TOLEDO EDISON
A Centerior Energy Company

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Docket Number 50-346

License Number NPF-3

Serial Number 1808

May 25, 1990

United States Nuclear Regulatory Commission
Document Control Desk
Washington, D. C. 20555

Subject: High Pressure Injection/Makeup Nozzle and Thermal Sleeve Program
Davis-Besse Nuclear Power Station Unit 1

On May 10, 1990, Toledo Edison and Toledo Edison's consultants, Babcock and Wilcox Nuclear Service Company (BWNS) and Structural Integrity Associates (SIA), met with the NRC Staff in Rockville, MD. The purpose of the meeting was to discuss Toledo Edison's May 3, 1990 letter (Serial Number 1802) to the NRC which provided the status of the HPI/Makeup nozzle program and requested NRC approval for plant operation in Cycle 7 and subsequent cycles. A list of attendees and a copy of the meeting handout are attached (Attachments 1 and 2).

Toledo Edison had requested this meeting to address any Staff questions regarding the actions taken during the sixth refueling outage (6RFO) resulting from the discovery of the failed HPI/Makeup nozzle thermal sleeve during the fifth refueling outage (5RFO). Toledo Edison's May 3, 1990 letter (Serial Number 1802) to the NRC summarized the background and previous Toledo Edison/NRC correspondence relating to this subject.

The 6RFO actions discussed at the meeting included: 1) Re-routing of the normal makeup flow path from HPI nozzle A1 to HPI nozzle A2; 2) Enhanced ultrasonic (UT) examination of HPI nozzles A1 and A2; 3) Visual examination of the thermal sleeve installed in HPI nozzle A1 (the former makeup flow path); and, 4) Updated fracture mechanics analysis of HPI nozzle A1. Future plans for enhanced UT of nozzle A1 and for continued investigation of mechanisms which affect thermal sleeve life were also discussed.

Staff interest focused on thermal sleeve life in makeup service and the fracture mechanics model used to determine limiting flaw size for brittle fracture in the updated fracture mechanics analysis. The Staff accepted the conclusion that the thermal sleeve effectively protects the HPI/Makeup nozzle from cold water induced thermal fatigue cracking. Consequently, the assurance of long term thermal sleeve integrity is a matter of continuing importance.



A001
1/1

The improvements made in makeup flow control described in Toledo Edison's September 14, 1988 letter to the NRC (Serial Number 1580) provide assurance that thermal sleeve life in makeup service is greater than the four operating cycles experienced by the original thermal sleeve. Minimum bypass makeup flow through a line bypassing the makeup flow control valve was increased to between 11 and 15 gallons per minute (gpm). Procedures govern setting of the minimum bypass makeup flow. The flow is initially set when the makeup system is started. Procedures require verification that the flow remains within this range during plant startup when reactor coolant system (RCS) pressure is at approximately 500 psi, 1000 psi, 1500 psi, and again at normal RCS operating pressure. Surveillance procedures require monthly verification of minimum bypass flow in conjunction with makeup pump surveillance testing.

By letter dated May 3, 1990 (Serial Number 1802) Toledo Edison stated its plans to continue to investigate mechanisms which affect thermal sleeve life, and evaluate alternatives which might be pursued to ensure long-term reliable operation. Toledo Edison's goal is to arrive at a practical basis for long term operation. The Staff indicated that they wished to be informed of the plans, schedule and results of activities by Toledo Edison related to the thermal sleeve lifetime issue. Toledo Edison expects to provide details of the plans to the NRC within approximately six months after restart from the 6RFO. As requested by the Staff, these plans will address any related needs for inservice inspection of the HPI/Makeup nozzle A2.

The second topic discussed at length at the meeting was the fracture mechanics model used to determine the limiting flaw size for brittle fracture. The results of three fracture mechanics analyses of the HPI nozzle which were submitted to the NRC by Toledo Edison's letters dated September 14, 1988 (Serial Number 1580), November 8, 1989 (Serial Number 1726) and May 3, 1990 (Serial Number 1802), were reviewed at the meeting. The earliest analysis, which was performed during the 5RFO after discovery of the failed thermal sleeve, was intentionally based on a conservative simplified model (single edge cracked plate) in order to support restart of the plant. The single edge cracked plate (SECP) model is conservative, but not geometrically representative of the nozzle configuration. Use of the SECP model resulted in an ASME Section XI allowable flaw size for brittle fracture prevention of 0.5 inch.

A second fracture mechanics analysis was performed in support of Toledo Edison's request (Serial Number 1726 dated November 8, 1989) for NRC approval of weld overlay repair of the HPI/makeup nozzle (A1), had the enhanced UT indicated that repair was necessary. This analysis used SIA's **pc-CRACK** code nozzle corner flaw model which is directly applicable to the actual configuration of the HPI nozzle. The ASME Section XI allowable flaw depth for brittle fracture prevention using this model is essentially through-wall indicating that brittle fracture is not a concern. The pc-CRACK nozzle corner flaw model has been verified and found to be highly accurate with respect to experimental results of a study of pressure vessels containing nozzle corner flaws. Two papers which support this conclusion, "Fracture Mechanics Analysis of Japan Atomic Energy Research Institute (JAERI) Model Pressure Vessel Test," and "Fatigue Behavior of Nozzles of Light Water Reactor Pressure Vessel Model," were included as Attachments 3 and 4 to Toledo Edison's February 20, 1990 letter to the NRC (Serial Number 1768).

The most recent analysis presented in Serial Number 1802 is an update to reflect the HPI-only duty of nozzle A1, thicker cladding, a sharper inside blend radius, and assumption of a conservative initial flaw depth consistent with the enhanced UT system detection capabilities. This analysis also used the **pc-CRACK** nozzle corner flaw model and concluded that brittle fracture is still not a concern.

At the May 10, 1990 meeting, the Staff questioned the degree of conservatism afforded by the **pc-CRACK** nozzle corner flaw model. The Staff suggested augmenting the analysis by using a crack emanating radially from a hole in an infinite plate model which is more conservative than the **pc-CRACK** corner flaw model, but is more representative of the configuration than the SECP model. The staff indicated that the use of this model would provide adequate additional assurance of nozzle integrity.

Toledo Edison believes that the **pc-CRACK** corner flaw model most accurately represents the nozzle configuration, is experimentally validated and is appropriately conservative. However, Toledo Edison will perform an additional analysis to provide information on the sensitivity of the results to a more conservative model. The configuration will be modeled as a crack emanating radially from a hole in an infinite plate. The results of this additional analysis will be submitted to the NRC approximately two months after restart from the 6RFO.

In summary, Toledo Edison has taken actions which have comprehensively addressed the HPI/Makeup nozzle thermal sleeve failure discovered during the fifth refueling outage. Toledo Edison considers that there are no additional activities which must be completed prior to restart from the 6RFO and intends to proceed on this basis. The additional follow-up activities described in this letter will be accomplished, after restart as noted above.

Should you have any questions concerning this matter, please contact Mr. R. W. Schrauder, Manager-Nuclear Licensing, at (419) 249-2366.

Very truly yours,

PWS

Attachment

cc: P. M. Byron, DB-1 NRC Senior Resident Inspector
A. B. Davis, Regional Administrator, NRC Region III
T. V. Wambach, DB-1 NRC Senior Project Manager.

DZ B/85

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Attachment 1

May 10, 1990 Meeting on HPI Nozzle Inspection

| Name | Affiliation |
|---|---|
| Thomas V. Wambach | NRR/PDIII-3 |
| Lynn Connor | SAIC |
| John Nevshemal | Toledo Edison |
| Peter Riccardella | Structural Integrity Assoc. |
| Mike Hacker | B&W Nuclear Service Co. |
| Michael Shepherd | Toledo Edison |
| F. B. Litton | NRR/MIEB |
| S. Lee | NRR/EMCB |
| Keith Wichman | NRR/EMCB |
| Peter Smith | Toledo Edison |
| Robert Hermann | NRR/EMCB |
| H. J. Cordle | Toledo Edison |

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Attachment 2

DAVIS-BESSE NUCLEAR POWER STATION, UNIT 1

# HPI/MAKEUP NOZZLE PROGRAM

PRESENTED TO

NUCLEAR REGULATORY COMMISSION

MAY 10, 1990

BY

TOLEDO EDISON COMPANY

B&W NUCLEAR SERVICE COMPANY

STRUCTURAL INTEGRITY ASSOCIATES

# OBJECTIVES

- To Review Actions Taken in 6RFO to Address the Consequences of Failed Thermal Sleeve Discovered in 5RFO

- To Support NRC Approval of Operation for Fuel Cycle 7 and Beyond

# AGENDA

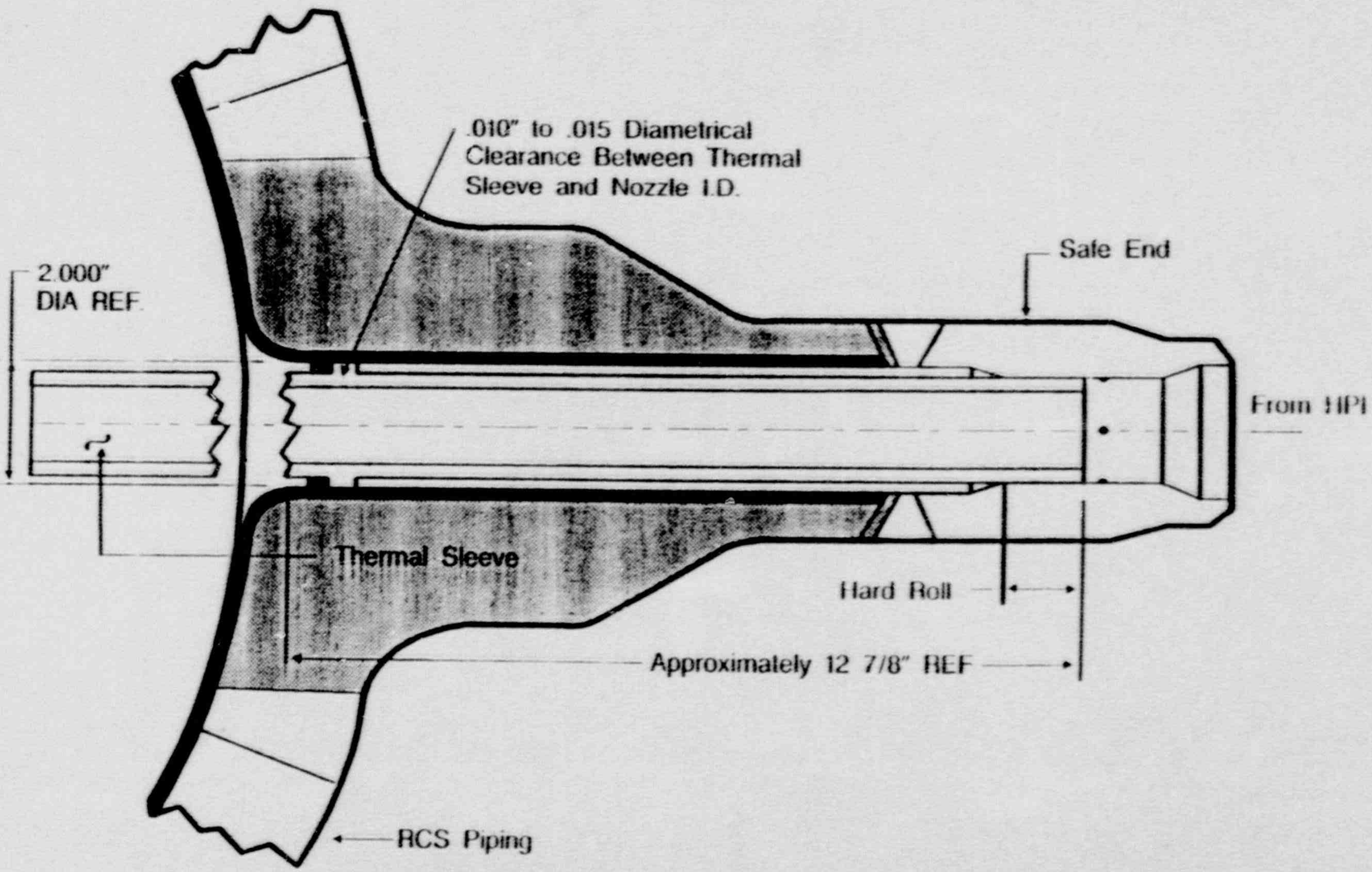
| | |
|---|---|
| •INTRODUCTION | P. SMITH |
| •SUMMARY OF ACTIONS - 6RFO | H. CORDLE |
| •ENHANCED UT | M. SHEPHERD / M. HACKER |
| •FRACTURE MECHANICS UPDATE | J. NEVSHEMAL / P. RICCARDELLA |

FUTURE ACTIONS & CONCLUSIONS

# BACKGROUND

- HPI/Makeup Nozzle Thermal Sleeve Failure Discovered During 5RFO
    - Failure Occured During Fifth Cycle of Operation
- Two Pieces From Discharge End Found Below Reactor Core
- Failure Attributed to Thermal Fatigue
- Failure Exposed End of Nozzle to Cold Makeup Water
- Dye Penetrant Examination Indications Seen in Exposed Area of Nozzle During 5RFO
- No Indications of Flaws Found With External Manual Ultrasonic Examination
- Conservative Fracture Mechanics Analysis Showed Potential Flaw Growth With Thermal Sleeve in Place to be Acceptable

# Makeup/HPI Nozzle Original Thermal Sleeve Design



# 5RFO ACTIONS

- Replacement of Thermal Sleeves
  - HPI/Makeup Nozzle A1
  - HPI Nozzle A2
- Increased Continuous Minimum Makeup Flow
- Made Provisions for Accurate Setting of Minimum Flow
- Improved Control Over Minimum Makeup Flow
- Conservative Analysis Demostrates Nozzle Flaw Growth to be Within Acceptable Limits for Additional 40 Years Operation With Thermal Sleeve in Place
- Toledo Edison Committed to Identify Additional Actions to be Taken During 6RFO
- NRC Approved Operation for Cycle 6 (LOG 2725, OCTOBER 4, 1988)

# PLANNED 6RFO ACTIONS

- Re-route the Makeup Flow Path to HPI Nozzle, A2

- Fiberoptic Examination of HPI/Makeup Thermal Sleeve

- Enhanced UT of the HPI/Makeup Nozzle (A1) From the Outside

- Enhanced UT of Alternate Nozzle (A2) to Provide Baseline Information

- Contingency Plans

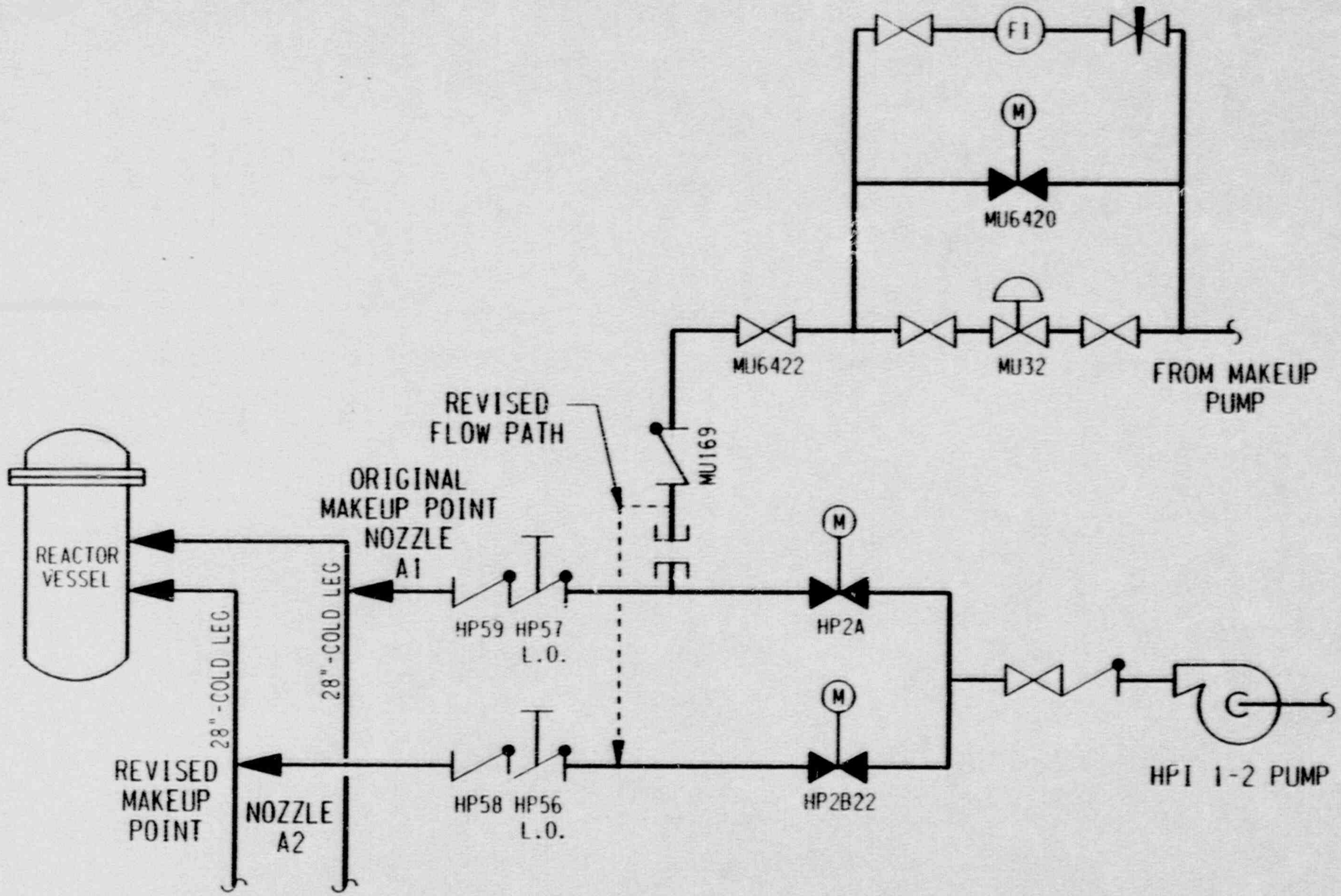
    - Weld Overlay Reinforcement

    - Thermal Sleeve Replacement

# 6RFO STATUS

- Plant Off-line on January 26, 1990 for Planned Four Month Outage
- Nozzle (UT) and Thermal Sleeve (VT) Inspection Complete
- Reroute of Makeup Line Complete
- Fuel Reloaded
- Currently In Mode 5
- Anticipate Mode 4 by May 30, 1990

# MU/HPI FLOW CONFIGURATION



# NORMAL MAKEUP FLOW PATH RE-ROUTED TO NOZZLE A2

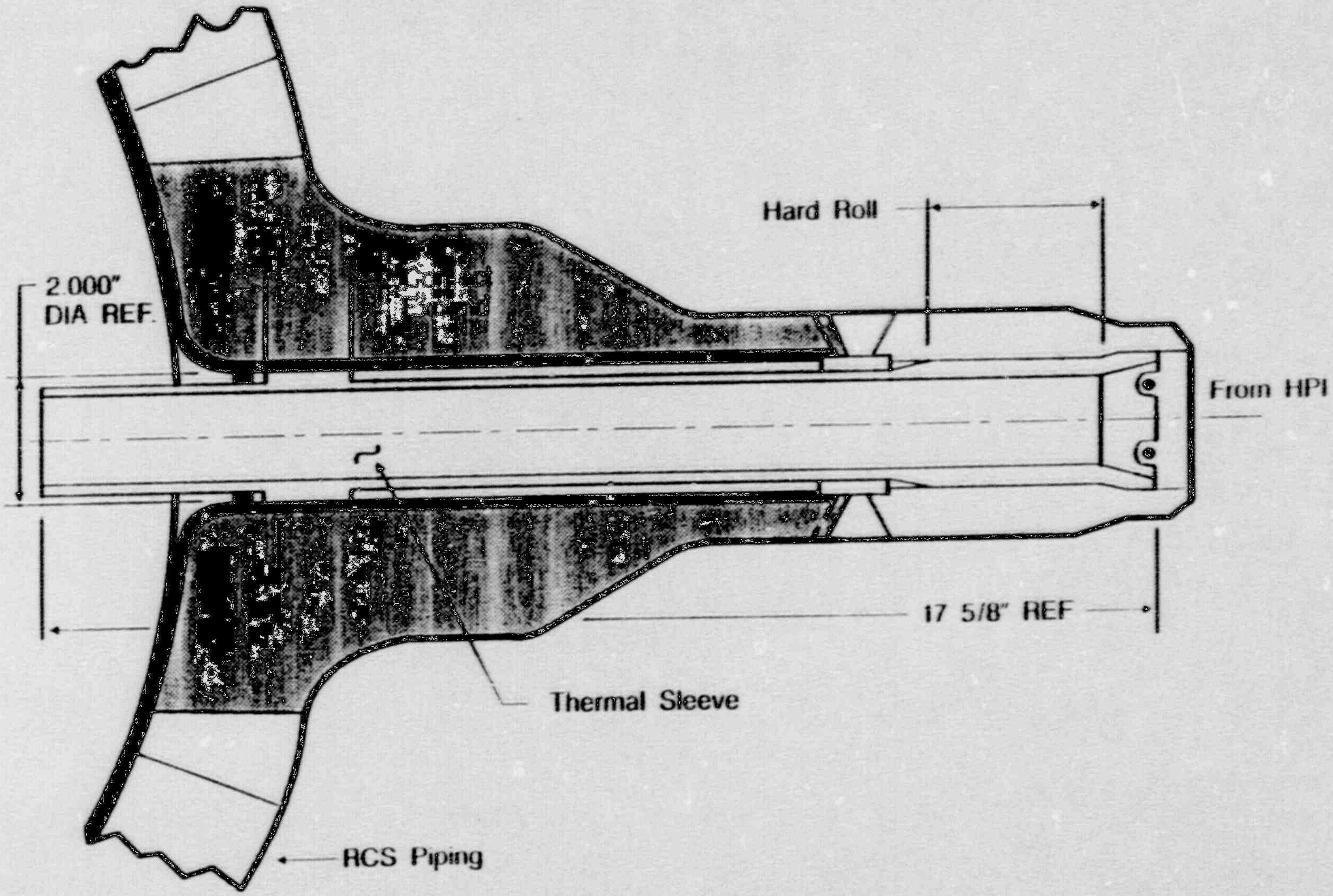
- Removes Exposure of Former HPI/Makeup Nozzle to Potential Fatigue Effect of Cold Makeup Water

- HPI Nozzle A2 Has No History of Makeup Flow Exposure

# VISUAL EXAMINATION REVEALS THERMAL SLEEVE IS ACCEPTABLE

- Fiberoptic Visual Examination Was Performed
- No Service-Induced Indications Were Found
- Observations Included Only
  - Shallow Scratches From Insertion of Camera or Tubing
  - Marks Due to Rolling Process at Installation of Sleeve
- Sleeve Was Determined Acceptable for Further Unrestricted Use in Intended Service

# Makeup/HPI Nozzle Replacement Thermal Sleeve Design



# ENHANCED ULTRASONIC EXAMINATION OF HPI/MAKEUP NOZZLE

Development and Inspection By B&W Nuclear Service Company

## RESULTS

- Development Program Proved the Methodology
  - Examination From Outside the Nozzle
  - Reliable Detection of Flaws Extending >1/8 Inch Into Nozzle Base Material
- No Service Induced Flaws Were Detected
  - Penetrating Into Base Metal
  - In Cladding
- Flaws Identified By PT During 5th RFO Are Probably Contained Within the Cladding

# FRACTURE MECHANICS ANALYSIS CONFIRMS EXISTING LARGE MARGINS

STRUCTURAL INTEGRITY ASSOCIATES (SIA) PERFORMED UPDATED FRACTURE MECHANICS ANALYSIS

RESULTS

- Finite Element Analysis Shows Section XI Allowable Flaw Size to be Through-Wall
- Large Margins to ASME Section III Structural Reinforcement Requirements
- Flaw Growth Analysis for Former HPI/Makeup Nozzle A1
  - Initial Flaw Size Was Conservatively Assumed At the Limit of Enhanced UT Resolution (Penetration 1/8 Inch Into Base Metal)
  - Potential Flaw Growth For Additional 40 Years < 20 Mils

# HPI

## DEVELOPMENT PROGRAM ACHIEVEMENTS

DESCRIPTION OF METHODOLOGY

Automated Capability

- ACCUSONEX$^R$
    - Provides automatic collection of UT data and imaging capability for analysis.
- PUMA Robot
    - Provides automated scanning of complex nozzle geometry.
- UT Techniques
    - Techniques were developed using various combinations of transducer angles and scan patterns to assure reliable flaw detection.
    - Detection and sizing capabilities have been quantified.

# DEVELOPED CAPABILITY

Battelle Blocks

- 100% detection of flaws.
- No flaws were called in non-flawed areas.

EPRI Blocks

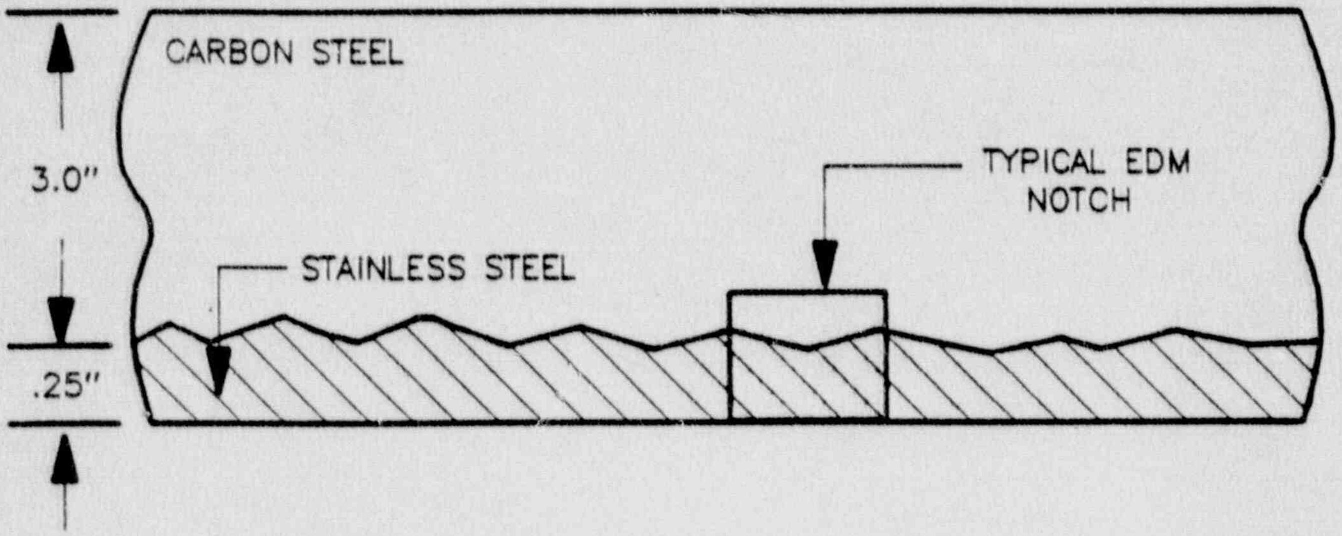
- 100% detection of flaws.
- No flaws were called in non-flawed areas.
- Flaw tips were detected better with shear waves.

HPI Mockup

- All flaws penetrating greater than 0.100" into the base metal were detected.
- No flaws were called in non-flawed areas.
- Three of the flaws contained entirely within the clad were detected.

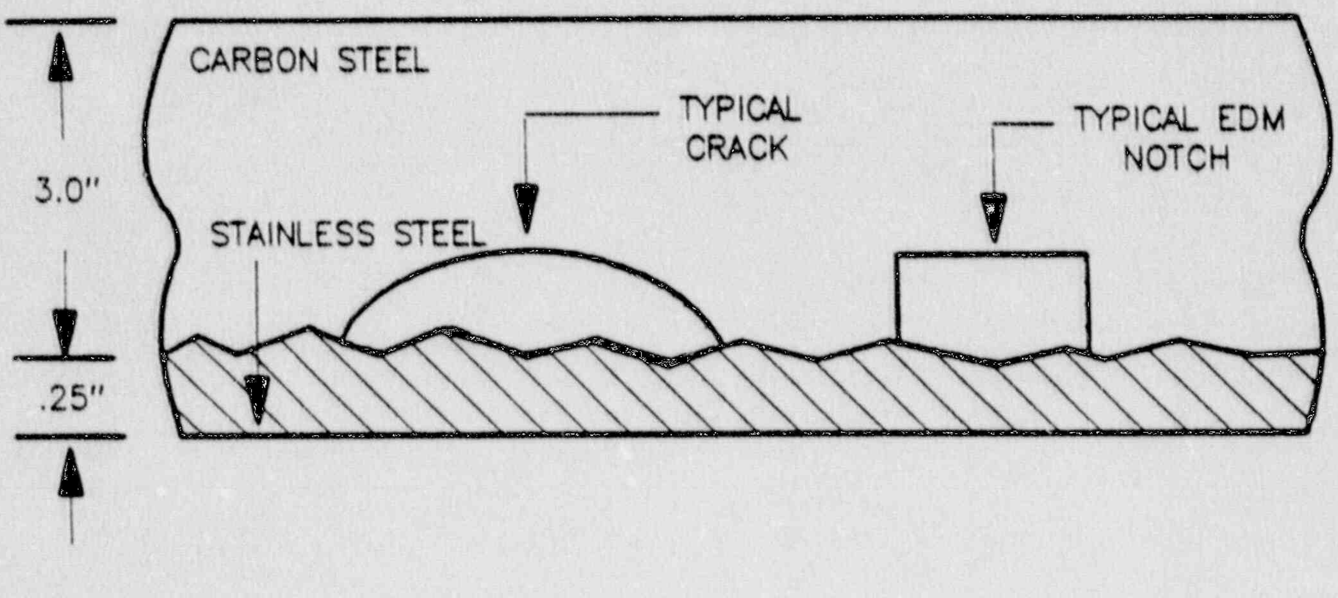
BWNS TEST BLOCK

- DEVELOP DETECTION TECHNIQUE
- DEVELOP SIZING TECHNIQUE
- DEFINE TRANSDUCER PARAMETERS
- DETERMINE DETECTABILITY AS A FUNCTION OF FLAW ORIENTATION



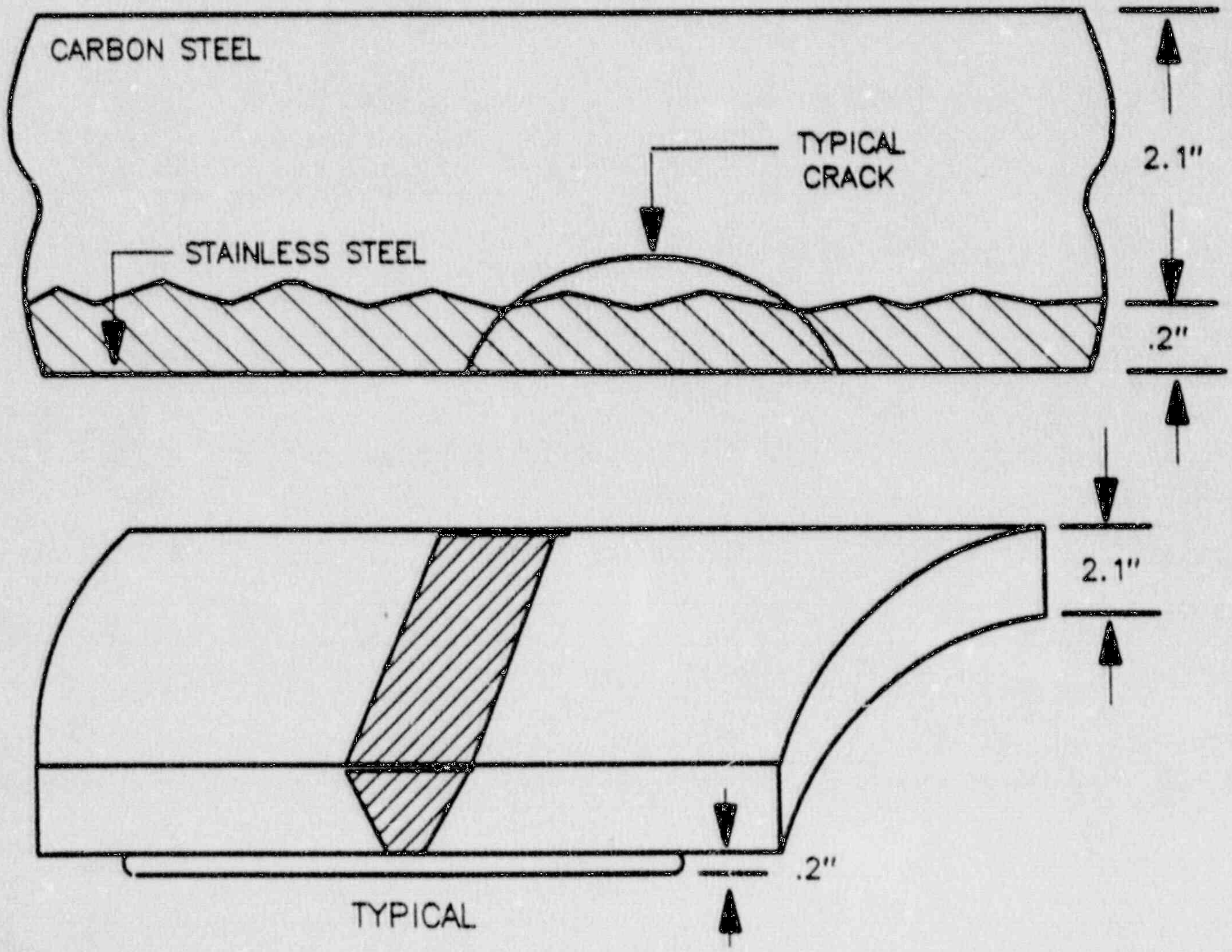
## EPRI NEAR SURFACE TEST BLOCKS (2)

- "FINE TUNE" DETECTION/SIZING TECHNIQUES
- DETERMINE DETECTION PROBABILITIES
- DETERMINE FALSE CALL PROBABILITIES
- DETERMINE SIZING ACCURACY



## BATTELLE PIPING TEST BLOCKS

- DETERMINE DETECTION PROBABILITIES
- DETERMINE FALSE CALL PROBABILITIES
- DETERMINE SIZING ACCURACY

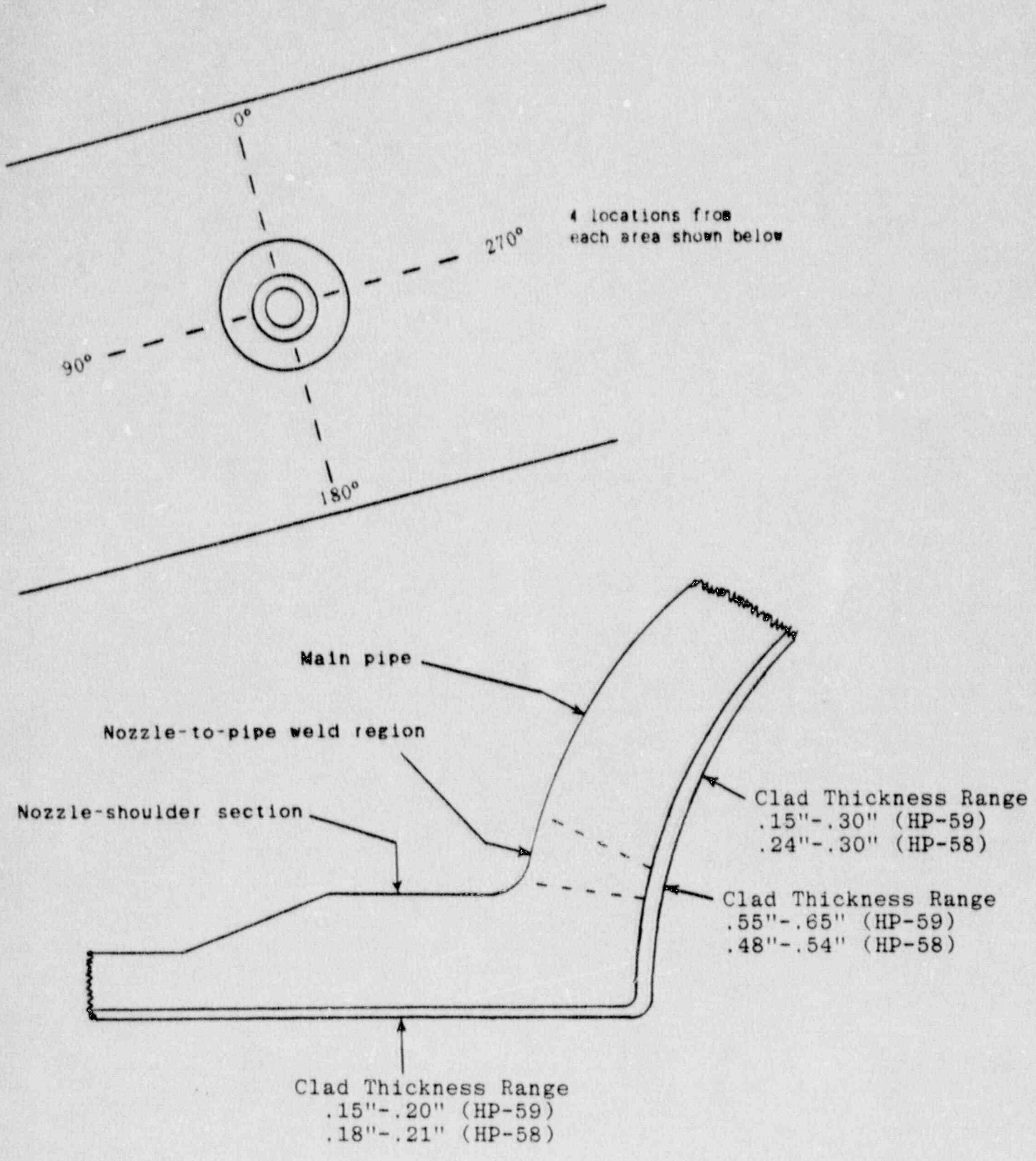


SUMMARY OF EXAMINATIONS

HP-59 (NOZZLE A1)

- No service induced flaws detected.
- Small volumetric inclusions were detected in nozzle to pipe weld.
- o Three were recordable (>20% DAC) to ASME standards-all acceptable.
- Base metal and clad thickness measurements were performed.

LOCATIONS FOR THICKNESS MEASUREMENTS



SUMMARY OF EXAMINATIONS

HP-58 (NOZZLE A2)

- No service induced flaws detected.
- Small volumetric inclusions were detected in nozzle to pipe weld.
  - o Four were recordable (>20% DAC) to ASME standards- all acceptable.
- Base metal and clad thickness measurements were performed.

# DAVIS-BESSE HPI/MAKEUP NOZZLE

## SUMMARY OF FRACTURE MECHANICS ANALYSES PERFORMED

- ORIGINAL ANALYSIS BY B&W DURING 5RFO

- UPDATED ANALYSES BY SI
  - In Support of Contingency Planning for 6RFO*
  - Nozzle Reinforcement Evaluation*
  - Revised to Reflect New Cladding Geometry During 6RFO

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* *previously presented - 1/24/90*



STRUCTURAL INTEGRITY ASSOCIATES, INC.

# ORIGINAL F.M. ANALYSIS BY B&W DURING 5RFO

- USED SINGLE EDGE CRACKED PLATE FRACTURE MECHANICS MODEL (SECP)

- PURPOSE - TO DEMONSTRATE THAT CLAD DEPTH FLAWS ARE ACCEPTABLE

- RESULTS:

  - Section XI Allowable Flaw Size > 0.5"

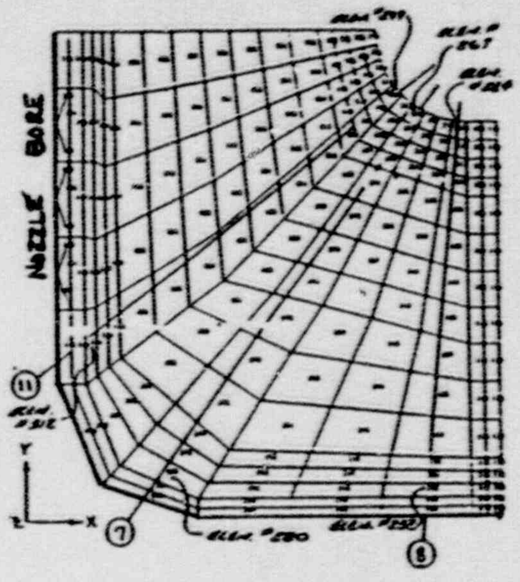
  - Not Exceeded by Expected Growth of Clad Depth Flaw (0.050")

# F.M. ANALYSIS BY SI IN SUPPORT OF CONTINGENCY PLANNING FOR 6RFO

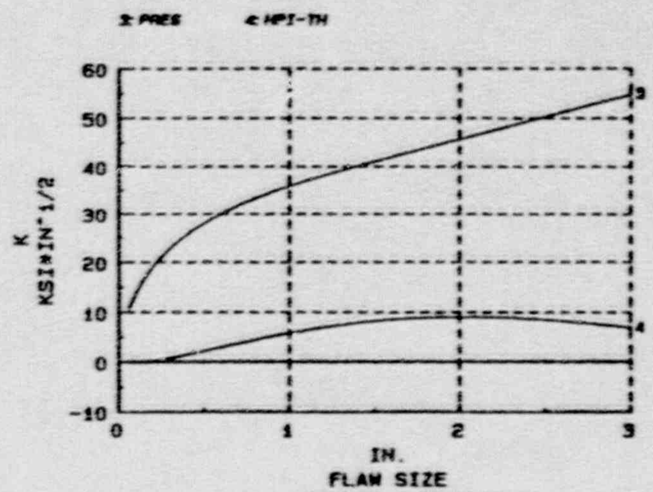
- USED STRESSES AND GEOMETRY PROVIDED BY B&W

- USED *pc-CRACK*™ NOZZLE CORNER FLAW MODEL
  - Directly Applicable to Davis-Besse HPI/Makeup Nozzle
  - Verified With Respect to JAERI Experimental Model
  - More Realistic Than B&W SECP Model

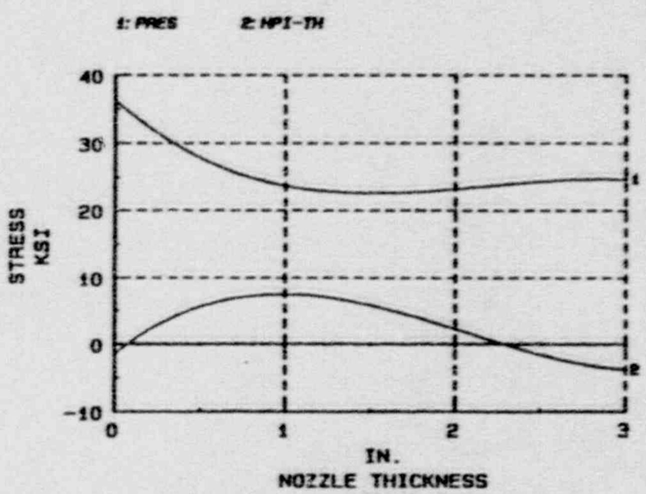
- RESULTS:
  - Section XI Allowable Flaw Size Essentially Through-wall
  - Ensures Brittle Fracture Prevention



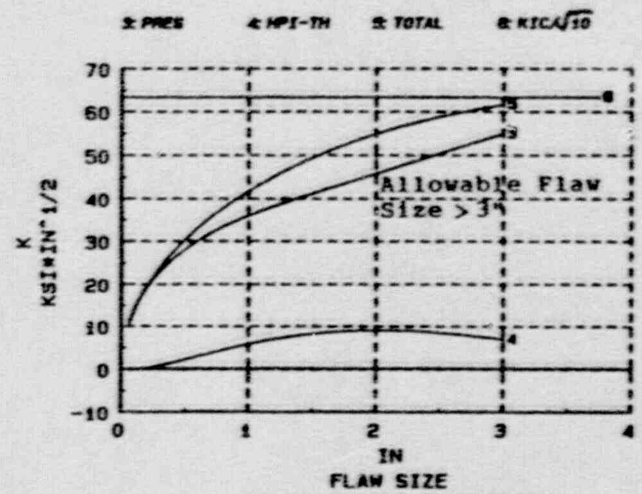

- Finite Element Model




- STRESS INTENSITIES




- STRESS DATA




ALLOWABLE FLAW DEPTH

# ASME SECTION XI ALLOWABLE FLAW DEPTH DETERMINATION

90-035PR

# NOZZLE REINFORCEMENT EVALUATION

- REQUIRED BY SECTION XI IN ADDITION TO FRACTURE MECHANICS ANALYSIS (IWB-3610-D-2)

- SECTION III NOZZLE AREA REPLACEMENT REQUIREMENTS EVALUATED WITH AND WITHOUT CORNER FLAW

- RESULTS:
  - Excess Reinforcement Available to Support 1.6" Radius "Flawed Zone" in Base Metal
  - More Limiting Than Brittle Fracture Considerations



STRUCTURAL INTEGRITY ASSOCIATES, INC.

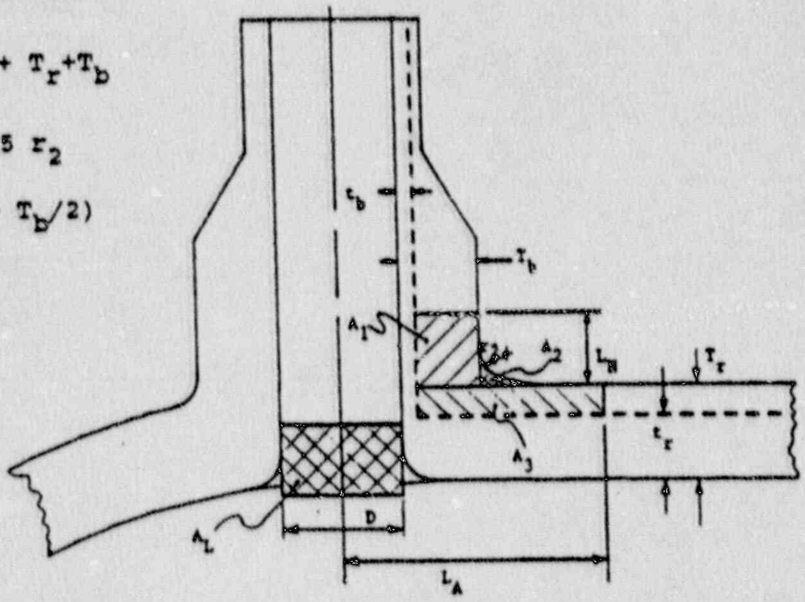
## LIMITS OF REINFORCEMENT

Greater of

$L_A = D$ (or) $D/2 + T_r + T_b$

$L_N = .5\sqrt{r_m T_b} + .5\ r_2$

$(r_m = D/2 + T_b/2)$




## AREA REQUIRED TO BE REPLACED:

$A_L = Dt_r$

## AREA AVAILABLE FOR REINFORCEMENT:

$$[A_1 + A_2 + A_3] \times \frac{S_m \text{ Nozz.}}{S_m \text{ Run}}$$

where: $A_1 = 2\ L_N\ (T_b - t_b)$

$A_2 = 2(r_2^2 - \frac{\pi}{4} r_2^2) = .43\ r_2^2$

$A_3 = 2(L_A - D/2 - t_b)(T_r - t_r)$

DAVIS-BESSE HPI NOZZLE
REINFORCEMENT REQUIREMENTS

90-037PR

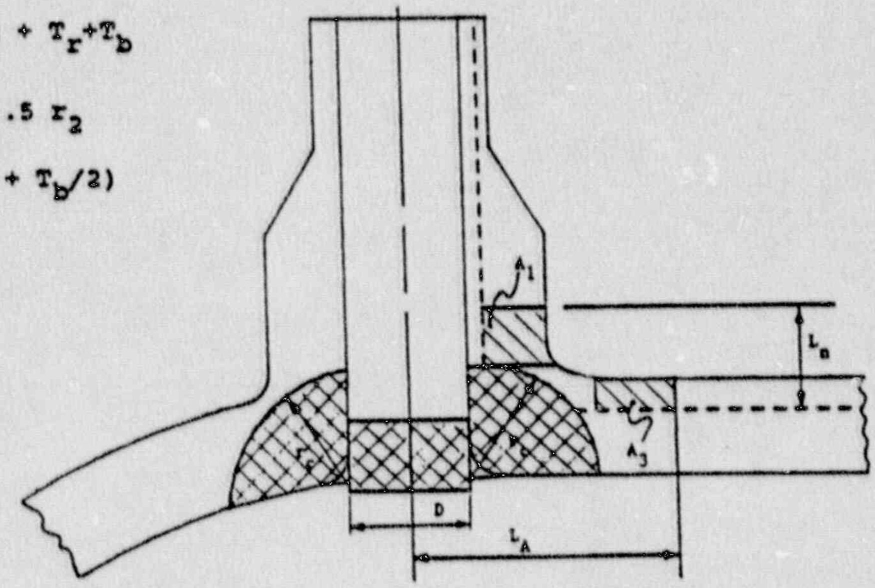
**LIMITS OF REINFORCEMENT**

Greater of

$L_A = D$ (or) $D/2 + T_r + T_b$

$L_N = .5\sqrt{r_m T_b} + .5\, r_2$

$(r_m = D/2 + T_b/2)$




**AREA REQUIRED TO BE REPLACED:**

$A = Dt_r + \pi r_c^2/2$

**AREA AVAILABLE FOR REINFORCEMENT:**

$A_1 = 2\,(L_N - X)\,(T_b - t_b)$

$X = (r_c - t_r)$ if>0
= 0 otherwise

$A_3 = 2(L_A - D/2 - r_c)\,(T_r - t_r)$

REINFORCEMENT REQUIREMENTS CONSIDERING FLAWED ZONE EFFECT

90-038PR

# REVISED F.M. ANALYSIS BY SI DURING 6RFO

- UT MOCKUP STUDY INDICATED DIFFERENT CLAD GEOMETRY THAN DESIGN DRAWING
  - Cladding Much Thicker (0.8" vs 0.2")
  - Sharper Corner Radius
  - Affects Flaw Depth/Location Assumptions in F.M. Analysis

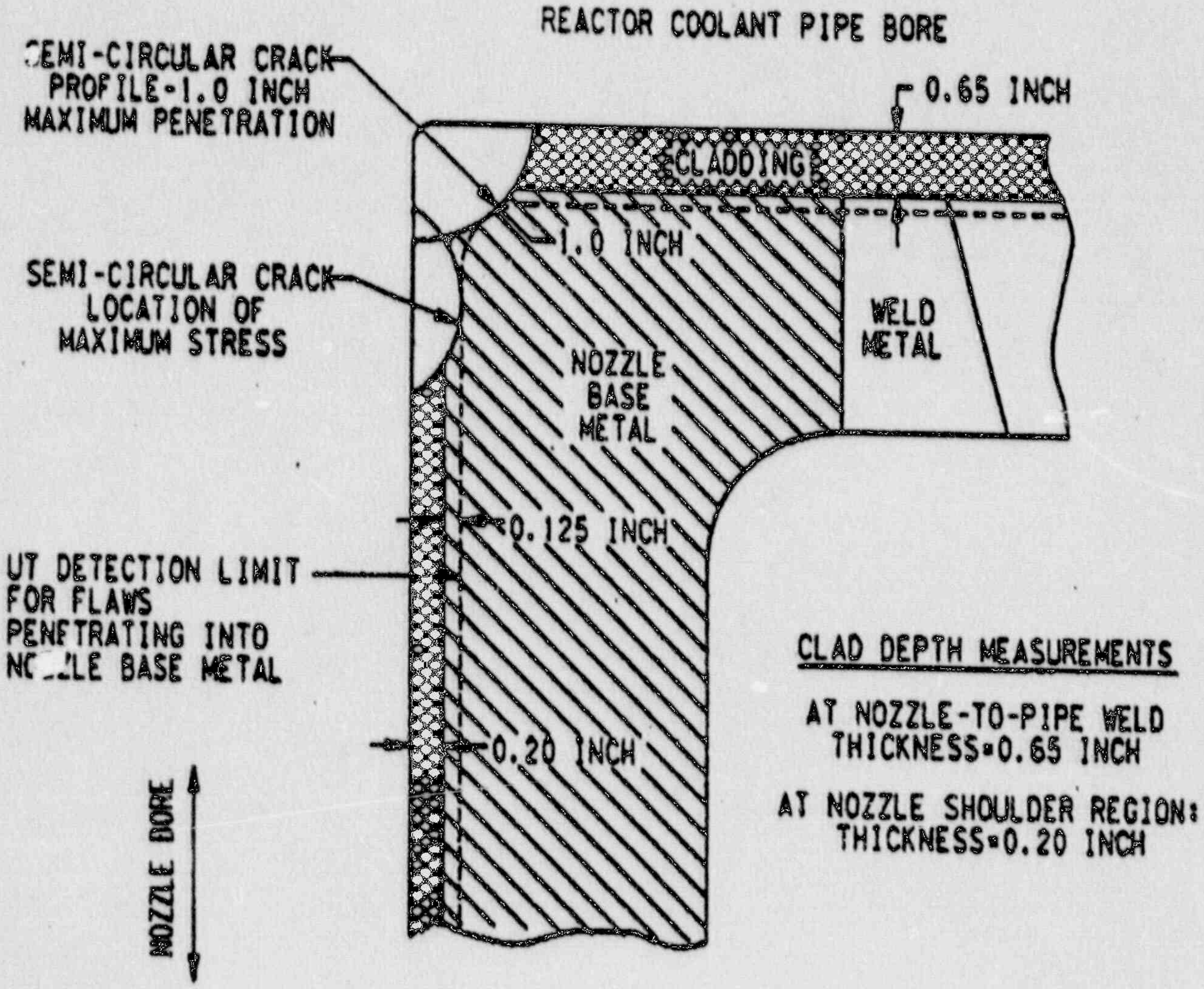
- F.M. ANALYSIS REDONE TO ADDRESS:
  - Pressure and Thermal Stresses from New Finite Element Model
  - Revised Flaw Depths and Locations

- NOZZLE REINFORCEMENT EVALUATION UNAFFECTED

- RESULTS:
  - Section XI Allowable Flaw Size Essentially Through-wall
  - Flaw Growth for 40 years HPI Operation Negligible (<.020")
  - Confirms Existing Large Margins Between Projected Flaws and Ductile and Brittle Fracture Limits

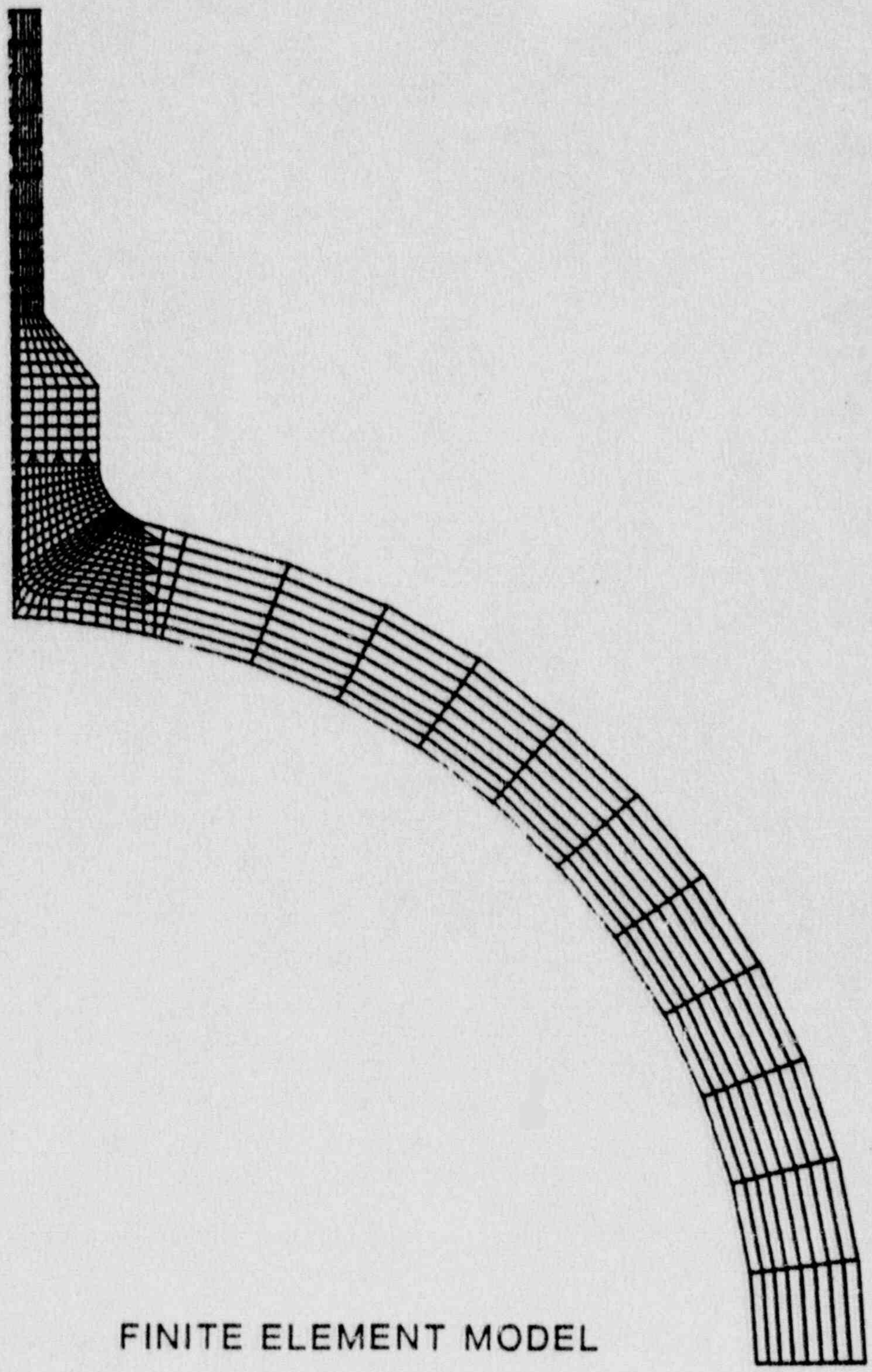


STRUCTURAL INTEGRITY ASSOCIATES, INC.



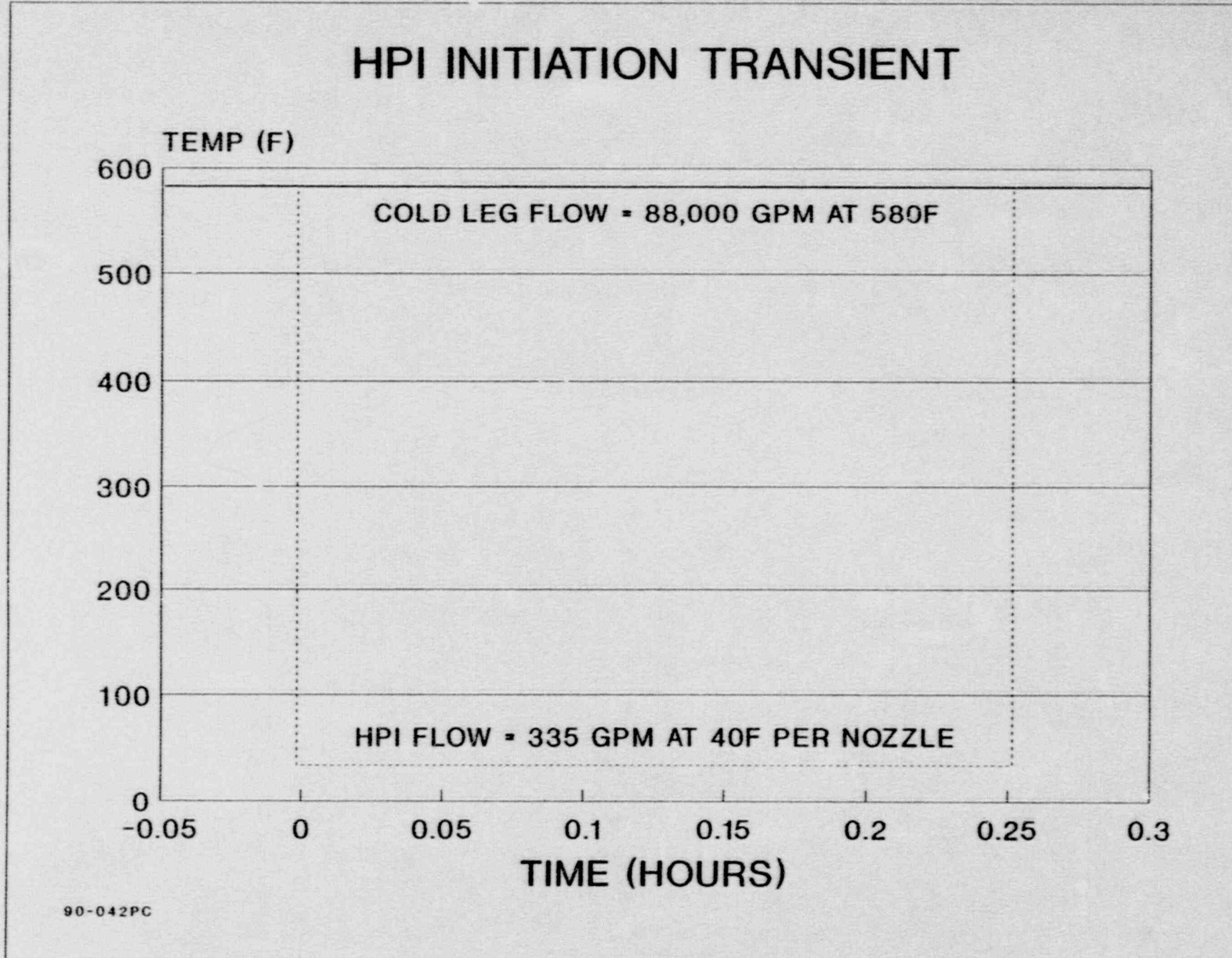

REVISED NOZZLE GEOMETRY AND ASSUMED CRACK CONFIGURATIONS

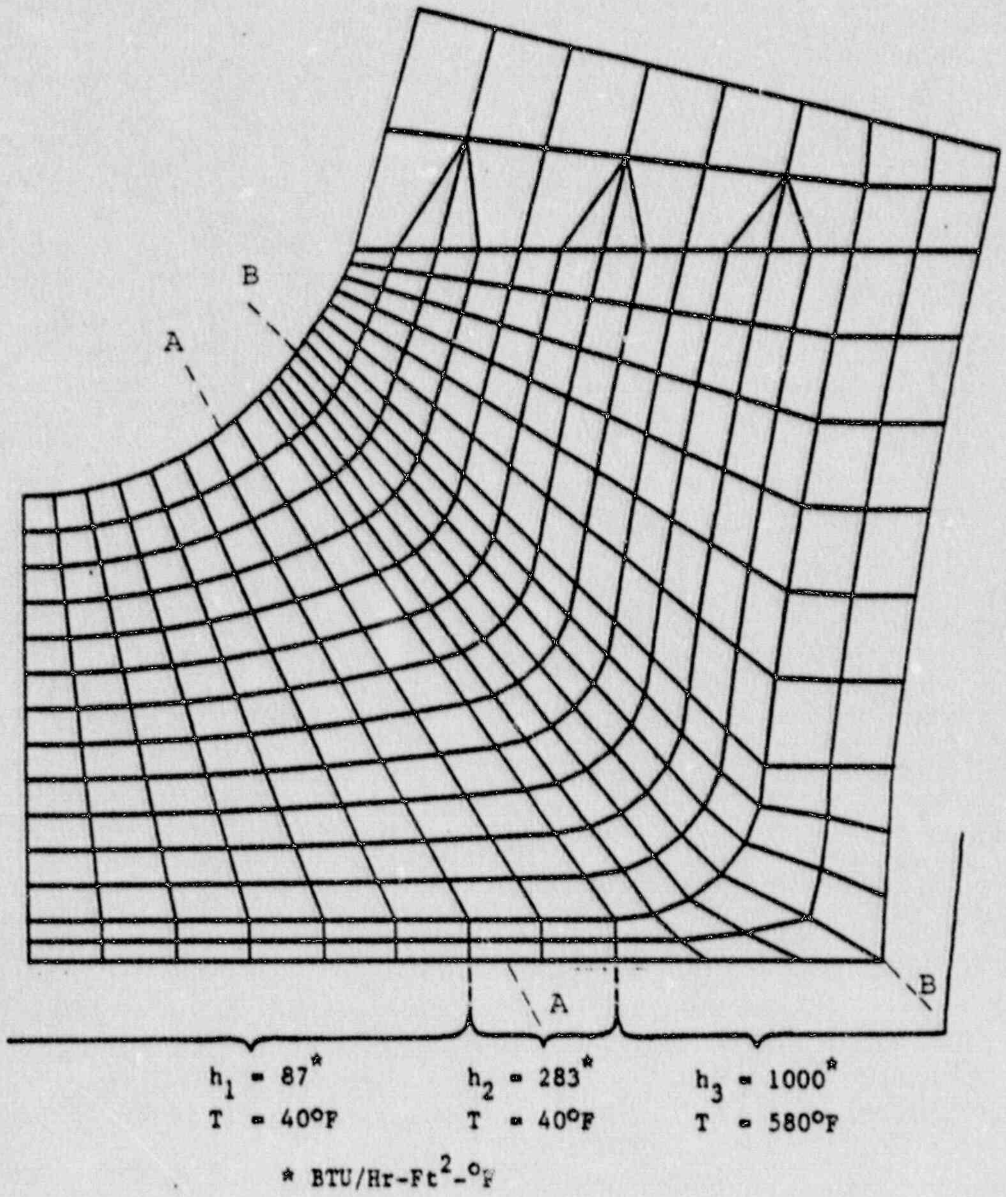
90-040PR



FINITE ELEMENT MODEL

90-041PR


HPI INITIATION TRANSIENT
TEMP (F)
600
500
400
300
200
100
0
COLD LEG FLOW = 88,000 GPM AT 580F
HPI FLOW = 335 GPM AT 40F PER NOZZLE
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
TIME (HOURS)
90-042PC

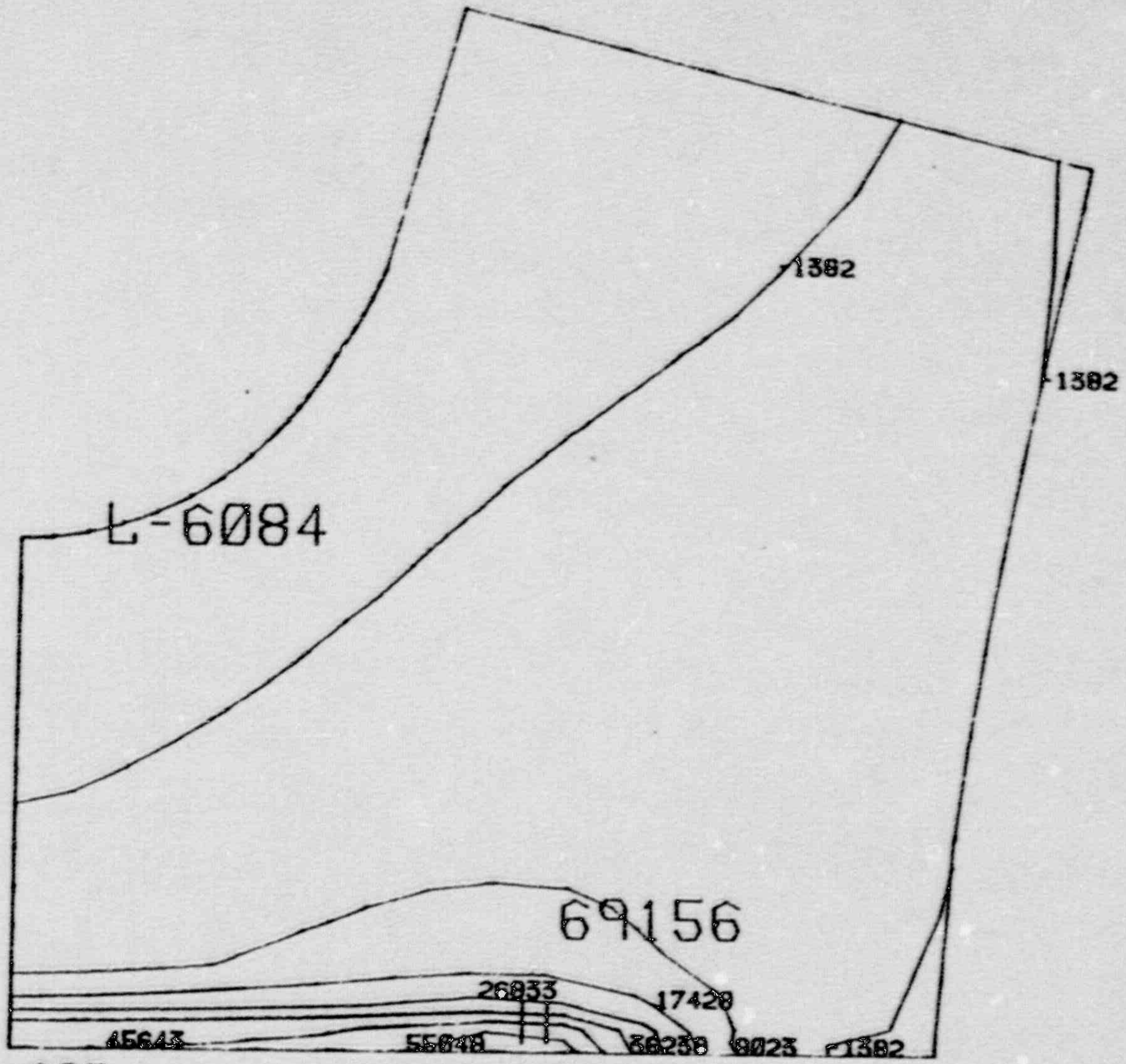



THERMAL BOUNDARY CONDITIONS

90-043PR

**Note:**

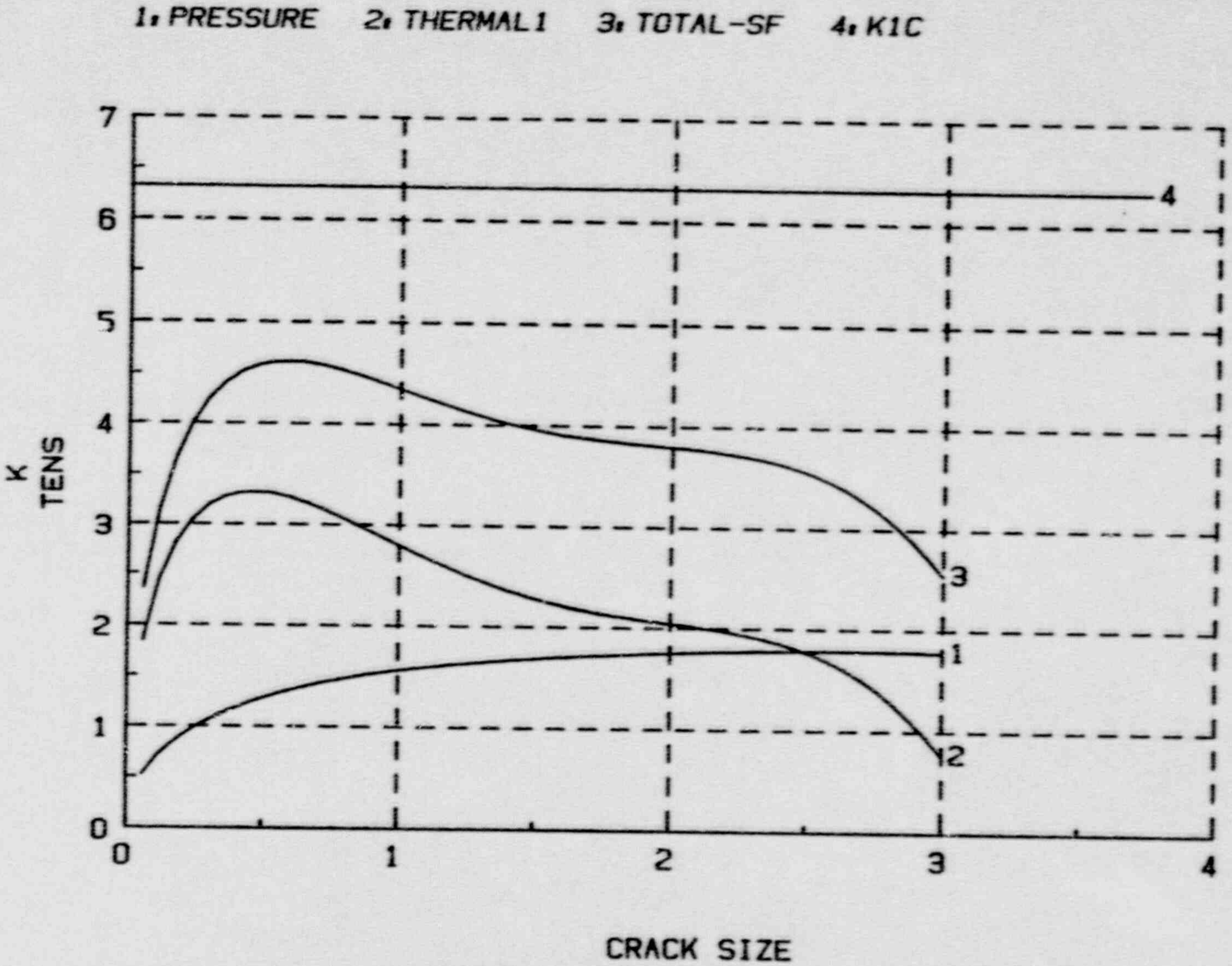
All stresses are in psi.




S33, t = 900 sec

HOOP STRESS CONTOURS FOR HPI INITIATION TRANSIENT AT 15 MINUTES

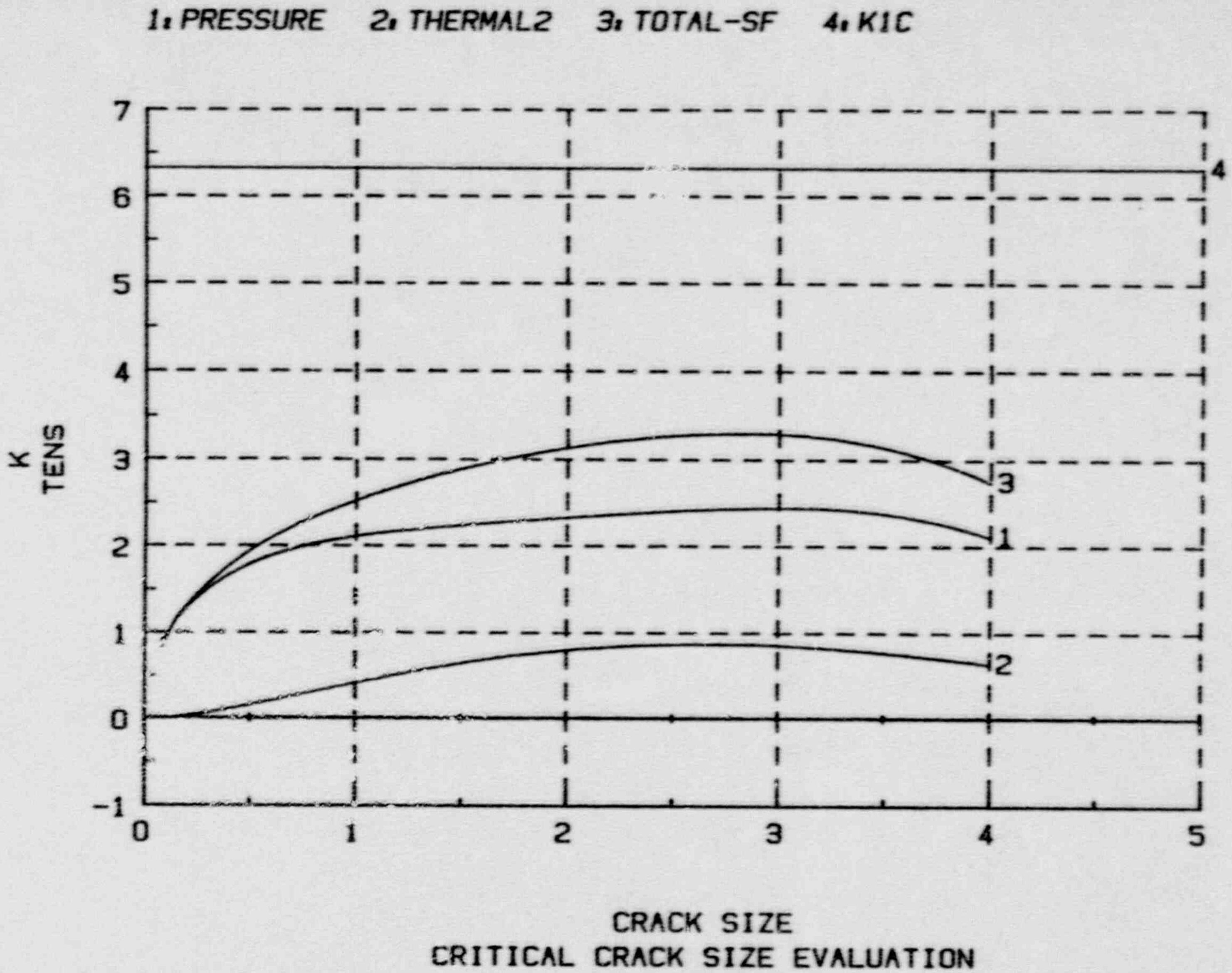
90-044PR




CRITICAL CRACK SIZE EVALUATION

APPLIED VERSUS ALLOWABLE STRESS INTENSITY
FOR SECTION A-A

90-047PR




APPLIED VERSUS ALLOWABLE STRESS INTENSITY FOR SECTION B-B

90-048PR

# OPERATION FOR CYCLE 7 AND BEYOND IS JUSTIFIED

- Re-route of Makeup Flow Eliminated Cold Makeup Water as a Driving Force for Thermal Fatigue in Former HPI/Makeup Nozzle A1

- Enhanced UT Indicated That There are No Mechanisms Acting to Cause Significant Flaw Propagation in Nozzle A1

- Fracture Mechanics Analysis Has Confirmed Existing Large Margins To:

    - ASME Section XI Allowable Flaw Size

    - ASME Section III Structural Reinforcement Requirements

# FUTURE PLANS

- Enhanced UT of Nozzle A1 During 7RFO

- Enhanced UT of Nozzle A1 at Next 10 YEAR ISI

- Continue to Investigate Thermal Sleeve Life and Alternatives Which Will Ensure Increased Reliability