NRC FORM 658
(9-1999)

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Do not include proprietary materials.

DATE OF MEETING
01/12/2000

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Docket Number(s)	PROJECT NUMBER 669
Plant/Facility Name	EPRI
TAC Number(s) (if available)	
Reference Meeting Notice	12/23/99
Purpose of Meeting (copy from meeting notice)	Discussion of the Material Reliability Project's thermal fatigue program

NAME OF PERSON WHO ISSUED MEETING NOTICE
L.N. OLSHAN

TITLE
PROJECT MANAGER

OFFICE
NRR

DIVISION
DLPM

BRANCH
PD II-1

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EPRI Materials Reliability Project

Thermal Fatigue ITG Meeting w/ USNRC

Rockville, MD

January 12, 2000

Agenda

9:00am	Introductions & Opening Comments	Mike Robinson, Duke
9:10am	Thermal Fatigue Program Status & Overview	Mike Robinson, Duke
9:30am	Thermal Fatigue Inspection Task	Stan Walker, EPRI Pedro Lara, EPRI
11:30am	Lunch	
12:30pm	Thermal Fatigue Screening & Evaluation Task	Bret Boman, FTI Dr. J. Gloudemans,FTI
2:00pm	Thermal Fatigue Operating Experience Task	Art Deardorff, SIA
2:30pm	Break	
2:45pm	Thermal Fatigue Interim Inspection Guidelines	Mike Robinson, Duke
3:15pm	NRC Interface	Dr. J Carey, EPRI
3:30pm	Open Discussion, Questions, Comments	All
4:15pm	Concluding Comments, Next Step	Mike Robinson, Duke Keith Wichman, NRC
4:30pm	Adjourn	

Thermal Fatigue Program

Status & Overview

Program Status

- All tasks have been defined and objectives established
- Tasks have been integrated into project plan and schedule
- Secured necessary resource commitments
- Working the Plan

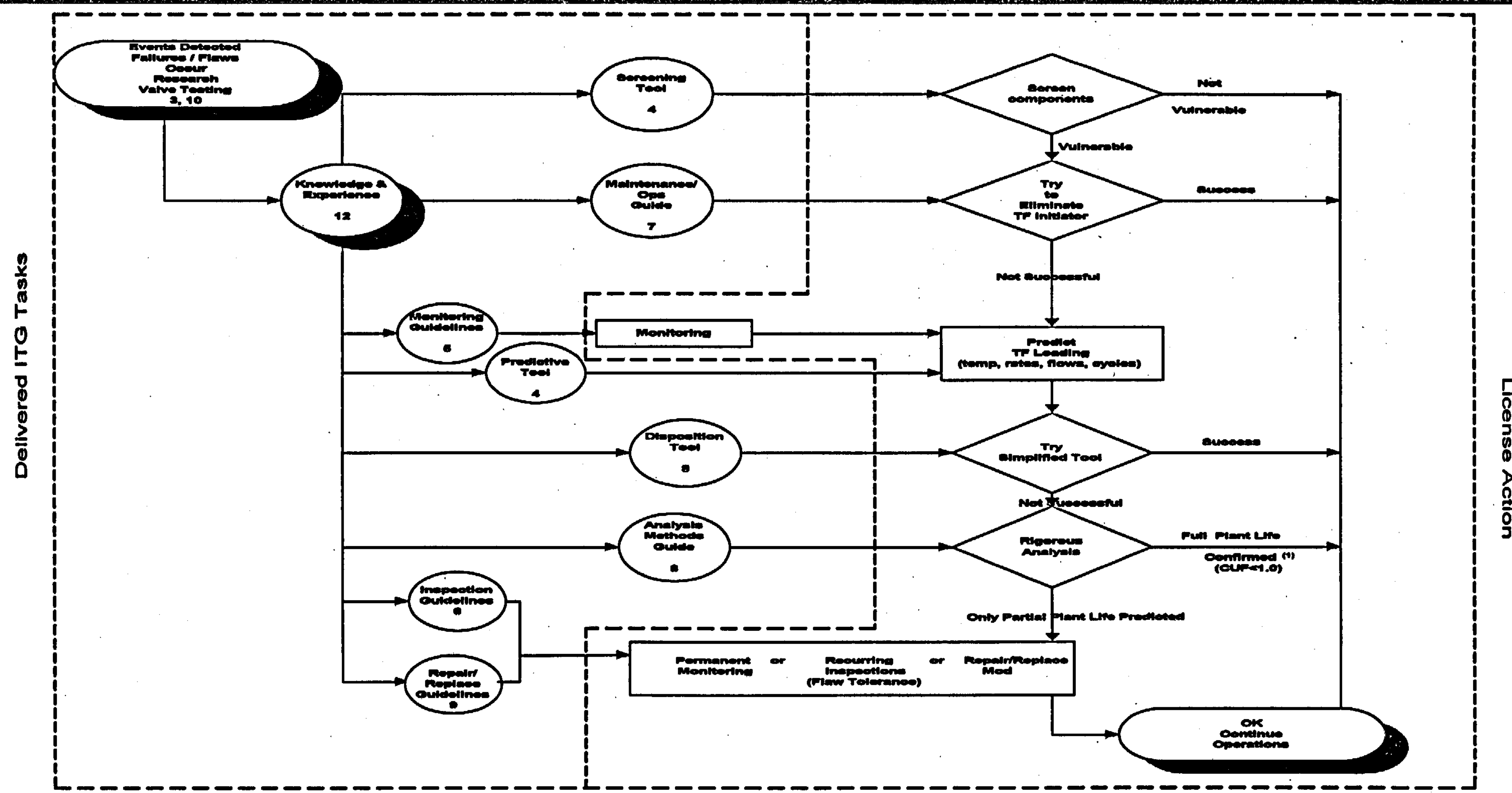
Project Goal

- Provide the EPRI MRP member utilities with a consistent set of guidelines and methodology for addressing piping thermal fatigue issues in 2001.

Project Scope

- The scope of this Project is thermal fatigue issues for those portions of ASME Code Class 1 piping systems that are connected to the Reactor Coolant Pressure Boundary AND are not isolatable from the Reactor Coolant Pressure Boundary. Included in the scope are effects due to cyclic thermal stratification.

Project Flowchart



(1) Permanent/semi-permanent monitoring may be recommended to confirm predicted significance

Thermal Fatigue ITG

Project Task Descriptions

Task 3: Industry Operating Experience

Description: Thermal fatigue operating experience will be documented in a report as a series of case histories, contained in a simple data base, using a program such as Microsoft Access, and installed on the EPRI web site.

Task 4: Thermal Fatigue Screening

Description: This task delivers a screening tool:

- in the form of Windows compatible EPRI software meeting 10CFR50 Appendix B and NQA-2
- assess the susceptibility of attached piping to significant stratification driven thermal fatigue

Task 5: Thermal Fatigue Monitoring Guidelines

Description: This task provides guidance for utility personnel to assure an effective monitoring program is in place to detect temperature distributions which could result in thermal stresses that could lead to cracking, if necessary.

- Guidance will be provided in the following areas:
  - establishing a technical basis for when a monitoring program is desired
  - identification and evaluation of state-of-the-art monitoring technologies
  - effective placement of monitoring sensors & frequency of monitoring
  - interpretation of monitoring data; what is significant/insignificant; action level thresholds
  - technical basis for discontinuing a monitoring program

Task 6: NDE Inspection Guidelines

Description: Thermal fatigue inspection guidance will be documented in an EPRI report and will include the following:

- guidance on NDE methodologies to detect thermal fatigue damage in piping
- recommendations for the qualification of NDE examiners and procedures
- guidance for evaluating NDE data
- limitations of current technologies to detect thermal fatigue damage

Task 7/9: Plant Modification and O&M Guidelines

Description: This task delivers a report that focuses on the following:

- maintenance practices that can lead to potential cyclic thermal stratification and what changes, if made, could minimize the potential for the phenomena to occur (Ex: valve PM frequency changes, material substitutions, gaskets, packing, etc)
- identifying plant operational practices that contribute to the potential for cyclic thermal conditions to exist and modifying those operational practices to minimize the potential for the phenomena to occur (Ex: cross flows or back flows when operating different RCP combinations, etc)
- identifying plant modifications that would eliminate the potential for thermal fatigue (Ex: adding other valves, changing slope of horizontal section of pipe, etc)

Task 8: Thermal Fatigue Evaluation

Description: This task delivers an evaluation tool:

- in the form of Windows compatible EPRI software, meeting 10CFR50 Appendix B and NQA-2
- quantifies the fatigue damage in those lines screened as susceptible by using an approach that bridges the gap between endurance based limits and a more rigorous detailed thermal fatigue analysis

- Screening and Evaluation, Tasks 4 & 8 will be developed in 2 phases:
  - Phase 1 is the methodology development
  - Phase 2 is a demonstration of the methodology to predict leakage events
  - Phase 2 solicits NRC acceptance of the methodology

Task 10: International Technical Exchange

Description: This task focuses on the identification of and possible participation in important foreign R&D activities which could contribute to resolution of the thermal fatigue issues. An international workshop on thermal fatigue experience and R&D is being planned by EPRI and NRC for August 2000 time period.

Task 11: Thermal Fatigue Management Guidelines

Description: This task delivers the principal product of this Project. The "TFMG" will be a compilation of methods for assessment, screening, monitoring, analysis, and management of thermal fatigue. It will assemble the results of the other tasks, document conclusions drawn from that work, and provide recommendations for managing thermal fatigue.

Task 12: Develop & Deliver Training Plan

Description: This task develops and delivers the training for utility engineers and others in applying the "TFMG". The objectives of this task are to:

- increase knowledge of cyclic thermal fatigue phenomena
- provide instruction on how to use the tools from the toolbox

MRP Thermal Fatigue ITG Milestone Schedule

Task	Task Completion Date
Task 3: Thermal Fatigue Operating Experience	October, 2000
Task 4: Thermal Fatigue Screening/Evaluation	July, 2001
Task 5: Thermal Fatigue Monitoring Guidelines	September, 2000
Task 6: Thermal Fatigue Inspection Guidelines	August, 2000
Task 7: Plant O&M and Modification Guidelines	September, 2000
Task 8: Thermal Fatigue Evaluation	See Task 4
Task 9: Combined with Task 7	See Task 7
Task 10: International Technical Exchange	On-going
Task 11a: Interim Thermal Fatigue Management Guideline	September, 2000
Task 11b: Final Thermal Fatigue Management Guideline	September, 2001
Task 12: Develop & Deliver Training	4th Qtr, 2001

Task 6: NDE Inspection Guidelines

Stan Walker

Pedro Lara

EPRI NDE Center

January 12, 2000

EPRI

Objectives

- Recommend Specific NDE Technologies and Variables for Inspection for Thermal Fatigue Damage for Small-Diameter, Butt-Welded Piping
  - Detection
  - Location
- Identify any Additional Qualification Requirements for NDE Examiners

Work Plan

- Inquire about International Experience
- Evaluation of NDE Techniques
- Qualification of NDE Examiners

International Experience

- U.S.
  - Thermal Fatigue Cracking Caused by Damaged Thermal Sleeves
    - Crystal River (1982), Oconee 2&3, Arkansas 1, Rancho Seco, Oconee 2 (1997)
  - Thermal Fatigue Cracking Caused by Valve Leakage
    - Farley 2 (1987)
- France, Belgium
  - Thermal Fatigue Cracking Caused by Valve Leakage
    - Bugey 3(1983), Tihange 1 (1988), Dampierre 2 (1992), Dampierre 1 (1996), Dampierre 3 (1997), Fessenheim 2 (1997), Tricastin 3 (1997)
- Japan
  - Tsuruga (1997) - Failure at Regenerative Heat Exchanger
  - Mihama (1999) - Failure of Surplus Letdown Pipe

International Experience - NDE

- Detection
  - Japan
    - Conventional Shear Wave Technique on Piping
    - TOFD on Vessels (Mitsubishi, IHI)
  - France
    - Conventional Shear Wave Technique on Piping
- Sizing
  - Procedures Not Disclosed

Design Basis for Mockups

Descriptions of Cracking

- Crazing - Shallow, Transgranular Network With Large Surface Extent & Extensive Branching
  - No Preferred Direction
- Deeper, Dominant Cracks
  - Preferred Direction Likely (With Exceptions)
    - Circumferential Near Welds
    - Axial (Skewed) Away From Welds

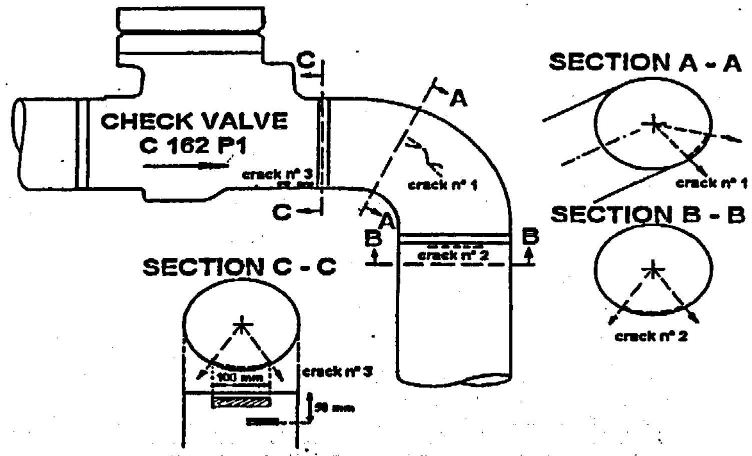


FIGURE 2. Field examination - Location of the cracks

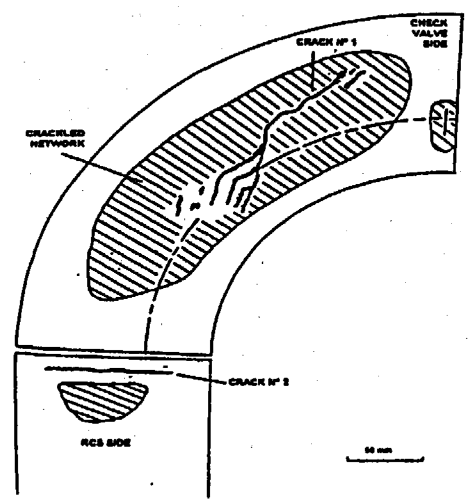
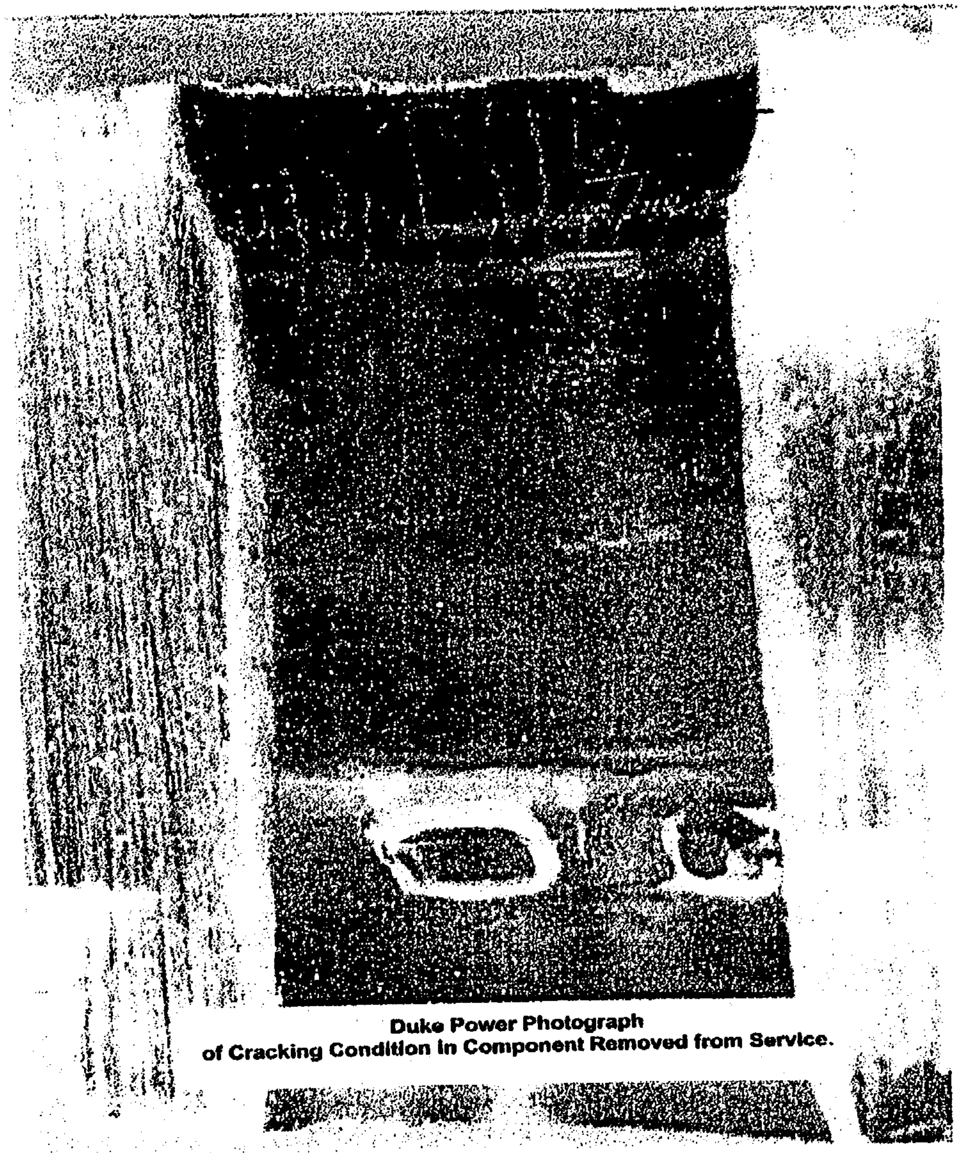


FIGURE 3. Laboratory examination - Location of cracks on ID



Duke Power Photograph
of Cracking Condition in Component Removed from Service.

Mockups

- Received
  - 2 Pipes (No weld) w/ Axial Crazing and Straight & Skewed Cracks
  - Pipe w/ Circumferential Crack & Craze at Weld
  - Safe-End w/ Craze and Straight & Skewed Cracks at Counterbore
- On Order
  - Elbow - Skewed Crack on Side
  - Elbow - Skewed Crack at Extrados

Evaluation of NDE Techniques - Ultrasonic Limitation

- High Pipe Curvature Causes Wedge Rocking & Induces Signal Noise
  - Entry Sound Point Variable
- Contoured Wedges Reduce Rocking
- Inspection With Contoured Wedges May Miss Skewed Cracks

Evaluation of NDE Techniques - Ultrasonic

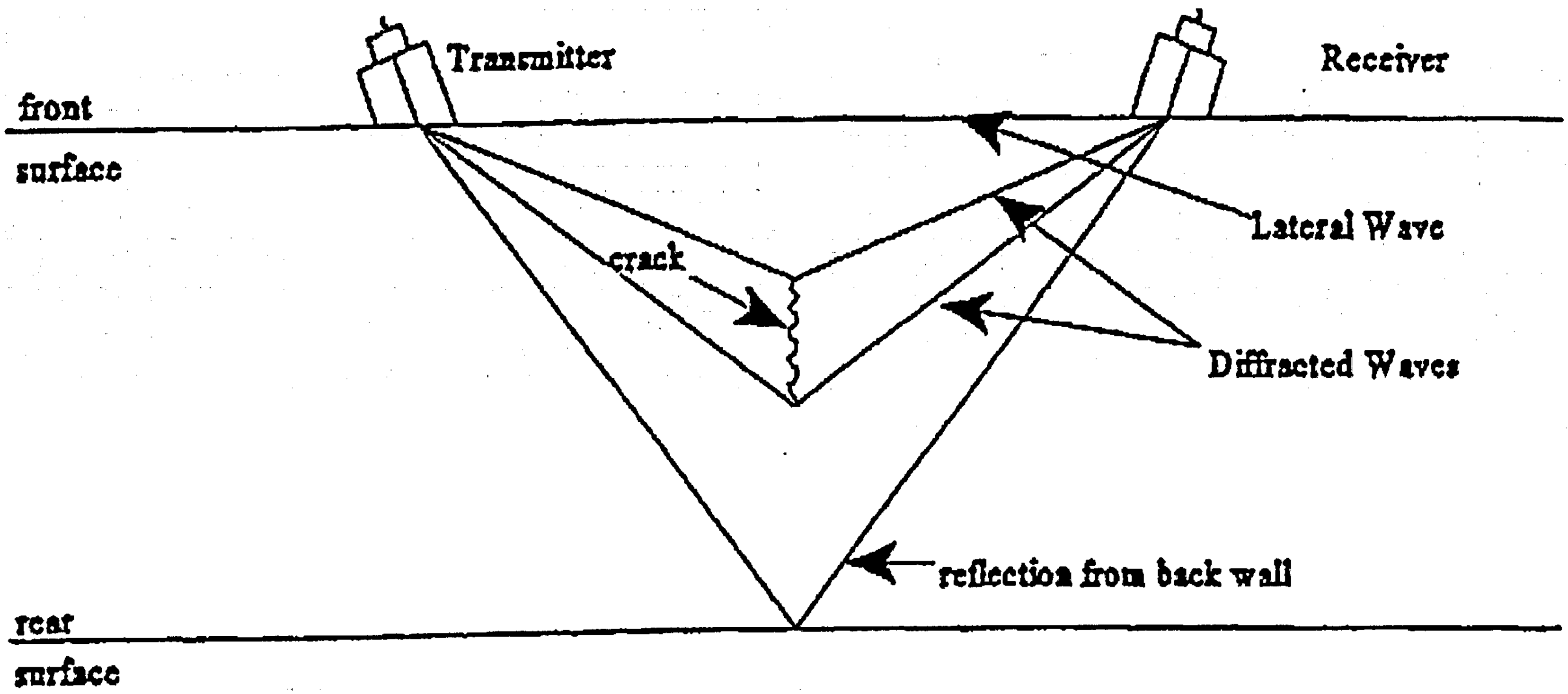
Ultrasonic Evaluation

- Transducer Selection
- Wedge Design for Small Bore Pipe
  - Flat
  - Contoured
  - Contoured and Pillowed
- Detection Technique
- Length Sizing Technique
- Depth Sizing Not Included In Current Plan

Evaluation of NDE Techniques - Alternative

- Conventional Radiography
- Time-of-Flight Diffraction
- Vibro-Modulation
- Acoustic Emission
- Ultrasonic Spectroscopy
- Conventional Eddy Current
- Pulsed Eddy Current

Time-of-Flight Diffraction



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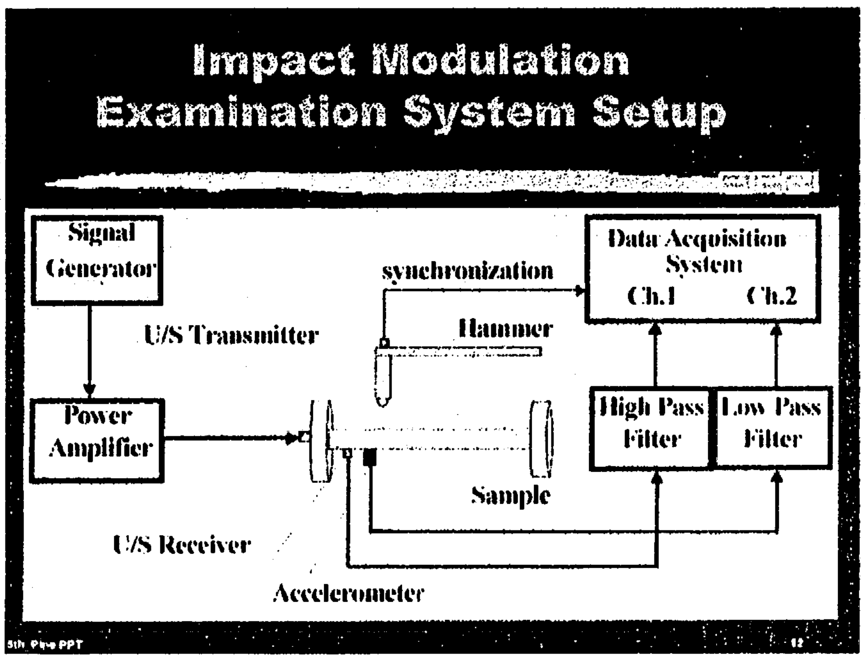
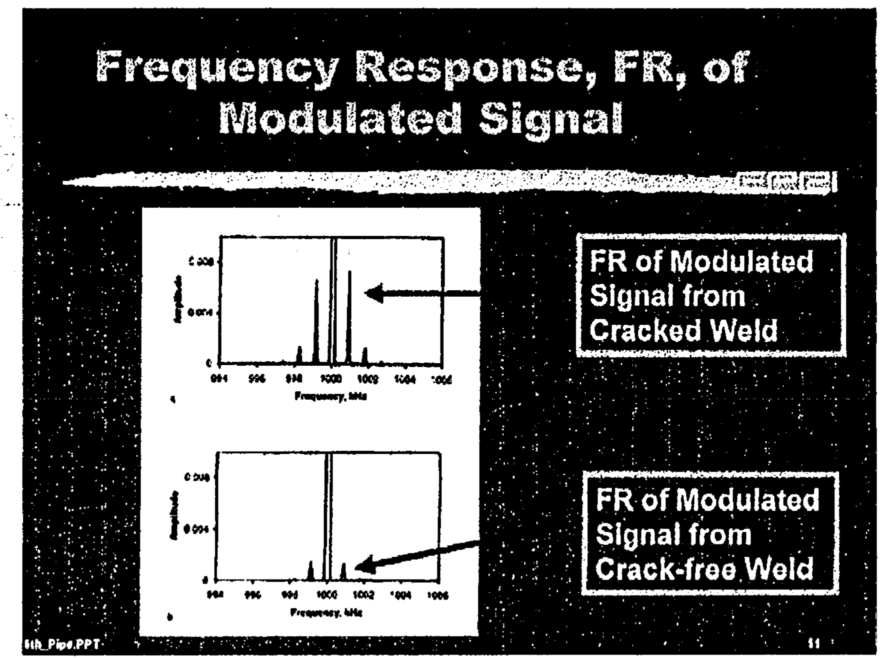
Vibro-Modulation





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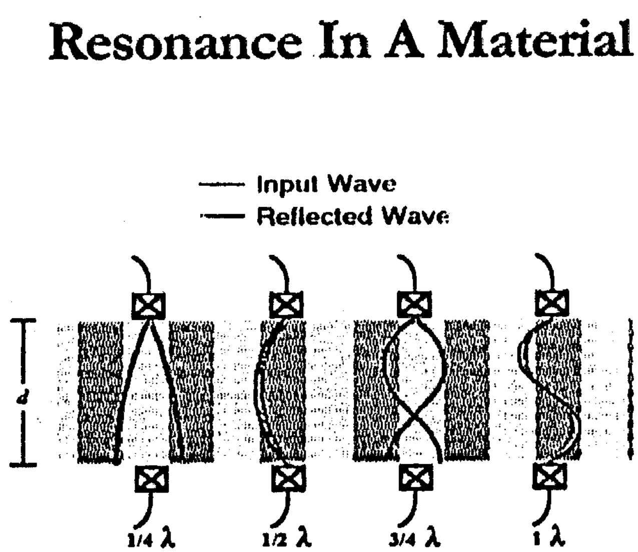
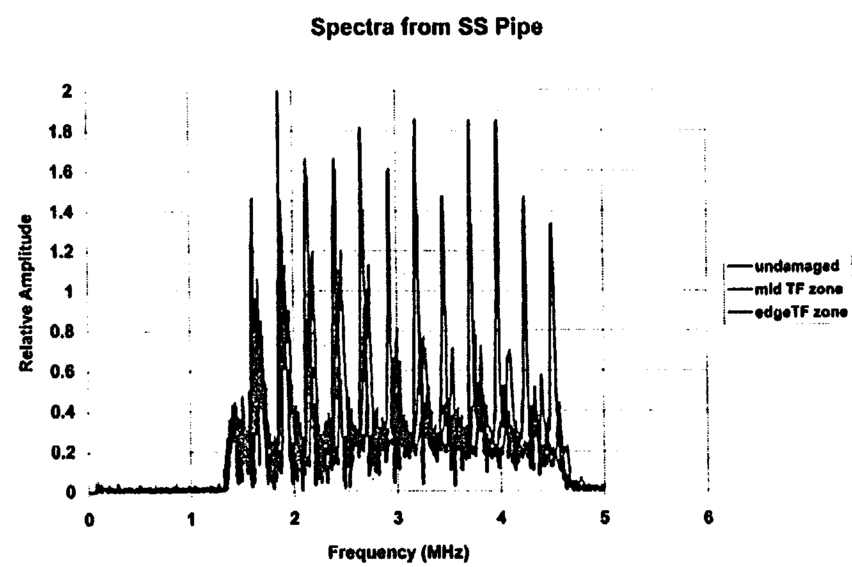
Acoustic Emission

- PNL to Provide Information From Prior Experiences
- EPRI Fossil Generation has Experience with AE for Larger Pipes

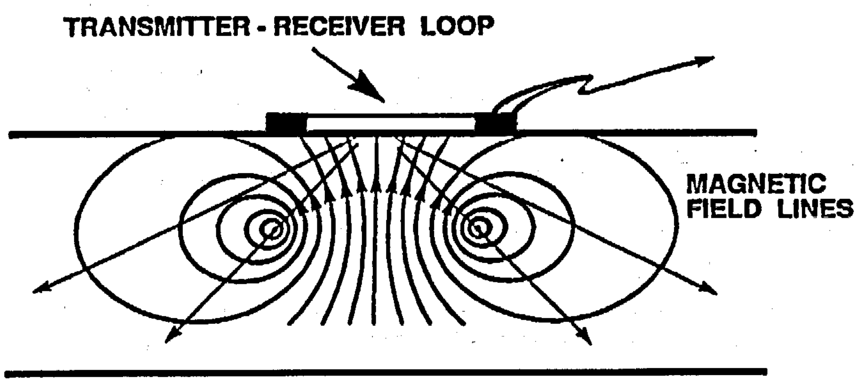
Ultrasonic Spectroscopy

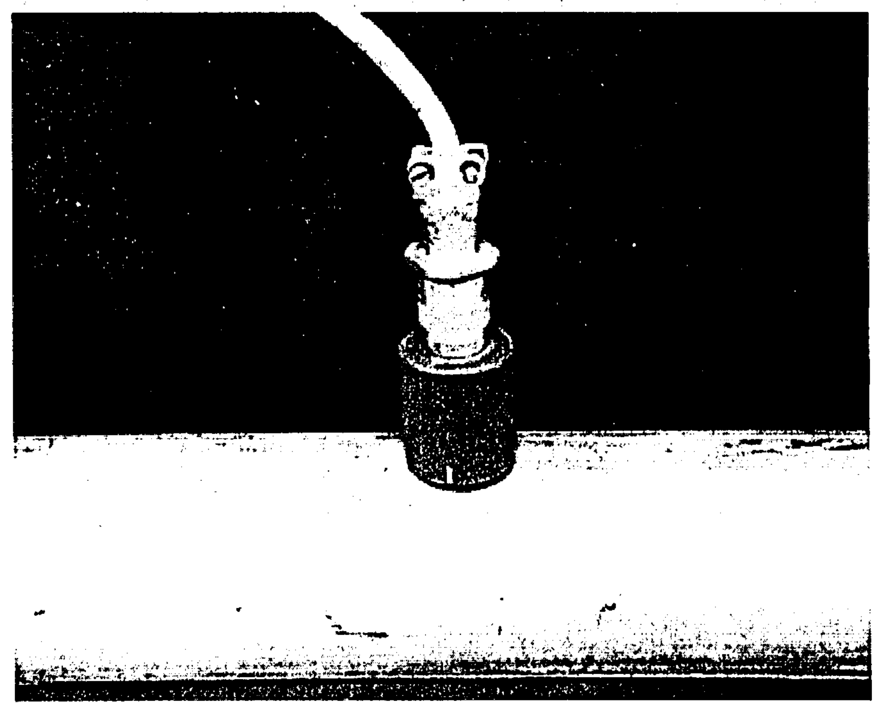




EPRI

Pulsed Eddy Current





Qualification of NDE Examiners

As the Recommended NDE Methodology Emerges From the Evaluations, it Will Become Necessary to Recommend Examiner Qualification

- UT
  - Possibly Current Qualification Through Industry Standard for Piping, Plus Additional Indoctrination for Thermal Fatigue
- Other
  - To be Determined

NRC Assistance

Information Offered by NRC Research Contractor

- Fatigue Crack Growth Rate & Critical Crack Size Data
- International NDE Activity Information
- Acoustic Emission Feasibility for Detection of Thermal Fatigue Cracks

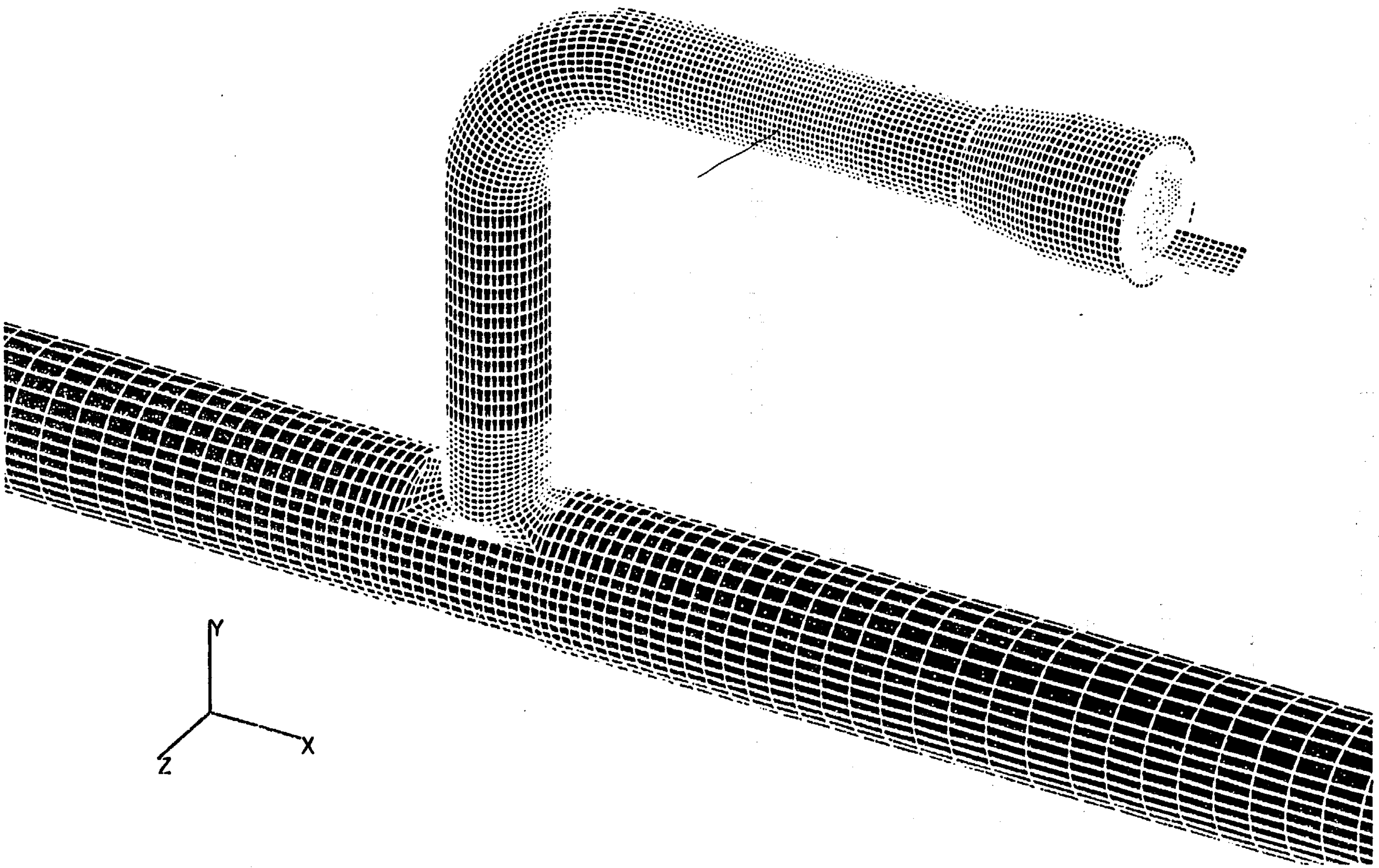
Results to Date - NDE Evaluations

- Contoured & Pillowed Wedges Best for Detecting Skewed Cracks
- Crazing Detectable (0.4 & 0.8 Inch Wall Thickness)
  - Ultrasonic (5% Throughwall)
  - Pulsed Eddy Current (>10% Throughwall)

Schedule

• Receive Remaining Mockups	Feb 2000
• Complete NDE Evaluations	May 2000
• Draft Report to ITG	June 2000
• Report Approved by ITG	August 2000

Thermal Fatigue Screening and Evaluation Task
MRP Thermal Fatigue ITG Meeting with NRC
January 12, 2000



Thermal Fatigue and Evaluation Tools – Agenda

- Objectives
- Applicability
- Flow Chart
- Methodology
- Details
  - Screening
  - Thermal Hydraulic Evaluation (incl: CFD examples)
  - Application

Thermal Fatigue Screening and Evaluation Tool - Objectives

- Provide Utility Engineer with Capability to Determine Where Potentially Significant Thermal Fatigue Damage May Occur

- Significant Thermal Fatigue Damage is where, without additional Management Activity, Cracking May Occur

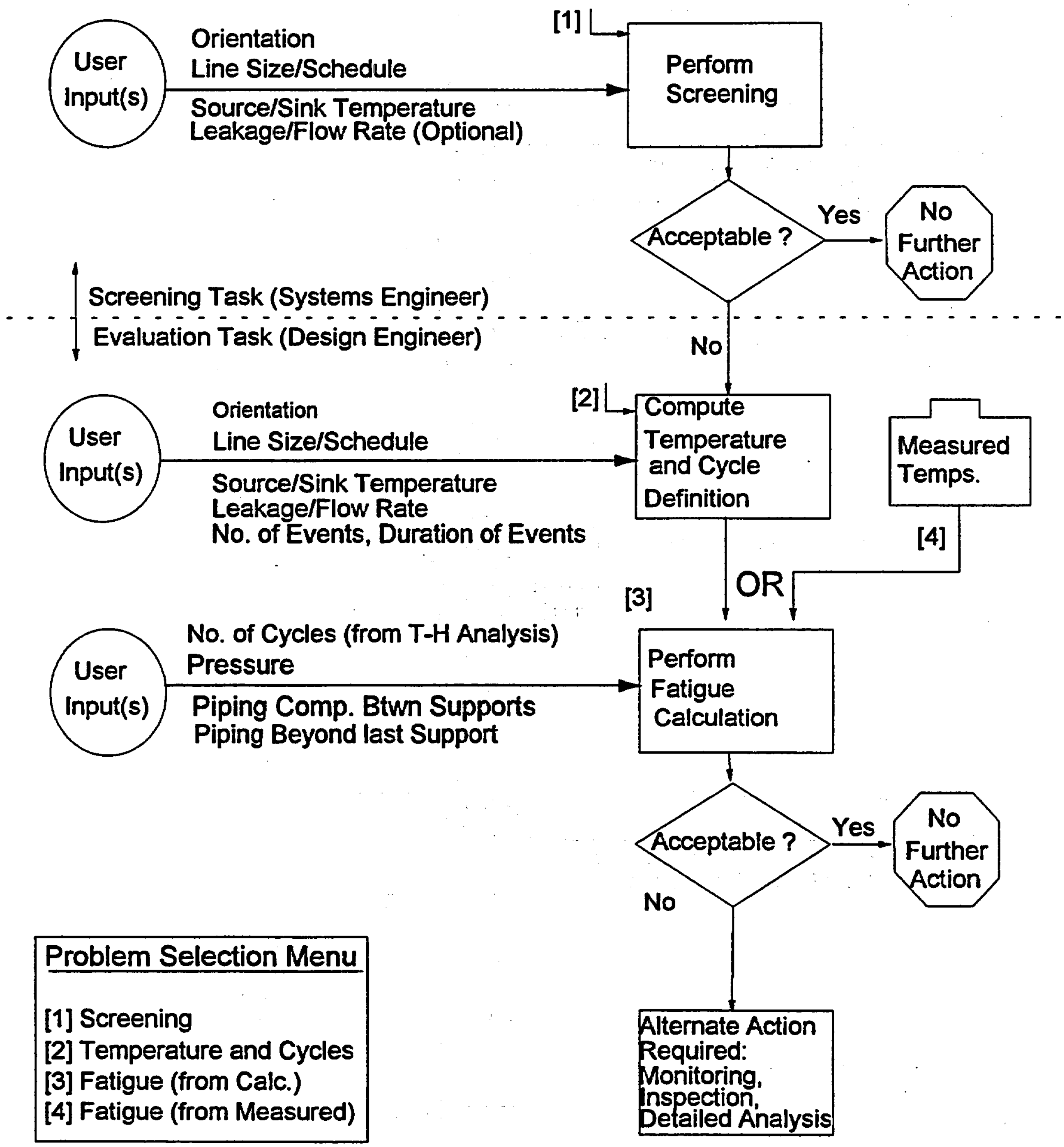
  - ✓ Use Screening Tool to Identify RCS Attached Piping Susceptible and non-Susceptible to Thermal Stratification

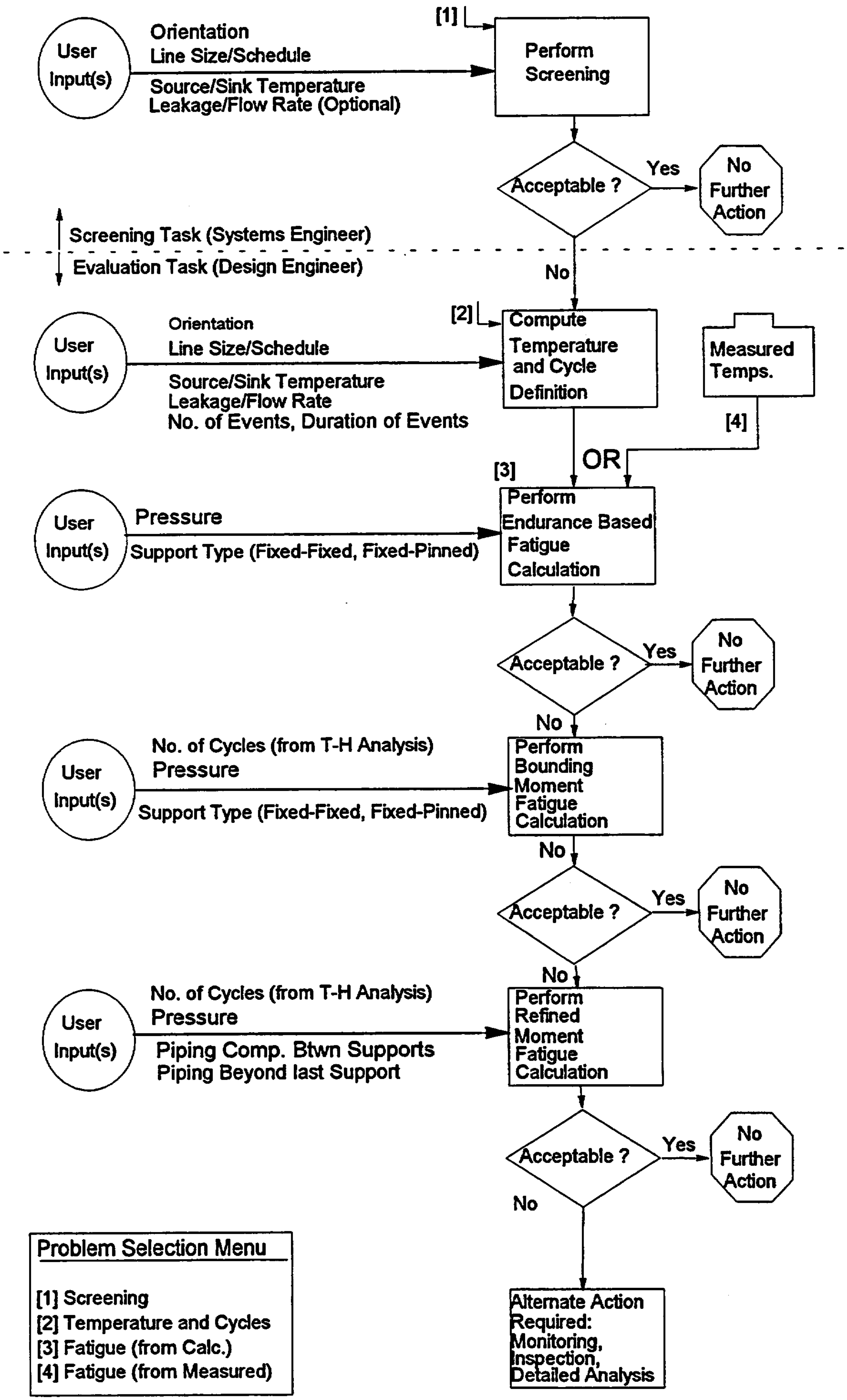
  - ✓ Use Evaluation Tool to Assist in Determining Appropriate Action

Thermal Fatigue and Evaluation Tools – Applicability

- RCS Attached Piping
- >1" Piping
- Most Common US PWR Attached Piping Configurations and Operation
- Will Not Include:
  - Thermal Sleeves
  - Design Flaws
  - Two Phase Flows
- Configurations Outside Tool's Applicability will Default to "Susceptible, Further Action Required"

Screening/Evaluation Tool Overview




[1]
User Input(s)
Orientation
Line Size/Schedule
Source/Sink Temperature
Leakage/Flow Rate (Optional)
Perform Screening
Acceptable ?
Yes
No Further Action
Screening Task (Systems Engineer)
Evaluation Task (Design Engineer)
No
[2]
User Input(s)
Orientation
Line Size/Schedule
Source/Sink Temperature
Leakage/Flow Rate
No. of Events, Duration of Events
Compute Temperature and Cycle Definition
Measured Temps.
[4]
OR
[3]
User Input(s)
Pressure
Support Type (Fixed-Fixed, Fixed-Pinned)
Perform Endurance Based Fatigue Calculation
Acceptable ?
Yes
No Further Action
No
User Input(s)
No. of Cycles (from T-H Analysis)
Pressure
Support Type (Fixed-Fixed, Fixed-Pinned)
Perform Bounding Moment Fatigue Calculation
No
Acceptable ?
Yes
No Further Action
No
User Input(s)
No. of Cycles (from T-H Analysis)
Pressure
Piping Comp. Btwn Supports
Piping Beyond last Support
Perform Refined Moment Fatigue Calculation
Acceptable ?
Yes
No Further Action
No
Alternate Action Required: Monitoring, Inspection, Detailed Analysis
Problem Selection Menu
[1] Screening
[2] Temperature and Cycles
[3] Fatigue (from Calc.)
[4] Fatigue (from Measured)

Thermal Fatigue and Evaluation Tools – Methodology

- **Use Computational Fluid Dynamics to Establish Basis for Thermal Stratification Screening and Load Prediction**
- **Use Established ASME Methodologies to Compute Bounding Usage with Varying Degrees of Complexity**

Key Item = Successful Benchmarking of CFD to Experimental and Plant Data

Thermal Fatigue Screening and Evaluation Tool – Project Plan

- Define Screening Methodology (Feb.)
- Define Attached Piping Orientations
  - ✓ Selected Configurations (Feb.)
  - ✓ Plant Survey (April)
- Benchmark CFD to MHI/Farley (March)
- Benchmark to Other Experimental and Plant Data (Dec.)
- Develop CFD Data Base for Applicability to Desired Configurations (Dec.)
- Develop Thermal Fatigue Software (Jan. 01)

THERMAL FATIGUE SCREENING

LINE SIZE

Consider only piping > 1" Diameter[1]

FEASIBILITY OF STRATIFICATION

- Estimate Richardson Number (Ri) using
  line size, imposed temperatures, flow rate

- Analyze only if Ri > Flushing[2] Ri

ENDURANCE LIMIT

- Determine applicability of endurance screening[3]

  - Piping includes straight pipe, elbows, and tees
  - Long-radius elbows
  - Branches connected to attached piping have negligible moments
  - < 7000 cycles

- Estimate max. allowable ΔT versus line size, material, at endurance limit

- Compare maximum allowable ΔT to imposed temperature difference, $\Delta T_{imposed}$

- Analyze only if $\Delta T_{imposed}$ > max allowable ΔT

ADDITIONAL SCREENING CRITERIA

Add screening criteria deduced from ongoing work

[FIGURE: PRELIMINARY Maximum ΔT Curves]

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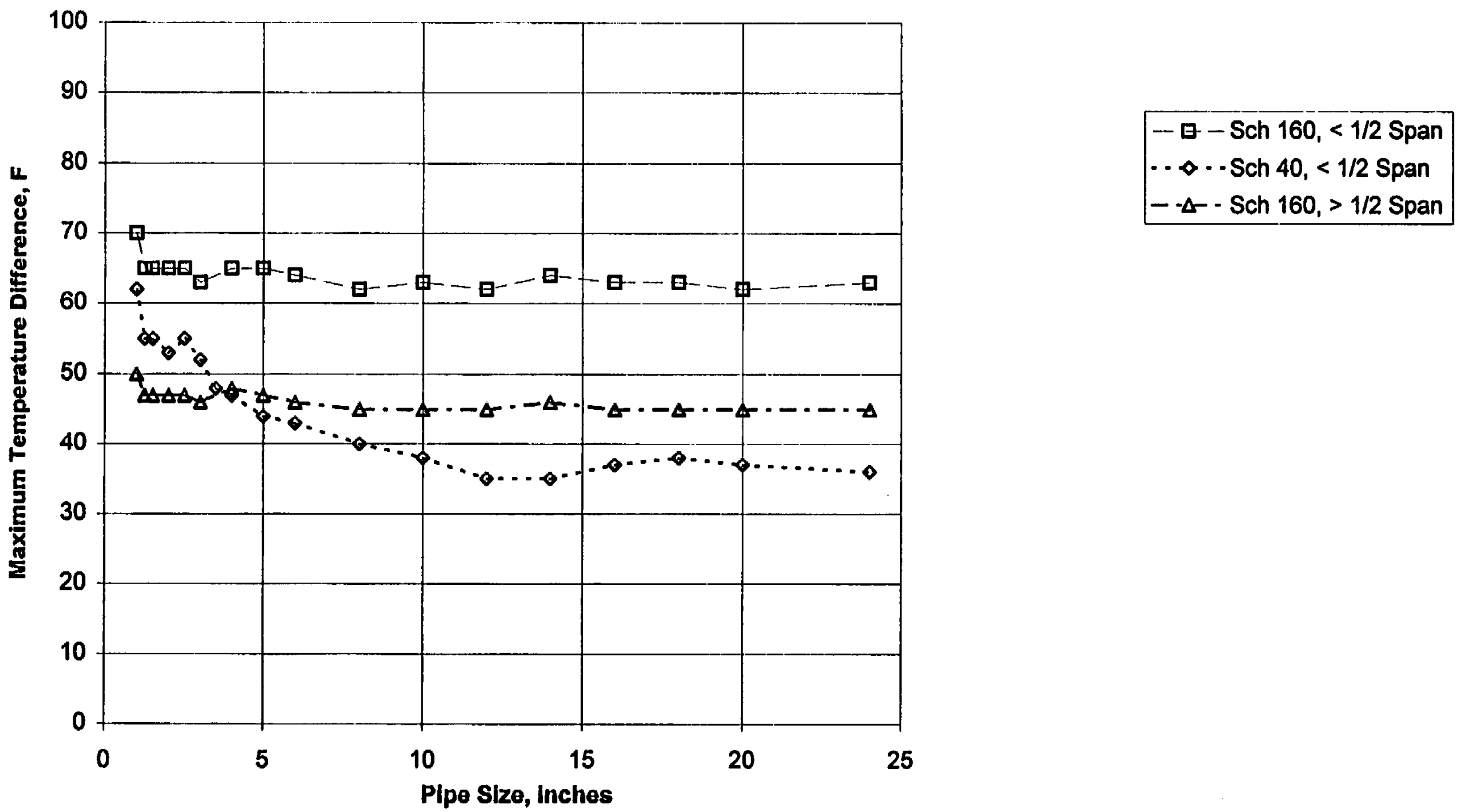
[1] ASME does not require thermal fatigue analysis of pipes 1".
[2] "Flushing" Ri: Imposed flow expels resident fluid from line, eliminating stratification.
[3] If screening not applicable , proceed directly to more detailed evaluation.

PRELIMINARY, APPROXIMATE SCREENING CRITERIA
Maximum dT versus Line Size for Stainless Steel Pipe,
Schedule 40 or 160, Stratification Length < or > Full Span
Source: FTI Doc. 86-1218598-02, "Thermal Stratification Screening / Fatigue"



THERMAL FATIGUE EVALUATION:

THERMAL-HYDRAULIC CONSIDERATIONS

OBJECTIVE: Develop tool to aid engineer in evaluation of thermal fatigue situations.

1. METHOD

    1.1 Outline

    1.2 Computational Fluid Dynamics

    1.3 Construction of TH Prediction Tool

2. APPLICATIONS

    2.1 Initial Application: MHI/Farley

    2.2 MHI-Farley Paradox

    2.3 Other Applications

    2.4 Applicability to Plant Leak Events

3. SUMMARY

1.1 OUTLINE OF METHOD

- Survey Plant Attached Piping

- Group Similar Configurations

  (same phenomena, layout, major components; similar dimensions)

- Select Key Configurations for Development of Prediction Tool

- Apply CFD

  - Benchmark to Available Data

  - Analyze Nominal Configuration, Conditions

  - Perform Additional Analyses to Complete Database

  - Supplement With Existing Test Data When Feasible

- Construct Prediction Tool

- Validate/Demonstrate Tool

1.2 COMPUTATIONAL FLUID DYNAMICS

CFD: Numerical description of a flow field by solving the conservation equations -- mass, momentum, and energy.

Requirements

- Accurate description of problem geometry, boundary conditions
- Sufficiently fine noding
- Appropriate turbulence model
- Convergence

Conditions For These Analyses

- Single phase
- Fluid stress proportional to time rate of strain (Newtonian fluid)
- Incompressible; density variations generate buoyant forces
- Turbulent

Validation

- Test solution sensitivity to mesh, turbulence models, other modeling options
- Examine results and trends
- Compare solution to observations (at conditions approximating those of interest)

CFD (Continued) -- FEATURES OF FLOTRAN

- Variable Fluid Properties: Density, Viscosity, Thermal Conductivity, Specific Heat

- Turbulence Models

  - Turbulent Viscosity from Turbulent Kinetic Energy (TKE) and Turbulence Dissipation Rate (TDR) -- "k-ϵ" Model plus Extensions

  - TKE and TDR Equations Include Buoyant Terms Described by Viollet

  - Wall Turbulence Models Available

- Iterative Solvers

  - Sweeping Method, Tri-Diagonal Matrix Algorithm (approximate)

  - Semi-Direct, Conjugate Direction Methods

CFD (Continued) -- FLOTRAN METHODS

- Conservation Equations Expressed as PDE's, Discretized Based on Finite Elements

- Segregated Solution Algorithm: Element Matrices for Each Degree of Freedom (DOF)
    - 7 DOFs: 3 Orthogonal Velocities, Pressure, Temperature, TKE, TDR
    - Element Matrices: Transient, Advection, Diffusion, and Sources

- Pressure Solved Separately
    - Velocity Expressed in Terms of Pressure Gradient from Momentum Equation
    - Applied to Continuity Equation

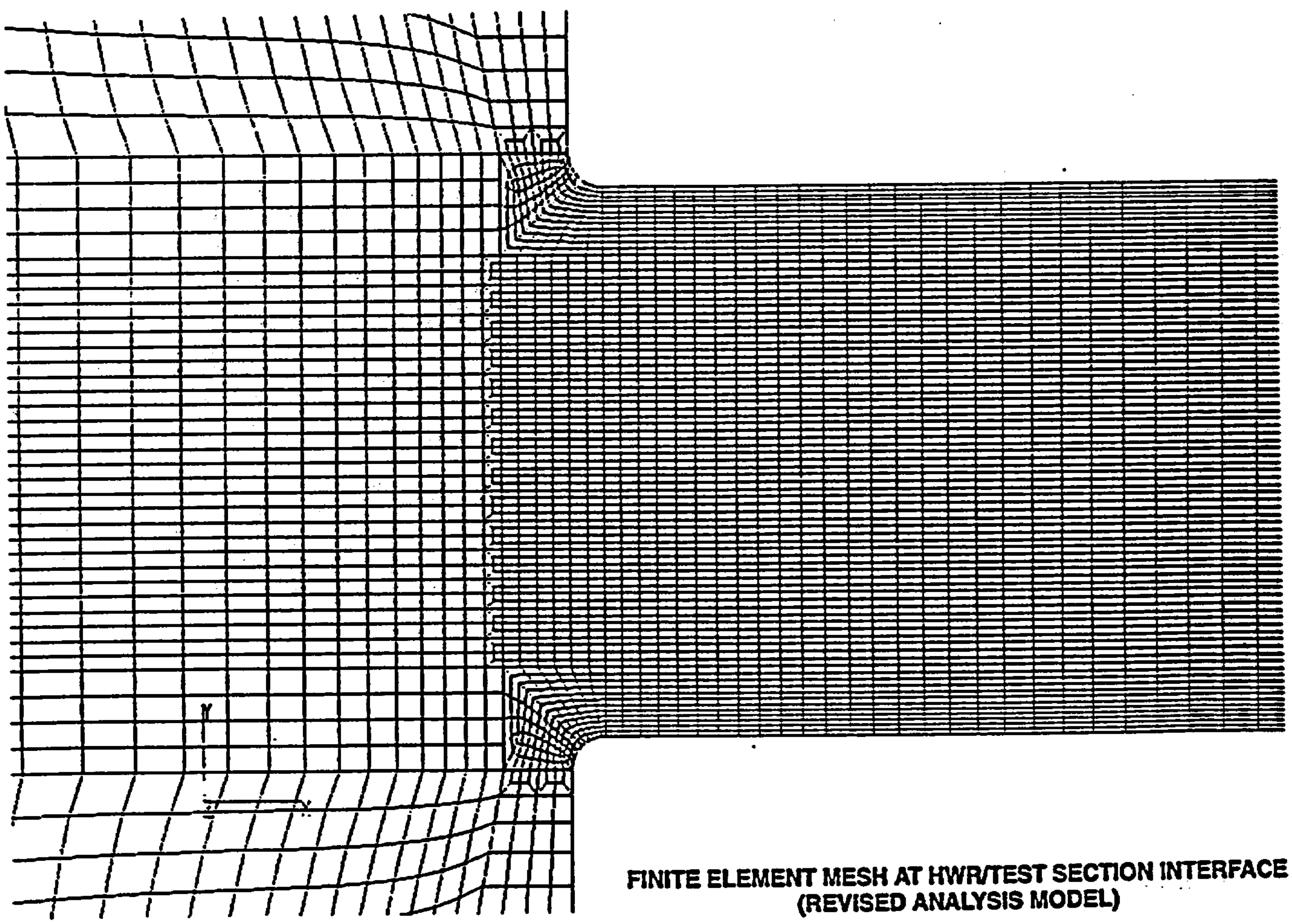
- Stabilization Methods
    - Relaxation
    - Inertial Relaxation
    - Artificial Viscosity

- Residuals Displayed to Provide Diagnostics

[FIGURES: CFD Applications]

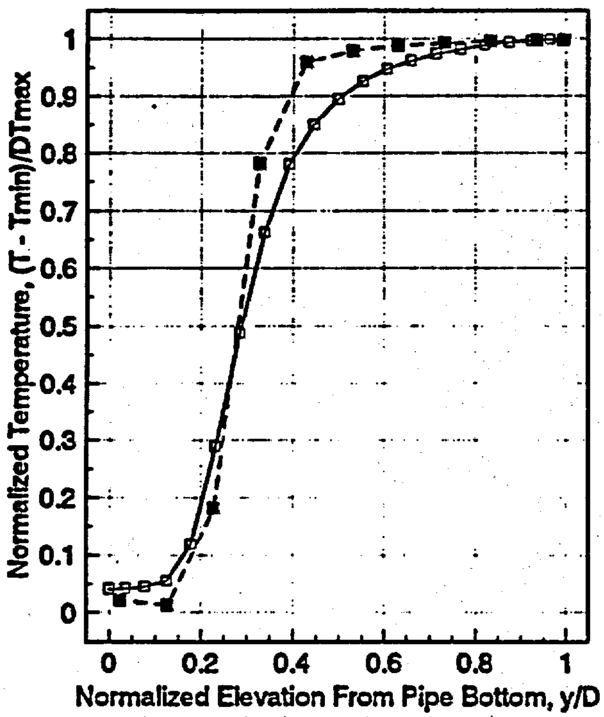
Predictions of Stratification Test Facility Measurements
Using 2-Dimensional FLOTRAN Model

Source: J. R. Smotrel, "Turbulent Thermal Stratification In a Long Horizontal pipe," Proc 7th Int ANSYS Conf (May, 1996).



FINITE ELEMENT MESH AT HWR/TEST SECTION INTERFACE
(REVISED ANALYSIS MODEL)

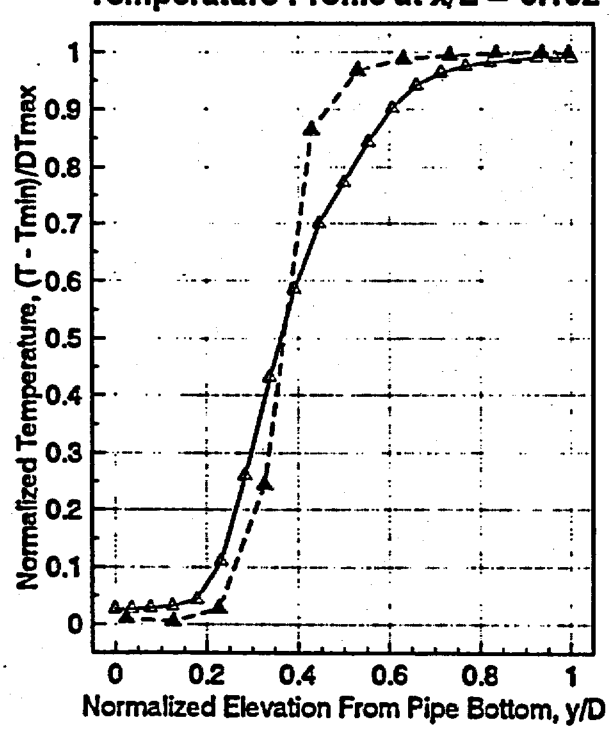
Temperature Profile at x/L = 0.038



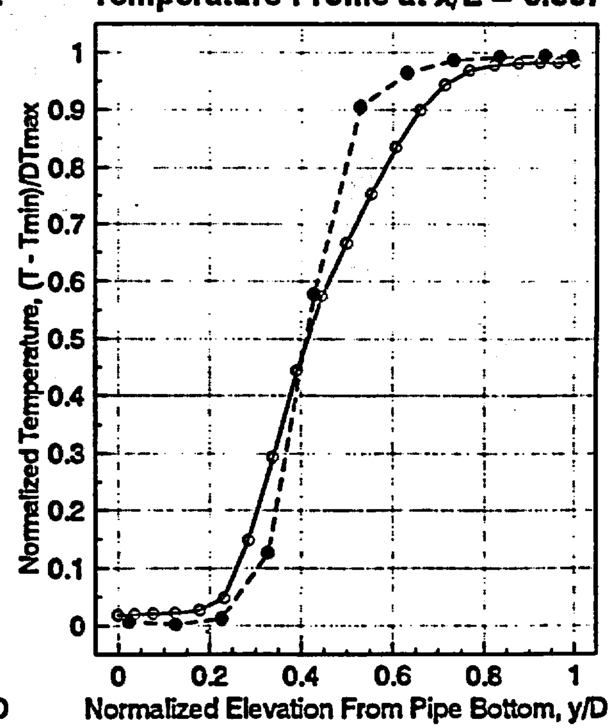
COMPARISON OF MEASURED AND CALCULATED TEMPERATURE PROFILES (Near Hot Water Reservoir)

MEASURED	- - - - - - -
CALCULATED	————

Temperature Profile at x/L = 0.192

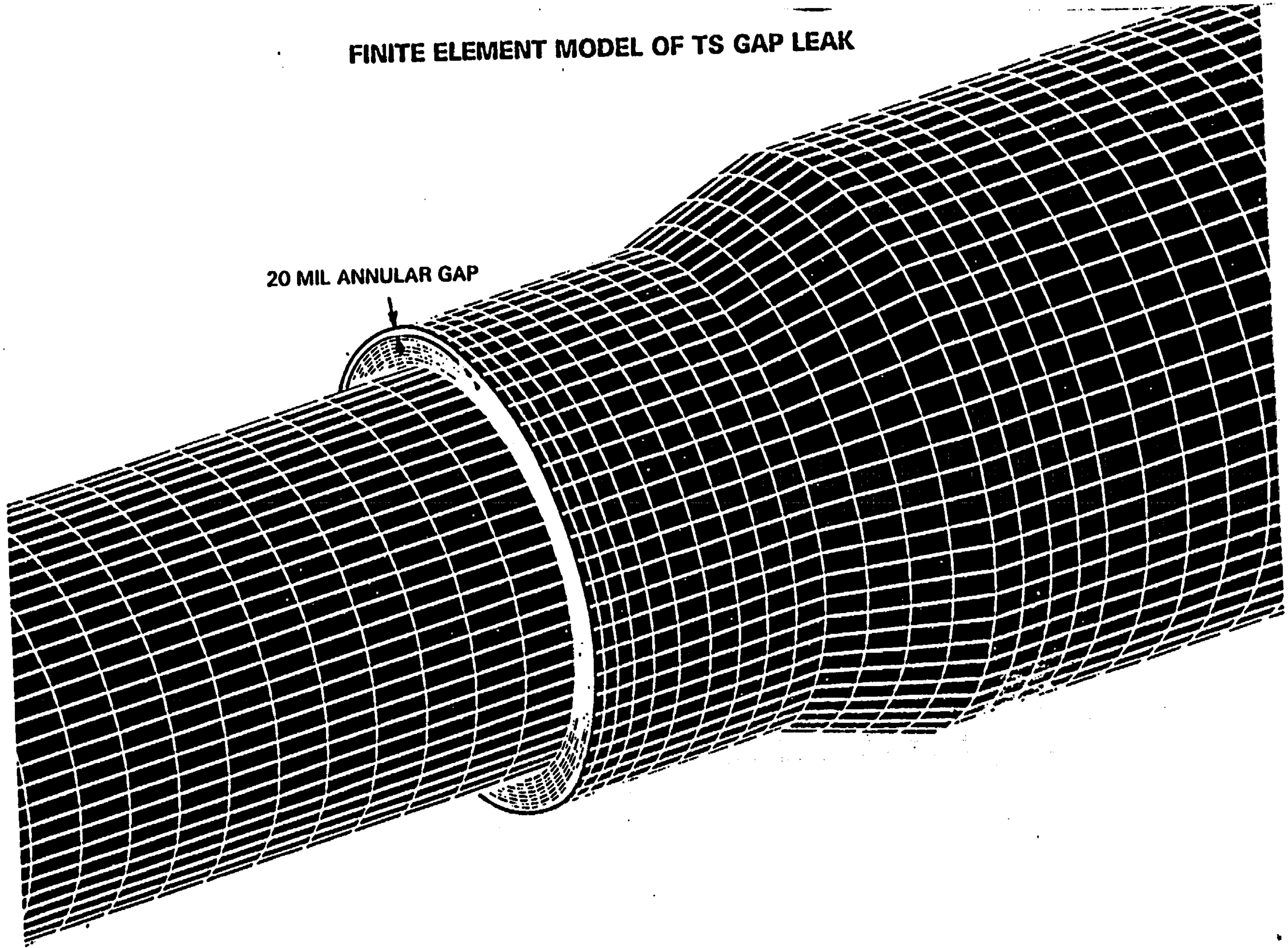


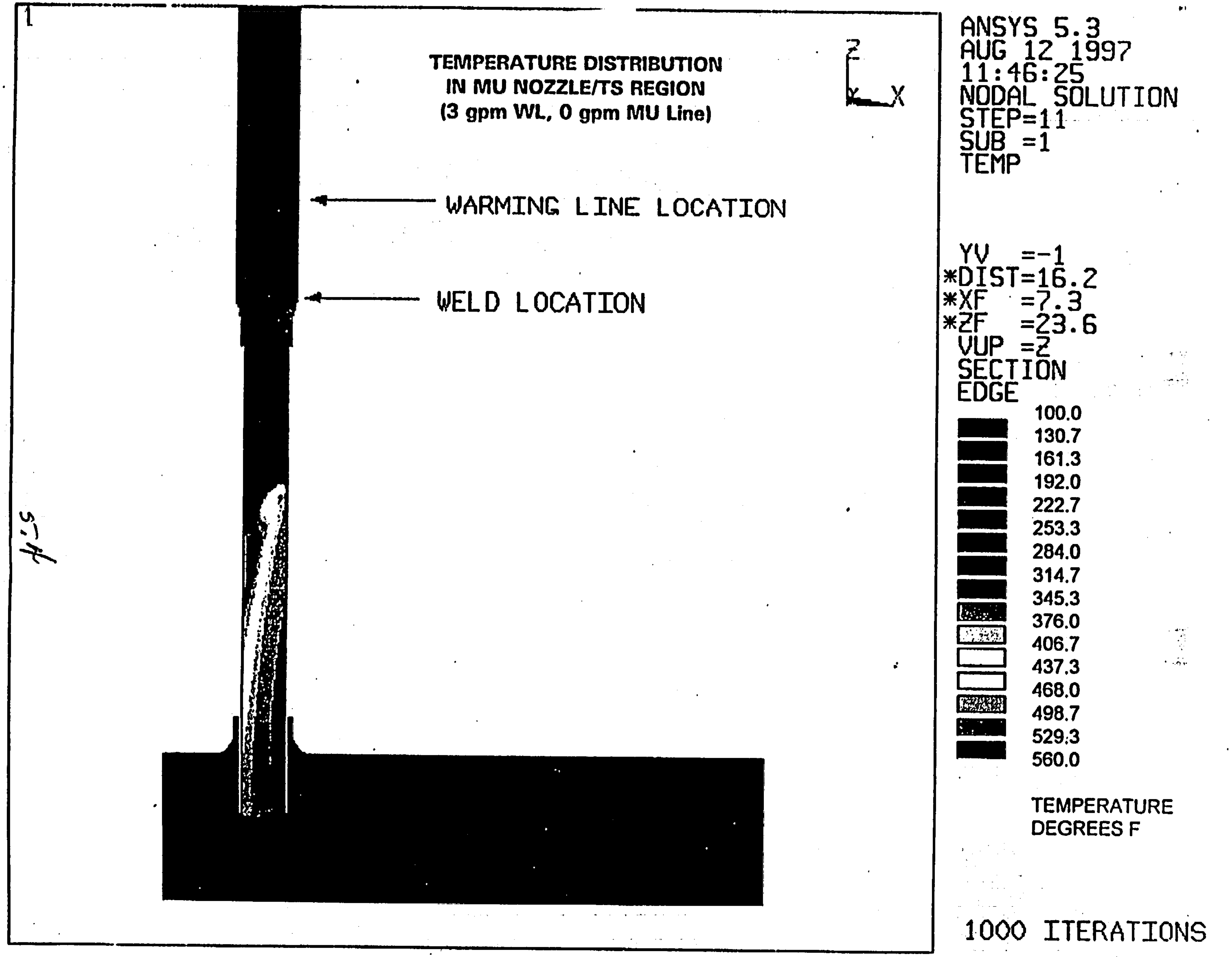
Temperature Profile at x/L = 0.367

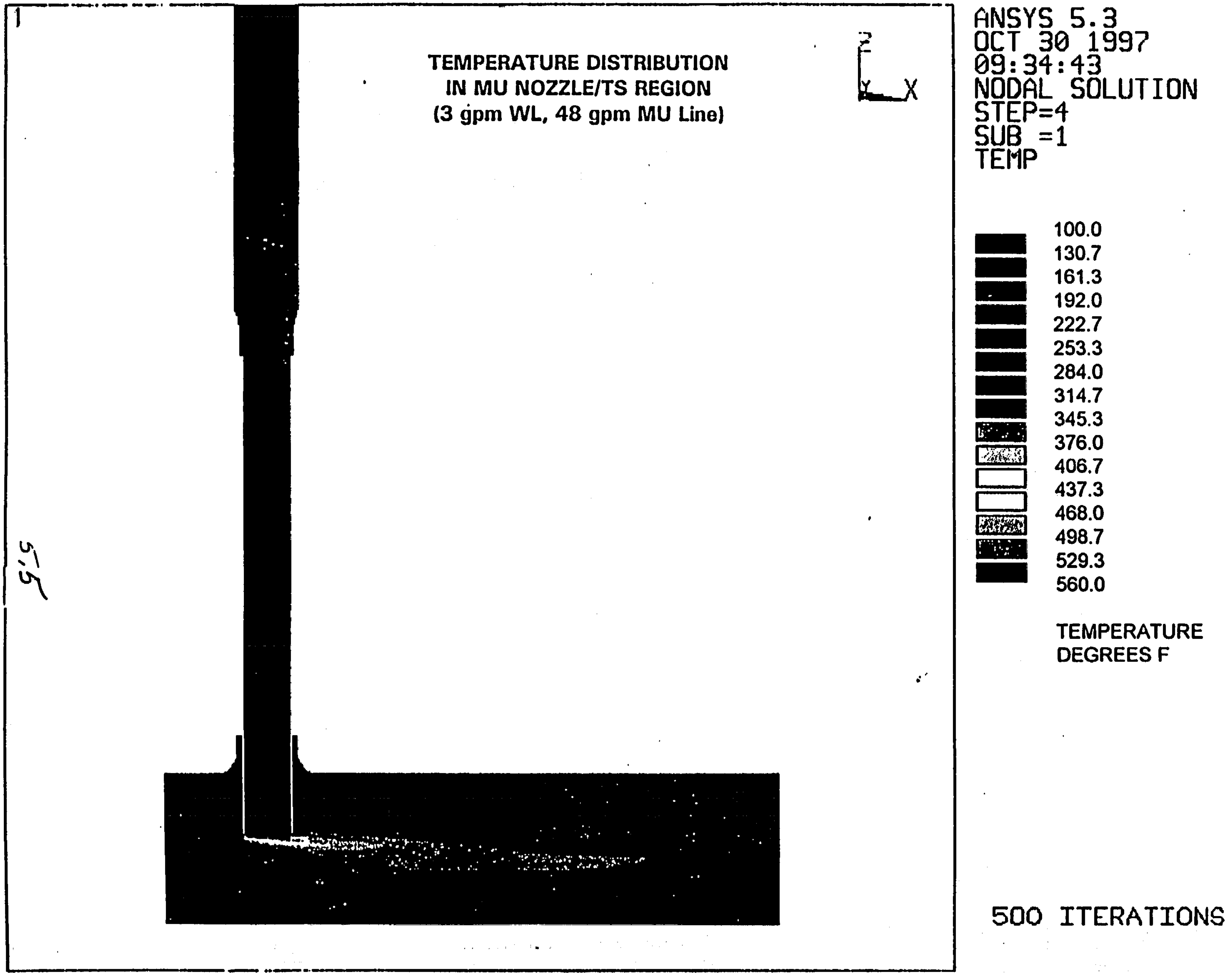


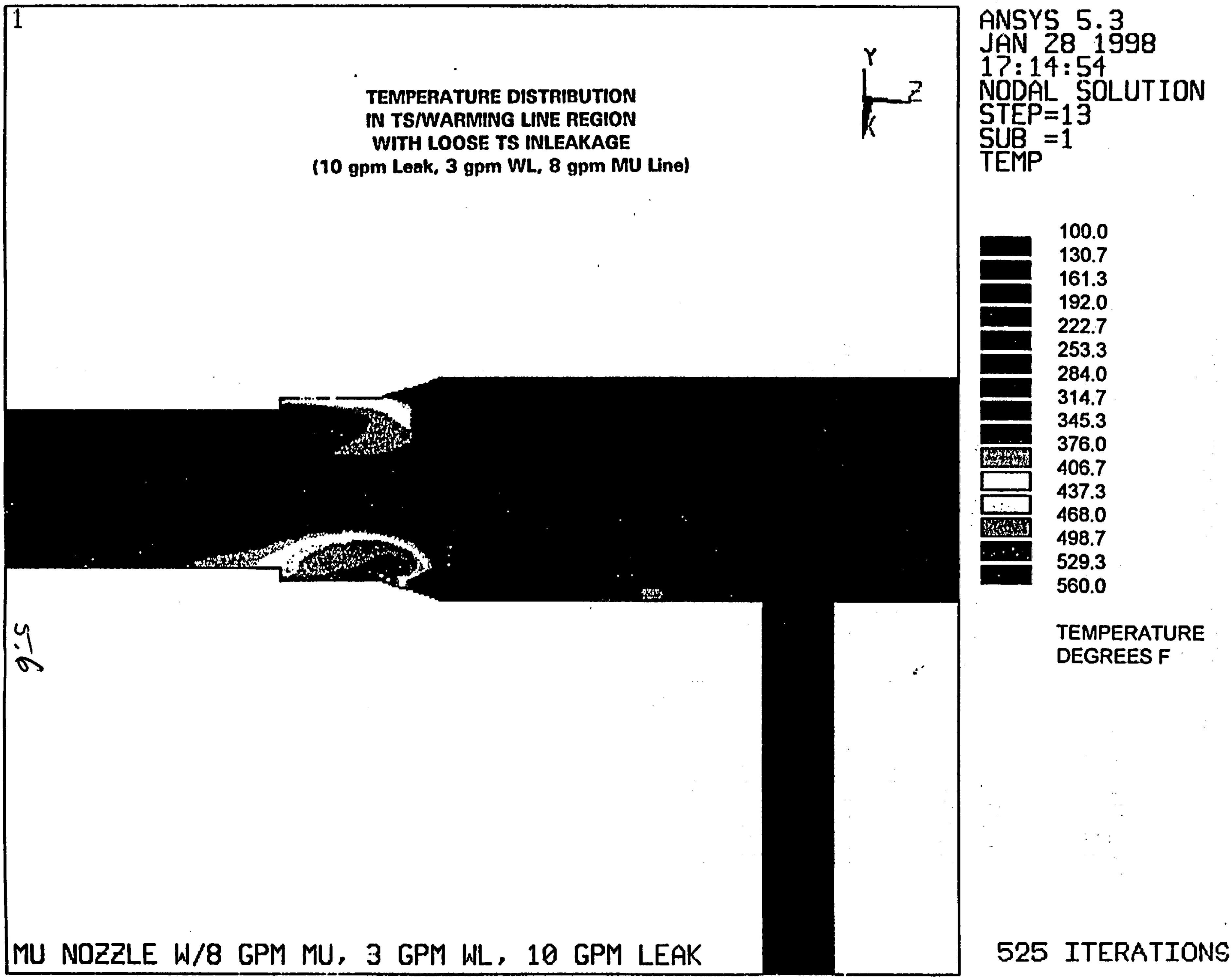
Predictions of Makeup Nozzle TH Interactions Using FLOTRAN

Source: FTI Doc. 32-5001590-00, "CFD Eval. of Thermal-Hydraulic Conditions in MU Nozzle/Thermal Sleeve" (December, 1999).




TEMPERATURE DISTRIBUTION
IN MU NOZZLE/TS REGION
(3 gpm WL, 0 gpm MU Line)
WARMING LINE LOCATION
WELD LOCATION
Z
X
ANSYS 5.3
AUG 12 1997
11:46:25
NODAL SOLUTION
STEP=11
SUB =1
TEMP
YV =-1
*DIST=16.2
*XF =7.3
*ZF =23.6
VUP =Z
SECTION
EDGE
100.0
130.7
161.3
192.0
222.7
253.3
284.0
314.7
345.3
376.0
406.7
437.3
468.0
498.7
529.3
560.0
TEMPERATURE
DEGREES F
1000 ITERATIONS


1
TEMPERATURE DISTRIBUTION
IN MU NOZZLE/TS REGION
(3 gpm WL, 48 gpm MU Line)
Z
Y
X
ANSYS 5.3
OCT 30 1997
09:34:43
NODAL SOLUTION
STEP=4
SUB =1
TEMP
100.0
130.7
161.3
192.0
222.7
253.3
284.0
314.7
345.3
376.0
406.7
437.3
468.0
498.7
529.3
560.0
TEMPERATURE
DEGREES F
500 ITERATIONS
5,5


1
TEMPERATURE DISTRIBUTION
IN TS/WARMING LINE REGION
WITH LOOSE TS INLEAKAGE
(10 gpm Leak, 3 gpm WL, 8 gpm MU Line)
Y
Z
X
ANSYS 5.3
JAN 28 1998
17:14:54
NODAL SOLUTION
STEP=13
SUB =1
TEMP
100.0
130.7
161.3
192.0
222.7
253.3
284.0
314.7
345.3
376.0
406.7
437.3
468.0
498.7
529.3
560.0
TEMPERATURE
DEGREES F
MU NOZZLE W/8 GPM MU, 3 GPM WL, 10 GPM LEAK
525 ITERATIONS

1.3 CONSTRUCTION OF TH PREDICTION TOOL

Detailed Purpose of Tool: Supply TH conditions appropriate for plant configuration and boundary conditions. Base prediction on CFD analyses plus supplementary data

Approach

- Identify Characteristics to Be Provided by Tool
- Estimate Dependencies of Characteristics
- Select Off-Nominal Conditions To Be Analyzed (Using CFD)
- Perform CFD Analyses. Supplement as Appropriate
- Examine Results, Verify Trends
- Correlate Composite Results

Farley Example -- Characteristics to Be Provided:

- Steady State

  Top, bottom, and average fluid and metal temperatures at limiting axial positions

  Interface elevation and thickness, stratified length

  ELTD: Equivalent linear metal temperature difference

  MaxDT4: Maximum difference between circumferential metal temperature and temperature from ELTD

  Metal temperature at MaxDT4

  Striping characteristics: Maximum amplitude, frequency distribution

- Transient: ΔT cycles -- amplitude and frequency

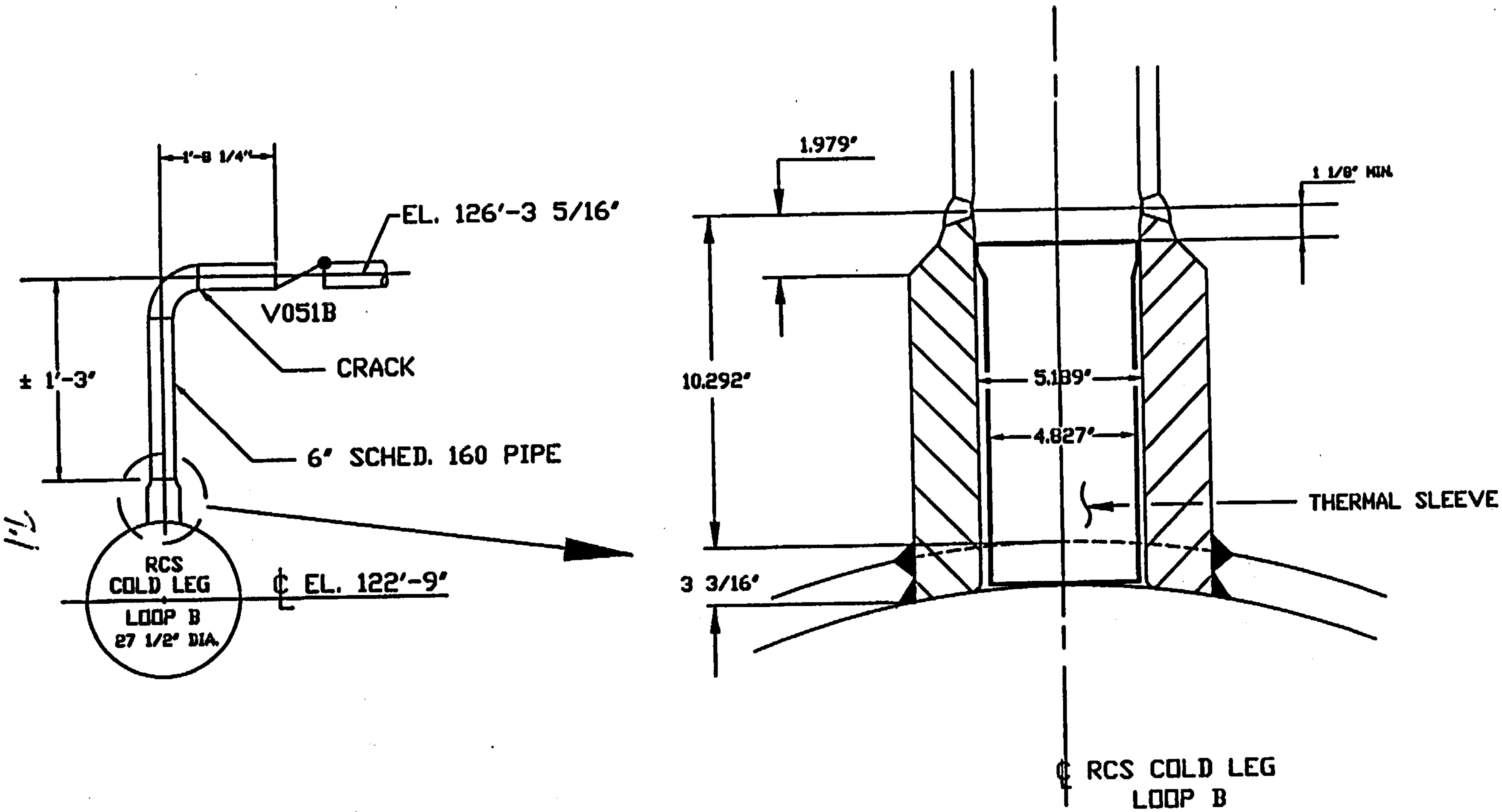
(Repeat information for each set of supplied conditions)

Estimated Variation of Fluid Temperatures with Leak Flow Rate (from MHI)

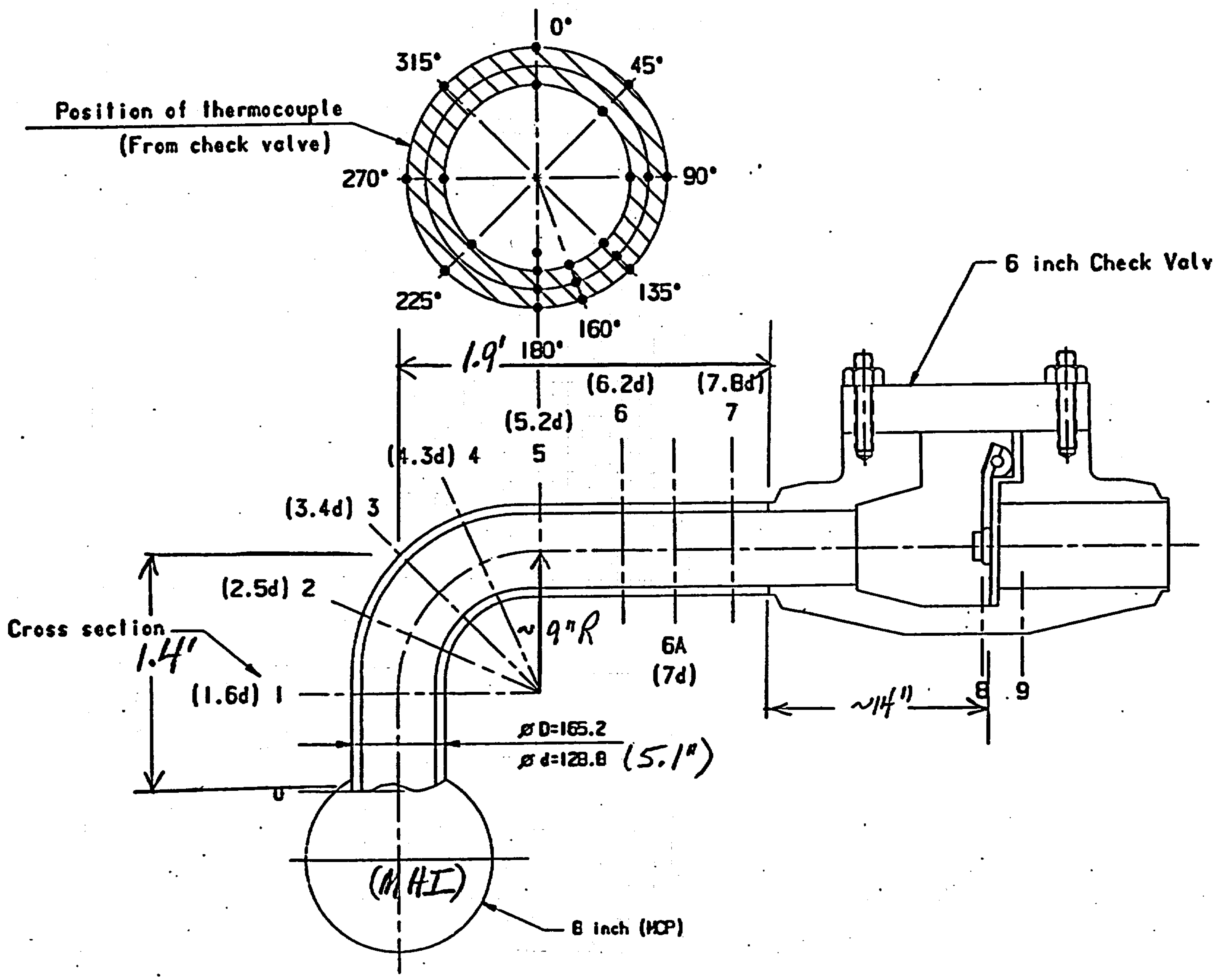
- Low flow rates: Top and Bottom temperatures remain at T_{hot}
- Increasing flow rates: Bottom begins to drop, approaching T_{cold} near 2 gpm, decrease most pronounced at check valve
- Higher flow rates: T_{Top} begins to drop, then line flushes (eliminating stratification)

[FIGURES: MHI and Farley layouts and data]

Farley-2 B Cold Leg Safety Injection

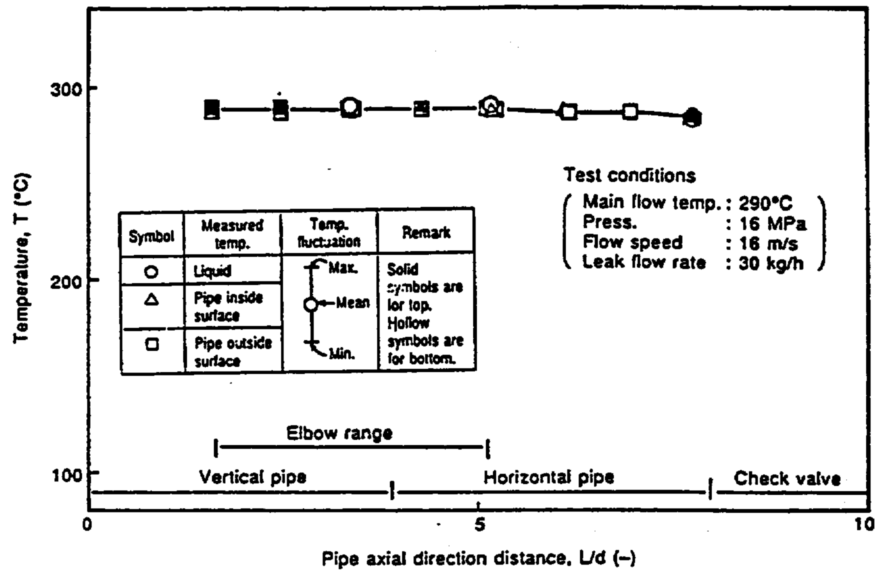


MHI Test Facility Showing Measurement Cross Sections

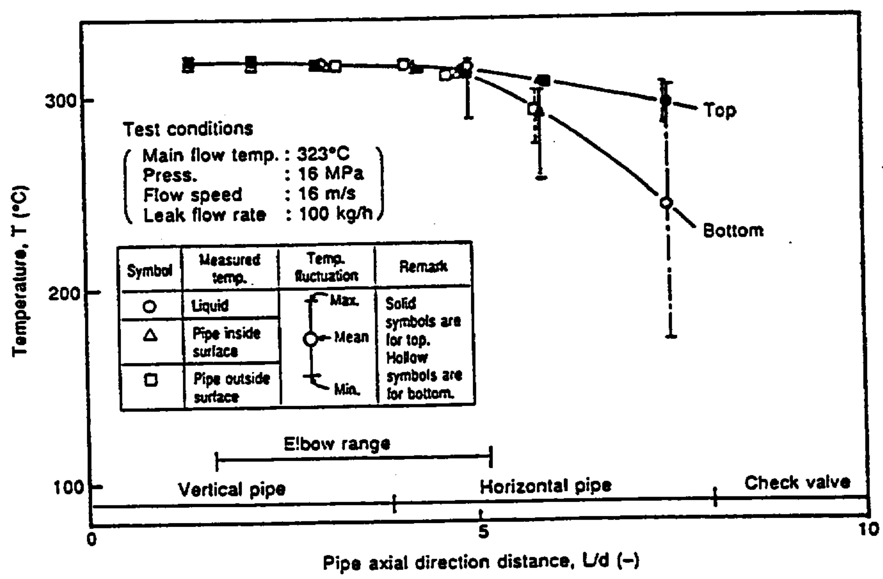


MHI Temperature Measurements at Three Leak Flow Rates

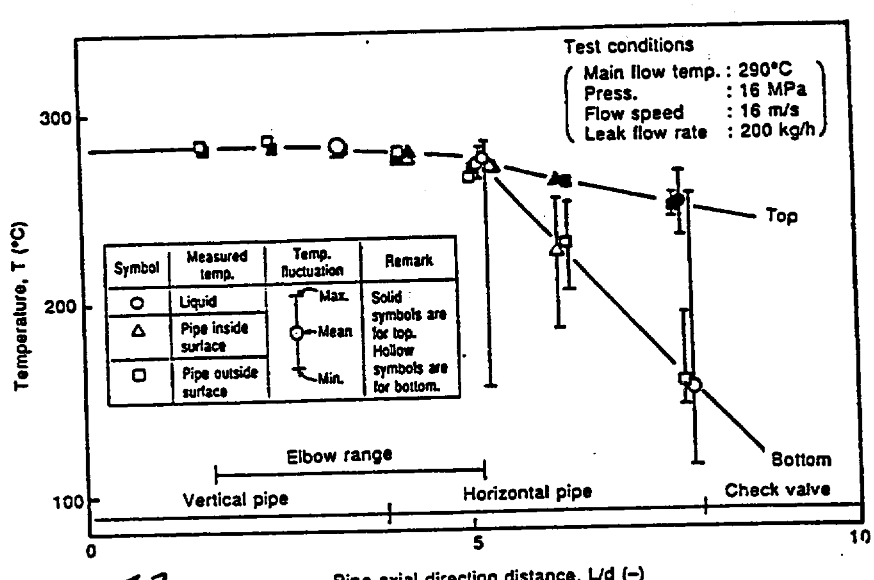
0.14 gpm



0.46 gpm



0.91 gpm



7.3

2.1 INITIAL APPLICATION: MHI/FARLEY

- Benchmark CFD prediction to MHI measurements[4]
  - Vary leak flow rate and main flow rate
  - Demonstrate ability to predict trends:

    ΔT magnitudes

    Periodic behavior

- Predict Farley Temperature Measurements (vary leak flow rate)
- Perform Additional Analyses to Complete Database
- Construct Prediction Tool, Combine with Stress & Fatigue Algorithm
- Predict Fatigue Usage at Selected Conditions

[4] The MHI tests are singular -- they include main pipe turbulence at plant-typical TH conditions.

2.2 MHI-FARLEY PARADOX

Paradox: Cracks occurred at locations removed from most limiting stratified conditions
- MHI Tests: Maximum ΔT & thermal cycling at check valve
- Farley: Cracks occurred at weld upstream of elbow

TH Causes
- Thermal Sleeve[5]
  - Increased attenuation of turbulence
  - Increased interaction between counterflowing streams
- Unequal Piping Lengths
- Differences of Turbulent Characteristics
- Leak Flow Rate Differences
- Check Valve Performance Differences (Stability)
- Unequal RCS Pipe Diameters

Non-TH Causes (Assumption: ΔT at valve > ΔT at elbow)

	Weld @ Elbow	Weld @ Valve
Quality	1.7 stress riser	1.0 stress riser
Cycles	"a + b" cycles/hour	"a" cycles/hour
Moment	"x + y" in-lbs	"x" in-lbs
Other Fatigue	"0.a + 0.b"	"0.a"

Resolution
- Predict MHI Temperature Measurements
- Predict Farley Temperature Measurements (Post-Repair)
- Estimate Farley Fatigue (with Thermal Sleeve, Various Leak Flow rates)
- Assess Results

[5] Farley Safety Injection Line was equipped with a thermal sleeve. The thermal sleeve was dislodged before the leak event. Post-repair temperatures were measured without sleeve. A sleeve was not installed in the MHI tests

2.3 OTHER APPLICATIONS

- Turbulent Penetration

  CE Plant RHR Drop Line (stratification variations w/ power level)

  Mihama Excess letdown line

- Internal Natural Circulation

  Prairie Island 1 Auxiliary Spray Line

- Outleakage

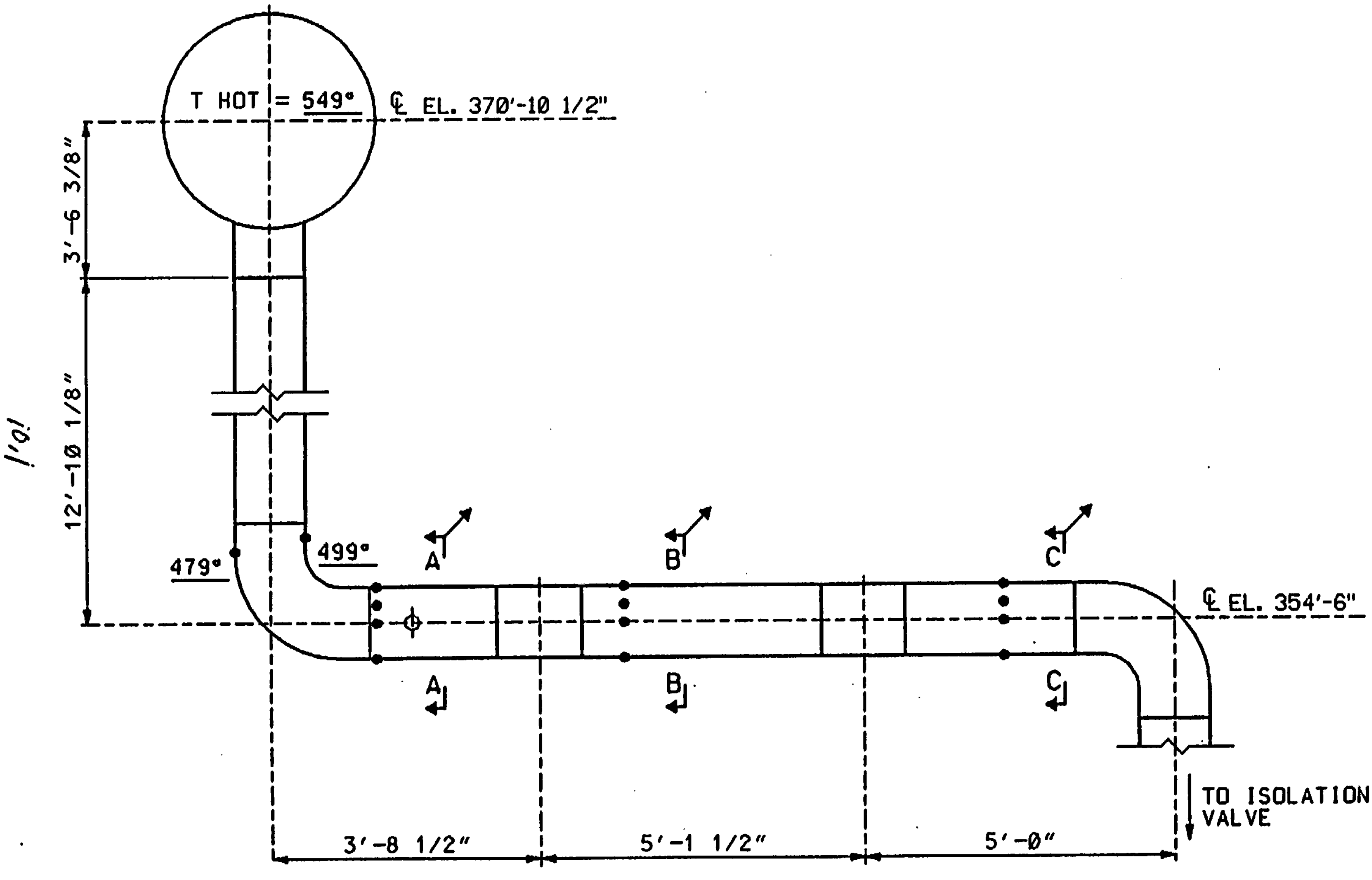
  Genkai RHR Line

  (Test Data available from several sources)

[FIGURES: Plant configurations, stratification test facilities]

ANO-2 Shut Down Cooling Line (14" Schedule 140)

Intermittent Turbulent Penetration Without Leakage

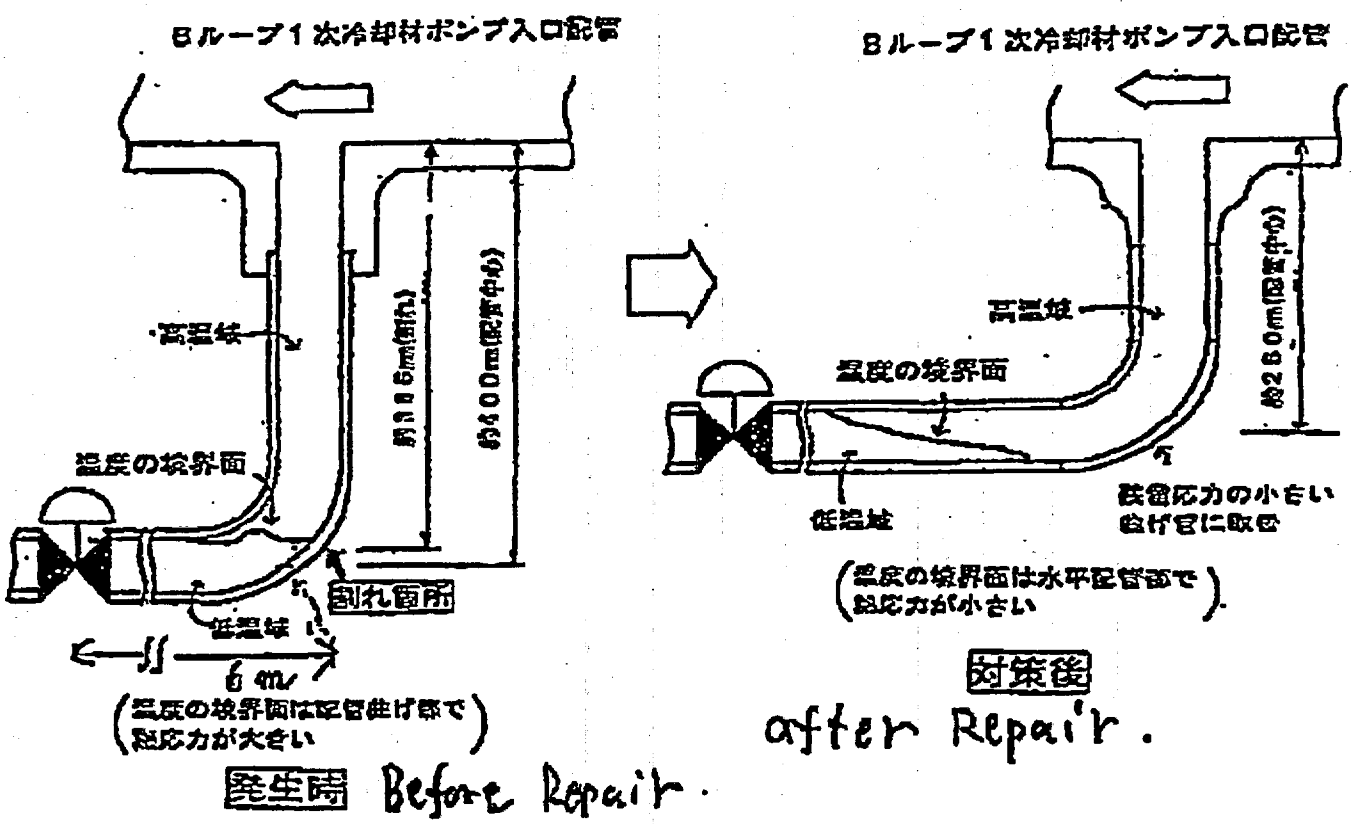


ELEVATION VIEW

Mihama-2 Excess letdown

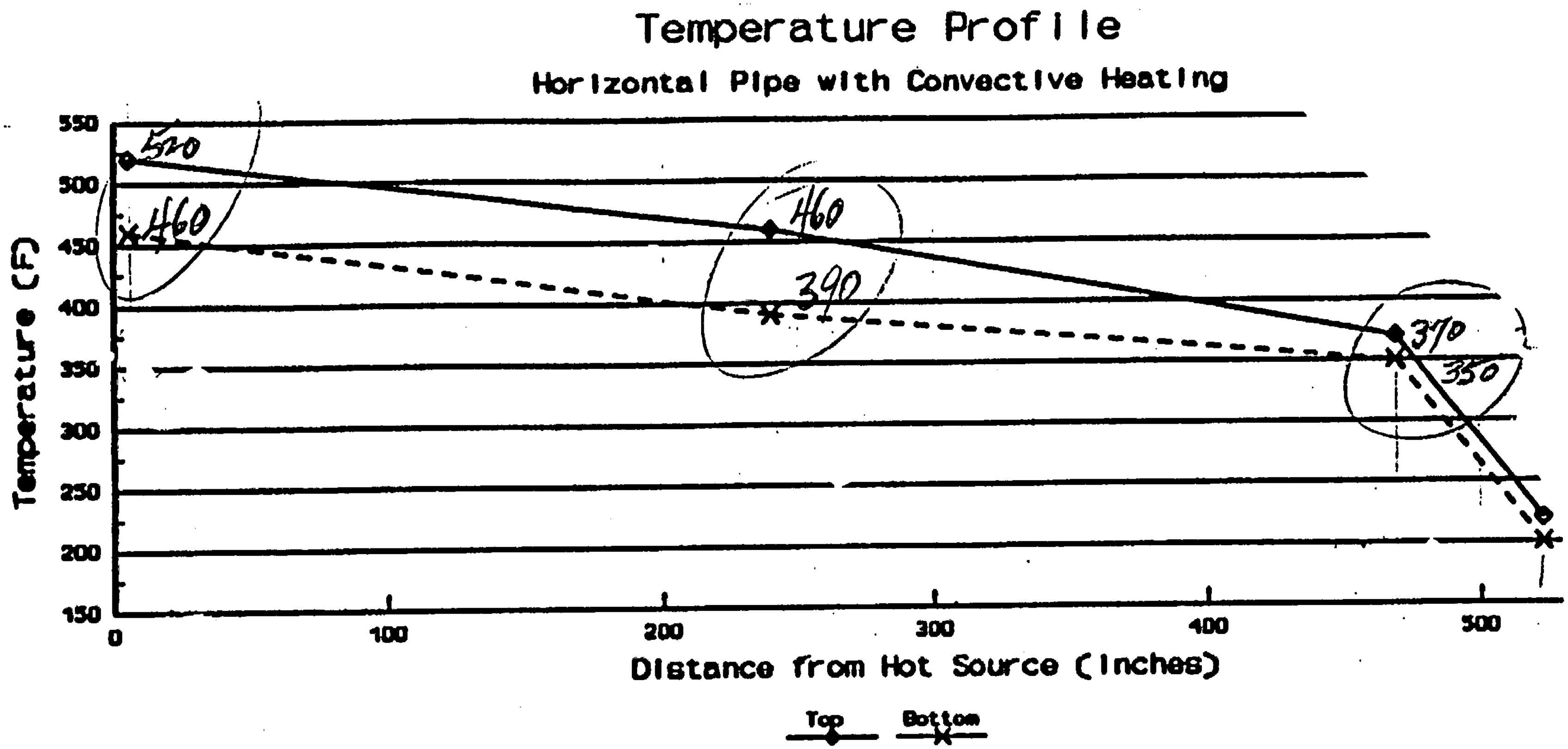
- Turbulent Penetration Without Leakage
- Repaired By Shortening Vertical Run

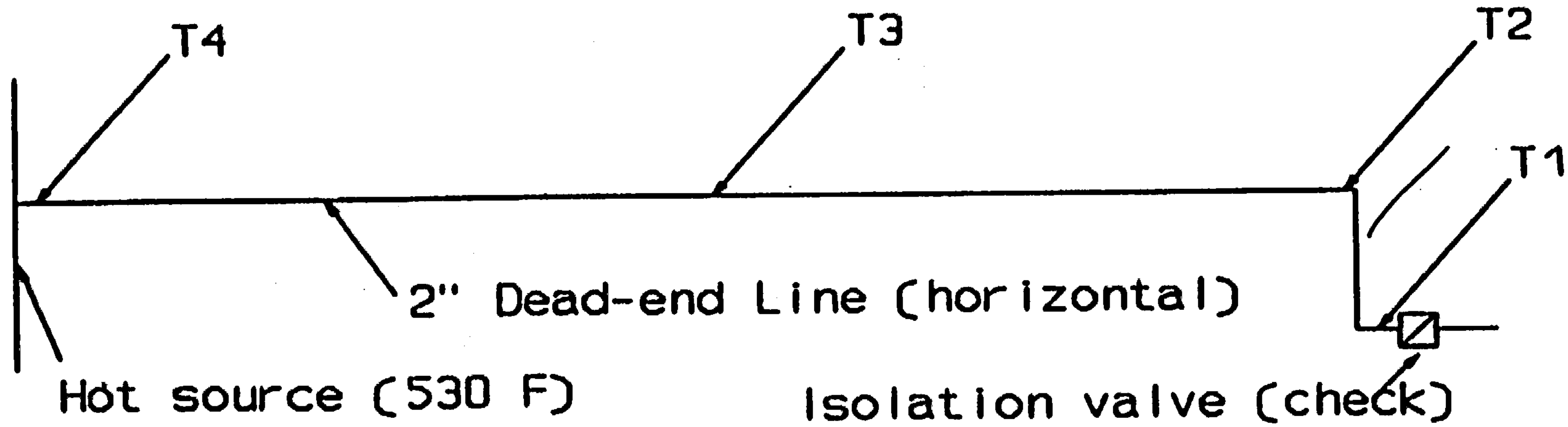
1次冷却水による温度の境界面の発生位置図



Prairie Island-1 Auxiliary Spray (40' x 2" Schedule 160)

Internal Natural Circulation Without Leakage



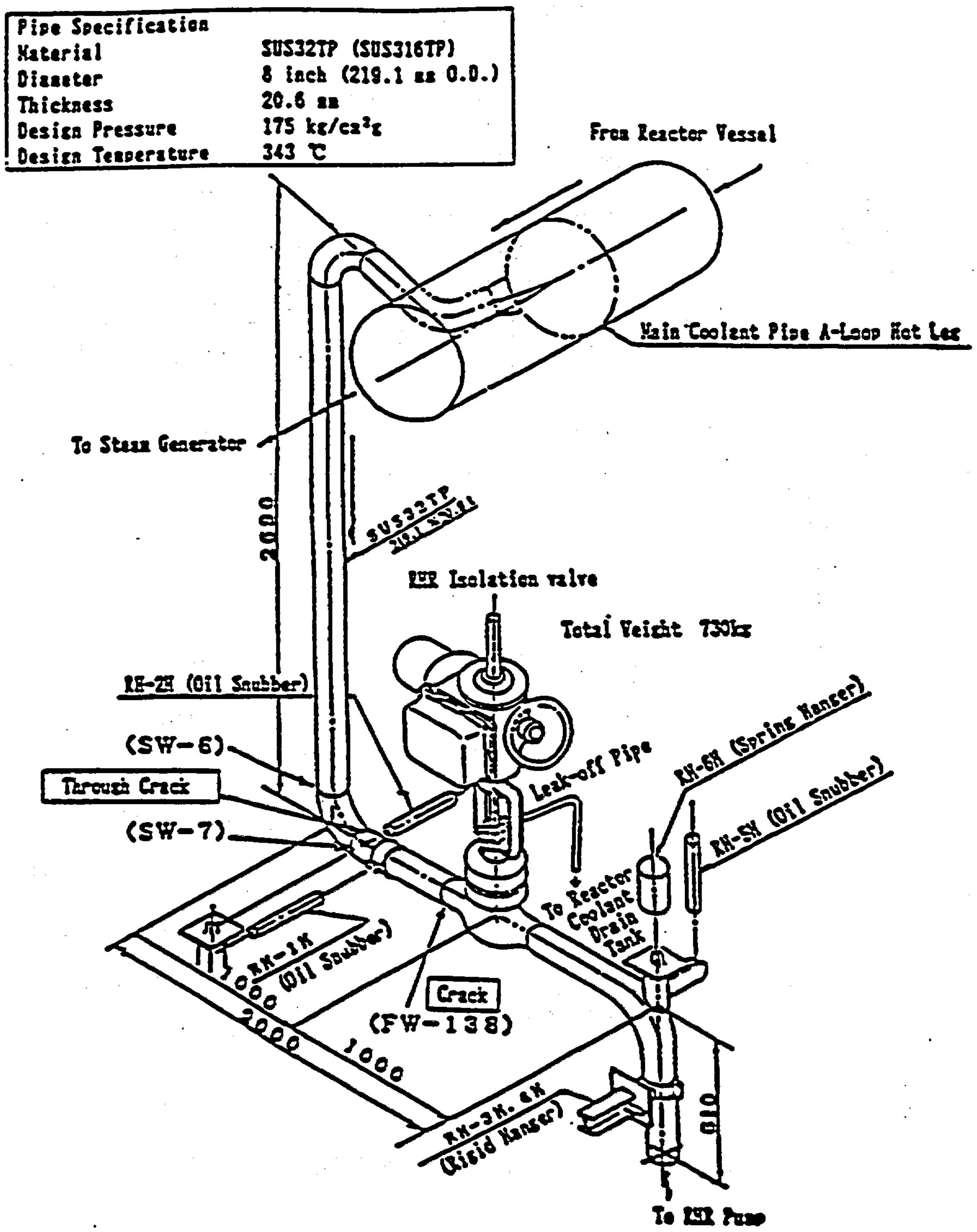


T1-T4 : Thermocouple locations

10.3

Genkai RHR

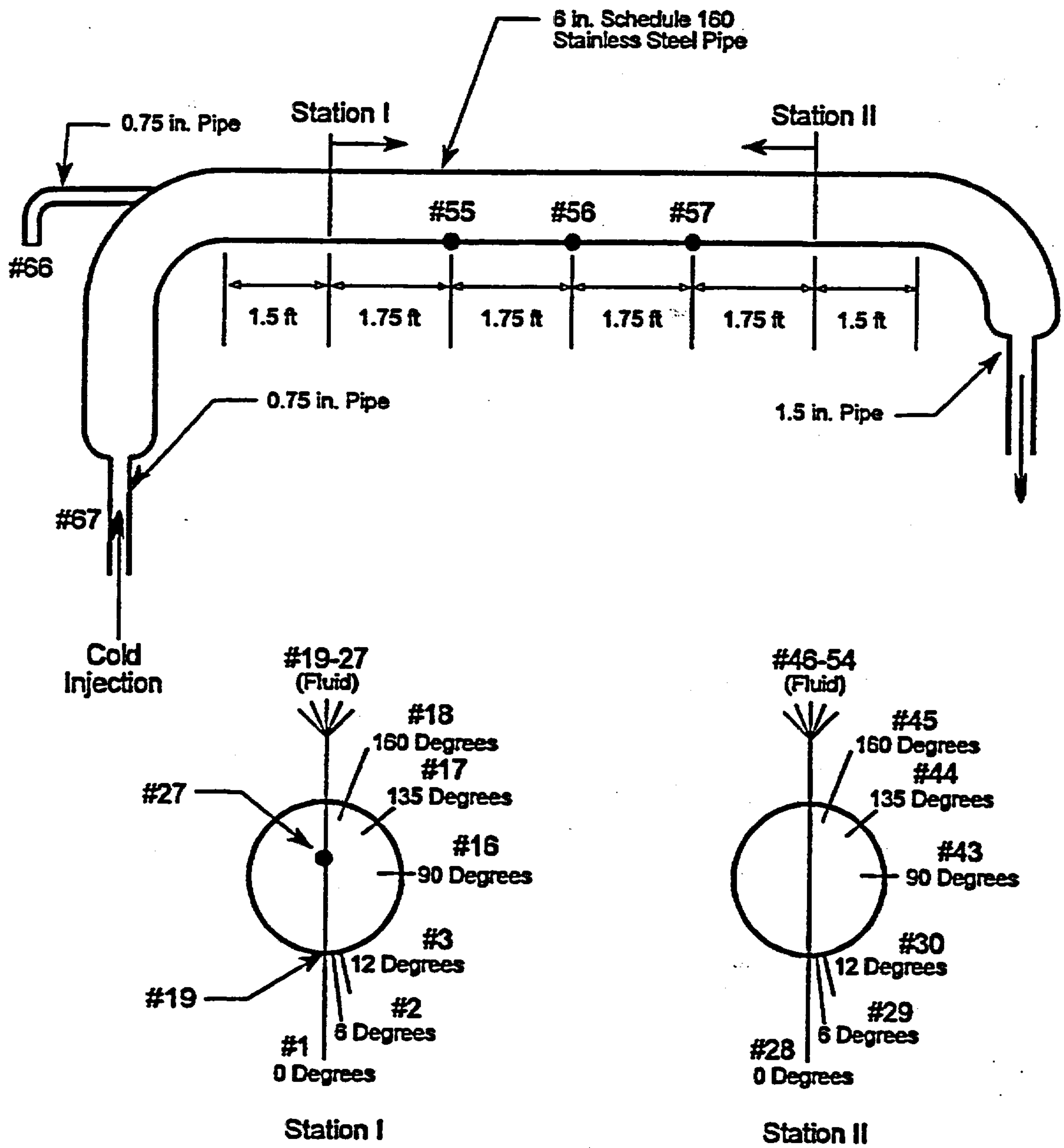
Outleakage (With Turbulent Penetration)



10.4

EPRI/TASCS High Temperature Stratification Test Facility
Source: EPRI TR-103581s (1994)

- 10' x 6" Schedule 160 Pipe
- 5 Tests
- Conditions
  Maximum ΔT: 510°F
  Imposed Cold Flow Rate: 0.2 to 8.5 gpm

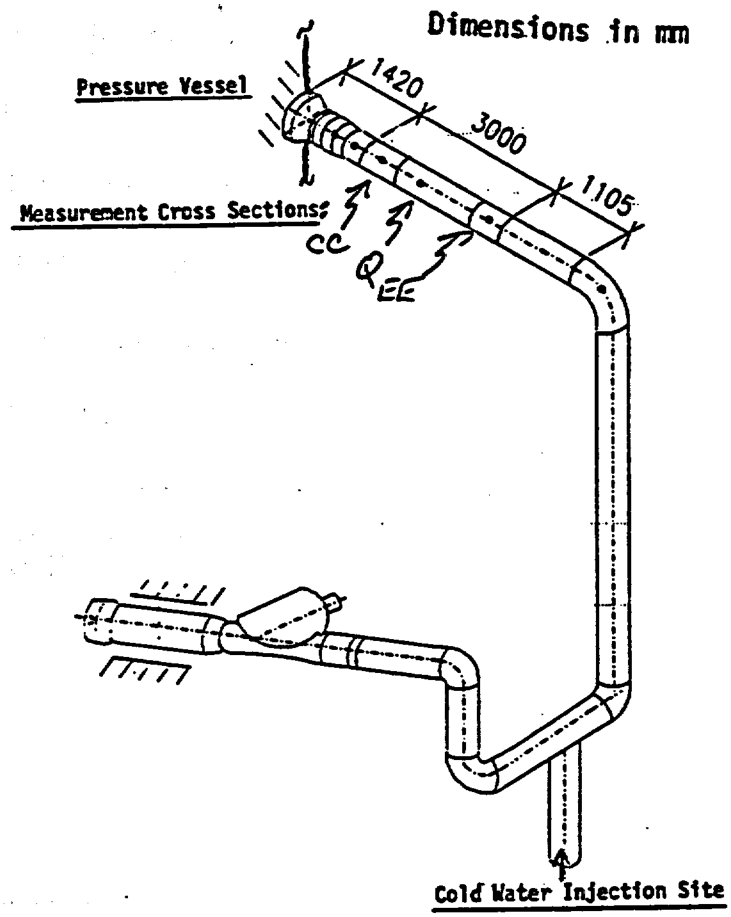


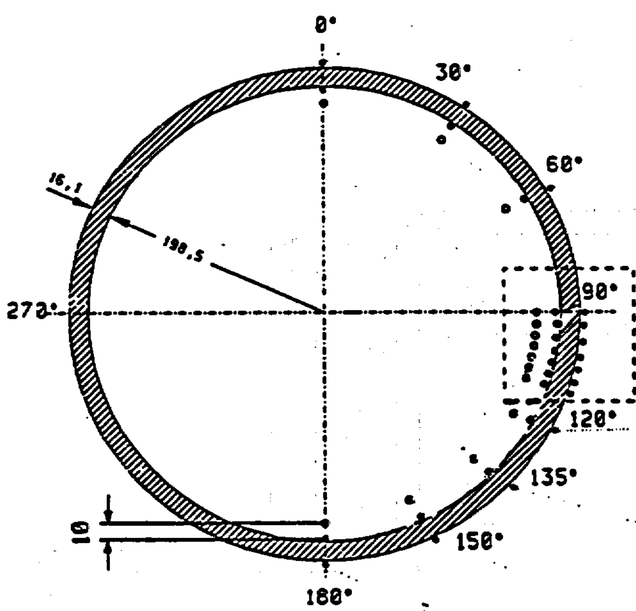
(Numbers 1 through 61 designate KK thermocouple number.)

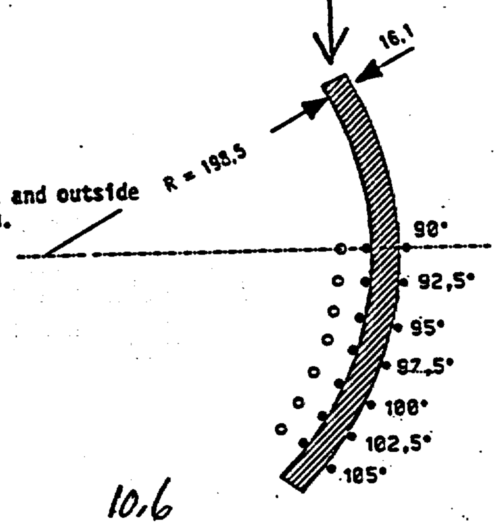
EPRI Proprietary Licensed Material

Battelle-FRG HDR-TEMR Test Section

- 18' x 15.6-in id Horizontal Pipe
- Data Recorded at 10 Hz
- 9 Sets of Test Conditions
- Conditions
  ΔT: 190 to 420°F
  Imposed Cold Flow Rate: 15 to 229 gpm





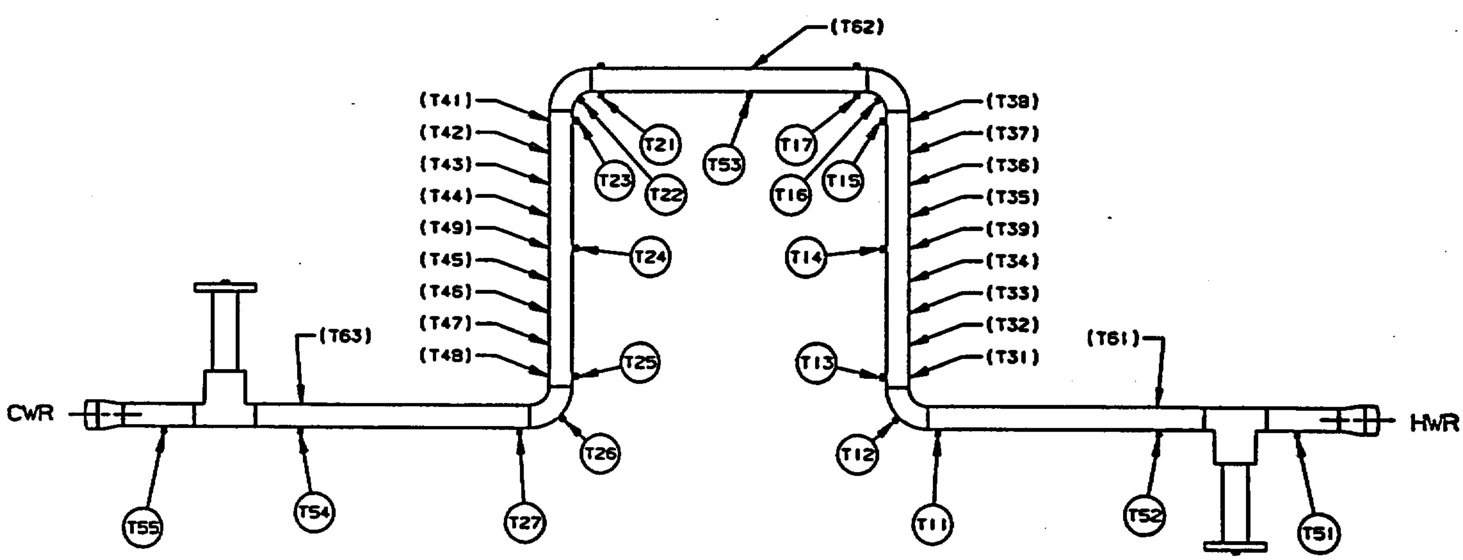


Thermocouple Placement
At Measurement Cross Section CC

Open circles denote fluid thermocouples.
Solid circles denote pipe inside surface and outside surface thermocouples. Dimensions in mm.

<u>B&WOG Stratification Test Facility</u>

- 21' x 4" Schedule 40 Pipe With 2 Full-Flow Gate Valves
- Straight or Inverted "U" Configuration
- Varied Valve Positions, Insulation, Inclination
- Observed Flushing, Effects of Bends and Verticals
- Approximately 100 Steady-State Data Points per Configuration
- Conditions
  Maximum ΔT: 300°F
  Imposed Flow Rate: 0.05 to 15 gpm (Hot or Cold)



THERMOCOUPLE LOCATIONS

- METAL TC LOCATIONS ARE SHOWN IN PARENTHESES
- EACH FLUID TC STALK CONSISTED OF 11 TCs
- METAL TC ARRAYS T31-T38 AND T41-T48 CONSISTED OF 2 TCs, THE REMAINING METAL TC ARRAYS CONSISTED OF 8 TCs

3. SUMMARY

- Configurations for Analyses to be Selected by Surveying Plants

- Data Base To Be Developed for Each Configuration Selected

  - CFD is primary tool

  - CFD to be validated using available data, trend analyses

  - Supplemented using existing plant and test data

- MHI/Farley Selected as Initial Configuration to be Analyzed

- Engineer Provided With Comprehensive Tool To Aid Evaluation of Thermal Fatigue in Attached Piping

MANAGEMENT OF PLANT LEAK EVENTS					
Events from Table 3-1 of NUREG/CR-6582. Mihama 2 and Tsuruga 2 from recent literature.					
PLANT	EVENT DATE	SYSTEM	LOCATION	CAUSE/DISCUSSION	MANAGEMENT TECHNIQUE
Crystal River 3	Jan-82	MU/HPI	Through-wall circumferential crack in safe end-to-check valve weld	Turbulent mixing and thermal striping due to loose thermal sleeve.	Thermal Sleeve
Obrigheim	1986	CVCS	Crack in weld in cold injection line between pipe bend and nozzle to RCS	Inleakage (w/ Turbulent Penetration?)	Tool
Farley 2	Dec-87	SInj	Crack in weld between horizontal and bend down to RCS	Turbulent Penetration and Inleakage. Defines the "Farley-Tihange" ("FT") Event	Tool
Tihange 1	Jun-88	SInj	Cracks in elbow down from check valve to RCS HL	Similar to Farley Tihange	Tool
Genkai 1	Jun-88	RHR	Weld cracks, elbow to horiz'l and horiz'l to isolation valve	Outleakage (w/ Turbulent Penetration?)	Tool
Dampierre 2	Sep-92	SInj	Through-wall circum'l crack to weld on downstream side of check valve	Similar to Farley Tihange	Tool
Loviisa 2	May-94	Aux Spray	Through-wall axial crack in valve body	Two-phase stratification	Two Phase
Biblis-B	Feb-95	CVCS	Between cold injection check valve and hot/cold tee	Measured higher-frequency vibrations (from RCPs) and cyclic thermal stratification. Crack attributed to incorrect snubber installation and vibrations.	Mechanical
Three Mile Island 1	Sep-95	CL Drain	Leak in weld on downstream end of 2" x 1-1/2" reducing elbow to horizontal	Turbulent Penetration (w/ Thermal Growth of RCS CL).	Tool
Dampierre 1	Dec-96	SInj	Through-wall circum'l cracks on horiz'l pipe between check valve & HL	Similar to Farley Tihange	Tool
Loviisa 2	Jan-97	HL Drain	Cracks in 2 separate small lines to 2 HLs	Low-cycle fatigue mechanism unknown. Possibly outleakage w/ thermal expansion of valve internals and missing thermal insulation.	Tool
Oconee 2	Apr-97	MU/HPI	Circumferential crack in safe-end to MU/HPI pipe weld upstream of nozzle	Turbulent mixing and thermal striping due to loose thermal sleeve.	Thermal Sleeve
Civaux 1	May-98	RHR	Crack in pipe elbow in RHR bypass system near hot-cold fluid junction	High-cycle thermal fatigue due to prolonged operation w/ large temperature difference between fluids mixing beyond heat exchanger, plus thermal striping.	Can Be Isolated
Tsuruga 2	Jul-99	CVCS	Crack in elbow of inter-heat-exchanger piping	Tentatively attributed to design flaw	Can Be Isolated
Mihama 2		Excess Letdown	Crack in elbow to horizontal	Turbulent Penetration (w/ Outleakage?)	Tool

MRP TF-ITG Thermal Fatigue Program
Task 3

Thermal Fatigue Operating Experience

Art Deardorff

Structural Integrity Associates

1/12/2000

PRS-99-070

Task 3 - Thermal Fatigue Operating Experience
OBJECTIVES

- ➤ Collect/Compile Experience on Thermal Fatigue
  - ➤ Small bore piping
  - ➤ Non-isolable
  - ➤ Foreign/Domestic
- ➤ Establish means to effectively capture future experience
- ➤ Experience = leaks + cracking + anomalies*

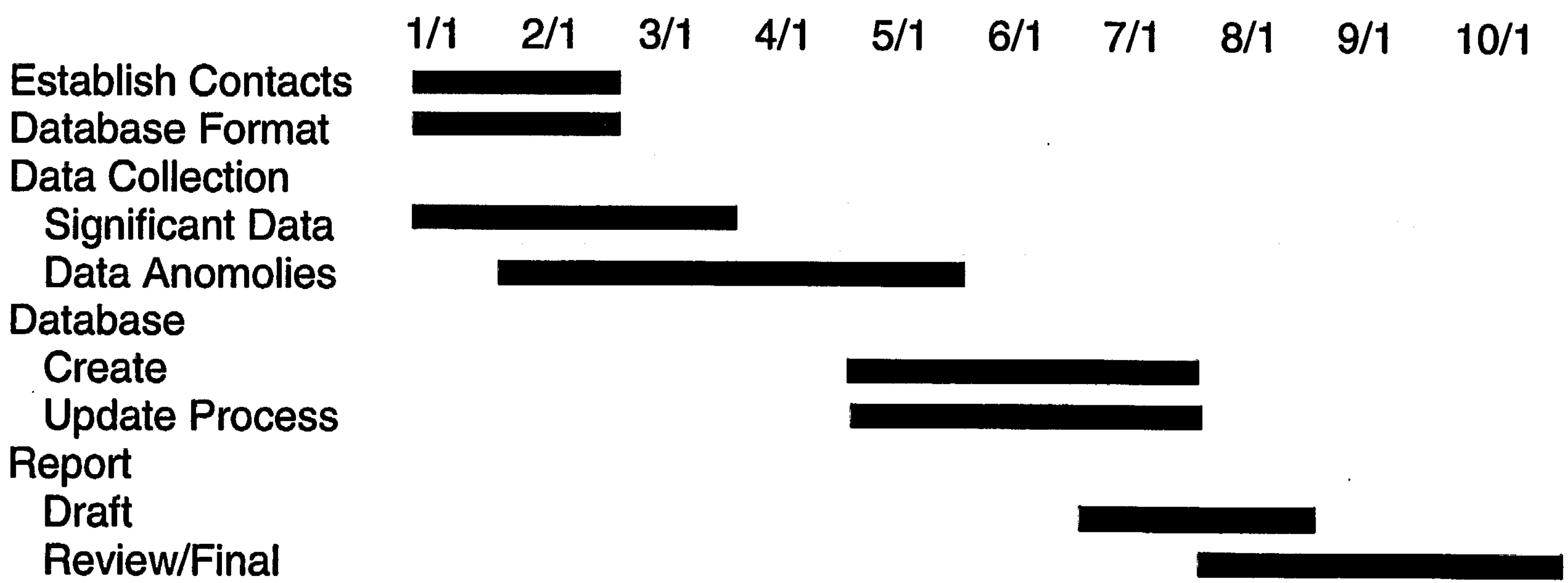
* Items not triggering an LER

Task 3 - Thermal Fatigue Operating Experience
SUBTASKS

- Identify utility/vendor contacts
- Establish format/content for data collection
- Collect plant information
  - Significant events
  - Thermal anomalies
- Establish EPRI-WEB thermal fatigue database and update process
- Final report

Task 3 - Thermal Fatigue Operating Experience
SCHEDULE

Year 2000



Task 3 - Thermal Fatigue Operating Experience STATUS

- Work Initiated 1/3/2000
- Preliminary List of Utility Contacts Prepared
  - for EPRI/TF-ITG review and input
- Preliminary Data Format Developed
  - for discussion at this meeting
  - only limited review of TF-ITG

Task 3 - Thermal Fatigue Operating Experience
CONTACTS

- Preliminary Utility Contact List is to Include:
  - RCS System Engineer
  - Piping Design Engineer
  - Engineer Responsible for Fatigue Issues
- Preliminary List Prepared from EPRI Programs + SI Contacts
- Next Step is to Get Review by TF-ITG and Utilities
- List of other Contacts to be Developed
  - NSSS Suppliers + Other Industry Experts

Task 3 - Thermal Fatigue Operating Experience
PRELIMINARY DATABASE FORMAT

- Plant/Unit/NSSS Supplier
- Plant System
- Operating Experience Type
  - Through Wall Leakage
  - Cracking/No Leakage
  - Observed Stratification/Cycling due to Inleakage
  - Observed Stratification/Cycling due to Outleakage
  - Observed Stratification/Cycling in Stagnant Line
  - Observed Stratification due to System Operation
  - Other (describe)
- Brief Description of Event/Observation (e.g., <100 words)

PRS-99-070

Task 3 - Thermal Fatigue Operating Experience
PRELIMINARY DATABASE FORMAT (cont'd)

- High Temperature Source (e.g., RCS Hot Leg)
- Conditions in High Temperature Source (e.g., temperature, velocity, diameter)
- Piping Segment Definition (up to 6 segments)
  - From/To (e.g., nozzle to short-radius elbow)
  - Orientation (e.g., horizontal/vertical/20 degrees from horizontal)
  - OD, ID, and Length
  - Welds (e.g., butt weld or socket weld)
  - Insulation or Not
- Isolation Valve/Type

Task 3 - Thermal Fatigue Operating Experience PRELIMINARY DATABASE FORMAT (concl'd)

- Narrative Report(s)
  - Formatted description as a minimum
  - Other "public information"
    - References
    - Linked PDF files
- EPRI WEB Database
  - Complete database
  - Links to PDF files
  - Links to NRC plant database
  - etc.

Interim Thermal Fatigue Management

Guidelines

Interim Thermal Fatigue Management Guidelines

- Objective
  - Common understanding with NRC on the Interim "TFMG" Guidelines
- Informational content of Guidelines
  - Recommended NDE method(s) for detecting thermal fatigue pipe damage
  - Procedural guidance for performing inspections for thermal fatigue damage
  - Examiner qualification guidance
  - Guidelines for pipe weld locations to inspect
- Availability of Guidelines
  - 9/2000 ITG Completion
- Use of Guidelines
  - Industry communications via EPRI, MRP, and NEI
  - Voluntary use of Guidelines by licensees

NRC Interface

- MRP TF-ITG requests NRC agreement with the adequacy of key MRP-TF products:
  - Interim TF Management Guideline (September, 2000)
  - Final TF Management Guideline (September, 2001

NRC Interface (Continued)

- NRC assistance requested for:
  - Access to International data
    - NDE
    - Thermal Fatigue Events (EDF, Japan)
- PNNL support
  - Acoustic Emission feasibility for detection of TF cracks
  - Fatigue crack growth rate and critical crack size data

NRC Interface (Continued)

- NRC participation in project activities (meetings, technical discussions, workshops) and TF-ITG product development
- Keith Wichman is primary interface with MRP TF-ITG

International Conference on Fatigue of Reactor Components

Preliminary Announcement

July 31-August 2, 2000
Silverado Country Club & Conference Center
Napa, California

Sponsored by:
EPRI
U.S. Nuclear Regulatory Commission
OECD NEA/CSNI (Organisation for Economic Co-operation and Development Nuclear Energy Agency/ Committee on The Safety of Nuclear Installations)

Overview
Fatigue is a primary degradation mechanism affecting nuclear power plant components worldwide. The effective management of fatigue is important to the continued safe operation of plant components during present operation and as plants consider long term operation. This conference is intended to bring together international experts to discuss significant fatigue issues affecting nuclear plant operations. Technical presentations and group discussions are anticipated in the following areas:

- Reactor water environmental effects
- Thermal fatigue resulting from unsteady thermal stratification
- Improvements in fatigue analysis methods
- Fatigue monitoring
- Vibration fatigue
- High cycle fatigue
- Fatigue-related Codes and Standards activities
- Nondestructive evaluation of fatigue cracks

Target Audience
Utility and plant managers, system engineers, materials engineers, structural integrity engineers, licensing engineers, and maintenance/repair engineers will benefit from attending this workshop. Vendor, consultant, university, and government personnel are invited to participate as well.

Accommodations and Travel
Just 45 minutes north of San Francisco in California's renowned Napa Valley lies Silverado. A historic, 1200 acre destination conference center set in the rolling, sunny hills of the wine country. This California landmark was built in the 1870s and offers two 18-hole golf courses, nine swimming pools, a spa and fitness center as well as an extensive tennis complex. Silverado has twice been honored California Resort of the Year. The 72-degree average temperature, abundant sunshine and clean, fresh air assure an exceptionally comfortable and relaxing visitor experience.

Persons attending the International Conference on Fatigue of Reactor Components must make their own hotel reservations. A block of rooms has been reserved for this workshop at the rate of $150/night. **To ensure accommodations at Silverado, contact the hotel directly by July 1, 2000.** After that date, neither availability nor the negotiated rate can be guaranteed, and attendees may be assessed the prevailing hotel rates.

Silverado
1600 Atlas Peak Road
Napa, CA 94558
+1 707.257.0200
http://www.silveradoresort.com
Room Rate: $150/night
Check-in: 4:00 PM; Check-out: 12:00 Noon

Registration

Attendance at the International Conference on Fatigue of Reactor Components will be limited. Advanced registration and payment are required. The registration fee includes continental breakfasts, luncheons, coffee breaks, and conference materials. Registration forms must be accompanied with payment. Cancellation notices in writing must be received by July 17, 2000; otherwise no refund will be granted. Substitutions are permissible.

Fee Structure

EPRI MRP Members/FPUG Members $200
EPRI Nuclear Power Group Members $250
Government, University and International Utility Personnel...............$400
EPRI Non-Nuclear Power Group Members.......................................$400
Ineligible Organizations* $450

(*includes consultants, vendors, and manufacturers)

Technical Contacts:

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John Carey
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E-mail: jcarey@epri.com

Meeting and Logistical Contact:

Susan Otto-Rodgers
Phone: +1 704.547.6072
Fax:+1 704.547.6168
E-Mail: sjotto@epri.com

A preliminary agenda and more detailed logistics are forthcoming. If you require additional information now regarding the meeting, please reply by e-mail to Susan Otto-Rodgers at sjotto@epri.com.

Registration

International Conference on Fatigue of Reactor Components
July 31-August 2, 2000
Silverado Country Club & Conference Center
Napa, California

Please print or attach business card:

Name

Title

Organization

Address

City / State / Zip

Country

Telephone

Fax

E-Mail

Please check the appropriate box:

☐ EPRI MRP Members/FPUG Members..$200
☐ EPRI Nuclear Power Group Members..$250
☐ Government, University and International Utility Personnel $400
☐ EPRI Non-Nuclear Power Group Members $400
☐ Ineligible Organizations* $450

(*includes consultants, vendors, and manufacturers)

Method of Payment--Registration Fees Must be Paid in Advance

☐ Check Enclosed (made payable to EPRI)

☐ Credit Card (circle): American Express Master Card Visa

Account Number:

Expiration Date:

Signature

☐ Check here if you have a disability and may require accommodation to fully participate.
Do you have any special dietary requirements? If so, explain:________________

Please return this form to:
Susan Otto-Rodgers
EPRI
1300 Harris Blvd.
Charlotte, NC 28262
Phone: +1 704.547.6072
Fax: +1 704.547.6168