Issues Regarding the Technical Basis for Reactor Pressure Vessel Closure Flange Rulemaking

Westinghouse Owners Group

Presentation to NRC

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Background

- WCAP-14040 Submitted to NRC to Obtain Review and Approval of Methodology used to Develop RCS Heatup (H/U) and Cooldown (C/D) Limit Curves and Cold Overpressure Mitigating System (COMS) Setpoints

- Approved Methodology Allows Relocating RCS H/U and C/D Limit Curves and COMS Setpoints from Tech Specs to a Pressure and Temperature Limits Report (PTLR)

- NRC approved WCAP-14040 in October 1995

Background (cont.)

- Several changes have been made in H/U and C/D Limit Curve Development Methods, and Incorporated into Appendix G of Section XI of the ASME Code since 1995

- WCAP-14040 is being revised to incorporate these changes into an updated Topical Report that contains the current Methodology used to Develop H/U and C/D Limit Curves

- These changes are incorporated as options, to allow plants the flexibility of implementing the changes, if desired

Summary of Revisions to WCAP-14040

- Code Case N514: Low Temperature Overpressure Protection (February 12, 1992)
- Code Case N640: Alternate Reference Fracture Toughness for Development of P-T Limit Curves (February 26, 1996)
- Code Case N588: Alternative to Reference Flaw Orientation of Appendix G for Circumferential Welds in the Reactor Vessel (December 12, 1997)
- Code Case N641: Alternative Pressure-Temperature Relationship and Low Temperature Overpressure Protection System Requirements (January 17, 2000)
- Proposed Elimination of Flange Requirement

RPV Closure Flange Requirement

- Required to be Included by 10CFR50 Appendix G
- High stresses in the closure head flange region during boltup
- OD surface stresses don't increase much between boltup and normal operating pressure, but the distribution changes from bending to membrane

RPV Closure Flange Requirement (cont.)

- Since boltup is performed at low temperatures, fracture margin is important there
- The original flange requirements were developed because of the relatively low toughness used at the time: K_{Ia}
- The recent approval of the use of K_{ic} eliminates the need to include the flange requirement

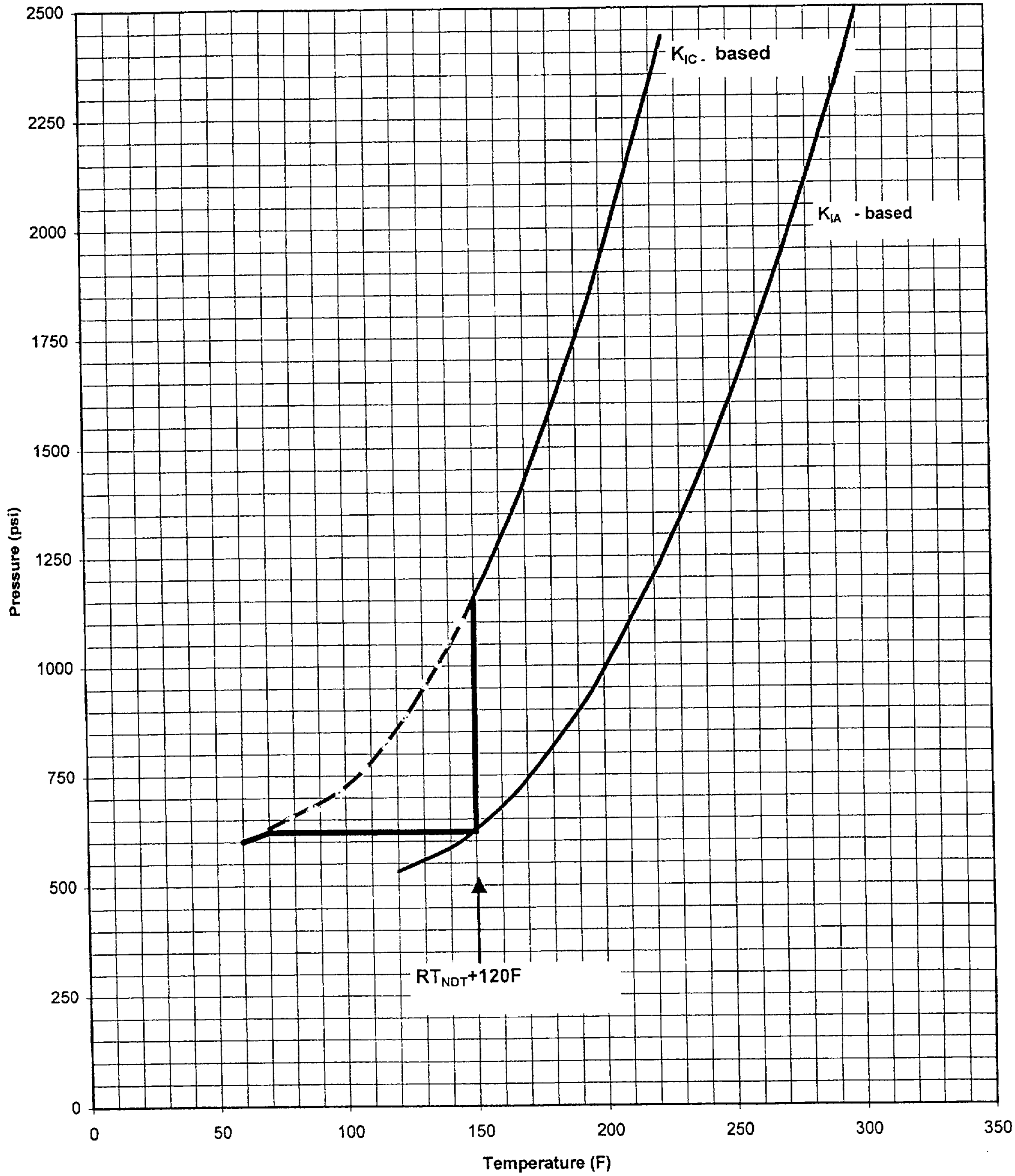
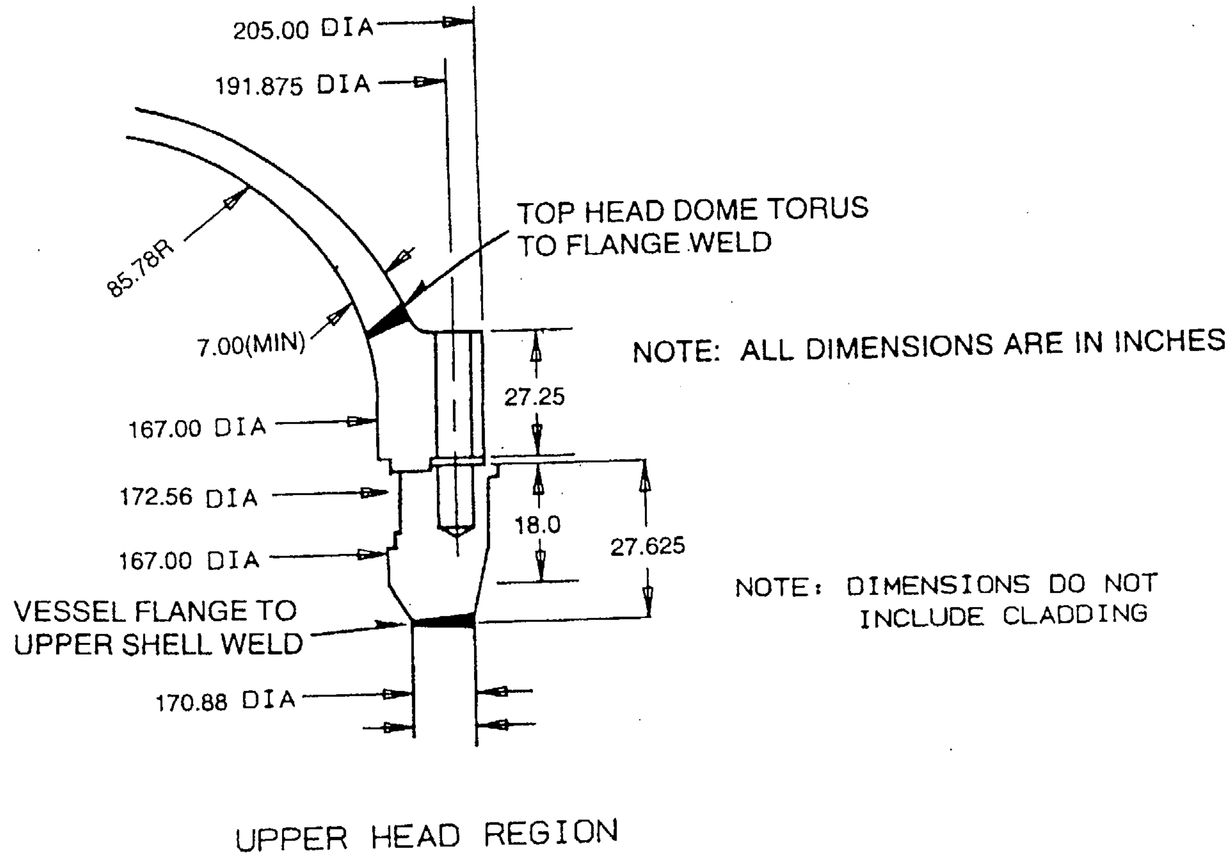


Figure 1-1 Illustration of the Impact of the Flange Requirement for a Typical PWR Plant



Typical Geometry - Closure Head/Flange Region

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Basis of the RPV Closure Flange Requirement
(From Neil Randal's discussion in the FR, 11/14/80)

- Consider closure head/flange region
- Stresses are higher at OD; use outside surface flaw
- A/T = 0.25
- Safety factor = 2
- For this combination, K* = 92.7 ksi in.
- Neil Randall's calculation was more conservative; K* = 98.3 ksi in. (A/T = 0.1, stress = 40-50 ksi)
- Using the K_{IA} curve, boltup should be at RT_{NDT} + 120
- Since this is unrealistic, the requirement was changed to allow pressure up to 20% of design hydro before imposing the temperature requirement

Plant Geometries Considered

Design	Thickness
Westinghouse (2 loop)	5.7
Westinghouse (3 loop)	5.8
Westinghouse (4 loop)	7.0
CE	7.4
B&W	6.8
GE (design 1)	3.6
GE (design 2)	4.0
GE (design 3)	4.8

Stress Analyses

- All cases were finite element results
- ASME code minimum properties are used
- Axisymmetic models are used
- Steady state stress is very similar for all designs
  - Mostly membrane stress
  - Bending stresses higher for BWRs
- Boltup stress is mostly bending
- Comparisons were not available for the Westinghouse 2 loop plants
  - Conservatively covered by the 4 loop results

Axial Stress Comparison: Steady State Operation @ 2250 psi

Plant	OD Stress	Membrane Stress	Bending Stress
W 4 Loop	22.8	10.0	12.8
W 3 Loop	20.9	11.6	9.3
CE	46.4	12.8	33.6
B&W	55.7	19.0	36.7

Stress Comparison: Boltup vs Steady State

Plant	Boltup Membrane	Boltup Bending	SS Membrane	SS Bending
W 4 Loop	1.1	14.2	10.0	12.8
W 3 Loop	2.1	14.5	11.6	9.3
CE	0.8	22.8	12.8	33.6
B&W	4.3	27.6	19.0	36.7

Fracture Analysis Methods

- Stress Intensity Factor: Raju and Newman
- Fracture Toughness: K_{Ia} and K_{Ic}
- Irradiation Effects Negligible

RPV Closure Flange Integrity Evaluation

- Semi-elliptic surface flaw postulated on head OD
- Orientation parallel to the weld
- Boltup cases analyzed to determine maximum value of K for any flaw depth
- PWR and BWR cases considered
- Typical boltup temperatures are:
  - 60 F for PWRs
  - 80 F for BWRs
- Using the K_{Ic} toughness, significant margin exists in all cases
  - Not true for K_{Ia}, the reason for the original concern

Proposed Elimination of RPV Closure Flange Requirement

- Consider developing a set of boltup requirements, using the following assumptions:
  - Postulated flaw depth - T/10
  - Safety factor = 2.0
  - K_{Ia} or K_{Ic} lower bound curves

- Using K_{Ia}, the governing case is RT_{NDT} + 118F, closely matching the original requirement of RT_{NDT} + 120F

- Using K_{Ic} , the requirement for PWRs is RT_{NDT} to RT_{NDT} + 41F
  Since RT_{NDT} is typically 10F, boltup would be at 10-51F
  Typically boltup is at 60F ⇨ no requirement needed

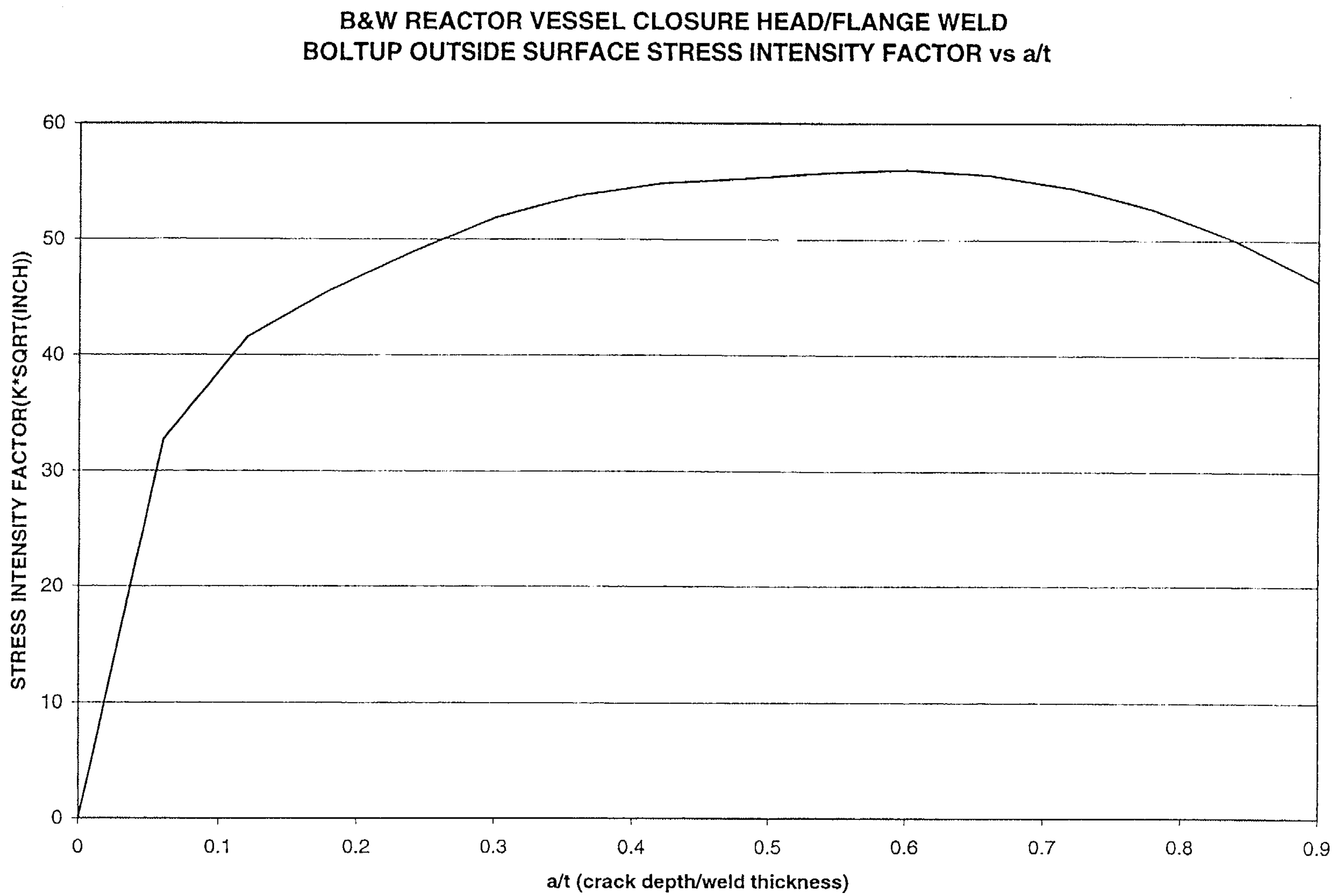
- Using K_{Ic}, the requirement for BWRs is RT_{NDT} to RT_{NDT} + 56F
  Since RT_{NDT} is typically 10F, boltup would be at 10-66F
  Typically boltup is at 80F ⇨ no requirement needed

Boltup Requirements: K_{Ic} VS K_{Ia}
Comparison of Stress Intensity Factors

Plant	K (a/t=0.1)*	K (SF=2)*	T-RT_{NDT} (K_{Ic})	T-RT_{NDT} (K_{Ia})
W 4 Loop	19.7	39.4	0.0 F	1.0 F
W 3 Loop	19.4	38.8	0.0 F	0.0 F
CE	30.0	60.0	13.0 F	68.0 F
B&W	39.4	79.8	41.0 F	100.0 F

* Note: All units in ksi $\sqrt{in}$.

BWR (1)	38.7	77.4	38.0	97.0
BWR (2)	48.0	96.0	56.0	118.0
BWR (3)	25.1	50.2	0	43.0



Stress Intensity Factor vs Flaw Size: B&W Plant (t = 6.82 inches)

RPV Closure Flange Integrity Summary

Design	(Depth, a/t)	K_{Ic}	K_{Ia}
CE	41 (0.42)	89.6	52.7
B&W	56 (0.60)	89.6	52.7
W 4 Loop	31 (0.44)	89.6	52.7
W 3 Loop	32 (0.44)	89.6	52.7
BWR Design 1	56 (0.42)	117.3	61.4
BWR Design 2	69 (0.40)	117.3	61.4
BWR Design 3	37 (0.42)	117.3	61.4

Safety Impact of Eliminating RPV Closure Flange Requirement for PWRs

- Current RPV closure flange requirements can cause severe operational limitations, after accounting for instrument uncertainty

- The lower limit of pressure is 20% of hydrotest, or 621 psig until the flange limit of RT_{NDT} + 120F is exceeded

- Minimum pressure to cool the RCP seals is 325 psi

Safety Impact of Eliminating RPV Closure Flange Requirement for PWRs (cont.)

- The operating window can become very small
- Example: For one plant, the operating window would increase from 121 psig to 262 psig
- This change would significantly reduce the potential of an RCP seal failure (small LOCA)

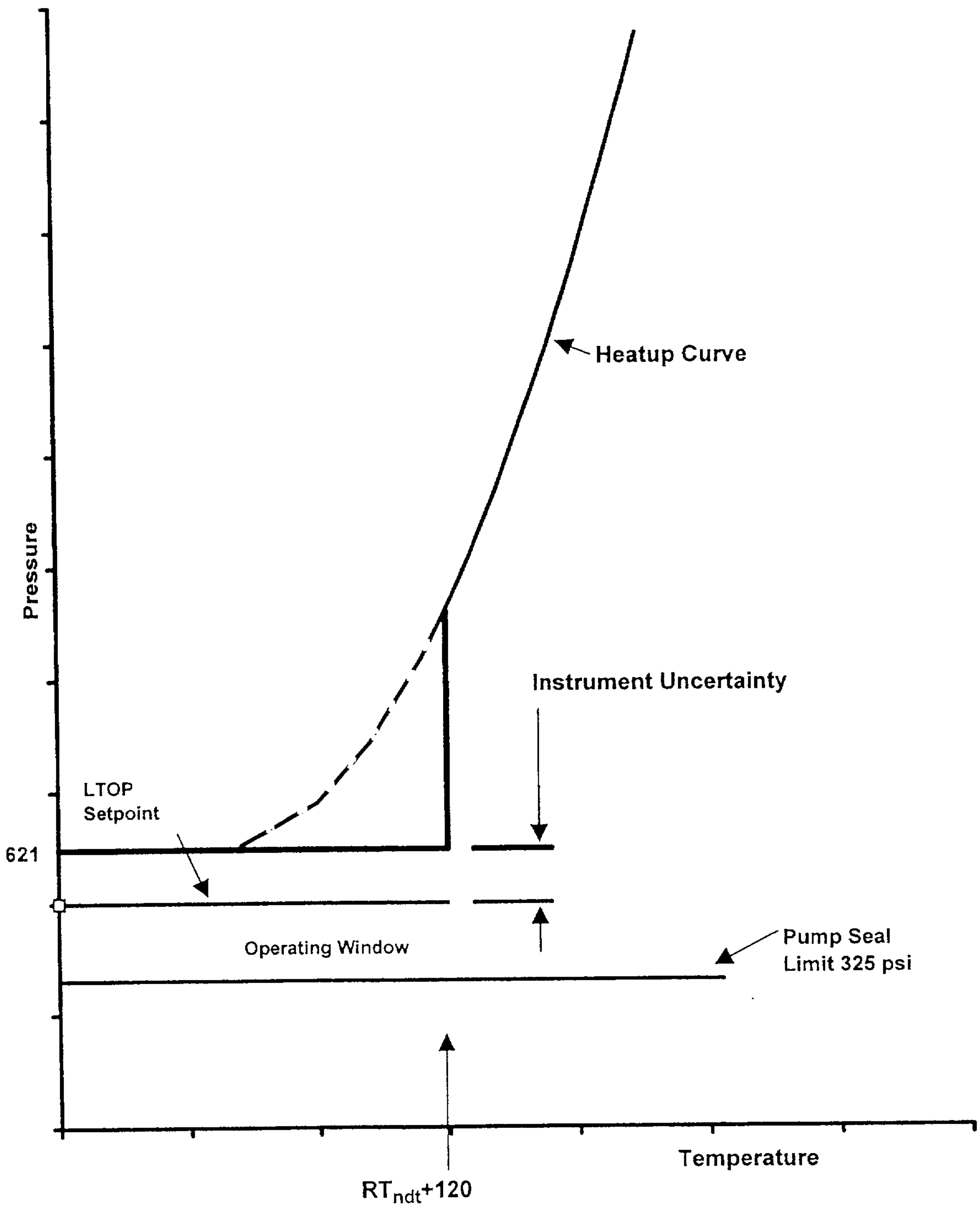


Figure 6-1 Illustration of the Flange Requirement and its Effect on the Operating Window for a Typical Heatup Curve

LIMITING MATERIAL: INTERMEDIATE SHELL FORGING 5P-5933 (using surv. capsule data)
LIMITING ART VALUES AT 12 EFPY: 1/4T, 70°F
3/4T, 60°F

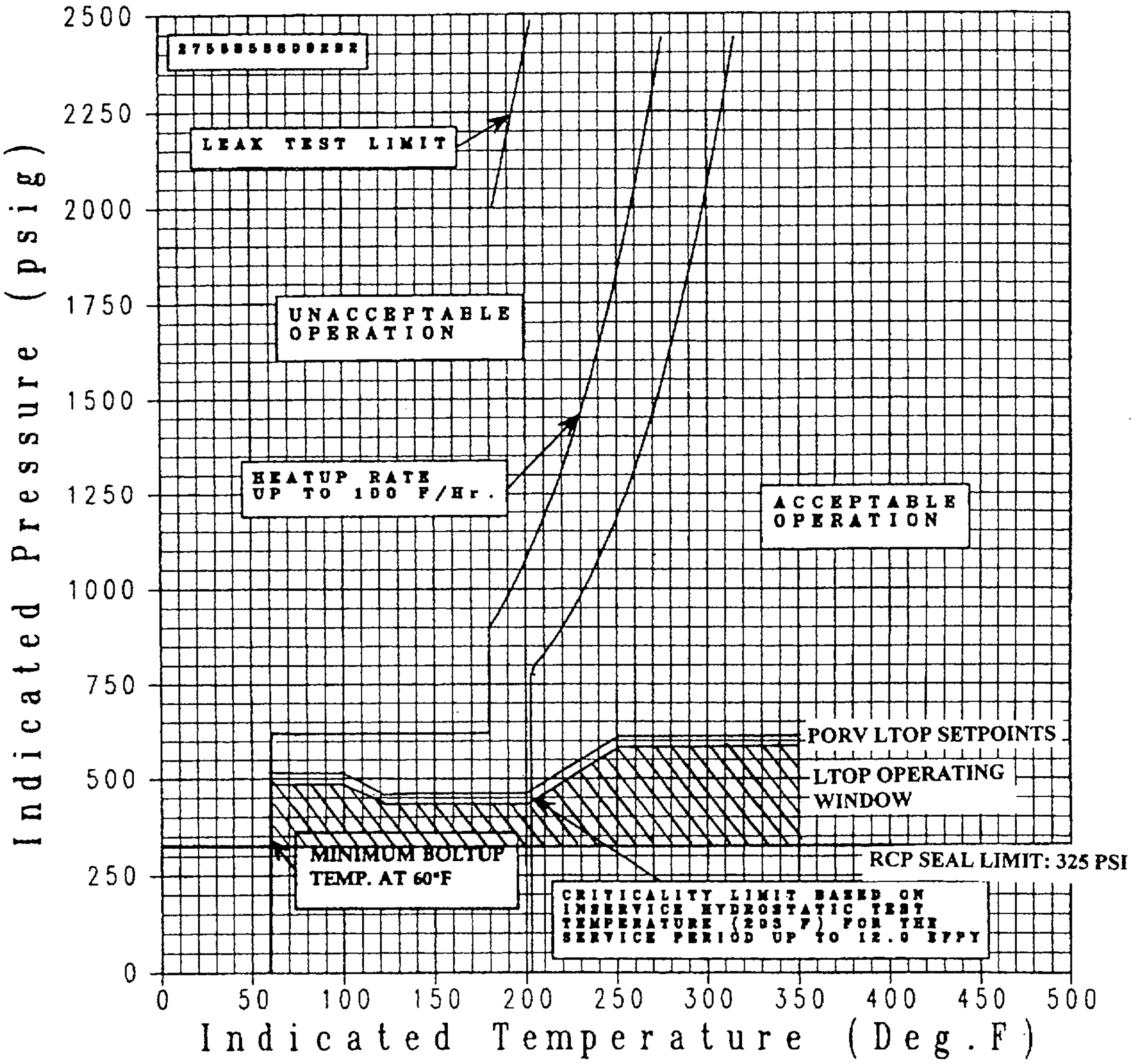


Figure 6-2 Illustration of the Actual Operating Window for Heatup of Byron Unit 1, a Low Copper Plant at 12 EFPY

LIMITING MATERIAL: INTERMEDIATE SHELL FORGING 5P-5933 (using surv. capsule data)
LIMITING ART VALUES AT 12 EFPY: 1/4T, 70°F
3/4T, 60°F

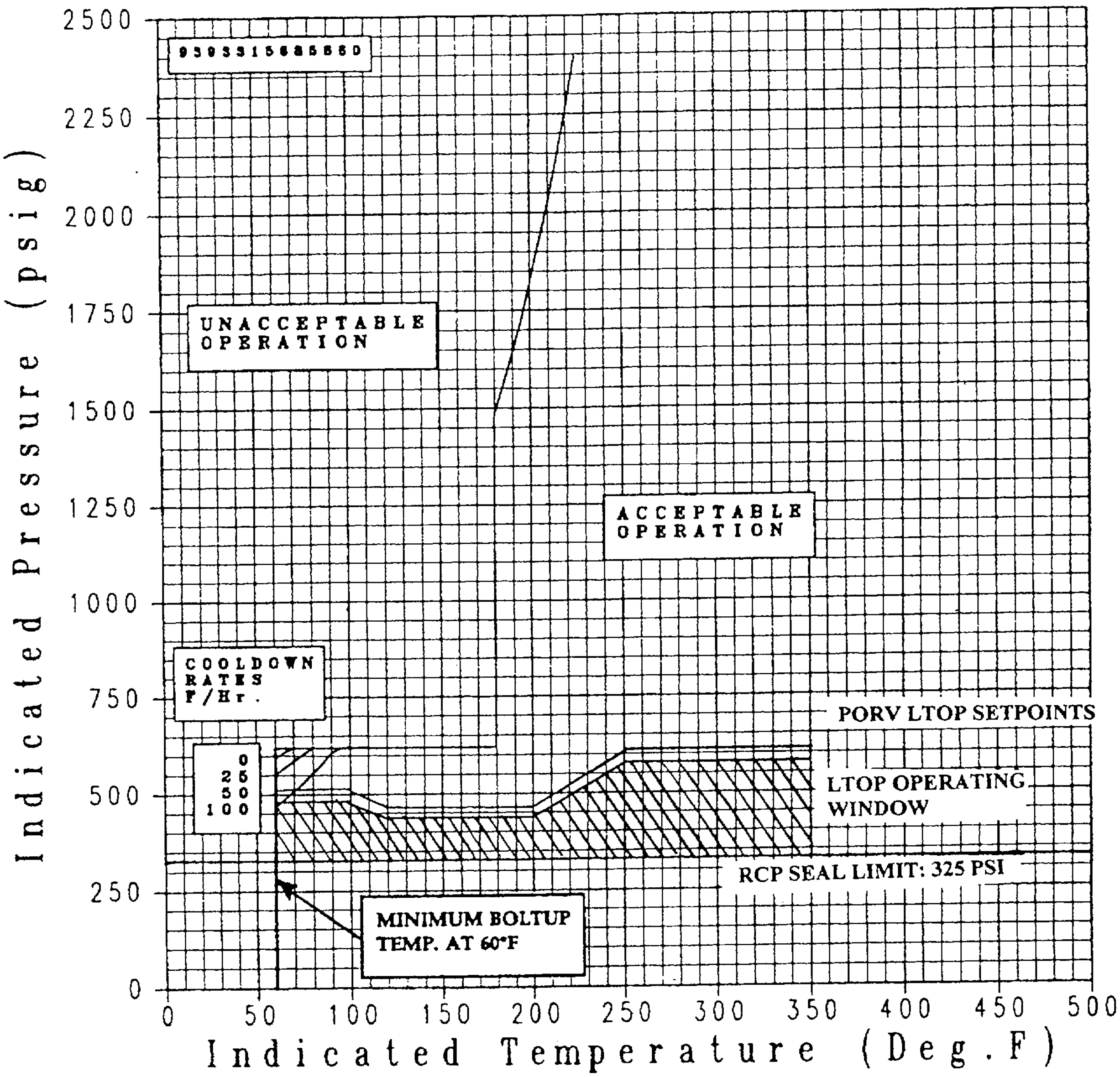


Figure 6-3 Illustration of the Actual Operating Window for Cooldown of Byron Unit 1, a Low Copper Plant at 12 EFPY

Summary and Conclusions

- The RPV closure flange requirement originated over 20 years ago, when the standard practice was to use the K_{Ia} reference toughness curve
- The development and approval of Code Case N640, allowing the use of K_{IC} has significantly improved the H/U and C/D curves
- Use of Code Case N640 significantly improves operational safety, by increasing the operating window between the P-T curve and the RCP Seal cooling pressure

Summary and Conclusions (cont.)

- The benefits of Code Case N640 are severely limited by the RPV closure flange requirement
- Use of K_{IC} has demonstrated that the RPV closure flange requirement is not required

Future Actions

- Schedule for Rulemaking
- Treatment of Exemption Requests
- Schedule for submittal of WCAP 14040 Rev. 3