Industry Response to Recent Thermal Fatigue Operating Experience

Mike McDevitt
Principal Technical Leader

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Industry Response to Recent Thermal Fatigue OE

- Presentation Content
  - Management of Thermal Stratification Fatigue
  - Historical Trends and Recent Operating Experience
  - Industry Action Plan
  - Analysis of Recent Operating Experience
  - Fatigue Management Program Changes
  - Considerations for Long Term Action Planning

Management of Thermal Stratification Fatigue
Thermal Fatigue Management Program Evolution

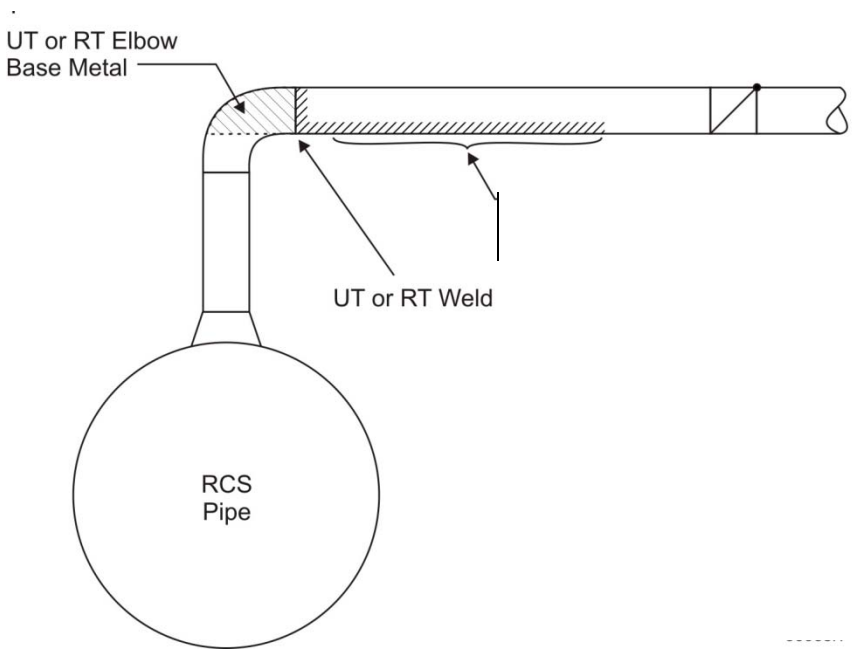
- Thermal (Stratification) Fatigue was not addressed in original designs, ISI programs or Regulations
- NRC Bulletin 88-08 responded to OE and required Utilities to evaluate and manage susceptibility
  - Initially addressed individually by Utilities
  - Industry guidance developed over the next 15-years
- Industry is self regulating in this area
  - Implemented under the Materials Initiative (NEI 03-08)
  - Mature thermal fatigue management guidelines established
    - MRP-146, RCS Branch Lines, June 2005 (August 2012 current)
    - MRP-192, RHR Mixing Tees, December 2006 (June 2011 current)

Management of Thermal Stratification Fatigue
EPRI-MRP Guidelines

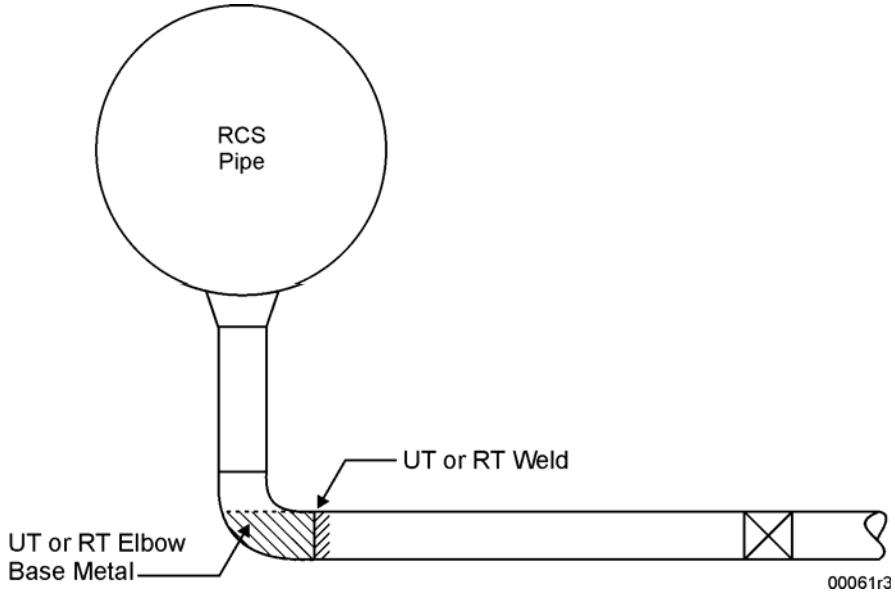
- *MRP-146, MRP-146(S), Management of Thermal Fatigue in Normally Stagnant Non-Isolable Reactor Coolant System Branch Lines*
  - Addresses interaction of hot swirl penetration into cooler fluids
  - Implementation is NEI 03-08 Needed for US PWRs
  - Identifies branch lines that are susceptible to thermal fatigue
  - Establishes examination requirements for susceptible locations
  - Revision is currently in progress for publication in early 2016
- *MRP-192, Assessment of RHR Mixing Tee Thermal Fatigue in PWR Plants*
  - Addresses mixing interaction of thermally different fluids
  - Implementation is NEI 03-08 Good Practice for US PWRs
  - Guidance is provided for determining examination requirements and schedules

Management of Thermal Stratification Fatigue Branch Line Examination Volumes (MRP-146)

Typical Examination Volume for Up-Horizontal (UH) Configurations

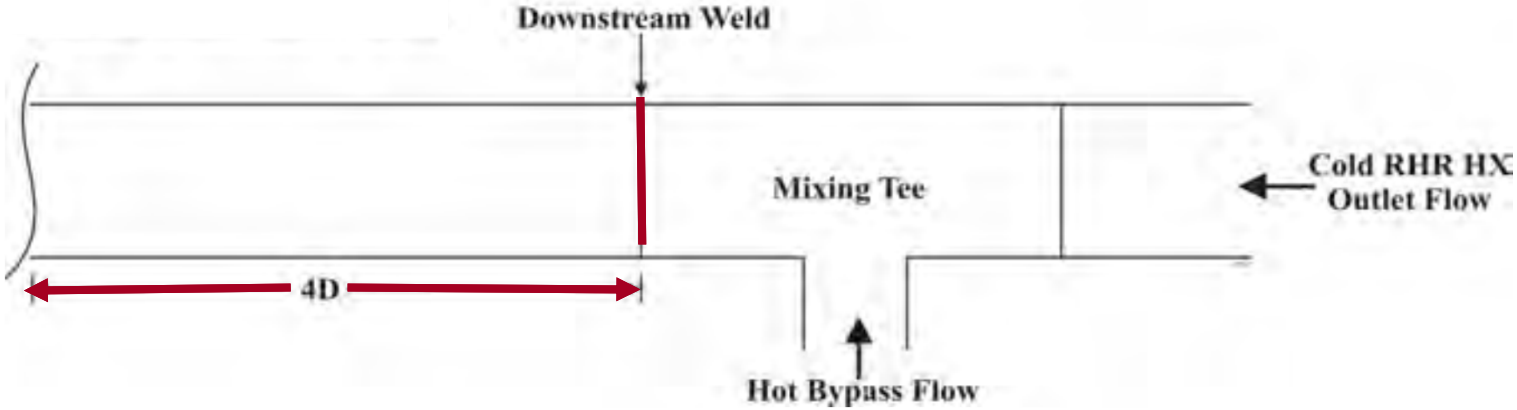


Typical Examination Volume for Down-Horizontal (DH) Configurations



Management of Thermal Stratification Fatigue
Mixing Tee Examination Volumes (MRP-192)

- Inspections are based on the number of effective differential temperature hours, N_{eff}
  - Schedule volumetric examination when N_{eff} exceed specified limits
    - Exam schedules also include elapsed calendar time limits
  - Includes the mixing tee *downstream* weld and all downstream welds within four pipe diameters



Historical Trends and Recent Operating Experience

- 5 Events leading into NRC Bulletin 88-08 (11 years)
  - 5 through wall leakage events
- 6 Events subsequent to Bulletin thru 2000 (11 years)
  - 5 through wall branch lines (4 were International plants)
  - 1 thru wall RHR Mixing Tee (International)
- 3 Events after Industry Guidance 2000 thru 2012 (12 years)
  - 2 part through branch line cracks (1 was International)
  - 1 part through RHR Mixing Tee (Domestic)
- 9 Domestic events since October 2013 *(18 months)*
  - 2 through wall leaks in branch line cracks
  - 5 part through branch line cracks
  - 1 through wall leak in RHR Mixing Tee
  - 1 part through RHR Mixing Tee

Historical Trends and Recent Operating
Significant Aspects of Recent OE

Date	Component	Significant Technical Aspects
Nov 2013	Cold Leg Drain Elbow 35% t-w Circumferential	Found during planned examination Repeat location of 1995 TF leak
Nov 2013	Cold Leg HPI Nozzle weld (H) Through wall (primary vibration)	Through Wall Leakage. Was missed in prior NDE
Apr 2014	Cold Leg HPI Nozzle weld (H) 85% t-w Axial	Found during planned examination Likely missed in prior NDE
Sep 2014	Cold Leg HPI Nozzle weld (UH) 50% t-w Axial	Found during Extent of Condition Exams Was exempted by MRP-146 screening
Sep 2014	Cold Leg HPI Nozzle weld (UH) 50% t-w Axial	Found during Extent of Condition Exams Was exempted by MRP-146 screening Cracks found in an unexpected region
Sep 2014	RHR Mixing Tee ~20% t-w various	Found during planned examination Larger than expected for low usage
Oct 2014	Reactor Water Clean Up Tee Through wall	Repeat of 2008 thru wall crack Original cause not resolved
Nov 2014	Cold Leg drain elbow ~20% t-w	Found during planned examination Repeat event, mitigation became degraded
Dec 2014	Cold Leg Drain Elbow Through wall	Through wall leakage Exempted based on MRP-146 analysis Complicated by chemistry sampling

Industry Action Plan
Emergent Issue Protocol Activated

- NEI 03-08 Emergent Issue process
  - Utilities report experience with generic significance to the industry
    - Issues having potential operational, regulatory or financial impact
  - Affected Issue Program (IP) assesses OE and determines Actions

- Issue Program Responsibility
  - Obtain data necessary to understand the event
  - Assess the technical, regulatory and Industry significance
  - Communicate the issue assessment to potentially affected Utilities
  - Assess the impact on existing guidance and regulations
    - Issue Interim Guidance to prevent re-occurrence if needed
  - Provide assistance and revised guidance as appropriate

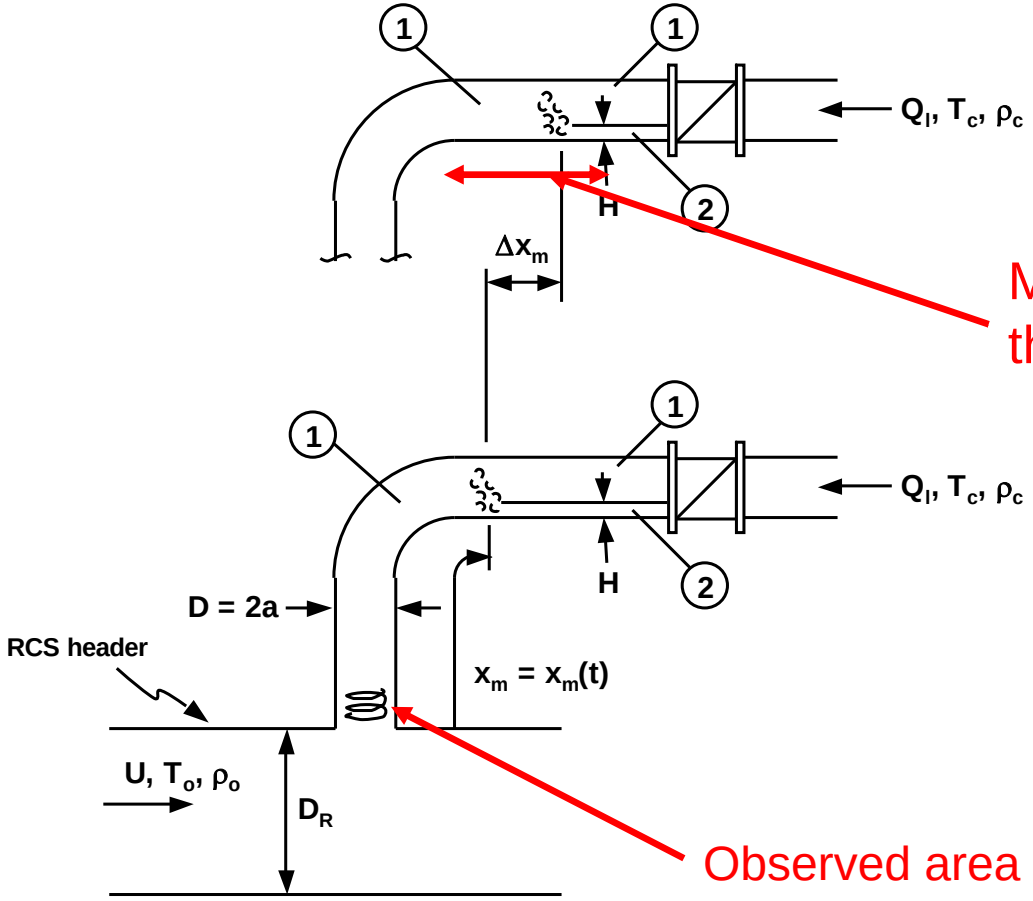
Industry Action Plan
Emergent Issue Industry Program Response

- Thermal Fatigue Focus Group (TFFG) was established under MRP
  - Duke Energy, Exelon, Dominion, Southern, Ameren, EdF, WCNOC, STP, APS, First Energy, SIA, INSS-Japan, EPRI-NDE, EPRI-MRP, and EPRI-BWRVIP
- Focus Group Objectives Defined:
  - Review OE and identify management program gaps
  - Assess Industry extent of condition and needed actions
  - Develop near term measures to eliminate unexpected events
  - Identify knowledge gaps and propose research to resolve
- Established Support & Resource Commitments
  - Utility support of TFWG member participation
  - Access to confidential examination data and cause evaluations
  - Support of TFWG requests for supplemental information
  - Implementation support of resulting actions
  - Prioritization of research

Industry Action Plan
Managed by Thermal Fatigue Focus Group

Perform Initial Assessment of the Operating Experience		
– Review Inputs and Establish Project Plan	1/13/15	a
– Analyze all OE, Exam & Cause Reports in detail	2/10/15	a
– Communicate OE for spring outage improvement	2/16/15	a
Develop Interim Guidance		
– Finalize observed gaps and possible Corrections	3/3/15	a
– TFFG finalize Interim Guidance content & draft letter	3/30/15	a
– Interim Guidance letter to TAC(s) for Review	4/3/15	a
– TFFG resolve TACs comments	4/17/15	a
– Interim Guidance to IC & PMMP for review	4/21/15	a
– TFFG resolve IC & PMMP comments	5/8/15	a
– TFFG publish MRP Interim Guidance Letter	5/28/15	a
Develop Long Term R&D Plans for Guideline Improvement		
– Identify gaps where better understanding is needed	working	
– Define elements of long term action plan	working	
– Present Long term conceptual plan to TAC	6/15/15	
– Outline L.T. project scope, schedules & resources	11/2015	
Communicate key conclusions to USNRC	6/2/15	
Conference Call to support Implementation Q&A	(7/7/15)	

Analysis of Recent Operating Experience
An Example: Small-Diameter UH Branch Line September 2014



MRP-146 Examination area for thermal fatigue

Observed area of axial cracking was outside of the expected region and in a pipe sixe not considered susceptible to swirl penetration cycling

Analysis of Recent Operating Experience
An Example: Small-Diameter UH Branch Line September 2014

Analysis Process	Result
Identify Conditions Deviating From Expectations	Cracks were detected in exempted line <2 NPS Cracking in vertical pipe not previously observed
Identify Potential Causes	Cyclic thermal interface w/o swirl penetration Cyclic breakup of cold laminar in-leakage Significant construction repairs in butt weld
Determine Mitigation Alternatives	Emphasize prevention of inleakage Impose examinations to detect new fatigue mode
Candidate Thermal Fatigue Guidance Change	Eliminate small diameter exemption, >1 NPS Examine vertical section of small D piping Remind program owners of construction repair risk
Identify Knowledge Gaps	Behavior of cold inleakage with RCS in small diameter UH branch lines is not understood Sensitivity to key variables not known
Propose Research	Construct physical mockups Benchmark Computational simulations Investigate International approaches

Analysis of Recent Operating Experience

Associated OE	Condition Deviating From Guideline Expectations	Potential Causes	Candidate Thermal Fatigue Guidance Change
Cold Leg Drain DH 2009	Location of cracking was slightly outside MRP-146 rev-0 volume (by 1-inch) This exam zone was fixed in rev-1, but the displacement may indicate slightly different mechanism	Out-flow valve leakage or chemistry sampling may have been contributing causes that influence crack location	DH lines with potential for outleakage or outflow must be examined every other outage unless an inclusive fatigue usage calculation is performed (Section 2.1.5.6)
		Insulation may have been damaged	Periodically confirm that corrective design changes implement to prevent crack re-occurrence remain intact.
Cold Leg Drain DH Nov 2013	Repeat cracking; crack size at detection was appropriate. Crack growth similar to initial event.	Vibration and/or possibility of outleakage were considered to have been the actual primary fatigue mode	Emphasize contribution from other fatigue modes in the letter text
	Corrective actions based on root cause of Thermal Fatigue were not effective.		
Horizontal HPI Nov 2013	Crack depth inappropriately large at detection (Through Wall leak)	Examination frequency was insufficient to detect in time. (already every RFO)	No Action
		Examination quality was insufficient to detect crack (validated by radiograph)	Upgrade NDE requirements to current standards. Ensure coverage is understood
	Repeat cracking event	Additional fatigue mode at play Vibration was the primary fatigue mode	Emphasize contribution from other fatigue modes in the letter text
Horizontal HPI April 2014	Crack depth inappropriately large at detection (85% Through Wall). Cold inleakage was probable Current guidance for NDE every RFO is adequate	Crack likely missed in prior exam	Upgrade NDE requirements to current standards. Ensure coverage is understood
		Examination frequency was insufficient to detect in time. (already every RFO)	No Action
Up Horizontal HPI September 2014 Two Locations	These 1 ½ inch lines were screened out because swirl not expected in small diameter UH, even with known cold-inleakage	Swirl penetration may be suppressed, but hot-cold interface will still exist	Remove <2-inch exemption for UH branches. Include exam of vertical pipe (where inleakage is possible)
	Cracks were located near bottom of vertical pipe. Not in expected zone	Hot-cold fluid cyclic interface relocated to where turbulent breakup resumed	Perform a one-time examination of vertical pipe in comparable UH geometries not later than the first RFO after 6-1-16
		Significant rework performed in safe end welds may have predisposed weld to cracking	Discuss this risk factor in the letter, suggest program owners review and understand fabrication history

Analysis of Recent Operating Experience

Associated OE	Condition Deviating From Guideline Expectations	Potential Causes	Candidate Thermal Fatigue Guidance Change
RHR Mixing Tee September 2014	Crack growth between examinations exceeded expectations based on usage estimates. Crack depth was acceptable on detection	Previous exam missed detection Additional fatigue mechanism at work unlikely because of widespread crazing	Emphasize importance and value of periodic mixing tee reinspection in the letter
	One weld crack was in an upstream branch weld, outside of required examination zone	Thermal eddies may enter upstream piping under certain flow conditions	Increase examination zone for RHR Mixing Tees to include this and other OE. (MRP-192 is Good Practice)
RWCU Mixing Tee October 2014	Through Wall leakage	Inadequate exam frequency	Identify that a follow up examination of repaired thermal fatigue cracks will reduce risk
	Repeat Failure	Cold leakage into Tee was present for entire period after initial event (~300F dT)	All sources of hot-cold liquid interface need priority isolation valve maintenance.
Cold Leg Drain November 2014	Repeat failure location.	Mitigative insulation was inadvertently removed	Periodically confirm that corrective design changes implement to prevent crack re-occurrence remain intact.
	Crack growth rate exceeded expectations	Crack was missed in the 2011 examination.	Upgrade NDE requirements to current standards. Ensure coverage is understood
	DH line was analyzed for fatigue usage – crack occurred prior to expectation	Fatigue usage assumptions were not valid because of insulation removal	Periodically confirm that corrective design changes implement to prevent crack re-occurrence remain intact.
Cold Leg Drain December 2014	Through wall leakage. Cracking was not detected in 2009 exam	Possible missed NDE detection was ruled out in Dominion RCE	No Action required
	Crack growth exceeded MRP-146 expectation based on Generic analysis of paragraph 2.1.5.4	Assessment of thermal fatigue significance based MRP-146 paragraph 2.1.5.4 may be non-conservative	Perform a one-time examination of excluded components not later than the first RFO after 6-1-16
		Chemistry sampling or other outleakage contributed to fatigue cracking	DH lines with potential for outleakage or outflow must be examined every other outage unless an inclusive fatigue usage calculation is performed

Fatigue Management Program Changes
Interim Guidance Communication

- 8 Beneficial Practices Identified

A. All fatigue contributions must be considered
B. Mitigation activities and cause analyses should validated
C. Construction repairs elevate cracking risk
D. Re-examinations are important regardless of predicted usage
E. Carefully maintain valves with a function to prevent thermal mixing
F. Examination coverage in areas of known cracking is critical
G. Good communication between Engineering and Examiners
H. Inspection of piping and supports can reveal design oversights

Fatigue Management Program Changes
NEI 03-08 Interim Guidance Communication

- 2 New ‘Good Practice’ recommendations provided
  - Review and validate thermal fatigue analysis assumptions
  - Expand RHR mixing tee exam volumes to include upstream welds

- 8 New ‘Needed’ requirements provided in four areas
  - Examination of DH lines with cyclic operational outflow (2)
    - A one-time exam if outflow is no longer performed
  - One-time exam of lines exempted using ‘Generic Analysis’ (1)
    - To determine if this analysis had a significant contribution to OE
  - Examination of vertical piping section in UH lines (2)
    - Expanded scope one time exam to confirm susceptible pipe sizes
  - NDE process improvements (3)
    - Provide focus on exam coverage & require use of CAP when essentially 100% coverage is not achieved

Considerations for Long Term Action Planning
(Various stages of project approval)

- Construct a physical mockup similar in design to recent operating experience that could be used for testing, and benchmarking of a computational fluid dynamics simulation
- Perform testing on a mixing tee to simulate low branch inlet flow conditions to investigate up-stream thermal cycling
- Benchmark International approaches to thermal fatigue management to identify differences and opportunities
- Complete revision of MRP-146 to incorporate Interim Guidance and improve usability
- Review results of One-Time examinations and determine if additional guidance is needed
- Modify volumetric NDE system requirements to better conform with existing Appendix VIII qualified procedures, construct additional mockups as necessary

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