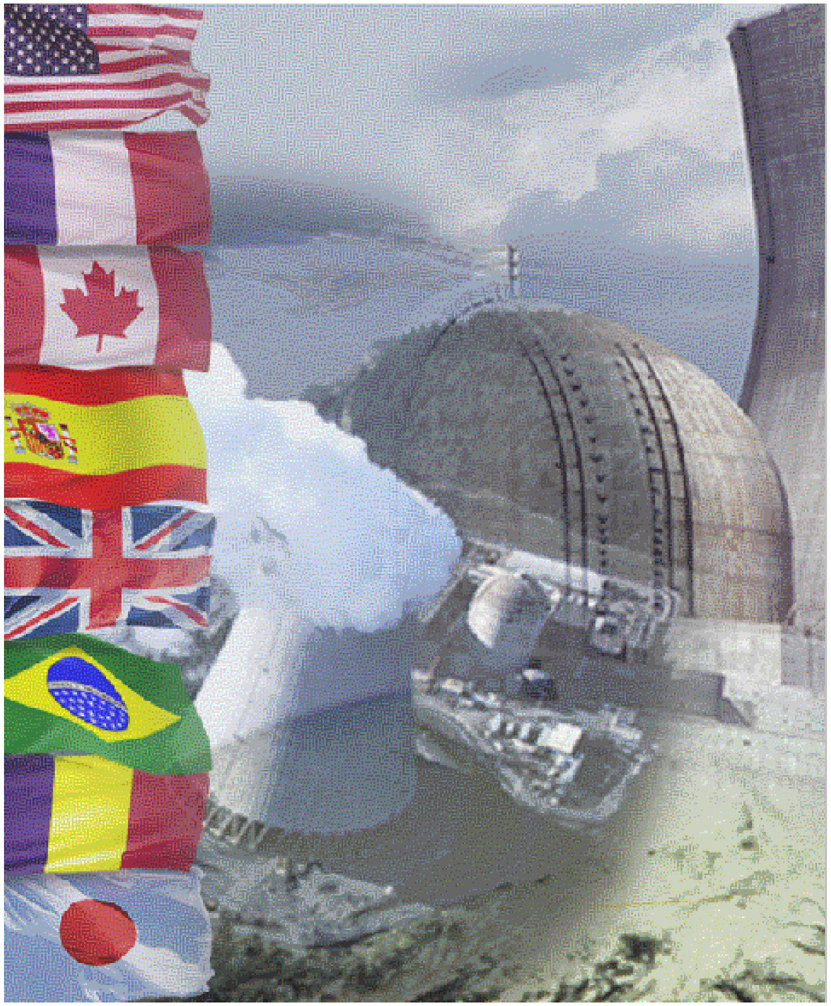
# Agenda for Meeting on Thermal Fatigue Guidelines
# May 24, 2005

| | |
|---|---|
| Meeting begin at 9:00 a.m. | |
| Welcome and introductions | NRC |
| Industry present content of thermal fatigue guidelines | NEI/MRP |
| NRC and industry discuss thermal fatigue guidelines | NEI/NRC |
| Public comments or questions | Public |
| Summary, staff comments, and conclusion | NRC |



# Thermal Fatigue Management Guideline For Normally Stagnant Non-Isolable Branch Lines

Les Spain – Dominion Generation
Jeff Keller—Continuum Dynamics, Inc.
Art Deardorff—Structural Integrity Associates
MRP/NRC Meeting

May 24, 2005

# Introduction and Agenda

- Meeting Objectives
- History
- Thermal cycling screening and evaluation model
  - Test/analysis program overview
  - Model development
  - Screening criteria for industry use
  - Benchmarking results
  - Model application to generic industry assessment
- Final guide assessment approach
  - Screening
  - Evaluation/Inspection
  - Implementation
- Summary
- Completed / Ongoing MRP Fatigue ITG activities

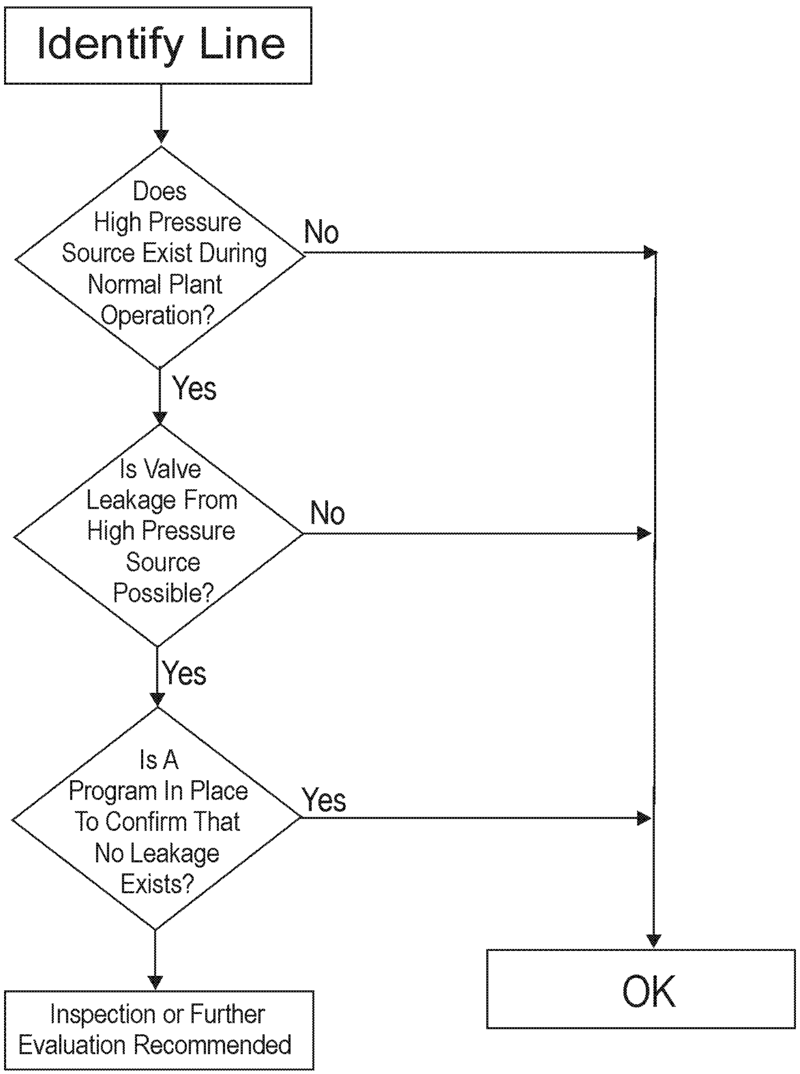
# Objectives

- Present Thermal Fatigue Management Guideline (TFMG)
  - History
  - Model Development
  - Guideline
  - Implementation
- ***We believe the TFMG is the ‘Right Stuff’ to close out the issue of pipe leaks due to thermal fatigue in unisolable RCS attached piping***
- Inform NRC of our progress and future plans
- Entertain comments / discussion
  - NRC approval not being requested

# Fatigue ITG History & Interim Guidelines

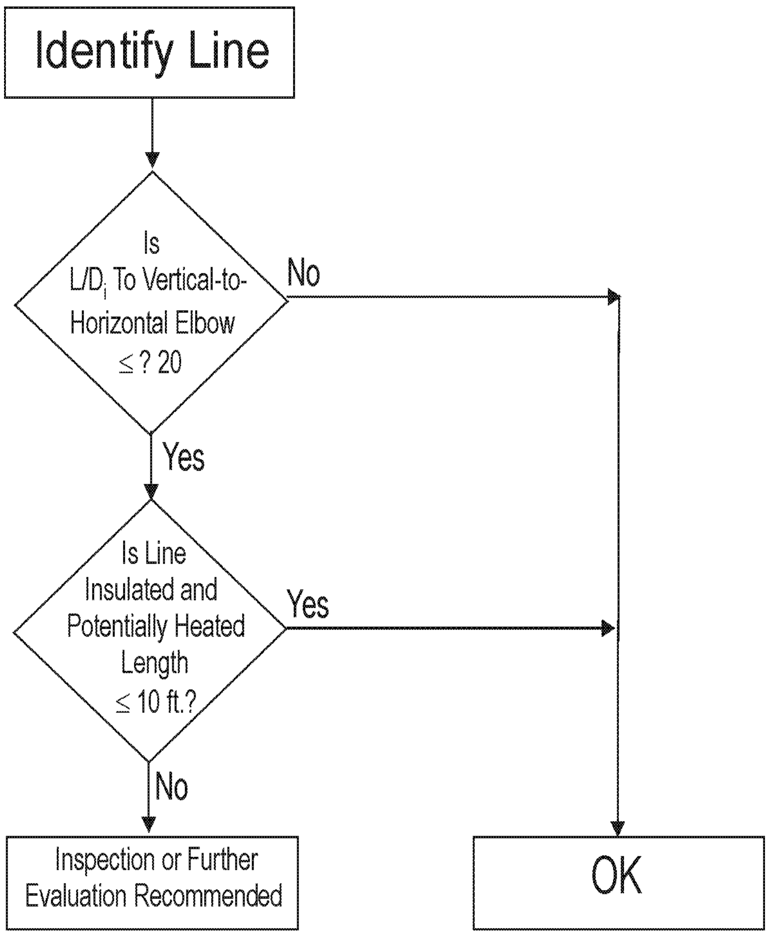
- Fatigue ITG formed in late 1999
  - Established to proactively address concerns with pipe leaks in unisolable piping attached to the RCS
- Interim guideline issued in 2001
  - Addressed lines which had exhibited leakage in service
    - High pressure safety injection lines
    - Drain and excess letdown lines
  - Provided screening criteria
    - Rules based on operating experience and limited experimental work
  - Provided inspection recommendations
  - No recommendations provided for:
    - Inspection interval
    - Other types of potentially susceptible lines

# Interim Guidelines For SI Lines




- Logic for Evaluation of SI Lines
  - Charging/make-up pumps are only high pressure source
  - Direct in-leakage from high pressure source not possible in many plants
  - Continued monitoring or in-leakage trending may confirm that in-leakage is not significant
- Inspections (if required)
  - only in horizontal piping between 5 to 20 diameters from loop pipe.

# Interim Guidelines For Drain Lines




- Drain line evaluation
  - Long vertical run would prevent heating of elbow
  - Short/insulated horizontal segments would not lose heat, such that ΔT would be small
- Monitoring or inspection (if required)
  - Only at vertical to horizontal elbow.

# Agenda

- Meeting Objectives
- History
- **Thermal cycling screening and evaluation model**
  - **Test/analysis program overview**
  - **Model development**
  - **Screening criteria for industry use**
  - **Benchmarking results**
  - **Model application to generic industry assessment**
- Final guide assessment approach
- Summary
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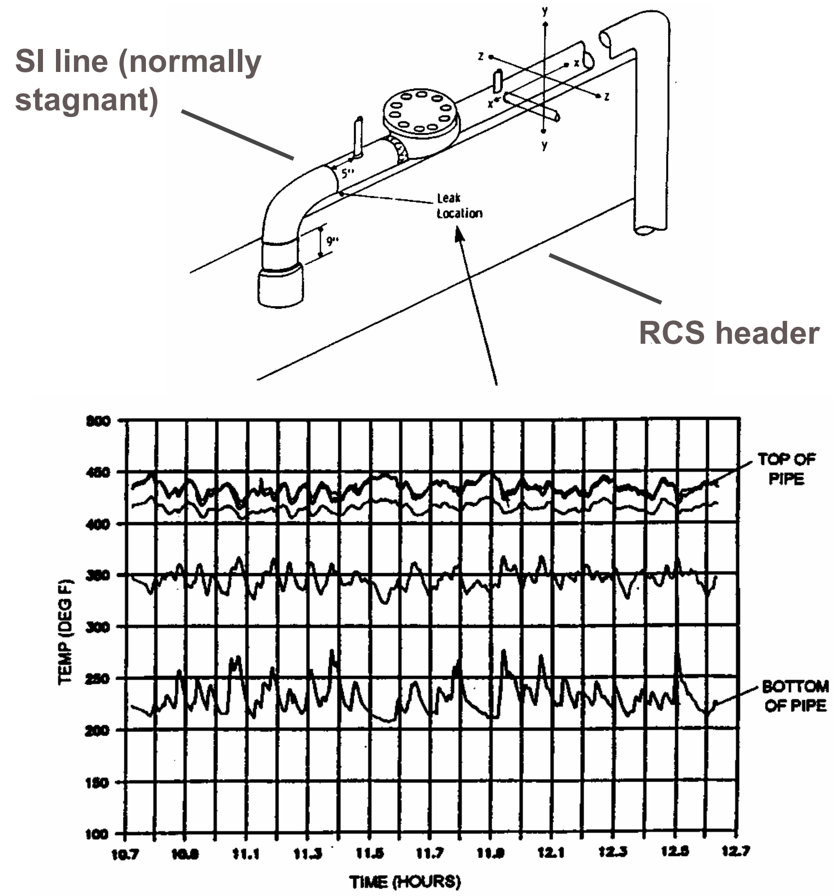
# Thermal Cycling Model Overview
## Motivation and Background

- Methods for thermal cycling screening/evaluation have been developed in support of Thermal Fatigue Management Guideline
  - Screening: Where (when) will thermal cycling occur and not occur?
  - Evaluation: What are the thermal loads for structural analysis (locations/heat transfer coefficients/frequency)?
- Scaled phenomenological testing significant part of model development program
- Primary outcome has been the development of a comprehensive evaluation methodology that builds upon prior work (EPRI TASCS program)

# Thermal Cycling Model Overview
## Prior Investigations

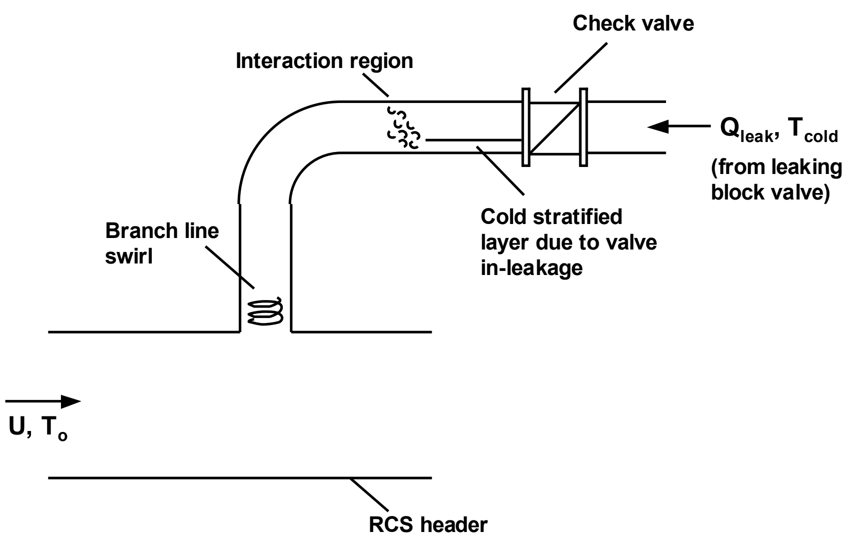
- Previous investigations:
  - EPRI thermal stratification, cycling and striping (TASCS) program (1989-1994)
  - Experimental programs (EDF, Japan)
  - Other efforts in response to NRC 88-08 and more recent leakage events
- Current modeling effort builds upon methods from prior investigations




*Farley SI Thermal Cycling Event (NRC 88-08)*

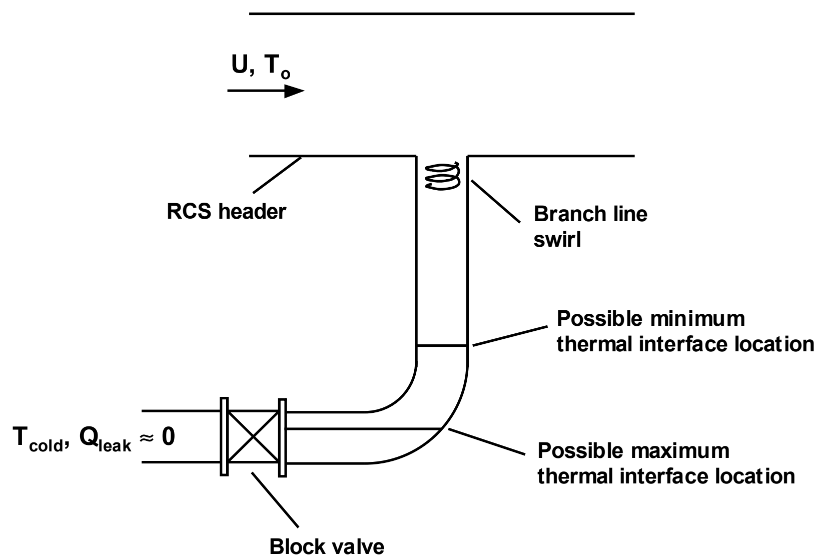
# Motivation and Background
## Branch Line Configurations and Mechanisms

- Approach separates screening/evaluation model into two basic configurations based on:
  - Geometry
  - Physical cycling mechanisms




*Up-Horizontal (UH) Configuration*

*Down-Horizontal (DH) Configuration*



# Motivation and Background
## Branch Line Configurations and Mechanisms

- Example configurations:
  - UH (valve in-leakage) –
    - SI lines (Farley, Tihange)
    - Charging/alternate charging
    - Some lines have only horizontal geometry (H configuration)
  - DH (“cold-trapped”) –
    - Drain/excess letdown (Mihama, Oconee, TMI)
    - RHR suction lines (Genkai)

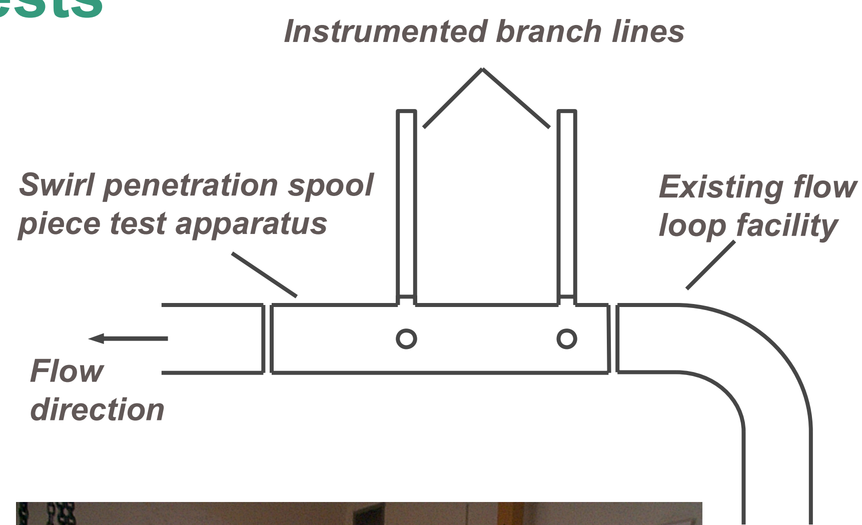
- Model considers two basic configurations (UH/H and DH); also addresses application to more complex lines

# Thermal Cycling Model Overview
## Scaled Phenomenological Tests

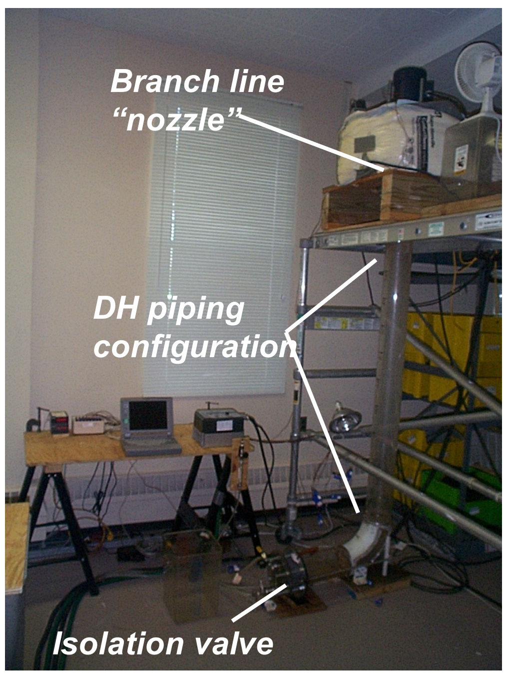
- Phenomenological testing played important role in overall model development program:
  - Identify mechanisms
  - Emphasis on qualitative and quantitative data
  - Model components given by engineering correlations
- Test program separated into several "sub-programs":
  - Low-temperature UH and H tests
  - Low-temperature DH tests
  - Swirl penetration tests (high Reynolds number)
  - Other "special effects" tests
- Test results documented in several EPRI MRP reports

# Thermal Cycling Model Overview
## Scaled Phenomenological Tests

- Simulate "branch line swirl" in low-temperature tests
- Characterize swirl in high Reynolds number tests




*DH Configuration Low Temperature Test Setup*

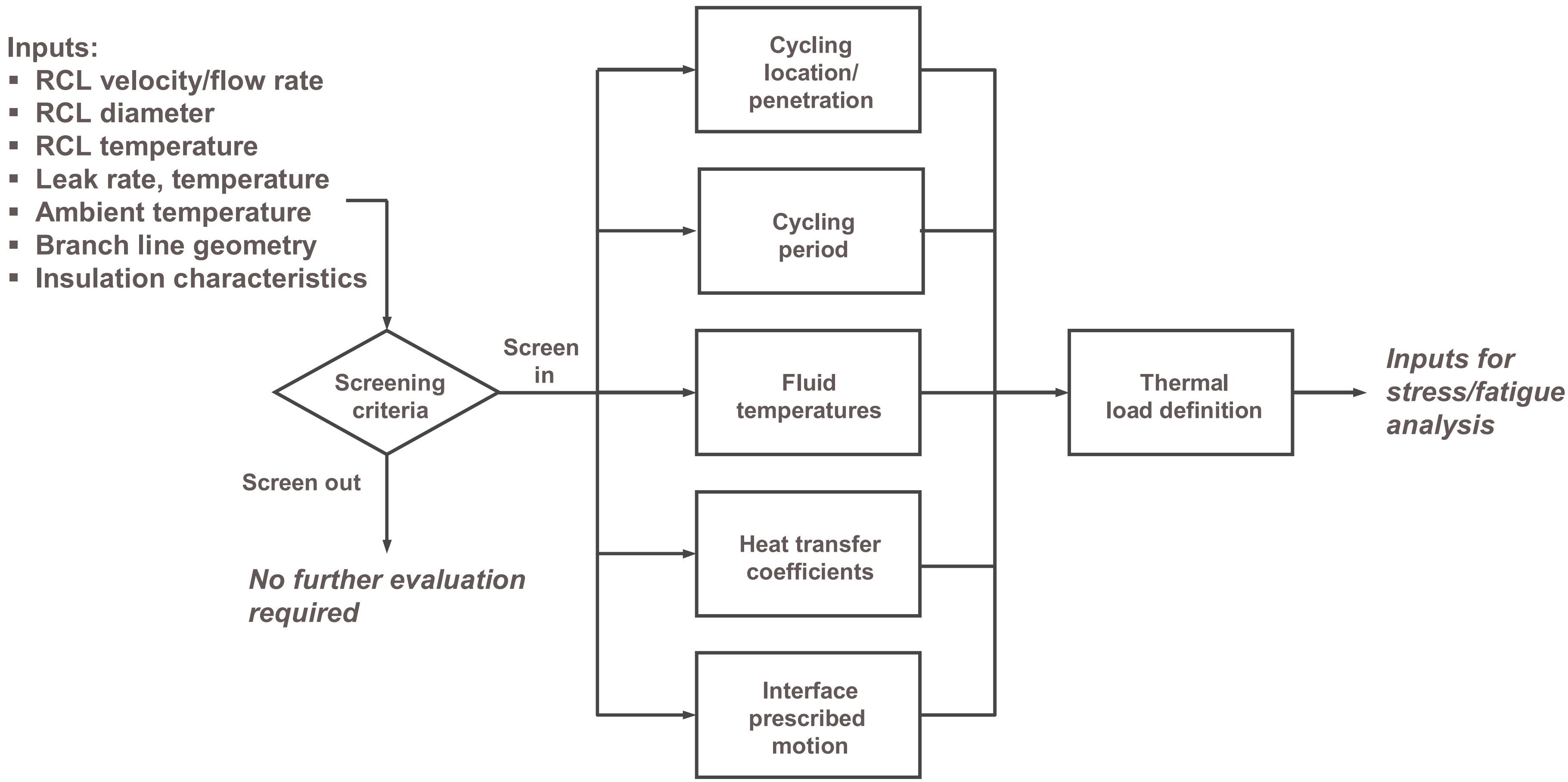



*High Reynolds Swirl Penetration Test Setup*

# Thermal Cycling Model Overview
## Overview of Model Structure

- Thermal cycling screening/evaluation model developed to:
  - Extend and improve current tools/models
  - Build upon methods from earlier EPRI TASCS program
- Key components that have been extended/improved:
  - Swirl penetration/cycling location prediction
  - Correlations to predict cycling period
- Conservative thermal loading defined for structural analysis:
  - Temperature in hot/cold fluid regions (assumed uniform)
  - Heat transfer coefficients in hot/cold regions
  - Prescribed (cyclic) motion of hot-cold fluid interface

# Thermal Cycling Model Overview
## Screening & Evaluation Model Structure



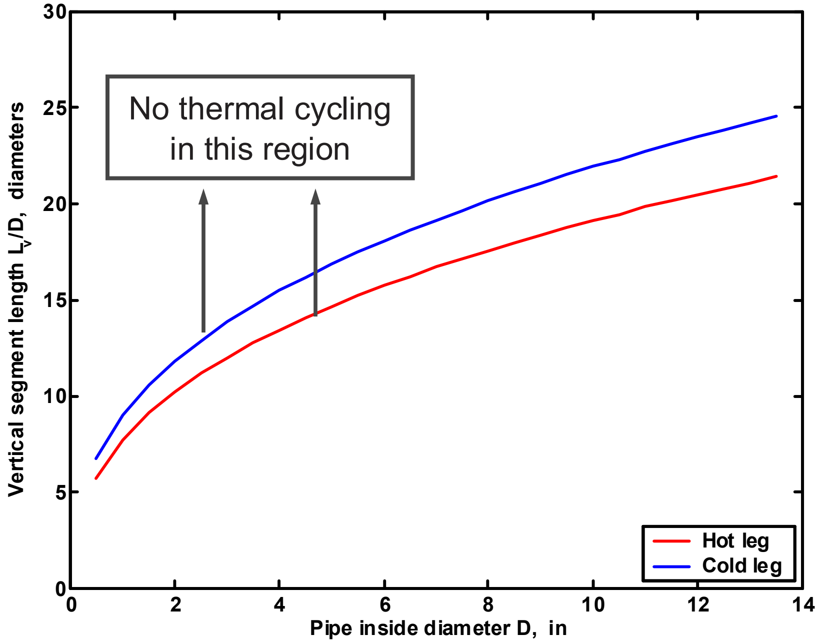

Note: Leak rate evaluated for UH/H; Insulation evaluated only for DH

# Thermal Cycling Screening Criteria
## Development Approach

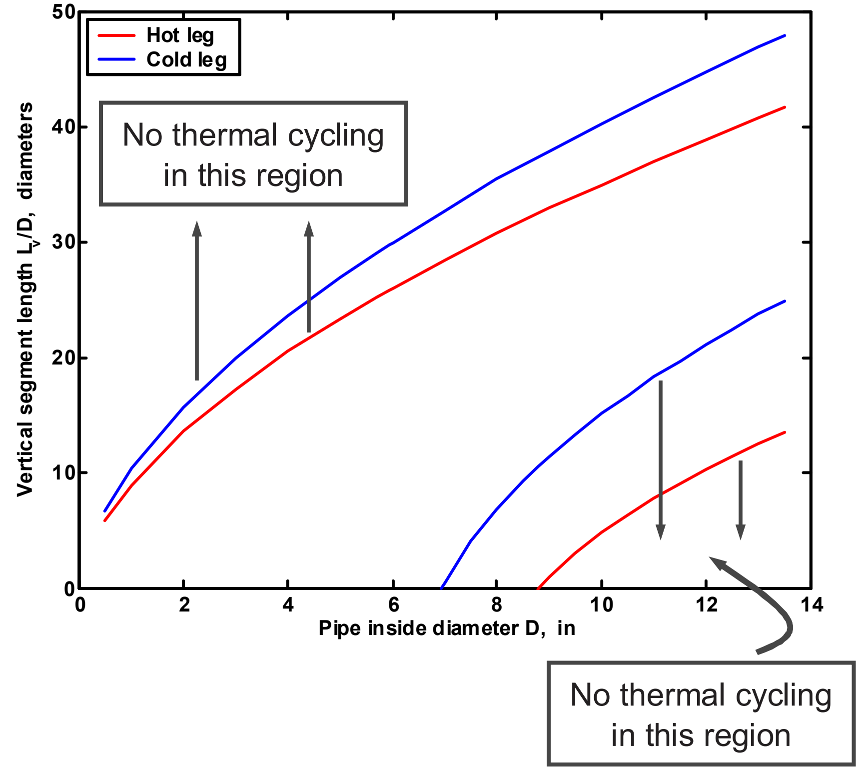
- Geometric Screening Criteria developed for use by the industry
- Derived from the Model for Conditions in which thermal cycling will not occur in susceptible region
- Screening boundary given by vertical segment length versus branch line inside diameter
- Boundaries depend on
  - Configuration (UH versus DH)
  - Attachment point (hot leg versus cold leg)
- No screening criteria for H line configurations

# Thermal Cycling Screening Criteria
## UH and DH Configurations

*Geometric Screening Criteria*
*UH Configurations with Valve In-leakage*

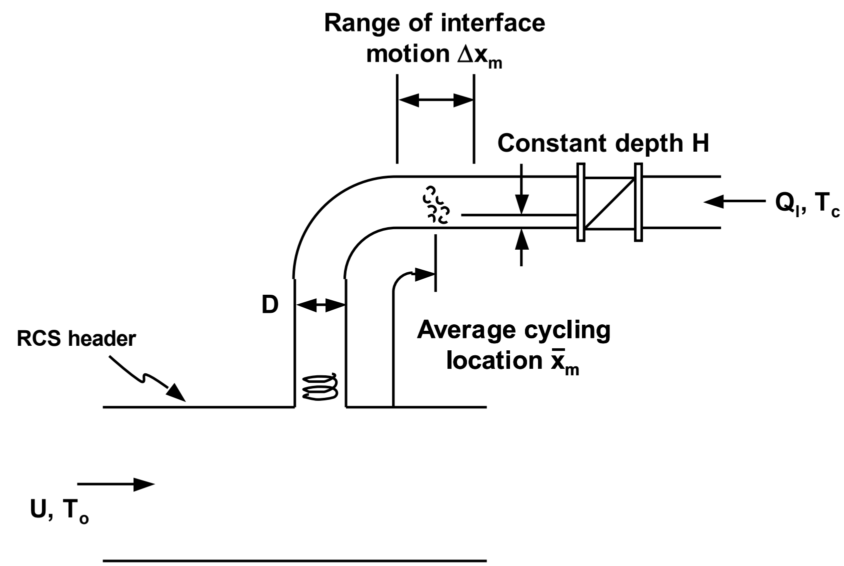



*Geometric Screening Criteria*
*DH Configurations*



# Thermal Cycling Model Overview
## Cycling Location in Lines with Valve In-leakage

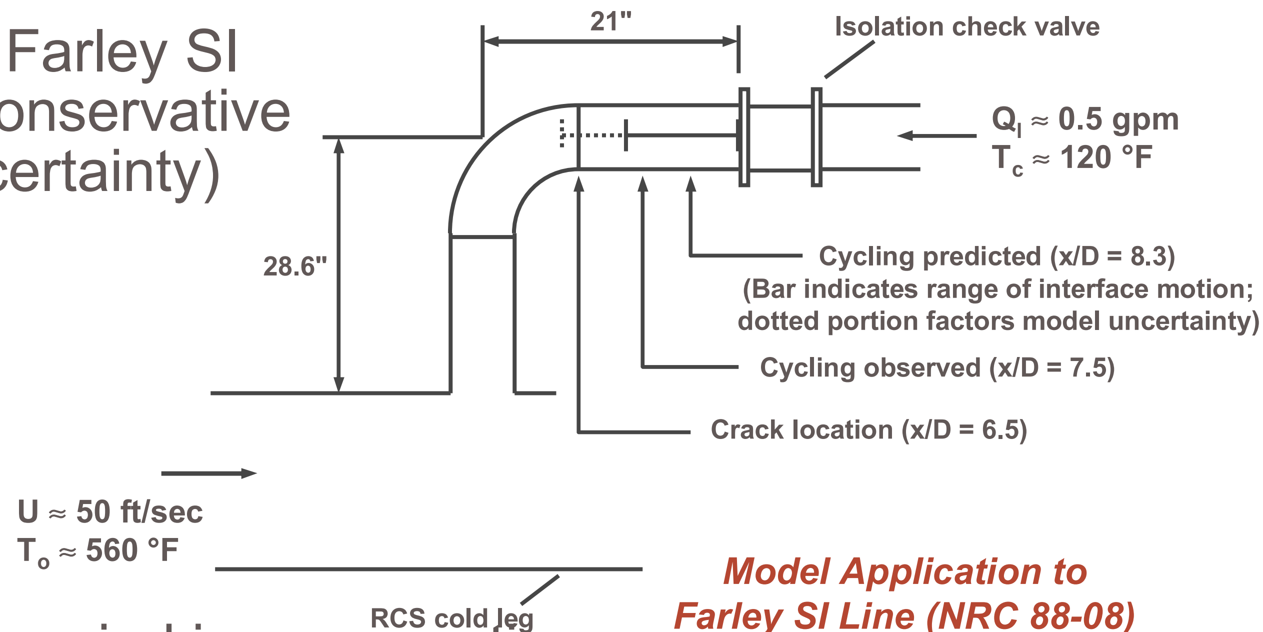
- Cycling location in branch lines with valve in-leakage (UH/H) given by semi-empirical correlation; depends on
  - Branch line swirl penetration/decay
  - Valve in-leakage rate/temperature
  - Geometric configuration
- Provided prediction of $x_m/D$
  - Cyclic motion = ±1 D
  - Additional uncertainty in model ±1 D
- Model applicable when in-leakage rate above minimum threshold




*Thermal Cycling Parameters in UH (H) Configurations*

# Thermal Cycling Model Overview
## UH Configuration Model Benchmarking

- Models for cycling location and cycling period benchmarked against Farley case
- Comparison with Farley SI configuration is conservative (within model uncertainty)



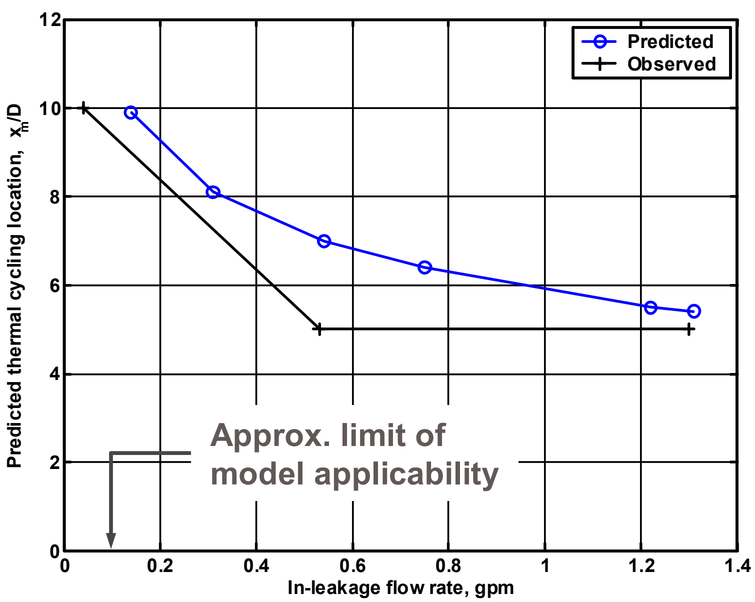

*Model Application to Farley SI Line (NRC 88-08)*

- Predicted cycling period is conservative
  - Predicted: 2 min
  - Observed: 5-6 min

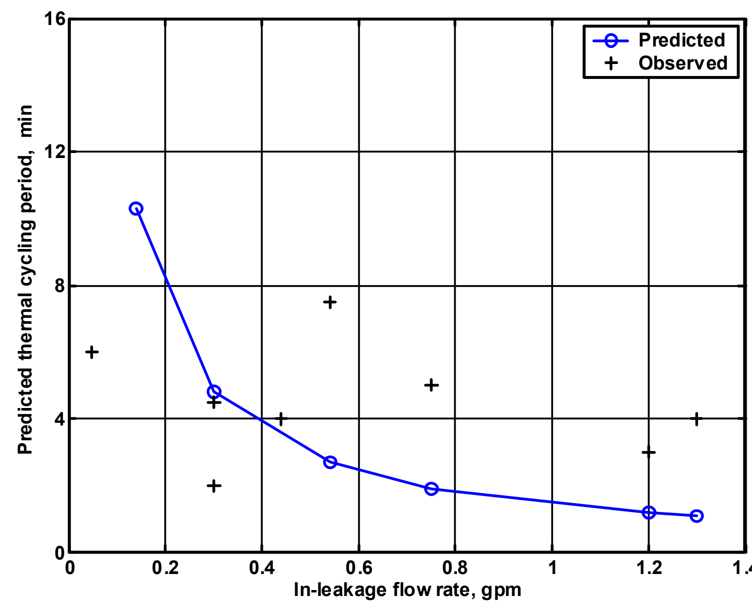
# Thermal Cycling Model Overview
## UH Configuration Model Benchmarking

- Model benchmarked against data obtained from cold water injection tests (EDF/Blayais SI line, 2001)
- Parameters inferred from thermocouples at 5 & 10D

***Thermal Cycling Location Comparison***




***Thermal Cycling Period Comparison***

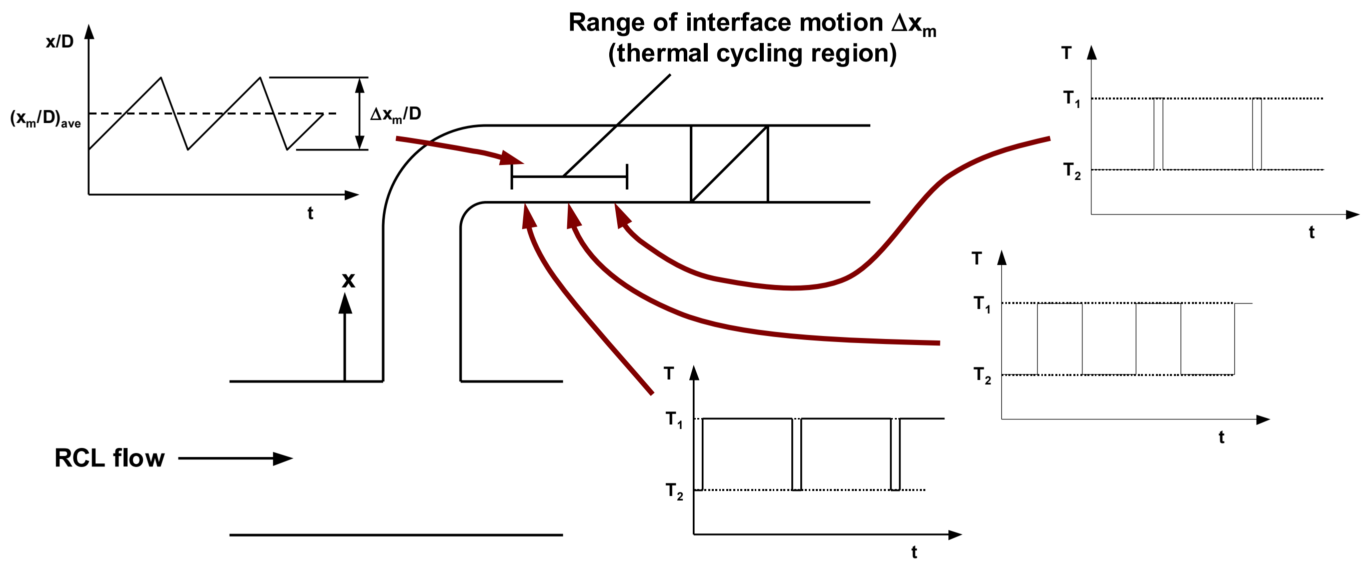


# Thermal Cycling Model Overview
## UH/H Thermal Load Definition

- Thermal load definition provided for stress analysis
- Defined from:
  - Temperature in hot/cold fluid regions (assumed uniform)
  - Heat transfer coefficients in hot/cold regions
  - Prescribed (cyclic) motion of hot-cold fluid interface
- Prescribed motion derived from test observations
- Period based on correlation:
  - Derived from test observations
  - Depends on valve in-leakage rate and geometry

# Thermal Cycling Model Overview
## UH/H Thermal Load Definition

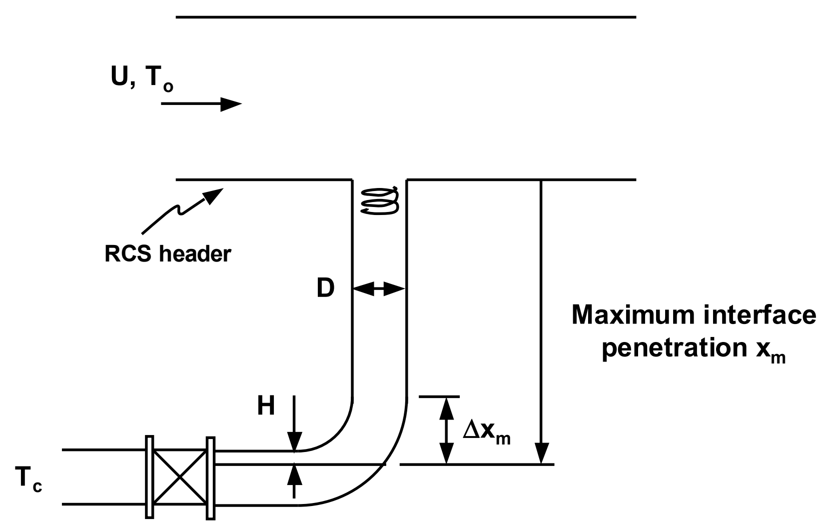
- "Fill-and-spill" load definition for UH configurations




- Higher frequency component of interface motion due to turbulence
  - Superimposed on fill-and-spill in UH lines
  - Only component in H lines

# Thermal Cycling Model Overview
## Thermal Penetration in "Cold Trapped" Lines

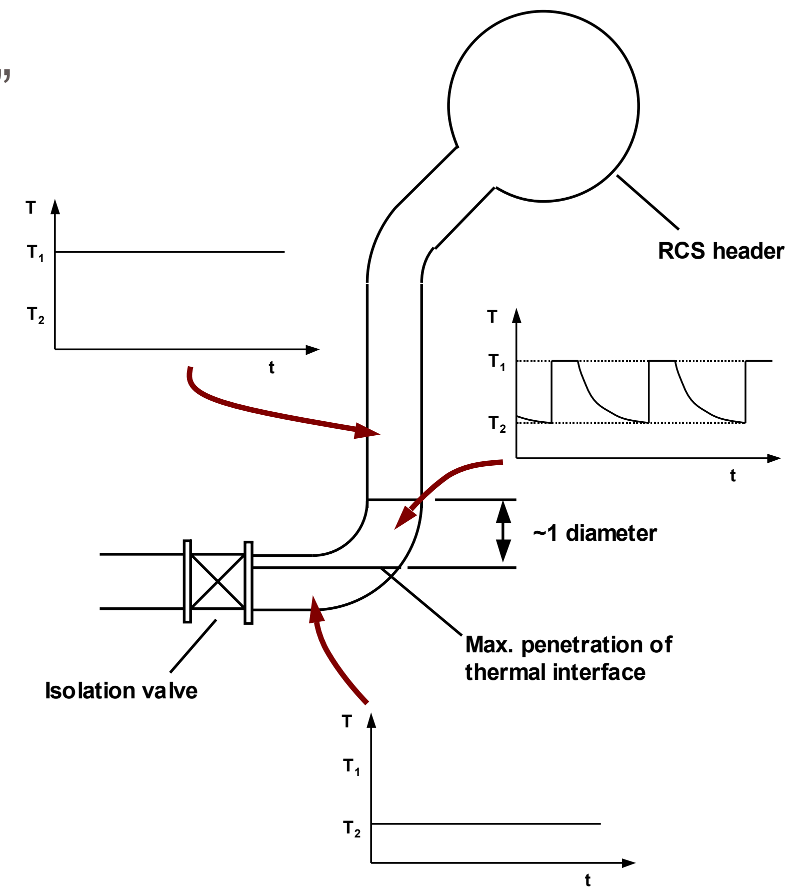
- Cycling location determined in cold trapped (DH) lines by penetration of thermal interface; depends on
  - Branch line swirl penetration/decay
  - Hot-cold density (temp) difference
  - Geometric configuration
- Model predictions within ±3D of test data/plant observations
  - Included as model uncertainty




*Thermal Cycling Parameters in DH Configurations*

# Thermal Cycling Model Overview
## Thermal Loading in DH Configurations

- Thermal load in DH configurations determined in similar manner as UH/H configurations:
  - Fluid temperatures – “lumped” heat transfer analysis
  - Cycling period – determined from heat loss from line
  - Interface motion – based on test observations
- Model formulated to give conservative load definition





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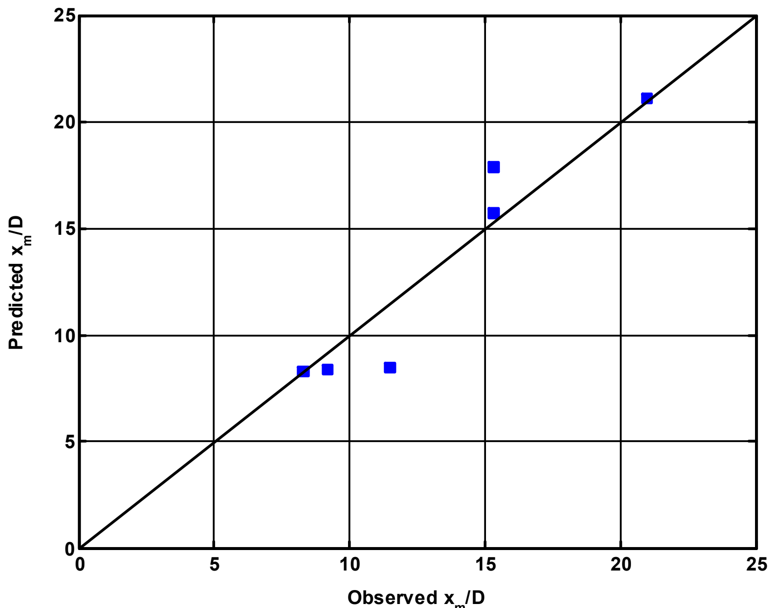
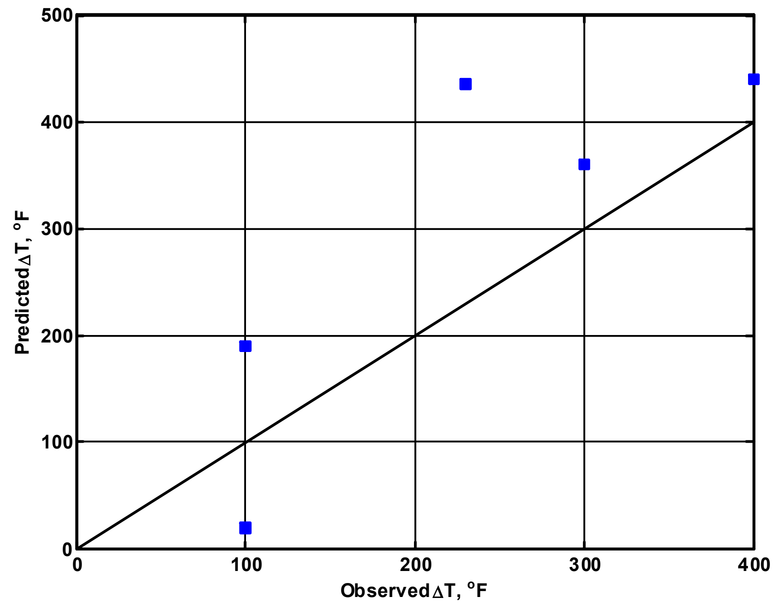
# Thermal Cycling Model Overview
## DH Configuration Model Benchmarking

- Model benchmarking for plants with thermal cycling/fatigue:
  - 3 drain lines
  - 3 RHR lines

*Cycling Location Benchmark*




*Top-Bottom Temperature Benchmark*



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# Generic Branch Line Application
## Assessment of Lines in U.S. PWR Plants

- Screening/evaluation model applied in generic assessment of normally-stagnant non-isolable lines
- Line details obtained during EPRI-sponsored Thermal Fatigue Workshops (540 lines total)
  - Approx. 35% UH configurations
  - Approx. 40% DH configurations
  - Approx. 10% H configurations
  - Remaining screened out for other reasons
- Model applied to determine thermal cycling susceptibility and representative loadings

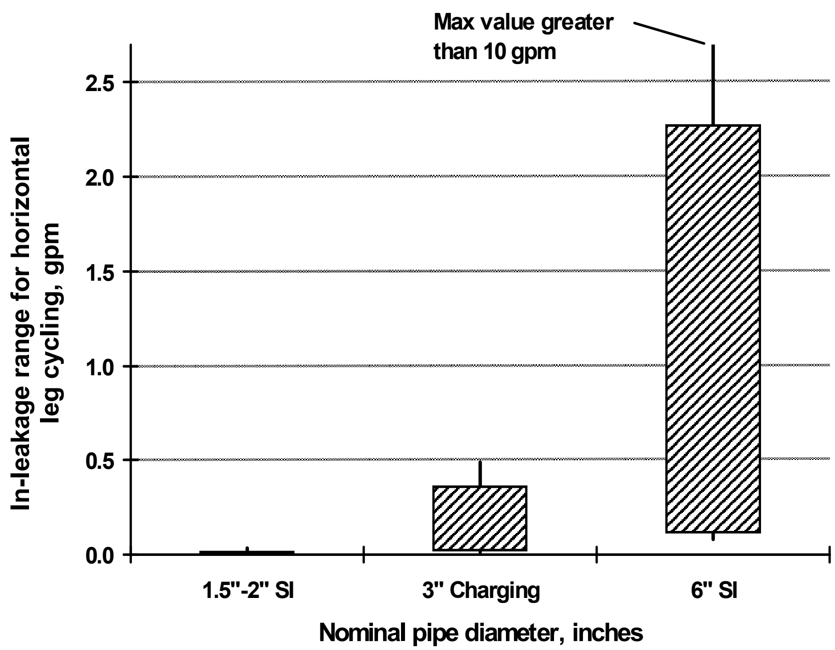
# Generic Branch Line Assessment
## Summary of Results for UH & H Lines

| | UH Lines | H Lines | IUxH Lines |
|---|---|---|---|
| Total number | 176 | 44 | 24 |
| No valve in-leakage possible | 99 | 18 | 22 |
| Screened out based on geometry | 24 | 0 | 0 |
| No cycling for $Q_l$ < 20 gpm | 0 | 1 | 0 |
| Potential cycling but $\Delta T$ < 50 °F | 0 | 0 | 0 |
| Remaining lines (cycling potential) | 53 | 25 | 2 |

- "UH Lines" include inclined (normal to RCS axis) upward lines and more complex configurations
- "IUxH Lines" (non-normal inclined up/horizontal)

# Generic Branch Line Assessment
## In-leakage Range in Susceptible UH Lines

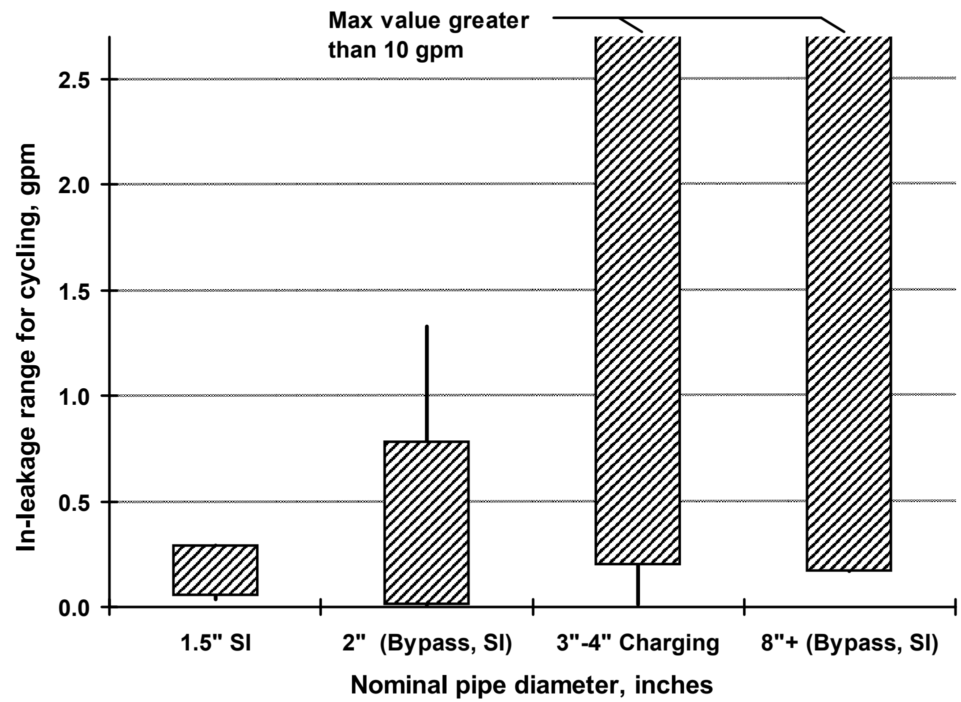
- Generic assessment determined range of valve in-leakage for cycling to occur
- Median in-leakage range plotted versus line type
- Most common line type with cycling susceptibility is 6-inch SI lines (Farley)
- Other conclusions:
  - Small lines (< 3-inch) do not cycle
  - Swirl penetration is more significant in large lines; cold water in-leakage/swirl interface will occur right by valve



# Generic Branch Line Assessment
## In-leakage Range in Susceptible H Lines

- Analogous result for H line configurations
- Valve in-leakage ranges for cycling were larger than similar UH lines in general
- Also showed that Aux Spray lines do not cycle since main spray line velocity normally very low

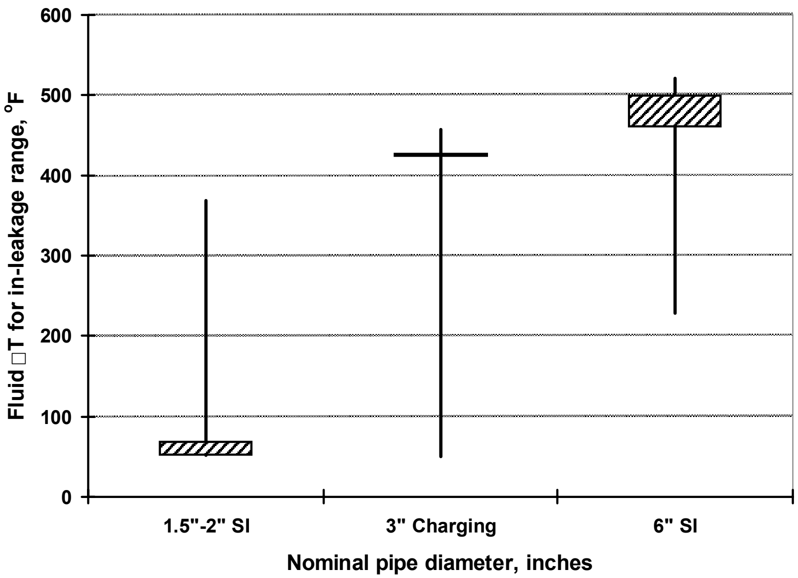
*In-leakage Range for Thermal Cycling in Susceptible H Configurations*



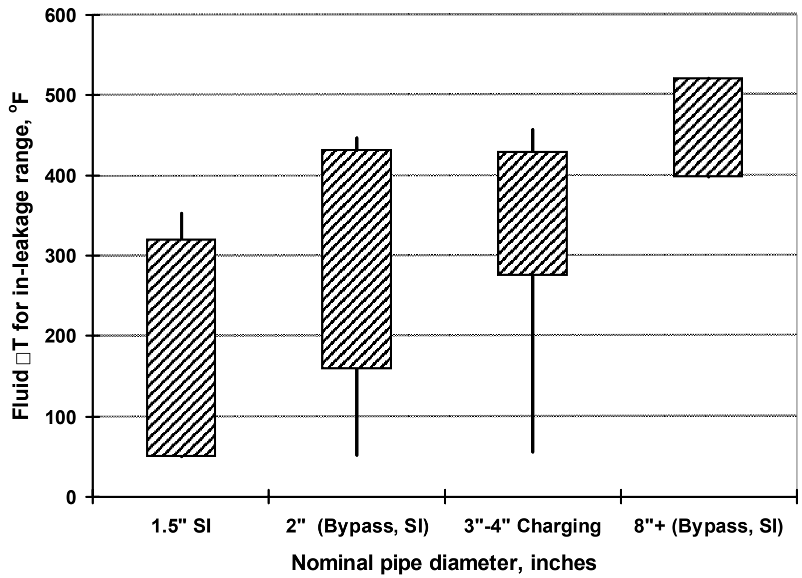
# Generic Branch Line Assessment
## Hot-Cold Temperature Ranges for UH & H Lines

- Temperature difference corresponding to calculated in-leakage ranges plotted versus line type (UH & H)
- Generally smaller ΔT for smaller diameter lines

***Hot-Cold Temperature Difference in Susceptible UH Configurations***




***Hot-Cold Temperature Difference in Susceptible H Configurations***



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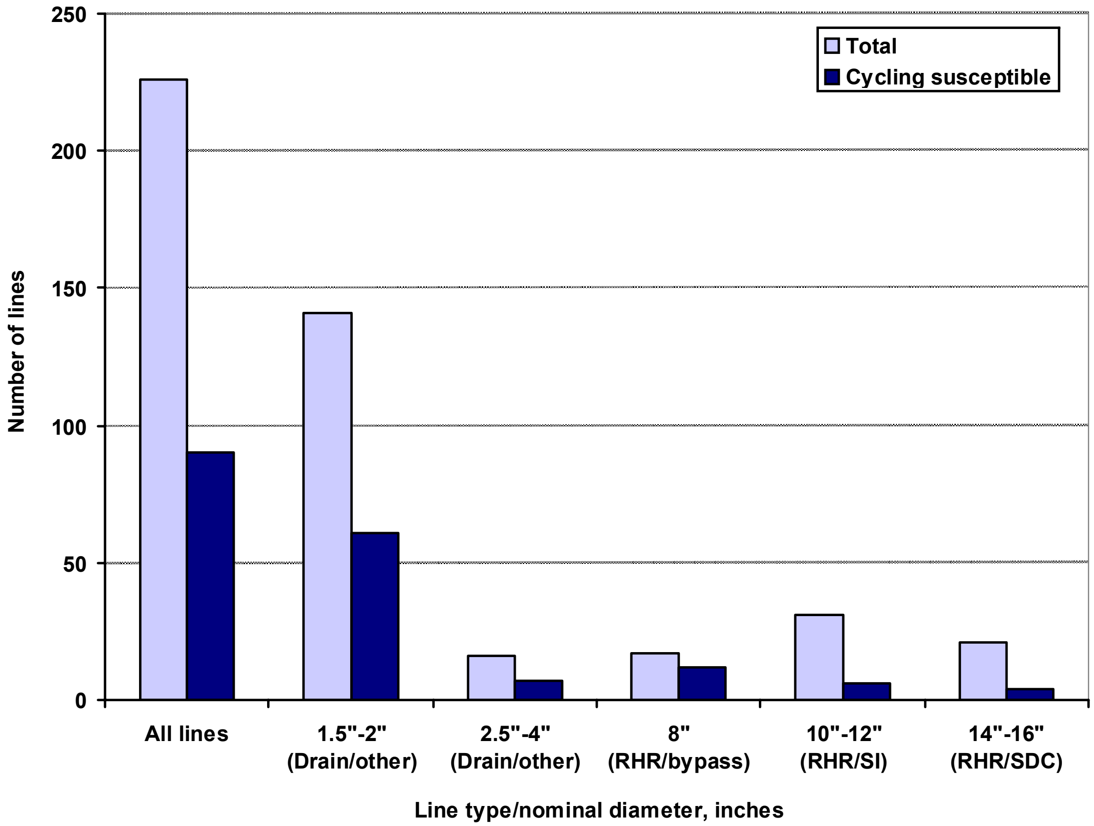
# Generic Branch Line Assessment
## Cycling Susceptibility in DH Lines

- Model applied to assess cycling susceptibility in DH lines
- Susceptible lines have
  - Penetration to (or near) horizontal
  - H/D < 1
  - $\Delta T > 50\ °F$
- Approx. 40% lines are susceptible

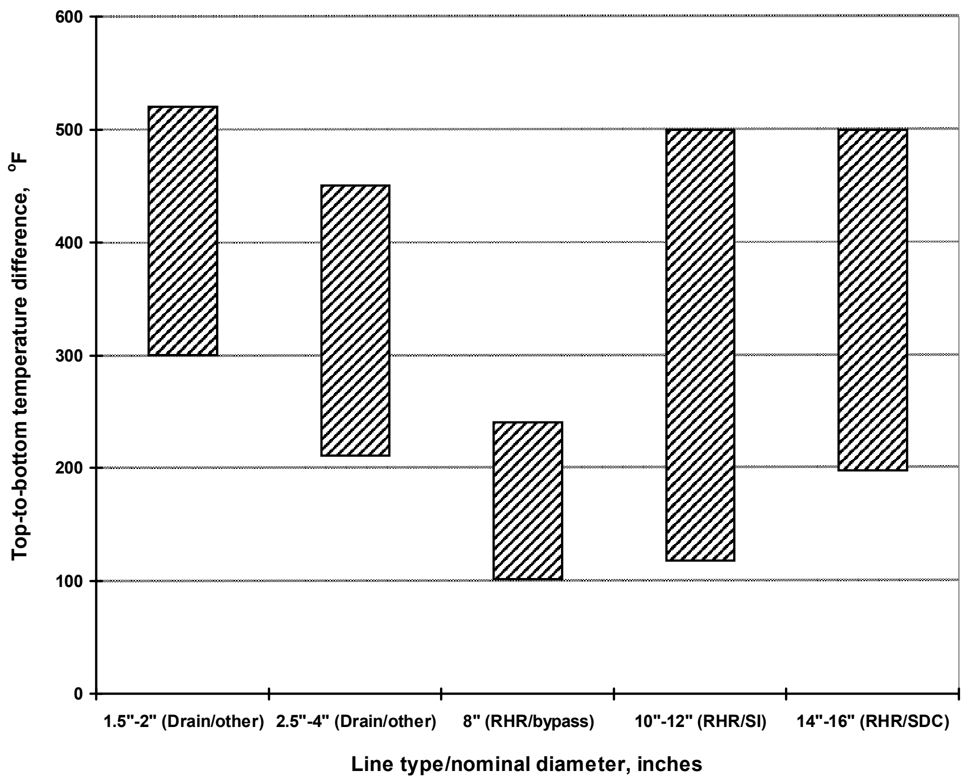
*DH Branch Line Population with Potential Cycling Susceptibility*



# Generic Branch Line Assessment
## Top-to-Bottom Temperature Difference in DH Lines

- Top-to-bottom difference calculated
- Calculated ΔT range plotted versus line population subset

*Calculated Top-Bottom Temperature Difference for Potentially Susceptible DH Lines*



# Thermal Cycling Model
## Summary

- Screening and evaluation model for swirl penetration thermal fatigue developed from extensive testing, analysis, and engineering modeling
- Model benchmarked against plant observations providing validation of model components
- Thermal cycling model provides technical basis for incorporation into Thermal Fatigue Management Guideline
- Generic application to lines in U.S. PWR plants performed; shows that many lines are unaffected and can be screened out
  - Additional results documented in EPRI report (MRP- 132/ 1009552)



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# Agenda

- Meeting Objectives
- History
- Thermal cycling screening and evaluation model
- **Final guide assessment approach**
  - **Screening**
  - **Evaluation/Inspection**
  - **Implementation**
- Summary
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# Final Thermal Fatigue Management Guideline

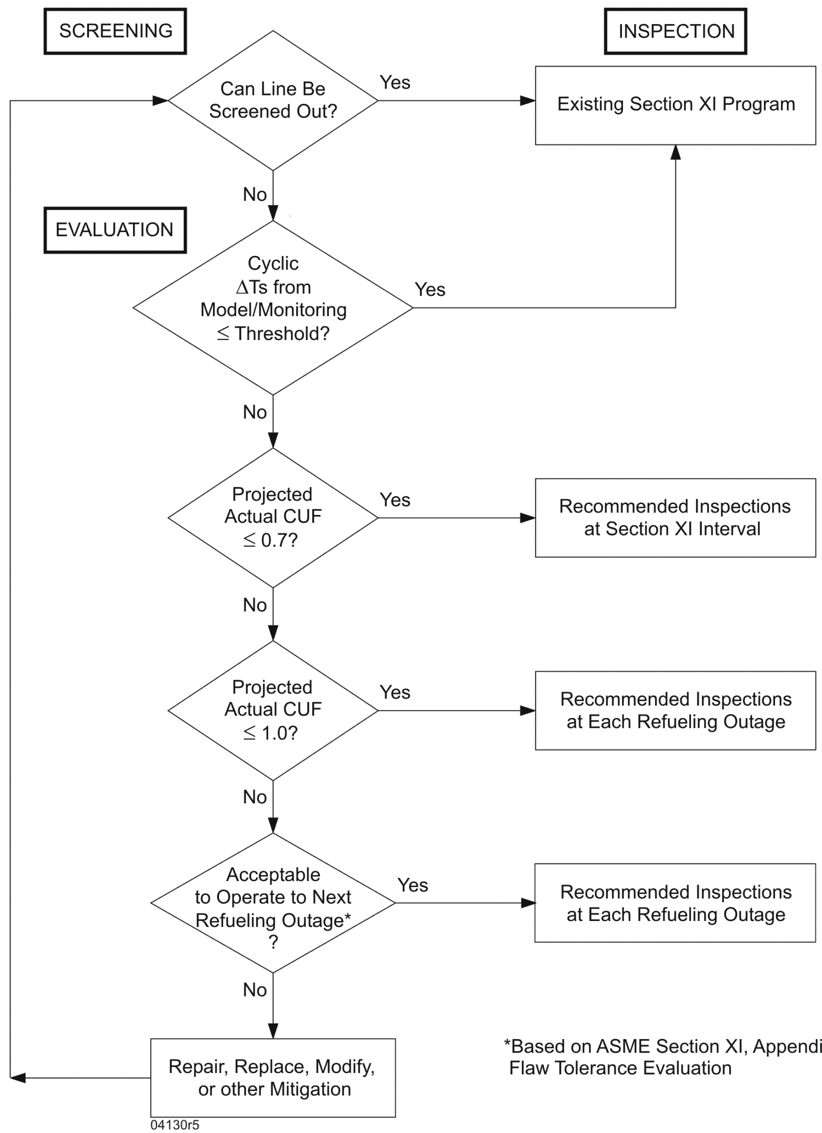
Scope:

- All nominally stagnant RCS-attached lines must be considered
  - Safety injection lines
  - Out-of-service charging lines (W plants)
  - Drain and excess letdown lines
  - Residual heat removal suction lines
  - Any other normally stagnant lines (diameter greater than 1 inch (25.4mm) nominal pipe size
- Separate but similar methods provided for two line classes
  - Up/Horizontal and Horizontal lines (UH/H)
  - Down/Horizontal lines (DH)

# Final Thermal Fatigue Management Guideline

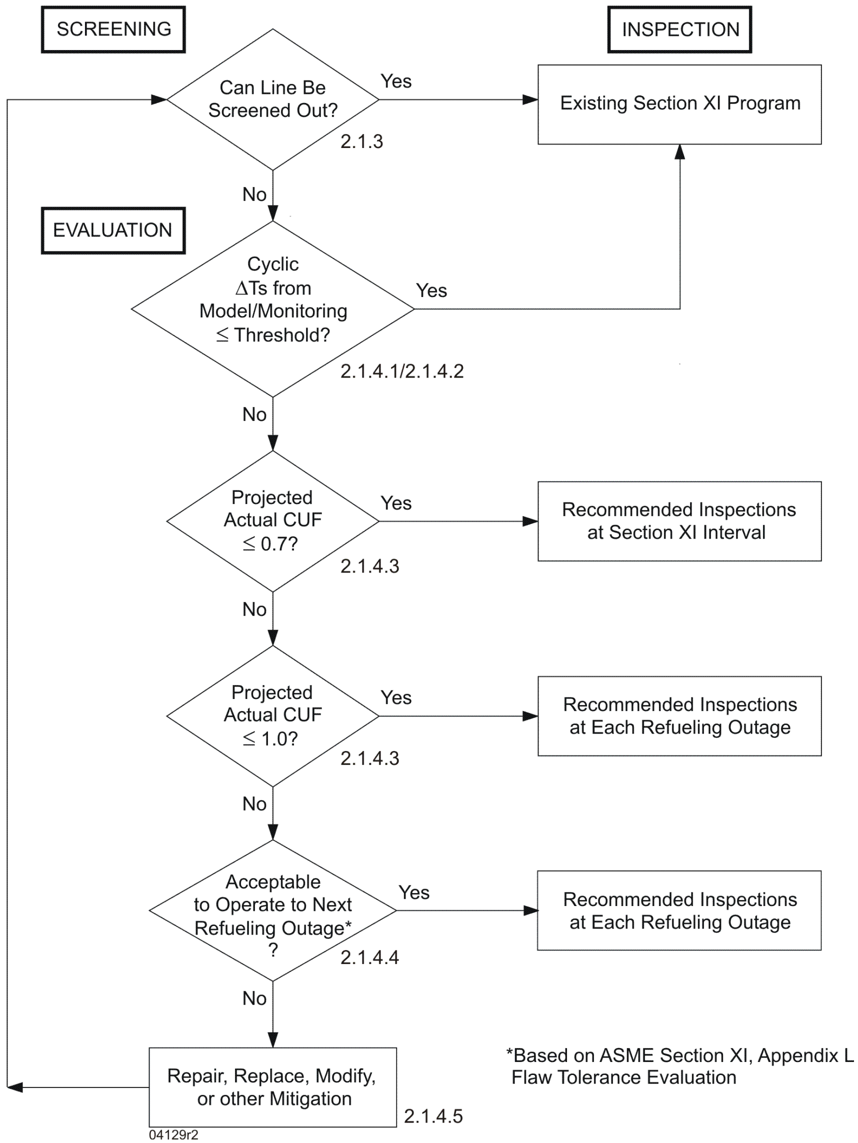
- Assessment Approach
  - Screening: Simple rules to show lines not susceptible
  - Evaluation: Predictive models to compute loading frequency, thermal transient, thermal stratification, stresses and/or fatigue usage
  - Inspection: Location and inspection interval
  - Mitigation: Reduction or elimination of thermal cycling
  - Repair/Replacement: Action if evaluation or inspection not successful
- Assessment approach also applicable to plant modifications.

# Assessment of Side/Top Connected Lines (UH/H)




*Based on ASME Section XI, Appendix L Flaw Tolerance Evaluation

# Assessment of Bottom Connected Lines (DH)

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# Screening of Top/Side Connected Lines (UH/H)

- To screen in for further evaluation
  - Must be high pressure source (e.g. charging pump)
- Lines screened out include:
  - Auxiliary spray lines (spray lines velocities very low)*
  - 2-inch UH nominal pipe size and less*
  - In-leakage path pressure less than RCS pressure
  - Certain top-connected lines with long vertical length (function of line diameter)*

* Revised criteria as compared to Interim Guideline

# Screening of Bottom Connected Lines

- Lines screened out include*:
  - – Certain lines with long vertical drop to horizontal section
    - horizontal piping always cold
  - – Certain lines with very short vertical drop to horizontal section
    - horizontal piping always hot
- Lengths for both screening criteria vary with pipe diameter

* Interim Guideline screening criteria related to vertical drop, and length of insulated piping

# Evaluation of Lines not Screened Out

- Two approaches
  - Evaluation methodology, and/or
  - Monitoring
- An allowable fluid ΔT threshold of 86.5ºF/$K_3$ established for stainless steel ($K_3$= piping component/weld stress index)
- If thermal cycling is significant, two types of evaluations can be conducted
  - Fatigue analysis
  - Flaw tolerance analysis*

*subject to NRC approval of Section XI, Appendix L

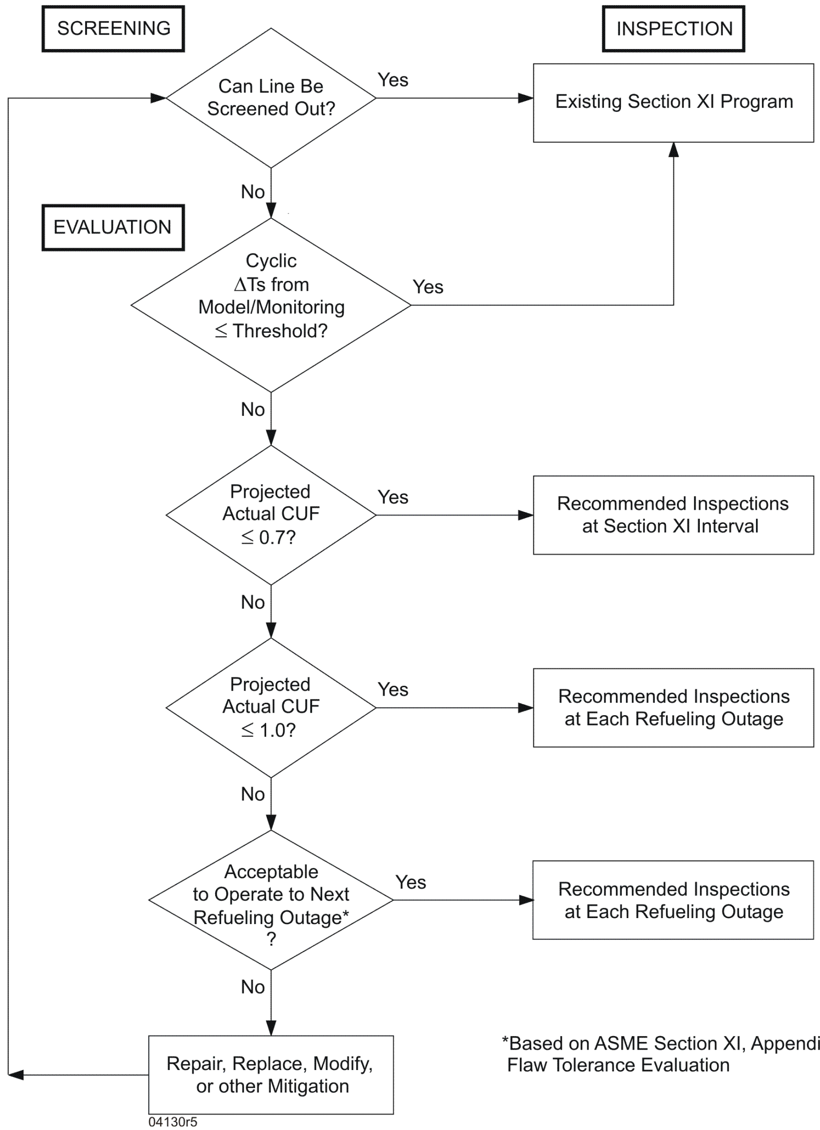
# Monitoring Guideline

- For UH/H in-leakage cases, monitoring must be conducted after each heatup from cold shutdown or after each potentially leaking valve open/close cycle
- For DH cases, monitoring may be removed after one operating cycle (if no cycling) or after two operating cycles (if data used in fatigue/flaw tolerance evaluation)
- Location guidance provided for thermal monitoring
- Guidance also provided for pressure and leakage rate monitoring

# Inspection Guidelines

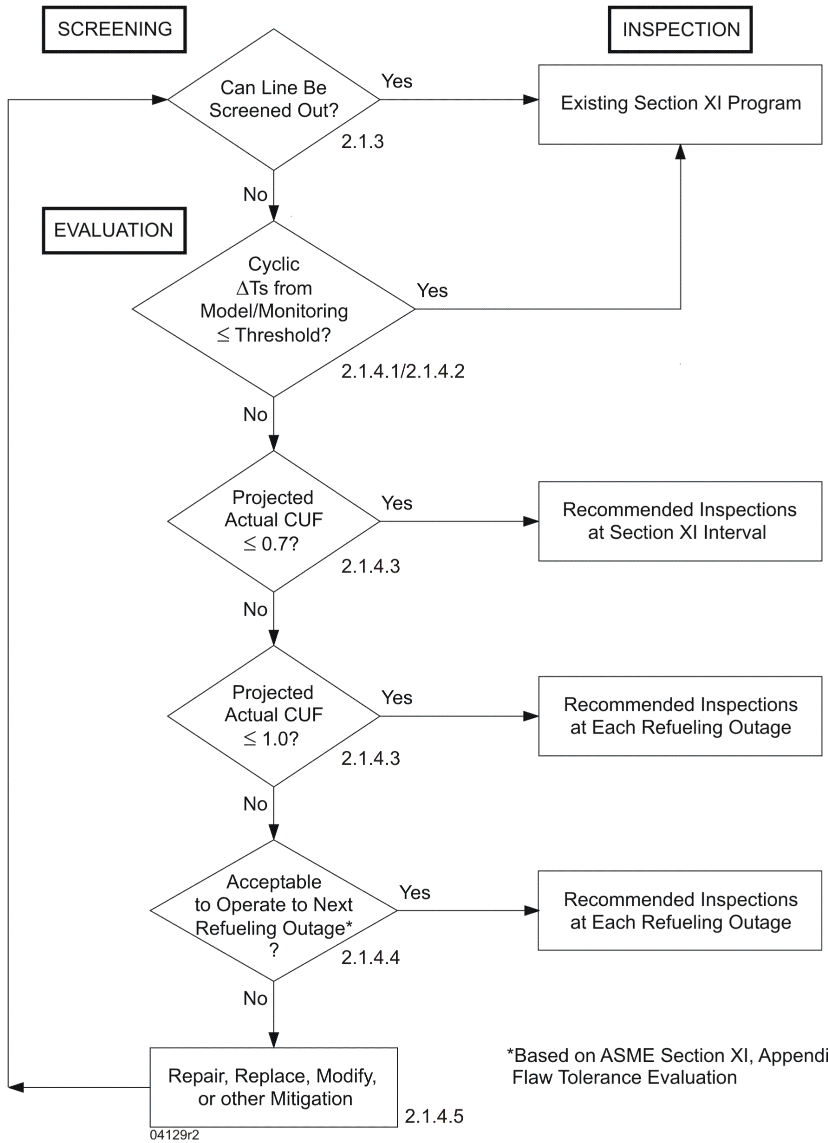
- Inspection Interval based on results of screening/evaluation/ monitoring of location
- General thermal fatigue inspection guidance provided
  - Personnel require specific training
  - Thermal fatigue training module provided by EPRI
- Regions for inspection based on experience supported by analytical modeling

# Inspection Approach for UH/H Lines



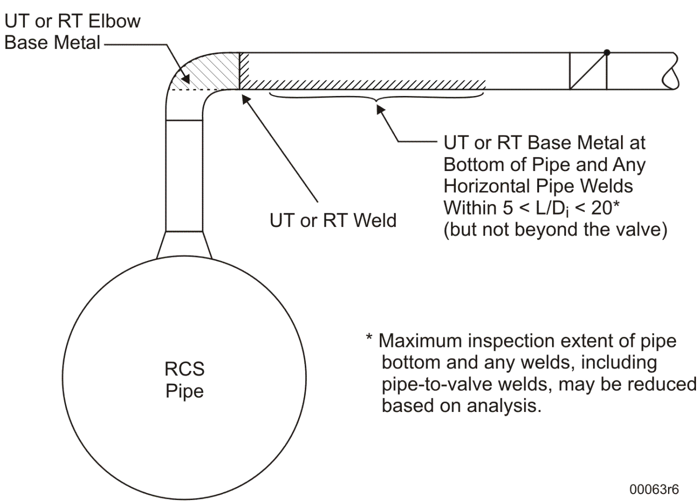

*Based on ASME Section XI, Appendix L Flaw Tolerance Evaluation

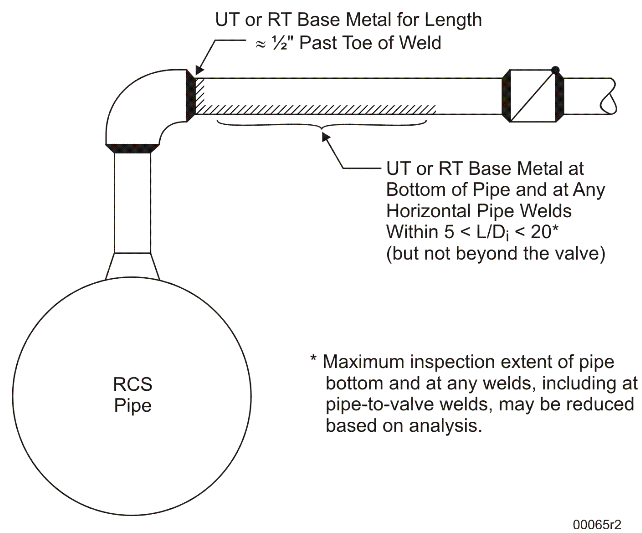
# Inspection of DH Lines




*Based on ASME Section XI, Appendix L Flaw Tolerance Evaluation

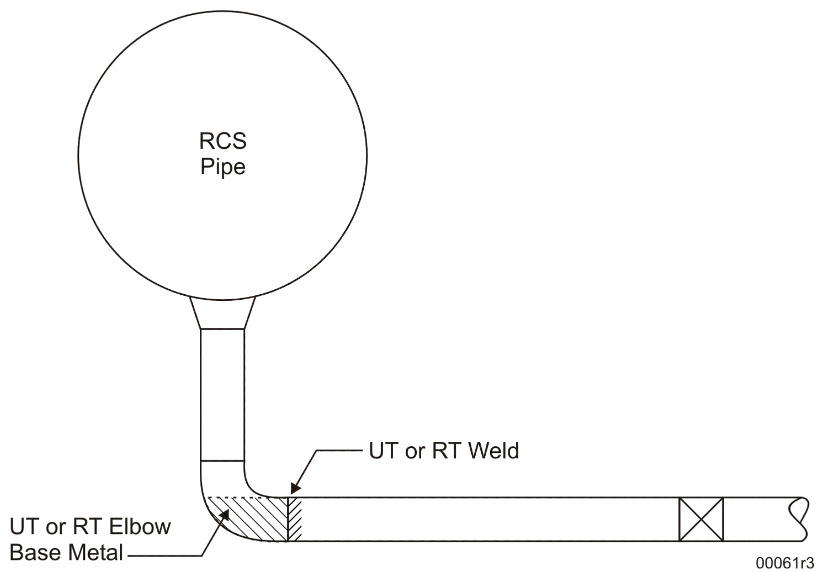
# Typical Inspection Regions (UH/H)

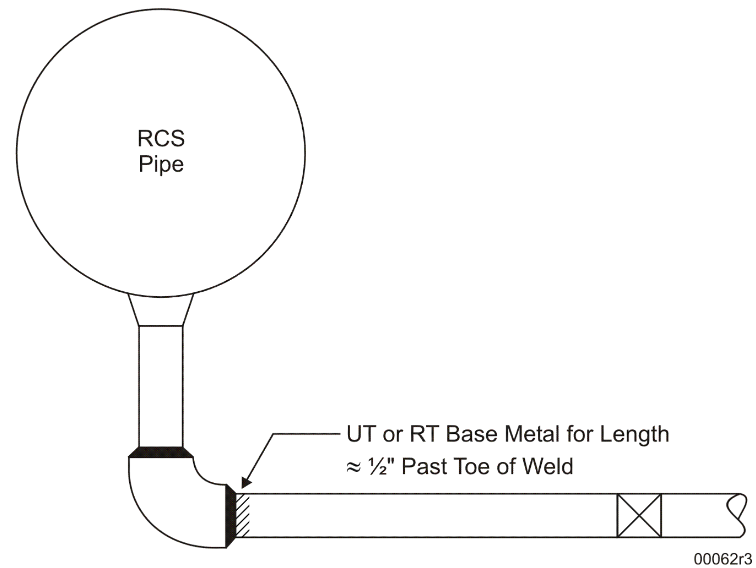



(Horizontal lines Similar)

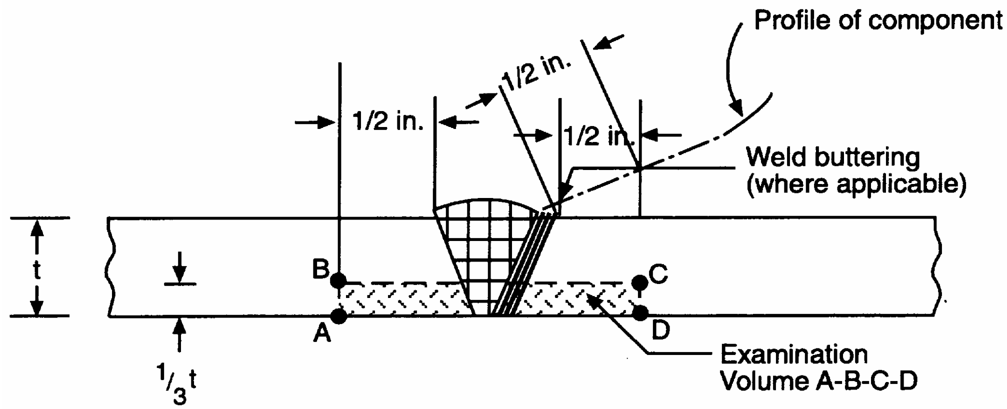
# Typical Inspection Regions (DH)



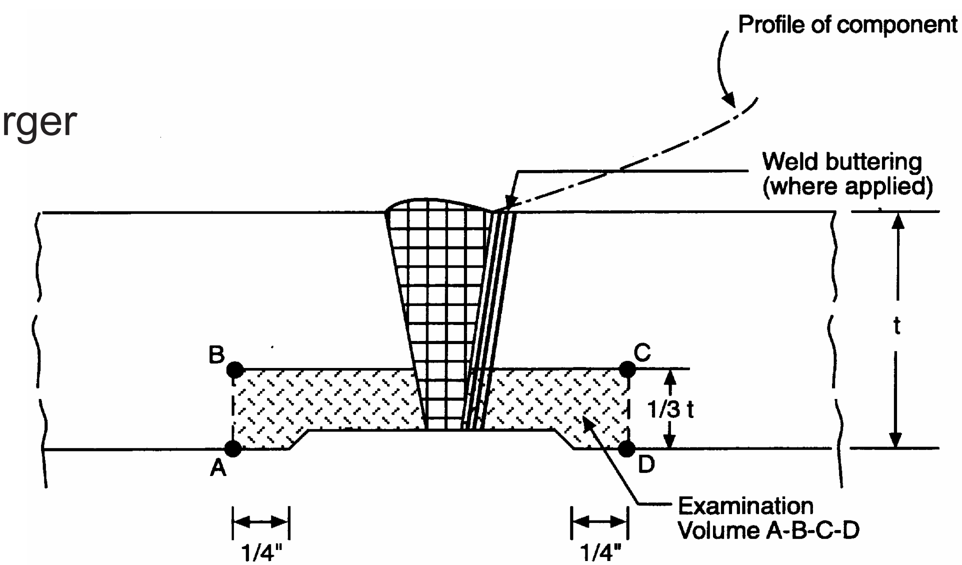



# Examination Volumes

NPSL 4"




NPSL 4" and larger



# General Guidance for Mitigation/Analysis

- Mitigation discussion provided on how to eliminate or reduce potential for thermal cycling
  - Maintenance
  - Modifications
  - Changes in plant operations
- Thermal stratification analysis general guidance provided
  - Definition of Operating/Loading Condition
  - Stress Analysis
  - Comparison to Code allowable stresses

# Use of Thermal Fatigue Management Guideline

- Each plant must perform assessment within two years
  - Any actions from assessment must be undertaken in a timely manner
  - Methods for screening and evaluation must be used
  - Inspection criteria must be met

- Remainder of document is a good practice guideline

# Agenda

- Meeting Objectives
- History
- Thermal cycling screening and evaluation model
- Final guide assessment approach
- **Summary**
  - **Implementation**
  - **Summary of Interim and Final Guideline**
  - **Discussion/Feedback**
- **Completed / Ongoing MRP Fatigue ITG Activities**

# Implementation

- Final guideline approved by utilities
- To be implemented per NEI 03-08 Protocol
  - Needed - means utilities must comply or offer acceptable alternative (Assessment, Screening & Evaluation, and Inspection)
  - 2 years to implement from date of issuance
- MRP is providing training for all US plant sites
  - Similar to Interim Guidance Training
  - Facilitates understanding
  - Assures timely and consistent implementation

# Summary – Comparison to Interim Guideline

Interim Guideline

- Scope
  - SI Lines
  - Drain Lines
- Methods
  - Experience based screening approach
  - No analytical evaluation approach provided
- For lines not screened out
  - Additional evaluation recommended – no defined methods
  - Monitoring and inspection also recommended

Final Guideline

- Scope
  - All normally stagnant RCS branch lines
- Methods
  - Screening and evaluation based on extensive test program
  - Analytical load definition methods
- For lines not screened out
  - Detailed evaluation methodology provided
  - Monitoring can be used



EPRI

# Summary – Comparison to Interim Guideline

## Interim Guideline

- No inspection interval defined
- Informally issued to utilities
- No specific commitment for plant assessment
- Training conducted for all sites
  – Interim screening conducted for essentially all sites

## Final Guideline

- Inspection interval based on results of screening and analytical evaluations
- Issued per NEI 03-08 protocol
- Plant assessment is "Needed" within two years
- Training to be conducted for all sites to cover new methods
  – More participation by utilities is required
  – Evaluation software to be provided

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# Conclusion

- Thermal Fatigue Management Guideline (MRP-146) and supporting documents provide an effective approach to managing thermal fatigue in normally stagnant, non-isolable branch lines connected to the RCS
- MRP-146 to be implemented over a two-year period beginning in July 2005
  - Training to be provided for all PWR utilities

# Comments / Discussion

# Completed / Ongoing Fatigue ITG Activities

- Completed – some highlights
  - NDE Technology for Detecting Thermal Fatigue Cracking
  - Interim Thermal Fatigue Management Guideline
  - Operating Experience Regarding Thermal Fatigue
  - Mitigation of Thermal Fatigue
  - NDE Training for Thermal Fatigue Cracking (CBT)
  - Thermal Fatigue Monitoring Guidelines
  - EdF Thermal Fatigue Monitoring Experience in RCS Auxiliary Lines
  - Lessons Learned from Thermal Fatigue Management Training
  - And of course the two documents discussed today

# Completed / Ongoing Fatigue ITG Activities

- Ongoing
  - Thermal Fatigue Management Guideline Training
  - MRP Integrated Fatigue Management Guideline
  - Thermal Fatigue Licensing Basis Monitoring Guideline
  - Assessment of mixing tee susceptibility to thermal fatigue
- **These efforts will complete our work on thermal fatigue**
- Other ongoing work:
  - Guidelines for Addressing Fatigue Environmental Effects in a License Renewal Application
  - High/Low Flow Environment Effects Testing (Stainless Steel)

# Thermal Fatigue Management Guideline and Supporting Documents

- Management of Thermal Fatigue in Normally Stagnant Non-Isolable Reactor Coolant System Branch Lines, (MRP-146), EPRI 1011955
- Thermal Cycling Screening and Evaluation Model for Normally Stagnant, Non-Isolable Reactor Coolant System Branch Line Piping with a Generic Application Assessment (MRP-132), EPRI 1009552
- Mitigation of Thermal Fatigue in Unisolable Piping Connected to PWR Reactor Coolant Systems (MRP-29), EPRI 1001017
- Thermal Fatigue Monitoring Guidelines (MRP-32), EPRI 1001016
- NDE Technology for Detection of Thermal Fatigue Damage in Piping (MRP-23), EPRI 1000152
- Computer-Based NDE Training for Thermal Fatigue Cracking (MRP-138), 1001317
- Operating Experience Regarding Thermal Fatigue of Unisolable Piping Connected to PWR Reactor Coolant Systems (MRP-85), EPRI 1007761