Pressure-Temperature Limits Technical Bases and RAIs

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Agenda

- Objectives of the Meeting
- Background of the Pressure-Temperature Limits, including Ferritic Components outside the Reactor Vessel
  - Original Westinghouse P-T limit basis- WCAP-7924-A
  - Current Westinghouse P-T limit basis- WCAP-14040-A, Rev. 4
  - Combustion Engineering P-T limit basis- CE-NPSD-683-A, Rev. 6
  - AREVA P-T limit basis- BAW-10046-A , Rev. 2
- Proposed Standard P-T limit RAI Response
- Extended Beltline Components
  - Nozzles
  - Transitions
- Industry Response
- Summary and Conclusions

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Objectives

- Discuss
  - Current NRC-approved P-T limit methodologies have ensured RV Integrity for 37 years of operation
  - The P-T limit technical basis is being challenged via RAIs

- Objectives
  - Recommend a short term approach to respond to the RAIs
  - Recommend long term approach to improve the technical basis for P-T limit methodology

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Ferritic Components of the Reactor Coolant Pressure Boundary

- Reactor Vessel
  - Traditional beltline
  - Extended beltline
- Steam Generator
  - Shell sections
  - Complex geometric discontinuities
- Pressurizer
  - Shell sections
  - Thickness Transitions
- Reactor Coolant Piping (B&W and CE Plants)

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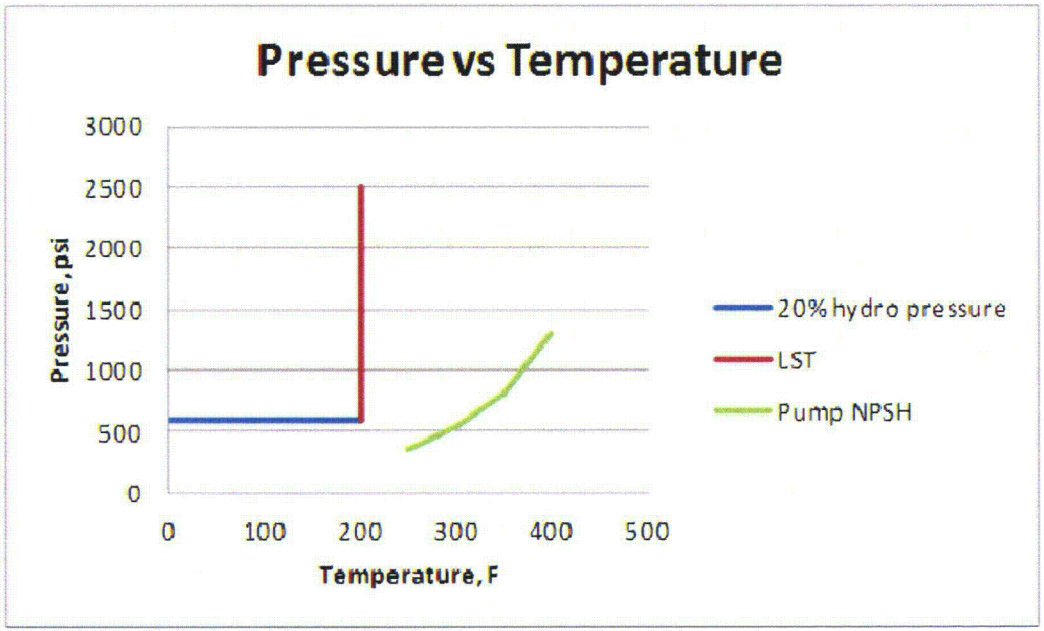
Lowest Service Temperature
Successful Approach for the First Generation of Plants

- To ensure operation in the ductile range: LST≥NDT + 60F
- P≤ 20% Hydrostatic Test Pressure when T≤ LST
- Irradiation shift would close the operating window with LST.



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Lowest Service Temperature
Successful Approach for the First Generation of Plants

- A gradual transition shown as K_{IR} from WRC-175 resolved the issue.
  - A fracture mechanics approach in the Summer 1972 ASME Addenda.

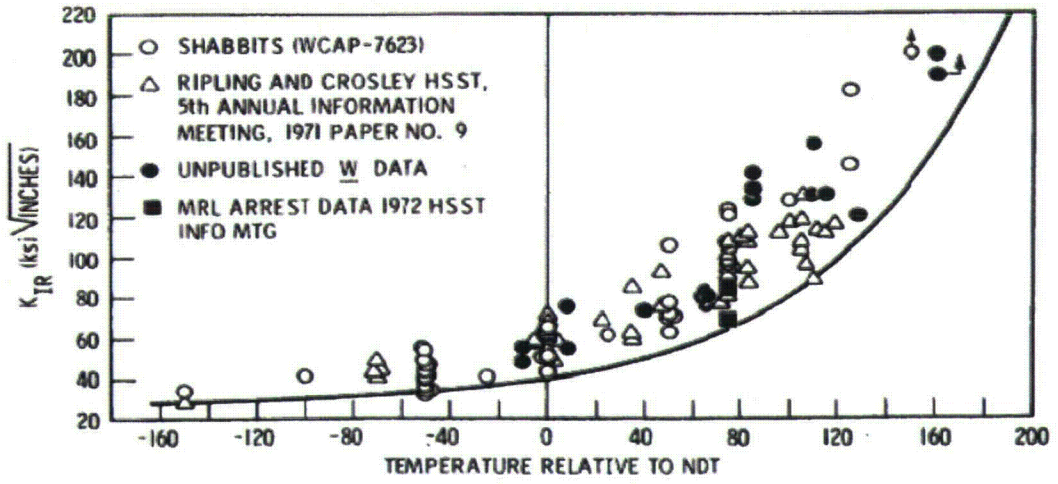

Fig. A1-1—Derivation of curve of reference stress intensity factor (K_{IR})

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ASME Code Rules for Prevention of Brittle Fracture in Vessels

- Section III, of Appendix G was used for the design and initial plant operating P-T limits based on Welding Research Council Bulletin 175

- The ASME Section III method became mandatory for all plants by 10CFR50, Appendix G (1972)
  - Applies to all ferritic components in RCS
  - Specific requirements focus on the RV beltline region

- The RT_{NDT} index, defined in ASME Section III, Subsection NB-2331 is used for establishing reference toughness (1972)

- ASME Section XI, Appendix G uses the same Section III requirement, and adds irradiated shift in accordance with Reg. Guide 1.99, Revision 2

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ASME Code Requirements

- Section III NB-3211
  - Design requirements for protection against nonductile failure
    - Evaluate service and test conditions by methods similar to those in Appendix G

    -OR-

    - For piping, pump, and valve thickness > 2½", establish a lowest service temperature ≥ RT_{NDT} + 100°F

    -and-

    - For piping, pump, and valve thickness ≤ 2½", meet Table NB-2332(a)-1 requirements for C_v specimens at a temperature ≤ the lowest service temperature in the design specification

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ASME Code Requirements

- Section XI IWB-3730 Fracture Toughness Criteria
  - Maintain load and temperature conditions (i.e., establish P-T limits) to provide protection against failure due to postulated flaws in ferritic portions of the RCPB
    - Procedures in Appendix G may be used
    - Fracture analysis is not required for nozzles and appurtenances with thicknesses ≤ 2½", provided the lowest service temperature ≥ RT_{NDT} + 60°F

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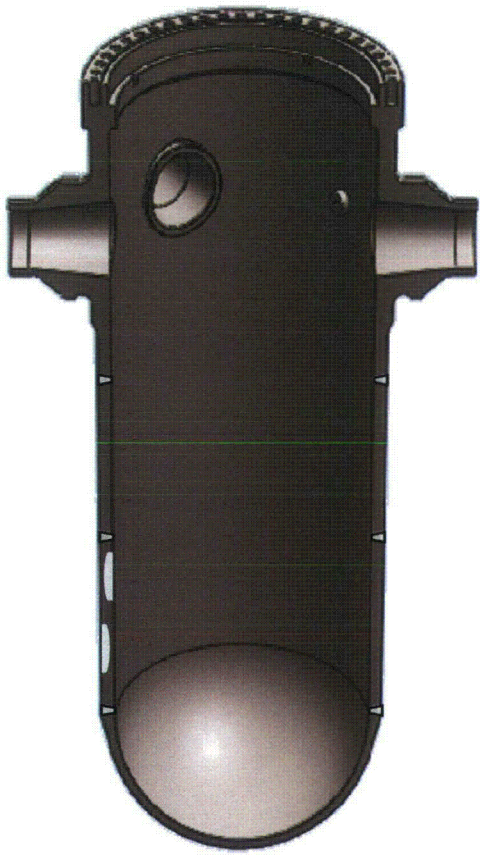
Basic Elements of Appendix G

- Semi-elliptical ¼ T surface flaw
  - Outside surface
  - Inside surface
  - Axial
  - Circumferential
- $2K_{Im} + K_{It} < K_{IR}$
- Lower bound (K_{IR} curve) toughness
- Consideration of irradiated properties
- Defines a simple, yet conservative approach for plant operation.



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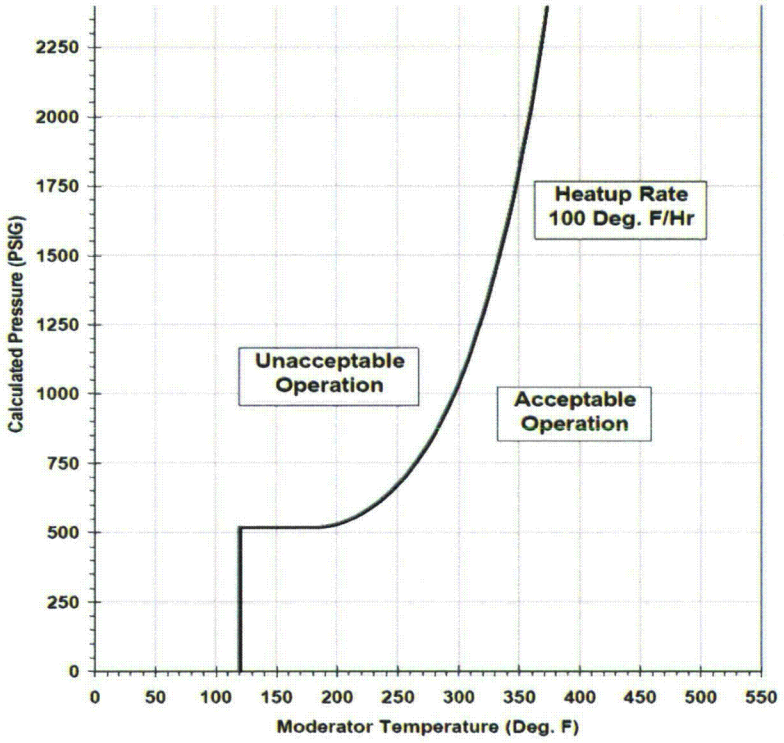
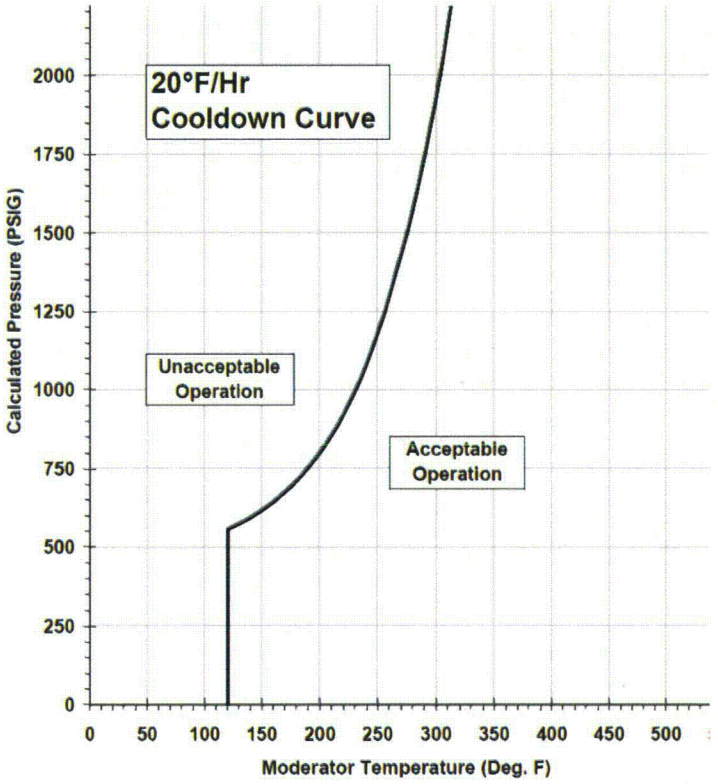
ASME Section XI, Appendix G
Example Heatup and Cooldown Curves





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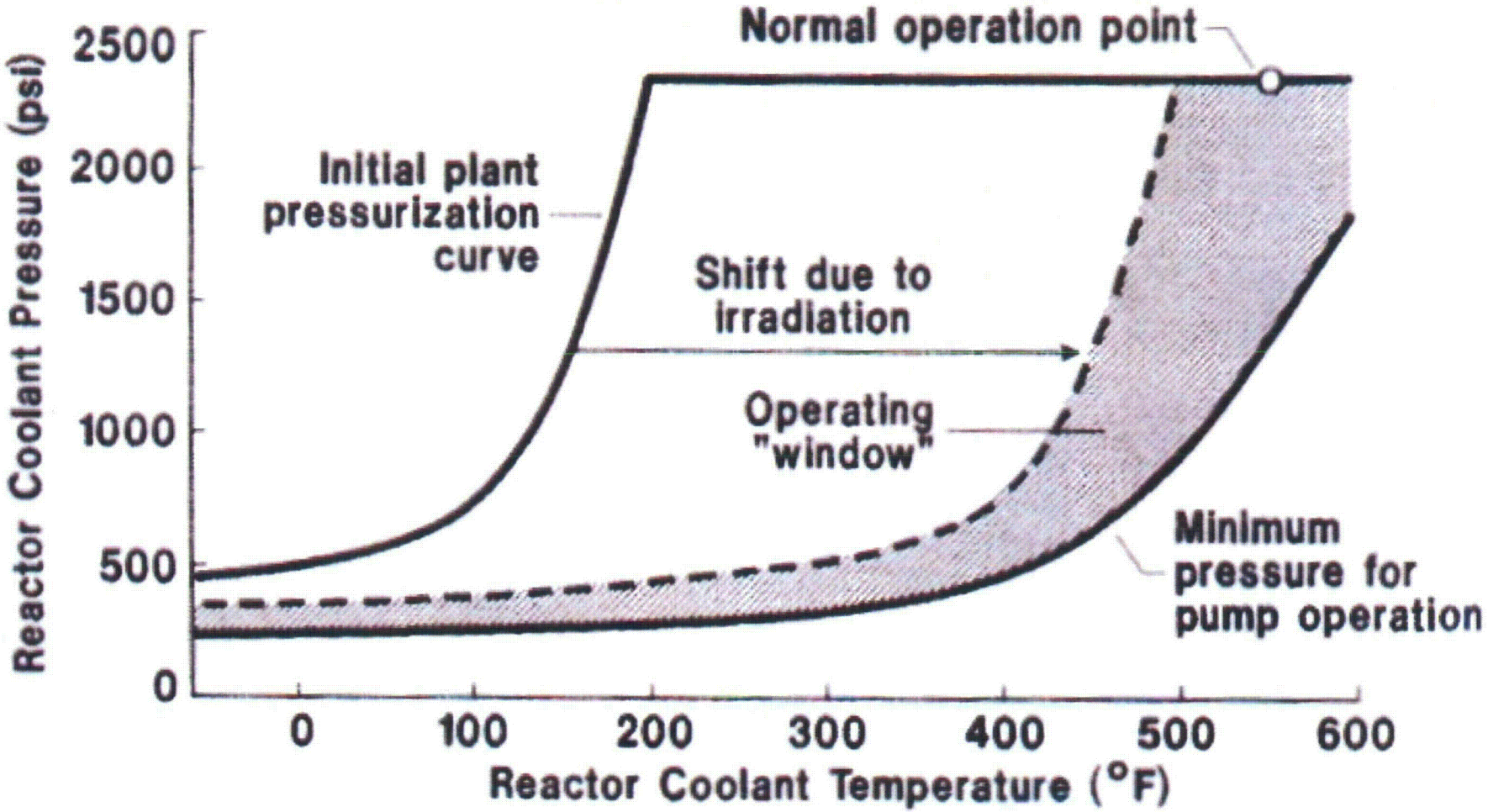
ASME Section XI, Appendix G
Effect of Radiation on P-T Limit Curve



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10 CFR 50 Appendix G

- Paragraph IV.A
  - Ferritic components of RCPB must meet requirements of ASME Code
  - Additional temperature requirements for the controlling material, defined as the material in the closure flange or beltline with the highest RT_{NDT}
- Table 1 of Appendix G to 10CFR50 for Normal Operation:
- Pressure $\leq$ 20% preservice hydrotest pressure:
  - Core not critical
    - P-T limits based on Appendix G
    - Minimum temperature = highest RV flange RTndt
  - Core critical
    - P-T limits based on Appendix G + 40F
    - Minimum temperature = highest RV flange RTndt + 40F
- Pressure> 20% preservice hydrotest pressure:
  - Core not critical
    - P-T limits based on Appendix G
    - Minimum temperature = highest RV flange RTndt + 120F
  - Core critical
    - P-T limits based on Appendix G + 40F
    - Minimum temperature = highest RV flange RTndt +160F

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Low Temperature Overpressure Protection System

- By the late 1970s, there were 29 events that resulted in pressure excursions above the P-T limits during PWR operation at low temperature.
- Based on the event frequency, the NRC classified LTOPS events as anticipated operational occurrences, and required systems to mitigate these events.
- LTOPS greatly reduces the probability of an overpressure event.
  - Pre-trip alarm alerts operator
  - Provides protection to the Appendix G curve

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WCAP-7924-A
"Basis for Heatup and Cooldown Limit Curves"
April 1975

- Describes how the "new" Appendix G Code provisions were used to develop P-T relationships for inclusion in the Technical Specifications.
- Addressed all ferritic components in the RCS pressure boundary
  - Established typical NDTT values
  - Assumed a 1/10T flaw in non-beltline locations
  - A factor of 1.25 on thermal stresses was added for conservatism
  - Considers an irradiation induced shift in the RV beltline region
- Provides the basis for focusing the P-T limit methodology on the RV beltline due to irradiation embrittlement.

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WCAP-7924-A
"Basis for Heatup and Cooldown Limit Curves"
Approved April 1975

- Approved by NRC as an acceptable method for developing P-T limit curves.

- Previous evaluations contained in WCAP-7924-A for components outside the extended beltline *remain valid and applicable,* since fluence accumulation is insignificant for these components.

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10 CFR 50 Appendix G, "Fracture Toughness Requirements"

II. Definitions

- Beltline or Beltline region of reactor vessel means the region of the reactor vessel (shell material including welds, heat affected zones, and plates or forgings) that directly surrounds the effective height of the active core and adjacent regions of the reactor vessel that are predicted to experience sufficient neutron radiation damage to be considered in the selection of the most limiting material with regard to radiation damage.

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10 CFR 50 Appendix G, "Fracture Toughness Requirements"

Branch Technical Position 5-3 Rev 3 (2007), "Fracture Toughness Requirements Review Responsibilities"

B.2.2.2

"Calculations need only be performed for the beltline region, if the RT_{NDT} of the beltline is demonstrated to be adequately higher than the RT_{NDT} for all higher stressed regions."

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SER for WCAP-7924-A

Approved January 1975

"WCAP-7924 presents methods for developing allowable pressure-temperature relationships for normal heatup and cooldown rates to assure the prevention of non-ductile failure. The staff finds these methods acceptable in accordance with Appendix G to 10 CFR Part 50, except for the methods given to determine the shift in RT_{NDT}."

WCAP-14040-A Background

- WCAP-14040 was developed to introduce the concept of a Pressure Temperature Limits Report (PTLR) - Allows licensees to relocate the P-T limits to a licensee controlled document from the plant Technical Specifications.
- WCAP-7924-A remains valid and applicable as the original basis for the P-T limits.
- WCAP-7924-A and WCAP-14040-A provide the current Westinghouse methodology to develop P-T limits and LTOPS setpoints.

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SERs for WCAP-14040

- **WCAP-14040-A, Rev 2, Approved October 1995**

"The staff concludes that WCAP-14040, Revision 1, is acceptable because….The methodology of calculating the minimum temperature in the P-T limit curves conforms to Appendix to 10 CFR Part 50."

- **WCAP-14040, Rev 4, Approved May 2004**

"Therefore, the NRC staff has concluded that the basic methodology specified in WCAP-14040, Revision 3, for establishing P-T limit curves meets the regulatory requirements of Appendix G to 10 CFR Part 50 and the guidance provided in SRP Section 5.3.2."

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Combustion Engineering P-T Limit Methodology based on CE-NPSD-683-A

- Methodology very similar to WCAP-14040-A and Appendix G
  - ***Exception***: Lowest Service Temperature (LST)
  - Most CE plants have carbon steel RCS piping, pumps, and valves.
  - LST – minimum required operating temperature for piping, pumps and valves in the RCS to exceed 20% of the Pre-Service Hydrostatic Test Pressure.
  - LST = Initial RT_{NDT} of piping, pumps, valves + 100°F (No irradiation effects)
  - LST is a very conservative method, used instead of a fracture mechanics evaluation.

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Methodology of BAW-10046-A, Rev. 2

- Required Service Temperatures for Pressures > 625 psig
  - Reactor coolant loop piping – 150°F (Lowest Service Temperature Approach)
  - Bounded by closure head flange limit – 180°F
- Appendix G Flaw Evaluations – Beltline and Closure Head Flange Regions
  - As previously discussed
- Appendix G Flaw Evaluations – Outlet Nozzle
  - Postulated flaw: Depth = ¼T, Length = 1½T
    - T = nozzle belt shell thickness
  - K_{Ip} per WRCB-175
  - K_{It} similar to beltline

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Summary of BAW-10046-A, Rev. 2 Approved June 1986

- BAW-10046-A, Rev. 2 Provides Approved Methodology for Developing P-T Limits
- Considering all RCPB Items and Lowest Service Temperatures, P-T Limits are Regulated by:
  - RV closure head flange region
  - RV outlet nozzle
  - RV beltline region

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SER for BAW-10046-A, Revision 2
Approved June 1986

- "BAW-10046, Rev. 2 describes acceptable methods for the development of allowable pressure-temperature limits for normal operation and for test conditions to assure the prevention of non-ductile fracture. It may be referenced in future applications for setting these limits in Technical Specifications."

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Proposed Standard P-T limit RAI Response

- P-T limit RAIs are currently being issued to multiple licensees on P-T limit submittals:
  - All Ferritic Components considered in P-T limits?
  - Geometric Discontinuities, such as nozzles considered?
- A Standard RAI response is proposed (Short Term):
  - Reference to the applicable NRC approved licensing basis methodology:
    - WCAP-14040-A, Rev. 2 or 4
    - CE-NPSD-683-A, Rev. 6
    - BAW-10046-A, Rev. 2
  - Summary of how the ferritic components have been historically treated – as less limiting than the RV beltline.
  - A commitment to follow the industry initiative to address extended beltline embrittlement, including nozzles and transitions, at ASME Code meetings.

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Extended Beltline Components

- The GALL Report, NUREG-1801, Rev. 2, Section XI.M31, states that the impact of neutron embrittlement for ferritic materials with a neutron fluence greater than 1.0 E+17 n/cm^2 (E > 1.0 MeV) should be evaluated.
- The PWROG is assessing the future extended operation effects of RV embrittlement beyond the beltline region where fluence **may** exceed 1.0 x 10^{17} n/cm^2 (E> 1.0MeV).
- The PWROG has developed assessment methods and performed initial conservative evaluations for P-T limit trends.

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Extended Beltline Technical Approach

- A ***scoping study*** for PWRs was conducted to understand the comparative effects and embrittlement trends between the traditional beltline and the extended beltline materials on the P-T curves.
- The scoping study made very conservative assumptions.
- The results of this study provide the *direction for future development* for refinement of the consideration of nozzles in P-T limits.
- The PWROG is pursuing an approach that refines the analysis for the extended beltline, and does not place excessive conservatism in comparison to the existing licensed basis components.

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Extended Beltline Components
Results of Study

- Results of the *Scoping Study* : Further work is needed to address the nozzles and transition regions in comparison with the RV beltline.
- Conservatisms to potentially be addressed:
  - Postulation of ¼T flaw in the nozzle corner.
  - Fluence attenuation in the nozzle region.
  - Nozzle material properties.
- Further progress on this issue will be made through industry activities.

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Industry Response

- The NRC-approved licensing basis for the current P-T limits is well established and remains valid and applicable.
- Establishing a stronger basis for the extended beltline P-T limits is a separate issue that is being addressed at the ASME Code meetings (Long Term)
  - Ferritic components outside the RV were considered in WCAP-7924-A, CE-NPSD-683-A and BAW-10046-A, Rev. 2.
  - The PWROG agrees that embrittlement in the extended beltline regions should be addressed for license renewal.
    - Being addressed by the PWROG.
    - The technical issues are being resolved, additional time is needed to more completely address the question.
    - Further technical discussions are needed to address the conservatisms and analyses between PWROG/ASME/EPRI members.

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Summary and Conclusions

- Westinghouse, CE, and AREVA have NRC-approved P-T limits methodologies that remain valid and applicable.
- A Standard RAI response is proposed:
  - Reference to the applicable NRC approved licensing basis methodology:
    - WCAP-14040-A, Rev. 2 or 4
    - CE-NPSD-683-A, Rev. 6
    - BAW-10046-A, Rev. 2
  - Summary of how the ferritic components have been historically treated – as less limiting than the RV beltline.
  - A commitment to follow the industry initiative to address extended beltline embrittlement, including nozzles and transitions, at ASME Code meetings.
- Time is needed to address nozzle and transition region issues with industry to obtain consensus.

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