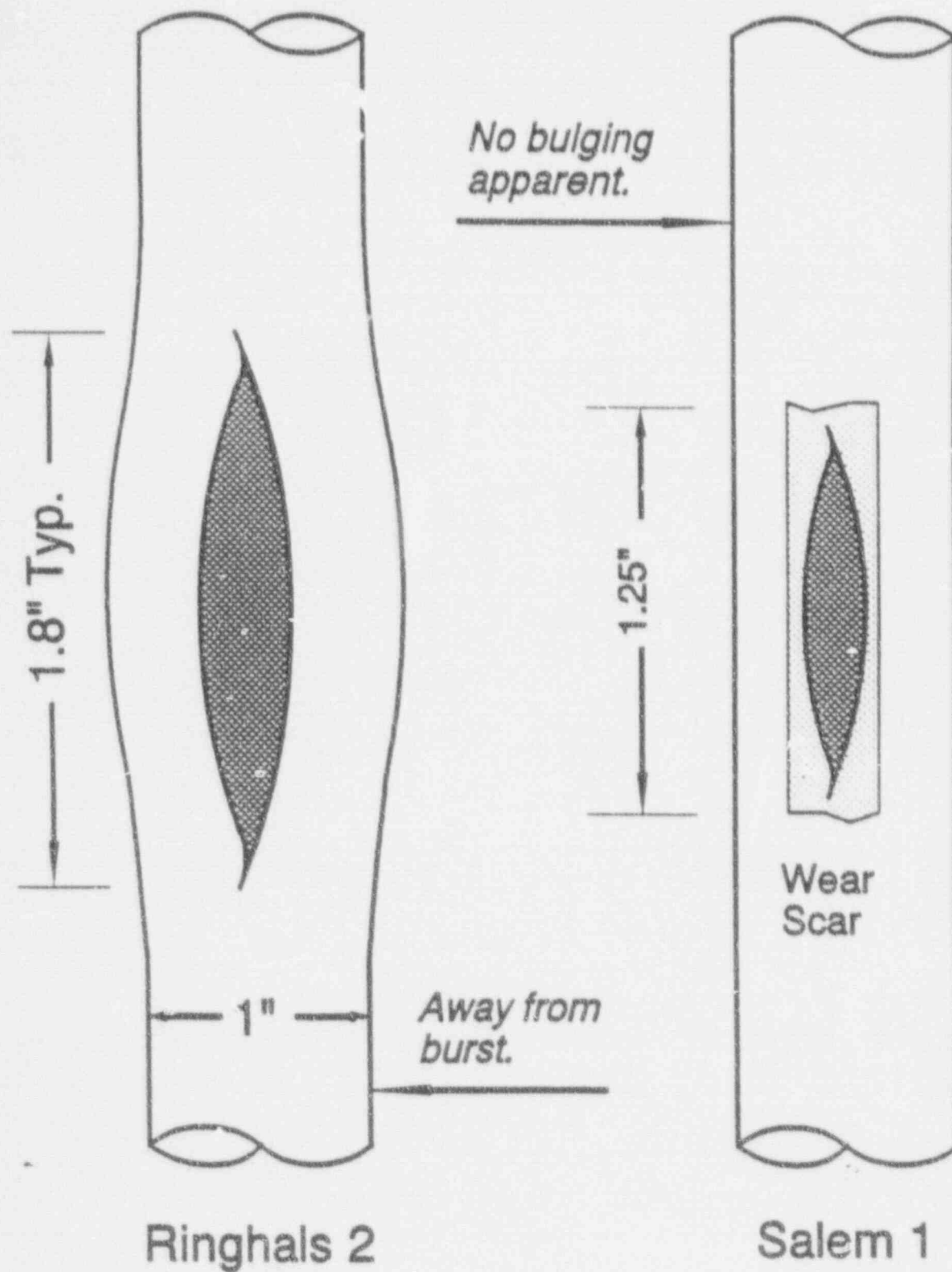
● *Burst Mechanism*

- *Diode Hypothesis*
- *Volumetric Expansion*
- *Burst Pressure*

● *Mechanical Plug Implications*

- *Observations*
- *Statistical Considerations*

Burst Geometry



KNOWN INFORMATION

- Explosive Plugs

- *Eight (8) known Bulged and/or Burst Tubes*

- Rolled Plugs

- *Zero (0) known Bulged and/or Burst Tubes*

- Welded Plugs

- *Zero (0) known Bulged and/or Burst Tubes*

- Mechanical Plugs

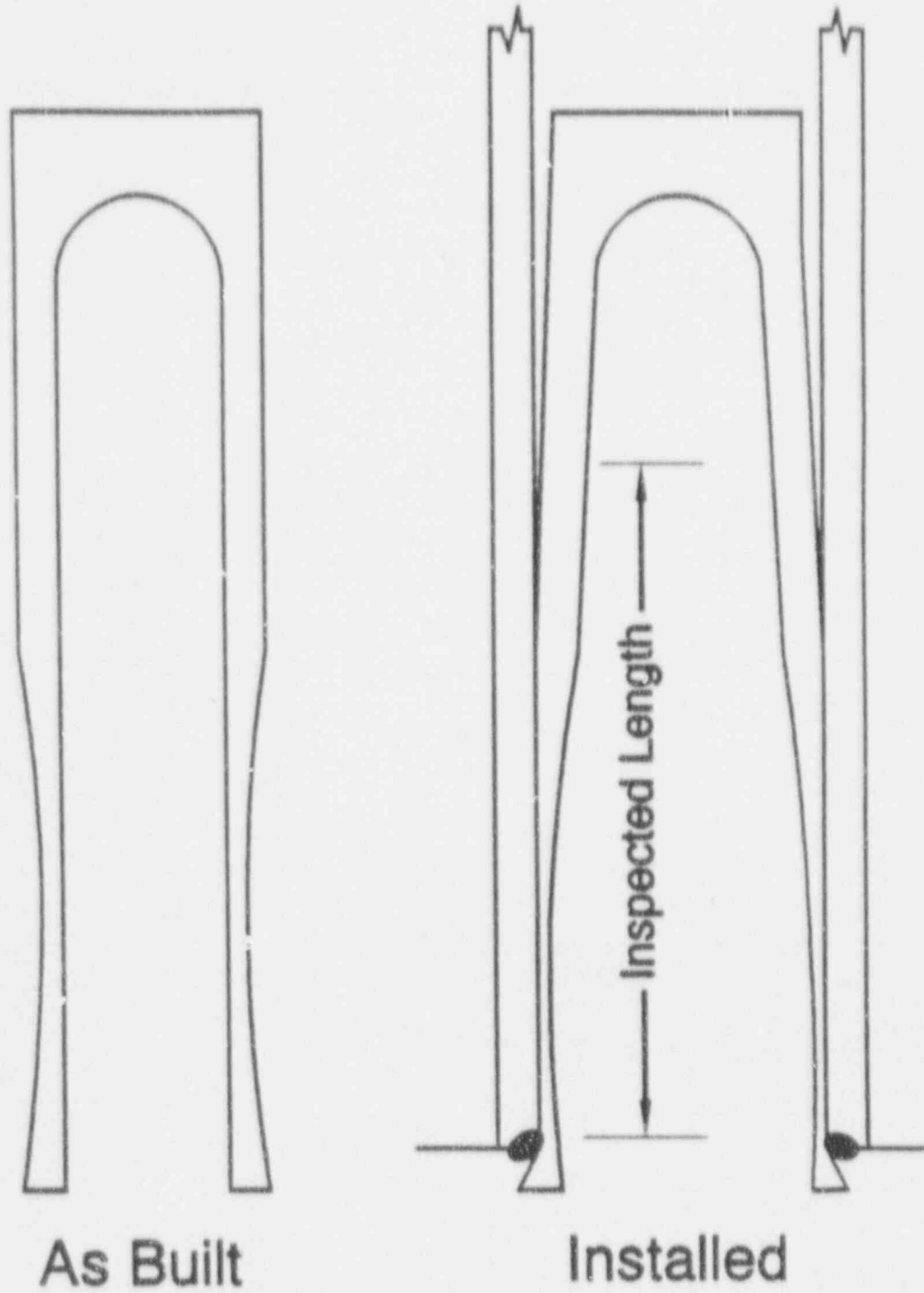
- *Zero (0) known bulged and/or Burst Tubes*

CRACKING POTENTIAL

- Temperature - *Common to All Plug Designs*
- Environment - *Common to All Plug Designs*
- Stress
- Material

COMPARISON OF CRACKING POTENTIAL						
Condition	Mechanical		Welded		Rolled	Explosive
	I600 TT	I690 TT	I600 Both	I690 TT	I600 TT	I600 MA
Stress	X	X			X	X
Material	X		X		X	X

- Only I600 Rolled, Explosive & Mechanical Plugs Considered



Explosive Plug

RINGHALS & SALEM EXPLOSIVE PLUGS

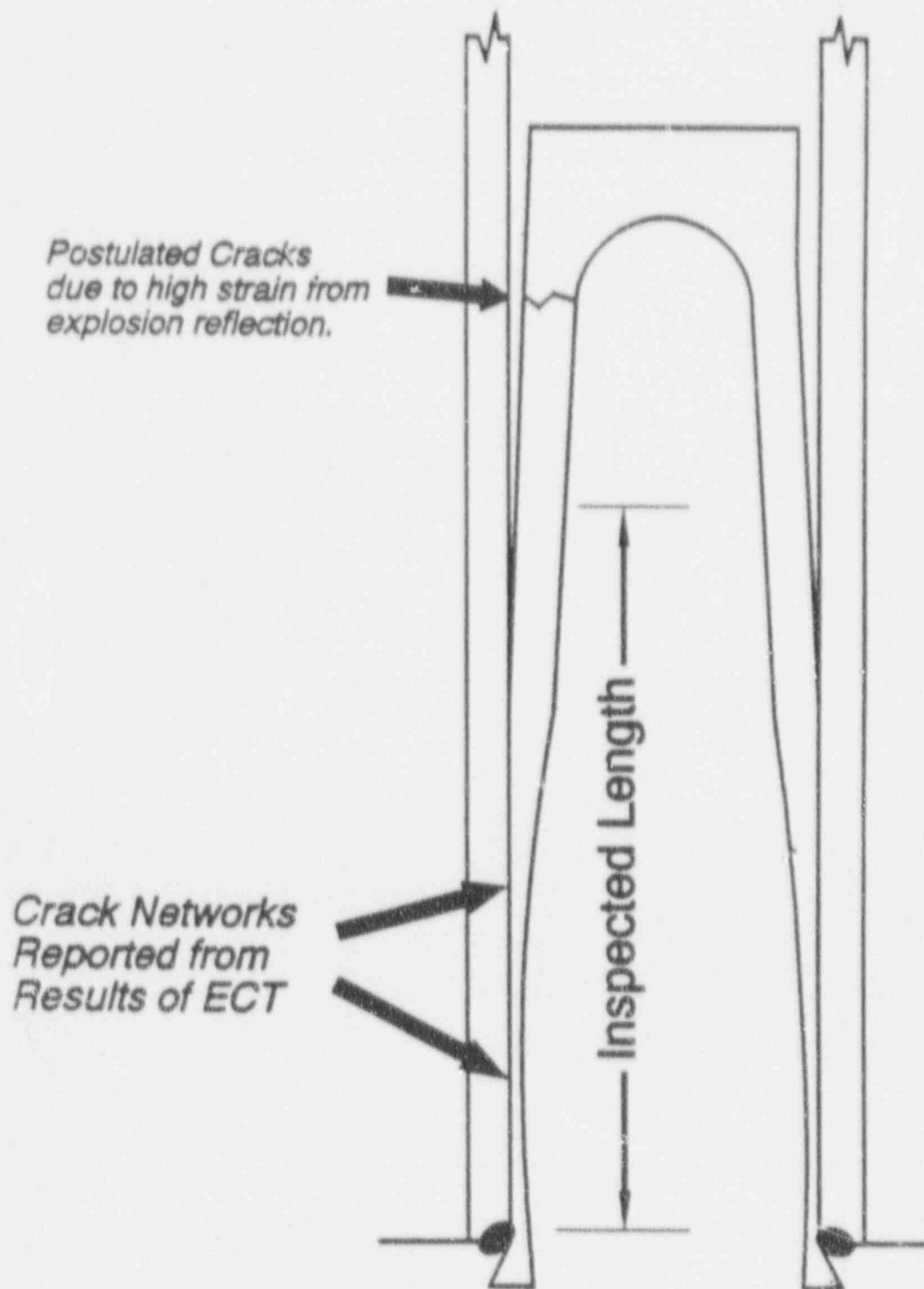
● Ringhals 2

- Spring, 1984 Outage
- Six Tubes Affected
 - One Known to have a Burst Opening
 - Section of Tube Removed
 - Ductile Rupture
 - No Tube Wall Reduction
 - No Degradation Prior to Burst
 - No Known Prior Indications

● Salem 1

- Spring, 1991 Outage
- Two Tubes Affected
- Visual Observations Only
- Wear Scars from Tube Lane Blocking Device
 - Removed in 1988

KNOWN BULGED OR RUPTURED TUBE LOCATIONS (All Occurrences in Row 1)				
Tube Col.	Dia. (in.)	Condition	Plug Date	Comments
Ringhals 2, Steam Generator No. 1				
18	> 0.93	Bulged	6/77	
27	> 0.875	Bulged	6/77*	Visual judgement
* Weld repair plugged in 2/82.				
Ringhals 2, Steam Generator No. 2				
1	0.98	Bulged	5/79	
11	0.98	HL Burst	6/77*	Both legs confirmed
14	0.98	Bulged	6/77	Both legs confirmed
49	0.98	Bulged	5/79	Both legs confirmed
* Weld repair plugged in 6/82.				
Salem 1, Steam Generator No. 14				
2		Burst	1977	Wear scar location
3		Burst	1977	Wear scar location



Explosive Plug Diode Considerations

RINGHALS ECT RESULTS

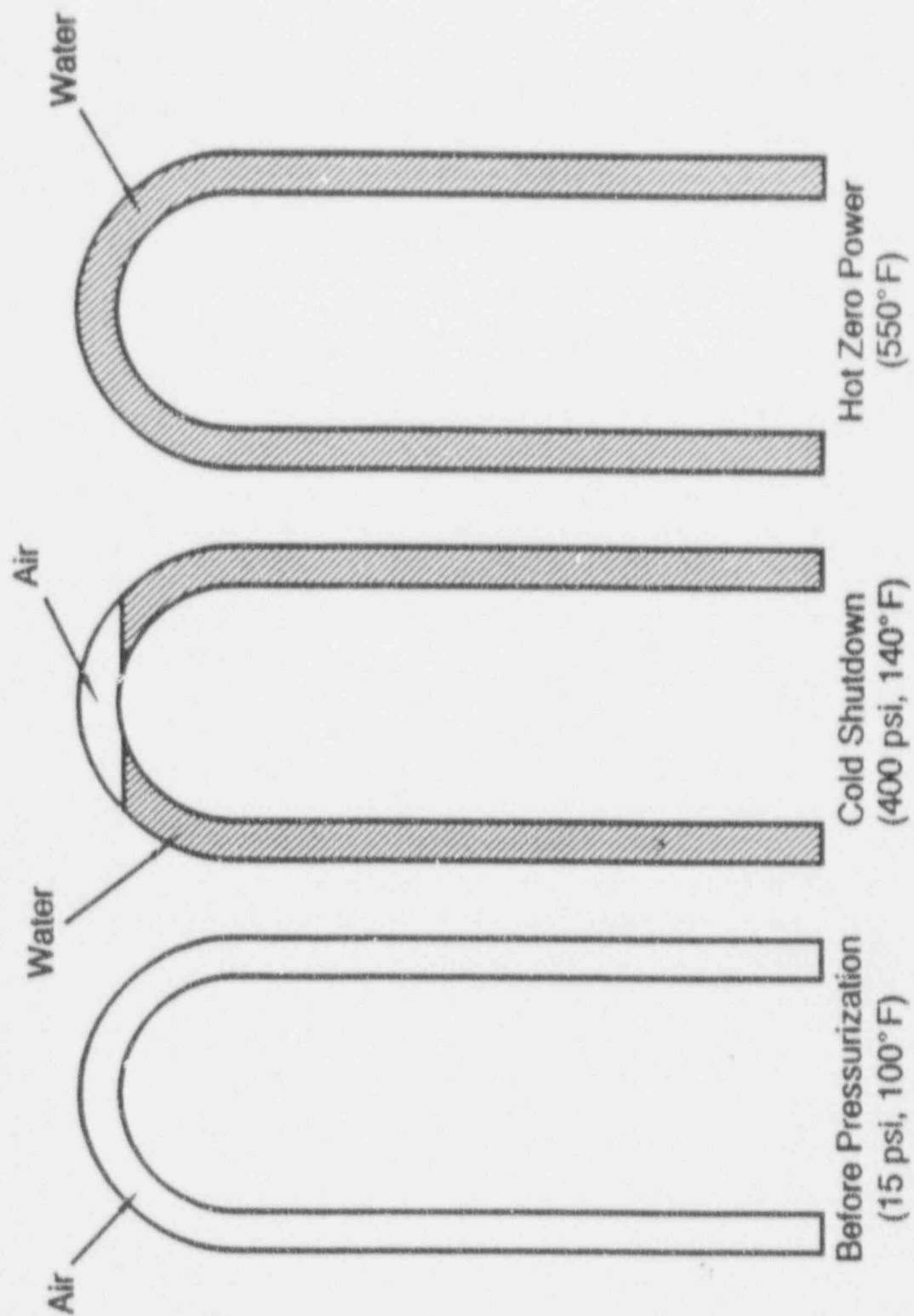
- *Conducted in 1982*

- Lower 4½" of the Plug Length
- Upper 1½" of the Plug was Not Inspected

SUMMARY OF RINGHALS 2 ECT RESULTS (All Occurrences in Row 1)			
Tube Col.	Boron Deposit	Wet or Dripping	ECT Observations
Steam Generator No. 1			
18	None	No	No Detectable Indications
27	None	No	Not Tested
Steam Generator No. 2			
1	None	No	No Detectable Indications
11	On Plug	Yes	Crack Networks 0.8"-0.9" Above End 1.4"-1.6" Above End
14	None	No	Crack Network 1.4"-1.6" Above End
49	None	No	No Detectable Indications

Note: Identification of "None" and "No" for boron deposits and wetness are based on "None Reported".

Steps for Tube Internal Pressurization



EXPLOSIVE PLUGS BULGE/FISHMOUTH PROCESS

● Cold Shutdown Conditions - *Initially Air Filled Tube*

- Postulated Leak in Plug or at Interface
- Water at 400 psi Enters the Tube
 - Cycles to Fill Tube Unknown
- Water Occupies about 96% of the Volume

● Heatup - *Water Expands Until Tube Filled All Air Entrained*

- Elastic Limit of the Tube Reached at 200-300°F
- Pressure ~ 6500 psi

● Hot Zero Power - *550°F*

- Tube Expanded About 9-10%
- Volume Controlled Expanded Diameter ~ 0.96"
(*Burst Not Expected During First Cycle*)
 - Ratio of SV water at 550°F & 9000 psi to 140°F & 400 psi is 122%
 - Internal Pressure ~ 9000 psi
 - Less Than Burst Pressure for a Non-degraded Tube
(~9500-10000 psi at 550°F)

- Cold Shutdown (Repeat Cycle)

- Water Contracts - *Pulling Vacuum*
- Water at 400 psi Enters the Tube Again

- Second Cycle

- Expansion Continues
- Total Water Volumetric Increase \Rightarrow 149%
- Pressure of > 500 psi @ 400-500°F
- May be Sufficient to Burst the Tube or Another Cycle Will Occur
- Local Bulge Usually Formed
 - Hoop Strain \sim 25% at Rupture

I600 MECHANICAL PLUGS STATISTICAL EVALUATION

- I600 Mechanical Plug Selection
 - Stress, Material, & Population
- *Zero Frequency of a Fishmouth Event*
- Phenomenon & Mechanism Independent
 - Dichotomous Population
 - Expected Susceptible Population Proportion is Zero
 - Sampling W/O Replacement (Hypergeometric)
 - Bernoulli Trials Assumption Conservative
 - Binomial Distribution Used

95% CONFIDENCE LIMIT

- True Proportion Value π
- Observed Proportion Value p
- Sample of Size n
- Number of Observations k
- **Estimated Sample size of 1000 to 2000 Tubes**
 - Two Plants Account for ~ 700
 - Additional ~ 900 Plugs Drilled W/O Water
- **For $k=0$ (As for 1600 Mechanical Plugs)**

$$\pi_U = 1 - \left(\frac{\alpha}{2} \right)^{\frac{1}{n}}$$

- For $n=1000$ With Zero Observations $\pi_U = 0.003$
- For $n=2000$ With Zero Observations $\pi_U = 0.0015$

I60u MECHANICAL PLUGS CONSEQUENCES STATISTICS

● Observations

- ~ 11300 I600 Mechanically Plugged Tubes in US
- ~ 60 Domestic Plants with Mechanical Plugs
- Installations Occurring Since 1980
 - Assume Average Operating Time is 5 Years
 - Assume Significant Number of Degraded Tubes
 - Could "Fishmouth" in Single Cycle
- **NO Known Consequences Experienced**
 - $\therefore \pi_U = 0.0$ Expected.

POTENTIAL FOR FLOW DIODE
PHENOMENON IN SG TUBES
PLUGGED DUE TO
CIRCUMFERENTIAL CRACKS

A. R. VAIA

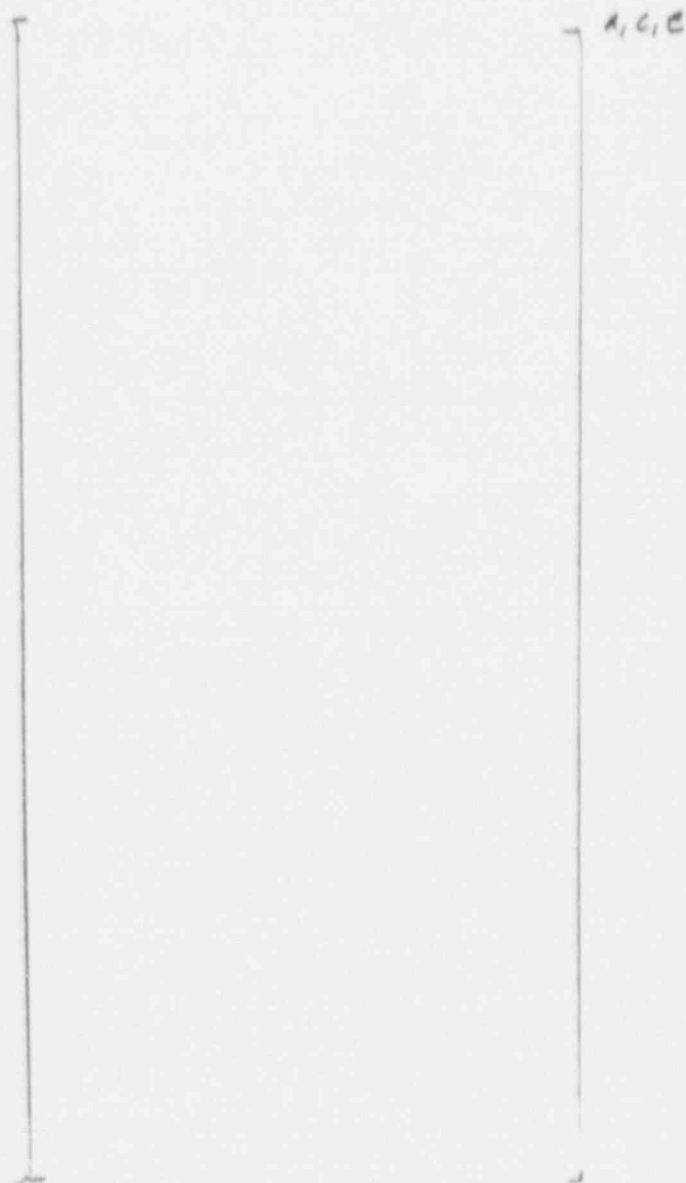
WESTINGHOUSE
EXPLOSIVE PLUG OVERVIEW

- MILL ANNEALED ALLOY 600
- 1971 - 1980 UTILIZATION
- 22,000+ PLUGS INSTALLED
- MAJORITY OF PLUGS INSTALLED IN STEAM GENERATORS WHICH HAVE SINCE BEEN REPLACED (APPROXIMATELY 2700 REMAIN)
- MOST TUBES PLUGGED EITHER PREVENTIVELY OR WITH AXIALLY ORIENTED CRACKING
 - NO TUBES PLUGGED DUE TO CIRCUMFERENTIAL INDICATIONS

WESTINGHOUSE
EXPLOSIVE PLUG OVERVIEW (CONT.)

- DURING ROUTINE TUBESHEET SCANS, LEAKING EXPLOSIVE PLUGS HAVE BEEN IDENTIFIED
- EDDY CURRENT AND DESTRUCTIVE EXAMINATION RESULTS SHOW INDICATIONS OF PWSCC
- CRACKING ASSOCIATED WITH RESIDUAL STRESSES AND MATERIAL SUSCEPTIBILITY
- ONLY PLUG TYPE WHERE FLOW DIODE EFFECT HAS BEEN OBSERVED

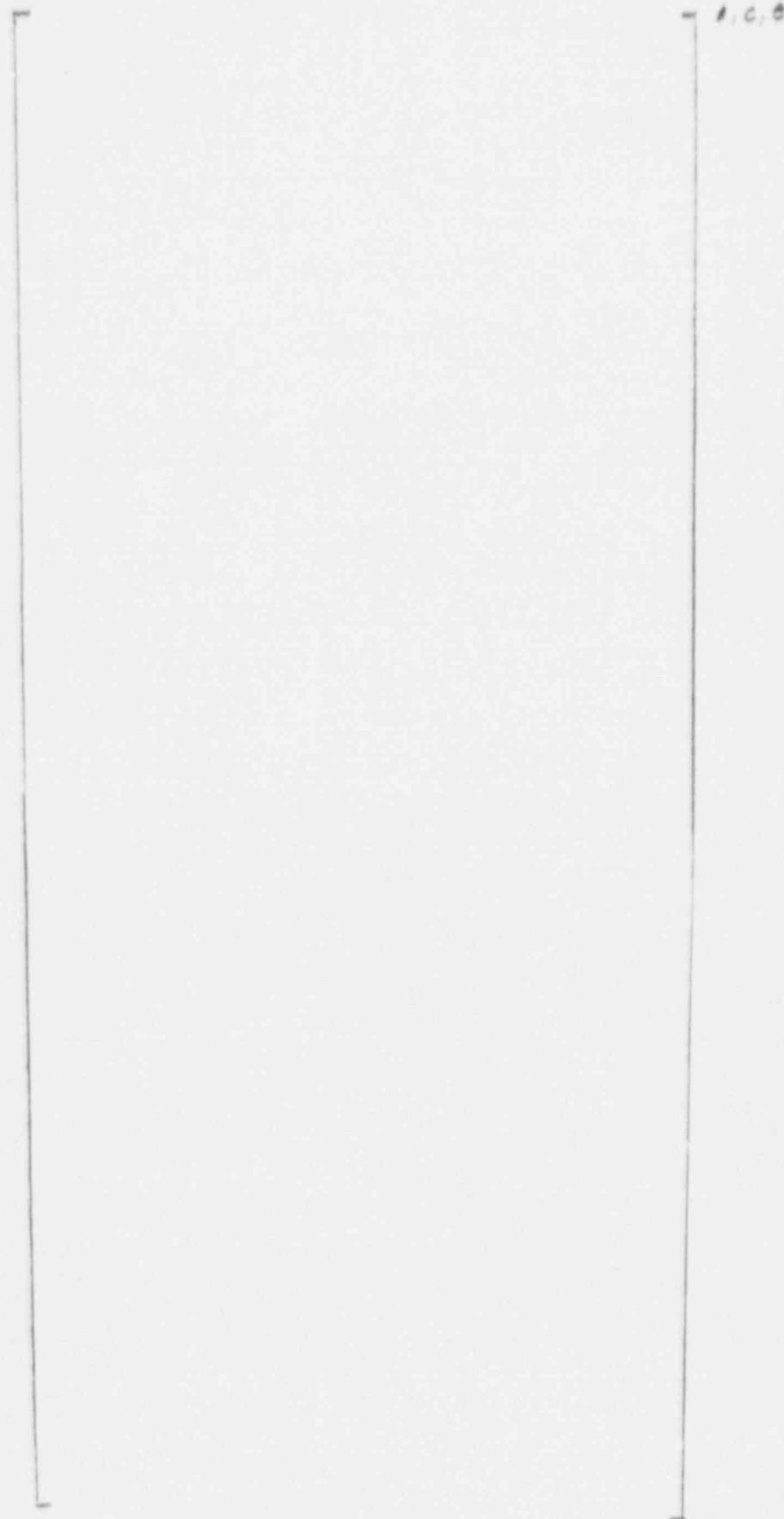
SCHEMATIC OF WESTINGHOUSE EXPLOSIVE PLUG



WESTINGHOUSE
ROLLED PLUG OVERVIEW

- THERMAL TREATED ALLOY 600
- 1980 - 1983 UTILIZATION
- APPROXIMATELY 1440 PLUGS INSTALLED
- NO TUBES PLUGGED DUE TO CIRCUMFERENTIAL INDICATIONS ABOVE THE TUBESHEET
- NO REPORTED FLOW DIODE PHENOMENON

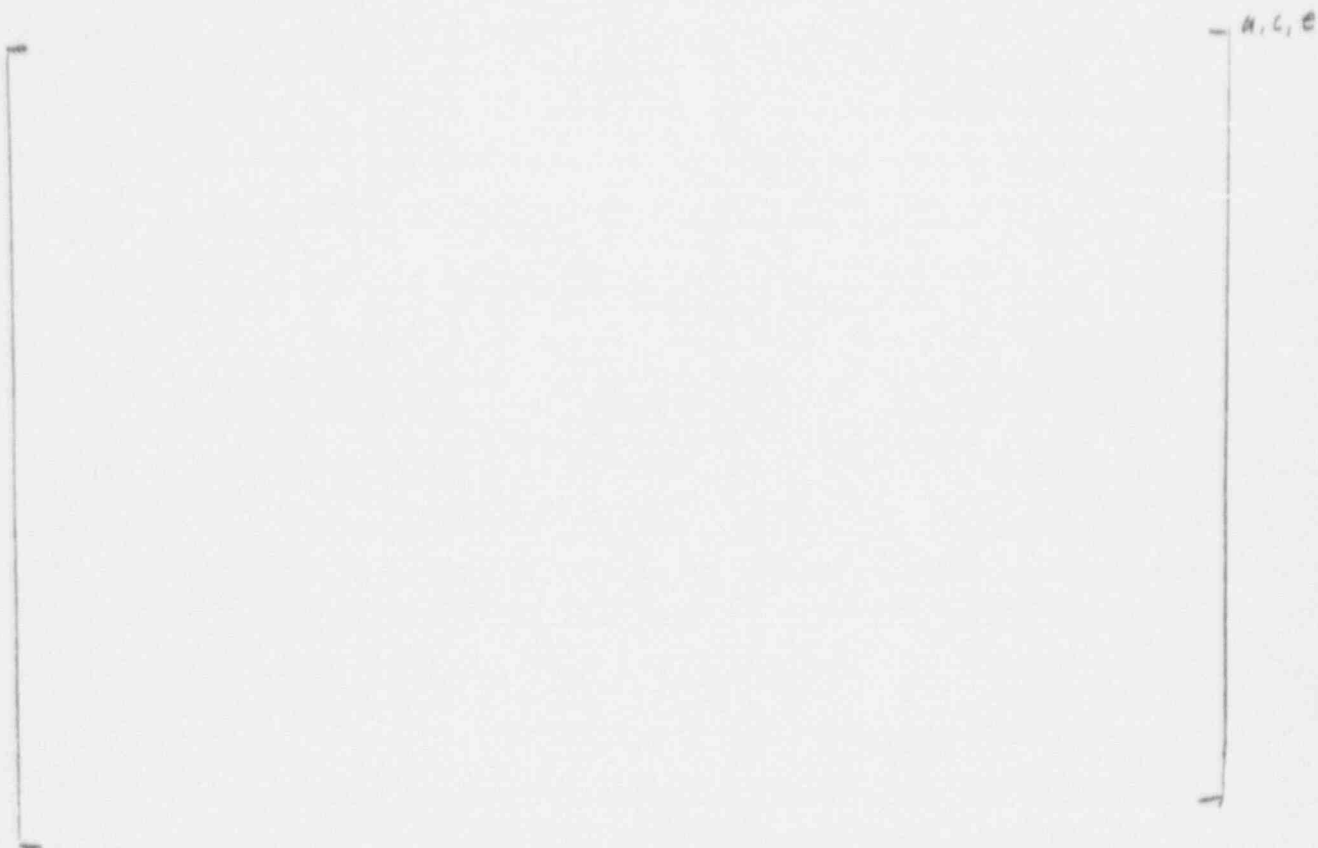
SCHEMATIC OF WESTINGHOUSE ROLLED PLUG



WESTINGHOUSE
WELDED PLUG OVERVIEW

- NO SIGNIFICANT RESIDUAL STRESS DUE TO PLUG INSTALLATION
- NO REPORTED CRACKING SUSCEPTIBILITY IDENTIFIED
- LEAKING WELD PLUGS NORMALLY DUE TO WELD POROSITY
- NO REPORTED FLOW DIODE PHENOMENON

SCHEMATIC OF WESTINGHOUSE WELD PLUG



WESTINGHOUSE
MECHANICAL PLUG OVERVIEW

- CRACKING ASSOCIATED WITH RESIDUAL STRESS AND MATERIAL SUSCEPTIBILITY
- NO REPORTED FLOW DIODE PHENOMENON
 - TUBELANE INSPECTIONS
 - IN-BUNDLE INSPECTIONS
 - PLUG REMOVAL
 - REPLUG
 - RETURN TO SERVICE
- DESIGN OF PLUG, I.E. INTERNAL EXPANDER AND INHERENT OVERALL STIFFNESS, REDUCES THE POTENTIAL FOR FLOW DIODE PHENOMENON

WESTINGHOUSE
MECHANICAL PLUG OVERVIEW (CONT.)

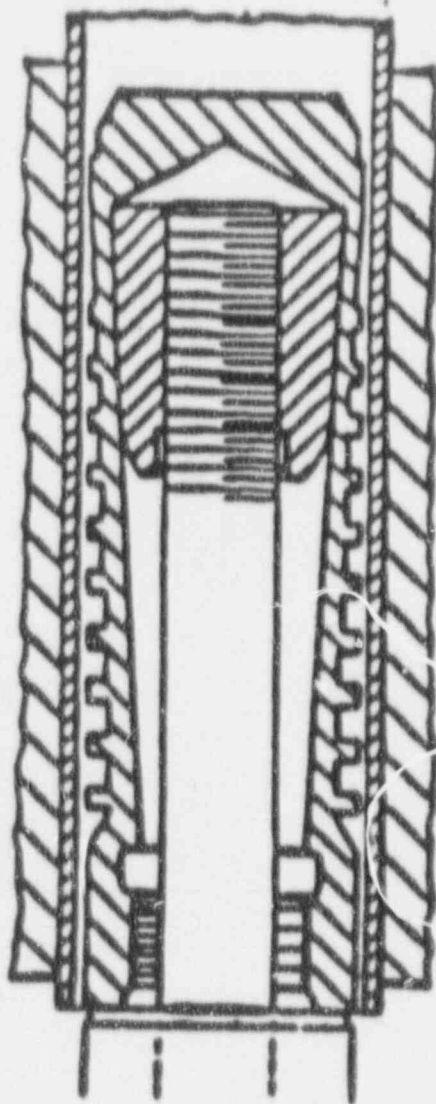
ALLOY 600 PLUGS

- NUMBER OF TUBES PLUGGED WITH ALLOY 600 MECHANICAL PLUG DUE TO CIRCUMFERENTIALLY ORIENTED CRACKS IS SMALL
 - ALL TUBES WERE STABILIZED OR HAVE HAD ALLOY 600 PLUGS REPLACED

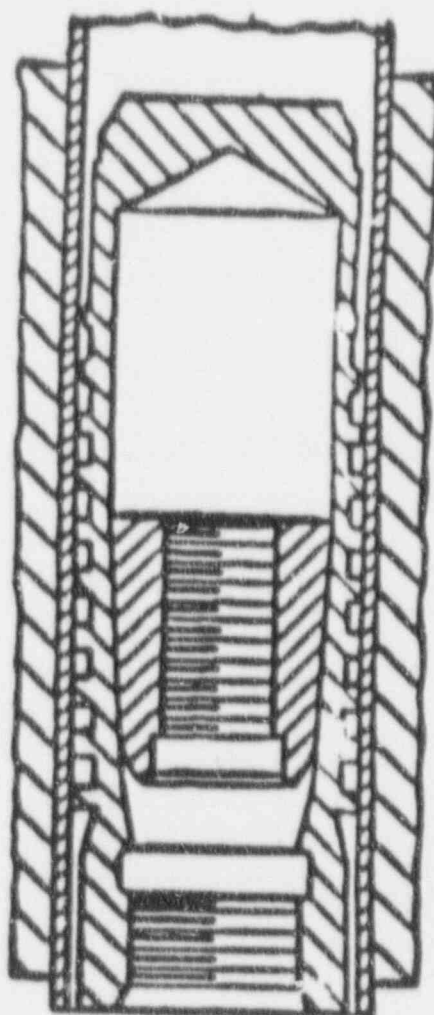
ALLOY 690 PLUGS

- PROBABILITY OF FLOW DIODE EFFECT IS NEGLIGIBLE

WESTINGHOUSE MECHANICAL PLUG



UNEXPANDED



EXPANDED

WESTINGHOUSE ACTIONS
TO ADDRESS THE
POTENTIAL FOR FLOW DIODE OF PLUGGED TUBES
WITH CIRCUMFERENTIAL CRACKS

WELDED PLUGS

- NO ACTION REQUIRED

EXPLOSIVE PLUGS

- NO ACTION REQUIRED

ROLLED PLUGS

- NO ACTION REQUIRED

MECHANICAL PLUGS

- ALLOY 600

REPLACE/REPAIR IN ACCORDANCE WITH THE CORROSION
ALGORITHM

- ALLOY 690

NO ACTION REQUIRED

PLUGGED TUBE MEETING

SUMMARY AND ACTIONS

- MECHANISM FOR THE FLOW DIODE EFFECT IS UNDERSTOOD
- THE PROBABILITY OF ALLOY 690 MECHANICAL PLUGS EXHIBITING THE FLOW DIODE EFFECT IS NEGLIGIBLE
- THE PROBABILITY OF ALLOY 600 MECHANICAL PLUGS EXHIBITING THE FLOW DIODE EFFECT IS ACCEPTABLY LOW
- WITH SPECIFIC REFERENCE TO TUBES PLUGGED WITH ALLOY 600 PLUGS FOR CIRCUMFERENTIAL INDICATIONS, THE PROBABILITY OF THE FLOW DIODE EFFECT IS ACCEPTABLY LOW
- WESTINGHOUSE PLANS TO ISSUE A CUSTOMER INFORMATION LETTER DURING THE 2 QTR OF 1991 EXPLAINING THE FLOW DIODE EFFECT AND IDENTIFYING ANY POTENTIAL ISSUE AS A RESULT OF THIS PHENOMENON