LEAK-BEFORE-BREAK EVALUATION of OVERLAID ALLOY 82/182 WELDS

Public Meeting on RIS 2010-07

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Summary of Presentation

- Background on Leak Before Break (LBB)
- LBB Criteria (SRP 3.6.3, 2007)
- SI LBB Methodology for recent WOL application
- SI Position on RIS-2010-07

Background on Leak-Before-Break (LBB)

- Original design basis accident (DBA) for US nuclear plants:
  Assumed instantaneous double-ended guillotine break of largest piping system.

- DBA used for:
  - Containment sizing and design
  - ECCS system design
  - Protection against dynamic effects of pipe rupture

- Last item required addition of huge pipe whip restraints and jet impingement shields
  - Expensive
  - Significant impediment to inspection and maintenance

Background on Leak-Before-Break (LBB)

- Industry and U.S. NRC worked together to develop criteria for showing that probability of pipe rupture was low.
- LBB concept developed as a deterministic approach to show low pipe rupture probability
  - No credible degradation mechanism
  - Brittle fracture not possible
  - Leakage detectable long before pipe rupture would occur
- LBB concept originally described in NUREG-1061, Volume 3 issued November 1984

  Defined LBB as "…the application of fracture mechanics technology to demonstrate that high energy fluid piping is very unlikely to experience double-ended ruptures or their equivalent as longitudinal or diagonal splits."

Background on Leak-Before-Break (LBB)

- Criteria from NUREG-1061 (Vol. 3) carried over to NUREG - 0800 Standard Review Plan 3.6.3
  - Originally issued March 1987
  - Revised March 2007 to accommodate new plant construction
- LBB Has been applied to most PWR plants
  - Originally applied to main reactor coolant loop piping
  - Later applied to smaller diameter piping
    - Piping > 10” diameter can generally be qualified for LBB
    - Some applications down to ~6” diameter can be qualified
  - Application in BWRs rare due to IGSCC susceptibility

LBB Criteria

- NUREG-0800 Standard Review Plan (SRP) 3.6.3 defines NRC review process and acceptance criteria
- SRP 3.6.3 lists a number of screening requirements, for application of LBB including:
  - Item 3: Corrosion

    Must demonstrate that PWSCC is not a potential source of pipe rupture
  - Item 7: Mitigation of SCC

    SCC piping that has been treated by two mitigating methods may qualify for LBB if the piping contains no flaws larger than those permitted by the ASME Code Section XI

LBB Criteria

Assuming the screening requirements are satisfied, NUREG-0800 Standard Review Plan 3.6.3 defines acceptance criteria for an LBB analysis:

Critical flaw size: Circumferential flaw length that would cause crack instability under normal loads plus SSE

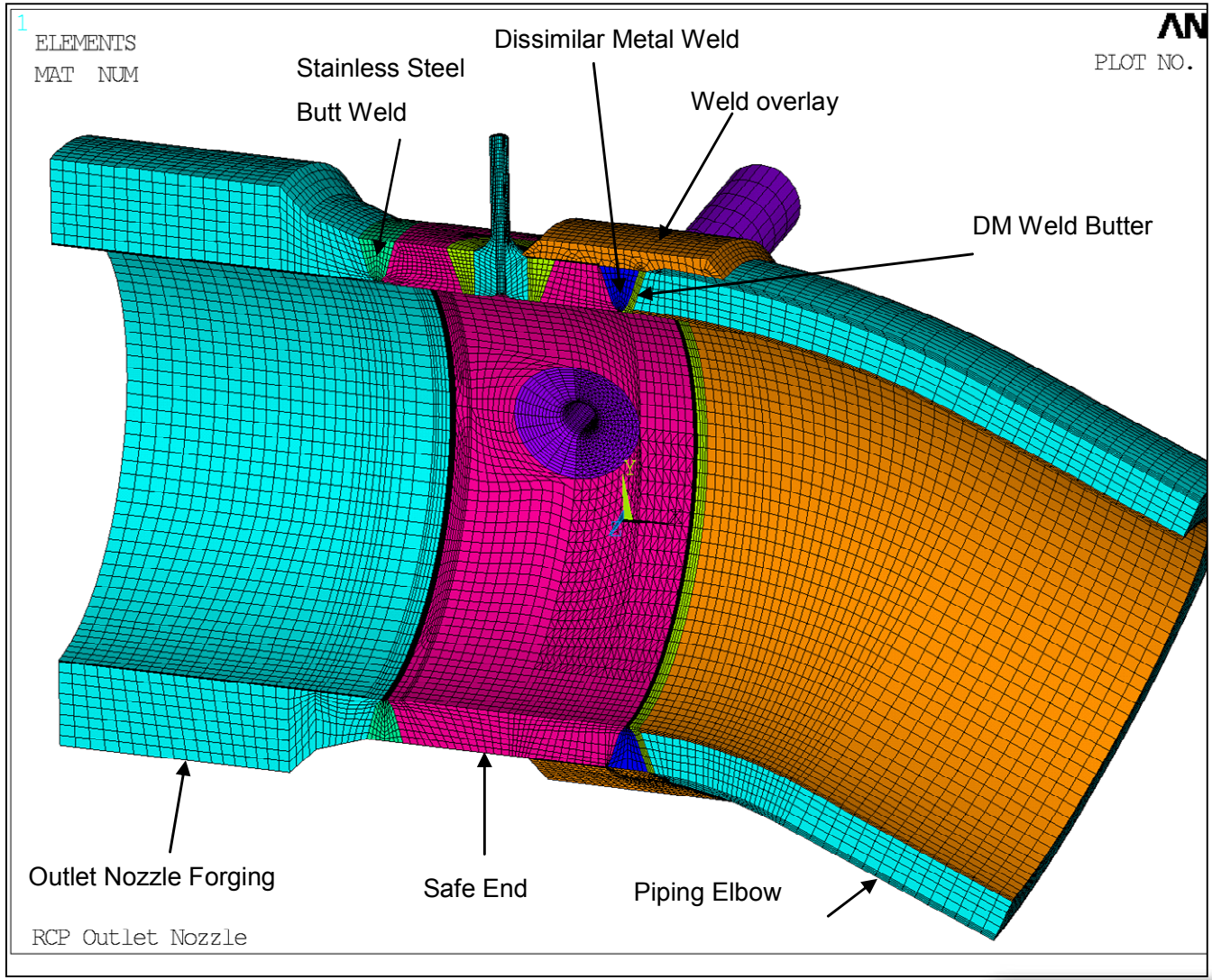
Leakage flaw size: Flaw length required to produce leakage = 10 times plant leakage detection capability

Margin on Flaw Size: Critical Flaw Size / Leakage Flaw Size ≥ 2

LBB for Weld Overlay Applications

- In response to NEI-03-08 and MRP-139 weld overlays are being applied as mitigation against PWSCC at susceptible locations
- Many of these locations have been previously qualified for LBB
  - Main loop piping
  - Some surge lines
  - Some safety injection suction and return lines
- RIS 2010-07
  - A weld overlay may invalidate original LBB analysis
  - Licensee may need to revise the LBB analysis, and
  - Apply 10CFR50.59 to determine whether a license amendment request is required to be submitted to NRC

Weld Overlay Design



LBB of Weld Overlaid Locations

- Weld Overlay LBB Evaluation per SRP 3.6.3
  - Weld overlay provides 2 mitigation measures to PWSCC
    - Compressive residual stresses at pipe ID and inner portion of original weld prevents future initiation and propagation
    - PWSCC resistant barrier on pipe OD (belt and suspenders)
  - Critical flaw size increases
    - Larger OD, thicker section reducing applied stresses
    - Added weld material toughness (Alloy 52)
  - Leakage flow resistance increased by additional thickness
    - Flow path is increased
    - Longer critical flaw size typically more than offsets increased resistance to leakage → Larger margin than original LBB analysis

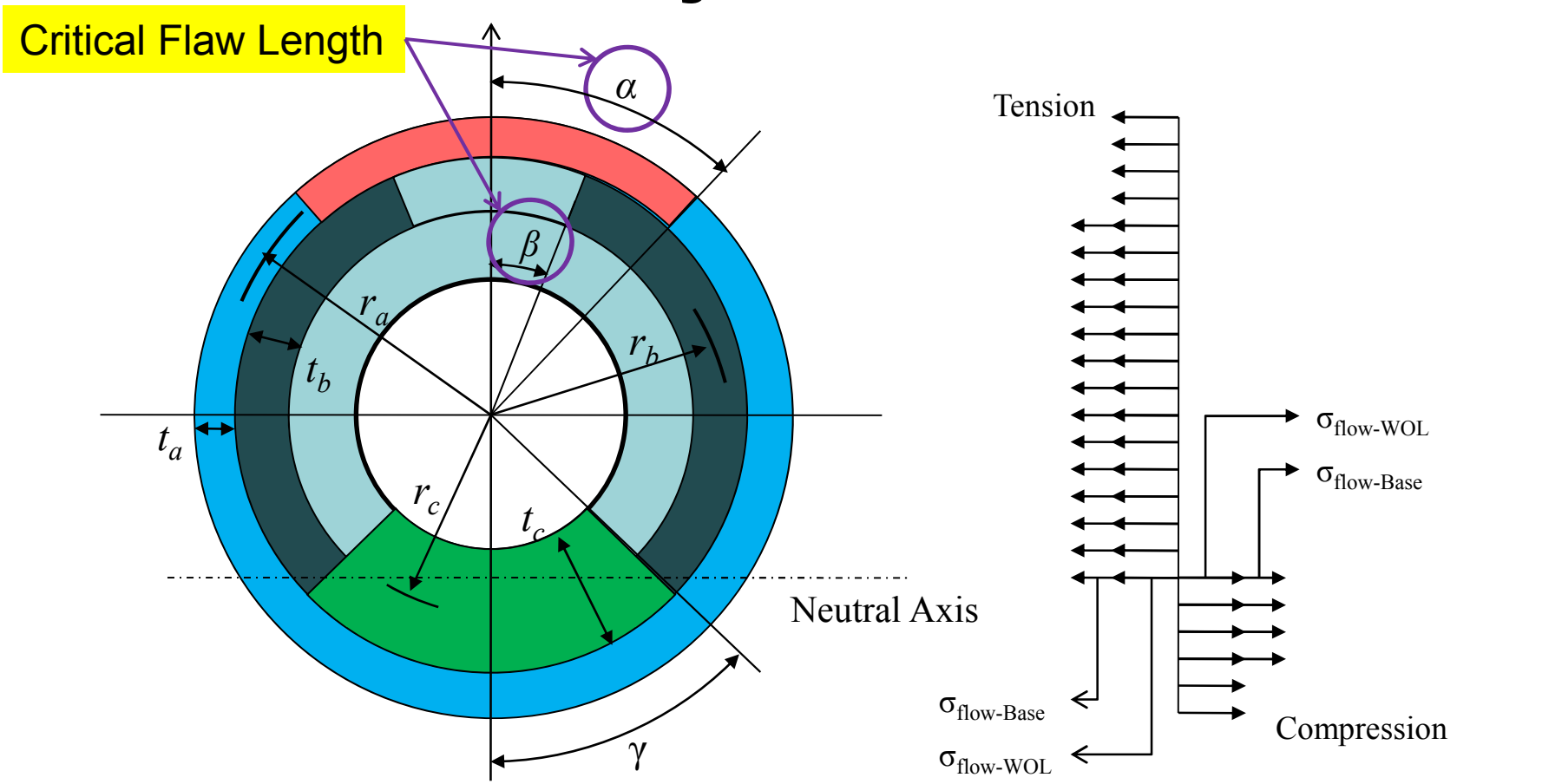
Summary of Recently Submitted WOL LBB Evaluation

- Material Properties
  - High toughness material in weld overlay
  - Potential low toughness material beneath weld overlay
- Loads
  - Same as in original LBB analysis
- Critical Flaw Size
  - Fracture mechanics (EPFM) analysis of two-layered section
- Leakage Flaw Size
  - Leakage through two-layered thicker pipe
  - Addressed Fatigue and PWSCC crack morphologies in prior evaluation

Recently Submitted WOL LBB Evaluation
Critical Flaw Size

- Critical Crack Sizing - Two Methods
  - Limit load and EPFM (with use of Z factors) similar to ASME XI Appendix C
  - Adapted to Two-Layered Materials Configuration
- Design Input from Plant Data
  - Piping geometry/weld locations/size, etc.
  - Materials data from CMTRs (desirable) or Code minimums
  - Applied loadings – pressure + moments & axial forces.
    - NOP = Dead weight + Thermal
    - SSE = Safe shutdown earthquake (or other critical load case)
    - Can evaluate loads parametrically

Net Section Collapse Analysis for Two-Layered Materials



Uncracked WOL Material

Uncracked Base Material

Base Material under Compression

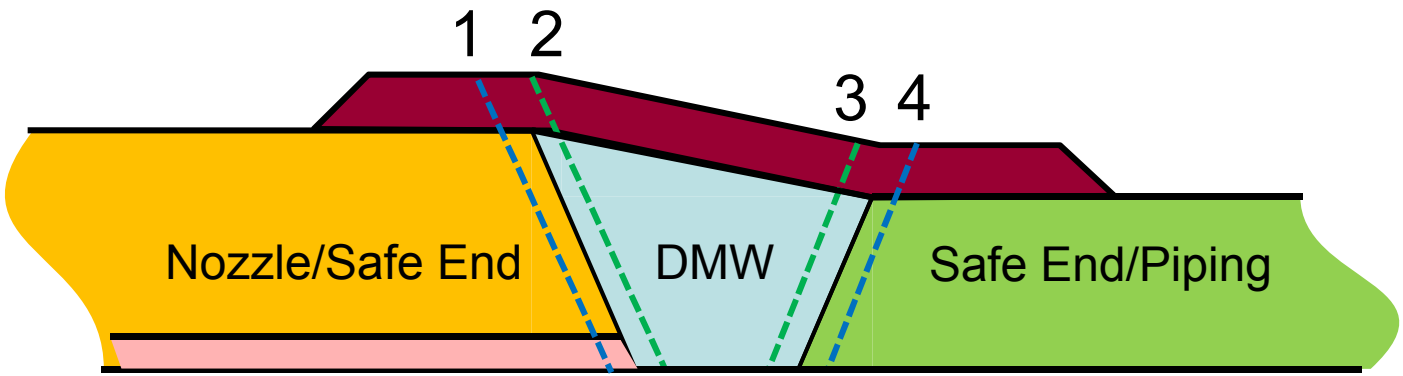
Through-Wall Crack in WOL

Crack in Base Material

Recently Submitted WOL LBB Evaluation
Leakage Rate Analysis

- Leakage Flaw Sizes Required
  - Based on plant leakage detection system capability times factor of 10
  - Alternatively predict leakage for ½ critical flaw sizes
  - RG 1.45 leakage is typically 1gpm
- Leakage Model Considerations
  - Crack opening area (COA) model considering tension and bending loads at crack
  - Two phase flow model using PICEP for leakage calculation (based on NRC-developed roughness/turns model)
  - PWSCC crack morphology through original Alloy 82/182 weld
  - Fatigue crack morphology through Alloy 52 weld overlay

Nozzle/WOL Dimensions



		Nozzle 1			Nozzle 2		
Location		1,2	3	4	1,2	3	4
Base Metal	D_o, in	34.874	34.125	34.332	33.500	34.059	34.059
	D_i, in	28.166	28.166	28.625	28.000	28.000	28.625
	Thickness, in	3.354	2.980	2.854	2.750	3.030	2.717
WOL (thickness)	Min., in	1.120	1.190	1.190	1.020	1.050	1.050
	Max., in	1.270	1.340	1.340	1.230	1.330	1.330

Leakage Flaw Sizes
(for 10 GPM)

Crack Location	Nozzle 1 (inches)		Nozzle 2 (inches)	
	Min. WOL Thickness	Max. WOL Thickness	Min. WOL Thickness	Max. WOL Thickness
Path 1 Nozzle/SE at Weld	10.82	11.19	8.40	9.48
Path 2 Weld/Nozzle Side	19.56	19.96	16.35	17.45
Path 3 Weld Elbow Side	18.37	18.77	17.53	18.78
Path 4 Elbow at Weld	11.27	11.61	10.14	11.17

Margins
(Crit. Flaw Size/Leakage Flaw Size)

Crack Location	Nozzle 1		Nozzle 2	
	Min. WOL Thickness	Max. WOL Thickness	Min. WOL Thickness	Max. WOL Thickness
Path 1 Nozzle/SE at Weld	4.60	4.59	5.42	5.30
Path 2 Weld/Nozzle Side	2.90	2.90	2.87	2.88
Path 3 Weld Elbow Side	2.98	2.98	2.81	2.82
Path 4 Elbow at Weld	4.29	4.30	3.97	4.05

Recently Submitted WOL LBB Evaluation
Conclusions

- LBB Evaluation performed for two weld overlaid nozzle DMWs using methodology and criteria applicable to original LBB qualification of SRP 3.6.3

- Modifications to LBB evaluation implemented to account for addition of weld overlay (two layers):
  - ✓ Critical flaw sizing
  - ✓ Leakage prediction
  - ✓ PWSCC crack morphology assumed in original DMW (for licensing expedience)

- LBB margins required in SRP 3.6.3 and NUREG-1061, Vol. 3 are maintained and generally exceed original LBB margins

SI Position on RIS 2010-07

SI has performed and submitted an updated LBB evaluation for two Large Diameter WOLs (FSWOL and OWOL)

- Methodology accepted by NRC – SER received
- Methodology is fundamentally the same as for original LBB evaluation but calculations revised to address effect of WOL on leakage and critical flaw size
- Conservatively assumed adverse crack morphology in original DMW (to reduce review risk and maintain schedule for submittal acceptance)
- While this gave acceptable results (i.e. satisfied SRP 3.6.3 margins) for large diameter nozzles (RCL piping), other work indicates approach will give marginal results for smaller diameter nozzles (e.g. surge or SI lines)

SI Position on RIS 2010-07

However, since WOL provides effective mitigation of PWSCC, fatigue crack morphology should be assumed in both layers for leakage calculations

- WOL represents two mitigation methods (residual stress improvement + reinforcement by resistant material), as stated in SRP 3.6.3, Rev. 1 for non-conforming piping to qualify for LBB
- Likelihood of crack large enough to extend through compressive stress region, and not be detected before or after WOL application is very small
- Use of fatigue morphology is consistent - by accepting original LBB analysis, NRC does not require adverse morphology for MSIP or unmitigated PWSCC susceptible welds
- From an xLPR perspective, WOL certainly reduces the probability of pipe rupture compared to an unmitigated weld. Why treat it differently in LBB space?

SI Position on RIS 2010-07

If fatigue morphology is accepted, prior LBB margins (factor of 2 on critical flaw size; factor of 10 on leakage) can easily be demonstrated for WOL treated welds

- WOL has a small effect on leakage rate (small increase in leak path thickness)
- WOL significantly increases critical flaw size
- Therefore, LBB margins increase compared to unmitigated weld
- Qualifying smaller diameter piping for LBB would become easier
- This could easily be demonstrated generically