
Joint CEOG/WOG Program on Reactor Vessel ISI Interval Extension

Presentation to NRC Staff



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Extension of Reactor Vessel ISI Interval

- **Meeting Purpose and Objectives**

- Update the Staff on progress since last meeting
 - January 27, 2000
- Discuss technical approach and preliminary results to date
 - Obtain Staff concurrence on both the approach and use of the tools/codes
- Present schedule for topical report submittal
 - Obtain preliminary Staff input on review time and schedule



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Extension of Reactor Vessel ISI Interval

- **Presentation Overview**
 - Introduction/Background
 - Project Overview
 - Progress Status
 - Technical Basis Development
 - Sample cases
 - Approach to Non-Beltline regions
 - Schedule Projection
 - Summary
 - Discussion



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Extension of Reactor Vessel ISI Interval

- **Introduction/Background**
 - Continue discussions on an approach to justify the extension of the RPV In-Service Inspection (ISI) Interval from the current 10 year requirement to 20 years.
 - We are not here to eliminate the inspection content but to demonstrate that by continuing with the same breadth of inspections at a longer interval there is no significant increase in risk of component failure.
 - Sponsored by CEOG Section XI & WOG Material Subcommittees (~ 70 operating plants)



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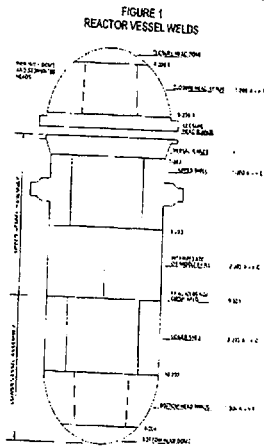
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• Introduction/Background (Cont'd)



- Ultimate objective is to address all weld and HAZ regions to be examined during a RPV inspection
 - via an alternative to the ASME Code Rules

- **Project Overview**

- Execute a broad based Owners Group Program
 - Perform Sample Plant Analysis which demonstrates that objective can be achieved
 - Formalize approval via a Topical submittal and ASME Code case
 - Apply to specific plants to get relief
 - Communicate with regulators
 - Establish Technical level dialogue
- Build on approach used on successful BWRVIP program

Extension of Reactor Vessel ISI Interval

- **Program Plan**

- Phase 1: *Conceptual Feasibility Evaluation*
- Phase 2: *Technical Feasibility / Sample Plant Application*
- Phase 3: Technical Application / Topical report
 - Complete work on representative pilot plants
 - Submit topical for review
- Phase 4: Licensing
 - Support topical review
- Phase 5: Plant / Vessel Specific Evaluations
 - Using Topical, apply generic methodology to support individual requests for Exemptions



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- **Plant Survey**

- Economic Survey
 - Man-Rem savings range 0.84 - 2.98 man-rem
 - Dollar savings range \$2.3m - \$7.1m



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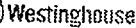
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DEVELOPMENT OF TECHNICAL BASIS FOR EXTENSION OF REACTOR LIFE



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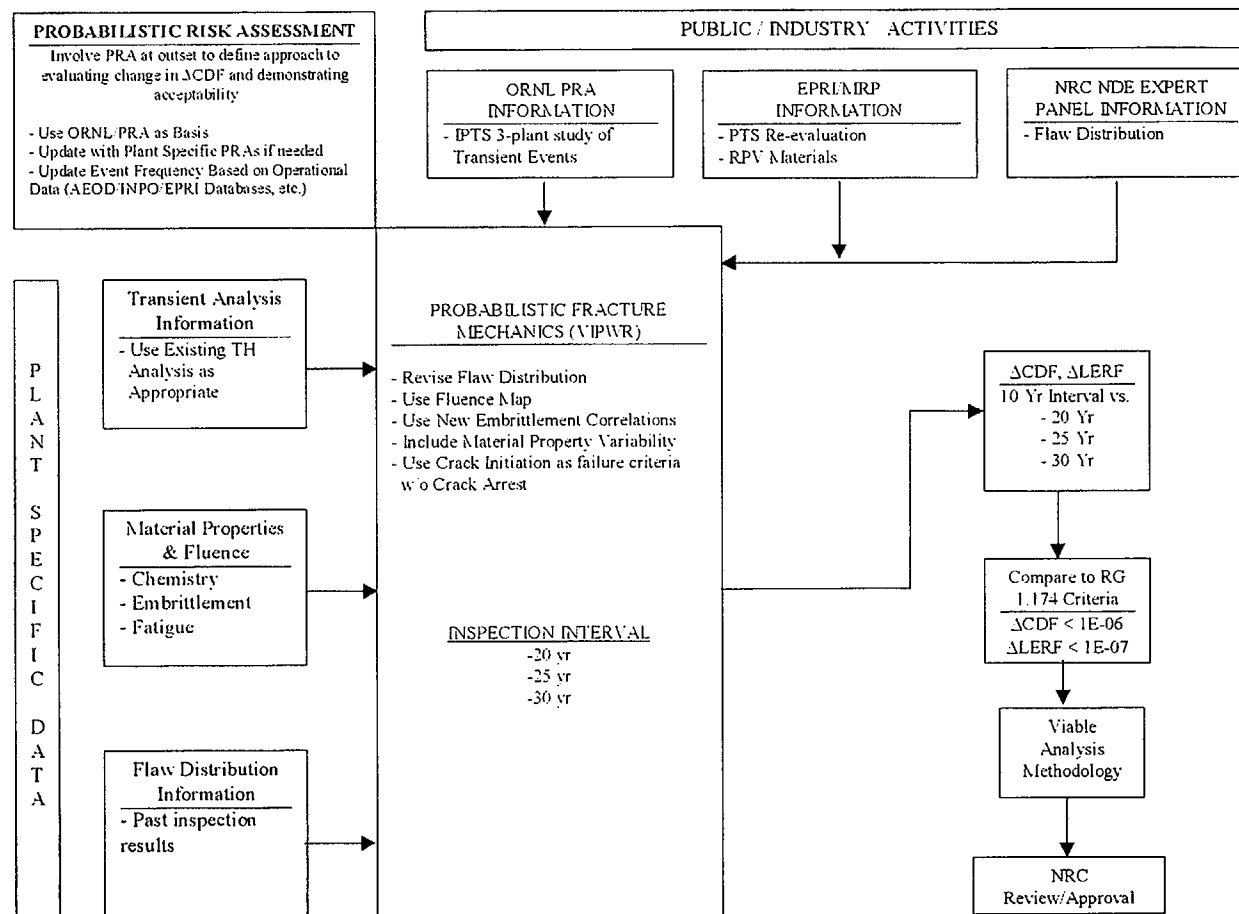
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Extension of Reactor Vessel ISI Interval

DEVELOPMENT OF TECHNICAL BASIS FOR EXTENSION OF RPV INSPECTION INTERVAL



Extension of Reactor Vessel ISI Interval

- Phase 2: Methodology Development
 - Input assumptions selected to test and evaluate methodology
 - ASME Lower Bound K_{IC} Assumption
 - Use of ORNL Transients subset in the Methodology Testing
 - Use of PVRUF flaw size Distribution



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Extension of Reactor Vessel ISI Interval

- Technical Basis Development
 - Material Properties / Fatigue
 - Comparison to NRC PTS Re-evaluation Effort
 - Probabilistic Fracture Mechanics
 - Preliminary Results
 - Non-Beltline Regions



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RPV Beltline Configuration, Properties & Crack Growth

**Presented by Chris Hoffmann
Westinghouse CEET**



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RPV Beltline Configuration

- **RPV Beltline Dimensions**
 - As-Built Dimensions
 - Weld Locations & Weld Joint Dimensions
 - Cladding Thickness (Min. Specified)
- **Definition of Beltline Subregions**
- **Stress Analysis Assumptions**
 - Weld Residual Stress Distribution (HSST Data)
 - Cladding Stress-Free Temperature



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RPV Beltline Material Properties

Beltline Plate and Weld Materials

- Initial RT_{NDT} Values (Measured, Generic or MTEB 5.2)
- Copper & Nickel Content
 - Chemistry Variability

Irradiated Beltline Material Properties

- RPV Fluence Calculation
 - Axial & Azimuthal Distributions
 - Reg. Guide 1.99, Rev. 2, Position 1.1
 - Adjusted Reference Temperatures (Initial + Shift + Margin)



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Fatigue Crack Growth & Fracture Toughness

RPV Beltline Flaw Growth & Crack Extension

- Fatigue Crack Growth
 - Section XI Crack Growth Correlation
 - Best estimate crack growth with distribution
- No Significant EAC or SCC Contribution to Flaw Growth for RPV Beltline
- Fracture Toughness Properties
 - Section XI, Appendix A-4200 K_{Ic} Curve



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Extension of Reactor Vessel ISI Interval

Discussion / Comments / Q&A



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Comparison of CEOG/WOG Approach with NRC PTS Re-evaluation Effort

**Presented by Stephen Byrne
Westinghouse CEET**



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Comparison of CEOG/WOG Task with NRC PTS Re-evaluation Effort

Objective:

- Compare CEOG/WOG and NRC approaches
- Demonstrate conservatisms in *VIPWR* Code relative to *FAVOR* Code



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Comparison of CEOG/WOG Task with NRC PTS Re-evaluation Effort

- Crack Initiation Toughness
- Embrittlement Correlation
- Flaw Distribution
- Material Properties and Distributions
- Vessel Geometry
- Transients



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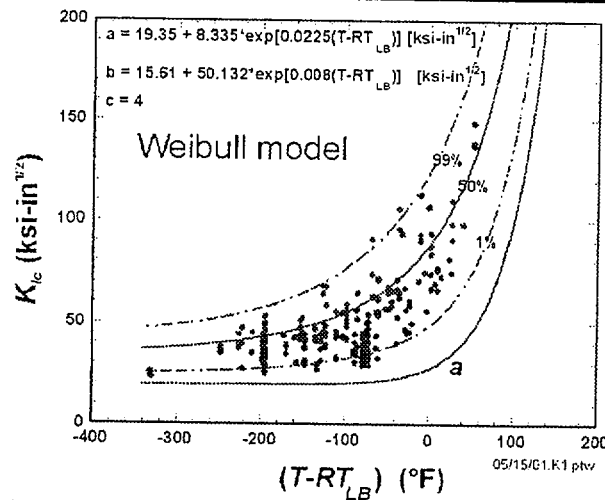
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Crack Initiation Toughness

- FAVOR Code uses mean K_{IC} curve indexed to RT_{LB} and assumes distribution of RT_{LB} using relation with fracture toughness measurements
- FAVOR Code also uses mean K_{Ia} curve indexed to RT_{LB} ; failure = crack does not arrest

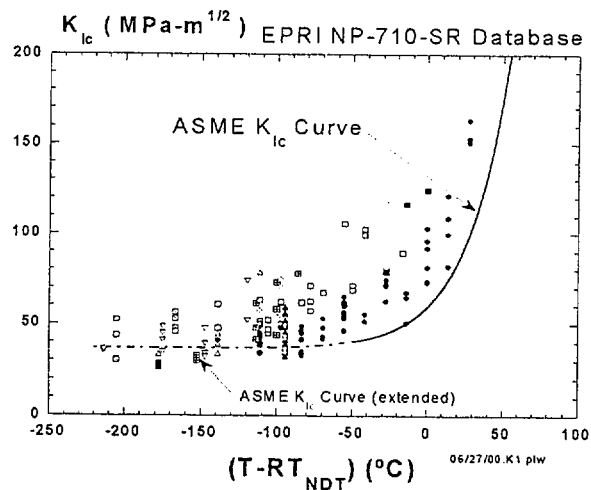
FAVOR Code K_{IC} Model



Crack Initiation Toughness

- *VIPWR* Code uses lower-bound K_{Ic} curve indexed to RT_{NDT}
- *VIPWR* Code does not credit crack arrest; failure = crack initiates

VIPWR Code K_{Ic} Model



Embrittlement Correlation

- *FAVOR* Code Embrittlement Prediction:
 - EASON Correlation = $f(\text{Cu, Ni, P, } \phi t, T, t)$ and product form
 - Fluence attenuation per Regulatory Guide 1.99, Revision 02
 - New
- *VIPWR* Code Embrittlement Prediction:
 - Regulatory Guide 1.99, Revision 02 (Position 1.1)
 - Correlation = $f(\text{Cu, Ni, } \phi t)$ and product form
 - Fluence attenuation per Regulatory Guide 1.99, Revision 02
 - Current regulatory requirement



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Flaw Distribution

- *FAVOR* Code Flaw Distribution:
 - input provided by PNNL (see next slide)
 - flaws distributed through thickness
 - surface flaws approximated from measurements
 - weld repair flaws approximated from measurements
- *VIPWR* Code Flaw Distribution:
 - size distribution based on PVRUF data
 - considers portion of flaws near inner surface of limiting weld
 - *VIPWR* modifies size of sampled flaw by fatigue crack growth



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Material Properties and Distributions

- Material chemistry (best estimate Cu, Ni) and initial RT_{NDT} based on RVID and NSSS designer information for both *FAVOR* and *VIPWR* inputs
- *FAVOR* uses local resampling for crack extension; *VIPWR* does not (crack initiation = failure)
- *FAVOR* uses generalized normal distribution for copper and nickel; *VIPWR* uses heat-specific normal distribution based on data in CE NPSD-1039, Revision 02



Vessel Region Sampling

- Vessel dimensions the same for both *FAVOR* and *VIPWR*
- *FAVOR* samples from each subregion
- *VIPWR* samples only from limiting location

[Note: *VIPWR* code can be modified to sample from different regions.]



Transients

- *VIPWR* Code sample analyses used transients and event frequencies from SECY-82-465 and plant-specific analysis
- *FAVOR* Code analyses using transients and event frequencies generated on plant-specific basis; available by mid-November 2001 (per SECY-01-0185)

Phase 3 *VIPWR* Code analyses intend to use transients and event frequencies generated for lead plant under PTS evaluation effort



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Summary Comparison of *VIPWR* and *FAVOR*

- crack initiation toughness- *VIPWR* uses ASME K_{IC} lower bound curve; *FAVOR* uses mean K_{IC} indexed to RT_{LB}
- embrittlement correlation- *VIPWR* uses RG 1.99, R. 2; *FAVOR* uses Eason equation; both use same attenuation assumptions
- flaw size distribution- *FAVOR* uses PVRUF and other data specific to welds, repairs and base metal; *VIPWR* uses PVRUF distribution for welds and modifies size by fatigue crack growth



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Summary Comparison of *VIPWR* and *FAVOR* (Cont'd)

- material properties- both use comparable inputs
- vessel region sampling- *FAVOR* samples from all regions; *VIPWR* samples from limiting locations
- transients- *FAVOR* using newly generated transients and event frequencies; *VIPWR* using transients and event frequencies generated for SECY-82-465



Extension of Reactor Vessel ISI Interval

Discussion / Comments / Q&A



Extension of PWR Reactor Vessel ISI Intervals - PFM Methodology

Peter C. Riccardella
S.S. (Stan) Tang



Structural Integrity Associates, Inc.



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Overview

- General approach built upon methodology developed for BWR Vessel Inspection Evaluation (VIPER, BWRVIP-05)
 - Retained agreed upon major assumptions
 - Adapted methodology, as appropriate, for applicability to PWR vessels (VIPWR)
- Overall goal - to determine permissible increase in inspection intervals consistent with RG 1.174 Guidelines
- Analysis considers probabilities of vessel failure with current 10 year inspection intervals versus with various proposed alternatives (20 years, 25 years, . . .)



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Key Inputs for VIPWR

- Flaw Distributions
- Vessel Fluence
- Material Fracture Toughness
- Limiting Operational Transients
- Crack Propagation
- Clad Residual Stress
- Effectiveness of Inspection (POD)



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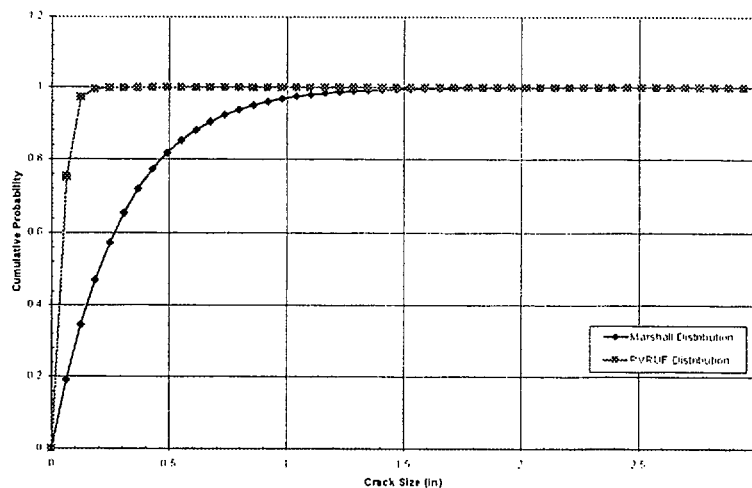
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Flaw Size Distributions



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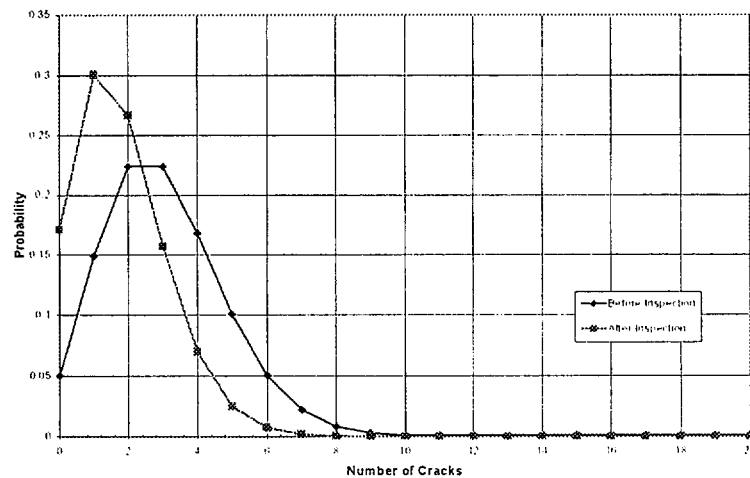
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Distribution of Number of Flaws



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Vessel Fluence

- Time Dependence:

$$f_{surf}(t) = \phi t$$

- Attenuation through-thickness:

$$f(x) = f_{surf}(e^{-0.24x})$$

- Axial and Circumferential Fluence Distributions may be addressed if available



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Fracture Toughness of Irradiated Weld Metal

- Chemistry Factor based on Cu & Ni Content (Per RG 1.99 Rev. 2)

$$CF = 360 * Cu * (1.0 + 1.38 * (\operatorname{erf}(\frac{0.3 * Ni - Cu}{Cu}) + 1))$$

- Fluence Factor (Per RG 1.99 Rev. 2)

$$FF = f^{(0.28 - 0.10 * \log f)}$$

- Adjusted Reference Temperature

$$ART = \text{Initial } RT_{ndt} + \Delta RT_{ndt} + \text{Margin}$$

- Fracture Toughness Curve

– ASME Section XI K_{Ic}



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Limiting Operational Transients

- Startup-Shutdown Transients used for Fatigue Crack Growth
- Various PTS Transients considered with Appropriate Event Frequencies
 - Small break LOCA with stagnated loop flow and stable pressure at ~900psi
 - Small break LOCA with stagnated loop flow and full repressurization late in the transient
 - Small break LOCA with stagnated loop flow and rapidly dropping pressure
 - Small steam line break at hot 0% power



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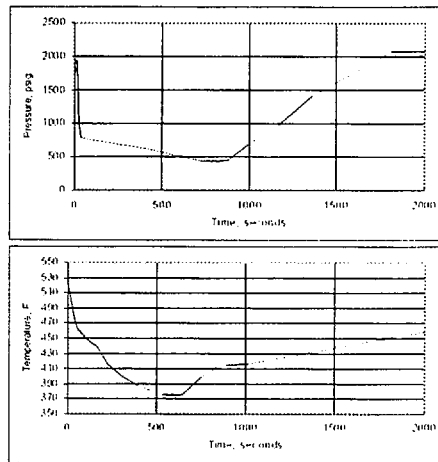
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Typical PTS Event (Steam Line Break)



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Other Key Parameters

- Crack Propagation (FCG)
- Cladding Residual Stress
 - Treated as a distributed variable
 - Indexed to clad temperature during transient
- Effectiveness of Inspection (POD)



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Consideration of Non-Beltline Regions of the Reactor Vessel

**Dave Ayres
John Ghergurovich**



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Consideration of Non-Beltline Regions of the Reactor Vessel

- **Previous discussions have focused on the beltline region of the vessel**
 - This is based on the presumption that the beltline is the governing region due to embrittlement.
- **In order to confirm that the beltline is the governing region, the fracture potential of other regions will be addressed**
- **Regions of high stress have previously been identified and evaluated to assess the impact on pressure – temperature (P-T) limits**



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Consideration of Non-Beltline Regions of the Reactor Vessel

- **Vessels have previously been evaluated according to ASME Section III Appendix G.**
 - KIR Fracture toughness Limit
 - 1/4 thickness flaw
 - Level A&B Transients
- **Regions typically considered:**
 - Beltline
 - Vessel Wall Transition
 - Bottom Head Juncture
 - Core Stabilizer Lug Attachment
 - Nozzle Inner Radius
 - Flange Region

...In-Process of being re-evaluated



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Consideration of Non-Beltline Regions of the Reactor Vessel

- **Approach Overview**

- All Vessel locations are evaluated for shutdown conditions of 70 °F or lower.
 - The lowest temperature of transients of concern is significantly higher than shut down temperatures.
- Non-beltline locations have significantly lower fluence.
- Therefore, non-beltline regions can be shown to be non-governing because of the relationship of the transient temperature and toughness properties.



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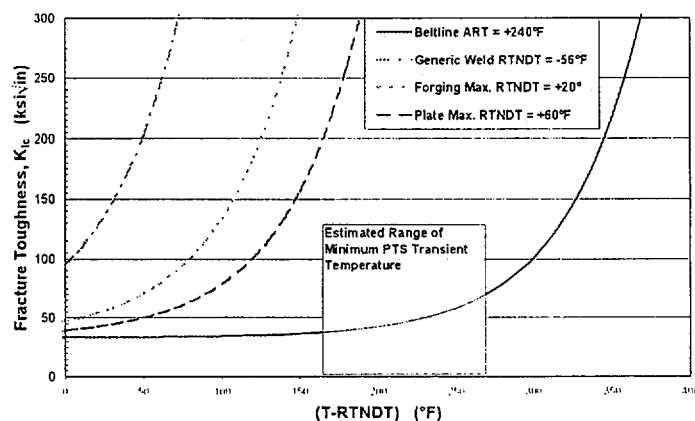


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Consideration of Non-Beltline Regions of the Reactor Vessel

Fracture Toughness of Various RV Regions



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Consideration of Non-Beltline Regions of the Reactor Vessel

- It is anticipated that the beltline will be shown to be the governing location for determination of the inspection interval.
 - **Action:** Perform sensitivity study
 - Using Level C&D Transients
 - Bounding material values

Extension of Reactor Vessel ISI Interval

Discussion / Comments / Q&A

Extension of Reactor Vessel ISI Interval

- **Schedule**

- **Phase 2: Technical Feasibility / Sample Plant Application**
 - Complete Major Modifications to the VIPWR Code and perform Initial Bounding Analyses and meet to discuss results
(Winter/Spring 2002)
- **Phase 3: Technical Application / Topical report**
 - Subsequent Topical Submittal to follow (Spring/Summer 2002)
- **Phase 4: Licensing**
 - Review of Pilot Plant Submittal (Summer/Fall 2002)
- **Phase 5: Plant / Vessel Specific Evaluations**
 - Per individual plant needs



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Extension of Reactor Vessel ISI Interval

- **Recent Industry Activities**

- PTS Re-evaluation ... Ongoing
- Embrittlement Correlation ... Ongoing
- Flaw Characterization and Distribution ... Ongoing
- ASME
 - RV Inner Radius Inspection ... Pending
 - RV Flange PT Limit Elimination ... Pending
 - RV ISI Code Case Development ... Initiated



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Extension of Reactor Vessel ISI Interval

- **In Summary**

- Technical Discussions
 - Material Properties / Fatigue
 - Comparison to NRC PTS Re-evaluation Effort
 - Probabilistic Fracture Mechanics
 - Preliminary Results
 - Non-Beltline Regions
- Industry Activities

... *Objective is Achievable*



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Extension of Reactor Vessel ISI Interval

- **Final Discussion /
Comments / Q&A**
- **Review Action Items /
Open Issues**



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