



UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

November 23, 1992

Docket No. 50-275

LICENSEE: Pacific Gas and Electric Company (PG&E)
FACILITY: Diablo Canyon Nuclear Power Plant, Unit 1
SUBJECT: SUMMARY OF OCTOBER 20, 1992 PUBLIC MEETING TO DISCUSS STEAM
GENERATOR FEEDWATER NOZZLE CRACKING

On October 20, 1992, the NRC staff met with the Pacific Gas and Electric Company (PG&E or the licensee) in Rockville, Maryland to discuss the issue stated above. Attendees at the meeting are listed in Enclosure 1. Slides shown by PG&E at the meeting are presented in Enclosure 2. The PG&E presentation summarized their analysis and long-term plans regarding the cracks associated with the steam generator nozzles.

PG&E discussed their analysis which included findings of nozzle-to-pipe weld cracks, thermal sleeve erosion, and elbow pipe cracks. Their actions to analyze and/or to resolve these problems consisted of replacing the piping and analyzing the thermal sleeve condition for (1) erosion gap growth, (2) waterhammer implications, and (3) nozzle implications.

The licensee presented their nondestructive examination (NDE) results. Ultrasonic testing (UT) examinations were scheduled for the first days of the outage. UT examinations were used to detect the presence of flaws in the piping. The UT manual and automatic testing results did verify indications of cracking. The possibility of cracking was also indicated by visual examinations. However, no cracks were indicated with the use of radiography.

From the results of the metallurgical analysis, the UT examination results were shown to be quite conservative (approximately by a factor of 10). The NDE testing of the samples, sectioned from the nozzle area, showed 0.35-inch-deep indications; whereas, from the metallurgical analysis, the actual samples showed indications no deeper than 0.037 inches. The metallurgical results also indicated evidence of microcracking in the spools.

As a result of the NDE testing, PG&E's action plans included: (1) reviewing the NDE assignment methods to ensure that the proper welds were clearly designated for exams and (2) analyzing the UT data and metallurgical results to determine methods for accurate sizing of thermal fatigue cracking.

The licensee also discussed the likelihood of waterhammer during draining and filling of the feedline with cold water. PG&E stated that waterhammer would not occur during draining because, by design, the J-tubes and thermal sleeve

See Reports

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allow steam to replace the water as the feedline drains. The licensee also stated that the possibility of waterhammer during filling is very unlikely due to the J-tubes; however, waterhammer could still be possible due to wave action. The licensee concluded the following: (1) due to Diablo Canyon's geometric configuration, a steam volume collapse waterhammer is very unlikely, (2) plant inspections indicate no evidence of waterhammer to date, and (3) in the unlikely event of occurrence, there would be insufficient energy to affect the piping system.

PG&E discussed the probable causes of thermal sleeve erosion. These causes include: (1) erosion/corrosion due to increased velocities and (2) turbulence as a result of the complex geometric configuration between the nozzle and the thermal sleeve.

The licensee stated that initiation of fatigue cracks in the steam generator nozzle at Indian Point were the result of a significant environmental effect (water chemistry). However, this was not a problem at Diablo Canyon because the water chemistry control at Diablo Canyon decreased the likelihood of the environmental influences.

In addition, the licensee stated that initiation of fatigue cracks in the knuckle region of the feedwater nozzle is not as likely at Diablo Canyon as it is at similarly designed facilities. PG&E also stated that fatigue cracks in the knuckle region are not predicted for Diablo Canyon. This is based on the following factors: (1) low fatigue usage, (2) the severity of thermal stratification loads being much less than at the plant where cracking was found, and (3) a recent UT inspection of a nozzle revealing no indications of cracking. PG&E stated, however, that if cracks were to exist in the nozzle region, the predicted size would be acceptable under Section XI of the ASME Code. The licensee demonstrated that the future growth of worst case cracks were found to be relatively small for the next 4 years or 100 days in Modes 2 or 3. Therefore, PG&E concluded that the integrity of the feedwater nozzles would be maintained through the next several years of service.

PG&E's long-term plans include installing resistance temperature detectors (RTDs) and scratch gages, and reviewing correlations between algorithms and operating data. The licensee's inspection plans consist of factoring in lessons learned from outage 1R5, performing a UT analysis every outage until a permanent fix is installed, and baselining the permanent fix after installation.



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The NRC staff stated that PG&E had completed a reasonable analysis on the feedwater nozzle crack issues. In addition, the NRC staff asked the licensee to keep them informed on their feedwater nozzle crack status and future plans.

Original signed by

Sheri R. Peterson, Project Manager
 Project Directorate V
 Division of Reactor Projects III/IV/V
 Office of Nuclear Reactor Regulation

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DATE	11/12/92	11/12/92	11/16/92	11/23/92



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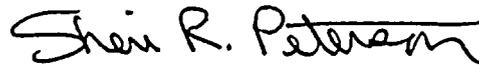
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Pacific Gas and Electric Company - 3 -

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Sheri R. Peterson, Project Manager
Project Directorate V
Division of Reactor Projects III/IV/V
Office of Nuclear Reactor Regulation

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November 23, 1992

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OCTOBER 20, 1992

PUBLIC MEETING

STEAM GENERATOR FEEDWATER NOZZLE CRACKS

AT DIABLO CANYON UNIT 1

LIST OF ATTENDEES

<u>NAME</u>	<u>ORGANIZATION</u>
Warren Bamford	Westinghouse - NATD
Lee Banic	NRC/NRR/EMCB
Eric Benner	NRC/NRR/OEAB
Warren Fujimoto	PG&E - NTS
David Gonzalez	PG&E - ISI & DCPD
Robert Hermann	NRC/NRR/EMCB
Geoff Hornseth	NRC/NRR/EMCB
John Houtman	Westinghouse - NSD
Meena Khanna	NRC/NRR/PD5
William Koo	NRC/NRR/EMCB
Michael Mayfield	NRC/OEDO
James Medoff	NRC/NRR/EMCB
Kris Parczewski	NRC/NRR/EMCB
Pete Riccardella	Structural Integrity Associates (SIA)
Jack Roe	NRC/NRR/DRPW
Mike Roidt	Westinghouse - STC
Harry Rood	NRC/NRR/PD5
Jack Strosnider	NRC/NRR/EMCB
Henry Thailer	PG&E - Engineering
James Tomkins	PG&E - Licensing

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**PACIFIC GAS AND ELECTRIC COMPANY
DIABLO CANYON POWER PLANT
PRESENTATION ON FEEDWATER NOZZLE ISSUES**

October 20, 1992



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AGENDA

Overview

Warren Fujimoto

NDE Results

Dave Gonzalez

Analysis

Henry Thailer

Long Term Plans

Henry Thailer



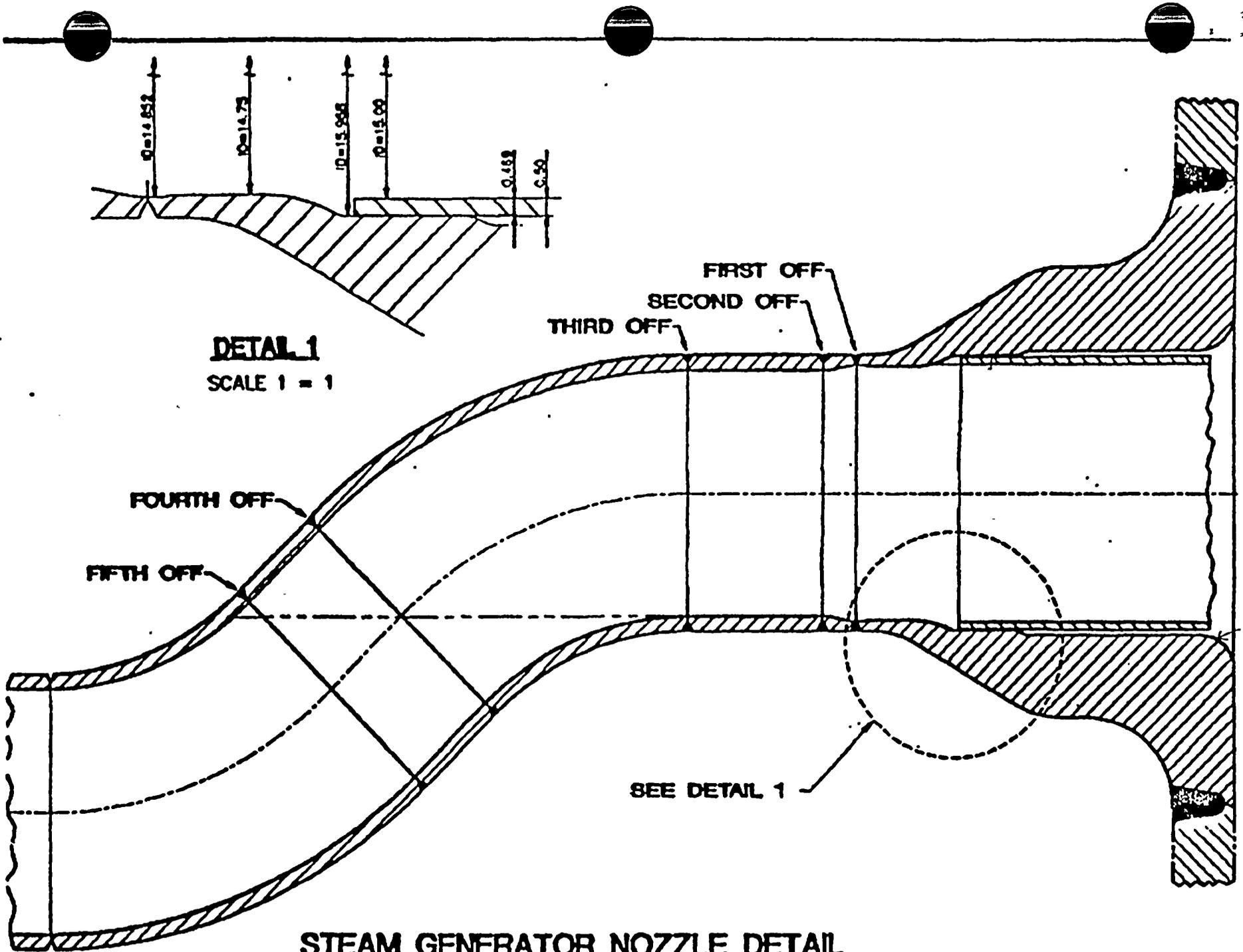
DIABLO CANYON POWER PLANT

Overview

Warren Fujimoto
Vice President-Nuclear Technical Services



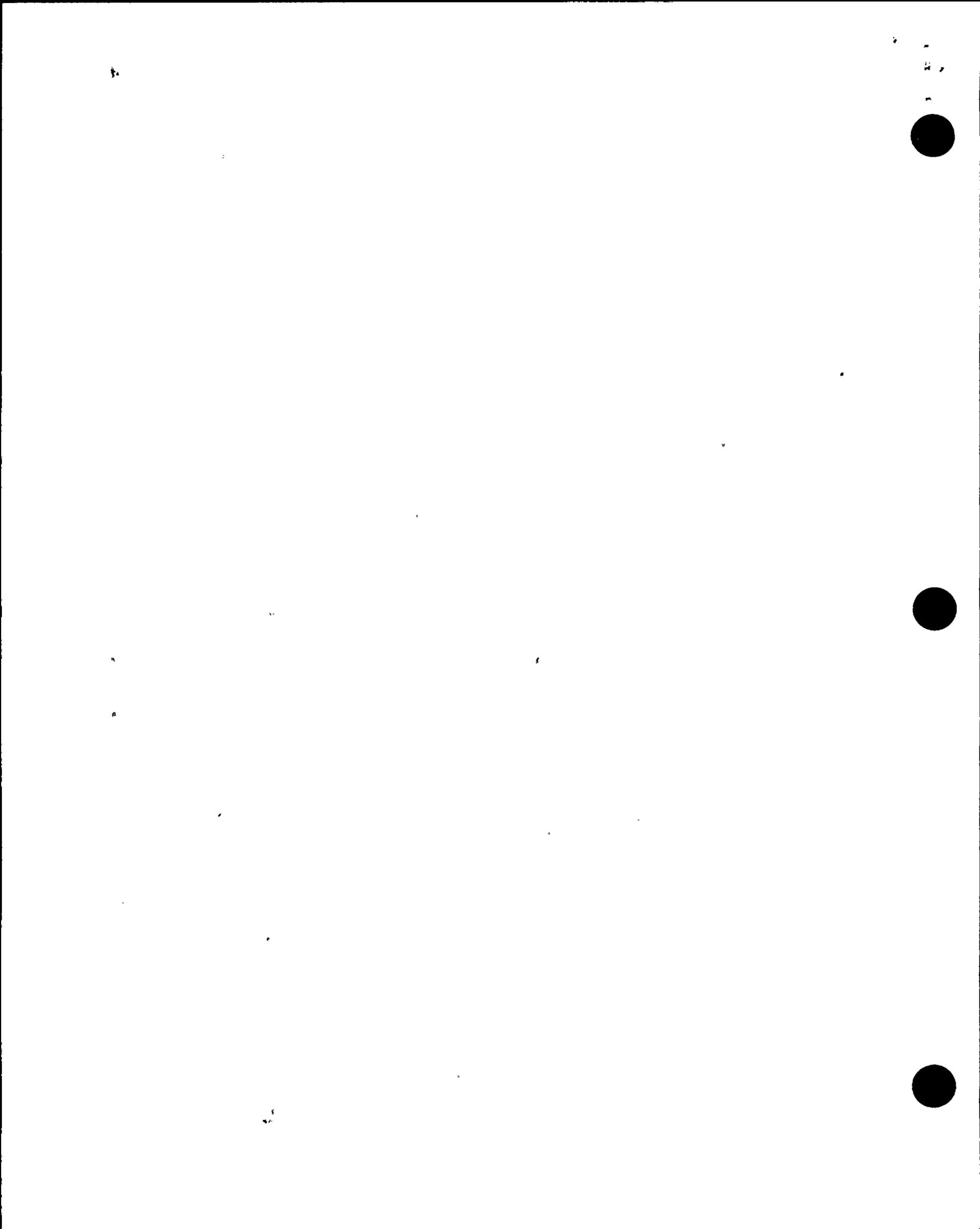


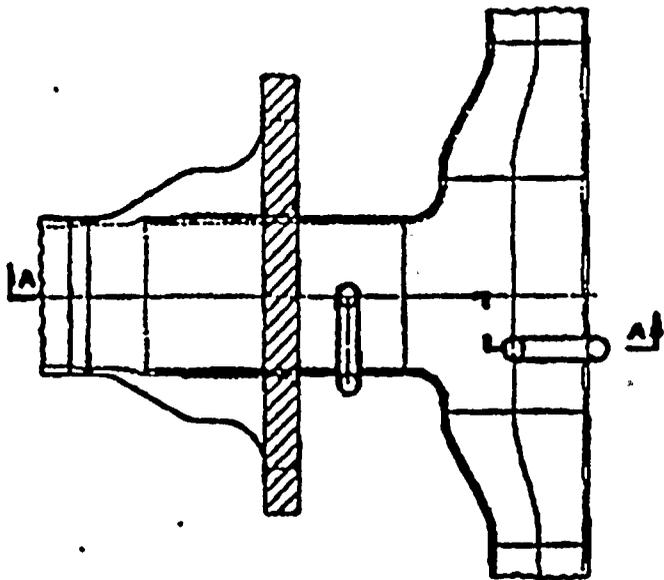


DETAIL 1
SCALE 1 = 1

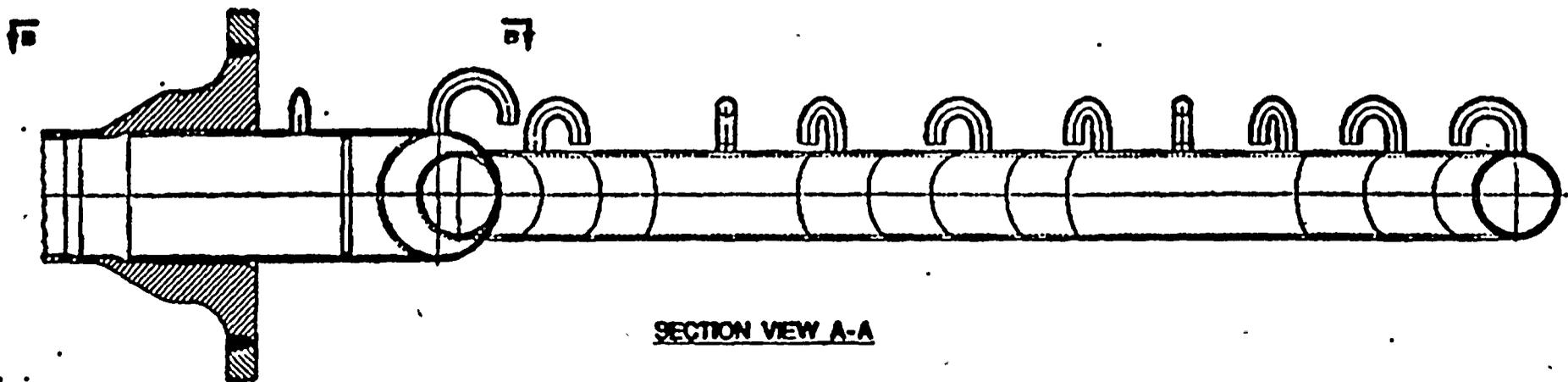
STEAM GENERATOR NOZZLE DETAIL

SCALE 6" = 1'-0"





PLAN VIEW B-B



SECTION VIEW A-A

STEAM GENERATOR NOZZLE DETAIL

SCALE 3" = 1'-0"



FINDINGS

- **Nozzle-to-Pipe Weld Cracks**
- **Analyzed Thermal Sleeve Erosion**
 - **Acceptable for Additional Cycle**
- **Elbow Cracks**
- **PG&E Operating Experience**
- **1986 Unit 1 Radiographs**





ACTIONS

- Replaced Piping
 - Flappered Elbow Counterbores
- Analyzed Thermal Sleeve Condition for:
 - Erosion Gap Growth:
 - Waterhammer Implications -
 - Nozzle Implications:
- Unit 2 Operability Evaluation Satisfactory -
- Evaluate PG&E Operating Experience
- Evaluate Lessons Learned, Long Term Solutions, and Data Collection



INDUSTRY EXPERIENCE

- IE Bulletin 79-13
- NUREG-0691
- NUREG/CR 5285
- U. S. Industry Experience
 - 25 of 54 Plants Reported Nozzle/
Pipe Cracking
 - One Plant Reported Nozzle Knuckle
Cracks, Poor Chemistry
- Thermal Sleeves



DIABLO CANYON POWER PLANT

NDE Results

David Gonzalez
Supervisor Inservice Inspection



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1992 NDE EXAMINATIONS OF FEEDWATER NOZZLES

- **Planning for Feedwater Exams
Commenced in May of 1992**
- **Inquiries for Industry Experience**
 - Sequoyah
 - Turkey Point
 - Code Examinations Not Adequate
for Small Thermal Fatigue Cracking
 - Became Aware of the Need
for Enhanced UT
- **Automated Scanning Selected for
Accuracy and Repeatability**





ULTRASONIC EXAMINATIONS

- **Scheduled for First Days of Outage**
- **UT Examinations Detect Presence of Indications**
 - **Use Multiple Techniques for Detection and Sizing**
 - **Calibrate Using Sizing Notch Block (.10" Up)**
 - **UT Results Not Immediately Conclusive**

Low Amplitude Signals

Some Crack Like Signal Characteristics

No Positive Geometrical Origins

Research ID Preparations

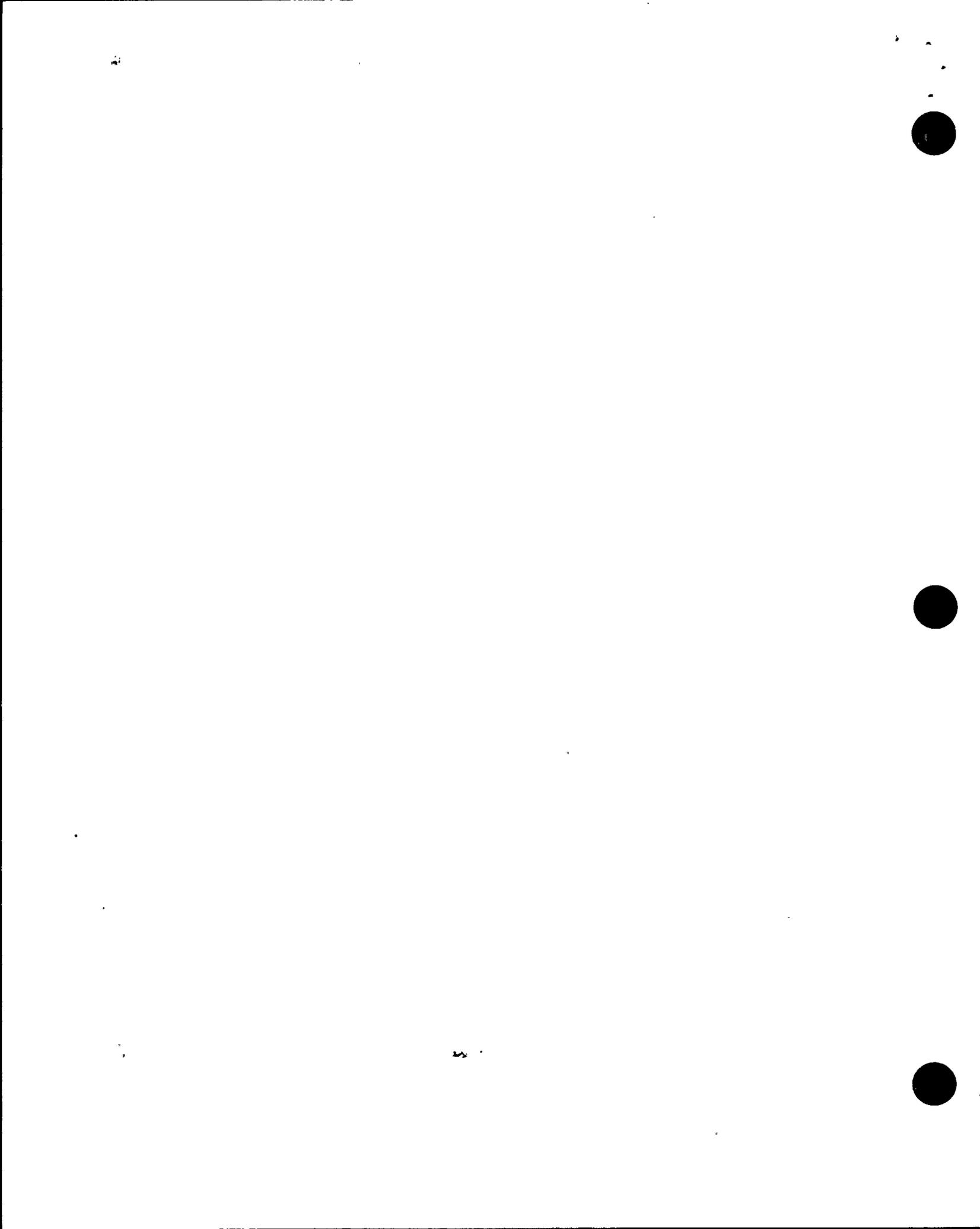




ATTEMPT TO VERIFY INDICATIONS

- Radiography Performed on S/G 1-4
 - Gamma Plug Removed
 - Single Wall Shots With Max Source/Film Distance
 - No Cracks Detected
- Radiography of S/G 1-1 and 1-2
 - Panoramic Shots
 - No Cracks Detected
- Video Probe Inspection of ID
 - Results Inconclusive (Possible Indication)





FINAL NDE RECOMMENDATIONS

- **UT Manual**
 - **Indications of Cracking**
- **UT Automated**
 - **Indications of Cracking**
- **Radiography**
 - **No Cracks**
- **Visual**
 - **Possible Indication**
- **Other Factors**
 - **Industry Experience**
 - **DCCP Experience**
 - **1977 Crack on 1-2**
 - **Extended Hot Functional Testing (U1)**
- **Final Disposition**
 - **Inform Management of Crack Indications**
 - **Discuss Uncertainties**
 - **Decide to Remove Spools**





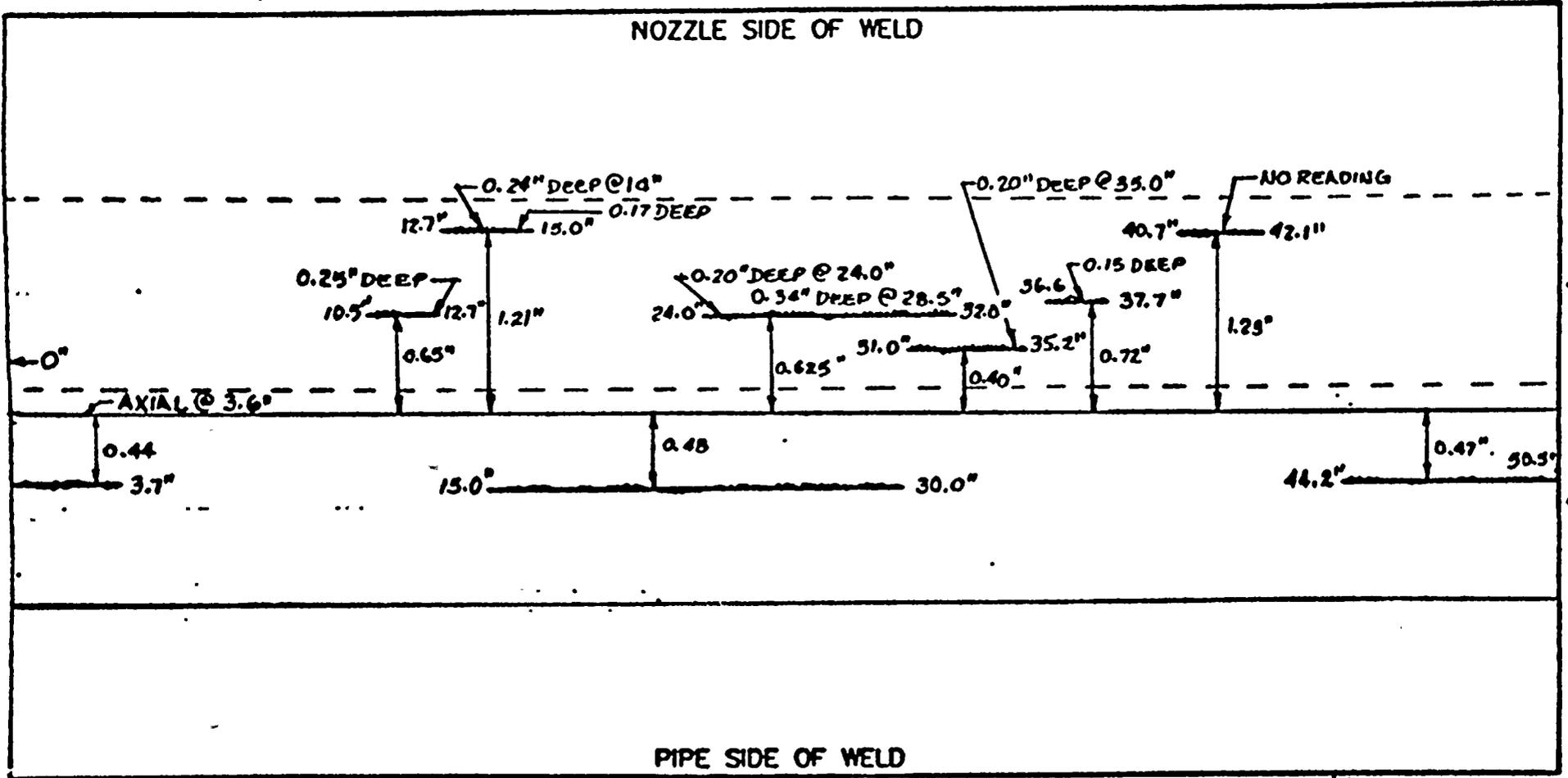


RESULTS OF ULTRASONIC INSPECTION

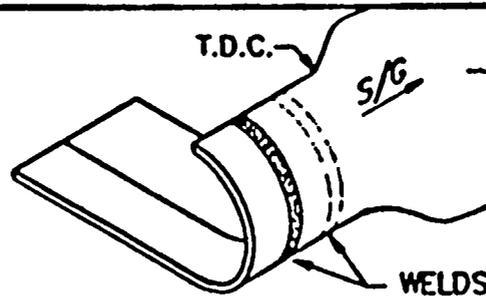
DCPP UNIT 1 - 1R5, FEEDWATER PIPE TO SG NOZZLE WELDS

DCPP ISI GROUP

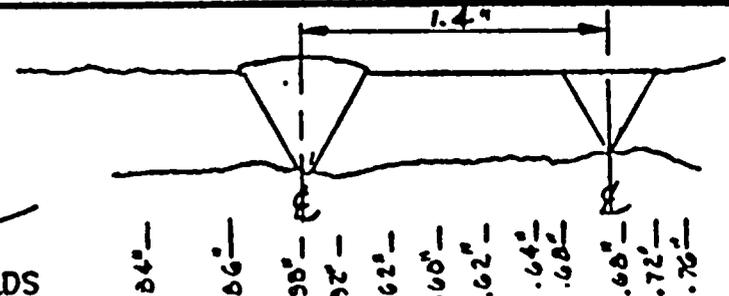
0 DEGREES
T.D.C. → CLOCKWISE



STEAM GENERATOR: 1-1
 WELD NO. WICG 101A1-1
 INSPECTOR NAME: HECHT/HOLLOW
 DATE: 9/24/92
 SCALE: NONE



ROLLOUT



PROFILE



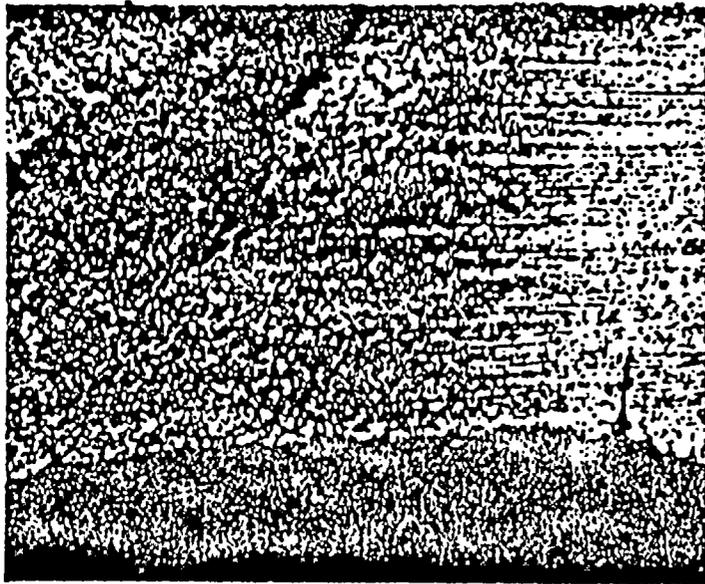
METALLURGICAL RESULTS

- **Metallurgical Sample Taken on 1-3 and 1-1 Spools**
- **Results Show UT Very Conservative**
 - UT Sized at "0.35" Deep
 - Samples Shows "0.037" Deepest
- **Evidence of Microcracking in Spools**
- **^{**} Segregates Found in Material**
 - May Mislead UT Sizing
- **Must Factor Into UT Analysis (Long Term)**

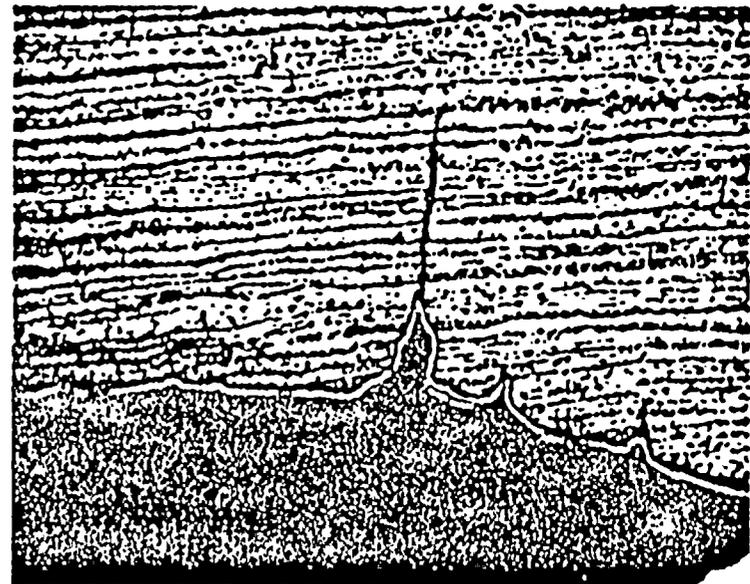




FW Nozzle 1-3: 8 3/8" CCW from TDC. Cracks in A106 spool attached to nozzle. Deepest crack is 0.035".



Magnification: 15X



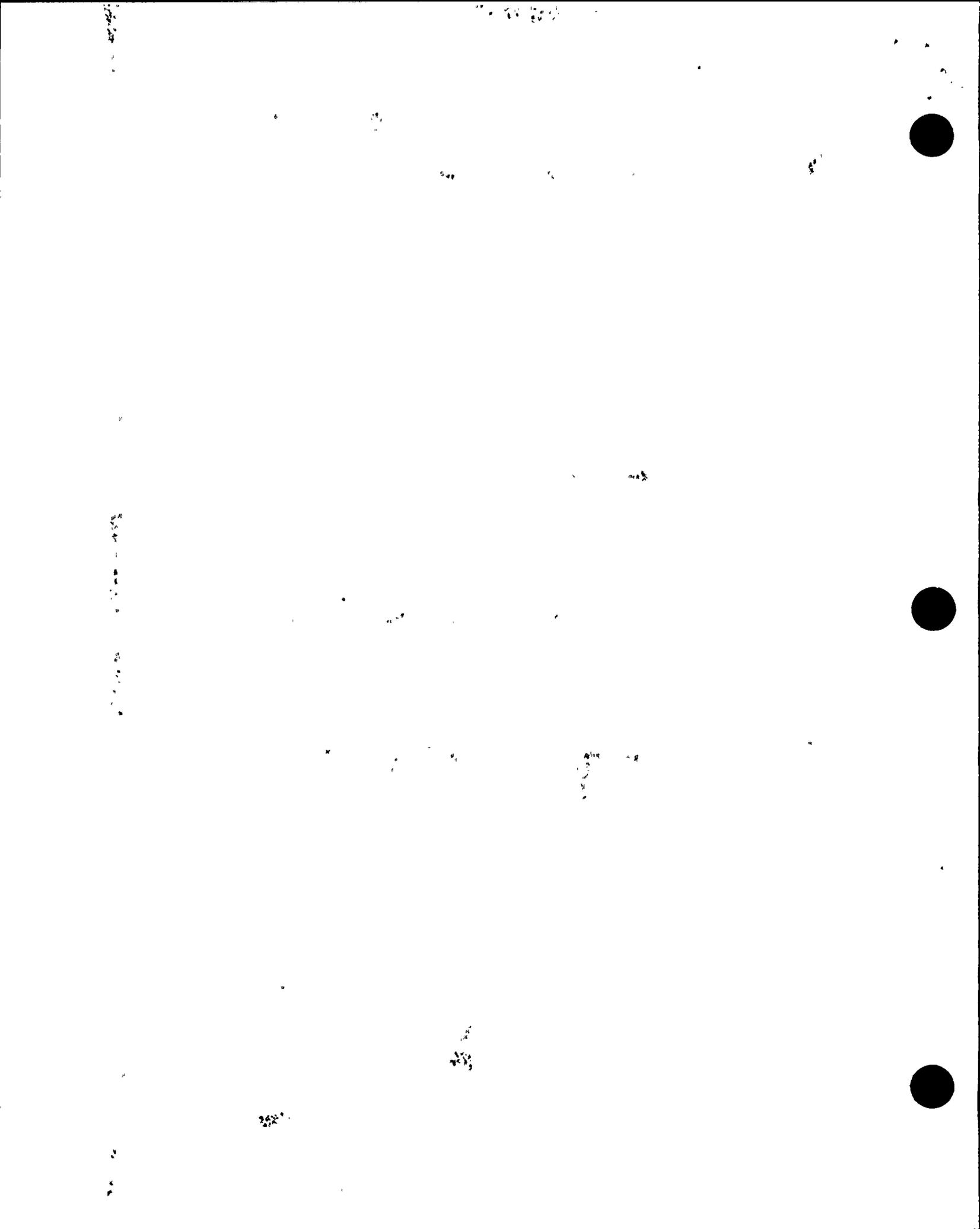
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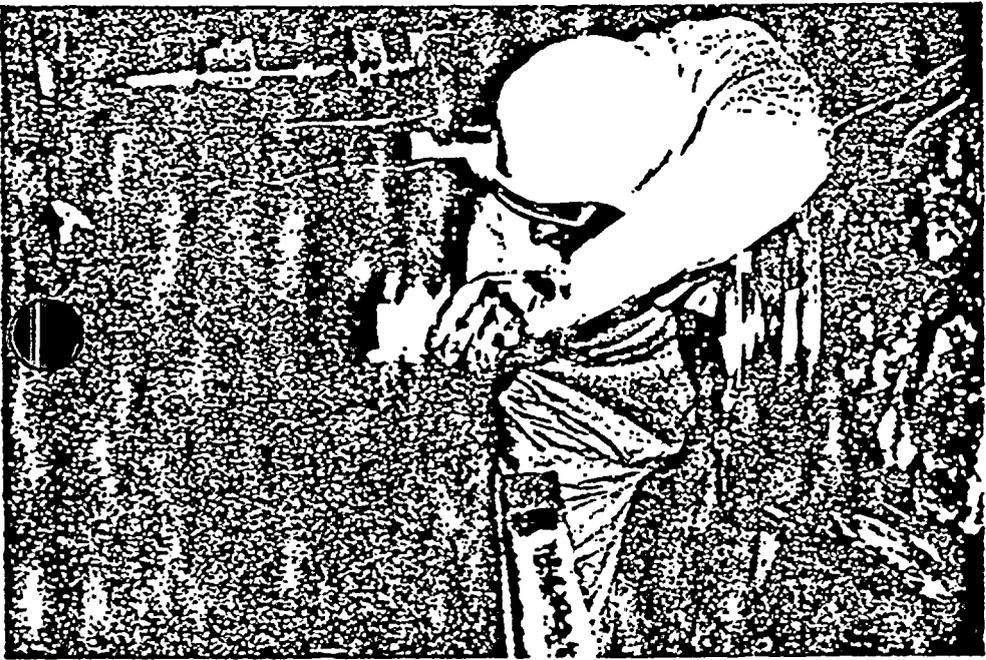


ELBOW EXAMINATION SUMMARY

- **Access for Prep/Exam Difficult**
- **Surface Preparation Necessary for Adequate Examination**
- **MT Indications Detected After Prep**
- **Indications Removed with Flapper Wheel**
- **Indications Were Allowable Per Code**
- **Deepest Indication (S/G 1-3) Did Not Appear to be a Crack**









ELBOW INDICATIONS

S/G	INDICATION DEPTH/LENGTH INCHES	CODE ALLOWABLE DEPTH/LENGTH INCHES
1-1	.030 / 7 3/4" Long Intermittent Ind's. Longest = 1/8"	.400 / 20
1-2	.010 / 2" Long Intermittent Ind's. Longest = 3/16"	.400 / 20
1-3	.107 / 360 Intermittent Ind's. Longest = 2.0"	.400 / 20
1-4	.047 / .125	.400 / 20





NDE SUMMARY

ACTION PLANS

- **Review NDE Assignment Methods to Ensure the Proper Welds are Clearly Designated for Exams.**
- **Analyze UT Data and Metallurgical Results and Determine Methods for Accurate Sizing of Thermal Fatigue Cracking.**





DIABLO CANYON POWER PLANT

Analysis

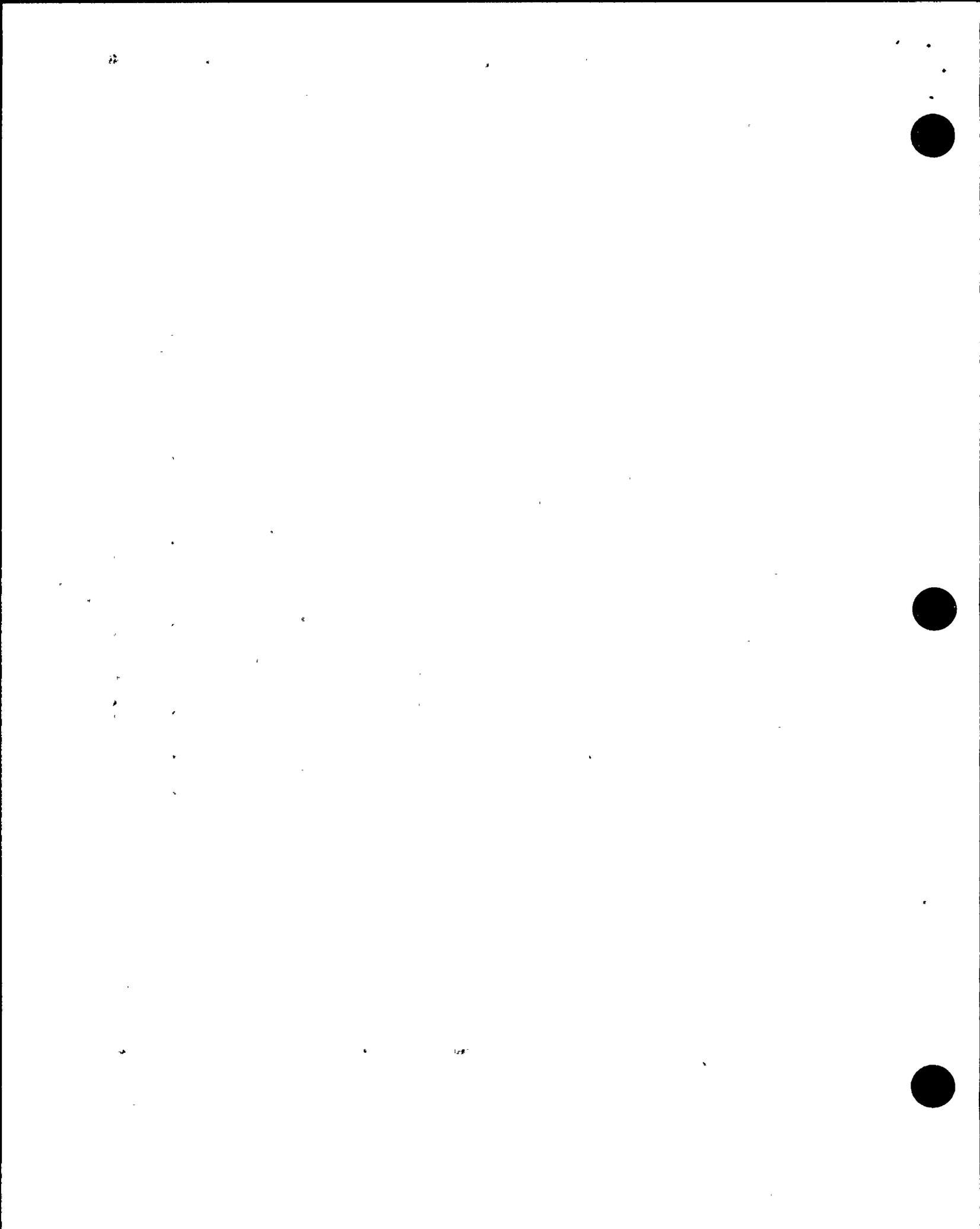
Henry Thaller, Assistant Project Engineer
William Crockett, Manager - Technical Services
Peter Riccardella, Structural Integrity
Warren Bamford, Westinghouse
Michael Roldt, Westinghouse





ANALYSES

- **AFW Operational Characteristics**
- **Nozzle-to-Pipe Cracks**
- **Elbow-to-Pipe Cracks**
- **Thermal Sleeve Degradation**
- **S/G Nozzle and Feeding**
 - **Drainage**
 - **Knuckle Region**
 - **Water Hammer**

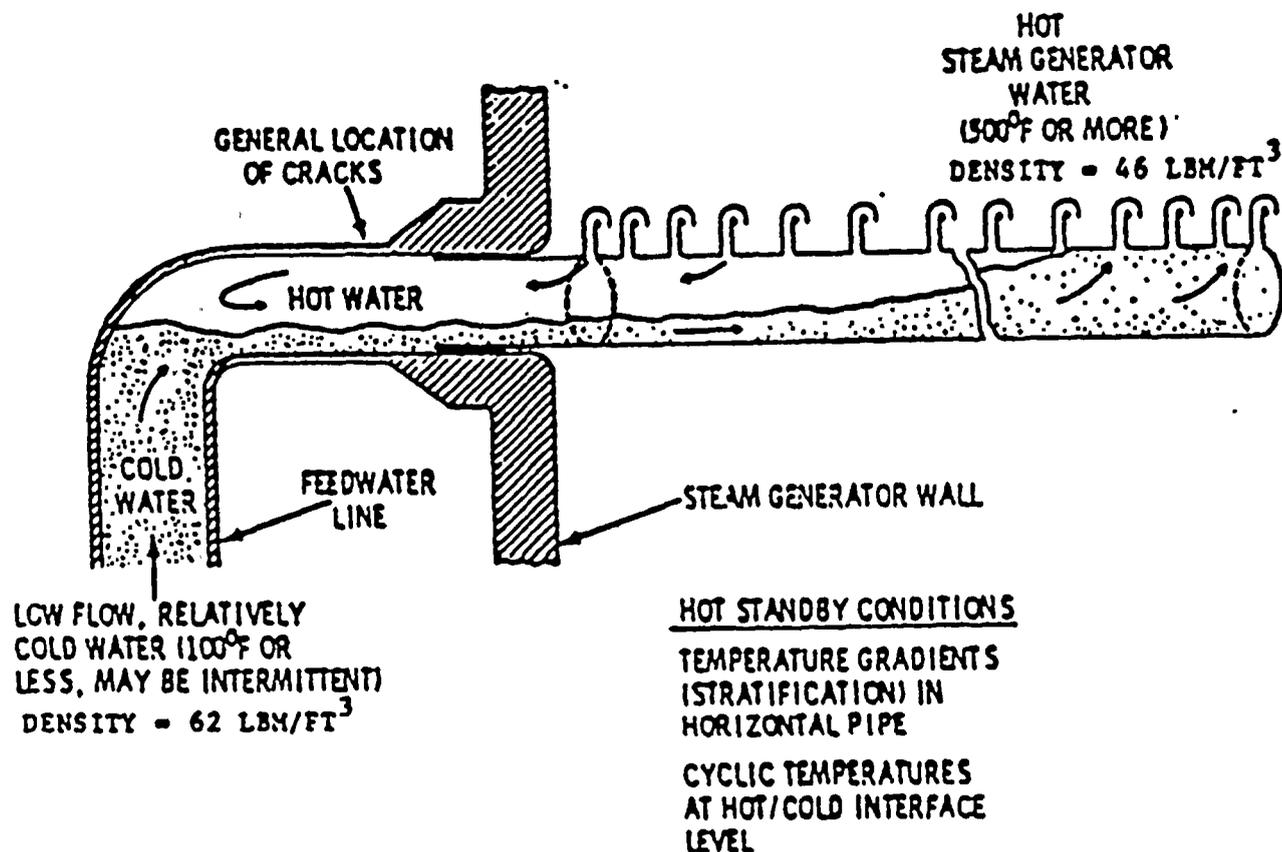


POSSIBLE CAUSES

- Thermal Fatigue
 - Stratification
- Erosion/Corrosion
- Corrosion Fatigue
 - Contributory Mechanism
- Overstress
 - Waterhammer
 - Locked/Bound Supports
 - Global Stratification:
- Fabrication







SCHEMATIC OF THERMAL STRATIFICATION AT LOW FLOW IN PWR FEEDWATER NOZZLES

PCR51739



***DIABLO CANYON POWER PLANT
UNITS 1 AND 2***

**Auxiliary Feedwater
Operational Characteristics**

**Bill Crockett
Manager-Technical Services**



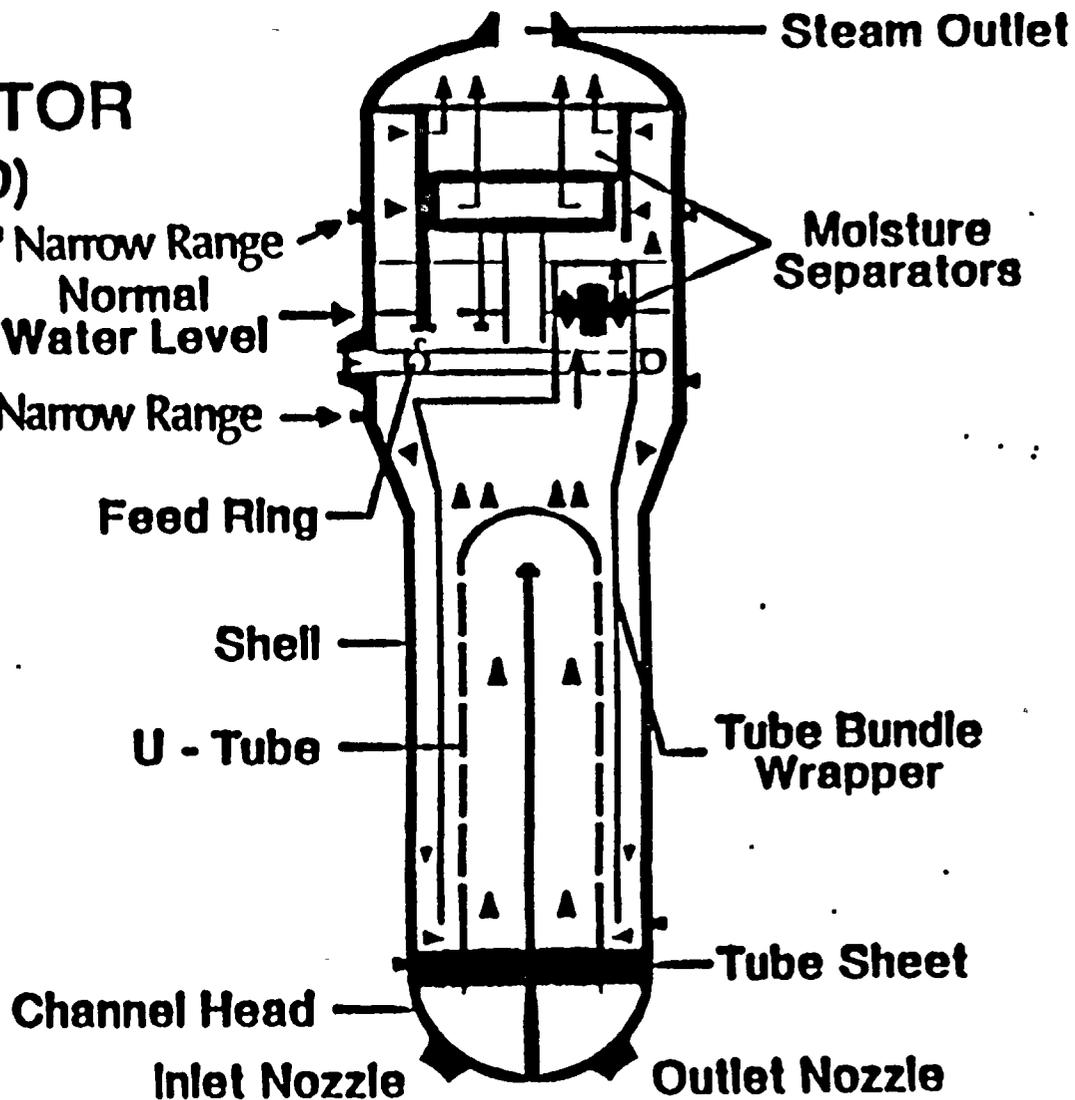


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STEAM GENERATOR (SIMPLIFIED)

587" Narrow Range
Normal Water Level
443" Narrow Range



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2



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TYPICAL AUXILIARY FEEDWATER EVOLUTIONS

EVOLUTION	DURATION	AUXILIARY FEEDWATER FLOW
REACTOR TRIP RECOVERY	20-30 MINUTES	APPROXIMATELY 400 GPM
HOLDING AT MODE 3 FROM A FORCED OUTAGE	TYPICALLY 2-4 DAYS	STEADY
SHUTDOWN (COOL-DOWN) TO RHR	BORATION = 8 HRS	INITIALLY STEADY 0-20 GPM AS YOU NEAR THE RHR TRANSFER POINT
	COOL-DOWN FROM 547F TO 300F = 8 HRS	
	TRANSFER TO RHR = 8 HRS	
	24 HRS	
STARTUP FROM A REFUELING OUTAGE	HEAT-UP TO MODE 3 = 20 HRS	0-40 GPM
	MODE 3 = 72 HRS	
	MODE 2 ON AUX FEEDWATER = 48 HRS	
	140 HRS	
HOT FUNCTIONAL TESTING	91 DAYS FOR UNIT 1 40 DAYS FOR UNIT 2	SIMILAR TO STARTUP FROM REFUELING OUTAGE



TIME SPENT IN MODES 2/3 (DAYS)

(RCS > 350°F)

	UNIT 1	UNIT 2
HOT FUNCTIONAL TESTING	90.80	40.26
CYCLE 1		
PRE-COMMERCIAL	129.56	86.84
FORCED OUTAGE	16.77	24.65
IN/OUT REFUEL	21.25	12.00
TOTAL	167.58	123.49
CYCLE 2		
FORCED OUTAGE	19.89	15.66
IN/OUT REFUEL	16.17	9.83
TOTAL	36.06	25.49
CYCLE 3		
FORCED OUTAGE	3.18	25.12
IN/OUT REFUEL	9.96	8.04
TOTAL	13.14	33.16
CYCLE 4		
FORCED OUTAGE	13.90	0
IN/OUT REFUEL	6.75	11.67
TOTAL	20.65	11.67
CYCLE 5		
FORCED OUTAGE	10.45	5.51
IN/OUT REFUEL	0.79	N/A
TOTAL	11.24	5.51
PRE-COMMERCIAL	220.36	127.10
POST-COMMERCIAL	119.11	112.48
TOTAL TIME	339.47	239.58



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IMPROVEMENTS

Outage Time

- Better Planning and Scheduling
- Hit
- OCC

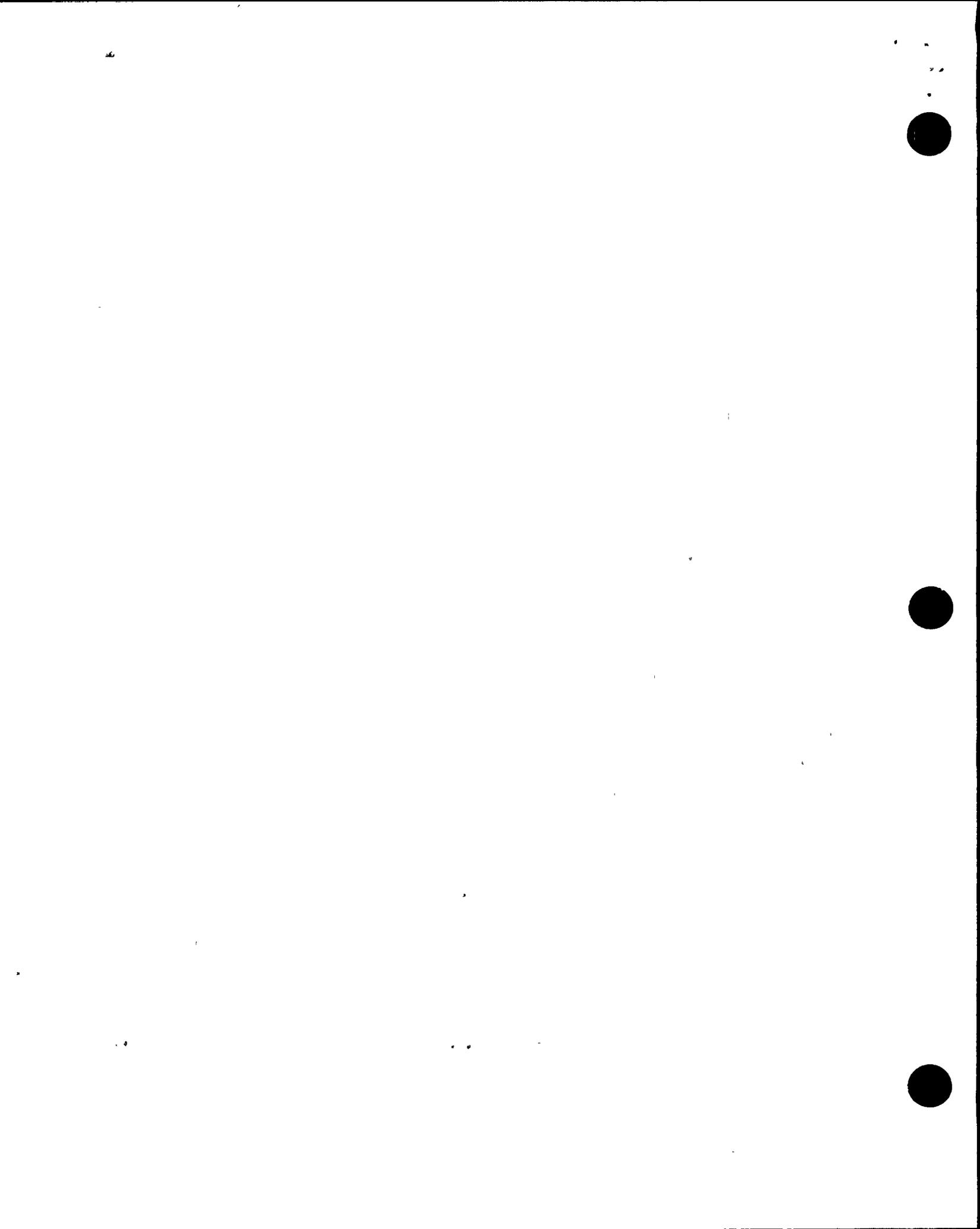
Best Maintenance Practices

- Training
- Procedures

Reliability for Extended Runs

- Equipment Modifications
- Quality Maintenance
- Minimize Reactor Trips





DIABLO CANYON POWER PLANT

Nozzle-to-Pipe Crack Evaluation

Peter Riccardella
Structural Integrity Associates

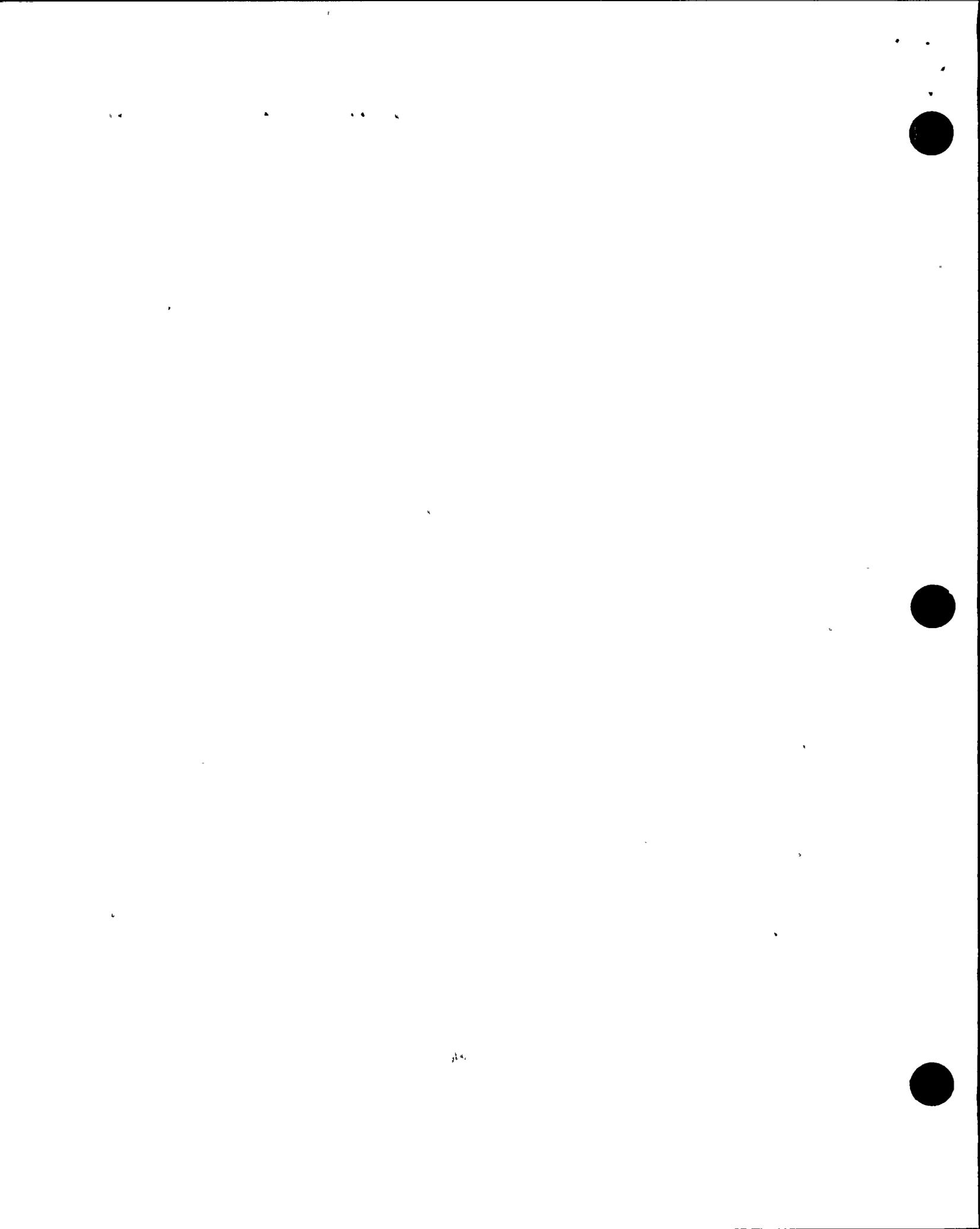




DCPP FEEDWATER NOZZLE/PIPE CRACKING EVALUATION

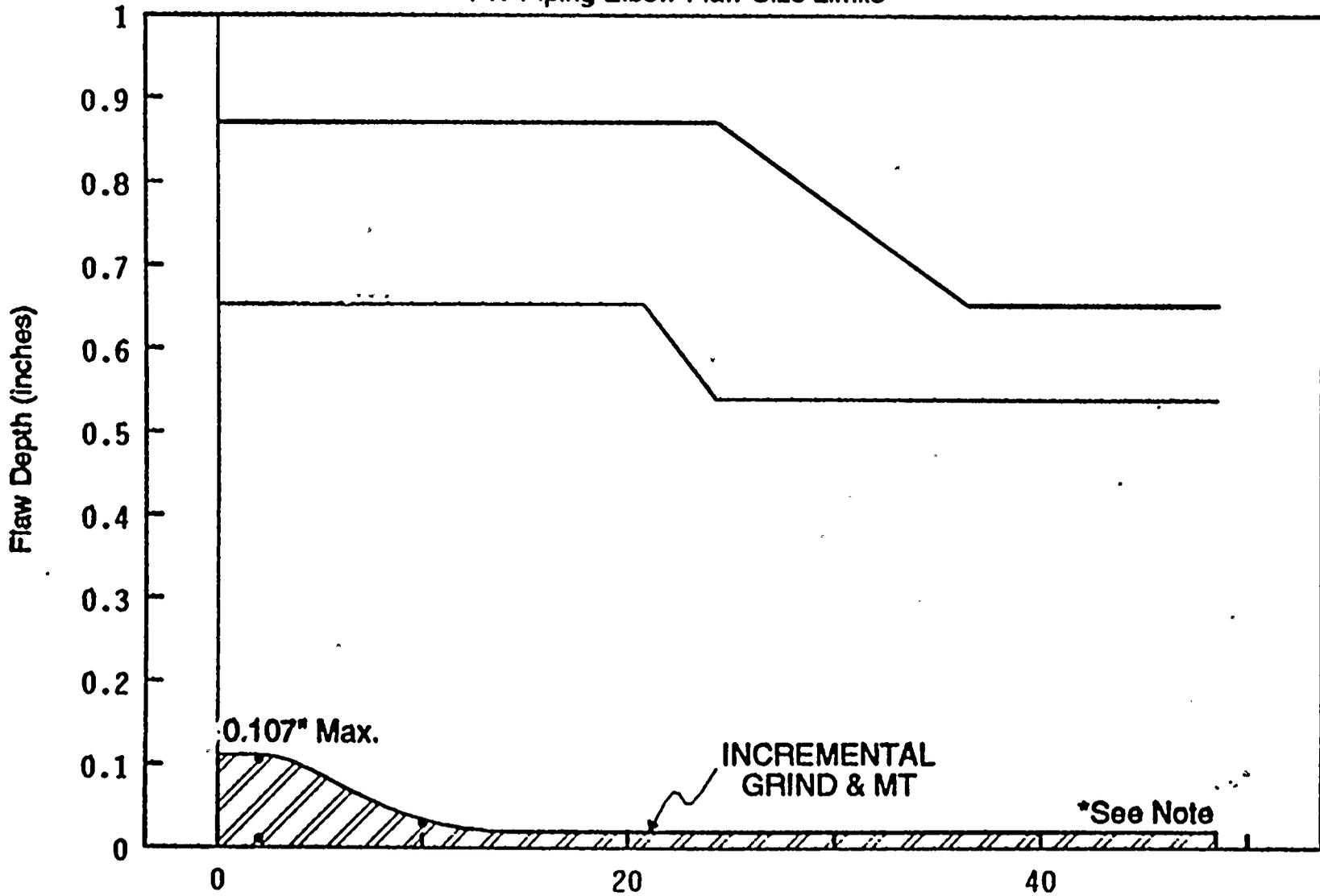
- **ASME Section XI Flaw Evaluation**
 - Allowable Flaw Size
 - Crack Growth Projections
- **AFW Cycling Estimates
(Flow Stratification)**
- **Critical Flaw Size Assessment
(Leak Before Break)**
- **Unit 2 Operability Evaluation**





Diablo Canyon Unit 1

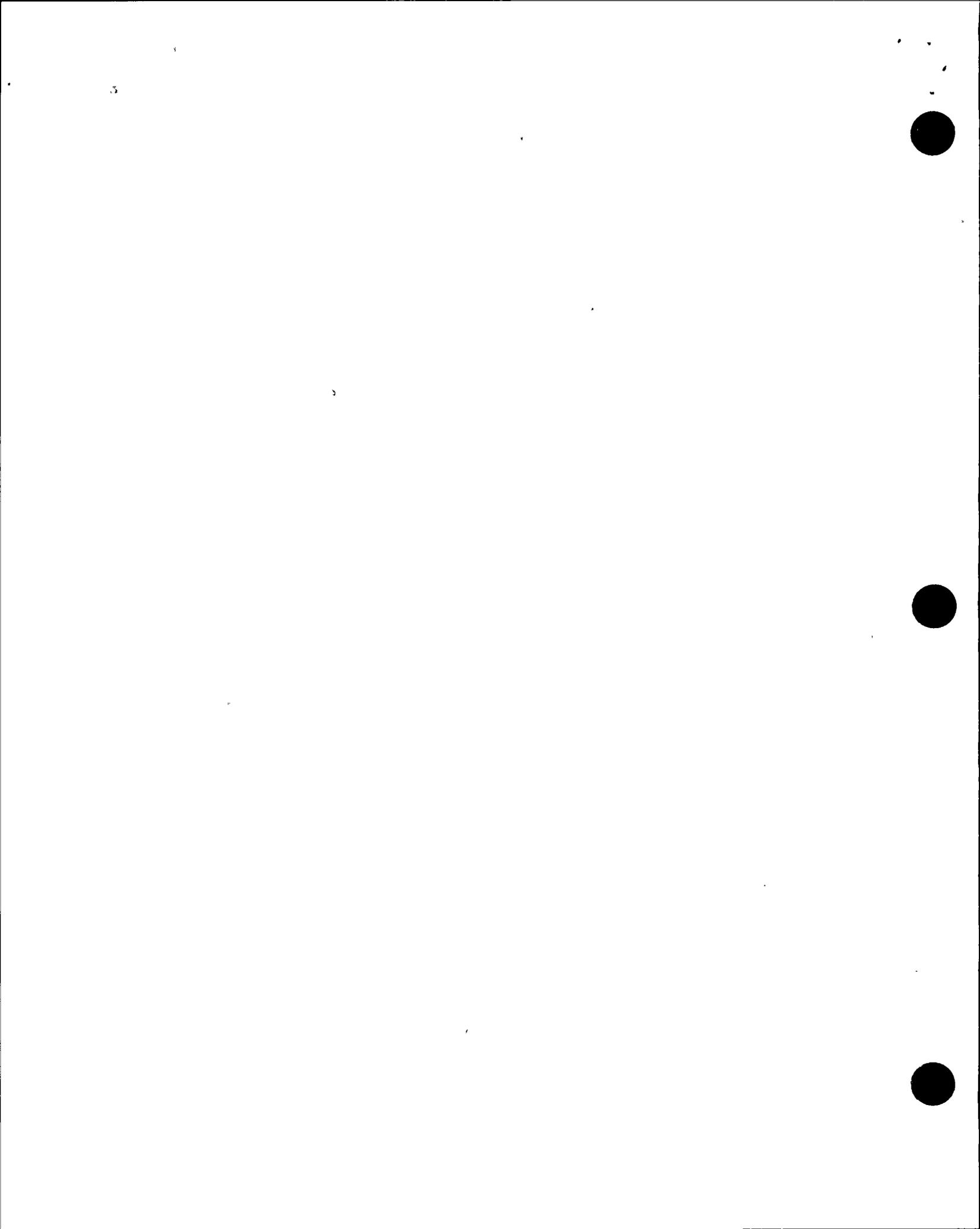
FW Piping Elbow Flaw Size Limits



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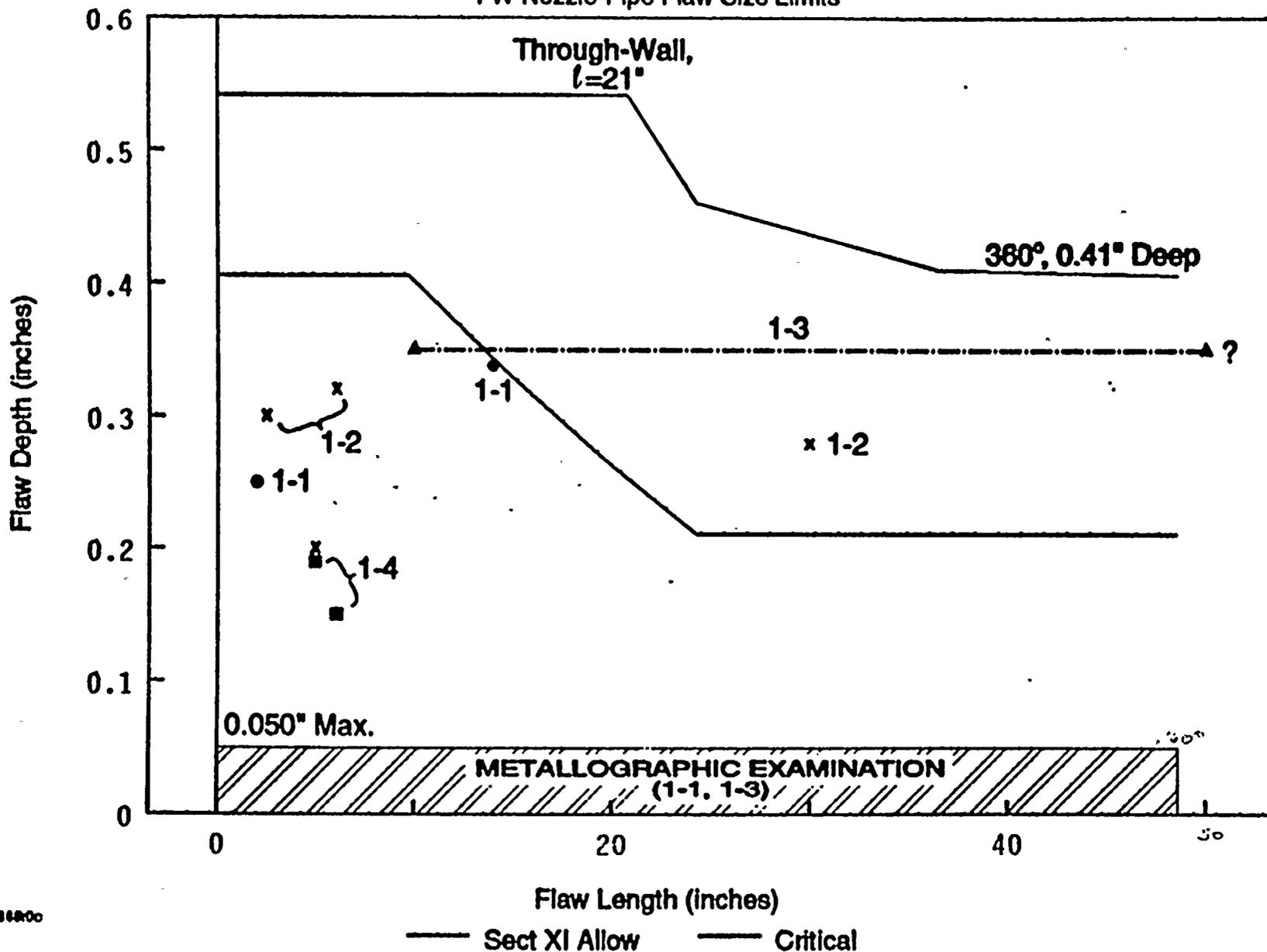
Flaw Length (inches)
—— Sect XI Allow - - - - Critical

*0.020" General Cleanup



Diablo Canyon Unit 1

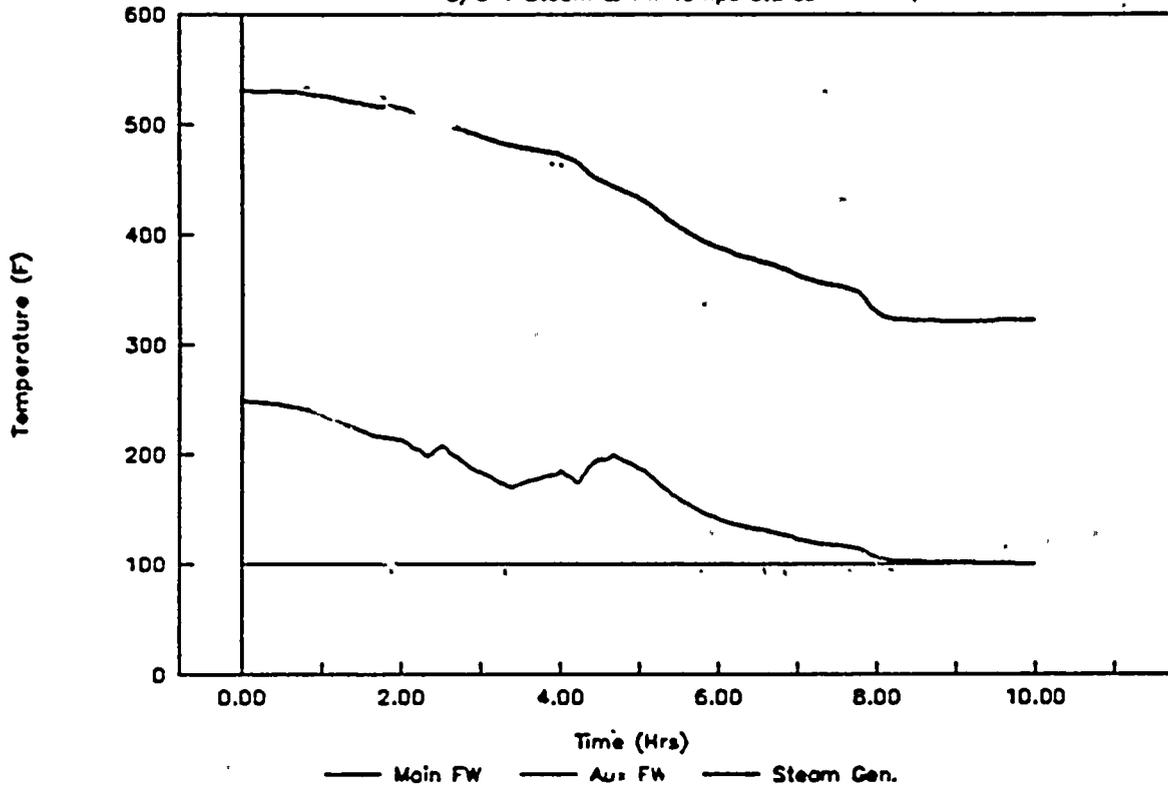
FW Nozzle-Pipe Flaw Size Limits





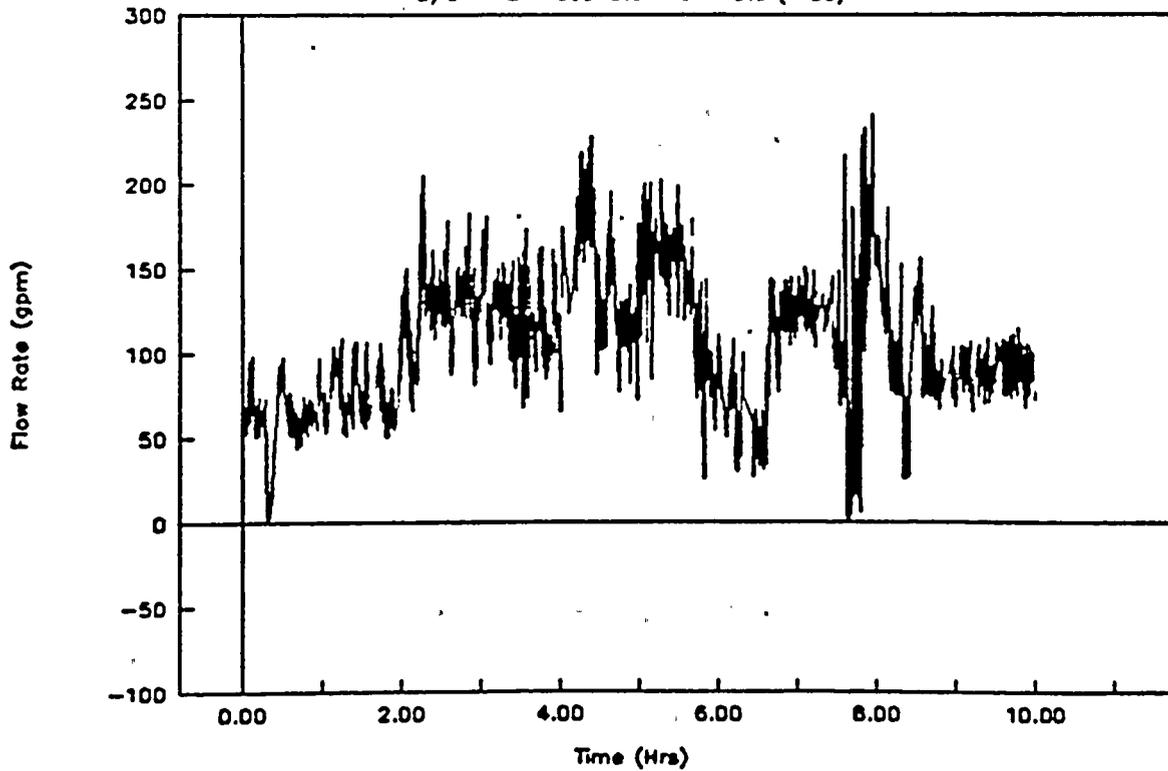
DIABLO CANYON UNIT 1 COOLDOWN 9/13/92

S/G 1 Steam & FW Temperatures



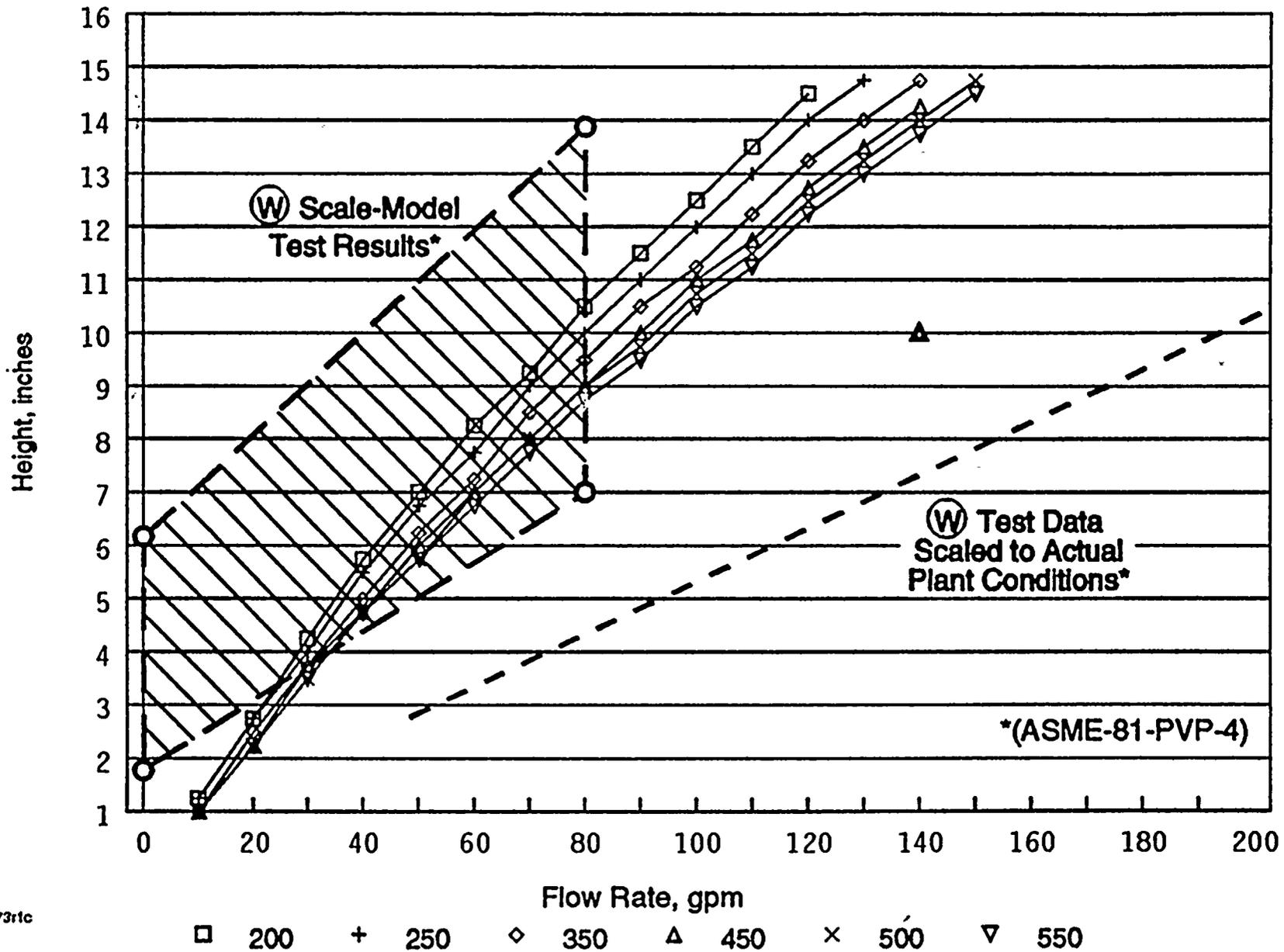
DIABLO CANYON UNIT 1 COOLDOWN (9/13/92)

S/G 1 Aux Feedwater Flow Rate (FT50)





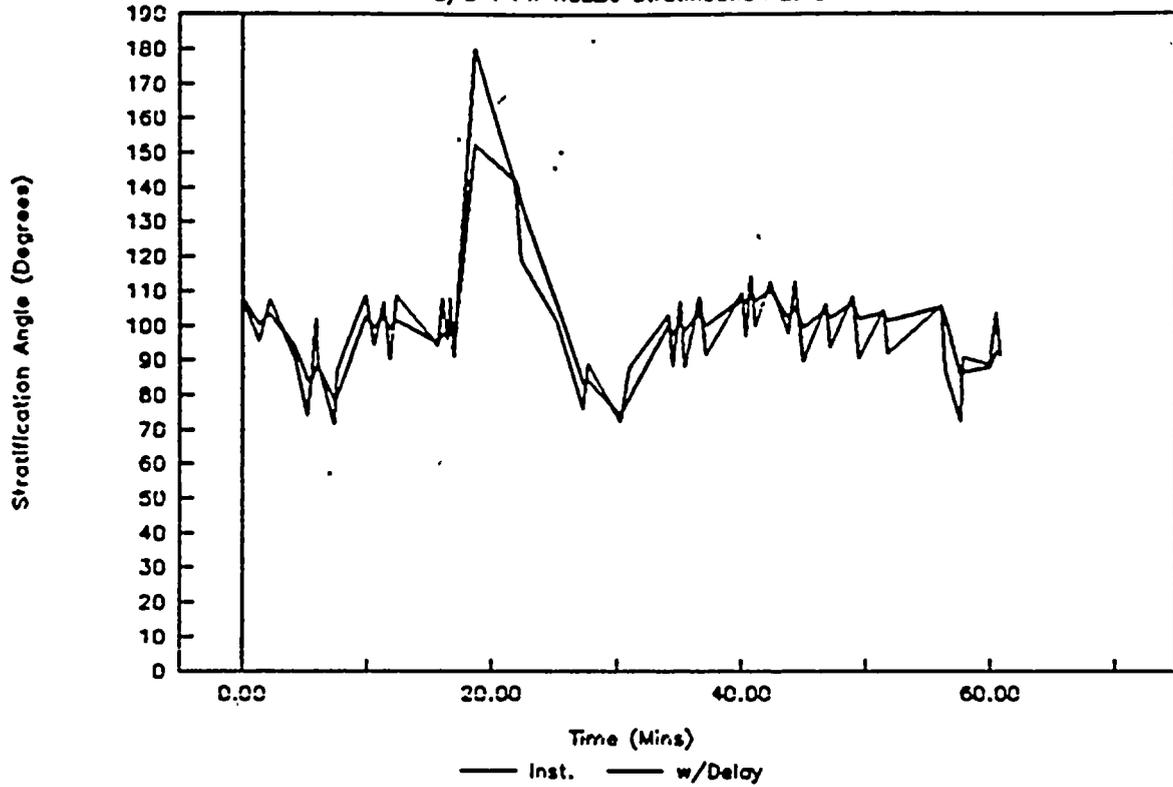
Stratification Height at FW Nozzle





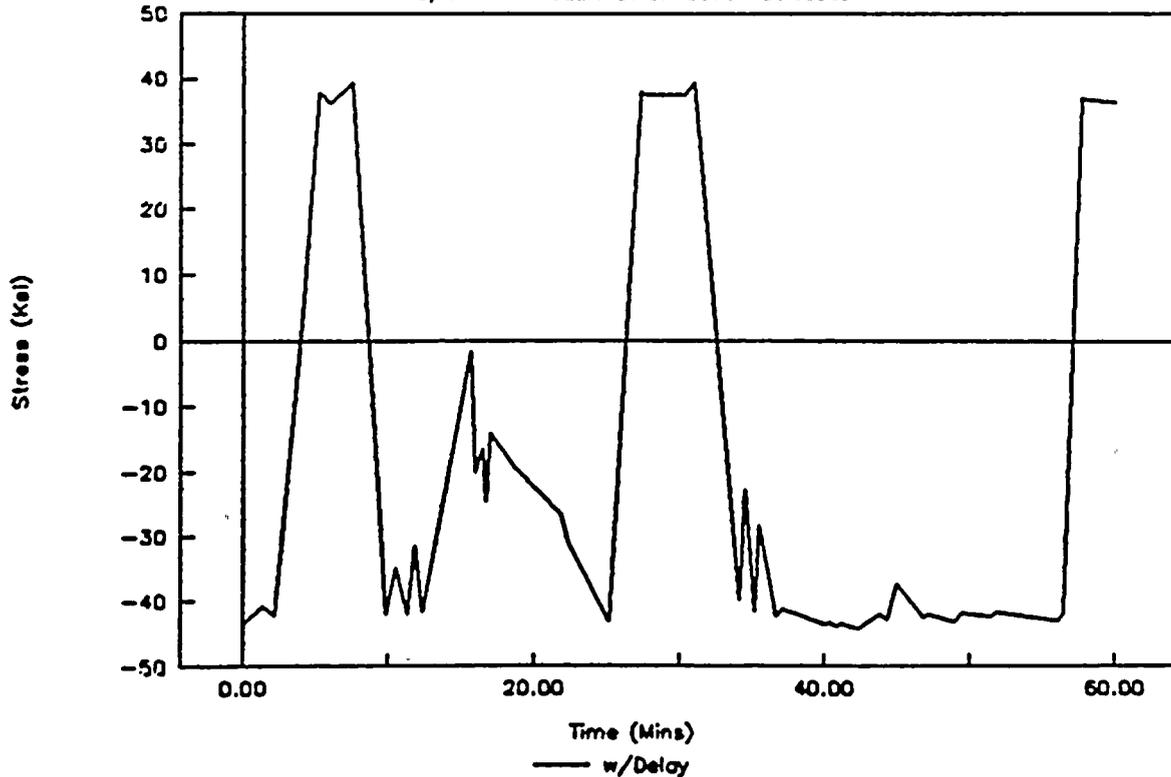
DIABLO CANYON U1 COOLDN (9/13/92-0100)

S/G 1 FW Nozzle Stratification Level



DCPP U1 COOLDOWN (9/13/92-0000-0100)

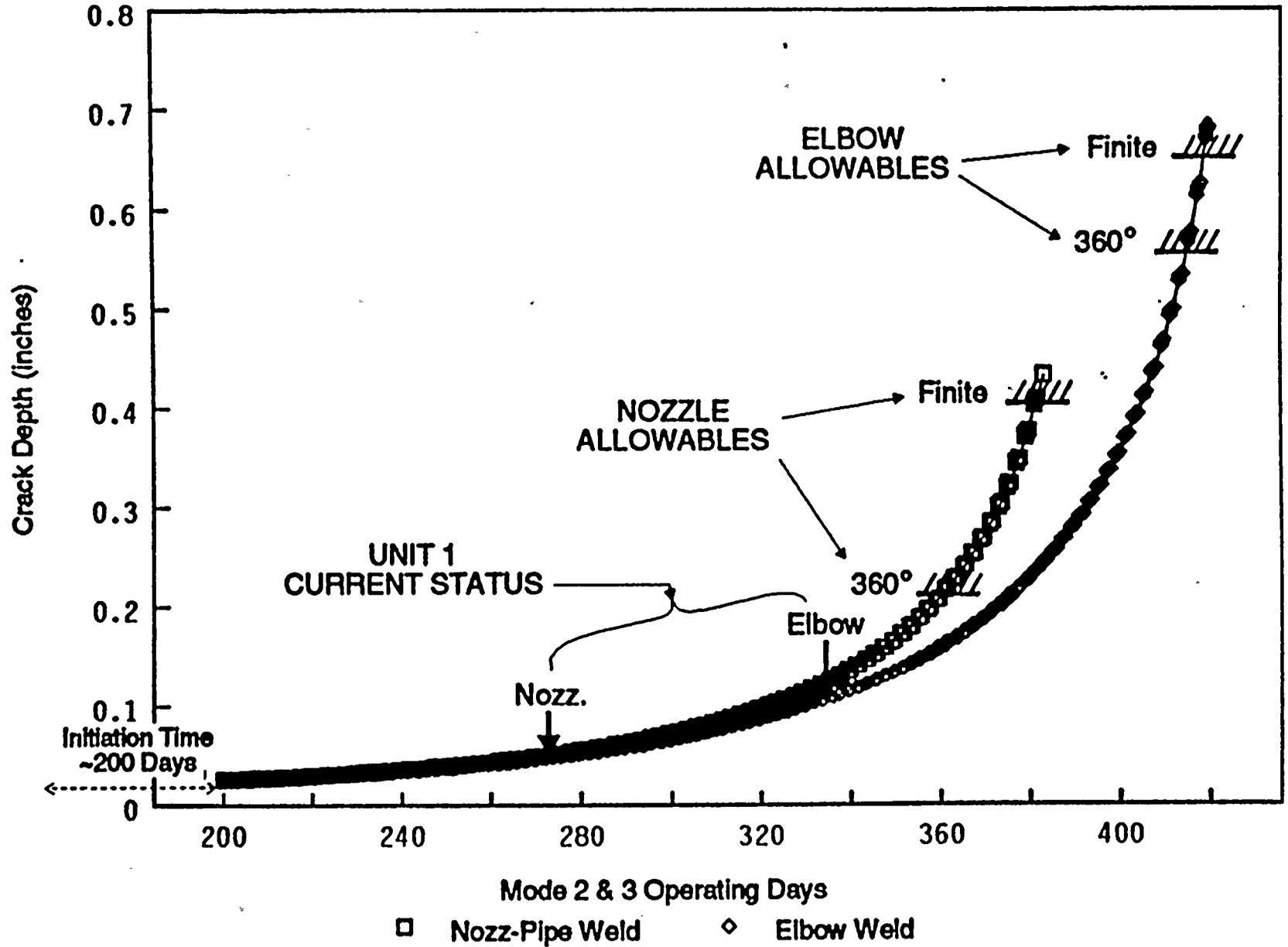
S/G 1 FW Nozzle Stratification Stresses





DCPP UNIT 1 FEEDWATER NOZZLE

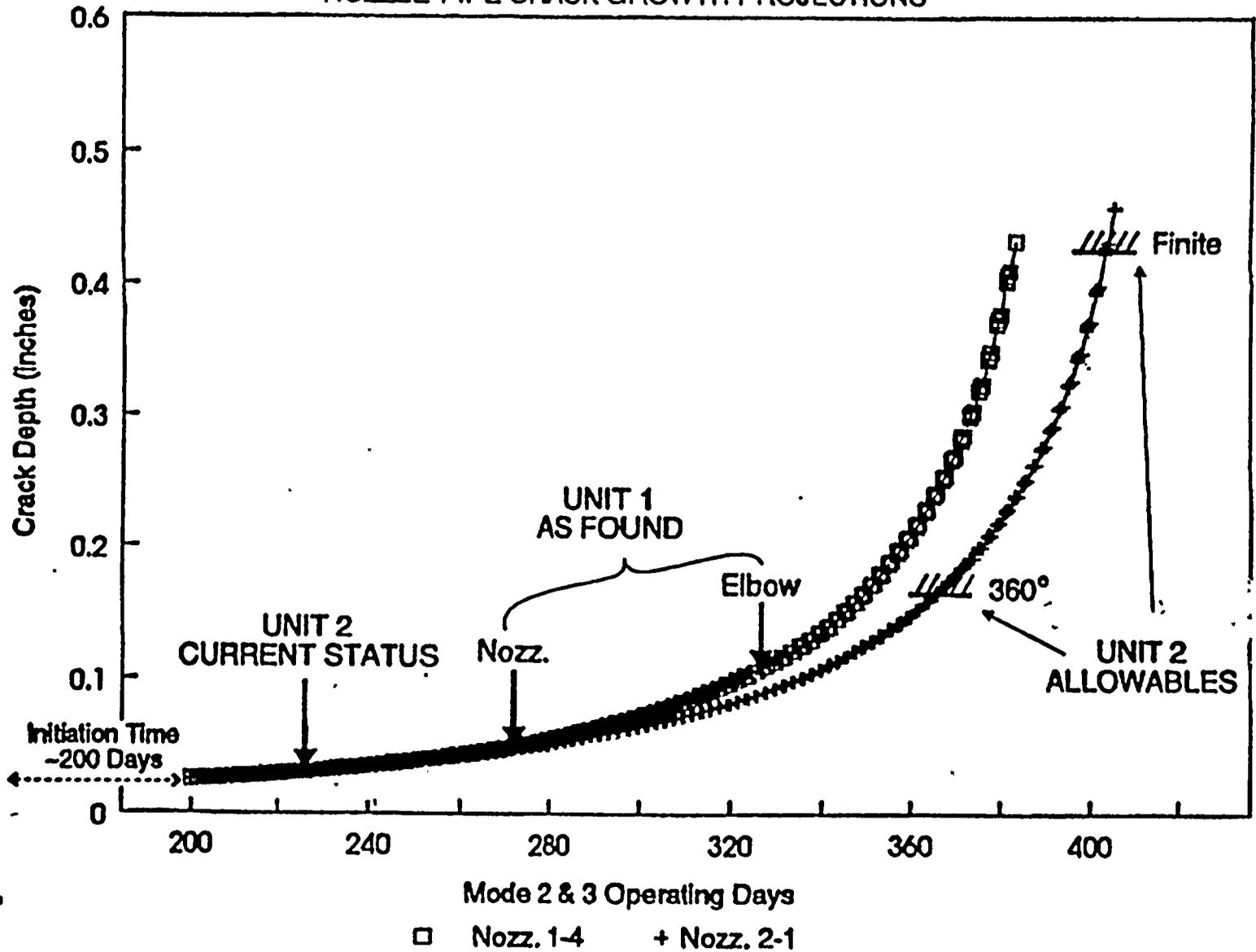
NOZZLE-PIPE CRACK GROWTH PROJECTIONS





DCPP UNIT 2 FEEDWATER NOZZLE

NOZZLE-PIPE CRACK GROWTH PROJECTIONS





NOZZLE/PIPE CRACKING CONCLUSIONS

- **Observed Cracking in Unit 1:**
 - **Significantly Below Code Allowables**
 - **Consistent with Industry Experience (IEB-79-13)**
 - **Consistent with DCPD AFW Flow/Stratification Cycles**
 - **Would Not Have Grown to Unacceptable Depth for Several Subsequent Fuel Cycles**

- **Potential for Unit 2 Cracking Evaluated and Not a Concern**
 - **100 Days Less AFW Days (240 vs 340)**
 - **> 150 Days Additional AFW Days Before Postulated Cracking Would Reach Code Allowable**
 - **~ 5 Additional AFW Days Expected Until 2R5 (Spring, 1993)**

- **AFW Cycling Will Be Accurately Monitored During Future Operation**
 - **Local Thermocouples (Unit 1)**
 - **On-Line Fatigue Monitoring (Both Units)**



FILM COEFFICIENT

- No Gap, $h \approx 100 \text{ B/hr. ft.}^2 \text{ }^\circ\text{F}$
- Large Gap, $h \approx 900 \text{ B/hr. ft.}^2 \text{ }^\circ\text{F}$



FATIGUE ANALYSIS

- All Design and Operating Transients were Considered
- Total Transient Cases About 30, Including a Complete Set of Feedwater Line Stratification Transients, at Various Interface Levels and Temperature Differences
- Two Cases: No Bypass, and Large Bypass
- Two Locations: Bore Region
Nozzle Knuckle Face Region
- All Other Locations Under the Thermal Sleeve were Less Limiting



FATIGUE RESULTS

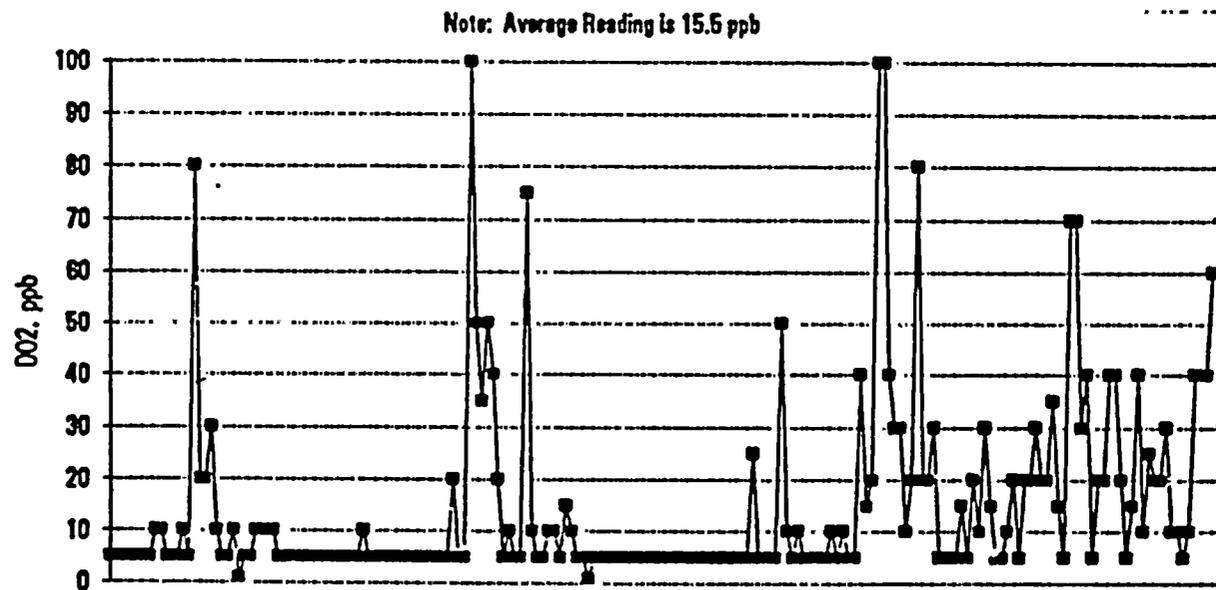
- **Results:** **Nozzle Bore for 9700 hrs @ Mode 2/3**

No Bypass:	U=0.17
Significant Bypass:	U=0.20
- **Results:** **Nozzle Knuckle Face 9700 hrs @ Mode 2/3**

No Bypass:	U=0.08
Significant Bypass:	U=0.22
- **The Fact that Cracks Did Initiate in these Regions at One Plant Indicates a Significant Environmental Effect was Present**
- **Water Chemistry Control at Diablo Canyon Makes Environmental Influences Here Much Less Likely. Therefore the Fatigue Usage Results are Considered Directly Applicable**



DISSOLVED OXYGEN: UNIT 1 CONDENSATE STORAGE TANK



Weekly Readings, January 1990 - October 1992



STRATIFICATION PROFILES

Distribution by Profile Type

Plant	% Cycles in Profile				
	#1	#3	#6	#5	#2
D.C. Cook	11.5	6.4	23.8	24.7	33.6
Salem	14.6	1.9	35.7	12.1	35.7
Ginna	22.4	20.9	14.9	28.4	13.1
Robinson	0.0	8.7	19.6	17.4	54.3

Interface Level

Profile	Percent of Pipe Diameter
1	>85
3	76 to 85
6	56 to 75
5	46 to 55
2	< 45

Distribution by Temperature Difference

Plant	Duration (Hours)	% Cycles by ΔT , °F			
		>350	>250	>150	<150
D.C. Cook	11143	74.1	13.2	9.2	3.0
	5587	2.8	35.1	28.1	34.1
Salem	5923	40.1	31.4	13.6	15.0
	3604	31.3	25.8	42.0	0.9
Ginna	3737	26.6	27.8	41.6	4.0
	Robinson	4374	54.5	39.7	5.1
2672		34.3	62.5	3.2	0.0



PLANT FATIGUE COMPARISONS

Hours at Hot Standby

Plant	S/G Model	Configuration	Hours	Cycle Mix
Ginna	44	Elbow	5038	Ginna
Salem	51	Elbow	8203	Salem
Indian Point 2	44	Straight Pipe	9764	Ginna
Diablo Canyon	51	Elbow	8160	Ginna/Salem

Fatigue Usage

Plant	Location	Cycle Mix	Fatigue Usage ⁽¹⁾	
			Minimum	Maximum
Ginna	0° ER	Ginna	7.2	32.5
	67.5° ER		2.5	11.0
Salem	0° ER	Salem	2.1	9.3
	97.5 ER		0.9	4.7
Indian Point 2 Straight Pipe	0° PR	Ginna	0.04	0.17
	90° PR		0.01	0.03
	Knuckle		0.10	0.47
Diablo Canyon	0° ER	Salem	2.09	9.25
	97.5° ER		0.90	4.68
	Knuckle	Ginna	0.09	0.39
		Salem	0.02	0.07

(1) Excludes thermal striping effects



DESTRUCTIVE EXAMINATION MAXIMUM CRACK DEPTHS (INCH)

Plant	Crack Location		Pipe Config
	Counterbore	Knuckle	
Ginna	0.11	—	Elbow
Salem	0.12	—	Elbow
Indian Point 2	0.34	0.40	Straight
Diablo Canyon	0.05 0.34 (UT)	Not Expected	Elbow

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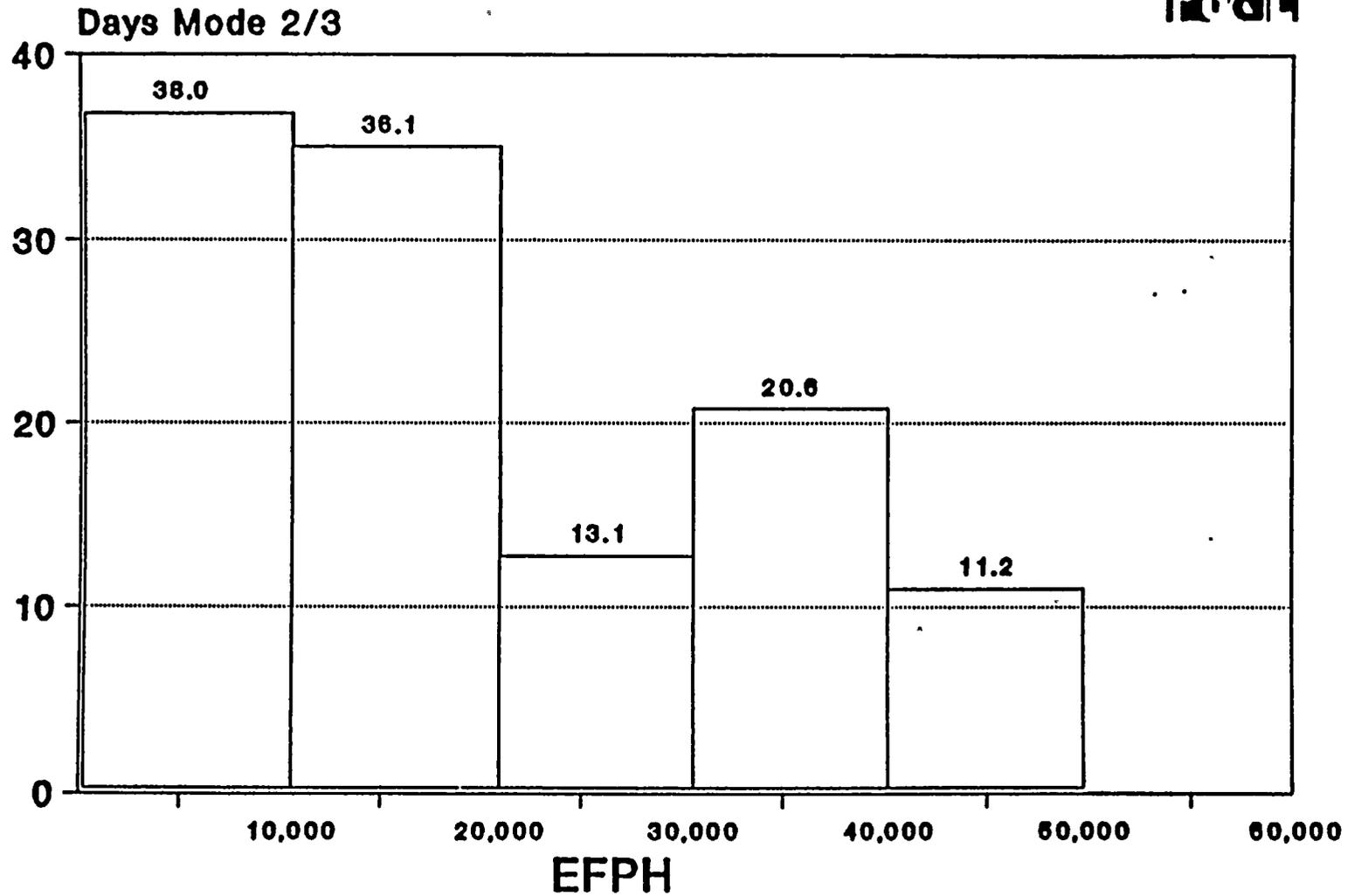
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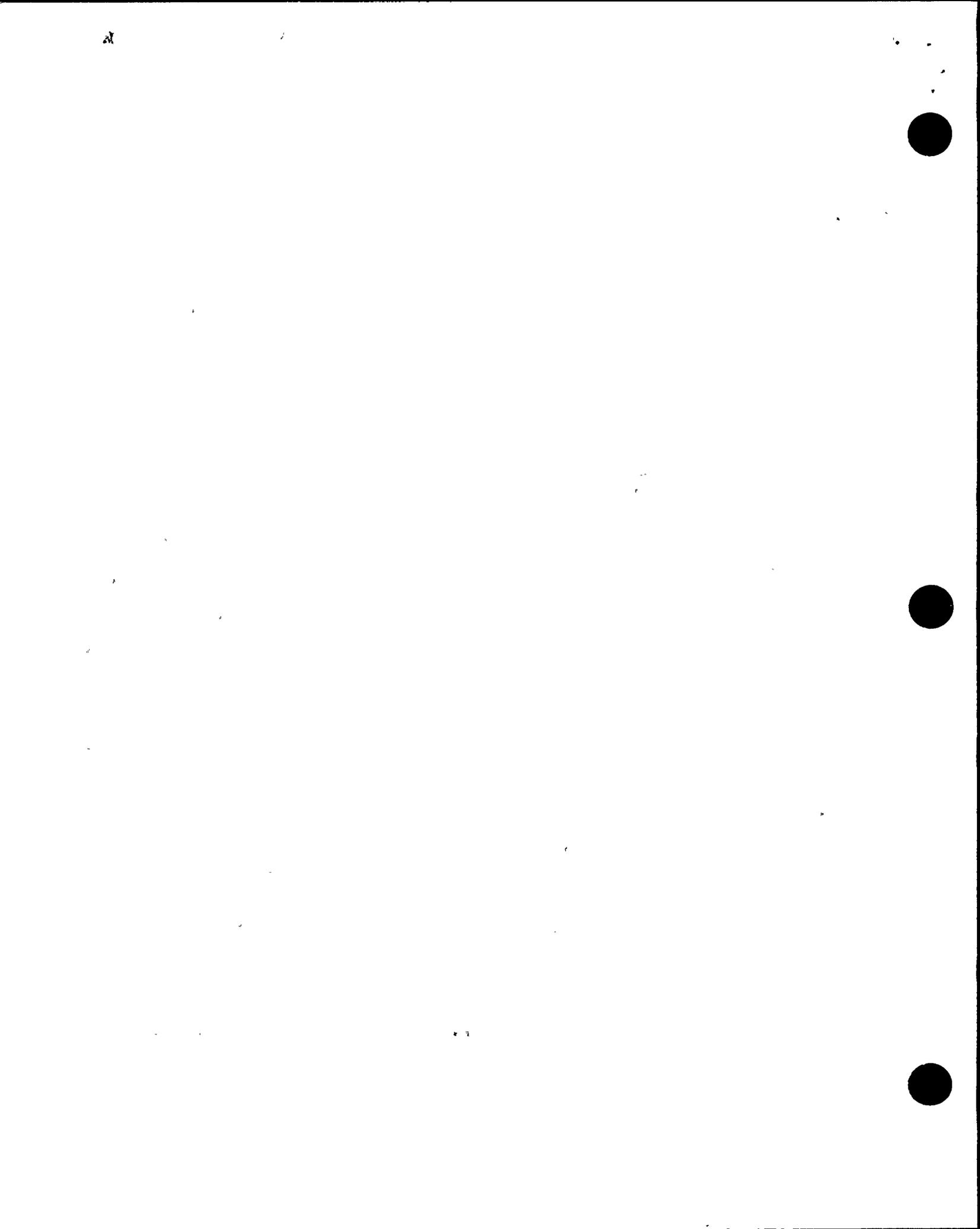
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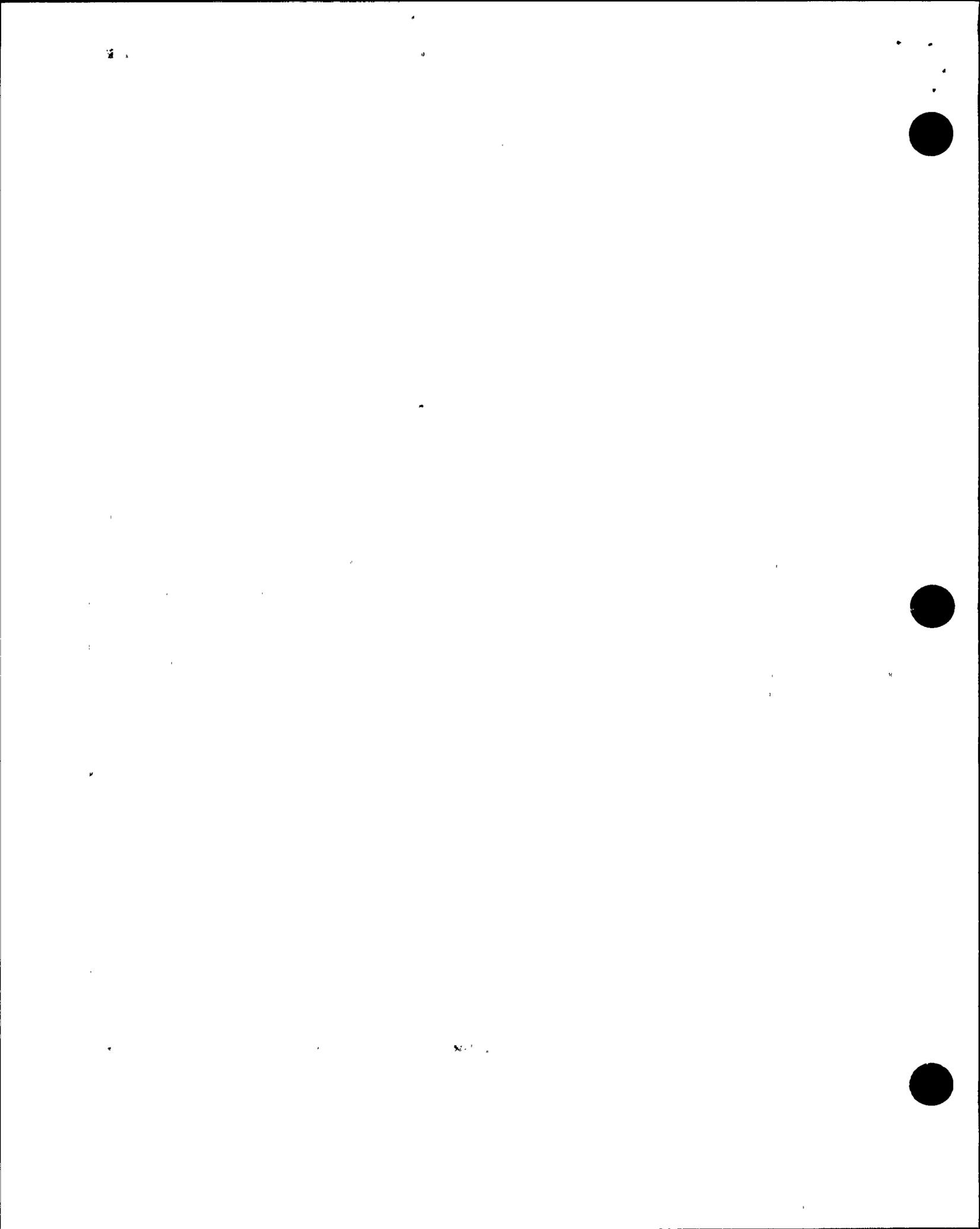
HISTORY OF MODE 2/MODE 3 OPERATION DCPP UNIT 1





FATIGUE CRACK GROWTH

- All Design and Operating Transients Considered
- Total Transient Cases About 30 - Same as Fatigue Analysis
- One Load Case: Large Bypass
- Two Locations: Bore Region
Nozzle Knuckle Face Region
- Two Fracture Analysis Approaches:
 - Raju Newman K Expression
 - BWR Nozzle Corner K Expression (Most Realistic Geometry)



CRACK GROWTH RESULTS

- Results: Nozzle Bore

Initial Flaw Depth	Flaw Depth in 4 Calendar Years	
	Raju Newman	Nozzle Knuckle
0.10	0.24	0.16
0.20	0.48	0.32

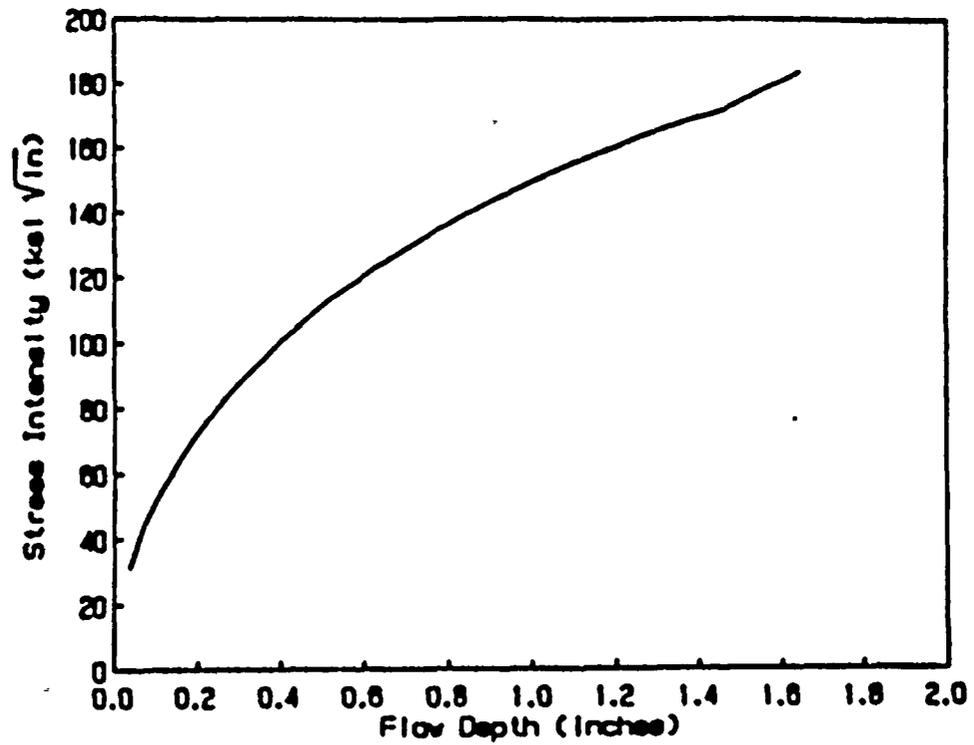
- Results: Nozzle Knuckle Face

0.10	0.23	0.16
0.20	0.46	0.32

Note: 4 Years Corresponds to Approximately 100 Days
at Mode 2/Mode 3

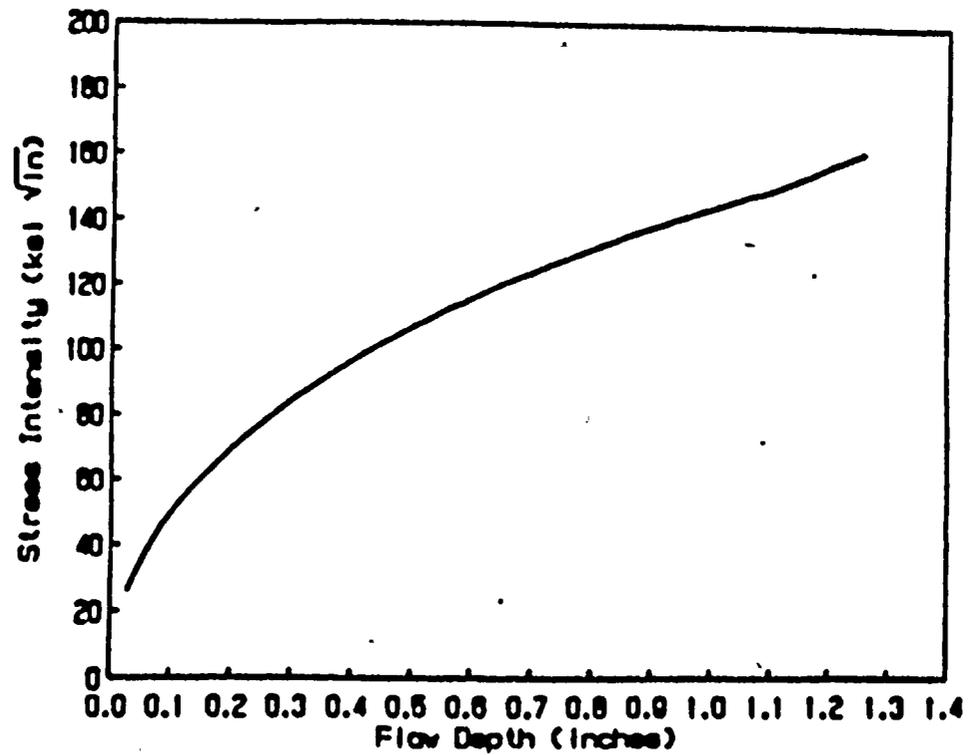


ALLOWABLE FLAW SIZE: FEEDWATER NOZZLE BORE





ALLOWABLE FLAW SIZE: FEEDWATER NOZZLE FACE



WHB16





CONCLUSIONS

- **Cracks in the Knuckle Region are not Predicted for Diablo Canyon**
 - **Fatigue Usage is Low**
 - **Severity of Thermal Stratification Loads is Much Less Than at the Plant Where Cracking Was Found**
 - **A Recent UT Inspection of One Nozzle Revealed no Cracking (2-15-91)**
- **Although Cracking is not Predicted, if Worst Case Cracks were to Exist in the Nozzle Region, the Predicted Size Would be Acceptable to Section XI**
- **Predicted Future Growth of Worst Case Cracks Was Found to be Relatively Small for a Future Service Period of 4 Years or 100 Days in Mode 2/Mode 3**
- **Therefore the Integrity of the Feedwater Nozzle Will be Maintained Through the Next Several Years of Service**



DIABLO CANYON POWER PLANT

Waterhammer

Mike Roidt
Westinghouse



WHAM1



WATERHAMMER

There are Two Ways of Developing Steam Void Collapse in the Horizontal Section of a Feedline

- **Isolation of a Steam Volume While Filling the Feedline with "Cold" Water**
- **Isolation of a Steam Volume While Draining a Feedline Filled with Cold Water**



Dwg. 7711A85

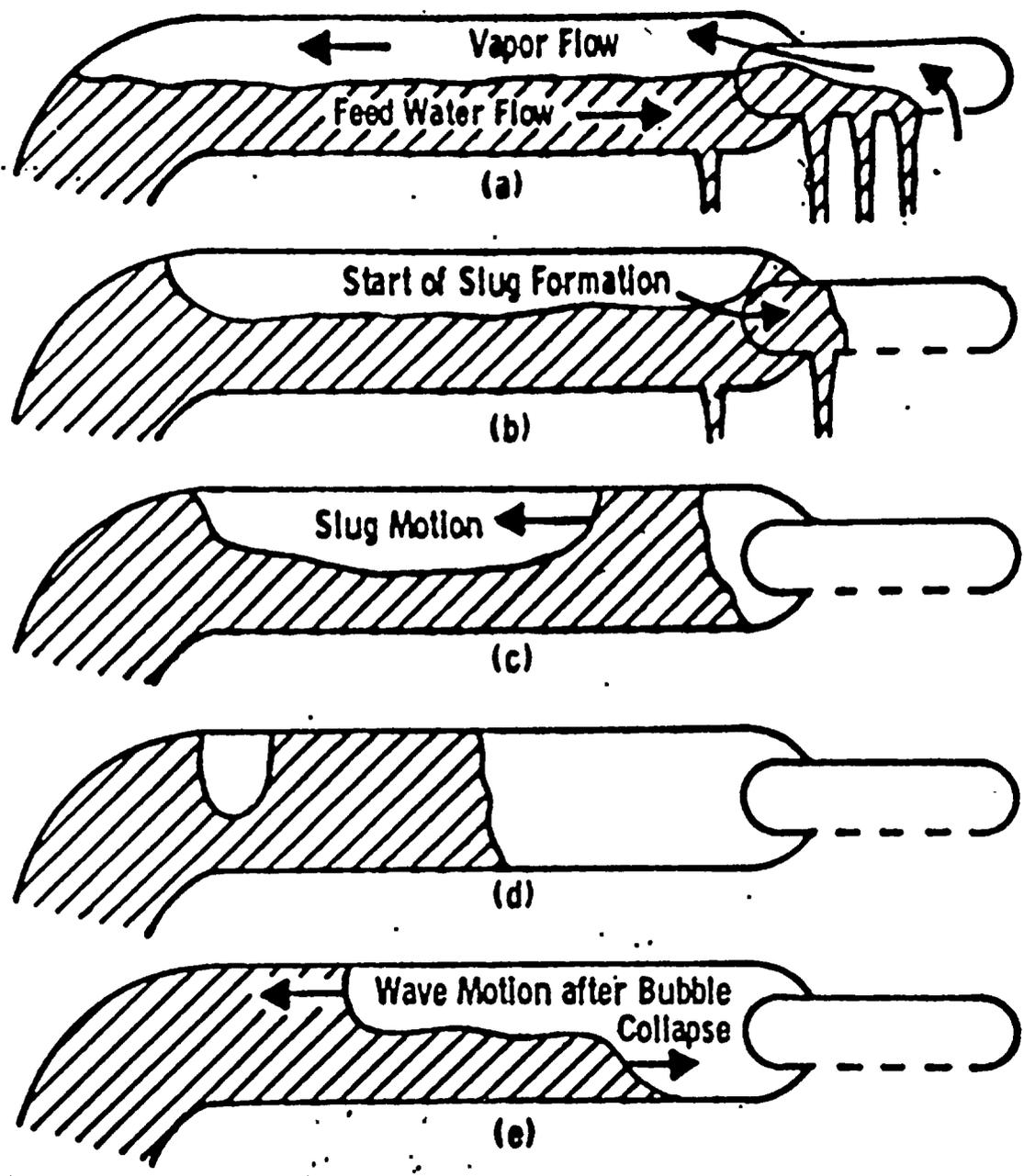
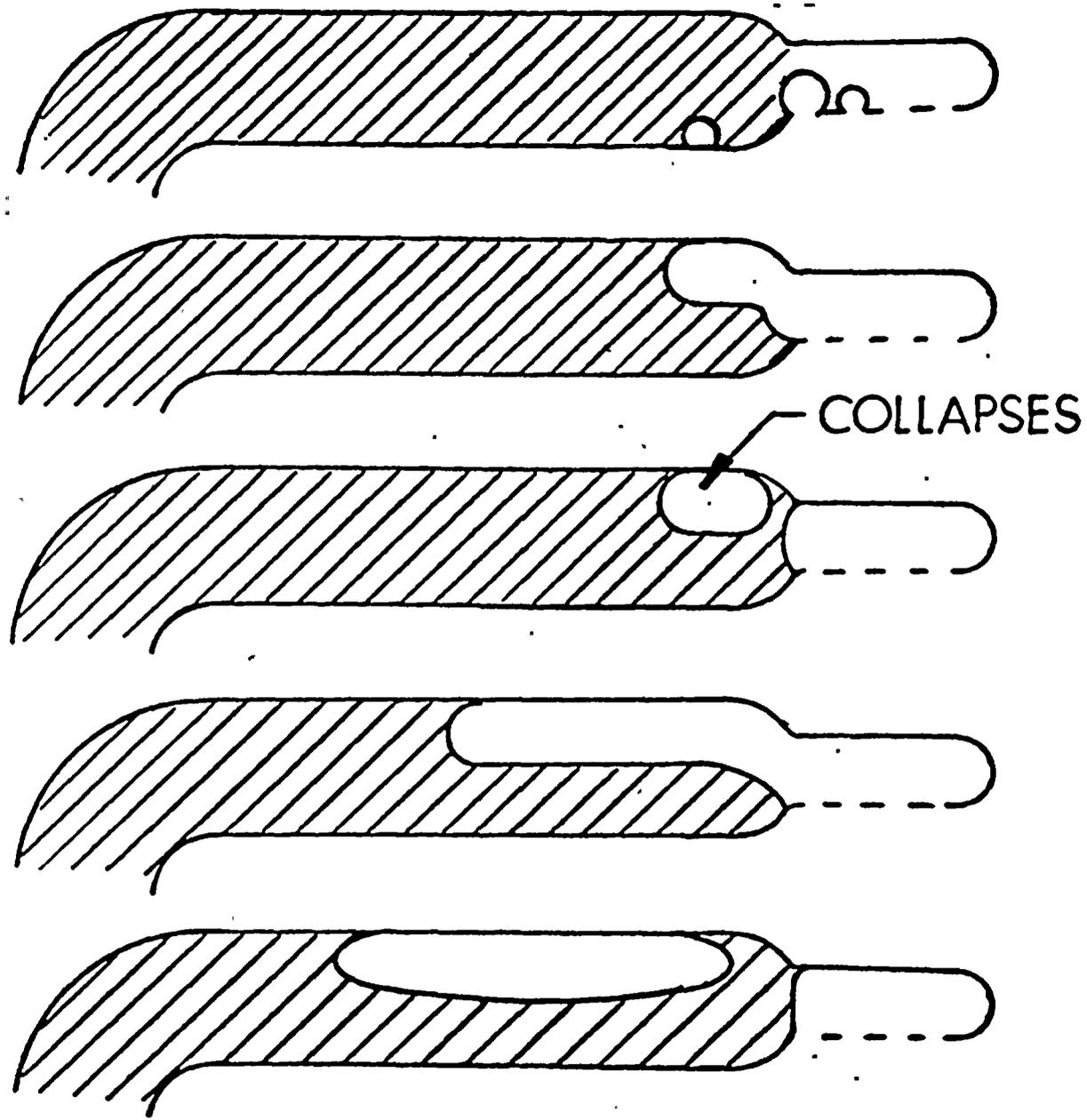
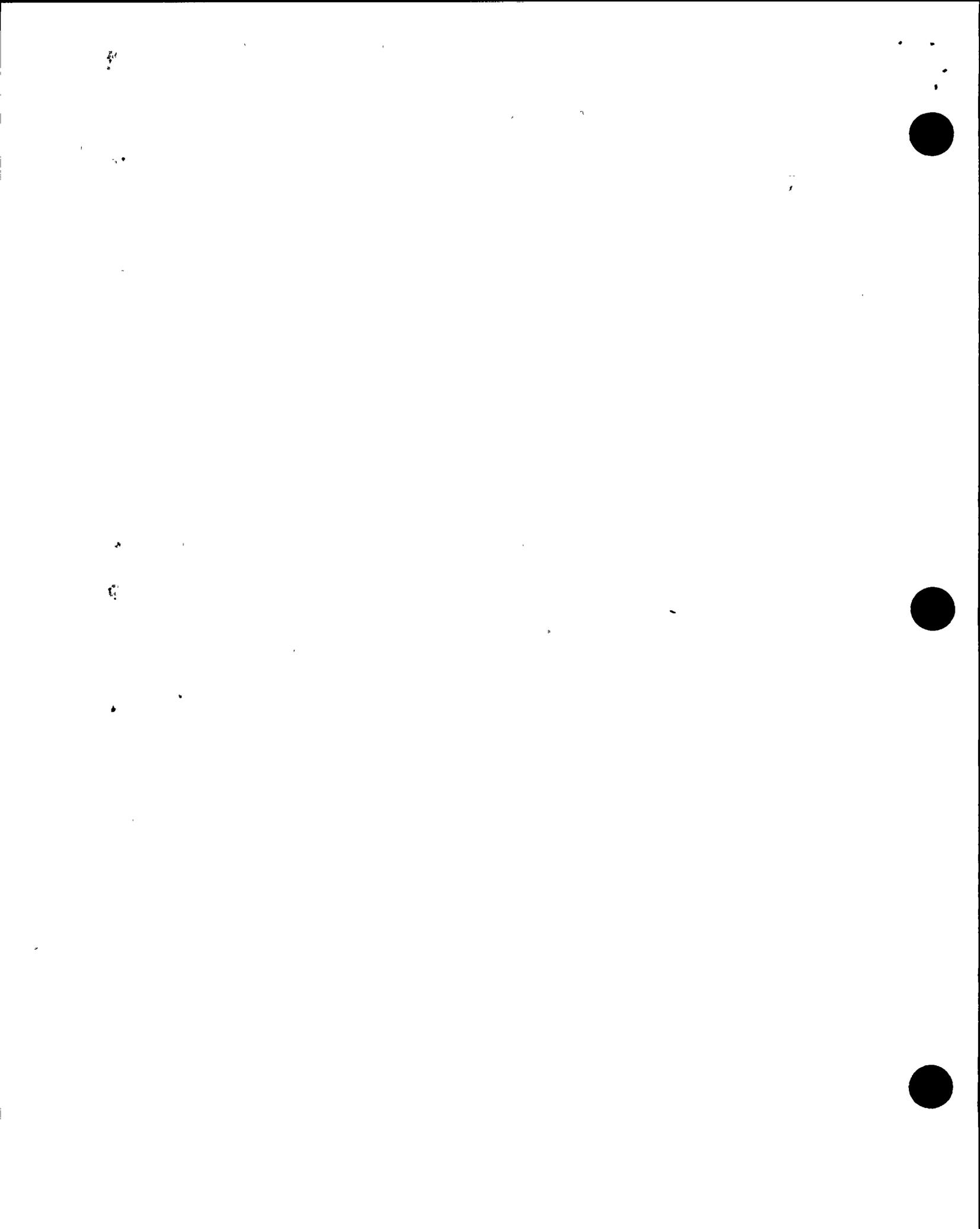


Fig. 9- Schematic representation of slugging mechanism .

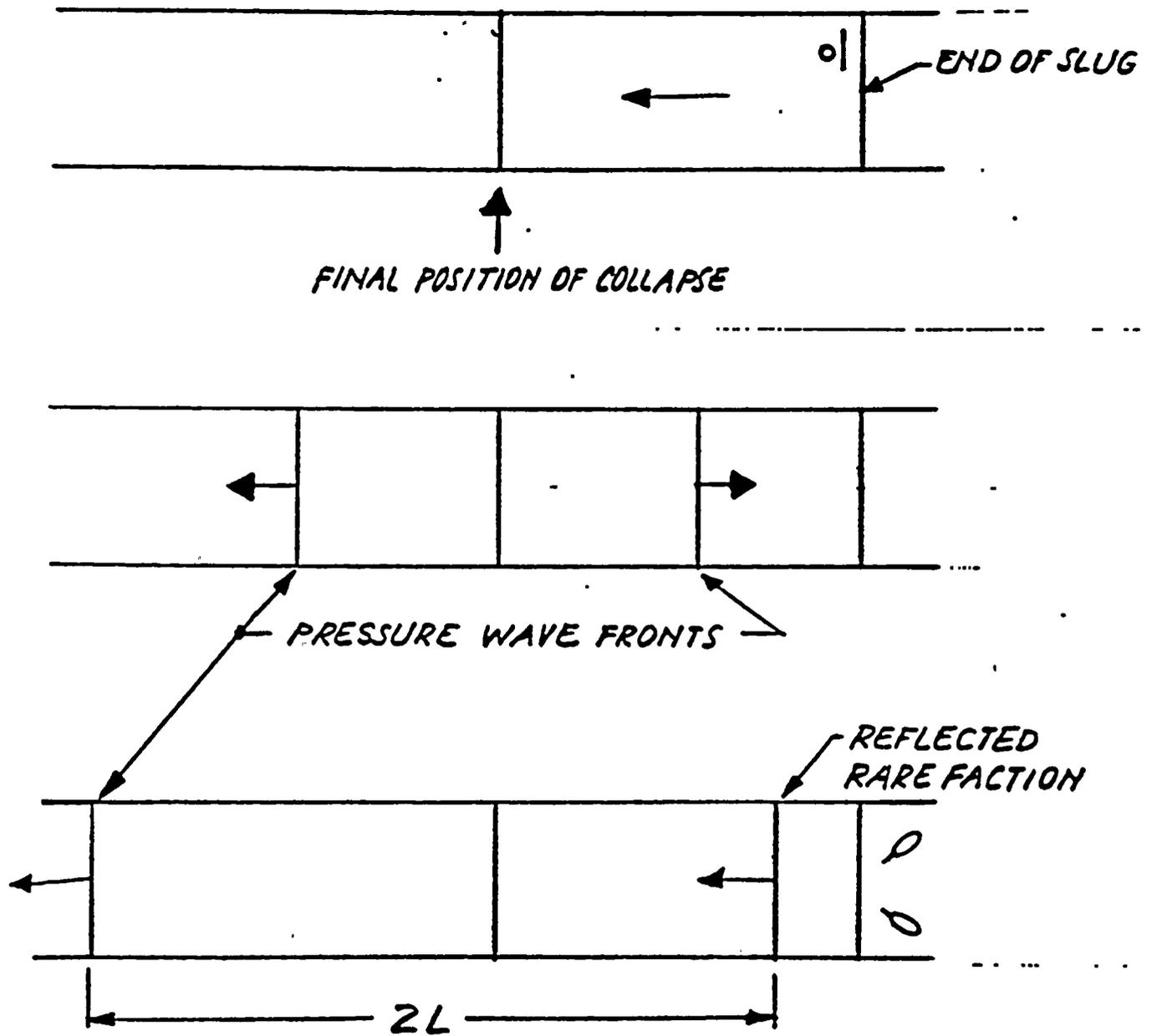




DRAINING A FEEDLINE FILLED WITH COLD WATER.



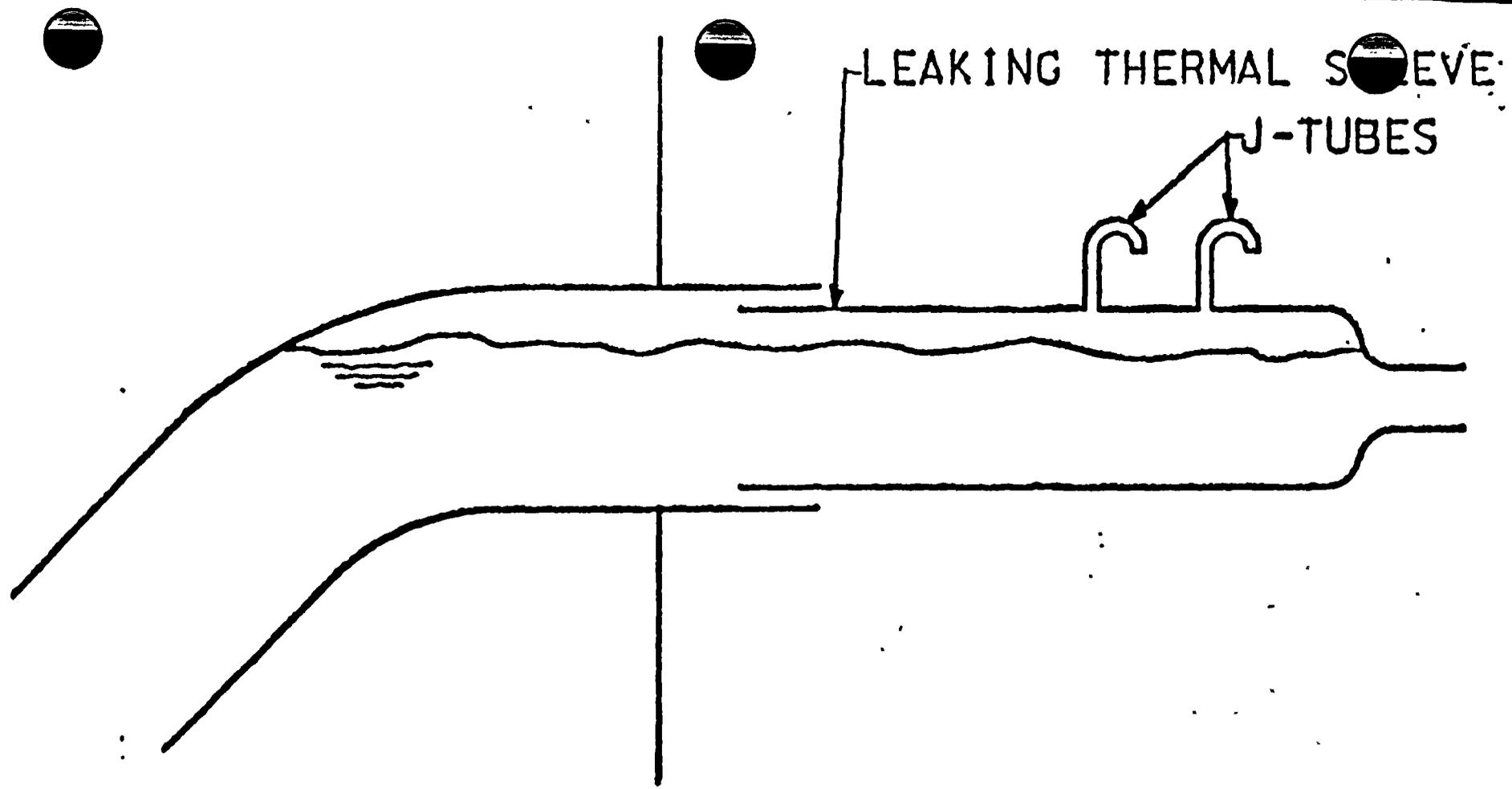
PHYSICS (APPROXIMATE) OF THE WATERHAMMER WAVE:





-
- Both Filling and Draining Configurations Require the Ability of the System to Isolate an Upper Section of Piping From the Steam Supply, the S/G
 - The Configuration at Diablo Canyon Does Not Lend Itself to Such Isolation





DIABLO CANYON LAYOUT



WATERHAMMER EVENTS CONSIDERED AT DIABLO CANYON

- **Waterhammer will Not Occur During Draining, Because, by Design the J Tubes and Thermal Sleeve Allow Steam to Replace the Water as the Feedline Drains**
- **Waterhammer is also Unlikely During Filling, Because of the J Tubes, but Cannot be Ruled Out, Because of the Possibility of Wave Action**
- **Therefore, the Cases of Waterhammer During Filling were Considered:**
 - **A Steam Volume Occupying 10% of the Pipe Cross-Section Extending from the Thermal Sleeve to the Elbows**
 - **A Steam Volume Occupying 10% of the Pipe Cross-Section Extending from the J Tube Nearest the Elbow to the Elbow**



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L ▪ Initial Length of the Isolated Steam Volume

C ▪ Acoustic Speed in Water

ΔP ▪ S/G Pressure - Feedwater Vapor Pressure

ρ ▪ Water Density

G ▪ Gravitational Constant

A ▪ Pipe Cross-Section Area

f ▪ Fraction of Pipe Cross-Section
Occupied by Steam Volume

Length of Pressure Wave ▪ $2L$

Duration of Pressure Wave ▪ $\frac{2L}{C}$

Increase in Pressure Across Wave ▪ $C \sqrt{\frac{\rho \Delta P}{2g}}$

Kinetic Energy in Wave ▪ K.E. ▪ $fL \Delta P A$





CONCLUSION

- **A Steam Volume Collapse Waterhammer is Extremely Unlikely at Diablo Canyon, Because of the Geometry**
- **Plant Inspections Indicate no Evidence of Waterhammer to Date**
- **In the Unlikely Event of an Occurrence, there Would be Insufficient Energy to Seriously Affect the Piping System**





DCPP EXPERIENCE

- **No Reports or Evidence of MFW Waterhammer**
- **No Evidence of FW System Support Damage**
 - **Walkdowns**
 - **Snubber Stroking**





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CONCLUSIONS

- DCPD Design of the Feeding is to Preclude and Minimize Effects of Waterhammer
 - Eroded Thermal Sleeve May Increase the Probability of a Waterhammer, but Also Acts to Decrease its Severity
 - Improbable Event
 - Waterhammer Effects are not Expected to Affect the Integrity of the DCPD Feedwater Line
 - Experience of a Hammer at Trojan, with an Eroded Sleeve, and Crack About 40% Through the Wall Did Not Affect the Pipe Integrity.
 - Over Twenty Waterhammers at Other Plants Have Been Experienced in Feedwater Lines, with Only One Failure. Calculated Kinetic Energy For This Case Was More than an Order of Magnitude Higher than for DCPD.
-





DIABLO CANYON POWER PLANT

Long Term Plans

Henry Thailer
Assistant Project Engineer

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2
3



PLANT MONITORING

- Install RTD Instrumentation
- Install Scratch Gages
- Software/Hardware
- On-Line Monitoring
- Data Evaluation
- Review Correlation Between Algorithm & Operating Data





INSPECTION PLAN

- **Factor in Lessons Learned from 1R5**
- **UT Every Outage Until Permanent Fix is Installed**
- **Baseline Permanent Fix After Installation**





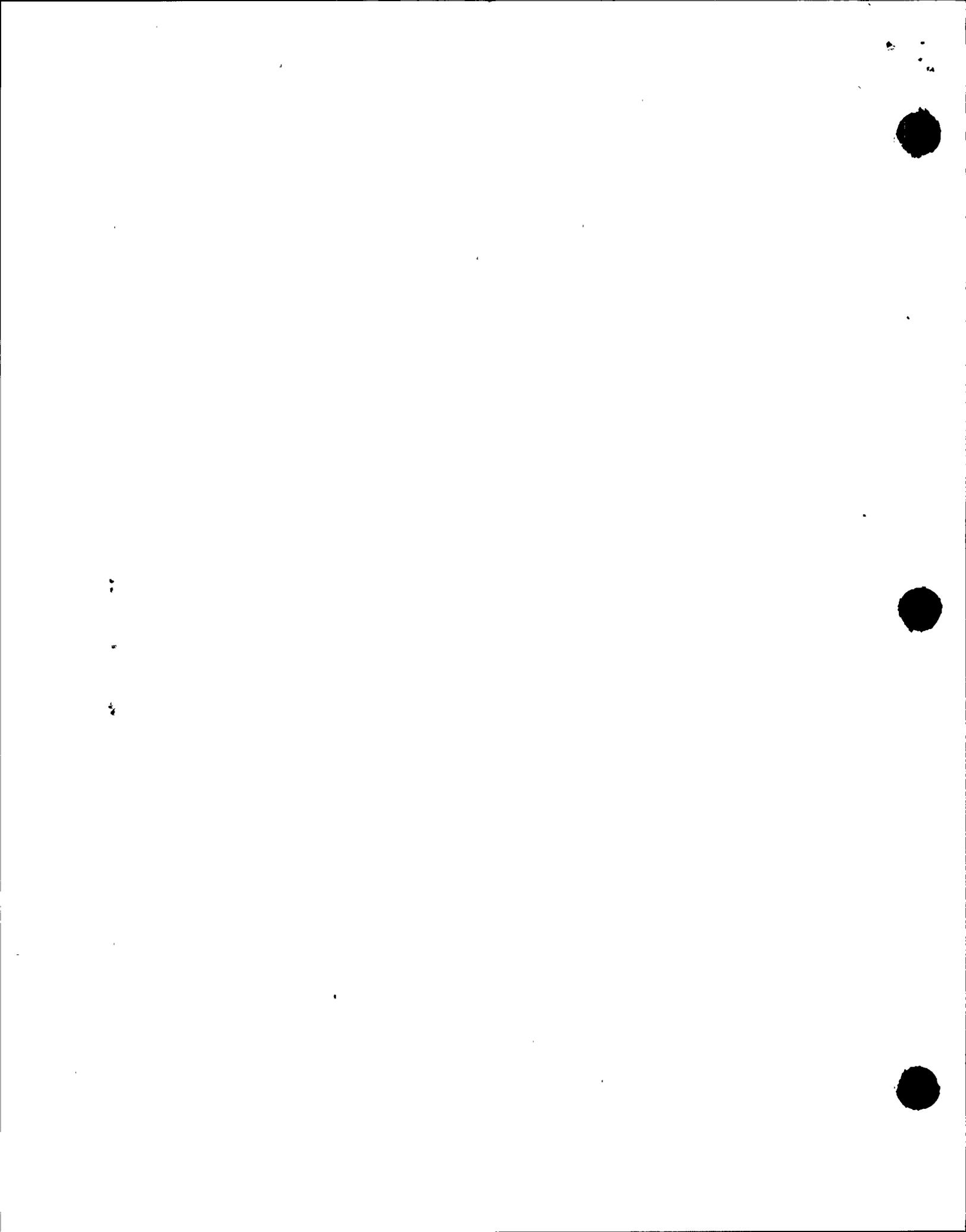
LONG-TERM OPTIONS

- **Pipe**
 - Monitor & Replace
 - Alternate Materials
 - Thermal Sleeve

- **Nozzle/Thermal Sleeve**
 - Replace
 - Westinghouse Elbow Liner Design
 - Altran Seal Design
 - SIA Seal Design
 - Flame Spray

- **Evaluate/Modify Operating Procedures**
 - Minimize Time in AFW
 - Reduce Cycling When in AFW
 - Digital AFW Control





THERMAL LINER ASSEMBLY

