Industry Response to Recent Thermal Fatigue Operating Experience

Mike McDevitt
Principal Technical Leader

NRC-Industry Materials Workshop
Washington, DC
June 2, 2015
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

UT or RT Elbow Base Metal

UT or RT Weld

RCS Pipe

UT or RT Elbow Base Metal

UT or RT Weld

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

- Inspections are based on the number of effective differential temperature hours, $N_{\text{eff}}$
  - Schedule volumetric examination when $N_{\text{eff}}$ 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
<table>
<thead>
<tr>
<th>Date</th>
<th>Component</th>
<th>Significant Technical Aspects</th>
</tr>
</thead>
</table>
| 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

- 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 Line September 2014

\[ x_m = x_m(t) \]

RCS header

\[ D = 2a \]

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

MRP-146 Examination area for thermal fatigue
### Analysis of Recent Operating Experience
#### An Example: Small-Diameter UH Branch Line

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

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

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