Technical Recommendations for New USNRC Reg. Guide for LBB

by

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Presented at SMiRT-16 Workshop on

"New Challenges to LBB"

August 16, 2001

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Historical Perspective

* Draft Standard Review Plan (SRP) 3.6.3 on “Leak Before Break Evaluation Procedures” published in 1987
  - Intentionally left in draft form
  - NRC now ready to publish Regulatory Guide on LBB since research coming to a close
* Late 1997 NRC contracted with Battelle to conduct study to provide technical support for Reg. Guide development
  - Scope and purpose of study to establish recommendations for an LBB Regulatory Guide to replace draft SRP 3.6.3, incorporating research results since initial SRP 3.6.3 publication

NRC LBB Reg. Guide Program Structure

Technical Tasks

* Task 2 – Review past LBB submittals
  - Database of past submittals
  - Lessons learned
  - Identify candidate piping systems to evaluate in Task 3 Case Studies
* Task 3 – Sensitivity studies and development of a three tiered approach for LBB
  - Subtask 3.1 – Sensitivity studies
  - Subtask 3.2 – Case studies of three-tiered approach to LBB
* Task 5 – NUREG report, including review of foreign experience
* Task 6 – LBLOCA efforts (new task)

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Proposed Tiered Approach to LBB

* Tiered approach will form basis for future development of LBB Reg. Guide
* Focus of tiered approach on estimating:
  - Postulated leakage crack size at normal operating loads
  - Critical crack size for transient loading conditions
* Other elements of overall LBB assessment not addressed – still need to be included in overall LBB approach
  - Definition of applicability of LBB
  - Demonstrating accuracy of leak rate and fracture codes
  - Subcritical flaw growth analysis

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Proposed Tiered Approach to LBB

Level 1

* Simple, yet conservative methodology
  - No need for advanced leak-rate or fracture mechanics codes
    - Leakage size crack based on pre-established influence functions or closed-form solutions
    - Critical crack sizes based on modified limit-load analyses
  - Crack-opening displacement analysis based on conservative Paris/Tada method (results of Task 3 sensitivity study)
* Level 1 specific screening criteria
* Piping systems that easily passed draft SRP approach (e.g., main coolant loop piping) should pass Level 1
  - Level 1 crack size margin (ratio of critical crack size to leakage crack size) for cross over leg in PWR was found to be 2.5 to 3.25

Proposed Tiered Approach to LBB

Level 2

* Structured in motif of draft SRP 3.6.3 procedures except incorporates recent enhancements in technology
  - Use of the best leak-rate codes with appropriate crack morphology parameters for estimating the leakage crack size at normal operating conditions (results from another Task 3 sensitivity study)
    - GE/EPRI COD analysis
    - Statistically determined crack morphology parameters from NUREG/CR-6004
    - Applicant's leakage size crack using proprietary code and 300 ⁻inch surface roughness almost a factor 2 shorter than calculated leakage crack using SQUIRT, GE/EPRI, and NUREG/CR-6004 parameters (Results documented in SMiRT paper)

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Proposed Tiered Approach to LBB

Level 2 (cont.)

* Recent enhancements in the technology (cont.)
  - Use of most accurate fracture mechanics codes for estimating critical crack sizes at the transient load conditions (e.g. seismic)
    - J-estimation schemes versus modified limit-load
      - ✓ LBB.ENG2 most accurate when compared with experimental data
      - ✓ GE/EPRI slightly less accurate, but slightly more conservative

Analysis Method	Mean Value of Experimental Load/Predicted Load			
	TWC Pipes Bending	Short TWC Pipes Bending	TWC Welded Pipes Bending	TWC Pipes Bending & Pressure
LBB.ENG2	1.04	0.96	1.08	1.18
GE/EPRI	1.15	1.12	1.18	1.31

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Proposed Tiered Approach to LBB

Level 2 (cont.)

* Recent enhancements in the technology (cont.)
  - Accounting for increased understanding of the behavior of nuclear grade pipe steels
    - Load history effects (dynamic and cyclic)
      - ✓ Dynamic strain aging effects on strength and toughness of ferrric steels
      - ✓ Cyclic effects on toughness
    - Aging mechanisms for cast stainless steels and stainless steel welds
    - Fusion line toughness concerns
    - Bimetallic welds, including impact of PWSCC on the LBB behavior
    - Toughness anisotropy of nuclear grade ferritic steels
    - Methods of extrapolating J-R curves from small-scale specimen data

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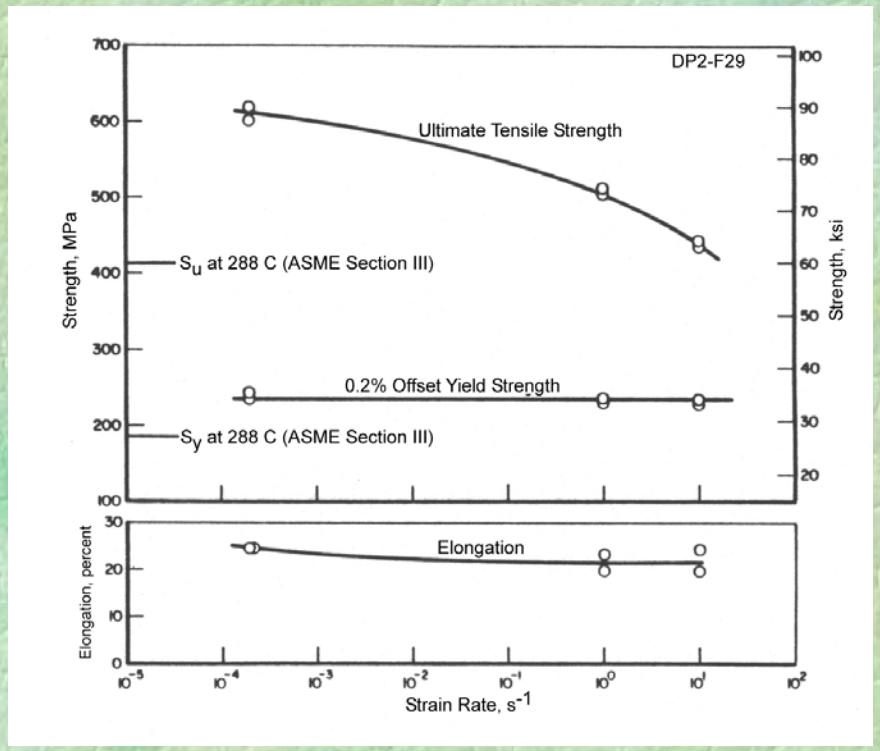
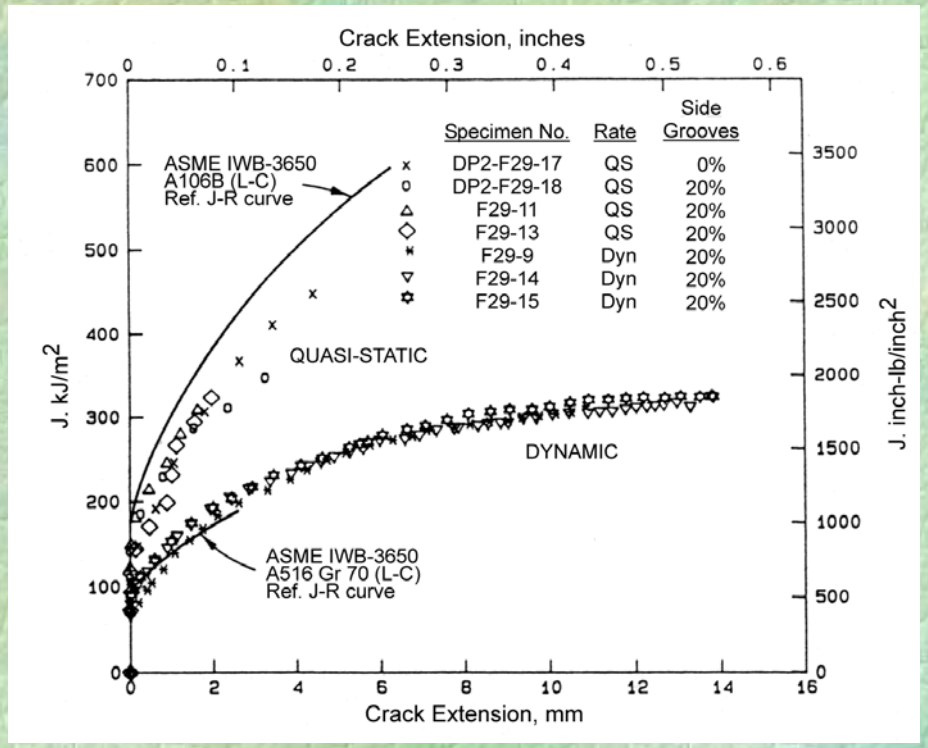
Load History Effects on Fracture

Dynamic Strain Aging Effects on Ferritic Steels





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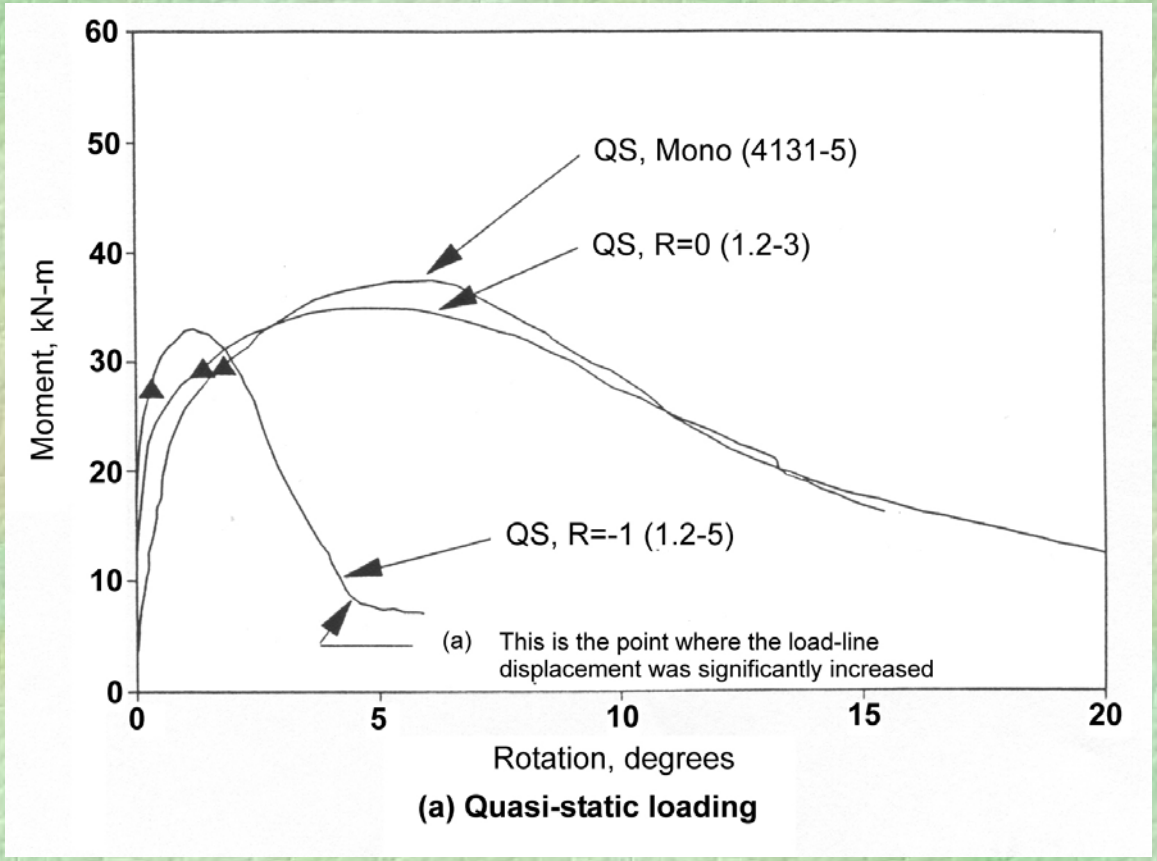
Load History Effects on Fracture

Cyclic Effects on Toughness



(a) Quasi-static loading

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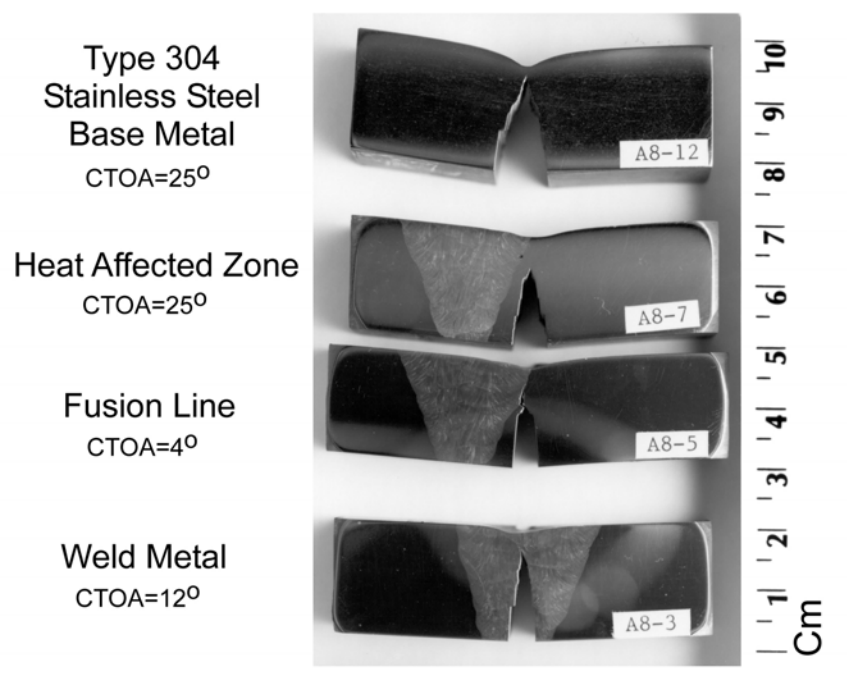
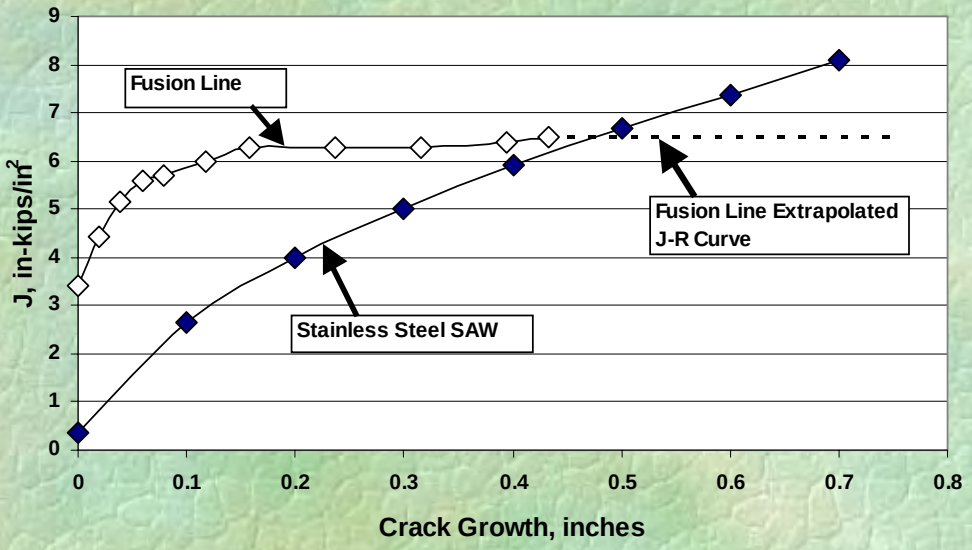
Fusion Line Toughness Concerns

Stainless Steel Welds





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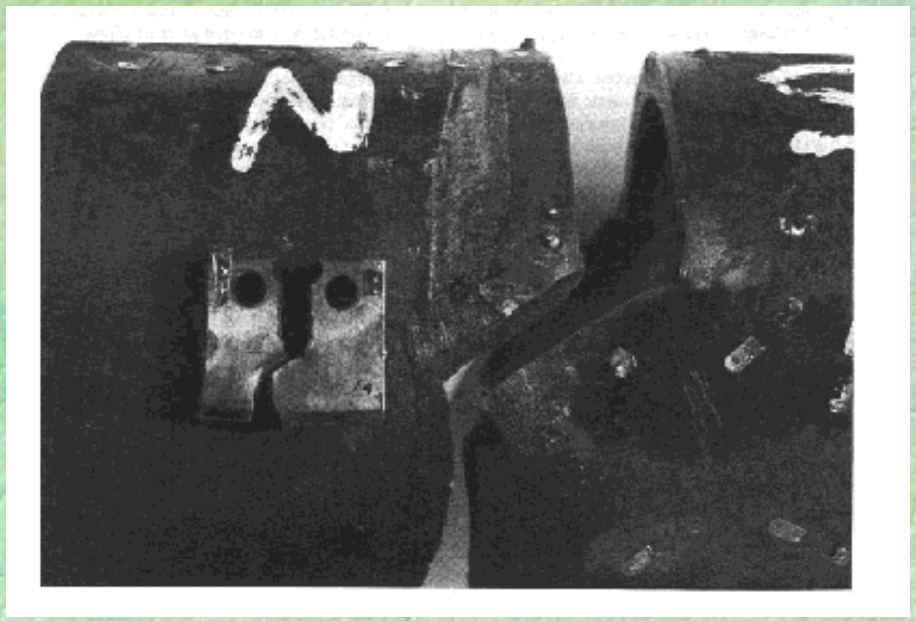
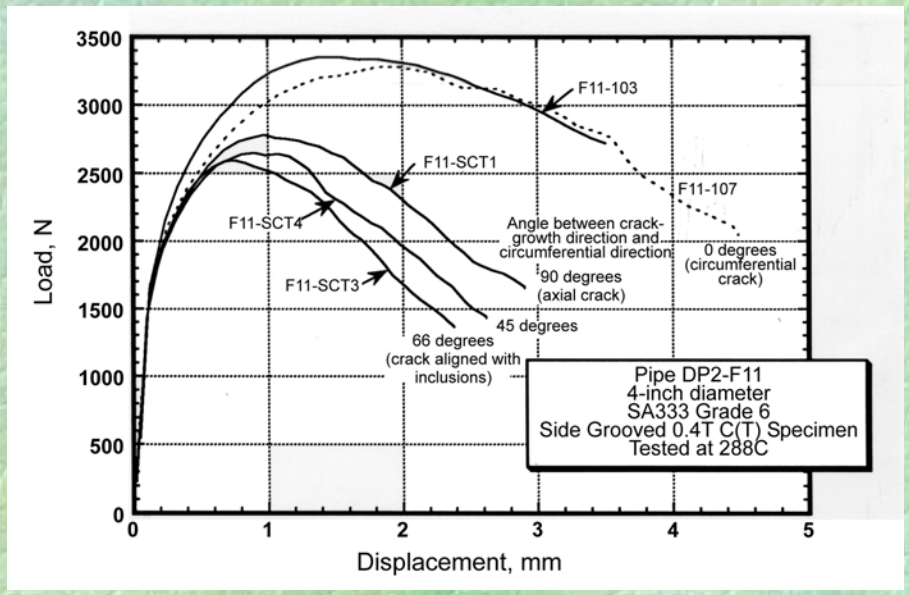
Toughness Anisotropy

Lower Toughness in Helical Direction (Ferritic Steels)





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Proposed Tiered Approach to LBB

Level 2 (cont.)

* Recent enhancements in the technology (cont.)
  - Better understanding of certain key effects on COD predictions for the leakage crack size analysis
    - Restraint of pressure induced bending (BINP task)
      - ✓ Function of crack size and restraint length
    - Weld residual stress effects (BINP task)
    - Crack face pressure (possible benefit to LBB)
  - Better understanding of the role that secondary and torsional stresses play in an LBB assessment
    - Effect of secondary stresses to be discussed in detail later
    - Effective bending stress relationship for combining torsional and bending stresses
    - Impact of toughness anisotropy on piping systems subjected to high torsional stresses

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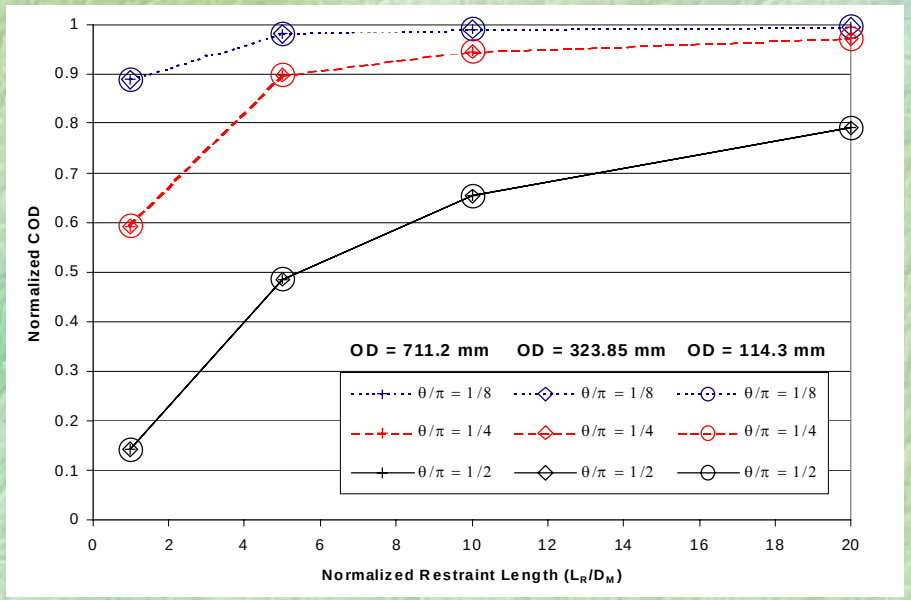
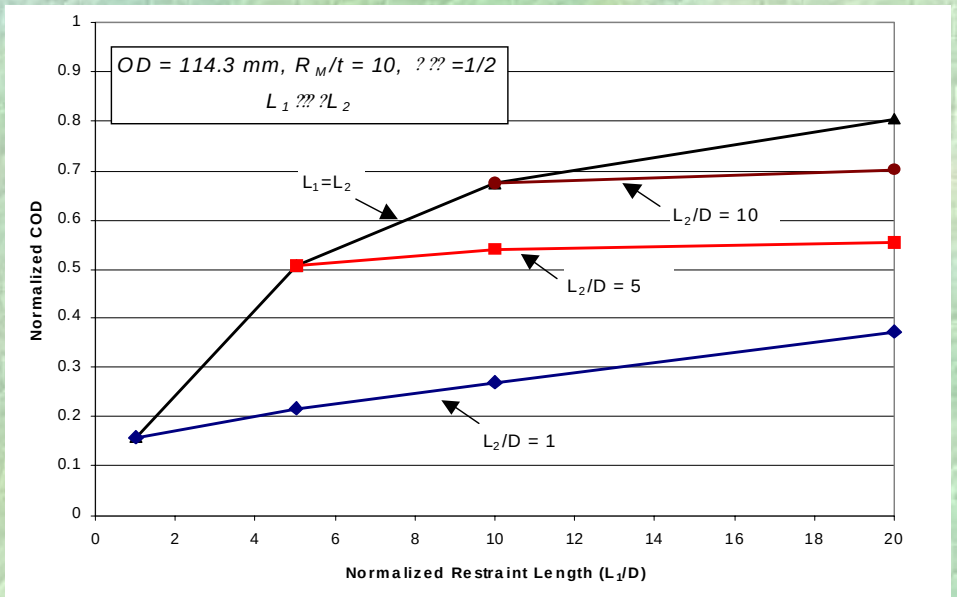
Effect of Restraint of Pressure Induced Bending on COD Predictions

Normalized COD versus Normalized Restraint Length





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Proposed Tiered Approach to LBB

Level 2 (cont.)

- Used whenever cannot satisfy both Level 1 screening and acceptance criteria
  - Level 1 analysis of surge line resulted in margin on crack size of less than 2
  - Level 2 analysis of same surge line resulted in margin on crack size of almost 3
- Level envisioned being used in majority of future LBB applications
- If cannot satisfy Level 2, then applicant has option of Level 3 analysis

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Proposed Tiered Approach to LBB

Level 3

* Most complex of three levels requiring greatest amount of information/data to apply
* Reserved for cases where one cannot demonstrate LBB using Level 2 assessment
  - Takes advantage of inherent margins one might realize by using a nonlinear analysis – accounts for increased energy absorption due to plastic deformation – 3 options
    - Uncracked nonlinear pipe analysis
    - Linear pipe with a nonlinear spring representation for the crack
    - Nonlinear pipe with a nonlinear spring representation of the crack
  - Level 3 analysis of a surge line resulted in 20 to 30 percent increase in crack size margin by incorporating nonlinear pipe with nonlinear spring crack element analysis

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Safety Factors for Tiered Approach to LBB

* Safety factors in existing draft SRP 3.6.3 are 2 on crack size and 10 on leak rate detection limit capability
* Safety factors for Level 1, which does not include many of the recent enhancements to the technology, may be similar
* Safety factors for Levels 2 and 3, which do include enhancements, may be less
* Final decision rests with NRC staff and will most likely be resolved as part of preparation of new LBB Reg. Guide

Current Status of LBB Reg. Guide Program

- Base program nearly complete
  - Draft NUREG/CR report complete with few exceptions
    - ✓ Studies looking at the effects of restraint of pressure induced bending and weld residual stresses on COD predictions still ongoing as part of BINP program
- Task 6 activities related to redefinition of Large Break Loss of Coolant Accidents (LBLOCA) is just beginning