

**Attachment 5**

**GE NON-PROPRIETARY REPORT FOR QUAD CITIES NUCLEAR POWER STATION,  
UNITS 1 AND 2, GE-NE-0000-0002-9600-02R2a and GE-NE-0000-0002-9600-03R2a**



## ***GE Nuclear Energy***

Engineering and Technology  
General Electric Company  
175 Curtner Avenue  
San Jose, CA 95125

GE-NE-0000-0002-9600-02R2a  
DRF 0000-0028-4024  
Revision 2  
Class I  
May 2004

# **Pressure-Temperature Curves For Exelon Quad Cities Unit 1**

Prepared by: *LJ Tilly*  
L.J. Tilly, Senior Engineer  
Structural Analysis & Hardware Design

Verified by: *BD Frew*  
B.D. Frew, Principal Engineer  
Structural Analysis & Hardware Design

Approved by: *BJ Branlund*  
B.J. Branlund, Principal Engineer  
Structural Analysis & Hardware Design

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## REPORT REVISION STATUS

Revision	Purpose
0	Initial Issue
1	The report was revised to eliminate conservatism in the upper vessel P-T curve. The required shift for this curve was reduced from 55°F to 48°F. Text was changed in Sections 4.3.2.1.3, 4.3.2.1.4, and 5.0. Figures 5-2, 5-6, and 5-9 through 5-14 were revised. The Appendix B tables were revised. The bounding P-T curve figures and tables contained in Appendix G were revised. This includes Figures G-2, G-6, and G-9 through G-14.
2	<ul style="list-style-type: none"><li>• Proprietary notations have been updated to meet current requirements.</li><li>• Revision bars have been provided in the right margin of each paragraph denoting change from the previous report.</li><li>• Discussion regarding a comparison of calculated flux vs. dosimetry results has been deleted from Section 4.2.1.2.</li><li>• The description of the transients considered in Section 4.3.2.1 has been revised.</li><li>• Section 4.3.2.1.2 has been revised to reflect a new analysis defining the CRD Penetration (Bottom Head) Core Not Critical P-T Curve; Appendix F provides a detailed discussion of the subject analysis and conclusions.</li><li>• A clarifying statement has been added to Section 4.3.2.2.4 regarding the use of <math>K_{lt}</math> in the Beltline Core Not Critical P-T curves.</li><li>• Reference 14b has been deleted; all required information from this reference is contained in Reference 14a. Reference 14c has been renumbered to Reference 14b.</li><li>• Reference 22 has been deleted and replaced with the NRC Safety Evaluation for the Dresden P-T curve reports.</li><li>• Reference 6 of Appendix E has been deleted; all required information from this reference is contained in Reference 5.</li><li>• Appendix F has been deleted and replaced with a discussion regarding the CRD (Bottom Head) Core Not Critical evaluation.</li><li>• Section 5.0 Figures 5-5, 5-12 and 5-14, Appendix G Figures G-5, G-12, and G-14 and all Appendix B and Appendix G Tables have been revised to incorporate changes to the CRD Penetration (Bottom Head) Core Not Critical P-T curves, as defined in Section 4.3.2.1.2 and Appendix F.</li></ul>

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**EXECUTIVE SUMMARY**

This report provides the pressure-temperature curves (P-T curves) developed to present steam dome pressure versus minimum vessel metal temperature incorporating appropriate non-beltline limits and irradiation embrittlement effects in the beltline. The methodology used to generate the P-T curves in this report is similar to the methodology used to generate the P-T curves in 2000 [1]; the P-T curves in this report represent 32 and 54 EFPY as determined for a 40- and 60-year life. The P-T curve methodology includes the following: 1) the incorporation of ASME Code Case N-640, and 2) the use of the  $M_m$  calculation in the ASME Code paragraph G-2214.1 for a postulated defect normal to the direction of maximum stress. ASME Code Case N-640 allows the use of  $K_{IC}$  of Figure A-4200-1 of Appendix A in lieu of Figure G-2210-1 in Appendix G to determine  $T-RT_{NDT}$ . This report incorporates a fluence [14a] calculated in accordance with the GE Licensing Topical Report NEDC-32983P, which has been approved by the NRC in a SER [14b], and is in compliance with Regulatory Guide 1.190. Additional detail regarding P-T curve methodology has been submitted in response to NRC questions, and was accepted in the Safety Evaluation for the Dresden Units 2 & 3 P-T curves [22].

**CONCLUSIONS**

The operating limits for pressure and temperature are required for three categories of operation: (a) hydrostatic pressure tests and leak tests, referred to as Curve A; (b) non-nuclear heatup/cooldown and low-level physics tests, referred to as Curve B; and (c) core critical operation, referred to as Curve C.

There are four vessel regions that should be monitored against the P-T curve operating limits; these regions are defined on the thermal cycle diagram [2]:

- Closure flange region (Region A)
- Core beltline region (Region B)
- Upper vessel (Regions A & B)
- Lower vessel (Regions B & C)

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For the core not critical and the core critical curves, the P-T curves specify a coolant heatup and cooldown temperature rate of 100°F/hr or less for which the curves are applicable. However, the core not critical and the core critical curves were also developed to bound transients defined on the RPV thermal cycle diagram [2] and the nozzle thermal cycle diagrams [3]. The bounding transients used to develop the curves are described in this report. For the hydrostatic pressure and leak test curve, a coolant heatup and cooldown temperature rate of 20°F/hr or less must be maintained at all times.

The P-T curves apply for both heatup and cooldown and for both the 1/4T and 3/4T locations because the maximum tensile stress for either heatup or cooldown is applied at the 1/4T location. For beltline curves this approach has added conservatism because irradiation effects cause the allowable toughness,  $K_{Ic}$ , at 1/4T to be less than that at 3/4T for a given metal temperature.

Composite P-T curves were generated for each of the Pressure Test, Core Not Critical and Core Critical conditions at 32 and 54 effective full power years (EFPY). The composite curves were generated by enveloping the most restrictive P-T limits from the separate bottom head, beltline, upper vessel and closure assembly P-T limits. Separate P-T curves were developed for the upper vessel, beltline (at 32 and 54 EFPY), and bottom head for the Pressure Test and Core Not Critical conditions.

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## 1.0 INTRODUCTION

The pressure-temperature (P-T) curves included in this report have been developed to present steam dome pressure versus minimum vessel metal temperature incorporating appropriate non-beltline limits and irradiation embrittlement effects in the beltline. Complete P-T curves were developed for 32 and 54 effective full power years (EFPY). The P-T curves are provided in Section 5.0 and a tabulation of the curves is included in Appendix B. This report incorporates a fluence [14a] calculated in accordance with the GE Licensing Topical Report NEDC-32983P, which has been approved by the NRC in a SER [14b], and is in compliance with Regulatory Guide 1.190.

The methodology used to generate the P-T curves in this report is presented in Section 4.3 and is similar to the methodology used to generate the P-T curves in 2000 [1]. The P-T curve methodology includes the following: 1) the incorporation of ASME Code Case N-640 [4], and 2) the use of the  $M_m$  calculation in the ASME Code paragraph G-2214.1 [6] for a postulated defect normal to the direction of maximum stress. ASME Code Case N-640 allows the use of  $K_{IC}$  of Figure A-4200-1 of Appendix A in lieu of Figure G-2210-1 in Appendix G to determine  $T-RT_{NDT}$ . P-T curves are developed using geometry of the RPV shells and discontinuities, the initial  $RT_{NDT}$  of the RPV materials, and the adjusted reference temperature (ART) for the beltline materials. Additional detail regarding P-T curve methodology has been submitted in response to NRC questions, and was accepted in the Safety Evaluation for the Dresden Units 2 & 3 P-T curves [22].

The initial  $RT_{NDT}$  is the reference temperature for the unirradiated material as defined in Paragraph NB-2331 of Section III of the ASME Boiler and Pressure Vessel Code. The Charpy energy data used to determine the initial  $RT_{NDT}$  values are tabulated from the Certified Material Test Report (CMTRs). The data and methodology used to determine initial  $RT_{NDT}$  is documented in Section 4.1.

Adjusted Reference Temperature (ART) is the reference temperature when including irradiation shift and a margin term. Regulatory Guide 1.99, Rev. 2 [7] provides the methods for calculating ART. The value of ART is a function of RPV 1/4T fluence and

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beltline material chemistry. The ART calculation, methodology, and ART tables for 32 and 54 EFPY are included in Section 4.2. The peak ID fluence values of  $3.3 \times 10^{17} \text{ n/cm}^2$  (32 EFPY) and  $5.7 \times 10^{17} \text{ n/cm}^2$  (54 EFPY) used in this report are discussed in Section 4.2.1.2. Beltline chemistry values are discussed in Section 4.2.1.1.

Comprehensive documentation of the RPV discontinuities that are considered in this report is included in Appendix A. This appendix also includes a table that documents which non-beltline discontinuity curves are used to protect the discontinuities.

Guidelines and requirements for operating and temperature monitoring are included in Appendix C. GE SIL 430, a GE service information letter regarding Reactor Pressure Vessel Temperature Monitoring is included in Appendix D. Appendix E demonstrates that all reactor vessel nozzles are outside the beltline region. Appendix F provides the core not critical calculation for the bottom head (CRD Penetration). Finally, Appendix G provides a set of P-T curves that bound all requirements for both Quad Cities Unit 1 and Quad Cities Unit 2.

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## 2.0 SCOPE OF THE ANALYSIS

The methodology used to generate the P-T curves in this report is similar to the methodology used to generate the P-T curves in 2000 [1]. A detailed description of the P-T curve bases is included in Section 4.3. The P-T curve methodology includes the following: 1) the incorporation of ASME Code Case N-640, and 2) the use of the  $M_m$  calculation in the ASME Code paragraph G-2214.1 for a postulated defect normal to the direction of maximum stress. ASME Code Case N-640 allows the use of  $K_{IC}$  of Figure A-4200-1 of Appendix A in lieu of Figure G-2210-1 in Appendix G to determine  $T-RT_{NDT}$ . Other features presented are:

- Generation of separate curves for the upper vessel in addition to those generated for the beltline, and bottom head.
- Comprehensive description of discontinuities used to develop the non-beltline curves (see Appendix A).

The pressure-temperature (P-T) curves are established to the requirements of 10CFR50, Appendix G [8] to assure that brittle fracture of the reactor vessel is prevented. Part of the analysis involved in developing the P-T curves is to account for irradiation embrittlement effects in the core region, or beltline. The method used to account for irradiation embrittlement is described in Regulatory Guide 1.99, Rev. 2 [7].

In addition to beltline considerations, there are non-beltline discontinuity limits such as nozzles, penetrations, and flanges that influence the construction of P-T curves. The non-beltline limits are based on generic analyses that are adjusted to the maximum reference temperature of nil ductility transition ( $RT_{NDT}$ ) for the applicable Quad Cities Unit 1 vessel components. The non-beltline limits are discussed in Section 4.3 and are also governed by requirements in [8].

Furthermore, curves are included to allow monitoring of the vessel bottom head and upper vessel regions separate from the beltline region. This refinement could minimize heating requirements prior to pressure testing. Operating and temperature monitoring requirements are found in Appendix C. Temperature monitoring requirements and methods are available in GE Services Information Letter (SIL) 430 contained in Appendix D. Appendix E demonstrates that all reactor vessel nozzles are outside the

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bellline region. Appendix F provides the core not critical calculation for the bottom head (CRD Penetration). Finally, Appendix G provides a set of P-T curves that bound all requirements for both Quad Cities Unit 1 and Quad Cities Unit 2.

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**3.0 ANALYSIS ASSUMPTIONS**

The following assumptions are made for this analysis:

For end-of-license (54 EFPY) fluence, a mixed capacity factor is used to determine the EFPY for a 60-year plant life. An 80% capacity factor is based on the objective to have BWR's available for full power production 80% of the year (refueling outages, etc. ~20% of the year).

For a 60-year license an 80% capacity factor is assumed for up to 21.1 EFPY, and to consider recent improvements in plant operation, a 97.5% capacity factor is used beginning at 21.1 EFPY; hence 54 EFPY is assumed to represent 60 years of operation.

The hydrostatic pressure test will be conducted at or below 1105.5 psig.

The shutdown margin, provided in the Quad Cities Unit 1 Technical Specification, is calculated for a water temperature of 68°F.

The flux is calculated using a pre-EPU and a post-EPU flux [14], both calculated in accordance with Regulatory Guide 1.190. The pre-EPU flux is applied for 21.1 EFPY and the post-EPU flux is applied for 10.9 EFPY and 32.9 EFPY for 32 and 54 EFPY, respectively.

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## 4.0 ANALYSIS

### 4.1 INITIAL REFERENCE TEMPERATURE

#### 4.1.1 Background

The initial  $RT_{NDT}$  values for all low alloy steel vessel components are needed to develop the vessel P-T limits. The requirements for establishing the vessel component toughness prior to 1972 were per the ASME Code Section III, Subsection NB-2300 and are summarized as follows:

- a. Test specimens shall be longitudinally oriented CVN specimens.
- b. At the qualification test temperature (specified in the vessel purchase specification), no impact test result shall be less than 25 ft-lb, and the average of three test results shall be at least 30 ft-lb.
- c. Pressure tests shall be conducted at a temperature at least 60°F above the qualification test temperature for the vessel materials.

The current requirements used to establish an initial  $RT_{NDT}$  value are significantly different. For plants constructed according to the ASME Code after Summer 1972, the requirements per the ASME Code Section III, Subsection NB-2300 are as follows:

- a. Test specimens shall be transversely oriented (normal to the rolling direction) CVN specimens.
- b.  $RT_{NDT}$  is defined as the higher of the dropweight NDT or 60°F below the temperature at which Charpy V-Notch 50 ft-lb energy and 35 mils lateral expansion is met.
- c. Bolt-up in preparation for a pressure test or normal operation shall be performed at or above the highest  $RT_{NDT}$  of the materials in the closure flange region or lowest service temperature (LST) of the bolting material, whichever is greater.

10CFR50 Appendix G [8] states that for vessels constructed to a version of the ASME Code prior to the Summer 1972 Addendum, fracture toughness data and data analyses must be supplemented in an approved manner. GE developed methods for analytically

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converting fracture toughness data for vessels constructed before 1972 to comply with current requirements. These methods were developed from data in WRC Bulletin 217 [9] and from data collected to respond to NRC questions on FSAR submittals in the late 1970s. In 1994, these methods of estimating  $RT_{NDT}$  were submitted for generic approval by the BWR Owners' Group [10], and approved by the NRC for generic use [11].

**4.1.2 Values of Initial  $RT_{NDT}$  and Lowest Service Temperature (LST)**

To establish the initial  $RT_{NDT}$  temperatures for the Quad Cities Unit 1 vessel per the current requirements, calculations were performed in accordance with the GE method for determining  $RT_{NDT}$ . Example  $RT_{NDT}$  calculations for vessel plate, forging, and for bolting material LST are summarized in the remainder of this section.

The  $RT_{NDT}$  values for the vessel weld materials were not calculated; these values were obtained from other sources (see Section 4.2, Tables 4-3 and 4-4).

For vessel plate material, the first step in calculating  $RT_{NDT}$  is to establish the 50 ft-lb transverse test temperature from longitudinal test specimen data (obtained from certified material test reports, CMTRs [12]). For Quad Cities Unit 1 CMTRs, typically six energy values were listed at a given test temperature, corresponding to two sets of Charpy tests. The lowest energy Charpy value is adjusted by adding 2°F per ft-lb energy difference from 50 ft-lb.

For example, for the Quad Cities Unit 1 bellline plate heat B5524-1 in the lower shell course; the lowest Charpy energy and test temperature from the CMTRs is 40.0 ft-lb at 10°F. The estimated 50 ft-lb longitudinal test temperature is:

$$T_{50L} = 10^{\circ}\text{F} + [(50 - 40) \text{ ft-lb} \cdot 2^{\circ}\text{F/ft-lb}] = 30^{\circ}\text{F}$$

The transition from longitudinal data to transverse data is made by adding 30°F to the 50 ft-lb longitudinal test temperature; thus, for this case above,

$$T_{50T} = 30^{\circ}\text{F} + 30^{\circ}\text{F} = 60^{\circ}\text{F}$$

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The initial  $RT_{NDT}$  is the greater of nil-ductility transition temperature (NDT) or  $(T_{50T} - 60^{\circ}\text{F})$ . Dropweight testing to establish NDT for plate material is listed in the CMTR; the NDT for the case above is  $-10^{\circ}\text{F}$ . Thus, the initial  $RT_{NDT}$  for plate heat B5524-1 is  $0^{\circ}\text{F}$ .

For the vessel HAZ material, the  $RT_{NDT}$  is assumed to be the same as for the base material, since ASME Code weld procedure qualification test requirements and post-weld heat treat data indicate this assumption is valid.

For vessel forging material, such as nozzles and closure flanges, the method for establishing  $RT_{NDT}$  is the same as for vessel plate material. For the feedwater nozzle at Quad Cities Unit 1 (Heat ZT2885), the NDT is  $30^{\circ}\text{F}$  and the lowest CVN data is 31 ft-lb at  $40^{\circ}\text{F}$ . The corresponding value of  $(T_{50T} - 60^{\circ}\text{F})$  is:

$$(T_{50T} - 60^{\circ}\text{F}) = \{[40 + (50 - 31) \text{ ft-lb} \cdot 2^{\circ}\text{F/ft-lb}] + 30^{\circ}\text{F}\} - 60^{\circ}\text{F} = 48^{\circ}\text{F}.$$

Therefore, the initial  $RT_{NDT}$  is the greater of nil-ductility transition temperature (NDT) or  $(T_{50T} - 60^{\circ}\text{F})$ , which is  $48^{\circ}\text{F}$ .

In the bottom head region of the vessel, the vessel plate method is applied for estimating  $RT_{NDT}$ . For the lower torus heat of Quad Cities Unit 1 (Heat C1478-3), the NDT is  $40^{\circ}\text{F}$  and the lowest CVN data was 25 ft-lb at  $40^{\circ}\text{F}$ . The corresponding value of  $(T_{50T} - 60^{\circ}\text{F})$  was:

$$(T_{50T} - 60^{\circ}\text{F}) = \{[40 + (50 - 25) \text{ ft-lb} \cdot 2^{\circ}\text{F/ft-lb}] + 30^{\circ}\text{F}\} - 60^{\circ}\text{F} = 60^{\circ}\text{F}.$$

Therefore, the initial  $RT_{NDT}$  was  $60^{\circ}\text{F}$ .

For bolting material, the current ASME Code requirements define the lowest service temperature (LST) as the temperature at which transverse CVN energy of 45 ft-lb and 25 mils lateral expansion (MLE) were achieved. If the required Charpy results are not met, or are not reported, but the CVN energy reported is above 30 ft-lb, the requirements of the ASME Code Section III, Subsection NB-2300 at construction are applied, namely that the 30 ft-lb test temperature plus  $60^{\circ}\text{F}$  is the LST for the bolting materials. Charpy data for the Quad Cities Unit 1 closure studs did not all meet the 45 ft-lb, 25 MLE requirements at  $10^{\circ}\text{F}$ . Therefore, the LST for the bolting material is  $70^{\circ}\text{F}$ . The highest  $RT_{NDT}$  in the closure flange region is  $23.1^{\circ}\text{F}$ , for the vertical electroslag weld material.

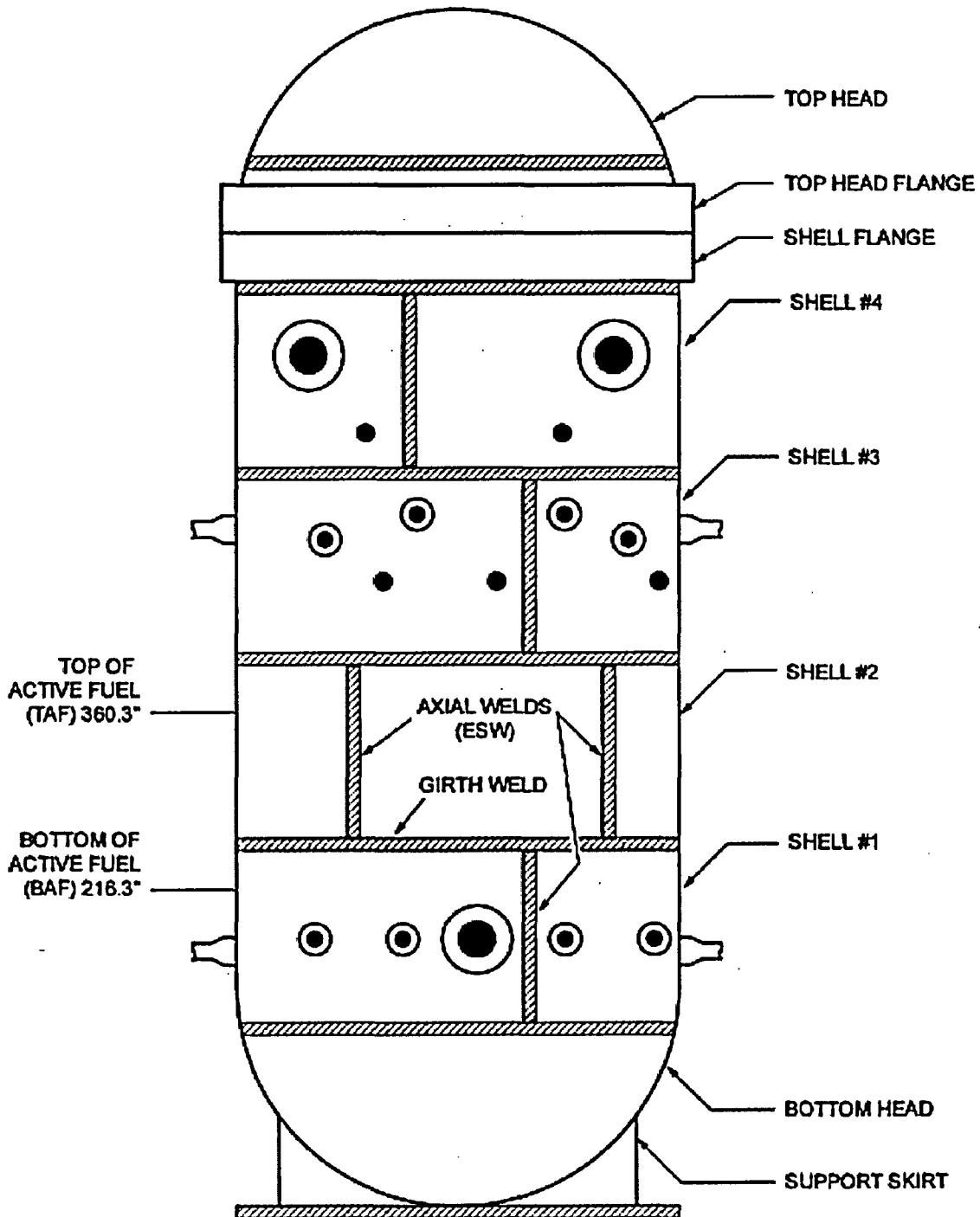
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Thus, the higher of the LST and the  $RT_{NDT} + 60^{\circ}\text{F}$  is  $83.1^{\circ}\text{F}$ , the boltup limit in the closure flange region.

The initial  $RT_{NDT}$  values for the Quad Cities Unit 1 reactor vessel (refer to Figure 4-1 for the Quad Cities Unit 1 Schematic) materials are listed in Tables 4-1 and 4-2. This tabulation includes beltline, closure flange, feedwater nozzle, and bottom head materials that are considered in generating the P-T curves.

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Notes: (1) Refer to Tables 4-1 and 4-2 for reactor vessel components and their heat identifications.

(2) See Appendix E for the definition of the beltline region.

**Figure 4-1: Schematic of the Quad Cities Unit 1 RPV Showing Arrangement of Vessel Plates and Welds**

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Table 4-1: RT<sub>NDT</sub> Values for Quad Cities Unit 1 Vessel Materials

COMPONENT	HEAT	TEST TEMP. (°F)	CHARPY ENERGY (FT-LB)			(T <sub>50T</sub> -60) (°F)	DROP WEIGHT NDT	RT <sub>NDT</sub> (°F)
PLATES & FORGINGS:								
TOP HEAD and FLANGE:								
Dollar Plate Mk 201	A0981-2	40	76	100	98	10	40	40
Torus MK 202	B5853-1	10	75	82	77	-20	10	10
	C2426-3	10	69	75	55	-20	10	10
	C1722-3	10	81	80	101	-20	10	10
	A0313-1	10	34	58	57	12	10	12
	C1501-3	10	48	94	94	-16	10	10
Flange Mk209 Mk48	4P1201	10	77.6	57.3	87	-20	10	10
	4P1104	10	84.3	86.1	108.9	-20	10	10
SHELL COURSES:								
Upper Shell Mk60	C1498-1	10	51	57	65	-20	10	10
	A0939-1	10	55	60	51	-20	10	10
	A0927-1	10	82	94	111	-20	10	10
Upper-Int. Shell Mk59	C1505-1	10	44	40	40	0	10	10
	C1501-1	10	46	60	55	-12	10	10
	B5918-1	10	65	52	54	-20	10	10
Lower-Int. Shell Mk58	C1505-2	10	48	43	48	-6	-20	-6
	C1498-2	10	75	68	100	-20	-30	-20
	A0931-1	10	75	81	72	-20	-30	-20
Lower Shell Mk57	B5524-1	10	40	53	55	0	-10	0
	A0610-1	10	84	55	62	-20	-20	-20
	C1485-2	10	54	45	53	-10	-30	-10
BOTTOM HEAD:								
Dollar plate Mk1	B5861-1	40	46	38	48	34	40	40
Torus, lower Mk4	B5764-2	40	45	41	40	30	40	40
	C1478-3	40	25	42	45	60	40	60
Torus, upper Mk2	C1466-1	40	78	70	62	10	40	40
	C1466-2	40	62	65	38	34	40	40
	A0237-2	40	92	91	109	10	40	40
	C1177-1	40	66	64	83	10	40	40

Note: These are the minimum Charpy values.

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Table 4-2: RT<sub>NDT</sub> Values for Quad Cities Unit 1 Nozzle and Weld Materials

COMPONENT	HEAT	TEST TEMP. (°F)	CHARPY ENERGY (FT-LB)			(T <sub>50T-60</sub> ) (°F)	DROP WEIGHT NDT	RT <sub>NDT</sub> (°F)
ATTACHMENTS:								
Skirt Attachment Mk24	A1349-5	10	46	46	45	-10	0	0
NOZZLES:								
Recirc outlet Mk8	ZT2885	40	36	39	39	38	30	38
	ZT2869	40	54	49	45.5	19	30	30
Recirc inlet Mk7	ZT2869-5	40	34	36.5	43	42	30	42
(Transverse data)	ZT2869	40	42	42	69	26	30	30
	ZT2405-4	40	42	61.5	76.5	4	40	40
	E25VW	40	98	107	108	10	40	40
Steam Outlet Mk14	ZT2869-2	40	31	38.5	32.5	48	30	48
Feedwater Mk10	ZT2885	40	31	35	36	48	30	48
Core Spray Mk11	ZT-2869-5	40	39	36	44.5	38	30	38
Drain Nozzle	212918	40	238	239	237	10	N/A	10
CRD Penetration	B5861-1	40	46	38	48	34	40	40
Closure Head, Vent, Jet Pump, CRD HSR & Core Diff. Press & Liq. Con. Noz Mk206 & 204 & 13 & 19 & 17	ZT3043	40	102	130	117	10	40	40
WELDS:								
Longitudinal Beltline Seams	ES							23.1
Low. Int. to Lower Girth Seam	SAW – Linde 80 Welds 72445/8688 406L44/8688						- -	-5 -5
STUDS:								
Studs MK61	6720372	10	53	35	58	LST 70		

Note: These are the minimum Charpy values.

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## 4.2 ADJUSTED REFERENCE TEMPERATURE FOR BELTLINE

The adjusted reference temperature (ART) of the limiting beltline material is used to adjust the beltline P-T curves to account for irradiation effects. Regulatory Guide 1.99, Revision 2 (RG1.99) [7] provides the methods for determining the ART. The RG1.99 methods for determining the limiting material and adjusting the P-T curves using ART are discussed in this section. An evaluation of ART for all beltline plates and several beltline welds was performed and summarized in Tables 4-3 and 4-4 for 32 and 54 EFPY, respectively.

### 4.2.1 Regulatory Guide 1.99, Revision 2 (RG1.99) Methods

The value of ART is computed by adding the SHIFT term for a given value of effective full power years (EFPY) to the initial  $RT_{NDT}$ . For RG1.99, the SHIFT equation consists of two terms:

$$SHIFT = \Delta RT_{NDT} + \text{Margin}$$

$$\text{where, } \Delta RT_{NDT} = [CF] \cdot f^{(0.28 - 0.10 \log f)}$$

$$\text{Margin} = 2(\sigma_I^2 + \sigma_\Delta^2)^{0.5}$$

CF = chemistry factor from Tables 1 or 2 of Rev. 2

$$f = \frac{1}{2}T \text{ fluence} / 10^{19}$$

$$\text{Margin} = 2(\sigma_I^2 + \sigma_\Delta^2)^{0.5}$$

$\sigma_I$  = standard deviation on initial  $RT_{NDT}$ , which is taken to be 0°F (13°F for electroslog welds and 20°F for SAW girth welds).

$\sigma_\Delta$  = standard deviation on  $\Delta RT_{NDT}$ , 28°F for welds and 17°F for base material, except that  $\sigma_\Delta$  need not exceed 0.50 times the  $\Delta RT_{NDT}$  value.

$$ART = \text{Initial } RT_{NDT} + SHIFT$$

The margin term  $\sigma_\Delta$  has constant values in RG1.99 of 17°F for plate and 28°F for weld. However,  $\sigma_\Delta$  need not be greater than  $0.5 \cdot \Delta RT_{NDT}$ . Since the GE/BWROG method of

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estimating  $RT_{NDT}$  operates on the lowest Charpy energy value (as described in Section 4.1.2) and provides a conservative adjustment to the 50 ft-lb level, the value of  $\sigma_I$  is taken to be 0°F for the vessel plate and most weld materials, except that  $\sigma_I$  is 13°F for the beltline electroslag weld materials [13d] and 20°F for the beltline SAW girth weld materials [13e].

#### 4.2.1.1 Chemistry

The vessel beltline chemistries were obtained from several sources as detailed below:

- Vessel Plates: Copper – plate manufacturer [13a]; Nickel – highest value from CMTRs [12]
- Submerged Arc Welds: Copper and nickel from separate evaluation [13b & 13c]
- Electroslag Welds: Copper and nickel from separate evaluations [13d & 13c]

The copper (Cu) and nickel (Ni) values were used with Tables 1 and 2 of RG1.99 [7], to determine a chemistry factor (CF) per Paragraph 1.1 of RG1.99 for welds and plates, respectively. Best estimate results are used for the beltline electroslag [13d] and submerged arc weld materials [13e] for the initial  $RT_{NDT}$ ; therefore, the standard deviation ( $\sigma_I$ ) is specified.

#### 4.2.1.2 Fluence

A bounding pre-EPU (Extended Power Uprate) and EPU flux [14] for the vessel ID wall are calculated using methods consistent with Regulatory Guide 1.190. The flux in Reference 14 is determined for the pre-EPU power of 2527 MW<sub>t</sub> and for the EPU rated power of 2957 MW<sub>t</sub>.

The bounding peak fast flux for the RPV inner surface from Reference 14 is 3.12e8 n/cm<sup>2</sup>-s for pre-EPU and 3.46e8 n/cm<sup>2</sup>-s for EPU conditions.



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**32 EFPY Fluence**

Quad Cities Unit 1 began EPU operation at 21.1 EFPY, thereby operating for 10.9 EFPY at EPU conditions for 32 EFPY. The RPV ID surface fluence for 32 EFPY is calculated as follows:

$$3.12\text{e}8 \text{ n/cm}^2\text{-s} * 1.01\text{e}9 \text{ s} * (21.1/32) + 3.46\text{e}8 \text{ n/cm}^2\text{-s} * 1.01\text{e}9 \text{ s} * (10.9/32) = 3.3\text{e}17 \text{ n/cm}^2.$$

This fluence applies to the lower-intermediate plates and axial weld materials. The fluence is adjusted for the lower shell and axial welds, as well as for the lower to lower-intermediate girth weld based upon a peak / lower shell location ratio of 0.71 for pre-EPU conditions and 0.74 for EPU conditions (at an elevation of approximately 258" above vessel "0"); hence the peak ID surface fluence used for these components is  $2.4\text{e}17 \text{ n/cm}^2$ .

The fluence at 1/4T is calculated per Equation 3 of Regulatory Guide 1.99, Revision 2 [7] using the Quad Cities Unit 1 plant specific fluence and vessel thickness of 6.125". The 32 EFPY 1/4T fluence for the lower-intermediate shell plate and axial welds is:

$$3.3\text{e}17 \text{ n/cm}^2 * \exp(-0.24 * (6.125/4)) = 2.3\text{e}17 \text{ n/cm}^2.$$

The 32 EFPY 1/4T fluence for the lower shell plate and axial welds and the lower to lower-intermediate girth weld is:

$$2.4\text{e}17 \text{ n/cm}^2 * \exp(-0.24 * (6.125/4)) = 1.6\text{e}17 \text{ n/cm}^2.$$

**54 EFPY Fluence**

As stated above, Quad Cities Unit 1 began EPU operation at 21.1 EFPY, thereby operating for 32.9 EFPY at EPU conditions for 54 EFPY. The RPV ID surface fluence for 54 EFPY is calculated as follows:

$$3.12\text{e}8 \text{ n/cm}^2\text{-s} * 1.7\text{e}9 \text{ s} * (21.1/54) + 3.46\text{e}8 \text{ n/cm}^2\text{-s} * 1.7\text{e}9 \text{ s} * (32.9/54) = 5.7\text{e}17 \text{ n/cm}^2.$$

This fluence applies to the lower-intermediate plates and axial weld materials. The fluence is adjusted for the lower shell and axial welds, as well as for the lower to lower-intermediate girth weld based upon a peak / lower shell location ratio of 0.71 for pre-EPU conditions and 0.74 for EPU conditions (at an elevation of approximately 258" above vessel "0"); hence the peak ID surface fluence used for these components is  $4.1\text{e}17 \text{ n/cm}^2$ .

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The fluence at 1/4T is calculated per Equation 3 of Regulatory Guide 1.99, Revision 2 [7] using the Quad Cities Unit 1 plant specific fluence and vessel thickness of 6.125". The 54 EFPY 1/4T fluence for the lower-intermediate shell plate and axial welds is:

$$5.7\text{e}17 \text{ n/cm}^2 * \exp (-0.24 * (6.125/4)) = 3.9\text{e}17 \text{ n/cm}^2.$$

The 54 EFPY 1/4T fluence for the lower shell plate and axial welds and the lower to lower-intermediate girth weld is:

$$4.1\text{e}17 \text{ n/cm}^2 * \exp (-0.24 * (6.125/4)) = 2.9\text{e}17 \text{ n/cm}^2.$$

#### **4.2.2 Limiting Beltline Material**

The limiting beltline material signifies the material that is estimated to receive the greatest embrittlement due to irradiation effects combined with initial  $RT_{NDT}$ . Using initial  $RT_{NDT}$ , chemistry, and fluence as inputs, RG1.99 [7] was applied to compute ART. Tables 4-3 and 4-4 list values of beltline ART for 32 and 54 EFPY, respectively.

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Table 4-3: Quad Cities Unit 1 Beltline ART Values (32 EFPY)

## Lower-Intermediate Plates and Axial Welds

Thickness = 6.13 inches

32 EFPY Peak I.D. fluence = 3.3E+17 n/cm<sup>2</sup>  
 32 EFPY Peak 1/4 T fluence = 2.3E+17 n/cm<sup>2</sup>  
 32 EFPY Peak 1/4 T fluence = 2.3E+17 n/cm<sup>2</sup>

## Lower Plates and Axial Welds and Lower to Lower-Intermediate Girth Weld

Thickness = 6.13 inches

32 EFPY Peak I.D. fluence = 2.4E+17 n/cm<sup>2</sup>  
 32 EFPY Peak 1/4 T fluence = 1.6E+17 n/cm<sup>2</sup>  
 32 EFPY Peak 1/4 T fluence = 1.6E+17 n/cm<sup>2</sup>

COMPONENT	HEAT OR HEAT/LOT	%Cu	%Ni	CF	Initial RTndt °F	1/4 T Fluence n/cm <sup>2</sup>	32 EFPY Δ RTndt °F	σ <sub>I</sub>	σ <sub>A</sub>	Margin °F	32 EFPY Shift °F	32 EFPY ART °F
<b>PLATES:</b>												
<b>Lower</b>												
6-122-1	B5524-1	0.27	0.57	180	0	1.6E+17	27	0	14	27	54	54
6-122-2	A0610-1	0.21	0.51	143	-20	1.6E+17	22	0	11	22	43	23
6-122-11	C1485-2	0.23	0.50	153	-10	1.6E+17	23	0	12	23	46	36
<b>Lower-Intermediate</b>												
6-122-4	C1505-2	0.18	0.52	126	-6	2.3E+17	23	0	12	23	47	41
6-122-6	C1498-2	0.17	0.50	119	-20	2.3E+17	22	0	11	22	44	24
6-122-13	A0931-1	0.14	0.51	96	-20	2.3E+17	18	0	9	18	36	16
<b>WELDS:</b>												
<b>Lower-Intermediate</b>												
ES*		0.24	0.37	141	23	2.3E+17	26	13	13	37	63	86
<b>Lower</b>												
ES*		0.24	0.37	141	23	1.6E+17	21	13	11	34	55	78
<b>Girth</b>												
<b>Lower to Lower-Intermediate</b>												
SAW**	72445/8688	0.22	0.54	158	-5	1.6E+17	24	20	12	47	70	65
SAW**	406L44/8688	0.27	0.59	183	-5	1.6E+17	28	20	14	49	76	71

\* Chemistry values are based on data from BAW-2259, dated January 1996, but adjusted. Values of Initial RTndt and σ<sub>I</sub> are obtained from the same document.\*\* Linde 80 weld chemistry values are based on data from BAW-2325, dated May 1998 and Initial RTndt and σ<sub>I</sub> are obtained from the BAW-1803-1, dated May 1991.

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Table 4-4: Quad Cities Unit 1 Beltline ART Values (54 EFPY)

## Lower-Intermediate Plates and Axial Welds

Thickness = 6.13 inches

54 EFPY Peak I.D. fluence = 5.7E+17 n/cm<sup>2</sup>  
 54 EFPY Peak 1/4 T fluence = 3.9E+17 n/cm<sup>2</sup>  
 54 EFPY Peak 1/4 T fluence = 3.9E+17 n/cm<sup>2</sup>

## Lower Plates and Axial Welds and Lower to Lower-Intermediate Girth Weld

Thickness = 6.13 inches

54 EFPY Peak I.D. fluence = 4.1E+17 n/cm<sup>2</sup>  
 54 EFPY Peak 1/4 T fluence = 2.9E+17 n/cm<sup>2</sup>  
 54 EFPY Peak 1/4 T fluence = 2.9E+17 n/cm<sup>2</sup>

COMPONENT	HEAT OR HEAT/LOT	%Cu	%Ni	CF	Initial RTndt °F	1/4 T Fluence n/cm <sup>2</sup>	54 EFPY Δ RTndt °F	σ <sub>I</sub>	σ <sub>A</sub>	Margin °F	54 EFPY Shift °F	54 EFPY ART °F
<b>PLATES:</b>												
<b>Lower</b>												
6-122-1	B5524-1	0.27	0.57	180	0	2.9E+17	38	0	17	34	72	72
6-122-2	A0610-1	0.21	0.51	143	-20	2.9E+17	31	0	15	31	61	41
6-122-11	C1485-2	0.23	0.50	153	-10	2.9E+17	33	0	16	33	65	55
<b>Lower-Intermediate</b>												
6-122-4	C1505-2	0.18	0.52	126	-6	3.9E+17	32	0	16	32	65	59
6-122-6	C1498-2	0.17	0.50	119	-20	3.9E+17	30	0	15	30	61	41
6-122-13	A0931-1	0.14	0.51	96	-20	3.9E+17	25	0	12	25	49	29
<b>WELDS:</b>												
<b>Lower-Intermediate</b>												
ES*		0.24	0.37	141	23	3.9E+17	36	13	18	44	81	104
<b>Lower</b>												
ES*		0.24	0.37	141	23	2.9E+17	30	13	15	40	70	93
<b>Girth</b>												
<b>Lower to Lower-Intermediate</b>												
SAW**	72445/8688	0.22	0.54	158	-5	2.9E+17	34	20	17	52	86	81
SAW**	406L44/8688	0.27	0.59	183	-5	2.9E+17	39	20	20	56	95	90

\* Chemistry values are based on data from BAW-2259, dated January 1996, but adjusted. Values of Initial RTndt and σ<sub>I</sub> are obtained from the same document.\*\* Linde 80 weld chemistry values are based on data from BAW-2325, dated May 1998 and Initial RTndt and σ<sub>I</sub> are obtained from the BAW-1803-1, dated May 1991.

## **4.3 PRESSURE-TEMPERATURE CURVE METHODOLOGY**

### **4.3.1 Background**

Nuclear Regulatory Commission (NRC) 10CFR50 Appendix G [8] specifies fracture toughness requirements to provide adequate margins of safety during the operating conditions to which a pressure-retaining component may be subjected over its service lifetime. The ASME Code (Appendix G of Section XI of the ASME Code [6]) forms the basis for the requirements of 10CFR50 Appendix G. The operating limits for pressure and temperature are required for three categories of operation: (a) hydrostatic pressure tests and leak tests, referred to as Curve A; (b) non-nuclear heatup/cooldown and low-level physics tests, referred to as Curve B; and (c) core critical operation, referred to as Curve C.

There are four vessel regions that should be monitored against the P-T curve operating limits; these regions are defined on the thermal cycle diagram [2]:

- Closure flange region            (Region A)
- Core beltline region            (Region B)
- Upper vessel                    (Regions A & B)
- Lower vessel                    (Regions B & C)

The closure flange region includes the bolts, top head flange, and adjacent plates and welds. The core beltline is the vessel location adjacent to the active fuel, such that the neutron fluence is sufficient to cause a significant shift of  $RT_{NDT}$ . The remaining portions of the vessel (i.e., upper vessel, lower vessel) include shells, components like the nozzles, the support skirt, and stabilizer brackets; these regions will also be called the non-beltline region.

For the core not critical and the core critical curves, the P-T curves specify a coolant heatup and cooldown temperature rate of 100°F/hr or less for which the curves are applicable. However, the core not critical and the core critical curves were also developed to bound transients defined on the RPV thermal cycle diagram [2] and the

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nozzle thermal cycle diagrams [3]. The bounding transients used to develop the curves are described in the sections below. For the hydrostatic pressure and leak test curve, a coolant heatup and cooldown temperature rate of 20°F/hr or less must be maintained at all times.

The P-T curves for the heatup and cooldown operating condition at a given EFPY apply for both the 1/4T and 3/4T locations. When combining pressure and thermal stresses, it is usually necessary to evaluate stresses at the 1/4T location (inside surface flaw) and the 3/4T location (outside surface flaw). This is because the thermal gradient tensile stress of interest is in the inner wall during cooldown and is in the outer wall during heatup. However, as a conservative simplification, the thermal gradient stress at the 1/4T location is assumed to be tensile for both heatup and cooldown. This results in the approach of applying the maximum tensile stress at the 1/4T location. This approach is conservative because irradiation effects cause the allowable toughness,  $K_{Ir}$ , at 1/4T to be less than that at 3/4T for a given metal temperature. This approach causes no operational difficulties, since the BWR is at steam saturation conditions during normal operation, well above the heatup/cooldown curve limits.

The applicable temperature is the greater of the 10CFR50 Appendix G minimum temperature requirement or the ASME Appendix G limits. A summary of the requirements is as follows in Table 4-5:

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Table 4-5: Summary of the 10CFR50 Appendix G Requirements

Operating Condition and Pressure	Minimum Temperature Requirement
I. Hydrostatic Pressure Test & Leak Test (Core is Not Critical) - Curve A	
1. At $\leq 20\%$ of preservice hydrotest pressure	Larger of ASME Limits or of highest closure flange region initial $RT_{NDT} + 60^{\circ}\text{F}^*$
2. At $> 20\%$ of preservice hydrotest pressure	Larger of ASME Limits or of highest closure flange region initial $RT_{NDT} + 90^{\circ}\text{F}$
II. Normal operation (heatup and cooldown), including anticipated operational occurrences	
a. Core not critical - Curve B	
1. At $\leq 20\%$ of preservice hydrotest pressure	Larger of ASME Limits or of highest closure flange region initial $RT_{NDT} + 60^{\circ}\text{F}^*$
2. At $> 20\%$ of preservice hydrotest pressure	Larger of ASME Limits or of highest closure flange region initial $RT_{NDT} + 120^{\circ}\text{F}$
b. Core critical - Curve C	
1. At $\leq 20\%$ of preservice hydrotest pressure, with the water level within the normal range for power operation	Larger of ASME Limits $+ 40^{\circ}\text{F}$ or of a.1
2. At $> 20\%$ of preservice hydrotest pressure	Larger of ASME Limits $+ 40^{\circ}\text{F}$ or of a.2 $+ 40^{\circ}\text{F}$ or the minimum permissible temperature for the inservice system hydrostatic pressure test

\*  $60^{\circ}\text{F}$  adder is included by GE as an additional conservatism as discussed in Section 4.3.2.3

There are four vessel regions that affect the operating limits: the closure flange region, the core beltline region, and the two regions in the remainder of the vessel (i.e., the upper vessel and lower vessel non-beltline regions). The closure flange region limits are controlling at lower pressures primarily because of 10CFR50 Appendix G [8] requirements. The non-beltline and beltline region operating limits are evaluated according to procedures in 10CFR50 Appendix G [8], ASME Code Appendix G [6], and Welding Research Council (WRC) Bulletin 175 [15]. The beltline region minimum temperature limits are adjusted to account for vessel irradiation.

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### 4.3.2 P-T Curve Methodology

#### 4.3.2.1 Non-Beltline Regions

Non-beltline regions are defined as the vessel locations that are remote from the active fuel and where the neutron fluence is not sufficient ( $<1.0E17$  n/cm<sup>2</sup>) to cause any significant shift of  $RT_{NDT}$ . Non-beltline components include nozzles (see Appendix E), the closure flanges, some shell plates, the top and bottom head plates and the control rod drive (CRD) penetrations.

Detailed stress analyses of the non-beltline components were performed for the BWR/6 specifically for the purpose of fracture toughness analysis. The BWR/6 stress analysis bounds for BWR/2 through BWR/5 designs, as will be demonstrated in the following evaluation. The analyses took into account all mechanical loading and anticipated thermal transients. Transients considered include 100°F/hr start-up and shutdown, SCRAM, loss of feedwater heaters or flow, and loss of recirculation pump flow. Primary membrane and bending stresses and secondary membrane and bending stresses due to the most severe of these transients were used according to the ASME Code [6] to develop plots of allowable pressure (P) versus temperature relative to the reference temperature ( $T - RT_{NDT}$ ). Plots were developed for the limiting BWR/6 components: the feedwater nozzle (FW) and the CRD penetration (bottom head). All other components in the non-beltline regions are categorized under one of these two components as described in Tables 4-6 and 4-7.



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**Table 4-6: Applicable BWR/3 Discontinuity Components  
for Use With FW (Upper Vessel) Curves A & B**

<b>Discontinuity Identification</b>
<b>FW Nozzle</b>
CRD HYD System Return
Core Spray Nozzle
Recirculation Inlet Nozzle
Steam Outlet Nozzle
Main Closure Flange
Support Skirt
Stabilizer Brackets
Shroud Support Attachments
Core $\Delta P$ and Liquid Control Nozzle
Steam Water Interface
Jet Pump Instrumentation Nozzle
Shell
CRD and Bottom Head (B only)
Top Head Nozzles (B only)
Recirculation Outlet Nozzle (B only)

**Table 4-7: Applicable BWR/3 Discontinuity Components  
for Use with CRD (Bottom Head) Curves A&B**

<b>Discontinuity Identification</b>
<b>CRD and Bottom Head</b>
Top Head Nozzles
Recirculation Outlet Nozzle
Shell**
Support Skirt**
Shroud Support Attachments**
Core $\Delta P$ and Liquid Control Nozzle**

\*\* These discontinuities are added to the bottom head curve discontinuity list to assure that the entire bottom head is covered, since separate bottom head P-T curves are provided to monitor the bottom head.

The P-T curves for the non-beltline region were conservatively developed for a large BWR/6 (nominal inside diameter of 251 inches). The analysis is considered appropriate for Quad Cities Unit 1 as the plant specific geometric values are bounded by the generic

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analysis for a large BWR/6, as determined in Section 4.3.2.1.1 through Section 4.3.2.1.4. The generic value was adapted to the conditions at Quad Cities Unit 1 by using plant specific  $RT_{NDT}$  values for the reactor pressure vessel (RPV). The presence of nozzles and CRD penetration holes of the upper vessel and bottom head, respectively, has made the analysis different from a shell analysis such as the beltline. This was the result of the stress concentrations and higher thermal stress for certain transient conditions experienced by the upper vessel and the bottom head.

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**4.3.2.1.1 Pressure Test - Non-Beltline, Curve A (Using Bottom Head)**

In a [[ ]] finite element analysis [[ ]], the CRD penetration region was modeled to compute the local stresses for determination of the stress intensity factor,  $K_I$ . The [[ ]] evaluation was modified to consider the new requirement for  $M_m$  as discussed in ASME Code Section XI Appendix G [6] and shown below. The results of that computation were  $K_I = 143.6 \text{ ksi-in}^{1/2}$  for an applied pressure of 1593 psig (1563 psig preservice hydrotest pressure at the top of the vessel plus 30 psig hydrostatic pressure at the bottom of the vessel). The computed value of  $(T - RT_{NDT})$  was 84°F. [[

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The limit for the coolant temperature change rate is 20°F/hr or less.

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The value of  $M_m$  for an inside axial postulated surface flaw from Paragraph G-2214.1 [6] was based on a thickness of 8.0 inches; hence,  $t^{1/2} = 2.83$ . The resulting value obtained was:

$$\begin{aligned}
 M_m &= 1.85 \text{ for } \sqrt{t} \leq 2 \\
 M_m &= 0.926 \sqrt{t} \text{ for } 2 \leq \sqrt{t} \leq 3.464 = 2.6206 \\
 M_m &= 3.21 \text{ for } \sqrt{t} > 3.464
 \end{aligned}$$

$K_{Im}$  is calculated from the equation in Paragraph G-2214.1 [6] and  $K_{Ib}$  is calculated from the equation in Paragraph G-2214.2 [6]:

$$\begin{aligned}
 K_{Im} &= M_m \cdot \sigma_{pm} = [[ \quad ]] \text{ ksi-in}^{1/2} \\
 K_{Ib} &= (2/3) M_m \cdot \sigma_{pb} = [[ \quad ]] \text{ ksi-in}^{1/2}
 \end{aligned}$$

The total  $K_I$  is therefore:

$$K_I = 1.5 (K_{Im} + K_{Ib}) + M_m \cdot (\sigma_{sm} + (2/3) \cdot \sigma_{sb}) = 143.6 \text{ ksi-in}^{1/2}$$

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This equation includes a safety factor of 1.5 on primary stress. The method to solve for  $(T - RT_{NDT})$  for a specific  $K_I$  is based on the  $K_{Ic}$  the equation of Paragraph A-4200 in ASME Appendix A [17]:

$$(T - RT_{NDT}) = \ln [(K_I - 33.2) / 20.734] / 0.02$$

$$(T - RT_{NDT}) = \ln [(144 - 33.2) / 20.734] / 0.02$$

$$(T - RT_{NDT}) = 84^\circ\text{F}$$

The generic curve was generated by scaling  $143.6 \text{ ksi-in}^{1/2}$  by the nominal pressures and calculating the associated  $(T - RT_{NDT})$ :

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The highest  $RT_{NDT}$  for the bottom head plates and welds is  $60^\circ\text{F}$ , as shown in Tables 4-1 and 4-2. [[

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Second, the P-T curve is dependent on the calculated  $K_I$  value, and the  $K_I$  value is proportional to the stress and the crack depth as shown below:

$$K_I \propto \sigma (\pi a)^{1/2} \quad (4-1)$$

The stress is proportional to  $R/t$  and, for the P-T curves, crack depth,  $a$ , is  $t/4$ . Thus,  $K_I$  is proportional to  $R/(t)^{1/2}$ . The generic curve value of  $R/(t)^{1/2}$ , based on the generic BWR/6 bottom head dimensions, is:

$$\text{Generic: } R / (t)^{1/2} = 138 / (8)^{1/2} = 49 \text{ inch}^{1/2} \quad (4-2)$$

The Quad Cities Unit 1 specific bottom head dimensions are  $R = 125.7$  inches and  $t = 8$  inches minimum [19], resulting in:

$$\text{Quad Cities Unit 1 specific: } R / (t)^{1/2} = 125.7 / (8)^{1/2} = 44 \text{ inch}^{1/2} \quad (4-3)$$

Since the generic value of  $R/(t)^{1/2}$  is larger, the generic P-T curve is conservative when applied to the Quad Cities Unit 1 bottom head.

## Non-Proprietary Version

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**4.3.2.1.2     Core Not Critical Heatup/Cooldown - Non-Beltline Curve B  
(Using Bottom Head)**

As discussed previously, the CRD penetration region limits were established primarily for consideration of bottom head discontinuity stresses during pressure testing. Heatup/cooldown limits were calculated by increasing the safety factor in the pressure testing stresses (Section 4.3.2.1.1) from 1.5 to 2.0. [[

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The calculated value of  $K_I$  for pressure test is multiplied by a safety factor (SF) of 1.5, per ASME Appendix G [6] for comparison with  $K_{IR}$ , the material fracture toughness. A safety factor of 2.0 is used for the core not critical. Therefore, the  $K_I$  value for the core not critical condition is  $(143.6 / 1.5) \cdot 2.0 = 191.5 \text{ ksi-in}^{1/2}$ .

## Non-Proprietary Version

Therefore, the method to solve for  $(T - RT_{NDT})$  for a specific  $K_I$  is based on the  $K_{Ic}$  equation of Paragraph A-4200 in ASME Appendix A [17] for the core not critical curve:

$$(T - RT_{NDT}) = \ln [(K_I - 33.2) / 20.734] / 0.02$$

$$(T - RT_{NDT}) = \ln [(191.5 - 33.2) / 20.734] / 0.02$$

$$(T - RT_{NDT}) = 102^\circ\text{F}$$

The generic curve was generated by scaling 192 ksi-in<sup>1/2</sup> by the nominal pressures and calculating the associated  $(T - RT_{NDT})$ :

**Core Not Critical CRD Penetration  $K_I$  and  $(T - RT_{NDT})$   
as a Function of Pressure**

Nominal Pressure (psig)	$K_I$ (ksi-in <sup>1/2</sup> )	$T - RT_{NDT}$ (°F)
1563	192	102
1400	172	95
1200	147	85
1000	123	73
800	98	57
600	74	33
400	49	-14

The highest  $RT_{NDT}$  for the bottom head plates and welds is 60°F, as shown in Tables 4-1 and 4-2. [[

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As discussed in Section 4.3.2.1.1 an evaluation is performed to assure that the CRD discontinuity bounds the other discontinuities that are to be protected by the CRD curve with respect to pressure stresses (see Table 4-7 and Appendix A). With respect to thermal stresses, the transients evaluated for the CRD are similar to or more severe than those of the other components being bounded. Therefore, for heatup/cooldown conditions, the CRD penetration provides bounding limits.

**Non-Proprietary Version**

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## Non-Proprietary Version

#### 4.3.2.1.3 Pressure Test - Non-Beltline Curve A (Using Feedwater Nozzle/Upper Vessel Region)

The stress intensity factor,  $K_I$ , for the feedwater nozzle was computed using the methods from WRC 175 [15] together with the nozzle dimension for a generic 251-inch BWR/6 feedwater nozzle. The result of that computation was  $K_I = 200 \text{ ksi-in}^{1/2}$  for an applied pressure of 1563 psig preservice hydrotest pressure. [[

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The respective flaw depth and orientation used in this calculation is perpendicular to the maximum stress (hoop) at a depth of  $1/4T$  through the corner thickness.

To evaluate the results,  $K_I$  is calculated for the upper vessel nominal stress,  $PR/t$ , according to the methods in ASME Code Appendix G (Section III or XI). The result is compared to that determined by CBIN in order to quantify the  $K$  magnification associated with the stress concentration created by the feedwater nozzles. A calculation of  $K_I$  is shown below using the BWR/6, 251-inch dimensions:

Vessel Radius, $R_v$	126.7 inches
Vessel Thickness, $t_v$	6.1875 inches
Vessel Pressure, $P_v$	1563 psig

Pressure stress:  $\sigma = PR / t = 1563 \text{ psig} \cdot 126.7 \text{ inches} / (6.1875 \text{ inches}) = 32,005 \text{ psi}$ . The Dead weight and thermal RFE stress of 2.967 ksi is conservatively added yielding  $\sigma = 34.97 \text{ ksi}$ . The factor  $F(a/r_n)$  from Figure A5-1 of WRC-175 is 1.4 where:

$a = \frac{1}{4} (t_n^2 + t_v^2)^{1/2}$	= 2.36 inches
$t_n$ = thickness of nozzle	= 7.125 inches
$t_v$ = thickness of vessel	= 6.1875 inches
$r_n$ = apparent radius of nozzle	= $r_i + 0.29 r_c = 7.09 \text{ inches}$
$r_i$ = actual inner radius of nozzle	= 6.0 inches
$r_c$ = nozzle radius (nozzle corner radius)	= 3.75 inches

Thus,  $a/r_n = 2.36 / 7.09 = 0.33$ . The value  $F(a/r_n)$ , taken from Figure A5-1 of WRC Bulletin 175 for an  $a/r_n$  of 0.33, is 1.4. Including the safety factor of 1.5, the stress intensity factor,  $K_I$ , is  $1.5 \sigma (\pi a)^{1/2} \cdot F(a/r_n)$ :

Non-Proprietary Version

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$$\text{Nominal } K_I = 1.5 \cdot 34.97 \cdot (\pi \cdot 2.36)^{1/2} \cdot 1.4 = 200 \text{ ksi-in}^{1/2}$$

The method to solve for  $(T - RT_{NDT})$  for a specific  $K_I$  is based on the  $K_{Ic}$  equation of Paragraph A-4200 in ASME Appendix A [17] for the pressure test condition:

$$(T - RT_{NDT}) = \ln [(K_I - 33.2) / 20.734] / 0.02$$

$$(T - RT_{NDT}) = \ln [(200 - 33.2) / 20.734] / 0.02$$

$$(T - RT_{NDT}) = 104.2^\circ\text{F}$$

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The generic pressure test P-T curve was generated by scaling 200 ksi-in<sup>1/2</sup> by the nominal pressures and calculating the associated  $(T - RT_{NDT})$ , [[

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**Non-Proprietary Version**

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The highest  $RT_{NDT}$  for the feedwater nozzle materials is 48°F as shown in Table 4-2. The generic pressure test P-T curve is applied to the Quad Cities Unit 1 feedwater nozzle curve by shifting the P vs.  $(T - RT_{NDT})$  values above to reflect the  $RT_{NDT}$  value of 48°F.

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## Non-Proprietary Version

Second, the P-T curve is dependent on the  $K_I$  value calculated. The Quad Cities Unit 1 specific vessel shell and nozzle dimensions applicable to the feedwater nozzle location [19] and  $K_I$  are shown below:

Vessel Radius, $R_v$	125.7 inches
Vessel Thickness, $t_v$	6.125 inches
Vessel Pressure, $P_v$	1563 psig

Pressure stress:  $\sigma = PR / t = 1563 \text{ psig} \cdot 125.7 \text{ inches} / (6.125 \text{ inches}) = 32,077 \text{ psi}$ .  
The Dead weight and thermal RFE stress of 2.967 ksi is conservatively added yielding  $\sigma = 35.04 \text{ ksi}$ . The factor  $F(a/r_n)$  from Figure A5-1 of WRC-175 is determined where:

$a = \frac{1}{4} (t_n^2 + t_v^2)^{1/2}$	= 2.35 inches
$t_n =$ thickness of nozzle	= 7.15 inches
$t_v =$ thickness of vessel	= 6.125 inches
$r_n =$ apparent radius of nozzle	= $r_i + 0.29 r_c = 6.9 \text{ inches}$
$r_i =$ actual inner radius of nozzle	= 6.0 inches
$r_c =$ nozzle radius (nozzle corner radius)	= 3.0 inches

Thus,  $a/r_n = 2.35 / 6.9 = 0.34$ . The value  $F(a/r_n)$ , taken from Figure A5-1 of WRC Bulletin 175 for an  $a/r_n$  of 0.34, is 1.4. Including the safety factor of 1.5, the stress intensity factor,  $K_I$ , is  $1.5 \sigma (\pi a)^{1/2} \cdot F(a/r_n)$ :

$$\text{Nominal } K_I = 1.5 \cdot 35.04 \cdot (\pi \cdot 2.35)^{1/2} \cdot 1.4 = 200 \text{ ksi-in}^{1/2}$$

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#### **4.3.2.1.4 Core Not Critical Heatup/Cooldown - Non-Beltline Curve B (Using Feedwater Nozzle/Upper Vessel Region)**

The feedwater nozzle was selected to represent non-beltline components for fracture toughness analyses because the stress conditions are the most severe experienced in the vessel. In addition to the pressure and piping load stresses resulting from the nozzle

**Non-Proprietary Version**

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discontinuity, the feedwater nozzle region experiences relatively cold feedwater flow in hotter vessel coolant.

Stresses were taken from a [[ ]] finite element analysis done specifically for the purpose of fracture toughness analysis [[ ]]. Analyses were performed for all feedwater nozzle transients that involved rapid temperature changes. The most severe of these was normal operation with cold 40°F feedwater injection, which is equivalent to hot standby, as seen in Figure 4-3.

The non-beltline curves based on feedwater nozzle limits were calculated according to the methods for nozzles in Appendix 5 of the Welding Research Council (WRC) Bulletin 175 [15].

The stress intensity factor for a nozzle flaw under primary stress conditions ( $K_{IP}$ ) is given in WRC Bulletin 175 Appendix 5 by the expression for a flaw at a hole in a flat plate:

$$K_{IP} = SF \cdot \sigma (\pi a)^{1/2} \cdot F(a/r_n) \quad (4-4)$$

where SF is the safety factor applied per WRC Bulletin 175 recommended ranges, and  $F(a/r_n)$  is the shape correction factor.

## Non-Proprietary Version

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Finite element analysis of a nozzle corner flaw was performed to determine appropriate values of  $F(a/r_n)$  for Equation 4-4. These values are shown in Figure A5-1 of WRC Bulletin 175 [15].

The stresses used in Equation 4-4 were taken from [[ ]] design stress reports for the feedwater nozzle. The stresses considered are primary membrane,  $\sigma_{pm}$ , and primary bending,  $\sigma_{pb}$ . Secondary membrane,  $\sigma_{sm}$ , and secondary bending,  $\sigma_{sb}$ , stresses are included in the total  $K_I$  by using ASME Appendix G [6] methods for secondary portion,  $K_{Is}$ :

$$K_{Is} = M_m (\sigma_{sm} + (2/3) \cdot \sigma_{sb}) \quad (4-5)$$

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In the case where the total stress exceeded yield stress, a plasticity correction factor was applied based on the recommendations of WRC Bulletin 175 Section 5.C.3 [15]. However, the correction was not applied to primary membrane stresses because primary stresses satisfy the laws of equilibrium and are not self-limiting.  $K_{IP}$  and  $K_{IS}$  are added to obtain the total value of stress intensity factor,  $K_I$ . A safety factor of 2.0 is applied to primary stresses for core not critical heatup/cooldown conditions.

Once  $K_I$  was calculated, the following relationship was used to determine  $(T - RT_{NDT})$ . The method to solve for  $(T - RT_{NDT})$  for a specific  $K_I$  is based on the  $K_{IC}$  equation of Paragraph A-4200 in ASME Appendix A [17]. The highest  $RT_{NDT}$  for the appropriate non-beltline components was then used to establish the P-T curves.

$$(T - RT_{NDT}) = \ln [(K_I - 33.2) / 20.734] / 0.02 \quad (4-6)$$

#### Example Core Not Critical Heatup/Cooldown Calculation for Feedwater Nozzle/Upper Vessel Region

The non-beltline core not critical heatup/cooldown curve was based on the [[ ]] feedwater nozzle [[ ]] analysis, where feedwater injection of 40°F into the vessel while at operating conditions (551.4°F and 1050 psig) was the limiting normal or upset condition from a brittle fracture perspective. The feedwater nozzle corner stresses were obtained from finite element analysis [[ ]]. To produce conservative thermal stresses, a vessel and nozzle thickness of 7.5 inches was used in the evaluation. However, a thickness of 7.5 inches is not conservative for the pressure stress evaluation. Therefore, the pressure stress ( $\sigma_{pm}$ ) was adjusted for the actual [[ ]] vessel thickness of 6.1875 inches (i.e.,  $\sigma_{pm} = 20.49$  ksi was revised to  $20.49$  ksi  $\cdot 7.5$  inches/6.1875 inches = 24.84 ksi). These stresses, and other inputs used in the generic calculations, are shown below:

$$\begin{array}{llll} \sigma_{pm} = 24.84 \text{ ksi} & \sigma_{sm} = 16.19 \text{ ksi} & \sigma_{ys} = 45.0 \text{ ksi} & t_v = 6.1875 \text{ inches} \\ \sigma_{pb} = 0.22 \text{ ksi} & \sigma_{sb} = 19.04 \text{ ksi} & a = 2.36 \text{ inches} & r_n = 7.09 \text{ inches} \\ t_n = 7.125 \text{ inches} & & & \end{array}$$

In this case the total stress, 60.29 ksi, exceeds the yield stress,  $\sigma_{ys}$ , so the correction factor,  $R$ , is calculated to consider the nonlinear effects in the plastic region according to

## Non-Proprietary Version

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the following equation based on the assumptions and recommendation of WRC Bulletin 175 [15]. (The value of specified yield stress is for the material at the temperature under consideration. For conservatism, the temperature assumed for the crack root is the inside surface temperature.)

$$R = [\sigma_{ys} - \sigma_{pm} + ((\sigma_{total} - \sigma_{ys}) / 30)] / (\sigma_{total} - \sigma_{pm}) \quad (4-7)$$

For the stresses given, the ratio,  $R = 0.583$ . Therefore, all the stresses are adjusted by the factor 0.583, except for  $\sigma_{pm}$ . The resulting stresses are:

$$\begin{aligned} \sigma_{pm} &= 24.84 \text{ ksi} & \sigma_{sm} &= 9.44 \text{ ksi} \\ \sigma_{pb} &= 0.13 \text{ ksi} & \sigma_{sb} &= 11.10 \text{ ksi} \end{aligned}$$

The value of  $M_m$  for an inside axial postulated surface flaw from Paragraph G-2214.1 [6] was based on the 4a thickness; hence,  $t^{1/2} = 3.072$ . The resulting value obtained was:

$$\begin{aligned} M_m &= 1.85 \text{ for } \sqrt{t} \leq 2 \\ M_m &= 0.926 \sqrt{t} \text{ for } 2 \leq \sqrt{t} \leq 3.464 = 2.845 \\ M_m &= 3.21 \text{ for } \sqrt{t} > 3.464 \end{aligned}$$

The value  $F(a/r_n)$ , taken from Figure A5-1 of WRC Bulletin 175 for an  $a/r_n$  of 0.33, is therefore,

$$F(a/r_n) = 1.4$$

$K_{IP}$  is calculated from Equation 4-4:

$$\begin{aligned} K_{IP} &= 2.0 \cdot (24.84 + 0.13) \cdot (\pi \cdot 2.36)^{1/2} \cdot 1.4 \\ K_{IP} &= 190.4 \text{ ksi-in}^{1/2} \end{aligned}$$

$K_{Is}$  is calculated from Equation 4-5:

$$K_{Is} = 2.845 \cdot (9.44 + 2/3 \cdot 11.10)$$


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$$K_{Is} = 47.9 \text{ ksi-in}^{1/2}$$

The total  $K_I$  is, therefore,  $238.3 \text{ ksi-in}^{1/2}$ .

The total  $K_I$  is substituted into Equation 4-6 to solve for  $(T - RT_{NDT})$ :

$$(T - RT_{NDT}) = \ln [(238.3 - 33.2) / 20.734] / 0.02$$

$$(T - RT_{NDT}) = 115^\circ\text{F}$$

The [[            ]] curve was generated by scaling the stresses used to determine the  $K_I$ ; this scaling was performed after the adjustment to stresses above yield. The primary stresses were scaled by the nominal pressures, while the secondary stresses were scaled by the temperature difference of the  $40^\circ\text{F}$  water injected into the hot reactor vessel nozzle. In the base case that yielded a  $K_I$  value of  $238 \text{ ksi-in}^{1/2}$ , the pressure is  $1050 \text{ psig}$  and the hot reactor vessel temperature is  $551.4^\circ\text{F}$ . Since the reactor vessel temperature follows the saturation temperature curve, the secondary stresses are scaled by

$(T_{\text{saturation}} - 40) / (551.4 - 40)$ . From  $K_I$  the associated  $(T - RT_{NDT})$  can be calculated:

**Core Not Critical Feedwater Nozzle  $K_I$  and  $(T - RT_{NDT})$   
as a Function of Pressure**

Nominal Pressure (psig)	Saturation Temp. (°F)	R	$K_I^*$ (ksi-in <sup>1/2</sup> )	$(T - RT_{NDT})$ (°F)
1563	604	0.23	303	128
1400	588	0.34	283	124
1200	557	0.48	257	119
1050	551	0.58	238	115
1000	546	0.62	232	113
800	520	0.79	206	106
600	489	1.0	181	98
400	448	1.0	138	81

\*Note: For each change in stress for each pressure and saturation temperature condition, there is a corresponding change to  $R$  that influences the determination of  $K_I$ .

The highest non-beltline  $RT_{NDT}$  for the feedwater nozzle at Quad Cities Unit 1 is  $48^\circ\text{F}$  as shown in Table 4-2. The generic curve is applied to the Quad Cities Unit 1 upper vessel

## Non-Proprietary Version

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by shifting the  $P$  vs.  $(T - RT_{NDT})$  values above to reflect the  $RT_{NDT}$  value of  $48^{\circ}\text{F}$  as discussed in Section 4.3.2.1.3.

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#### 4.3.2.2 CORE BELTLINE REGION

The pressure-temperature ( $P$ - $T$ ) operating limits for the beltline region are determined according to the ASME Code. As the beltline fluence increases with the increase in operating life, the  $P$ - $T$  curves shift to a higher temperature.

The stress intensity factors ( $K_I$ ), calculated for the beltline region according to ASME Code Appendix G procedures [6], were based on a combination of pressure and thermal stresses for a  $1/4T$  flaw in a flat plate. The pressure stresses were calculated using thin-walled cylinder equations. Thermal stresses were calculated assuming the through-wall temperature distribution of a flat plate; values were calculated for  $100^{\circ}\text{F/hr}$  coolant thermal gradient. The shift value of the most limiting ART material was used to adjust the  $RT_{NDT}$  values for the  $P$ - $T$  limits.

##### 4.3.2.2.1 Beltline Region - Pressure Test

The methods of ASME Code Section XI, Appendix G [6] are used to calculate the pressure test beltline limits. The vessel shell, with an inside radius ( $R$ ) to minimum thickness ( $t_{min}$ ) ratio of 15, is treated as a thin-walled cylinder. The maximum stress is the hoop stress, given as:

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$$\sigma_m = PR / t_{min} \quad (4-8)$$

The stress intensity factor,  $K_{Im}$ , is calculated using Paragraph G-2214.1 of the ASME Code.

The calculated value of  $K_{Im}$  for pressure test is multiplied by a safety factor (SF) of 1.5, per ASME Appendix G [6] for comparison with  $K_{IC}$ , the material fracture toughness. A safety factor of 2.0 is used for the core not critical and core critical conditions.

The relationship between  $K_{IC}$  and temperature relative to reference temperature ( $T - RT_{NDT}$ ) is based on the  $K_{IC}$  equation of Paragraph A-4200 in ASME Appendix A [17] for the pressure test condition:

$$K_{Im} \cdot SF = K_{IC} = 20.734 \exp[0.02 (T - RT_{NDT})] + 33.2 \quad (4-9)$$

This relationship provides values of pressure versus temperature (from  $K_{IR}$  and  $(T - RT_{NDT})$ , respectively).

GE's current practice for the pressure test curve is to add a stress intensity factor,  $K_{It}$ , for a coolant heatup/cooldown rate of 20°F/hr to provide operating flexibility. For the core not critical and core critical condition curves, a stress intensity factor is added for a coolant heatup/cooldown rate of 100°F/hr. The  $K_{It}$  calculation for a coolant heatup/cooldown rate of 100°F/hr is described in Section 4.3.2.2.3 below.

## Non-Proprietary Version

**4.3.2.2.2 Calculations for the Beltline Region - Pressure Test**

This sample calculation is for a pressure test pressure of 1105 psig at 32 EFPY. The following inputs were used in the beltline limit calculation:

Adjusted $RT_{NDT} = \text{Initial } RT_{NDT} + \text{Shift}$	$A = 23 + 63 = 86^{\circ}\text{F}$ (Based on ART values in Table 4-3)
Vessel Height	$H = 823$ inches
Bottom of Active Fuel Height	$B = 216.3$ inches
Vessel Radius (to inside of clad)	$R = 125.7$ inches
Minimum Vessel Thickness (without clad)	$t = 6.125$ inches

Pressure is calculated to include hydrostatic pressure for a full vessel:

$$\begin{aligned}
 P &= 1105 \text{ psi} + (H - B) 0.0361 \text{ psi/inch} = P \text{ psig} \\
 &= 1105 + (823 - 216.3) 0.0361 = 1127 \text{ psig}
 \end{aligned}
 \tag{4-10}$$

Pressure stress:

$$\begin{aligned}
 \sigma &= PR/t \\
 &= 1.127 \cdot 125.7 / 6.125 = 23.1 \text{ ksi}
 \end{aligned}
 \tag{4-11}$$

The value of  $M_m$  for an inside axial postulated surface flaw from Paragraph G-2214.1 [6] was based on a thickness of 6.125 inches (the minimum thickness without cladding); hence,  $t^{1/2} = 2.47$ . The resulting value obtained was:

$$M_m = 1.85 \text{ for } \sqrt{t} \leq 2$$

$$M_m = 0.926 \sqrt{t} \text{ for } 2 \leq \sqrt{t} \leq 3.464 = 2.29$$

$$M_m = 3.21 \text{ for } \sqrt{t} > 3.464$$

The stress intensity factor for the pressure stress is  $K_{Im} = M_m \cdot \sigma$ . The stress intensity factor for the thermal stress,  $K_{It}$ , is calculated as described in Section 4.3.2.2.4 except that the value of "G" is 20°F/hr instead of 100°F/hr.

## Non-Proprietary Version

Equation 4-9 can be rearranged, and  $1.5 K_{Im}$  substituted for  $K_{IC}$ , to solve for  $(T - RT_{NDT})$ . Using the  $K_{IC}$  equation of Paragraph A-4200 in ASME Appendix A [17],  $K_{Im} = 52.96$ , and  $K_{It} = 2.29$  for a  $20^\circ\text{F/hr}$  coolant heatup/cooldown rate with a vessel thickness,  $t$ , that includes cladding:

$$\begin{aligned}(T - RT_{NDT}) &= \ln[(1.5 \cdot K_{Im} + K_{It} - 33.2) / 20.734] / 0.02 \\ &= \ln[(1.5 \cdot 52.96 + 2.29 - 33.2) / 20.734] / 0.02 \\ &= 42.5^\circ\text{F}\end{aligned}\tag{4-12}$$

$T$  can be calculated by adding the adjusted  $RT_{NDT}$ :

$$T = 42.5 + 86 = 128.5^\circ\text{F} \quad \text{for } P = 1105 \text{ psig at 32 EFY}$$

#### 4.3.2.2.3 Beltline Region - Core Not Critical Heatup/Cooldown

The beltline curves for core not critical heatup/cooldown conditions are influenced by pressure stresses and thermal stresses, according to the relationship in ASME Section XI Appendix G [6]:

$$K_{IC} = 2.0 \cdot K_{Im} + K_{It}\tag{4-13}$$

where  $K_{Im}$  is primary membrane  $K$  due to pressure and  $K_{It}$  is radial thermal gradient  $K$  due to heatup/cooldown.

The pressure stress intensity factor  $K_{Im}$  is calculated by the method described above, the only difference being the larger safety factor applied. The thermal gradient stress intensity factor calculation is described below.

The thermal stresses in the vessel wall are caused by a radial thermal gradient that is created by changes in the adjacent reactor coolant temperature in heatup or cooldown conditions. The stress intensity factor is computed by multiplying the coefficient  $M_t$  from Figure G-2214-1 of ASME Appendix G [6] by the through-wall temperature gradient  $\Delta T_w$ ,

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given that the temperature gradient has a through-wall shape similar to that shown in Figure G-2214-2 of ASME Appendix G [6]. The relationship used to compute the through-wall  $\Delta T_w$  is based on one-dimensional heat conduction through an insulated flat plate:

$$\partial^2 T(x,t) / \partial x^2 = 1 / \beta (\partial T(x,t) / \partial t) \quad (4-14)$$

where  $T(x,t)$  is temperature of the plate at depth  $x$  and time  $t$ , and  $\beta$  is the thermal diffusivity.

The maximum stress will occur when the radial thermal gradient reaches a quasi-steady state distribution, so that  $\partial T(x,t) / \partial t = dT(t) / dt = G$ , where  $G$  is the coolant heatup/cooldown rate, normally 100°F/hr. The differential equation is integrated over  $x$  for the following boundary conditions:

1. Vessel inside surface ( $x = 0$ ) temperature is the same as coolant temperature,  $T_0$ .
2. Vessel outside surface ( $x = C$ ) is perfectly insulated; the thermal gradient  $dT/dx = 0$ .

The integrated solution results in the following relationship for wall temperature:

$$T = Gx^2 / 2\beta - GCx / \beta + T_0 \quad (4-15)$$

This equation is normalized to plot  $(T - T_0) / \Delta T_w$  versus  $x / C$ .

The resulting through-wall gradient compares very closely with Figure G-2214-2 of ASME Appendix G [6]. Therefore,  $\Delta T_w$  calculated from Equation 4-15 is used with the appropriate  $M_t$  of Figure G-2214-1 of ASME Appendix G [6] to compute  $K_{It}$  for heatup and cooldown.

The  $M_t$  relationships were derived in the Welding Research Council (WRC) Bulletin 175 [15] for infinitely long cracks of  $1/4T$  and  $1/8T$ . For the flat plate geometry and radial thermal gradient, orientation of the crack is not important.

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#### 4.3.2.2.4 *Calculations for the Beltline Region Core Not Critical Heatup/Cooldown*

This sample calculation is for a pressure of 1105 psig for 32 EFPY. The core not critical heatup/cooldown curve at 1105 psig uses the same  $K_{lm}$  as the pressure test curve, but with a safety factor of 2.0 instead of 1.5. The increased safety factor is used because the heatup/cooldown cycle represents an operational rather than test condition that necessitates a higher safety factor. In addition, there is a  $K_{lt}$  term for the thermal stress. The additional inputs used to calculate  $K_{lt}$  are:

Coolant heatup/cooldown rate, normally 100°F/hr	$G = 100 \text{ °F/hr}$
Minimum vessel thickness, including clad thickness	$C = 0.526 \text{ ft (6.3125 inches)}$
Thermal diffusivity at 550°F (most conservative value)	$\beta = 0.354 \text{ ft}^2/\text{hr [21]}$

Equation 4-15 can be solved for the through-wall temperature ( $x = C$ ), resulting in the absolute value of  $\Delta T$  for heatup or cooldown of:

$$\begin{aligned}\Delta T &= GC^2 / 2\beta \\ &= 100 \cdot (0.526)^2 / (2 \cdot 0.354) = 39^\circ\text{F}\end{aligned}\tag{4-16}$$

The analyzed case for thermal stress is a 1/4T flaw depth with wall thickness of C. The corresponding value of  $M_t$  ( $\approx 0.2914$ ) can be interpolated from ASME Appendix G, Figure G-2214-2 [6]. Thus the thermal stress intensity factor,  $K_{lt} = M_t \cdot \Delta T = 11.39$ , can be calculated. The conservative value for thermal diffusivity at 550°F is used for all calculations; therefore,  $K_{lt}$  is constant for all pressures.  $K_{lm}$  has the same value as that calculated in Section 4.3.2.2.2.

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The pressure and thermal stress terms are substituted into Equation 4-9 to solve for  $(T - RT_{NDT})$ :

$$\begin{aligned}
 (T - RT_{NDT}) &= \ln[(2 \cdot K_{Im} + K_{It}) - 33.2] / 20.734 / 0.02 & (4-17) \\
 &= \ln[(2 \cdot 52.96 + 11.39 - 33.2) / 20.734] / 0.02 \\
 &= 70^\circ\text{F}
 \end{aligned}$$

T can be calculated by adding the adjusted  $RT_{NDT}$ :

$$T = 70 + 86 = 156^\circ\text{F} \quad \text{for } P = 1105 \text{ psig at 32 EFPY}$$

#### 4.3.2.3 CLOSURE FLANGE REGION

10CFR50 Appendix G [8] sets several minimum requirements for pressure and temperature in addition to those outlined in the ASME Code, based on the closure flange region  $RT_{NDT}$ . Similar to the evaluations performed for the bottom head and upper vessel, a BWR/6 finite element analysis [18] was used to model the flange region. The local stresses were computed for determination of the stress intensity factor,  $K_I$ . Using a  $1/4T$  flaw size and the  $K_{Ic}$  formulation to determine  $T - RT_{NDT}$ , for pressures above 312 psig the P-T limits for all flange regions are bounded by the 10 CFR50 Appendix G requirement of  $RT_{NDT} + 90^\circ\text{F}$  (the largest  $T - RT_{NDT}$  for the flange at 1563 psig is  $73^\circ\text{F}$ ). For pressures below 312 psig, the flange curve is bounded by  $RT_{NDT} + 60$  (the largest  $T - RT_{NDT}$  for the flange at 312 psig is  $54^\circ\text{F}$ ), therefore, instead of determining a T (temperature) versus pressure curve for the flange (i.e.,  $T - RT_{NDT}$ ) the value  $RT_{NDT} + 60$  is used for the closure flange limits.

In some cases, the results of analysis for other regions exceed these requirements and closure flange limits do not affect the shape of the P-T curves. However, some closure flange requirements do impact the curves, as is true with Quad Cities Unit 1 at low pressures.



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The approach used for Quad Cities Unit 1 for the bolt-up temperature was based on the conservative value of  $(RT_{NDT} + 60)$ , or the LST of the bolting materials, whichever is greater. The 60°F adder is included by GE for two reasons: 1) the pre-1971 requirements of the ASME Code Section III, Subsection NA, Appendix G included the 60°F adder, and 2) inclusion of the additional 60°F requirement above the  $RT_{NDT}$  provides the additional assurance that a 1/4T flaw size is acceptable. As shown in Tables 4-1 and 4-2, the limiting initial  $RT_{NDT}$  for the closure flange region is represented by the electroslag weld materials in the upper shell at 23.1°F, and the LST of the closure studs is 70°F; therefore, the bolt-up temperature value used is 83°F. This conservatism is appropriate because bolt-up is one of the more limiting operating conditions (high stress and low temperature) for brittle fracture.

10CFR50 Appendix G, paragraph IV.A.2 [8] including Table 1, sets minimum temperature requirements for pressure above 20% hydrotest pressure based on the  $RT_{NDT}$  of the closure region. Curve A temperature must be no less than  $(RT_{NDT} + 90°F)$  and Curve B temperature no less than  $(RT_{NDT} + 120°F)$ .

For pressures below 20% of preservice hydrostatic test pressure (312 psig) and with full bolt preload, the closure flange region metal temperature is required to be at  $RT_{NDT}$  or greater as described above. At low pressure, the ASME Code [6] allows the bottom head regions to experience even lower metal temperatures than the flange region  $RT_{NDT}$ . However, temperatures should not be permitted to be lower than 68°F for the reason discussed below.

The shutdown margin, provided in the Quad Cities Unit 1 Technical Specification, is calculated for a water temperature of 68°F. Shutdown margin is the quantity of reactivity needed for a reactor core to reach criticality with the strongest-worth control rod fully withdrawn and all other control rods fully inserted. Although it may be possible to safely allow the water temperature to fall below this 68°F limit, further extensive calculations would be required to justify a lower temperature. The 83°F limit for the upper vessel and beltline region and the 68°F limit for the bottom head curve apply when the head is on and tensioned and when the head is off while fuel is in the vessel. When the head is not

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tensioned and fuel is not in the vessel, the requirements of 10CFR50 Appendix G [8] do not apply, and there are no limits on the vessel temperatures.

#### 4.3.2.4 CORE CRITICAL OPERATION REQUIREMENTS OF 10CFR50, APPENDIX G

Curve C, the core critical operation curve, is generated from the requirements of 10CFR50 Appendix G [8], Table 1. Table 1 of [8] requires that core critical P-T limits be 40°F above any Curve A or B limits when pressure exceeds 20% of the pre-service system hydrotest pressure. Curve B is more limiting than Curve A, so limiting Curve C values are at least Curve B plus 40°F for pressures above 312 psig.

Table 1 of 10CFR50 Appendix G [8] indicates that for a BWR with water level within normal range for power operation, the allowed temperature for initial criticality at the closure flange region is ( $RT_{NDT} + 60^{\circ}\text{F}$ ) at pressures below 312 psig. This requirement makes the minimum criticality temperature 83°F, based on an  $RT_{NDT}$  of 23.1°F. In addition, above 312 psig the Curve C temperature must be at least the greater of  $RT_{NDT}$  of the closure region + 160°F or the temperature required for the hydrostatic pressure test (Curve A at 1105 psig). The requirement of closure region  $RT_{NDT} + 160^{\circ}\text{F}$  causes a temperature shift in Curve C at 312 psig.

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## 5.0 CONCLUSIONS AND RECOMMENDATIONS

The operating limits for pressure and temperature are required for three categories of operation: (a) hydrostatic pressure tests and leak tests, referred to as Curve A; (b) non-nuclear heatup/cooldown and low-level physics tests, referred to as Curve B; and (c) core critical operation, referred to as Curve C.

There are four vessel regions that should be monitored against the P-T curve operating limits; these regions are defined on the thermal cycle diagram [2]:

- Closure flange region (Region A)
- Core beltline region (Region B)
- Upper vessel (Regions A & B)
- Lower vessel (Regions B & C)

For the core not critical and the core critical curve, the P-T curves specify a coolant heatup and cooldown temperature rate of 100°F/hr or less for which the curves are applicable. However, the core not critical and the core critical curves were also developed to bound transients defined on the RPV thermal cycle diagram [2] and the nozzle thermal cycle diagrams [3]. For the hydrostatic pressure and leak test curve, a coolant heatup and cooldown temperature rate of 20°F/hr or less must be maintained at all times.

The P-T curves apply for both heatup/cooldown and for both the 1/4T and 3/4T locations because the maximum tensile stress for either heatup or cooldown is applied at the 1/4T location. For beltline curves this approach has added conservatism because irradiation effects cause the allowable toughness,  $K_{Ic}$ , at 1/4T to be less than that at 3/4T for a given metal temperature.

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The following P-T curves were generated for Quad Cities Unit 1.

- Composite P-T curves were generated for each of the Pressure Test and Core Not Critical conditions at 32 and 54 effective full power years (EFPY). The composite curves were generated by enveloping the most restrictive P-T limits from the separate beltline, upper vessel and closure assembly P-T limits. A separate Bottom Head Limits (CRD Nozzle) curve is also individually included with the composite curve for the Pressure Test and Core Not Critical condition.
- Separate P-T curves were developed for the upper vessel, beltline (at 32 and 54 EFPY), and bottom head for the Pressure Test and Core Not Critical conditions.
- A composite P-T curve was also generated for the Core Critical condition at 32 and 54 EFPY. The composite curves were generated by enveloping the most restrictive P-T limits from the separate beltline, upper vessel, bottom head, and closure assembly P-T limits.

Using the flux from Reference 14, the P-T curves are non-beltline (upper vessel) limited for Curves A and B at 32 EFPY. At 54 EFPY, the P-T curves are beltline limited above 770 psig for Curve A and above 820 psig for Curve B.

Table 5-1 shows the figure numbers for each P-T curve. A tabulation of the curves is presented in Appendix B.

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**Table 5-1: Composite and Individual Curves Used To Construct  
Composite P-T Curves**

<b>Curve</b>	<b>Curve Description</b>	<b>Figure Numbers for Presentation of the P-T Curves</b>	<b>Table Numbers for Presentation of the P-T Curves</b>
<b>Curve A</b>			
	Bottom Head Limits (CRD Nozzle)	Figure 5-1	Table B-1 & 3
	Upper Vessel Limits (FW Nozzle)	Figure 5-2	Table B-1 & 3
	Beltline Limits for 32 EFPY	Figure 5-3	Table B-1
	Beltline Limits for 54 EFPY	Figure 5-4	Table B-3
<b>Curve B</b>			
	Bottom Head Limits (CRD Nozzle)	Figure 5-5	Table B-1 & 3
	Upper Vessel Limits (FW Nozzle)	Figure 5-6	Table B-1 & 3
	Beltline Limits for 32 EFPY	Figure 5-7	Table B-1
	Beltline Limits for 54 EFPY	Figure 5-8	Table B-3
<b>Curve C</b>			
	Composite Curve for 32 EFPY**	Figure 5-9	Table B-2
	Composite Curve for 54 EFPY**	Figure 5-10	Table B-4
<b>A &amp; B</b>	<b>Composite Curves for 32 EFPY</b>		
	Bottom Head and Composite Curve A for 32 EFPY*	Figure 5-11	Table B-2
	Bottom Head and Composite Curve B for 32 EFPY*	Figure 5-12	Table B-2
<b>A &amp; B</b>	<b>Composite Curves for 54 EFPY</b>		
	Bottom Head and Composite Curve A for 54 EFPY*	Figure 5-13	Table B-4
	Bottom Head and Composite Curve B for 54 EFPY*	Figure 5-14	Table B-4

\* The Composite Curve A & B curve is the more limiting of three limits: 10CFR50 Bolt-up Limits, Upper Vessel Limits (FW Nozzle), and Beltline Limits. A separate Bottom Head Limits (CRD Nozzle) curve is individually included on this figure.

\*\* The Composite Curve C curve is the more limiting of four limits: 10CFR50 Bolt-up Limits, Bottom Head Limits (CRD Nozzle), Upper Vessel Limits (FW Nozzle), and Beltline Limits.

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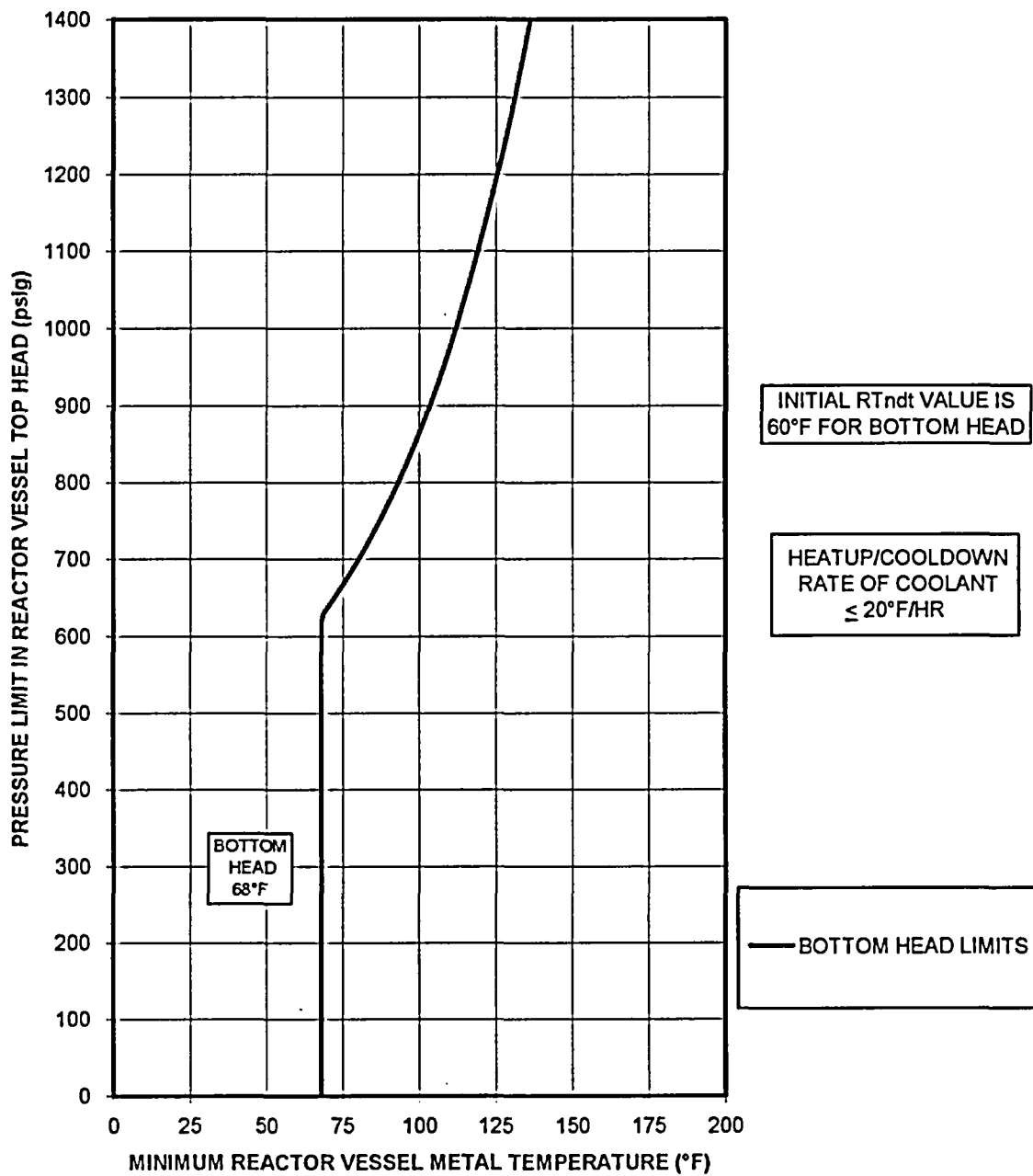


Figure 5-1: Bottom Head P-T Curve for Pressure Test [Curve A]  
[20°F/hr or less coolant heatup/cooldown]

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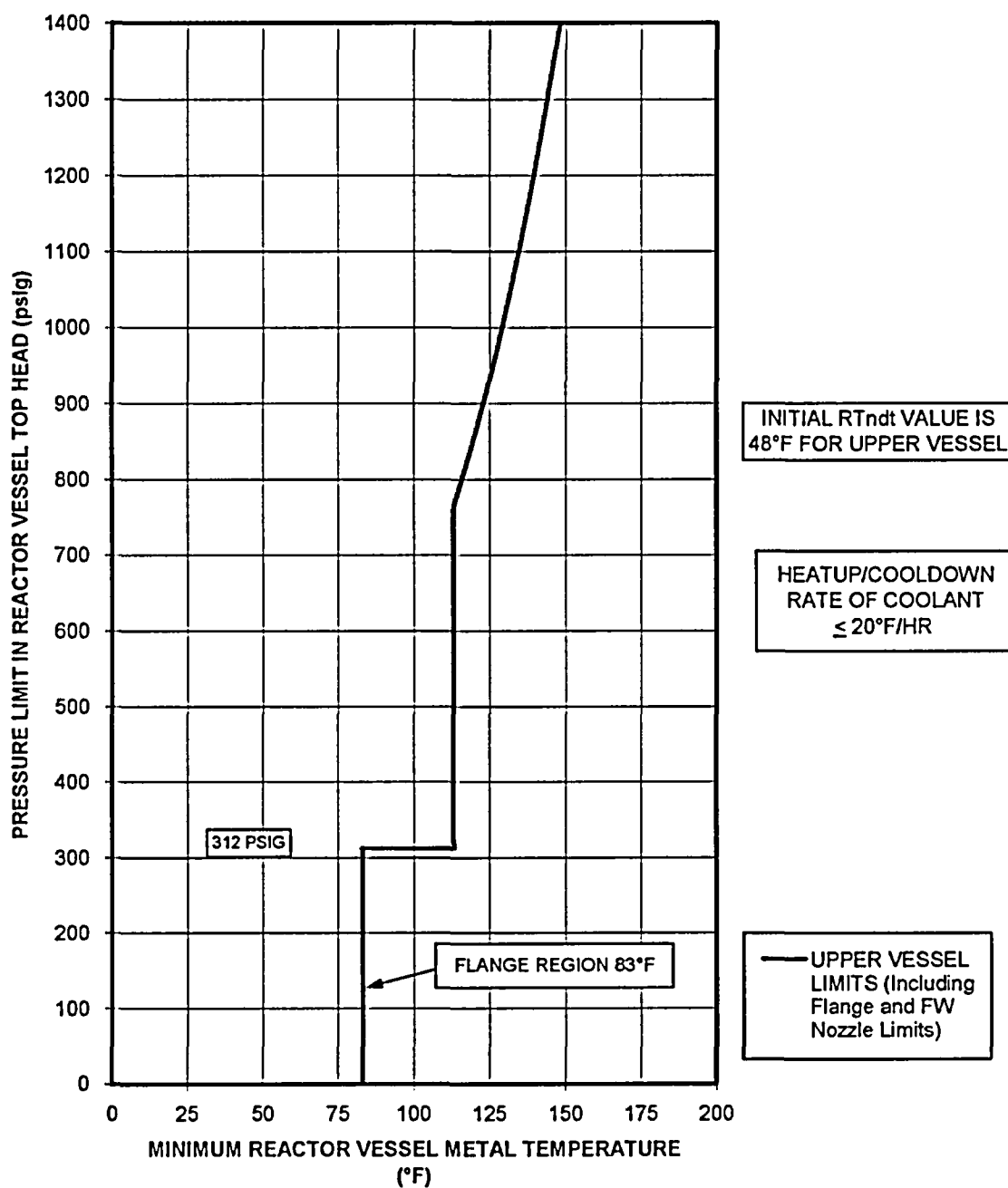


Figure 5-2: Upper Vessel P-T Curve for Pressure Test [Curve A]  
[20°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

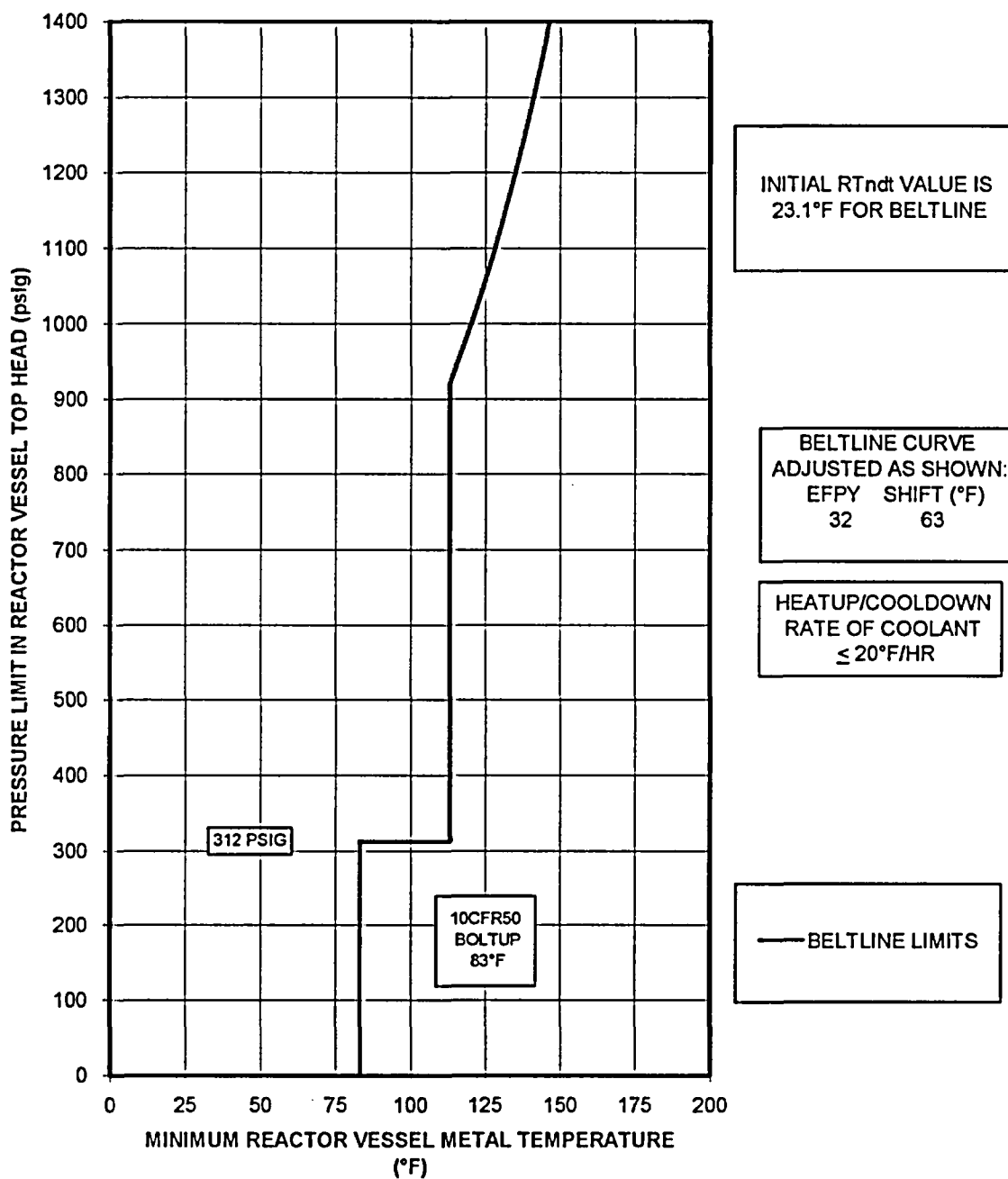


Figure 5-3: Beltline P-T Curve for Pressure Test [Curve A] up to 32 EFY  
[20°F/hr or less coolant heatup/cooldown]



## Non-Proprietary Version

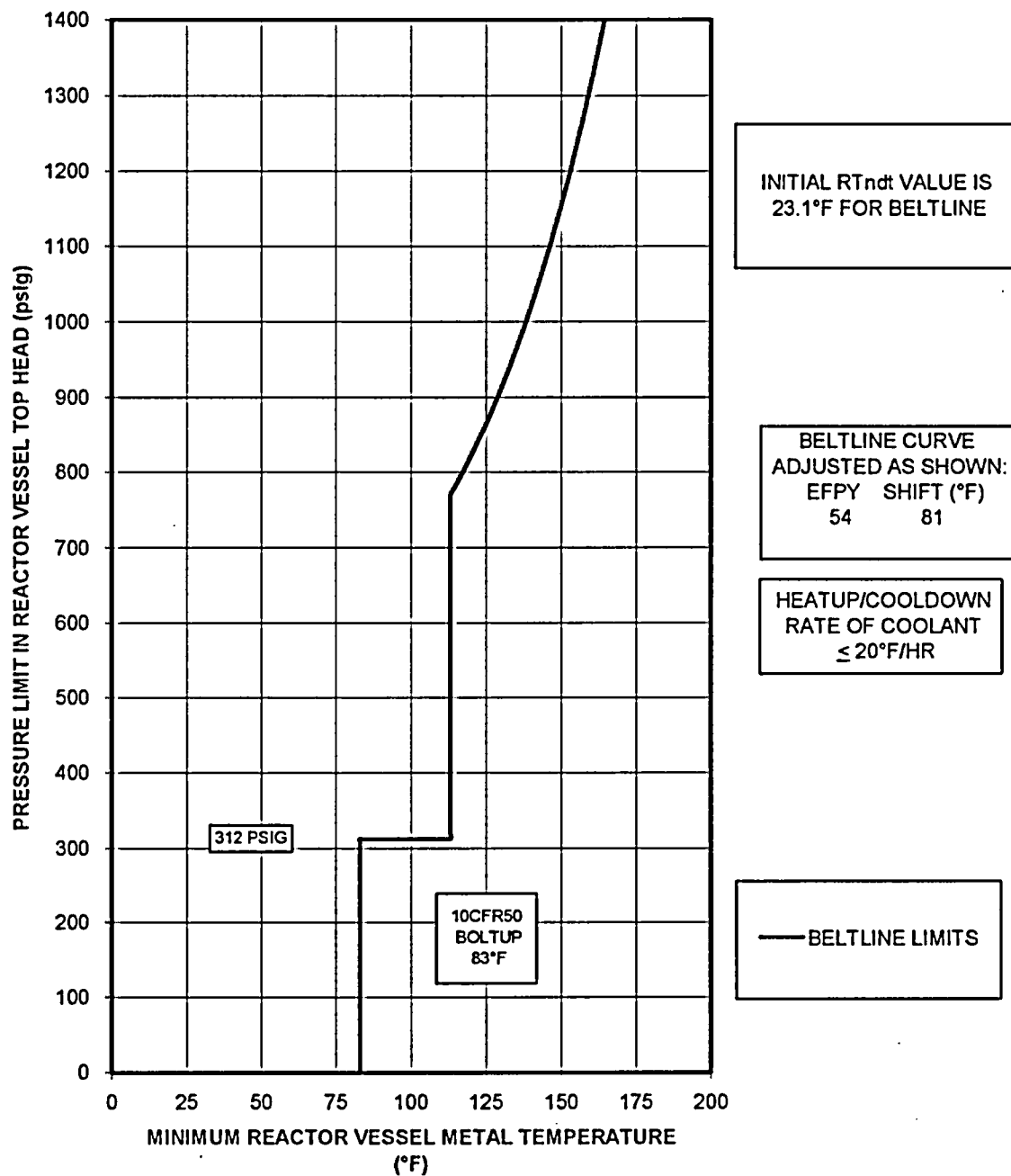


Figure 5-4: Beltline P-T Curve for Pressure Test [Curve A] up to 54 EFPY  
[20°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

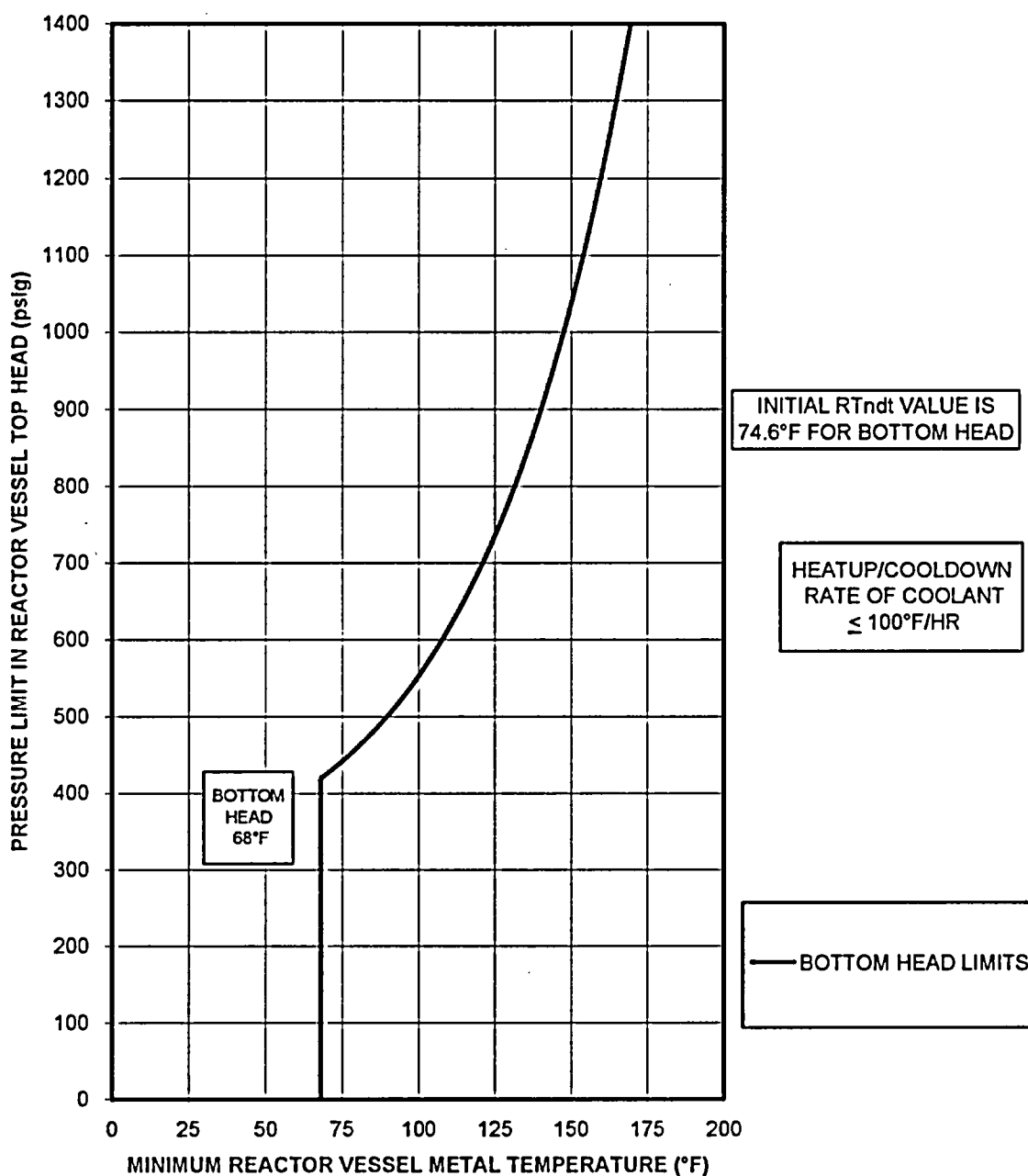


Figure 5-5: Bottom Head P-T Curve for Core Not Critical [Curve B]  
[100°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

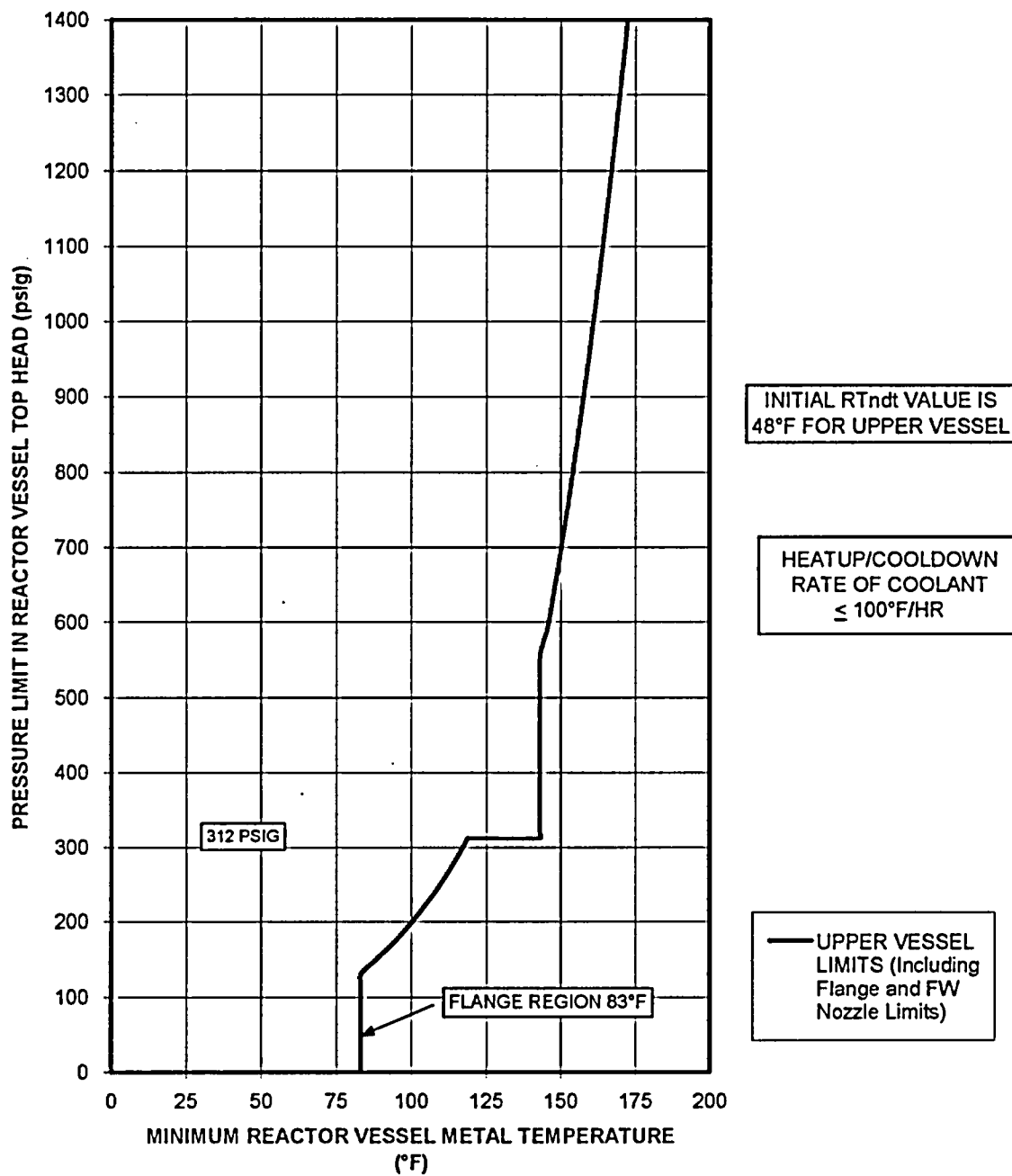


Figure 5-6: Upper Vessel P-T Curve for Core Not Critical [Curve B]  
[100°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

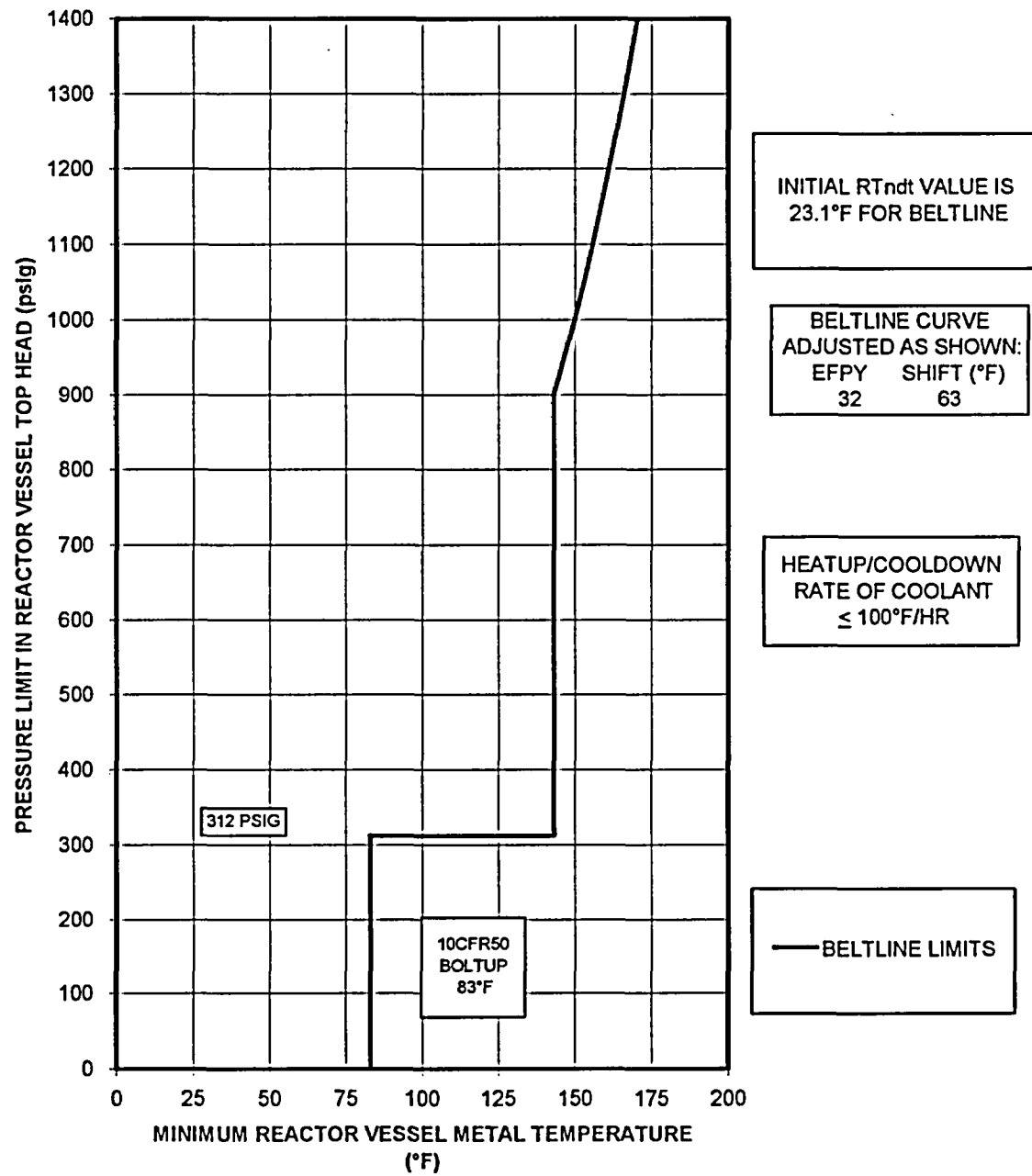


Figure 5-7: Beltline P-T Curve for Core Not Critical [Curve B] up to 32 EFPY  
[100°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

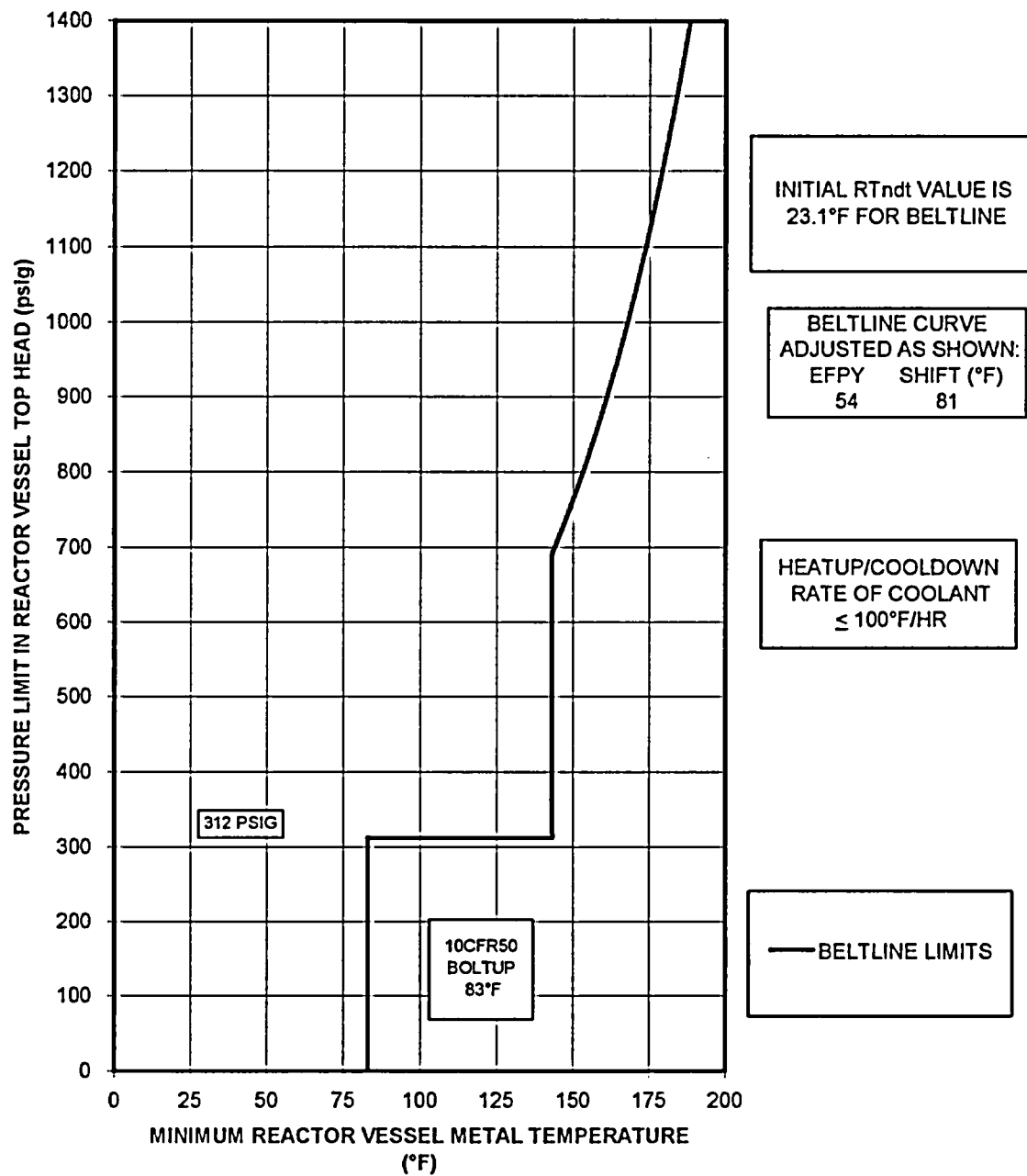


Figure 5-8: Beltline P-T Curve for Core Not Critical [Curve B] up to 54 EFPY  
[100°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

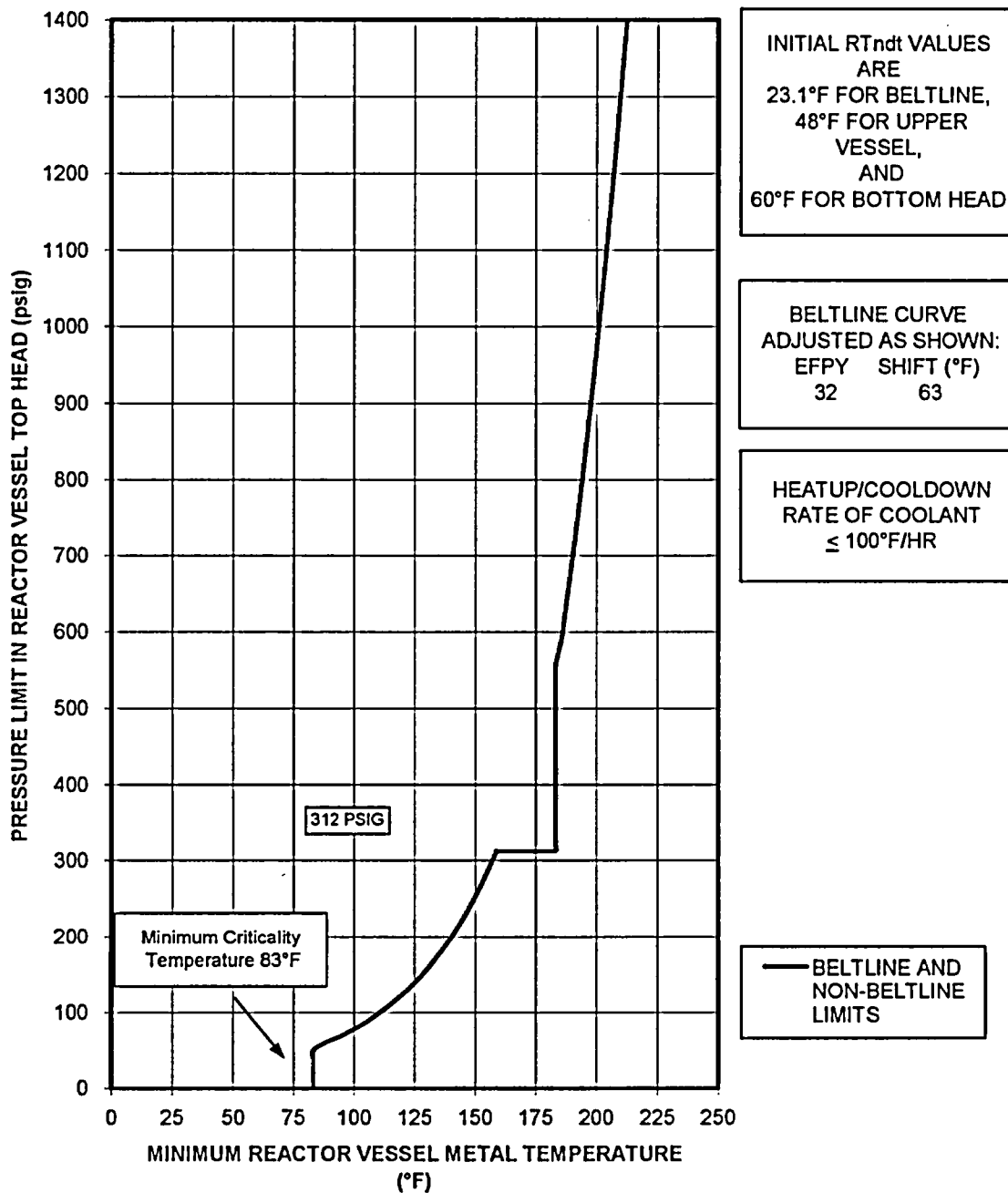


Figure 5-9: Core Critical P-T Curves [Curve C] up to 32 EFPY  
[100°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

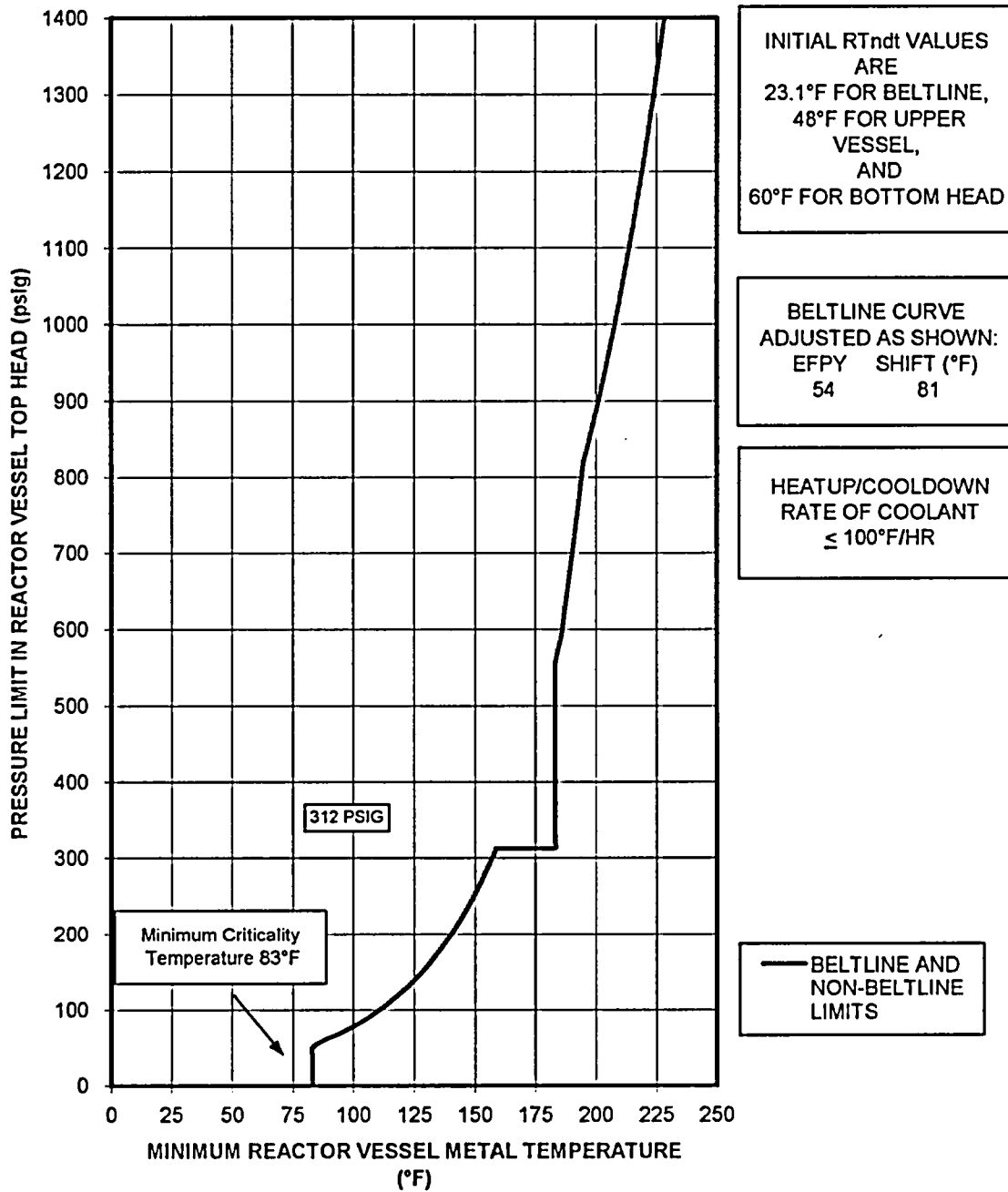


Figure 5-10: Core Critical P-T Curves [Curve C] up to 54 EFPY  
[100°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

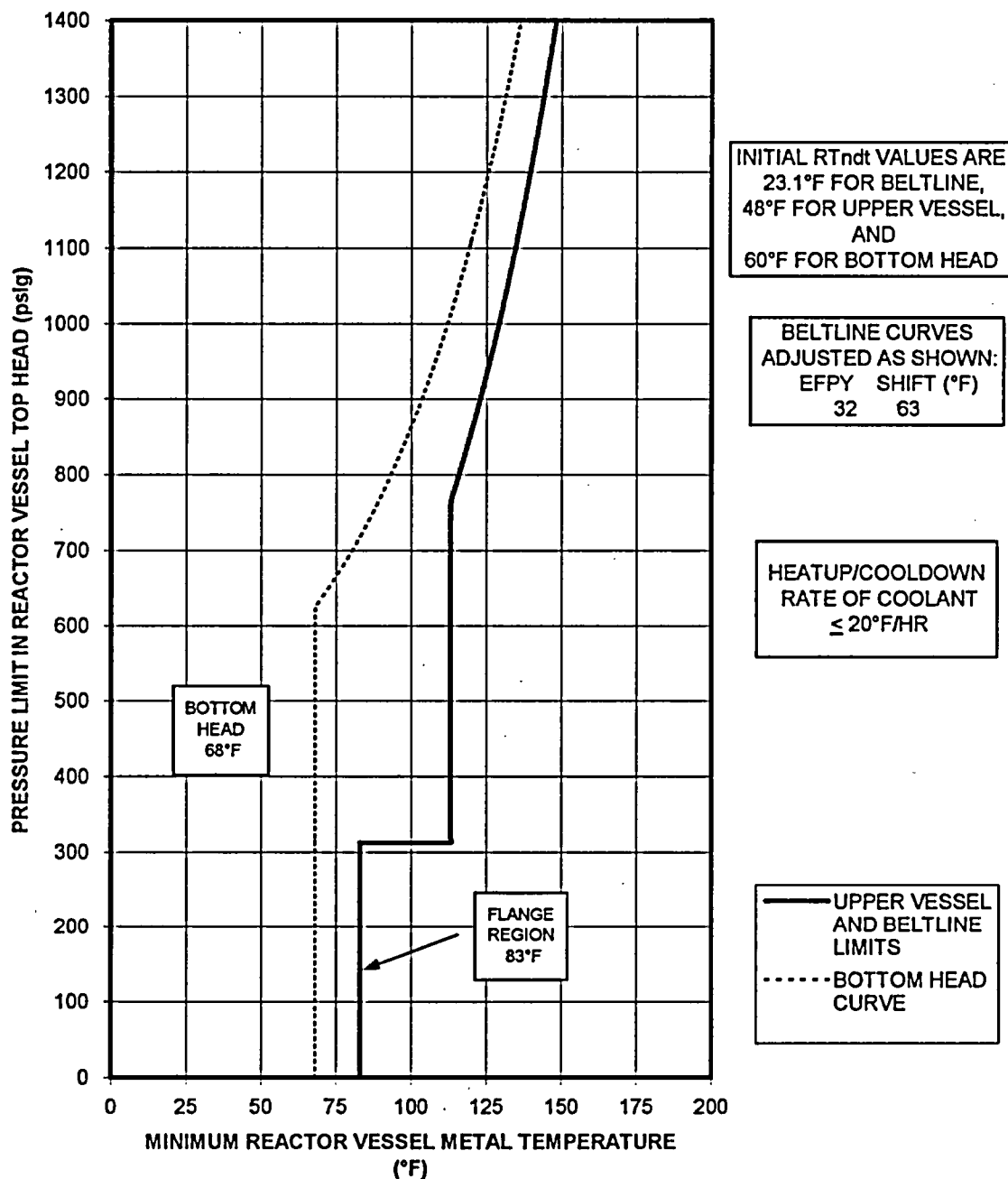


Figure 5-11: Composite Pressure Test P-T Curves [Curve A] up to 32 EFPY  
[20°F/hr or less coolant heatup/cooldown]



## Non-Proprietary Version

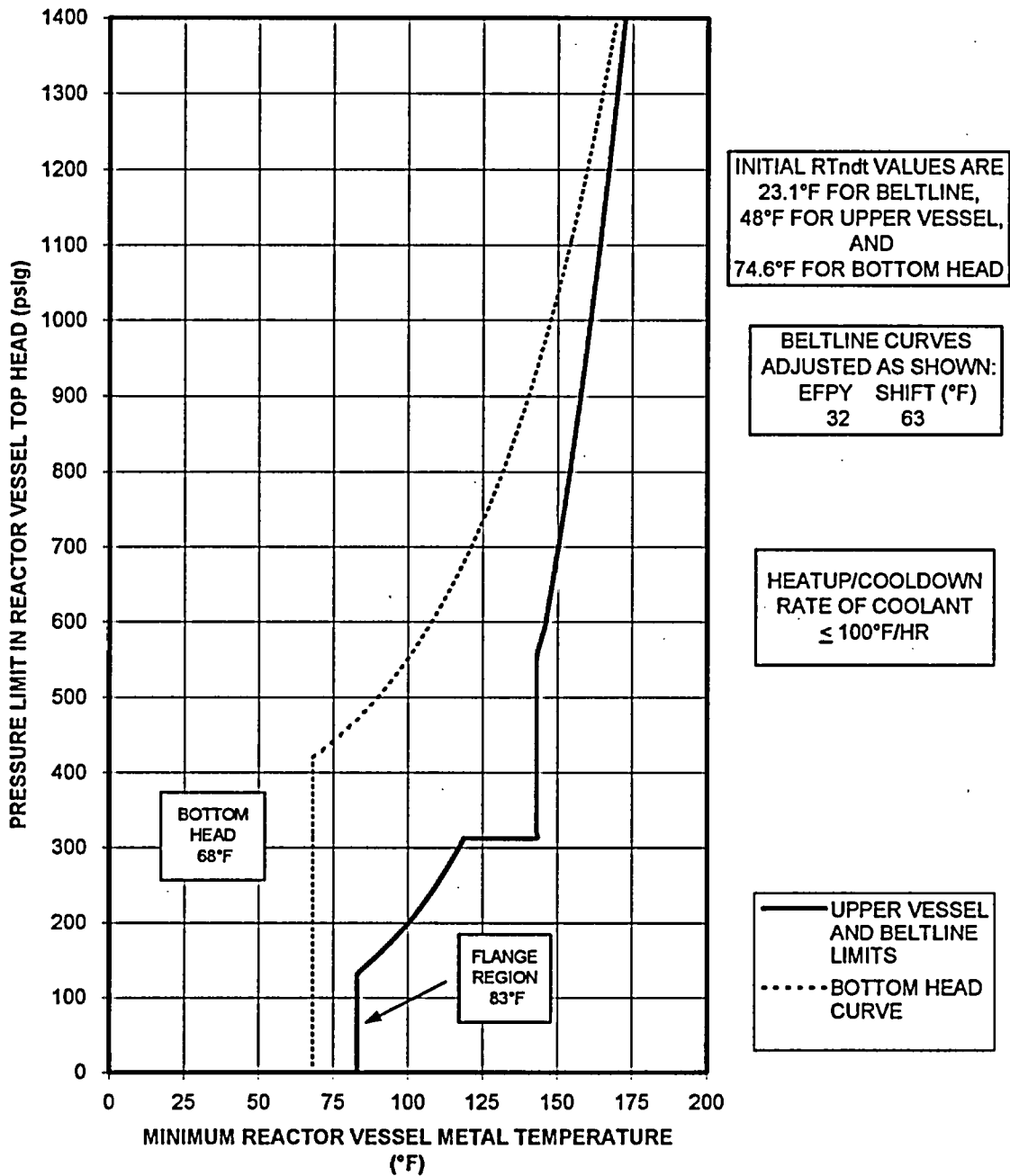


Figure 5-12: Composite Core Not Critical P-T Curves [Curve B] up to 32 EFPY  
[100°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

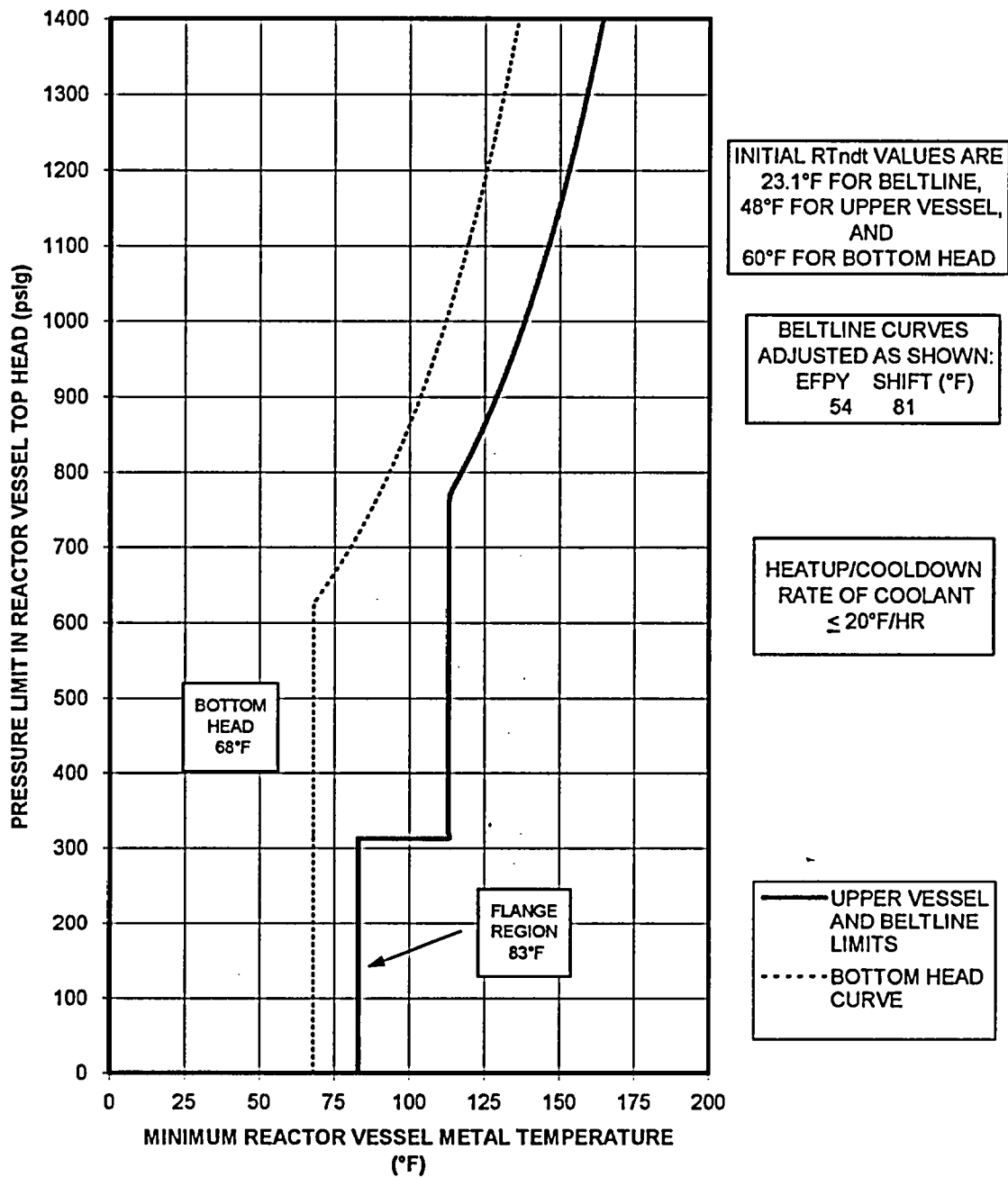


Figure 5-13: Composite Pressure Test P-T Curves [Curve A] up to 54 EFPY  
[20°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

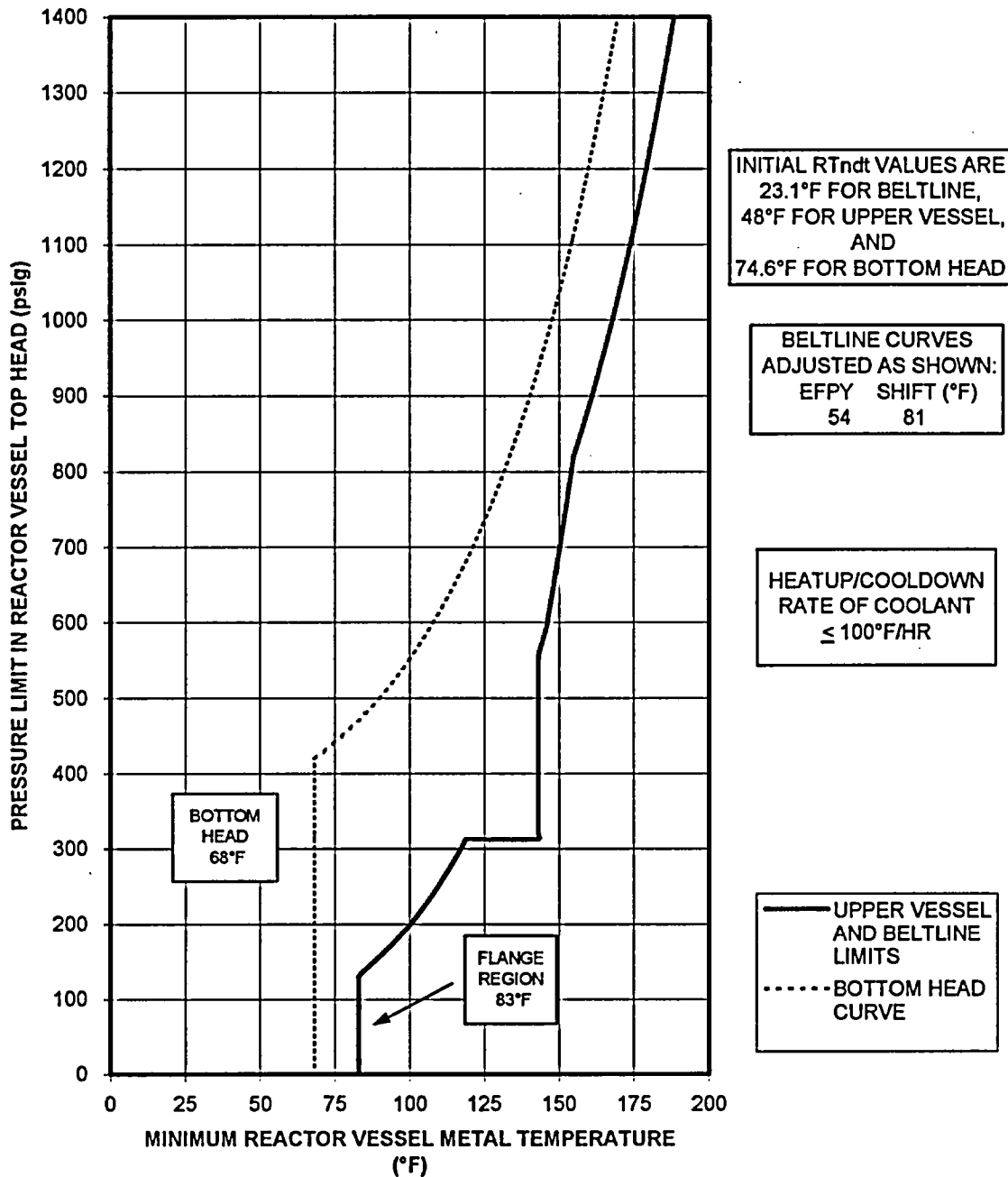


Figure 5-14: Composite Core Not Critical P-T Curves [Curve B] up to 54 EFPY  
[100°F/hr or less coolant heatup/cooldown]

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## 6.0 REFERENCES

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3. GE Drawing Number 158B7279, "Nozzle Thermal Cycles - Reactor Vessel", GE-APED, San Jose, CA, Revision 1. Dresden and Quad Cities Nozzle Thermal Cycle Diagram (GE Proprietary).
4. "Alternative Reference Fracture Toughness for Development of P-T Limit Curves Section XI, Division 1", Code Case N-640 of the ASME Boiler & Pressure Vessel Code, Approval Date February 26, 1999.
5. "Alternative to Reference Flaw Orientation of Appendix G for Circumferential Welds in Reactor Vessels Section XI, Division 1", Code Case N-588 of the ASME Boiler & Pressure Vessel Code, Approval Date December 12, 1997. (Note this reference is not used in this report because the girth welds are not limiting.)
6. "Fracture Toughness Criteria for Protection Against Failure", Appendix G to Section III or XI of the ASME Boiler & Pressure Vessel Code, 1995 Edition with Addenda through 1996.
7. "Radiation Embrittlement of Reactor Vessel Materials", USNRC Regulatory Guide 1.99, Revision 2, May 1988.
8. "Fracture Toughness Requirements", Appendix G to Part 50 of Title 10 of the Code of Federal Regulations, December 1995.
9. Hodge, J. M., "Properties of Heavy Section Nuclear Reactor Steels", Welding Research Council Bulletin 217, July 1976.

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10. GE Nuclear Energy, NEDC-32399-P, "Basis for GE RT<sub>NDT</sub> Estimation Method", Report for BWR Owners' Group, San Jose, California, September 1994 (GE Proprietary).
  11. Letter from B. Sheron to R.A. Pinelli, "Safety Assessment of Report NEDC-32399-P, Basis for GE RT<sub>NDT</sub> Estimation Method, September 1994", USNRC, December 16, 1994.
  12. QA Records & RPV CMTR's:  
  
Quad Cities 1 – (QA Records & RPV CMTR's Quad Cities Unit 1 GE PO# 205-55599, Manufactured by B&W), General Electric Company Atomic Power Equipment Department (APED) Quality Control – Procured Equipment, RPV QC", Barberton, Ohio, Mt. Vernon, Indiana, and Madison, Indiana.
  13. a). Letter, J.F. Longnecker (Lukens Steel) to T.A. Caine (GE), "Copper Content of Reactor Vessel Plates", dated August 27, 1985.  
  
b). Howell Letter to NRC dated May 28, 1998, transmitting B&WOG Report, "Response to Request for Additional Information Regarding Reactor Pressure Vessel Integrity", BAW-2325, May 1998.  
  
c). Letter from R.M. Krich to the NRC, "Response to Request for Additional Information Regarding Reactor Pressure Vessel Integrity – Dresden Nuclear Power Station, Units 2 and 3 Facility Operating License Nos. DPR-19 and DPR-25 NRC Docket Nos. 50-237 and 50-249 – LaSalle County Nuclear Power Station, Units 1 and 2 Facility Operating License Nos. NPF-11 and NPF-18 NRC Docket Nos. 50-373 and 50-374 – Quad Cities Nuclear Power Station, Units 1 and 2 Facility Operating License Nos. DPR-29 and DPR-30 NRC Docket Nos. 50-254 and 50-265", Commonwealth Edison Company, Downers Grove, IL, July 30, 1998.  
  
d). "Evaluation of RT<sub>NDT</sub>, USE and Chemical Composition of Core Region Electroslag Welds for Quad Cities Units 1 and 2", BAW-2259, January 1996.  
  
e). "Correlations for Predicting the Effects of Nuclear Reactors on Linde 80 Submerged Arc Welds", BAW-1803, Revision 1, May 1991.
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14. a) S. Sitaraman, "Dresden and Quad Cities Neutron Flux Evaluation", GE-NE, San Jose, CA, March 2003, (GE-NE-0000-0011-0531-R2, Revision 2)(GE Proprietary Information).
- b). Letter, S.A. Richard, USNRC to J.F. Klapproth, GE-NE, "Safety Evaluation for NEDC-32983P, General Electric Methodology for Reactor Pressure Vessel Fast Neutron Flux Evaluation (TAC No. MA9891)", MFN 01-050, September 14, 2001.
15. "PVRC Recommendations on Toughness Requirements for Ferritic Materials", Welding Research Council Bulletin 175, August 1972.
16. [[  
  
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19. Bottom Head and Feedwater Nozzle Dimensions: "Certified Design Document for Quad Cities I & II, B&W Contract No. 610-0122-51/52, GE Order No. 205-55599, Vol. 1 of 6", Nuclear Power Generation Division, Babcock & Wilcox Co., Mt. Vernon, Indiana, November 1970 (GE VPF 1744-211-1).
20. [[  
  
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21. "Materials - Properties", Part D to Section II of the ASME Boiler & Pressure Vessel Code, 1995 Edition with Addenda through 1996.

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22. Letter, M. Banerjee, USNRC to J.L. Skolds, Exelon Generation Company, LLC, "Dresden Nuclear Power Station, Units 2 and 3 – Issuance of Amendments Regarding Pressure and Temperature Limits (TAC Nos. MB7850 and MB7851)", November 26, 2003 (GE Proprietary).

## **APPENDIX A**

### **DESCRIPTION OF DISCONTINUITIES**



Non-Proprietary Version

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## Non-Proprietary Version

**Table A-2 - Geometric Discontinuities Not Requiring Fracture Toughness Evaluations**

Per ASME Code Appendix G, Section G2223 (c), fracture toughness analysis to demonstrate protection against non-ductile failure is not required for portions of nozzles and appurtenances having a thickness of 2.5" or less provided the lowest service temperature is not lower than  $RT_{NDT}$  plus 60°F. Also Inconel discontinuities require no fracture toughness evaluations. The RPV penetrations of the nozzles listed in Table A-1 and bound the RPV penetration for the nozzles listed below, therefore, no further fracture toughness evaluation is performed for these nozzles. Nozzles and appurtenances < 2.5" or made from Inconel are not included in Table A-1 and are listed below. The Top Head Lifting Lugs are also not included in Table A-1 because the loads only occur on these components when the reactor is shutdown during an outage. Components not requiring a fracture toughness evaluation are listed below:

Nozzle or Appurtenance Identification	Nozzle or Appurtenance	Material	Reference	$RT_{NDT}$ (°F)**	LST (°F)**
MK 12	2" Instrumentation $\leq 2.5"$ Penetration in RPV Shell	Alloy 600	1, 2 & 7	N/A	N/A
MK 22	Drain- Penetration $\leq 2.5"$ – Bottom Head	SA105-GR 2	2 & 7	40	100
MK 51 - 54	Shroud Support Attachment to RPV Wall Attachment to Bottom Head	Alloy 600	1, 2 & 7	N/A	N/A
MK 77 & 81-84	Insulation Brackets – Shells and Bottom Head Attachment to RPV Shells Attachment to Dollar Plate and RPV Shells	Carbon Steel	1,2 & 7	N/A	N/A
MK 101-127	Control Rod Drive Stub Tubes – Bottom Head Penetration in Dollar Plate	Alloy 600	2 & 7	N/A	N/A
Mk 139	High and Low Pressure Seal Leak Detection- Penetration $\approx 1"$ - Flange Not a pressure boundary component; therefore, no fracture toughness evaluation required.	SA105-GR 2	7		
MK 210	Top Head Lifting Lugs (only loads at outage) Attachment to Torus Not a pressure boundary component; therefore, no fracture toughness evaluation required.		1, 2 & 7		

\* The high/low pressure leak detector, and the seal leak detector are the same nozzle; these nozzles are the closure flange leak detection nozzles.

\*\* N/A – Not applicable for this material type.

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**APPENDIX A REFERENCES:**

1. RPV Outline or As-Built
  - Babcock & Wilcox Co. Drawing # 26906F, Revision 7, "General Outline", Babcock & Wilcox Co, Mt. Vernon, Indiana, (GE-NE VPF# 1744-145-8) - Quad Cities Unit 1
  - Babcock & Wilcox Co. Drawing # 26907F, Revision 4, "General Outline", Babcock & Wilcox Co, Mt. Vernon, Indiana, (GE-NE VPF# 1744-128-6) - Quad Cities Unit 1
2. Certified Stress Report
  - "Certified Design Document for Quad Cities I & II, vol. 1 of 6" B&W contract No. 610-0122-51/52, GE Order No. 205-55599", Babcock & Wilcox Co, Mt. Vernon, Indiana, November, 1970, (GE-NE VPF# 1744-211-1) - Quad Cities Unit 1&2
3. Babcock & Wilcox Co. Drawing # 149900E, Revision 5, "Support Skirt Assy & Details", Babcock & Wilcox Co, Mt. Vernon, Indiana, (GE-NE VPF# 1744-22-7) - Quad Cities Unit 1
4. GE Drawing # 104R921, Revision 7, "Reactor Assembly, Nuclear Boiler", GE-NED, San Jose, CA.) - Quad Cities Unit 1 & 2
5. Dresden/Quad Cities LR PT Curves – Design Input Request (DIR), Robert Stachniak (Exelon), 4/26/02.
6. Babcock & Wilcox Co. Drawing &151838E, Revision 3, "Shroud Support" 1744-139-4, Babcock & Wilcox Co, Mt. Vernon, Indiana, (GE-NE VPF# 1744-139-4) - Quad Cities Unit 1.
7. QA Records & RPV CMTR's
  - Quad Cities 1 - (QA Records & RPV CMTR's Quad Cities Unit 1 GE PO# 205-55599, Mfg by B&W)"General Electric Company Atomic Power Equipment Department (APED) Quality Control - Procured Equipment, RPV QC" Project: Quad Cities I, Purchase Order: 205-55599, Vendor: Babcock & Wilcox, Location: Barberton, Ohio, Mt. Vernon, Indiana, and Madison, Indiana.

## **APPENDIX B**

### **PRESSURE TEMPERATURE CURVE DATA TABULATION**

## Non-Proprietary Version

TABLE B-1. Quad Cities Unit 1 P-T Curve Values for 32 EFY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
For Figures 5-1, 5-2, 5-3, 5-5, 5-6 and 5-7

PRESSURE	BOTTOM HEAD CURVE A	UPPER VESSEL CURVE A	32 EFY BELTLINE CURVE A	BOTTOM HEAD CURVE B	UPPER VESSEL CURVE B	32 EFY BELTLINE CURVE B
(PSIG)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)
0	68.0	83.1	83.1	68.0	83.1	83.1
10	68.0	83.1	83.1	68.0	83.1	83.1
20	68.0	83.1	83.1	68.0	83.1	83.1
30	68.0	83.1	83.1	68.0	83.1	83.1
40	68.0	83.1	83.1	68.0	83.1	83.1
50	68.0	83.1	83.1	68.0	83.1	83.1
60	68.0	83.1	83.1	68.0	83.1	83.1
70	68.0	83.1	83.1	68.0	83.1	83.1
80	68.0	83.1	83.1	68.0	83.1	83.1
90	68.0	83.1	83.1	68.0	83.1	83.1
100	68.0	83.1	83.1	68.0	83.1	83.1
110	68.0	83.1	83.1	68.0	83.1	83.1
120	68.0	83.1	83.1	68.0	83.1	83.1
130	68.0	83.1	83.1	68.0	83.1	83.1
140	68.0	83.1	83.1	68.0	85.4	83.1
150	68.0	83.1	83.1	68.0	88.2	83.1
160	68.0	83.1	83.1	68.0	90.9	83.1
170	68.0	83.1	83.1	68.0	93.5	83.1
180	68.0	83.1	83.1	68.0	95.9	83.1
190	68.0	83.1	83.1	68.0	98.2	83.1
200	68.0	83.1	83.1	68.0	100.3	83.1
210	68.0	83.1	83.1	68.0	102.3	83.1
220	68.0	83.1	83.1	68.0	104.3	83.1
230	68.0	83.1	83.1	68.0	106.1	83.1

## Non-Proprietary Version

TABLE B-1. Quad Cities Unit 1 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
For Figures 5-1, 5-2, 5-3, 5-5, 5-6 and 5-7

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	32 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	32 EFPY BELTLINE CURVE B (°F)
240	68.0	83.1	83.1	68.0	107.9	83.1
250	68.0	83.1	83.1	68.0	109.6	83.1
260	68.0	83.1	83.1	68.0	111.2	83.1
270	68.0	83.1	83.1	68.0	112.8	83.1
280	68.0	83.1	83.1	68.0	114.3	83.1
290	68.0	83.1	83.1	68.0	115.8	83.1
300	68.0	83.1	83.1	68.0	117.2	83.1
310	68.0	83.1	83.1	68.0	118.5	83.1
312.5	68.0	83.1	83.1	68.0	118.9	83.1
312.5	68.0	113.1	113.1	68.0	143.1	143.1
320	68.0	113.1	113.1	68.0	143.1	143.1
330	68.0	113.1	113.1	68.0	143.1	143.1
340	68.0	113.1	113.1	68.0	143.1	143.1
350	68.0	113.1	113.1	68.0	143.1	143.1
360	68.0	113.1	113.1	68.0	143.1	143.1
370	68.0	113.1	113.1	68.0	143.1	143.1
380	68.0	113.1	113.1	68.0	143.1	143.1
390	68.0	113.1	113.1	68.0	143.1	143.1
400	68.0	113.1	113.1	68.0	143.1	143.1
410	68.0	113.1	113.1	68.0	143.1	143.1
420	68.0	113.1	113.1	68.1	143.1	143.1
430	68.0	113.1	113.1	71.4	143.1	143.1
440	68.0	113.1	113.1	74.4	143.1	143.1
450	68.0	113.1	113.1	77.3	143.1	143.1
460	68.0	113.1	113.1	80.0	143.1	143.1
470	68.0	113.1	113.1	82.6	143.1	143.1

## Non-Proprietary Version

TABLE B-1. Quad Cities Unit 1 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
For Figures 5-1, 5-2, 5-3, 5-5, 5-6 and 5-7

PRESSURE	BOTTOM HEAD CURVE A	UPPER VESSEL CURVE A	32 EFPY BELTLINE CURVE A	BOTTOM HEAD CURVE B	UPPER VESSEL CURVE B	32 EFPY BELTLINE CURVE B
(PSIG)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)
480	68.0	113.1	113.1	85.1	143.1	143.1
490	68.0	113.1	113.1	87.4	143.1	143.1
500	68.0	113.1	113.1	89.6	143.1	143.1
510	68.0	113.1	113.1	91.8	143.1	143.1
520	68.0	113.1	113.1	93.8	143.1	143.1
530	68.0	113.1	113.1	95.8	143.1	143.1
540	68.0	113.1	113.1	97.7	143.1	143.1
550	68.0	113.1	113.1	99.5	143.1	143.1
560	68.0	113.1	113.1	101.3	143.4	143.1
570	68.0	113.1	113.1	103.0	144.1	143.1
580	68.0	113.1	113.1	104.6	144.9	143.1
590	68.0	113.1	113.1	106.2	145.6	143.1
600	68.0	113.1	113.1	107.8	146.1	143.1
610	68.0	113.1	113.1	109.3	146.6	143.1
620	68.0	113.1	113.1	110.7	147.0	143.1
630	68.6	113.1	113.1	112.1	147.4	143.1
640	70.5	113.1	113.1	113.5	147.8	143.1
650	72.2	113.1	113.1	114.8	148.2	143.1
660	73.9	113.1	113.1	116.1	148.7	143.1
670	75.6	113.1	113.1	117.4	149.1	143.1
680	77.2	113.1	113.1	118.7	149.5	143.1
690	78.7	113.1	113.1	119.9	149.9	143.1
700	80.2	113.1	113.1	121.0	150.3	143.1
710	81.7	113.1	113.1	122.2	150.7	143.1
720	83.1	113.1	113.1	123.3	151.1	143.1
730	84.5	113.1	113.1	124.4	151.5	143.1

## Non-Proprietary Version

TABLE B-1. Quad Cities Unit 1 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
For Figures 5-1, 5-2, 5-3, 5-5, 5-6 and 5-7

PRESSURE	BOTTOM HEAD CURVE A	UPPER VESSEL CURVE A	32 EFPY BELTLINE CURVE A	BOTTOM HEAD CURVE B	UPPER VESSEL CURVE B	32 EFPY BELTLINE CURVE B
(PSIG)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)
740	85.8	113.1	113.1	125.5	151.9	143.1
750	87.1	113.1	113.1	126.6	152.2	143.1
760	88.4	113.1	113.1	127.6	152.6	143.1
770	89.6	113.6	113.1	128.6	153.0	143.1
780	90.8	114.3	113.1	129.6	153.4	143.1
790	92.0	115.1	113.1	130.6	153.8	143.1
800	93.2	115.9	113.1	131.5	154.1	143.1
810	94.3	116.6	113.1	132.5	154.5	143.1
820	95.4	117.4	113.1	133.4	154.9	143.1
830	96.5	118.1	113.1	134.3	155.2	143.1
840	97.5	118.8	113.1	135.2	155.6	143.1
850	98.6	119.5	113.1	136.0	155.9	143.1
860	99.6	120.2	113.1	136.9	156.3	143.1
870	100.6	120.9	113.1	137.7	156.6	143.1
880	101.5	121.6	113.1	138.6	157.0	143.1
890	102.5	122.3	113.1	139.4	157.3	143.1
900	103.4	122.9	113.1	140.2	157.7	143.1
910	104.4	123.6	113.1	141.0	158.0	143.8
920	105.3	124.2	113.1	141.7	158.4	144.5
930	106.1	124.9	113.9	142.5	158.7	145.2
940	107.0	125.5	114.9	143.3	159.0	145.9
950	107.9	126.1	115.8	144.0	159.4	146.6
960	108.7	126.7	116.8	144.7	159.7	147.2
970	109.6	127.3	117.7	145.5	160.0	147.9
980	110.4	127.9	118.6	146.2	160.4	148.5
990	111.2	128.5	119.4	146.9	160.7	149.2



## Non-Proprietary Version

TABLE B-1. Quad Cities Unit 1 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
For Figures 5-1, 5-2, 5-3, 5-5, 5-6 and 5-7

PRESSURE	BOTTOM HEAD CURVE A	UPPER VESSEL CURVE A	32 EFPY BELTLINE CURVE A	BOTTOM HEAD CURVE B	UPPER VESSEL CURVE B	32 EFPY BELTLINE CURVE B
(PSIG)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)
1000	112.0	129.1	120.3	147.6	161.0	149.8
1010	112.7	129.7	121.1	148.2	161.3	150.5
1020	113.5	130.2	122.0	148.9	161.6	151.1
1030	114.3	130.8	122.8	149.6	162.0	151.7
1040	115.0	131.4	123.6	150.2	162.3	152.3
1050	115.7	131.9	124.4	150.9	162.6	152.9
1060	116.4	132.5	125.2	151.5	162.9	153.5
1070	117.2	133.0	126.0	152.1	163.2	154.1
1080	117.9	133.5	126.7	152.8	163.5	154.7
1090	118.6	134.1	127.5	153.4	163.8	155.2
1100	119.2	134.6	128.2	154.0	164.1	155.8
1105	119.6	134.8	128.6	154.3	164.3	156.1
1110	119.9	135.1	128.9	154.6	164.4	156.3
1120	120.6	135.6	129.6	155.2	164.7	156.9
1130	121.2	136.1	130.4	155.8	165.0	157.4
1140	121.9	136.6	131.1	156.3	165.3	158.0
1150	122.5	137.1	131.7	156.9	165.6	158.5
1160	123.1	137.6	132.4	157.5	165.9	159.0
1170	123.8	138.1	133.1	158.0	166.2	159.6
1180	124.4	138.6	133.7	158.6	166.5	160.1
1190	125.0	139.1	134.4	159.1	166.7	160.6
1200	125.6	139.5	135.0	159.7	167.0	161.1
1210	126.2	140.0	135.7	160.2	167.3	161.6
1220	126.8	140.5	136.3	160.8	167.6	162.1
1230	127.3	140.9	136.9	161.3	167.9	162.6
1240	127.9	141.4	137.5	161.8	168.2	163.1

## Non-Proprietary Version

TABLE B-1. Quad Cities Unit 1 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
For Figures 5-1, 5-2, 5-3, 5-5, 5-6 and 5-7

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	32 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	32 EFPY BELTLINE CURVE B (°F)
1250	128.5	141.8	138.1	162.3	168.4	163.6
1260	129.0	142.3	138.7	162.8	168.7	164.1
1270	129.6	142.7	139.3	163.3	169.0	164.5
1280	130.1	143.2	139.9	163.8	169.2	165.0
1290	130.7	143.6	140.5	164.3	169.5	165.5
1300	131.2	144.0	141.0	164.8	169.8	165.9
1310	131.7	144.5	141.6	165.3	170.1	166.4
1320	132.3	144.9	142.2	165.8	170.3	166.8
1330	132.8	145.3	142.7	166.2	170.6	167.3
1340	133.3	145.7	143.3	166.7	170.8	167.7
1350	133.8	146.1	143.8	167.2	171.1	168.2
1360	134.3	146.6	144.3	167.6	171.4	168.6
1370	134.8	147.0	144.9	168.1	171.6	169.0
1380	135.3	147.4	145.4	168.5	171.9	169.5
1390	135.8	147.8	145.9	169.0	172.1	169.9
1400	136.3	148.2	146.4	169.4	172.4	170.3

## Non-Proprietary Version

TABLE B-2. Quad Cities Unit 1 Composite P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
For Figures 5-9, 5-11 and 5-12

PRESSURE (PSIG)	BOTTOM HEAD CURVE A	UPPER RPV & BELTLINE AT 32 EFPY CURVE A	BOTTOM HEAD CURVE B	UPPER RPV & BELTLINE AT 32 EFPY CURVE B	UPPER RPV & BELTLINE AT 32 EFPY CURVE C
	(°F)	(°F)	(°F)	(°F)	(°F)
0	68.0	83.1	68.0	83.1	83.1
10	68.0	83.1	68.0	83.1	83.1
20	68.0	83.1	68.0	83.1	83.1
30	68.0	83.1	68.0	83.1	83.1
40	68.0	83.1	68.0	83.1	83.1
50	68.0	83.1	68.0	83.1	83.1
60	68.0	83.1	68.0	83.1	88.0
70	68.0	83.1	68.0	83.1	95.2
80	68.0	83.1	68.0	83.1	101.2
90	68.0	83.1	68.0	83.1	106.3
100	68.0	83.1	68.0	83.1	110.8
110	68.0	83.1	68.0	83.1	114.9
120	68.0	83.1	68.0	83.1	118.7
130	68.0	83.1	68.0	83.1	122.2
140	68.0	83.1	68.0	85.4	125.4
150	68.0	83.1	68.0	88.2	128.2
160	68.0	83.1	68.0	90.9	130.9
170	68.0	83.1	68.0	93.5	133.5
180	68.0	83.1	68.0	95.9	135.9
190	68.0	83.1	68.0	98.2	138.2
200	68.0	83.1	68.0	100.3	140.3
210	68.0	83.1	68.0	102.3	142.3
220	68.0	83.1	68.0	104.3	144.3

## Non-Proprietary Version

TABLE B-2. Quad Cities Unit 1 Composite P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
For Figures 5-9, 5-11 and 5-12

PRESSURE	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	UPPER RPV & BELTLINE AT 32 EFPY
(PSIG)	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
230	68.0	83.1	68.0	106.1	146.1
240	68.0	83.1	68.0	107.9	147.9
250	68.0	83.1	68.0	109.6	149.6
260	68.0	83.1	68.0	111.2	151.2
270	68.0	83.1	68.0	112.8	152.8
280	68.0	83.1	68.0	114.3	154.3
290	68.0	83.1	68.0	115.8	155.8
300	68.0	83.1	68.0	117.2	157.2
310	68.0	83.1	68.0	118.5	158.5
312.5	68.0	83.1	68.0	118.9	158.9
312.5	68.0	113.1	68.0	143.1	183.1
320	68.0	113.1	68.0	143.1	183.1
330	68.0	113.1	68.0	143.1	183.1
340	68.0	113.1	68.0	143.1	183.1
350	68.0	113.1	68.0	143.1	183.1
360	68.0	113.1	68.0	143.1	183.1
370	68.0	113.1	68.0	143.1	183.1
380	68.0	113.1	68.0	143.1	183.1
390	68.0	113.1	68.0	143.1	183.1
400	68.0	113.1	68.0	143.1	183.1
410	68.0	113.1	68.0	143.1	183.1
420	68.0	113.1	68.1	143.1	183.1
430	68.0	113.1	71.4	143.1	183.1
440	68.0	113.1	74.4	143.1	183.1
450	68.0	113.1	77.3	143.1	183.1

## Non-Proprietary Version

TABLE B-2. Quad Cities Unit 1 Composite P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
For Figures 5-9, 5-11 and 5-12

PRESSURE (PSIG)	BOTTOM HEAD CURVE A	UPPER RPV & BELTLINE AT 32 EFPY CURVE A	BOTTOM HEAD CURVE B	UPPER RPV & BELTLINE AT 32 EFPY CURVE B	UPPER RPV & BELTLINE AT 32 EFPY CURVE C
	(°F)	(°F)	(°F)	(°F)	(°F)
460	68.0	113.1	80.0	143.1	183.1
470	68.0	113.1	82.6	143.1	183.1
480	68.0	113.1	85.1	143.1	183.1
490	68.0	113.1	87.4	143.1	183.1
500	68.0	113.1	89.6	143.1	183.1
510	68.0	113.1	91.8	143.1	183.1
520	68.0	113.1	93.8	143.1	183.1
530	68.0	113.1	95.8	143.1	183.1
540	68.0	113.1	97.7	143.1	183.1
550	68.0	113.1	99.5	143.1	183.1
560	68.0	113.1	101.3	143.4	183.4
570	68.0	113.1	103.0	144.1	184.1
580	68.0	113.1	104.6	144.9	184.9
590	68.0	113.1	106.2	145.6	185.6
600	68.0	113.1	107.8	146.1	186.1
610	68.0	113.1	109.3	146.6	186.6
620	68.0	113.1	110.7	147.0	187.0
630	68.6	113.1	112.1	147.4	187.4
640	70.5	113.1	113.5	147.8	187.8
650	72.2	113.1	114.8	148.2	188.2
660	73.9	113.1	116.1	148.7	188.7
670	75.6	113.1	117.4	149.1	189.1
680	77.2	113.1	118.7	149.5	189.5
690	78.7	113.1	119.9	149.9	189.9
700	80.2	113.1	121.0	150.3	190.3

## Non-Proprietary Version

TABLE B-2. Quad Cities Unit 1 Composite P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
For Figures 5-9, 5-11 and 5-12

PRESSURE	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	UPPER RPV & BELTLINE AT 32 EFPY
(PSIG)	CURVE A	CURVE A	CURVE B	CURVE B	CURVE C
(°F)	(°F)	(°F)	(°F)	(°F)	(°F)
710	81.7	113.1	122.2	150.7	190.7
720	83.1	113.1	123.3	151.1	191.1
730	84.5	113.1	124.4	151.5	191.5
740	85.8	113.1	125.5	151.9	191.9
750	87.1	113.1	126.6	152.2	192.2
760	88.4	113.1	127.6	152.6	192.6
770	89.6	113.6	128.6	153.0	193.0
780	90.8	114.3	129.6	153.4	193.4
790	92.0	115.1	130.6	153.8	193.8
800	93.2	115.9	131.5	154.1	194.1
810	94.3	116.6	132.5	154.5	194.5
820	95.4	117.4	133.4	154.9	194.9
830	96.5	118.1	134.3	155.2	195.2
840	97.5	118.8	135.2	155.6	195.6
850	98.6	119.5	136.0	155.9	195.9
860	99.6	120.2	136.9	156.3	196.3
870	100.6	120.9	137.7	156.6	196.6
880	101.5	121.6	138.6	157.0	197.0
890	102.5	122.3	139.4	157.3	197.3
900	103.4	122.9	140.2	157.7	197.7
910	104.4	123.6	141.0	158.0	198.0
920	105.3	124.2	141.7	158.4	198.4
930	106.1	124.9	142.5	158.7	198.7
940	107.0	125.5	143.3	159.0	199.0
950	107.9	126.1	144.0	159.4	199.4

## Non-Proprietary Version

TABLE B-2. Quad Cities Unit 1 Composite P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
For Figures 5-9, 5-11 and 5-12

PRESSURE	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	UPPER RPV & BELTLINE AT 32 EFPY
(PSIG)	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
960	108.7	126.7	144.7	159.7	199.7
970	109.6	127.3	145.5	160.0	200.0
980	110.4	127.9	146.2	160.4	200.4
990	111.2	128.5	146.9	160.7	200.7
1000	112.0	129.1	147.6	161.0	201.0
1010	112.7	129.7	148.2	161.3	201.3
1020	113.5	130.2	148.9	161.6	201.6
1030	114.3	130.8	149.6	162.0	202.0
1040	115.0	131.4	150.2	162.3	202.3
1050	115.7	131.9	150.9	162.6	202.6
1060	116.4	132.5	151.5	162.9	202.9
1070	117.2	133.0	152.1	163.2	203.2
1080	117.9	133.5	152.8	163.5	203.5
1090	118.6	134.1	153.4	163.8	203.8
1100	119.2	134.6	154.0	164.1	204.1
1105	119.6	134.8	154.3	164.3	204.3
1110	119.9	135.1	154.6	164.4	204.4
1120	120.6	135.6	155.2	164.7	204.7
1130	121.2	136.1	155.8	165.0	205.0
1140	121.9	136.6	156.3	165.3	205.3
1150	122.5	137.1	156.9	165.6	205.6
1160	123.1	137.6	157.5	165.9	205.9
1170	123.8	138.1	158.0	166.2	206.2
1180	124.4	138.6	158.6	166.5	206.5
1190	125.0	139.1	159.1	166.7	206.7

## Non-Proprietary Version

TABLE B-2. Quad Cities Unit 1 Composite P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
For Figures 5-9, 5-11 and 5-12

PRESSURE (PSIG)	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	UPPER RPV & BELTLINE AT 32 EFPY
	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
1200	125.6	139.5	159.7	167.0	207.0
1210	126.2	140.0	160.2	167.3	207.3
1220	126.8	140.5	160.8	167.6	207.6
1230	127.3	140.9	161.3	167.9	207.9
1240	127.9	141.4	161.8	168.2	208.2
1250	128.5	141.8	162.3	168.4	208.4
1260	129.0	142.3	162.8	168.7	208.7
1270	129.6	142.7	163.3	169.0	209.0
1280	130.1	143.2	163.8	169.2	209.2
1290	130.7	143.6	164.3	169.5	209.5
1300	131.2	144.0	164.8	169.8	209.8
1310	131.7	144.5	165.3	170.1	210.1
1320	132.3	144.9	165.8	170.3	210.3
1330	132.8	145.3	166.2	170.6	210.6
1340	133.3	145.7	166.7	170.8	210.8
1350	133.8	146.1	167.2	171.1	211.1
1360	134.3	146.6	167.6	171.4	211.4
1370	134.8	147.0	168.1	171.6	211.6
1380	135.3	147.4	168.5	171.9	211.9
1390	135.8	147.8	169.0	172.1	212.1
1400	136.3	148.2	169.4	172.4	212.4



## Non-Proprietary Version

TABLE B-3. Quad Cities Unit 1 P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures 5-1, 5-2, 5-4, 5-5, 5-6 and 5-8

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	54 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	54 EFPY BELTLINE CURVE B (°F)
0	68.0	83.1	83.1	68.0	83.1	83.1
10	68.0	83.1	83.1	68.0	83.1	83.1
20	68.0	83.1	83.1	68.0	83.1	83.1
30	68.0	83.1	83.1	68.0	83.1	83.1
40	68.0	83.1	83.1	68.0	83.1	83.1
50	68.0	83.1	83.1	68.0	83.1	83.1
60	68.0	83.1	83.1	68.0	83.1	83.1
70	68.0	83.1	83.1	68.0	83.1	83.1
80	68.0	83.1	83.1	68.0	83.1	83.1
90	68.0	83.1	83.1	68.0	83.1	83.1
100	68.0	83.1	83.1	68.0	83.1	83.1
110	68.0	83.1	83.1	68.0	83.1	83.1
120	68.0	83.1	83.1	68.0	83.1	83.1
130	68.0	83.1	83.1	68.0	83.1	83.1
140	68.0	83.1	83.1	68.0	85.4	83.1
150	68.0	83.1	83.1	68.0	88.2	83.1
160	68.0	83.1	83.1	68.0	90.9	83.1
170	68.0	83.1	83.1	68.0	93.5	83.1
180	68.0	83.1	83.1	68.0	95.9	83.1
190	68.0	83.1	83.1	68.0	98.2	83.1
200	68.0	83.1	83.1	68.0	100.3	83.1
210	68.0	83.1	83.1	68.0	102.3	83.1
220	68.0	83.1	83.1	68.0	104.3	83.1
230	68.0	83.1	83.1	68.0	106.1	83.1

## Non-Proprietary Version

TABLE B-3. Quad Cities Unit 1 P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures 5-1, 5-2, 5-4, 5-5, 5-6 and 5-8

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	54 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	54 EFPY BELTLINE CURVE B (°F)
240	68.0	83.1	83.1	68.0	107.9	83.1
250	68.0	83.1	83.1	68.0	109.6	83.1
260	68.0	83.1	83.1	68.0	111.2	83.1
270	68.0	83.1	83.1	68.0	112.8	83.1
280	68.0	83.1	83.1	68.0	114.3	83.1
290	68.0	83.1	83.1	68.0	115.8	83.1
300	68.0	83.1	83.1	68.0	117.2	83.1
310	68.0	83.1	83.1	68.0	118.5	83.1
312.5	68.0	83.1	83.1	68.0	118.9	83.1
312.5	68.0	113.1	113.1	68.0	143.1	143.1
320	68.0	113.1	113.1	68.0	143.1	143.1
330	68.0	113.1	113.1	68.0	143.1	143.1
340	68.0	113.1	113.1	68.0	143.1	143.1
350	68.0	113.1	113.1	68.0	143.1	143.1
360	68.0	113.1	113.1	68.0	143.1	143.1
370	68.0	113.1	113.1	68.0	143.1	143.1
380	68.0	113.1	113.1	68.0	143.1	143.1
390	68.0	113.1	113.1	68.0	143.1	143.1
400	68.0	113.1	113.1	68.0	143.1	143.1
410	68.0	113.1	113.1	68.0	143.1	143.1
420	68.0	113.1	113.1	68.1	143.1	143.1
430	68.0	113.1	113.1	71.4	143.1	143.1
440	68.0	113.1	113.1	74.4	143.1	143.1
450	68.0	113.1	113.1	77.3	143.1	143.1
460	68.0	113.1	113.1	80.0	143.1	143.1
470	68.0	113.1	113.1	82.6	143.1	143.1
480	68.0	113.1	113.1	85.1	143.1	143.1

## Non-Proprietary Version

TABLE B-3. Quad Cities Unit 1 P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures 5-1, 5-2, 5-4, 5-5, 5-6 and 5-8

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	54 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	54 EFPY BELTLINE CURVE B (°F)
490	68.0	113.1	113.1	87.4	143.1	143.1
500	68.0	113.1	113.1	89.6	143.1	143.1
510	68.0	113.1	113.1	91.8	143.1	143.1
520	68.0	113.1	113.1	93.8	143.1	143.1
530	68.0	113.1	113.1	95.8	143.1	143.1
540	68.0	113.1	113.1	97.7	143.1	143.1
550	68.0	113.1	113.1	99.5	143.1	143.1
560	68.0	113.1	113.1	101.3	143.4	143.1
570	68.0	113.1	113.1	103.0	144.1	143.1
580	68.0	113.1	113.1	104.6	144.9	143.1
590	68.0	113.1	113.1	106.2	145.6	143.1
600	68.0	113.1	113.1	107.8	146.1	143.1
610	68.0	113.1	113.1	109.3	146.6	143.1
620	68.0	113.1	113.1	110.7	147.0	143.1
630	68.6	113.1	113.1	112.1	147.4	143.1
640	70.5	113.1	113.1	113.5	147.8	143.1
650	72.2	113.1	113.1	114.8	148.2	143.1
660	73.9	113.1	113.1	116.1	148.7	143.1
670	75.6	113.1	113.1	117.4	149.1	143.1
680	77.2	113.1	113.1	118.7	149.5	143.1
690	78.7	113.1	113.1	119.9	149.9	143.1
700	80.2	113.1	113.1	121.0	150.3	144.0
710	81.7	113.1	113.1	122.2	150.7	145.0
720	83.1	113.1	113.1	123.3	151.1	146.0
730	84.5	113.1	113.1	124.4	151.5	146.9
740	85.8	113.1	113.1	125.5	151.9	147.9
750	87.1	113.1	113.1	126.6	152.2	148.8

## Non-Proprietary Version

TABLE B-3. Quad Cities Unit 1 P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures 5-1, 5-2, 5-4, 5-5, 5-6 and 5-8

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	54 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	54 EFPY BELTLINE CURVE B (°F)
760	88.4	113.1	113.1	127.6	152.6	149.7
770	89.6	113.6	113.2	128.6	153.0	150.6
780	90.8	114.3	114.6	129.6	153.4	151.5
790	92.0	115.1	116.0	130.6	153.8	152.4
800	93.2	115.9	117.3	131.5	154.1	153.2
810	94.3	116.6	118.6	132.5	154.5	154.1
820	95.4	117.4	119.9	133.4	154.9	154.9
830	96.5	118.1	121.1	134.3	155.2	155.7
840	97.5	118.8	122.3	135.2	155.6	156.5
850	98.6	119.5	123.4	136.0	155.9	157.3
860	99.6	120.2	124.6	136.9	156.3	158.1
870	100.6	120.9	125.7	137.7	156.6	158.8
880	101.5	121.6	126.8	138.6	157.0	159.6
890	102.5	122.3	127.9	139.4	157.3	160.3
900	103.4	122.9	128.9	140.2	157.7	161.1
910	104.4	123.6	129.9	141.0	158.0	161.8
920	105.3	124.2	130.9	141.7	158.4	162.5
930	106.1	124.9	131.9	142.5	158.7	163.2
940	107.0	125.5	132.9	143.3	159.0	163.9
950	107.9	126.1	133.8	144.0	159.4	164.6
960	108.7	126.7	134.8	144.7	159.7	165.2
970	109.6	127.3	135.7	145.5	160.0	165.9
980	110.4	127.9	136.6	146.2	160.4	166.5
990	111.2	128.5	137.4	146.9	160.7	167.2
1000	112.0	129.1	138.3	147.6	161.0	167.8
1010	112.7	129.7	139.1	148.2	161.3	168.5
1020	113.5	130.2	140.0	148.9	161.6	169.1

## Non-Proprietary Version

TABLE B-3. Quad Cities Unit 1 P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures 5-1, 5-2, 5-4, 5-5, 5-6 and 5-8

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	54 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	54 EFPY BELTLINE CURVE B (°F)
1030	114.3	130.8	140.8	149.6	162.0	169.7
1040	115.0	131.4	141.6	150.2	162.3	170.3
1050	115.7	131.9	142.4	150.9	162.6	170.9
1060	116.4	132.5	143.2	151.5	162.9	171.5
1070	117.2	133.0	144.0	152.1	163.2	172.1
1080	117.9	133.5	144.7	152.8	163.5	172.7
1090	118.6	134.1	145.5	153.4	163.8	173.2
1100	119.2	134.6	146.2	154.0	164.1	173.8
1105	119.6	134.8	146.6	154.3	164.3	174.1
1110	119.9	135.1	146.9	154.6	164.4	174.3
1120	120.6	135.6	147.6	155.2	164.7	174.9
1130	121.2	136.1	148.4	155.8	165.0	175.4
1140	121.9	136.6	149.1	156.3	165.3	176.0
1150	122.5	137.1	149.7	156.9	165.6	176.5
1160	123.1	137.6	150.4	157.5	165.9	177.0
1170	123.8	138.1	151.1	158.0	166.2	177.6
1180	124.4	138.6	151.7	158.6	166.5	178.1
1190	125.0	139.1	152.4	159.1	166.7	178.6
1200	125.6	139.5	153.0	159.7	167.0	179.1
1210	126.2	140.0	153.7	160.2	167.3	179.6
1220	126.8	140.5	154.3	160.8	167.6	180.1
1230	127.3	140.9	154.9	161.3	167.9	180.6
1240	127.9	141.4	155.5	161.8	168.2	181.1
1250	128.5	141.8	156.1	162.3	168.4	181.6
1260	129.0	142.3	156.7	162.8	168.7	182.1
1270	129.6	142.7	157.3	163.3	169.0	182.5
1280	130.1	143.2	157.9	163.8	169.2	183.0

## Non-Proprietary Version

TABLE B-3. Quad Cities Unit 1 P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures 5-1, 5-2, 5-4, 5-5, 5-6 and 5-8

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	54 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	54 EFPY BELTLINE CURVE B (°F)
1290	130.7	143.6	158.5	164.3	169.5	183.5
1300	131.2	144.0	159.0	164.8	169.8	183.9
1310	131.7	144.5	159.6	165.3	170.1	184.4
1320	132.3	144.9	160.2	165.8	170.3	184.8
1330	132.8	145.3	160.7	166.2	170.6	185.3
1340	133.3	145.7	161.3	166.7	170.8	185.7
1350	133.8	146.1	161.8	167.2	171.1	186.2
1360	134.3	146.6	162.3	167.6	171.4	186.6
1370	134.8	147.0	162.9	168.1	171.6	187.0
1380	135.3	147.4	163.4	168.5	171.9	187.5
1390	135.8	147.8	163.9	169.0	172.1	187.9
1400	136.3	148.2	164.4	169.4	172.4	188.3

## Non-Proprietary Version

TABLE B-4. Quad Cities Unit 1 Composite P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures 5-10, 5-13 and 5-14

	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	UPPER RPV & BELTLINE AT 54 EFPY
PRESSURE	CURVE A	CURVE A	CURVE B	CURVE B	CURVE C
(PSIG)	(°F)	(°F)	(°F)	(°F)	(°F)
0	68.0	83.1	68.0	83.1	83.1
10	68.0	83.1	68.0	83.1	83.1
20	68.0	83.1	68.0	83.1	83.1
30	68.0	83.1	68.0	83.1	83.1
40	68.0	83.1	68.0	83.1	83.1
50	68.0	83.1	68.0	83.1	83.1
60	68.0	83.1	68.0	83.1	88.0
70	68.0	83.1	68.0	83.1	95.2
80	68.0	83.1	68.0	83.1	101.2
90	68.0	83.1	68.0	83.1	106.3
100	68.0	83.1	68.0	83.1	110.8
110	68.0	83.1	68.0	83.1	114.9
120	68.0	83.1	68.0	83.1	118.7
130	68.0	83.1	68.0	83.1	122.2
140	68.0	83.1	68.0	85.4	125.4
150	68.0	83.1	68.0	88.2	128.2
160	68.0	83.1	68.0	90.9	130.9
170	68.0	83.1	68.0	93.5	133.5
180	68.0	83.1	68.0	95.9	135.9
190	68.0	83.1	68.0	98.2	138.2
200	68.0	83.1	68.0	100.3	140.3
210	68.0	83.1	68.0	102.3	142.3
220	68.0	83.1	68.0	104.3	144.3

## Non-Proprietary Version

TABLE B-4. Quad Cities Unit 1 Composite P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures 5-10, 5-13 and 5-14

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 54 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 54 EFPY CURVE B (°F)	UPPER RPV & BELTLINE AT 54 EFPY CURVE C (°F)
230	68.0	83.1	68.0	106.1	146.1
240	68.0	83.1	68.0	107.9	147.9
250	68.0	83.1	68.0	109.6	149.6
260	68.0	83.1	68.0	111.2	151.2
270	68.0	83.1	68.0	112.8	152.8
280	68.0	83.1	68.0	114.3	154.3
290	68.0	83.1	68.0	115.8	155.8
300	68.0	83.1	68.0	117.2	157.2
310	68.0	83.1	68.0	118.5	158.5
312.5	68.0	83.1	68.0	118.9	158.9
312.5	68.0	113.1	68.0	143.1	183.1
320	68.0	113.1	68.0	143.1	183.1
330	68.0	113.1	68.0	143.1	183.1
340	68.0	113.1	68.0	143.1	183.1
350	68.0	113.1	68.0	143.1	183.1
360	68.0	113.1	68.0	143.1	183.1
370	68.0	113.1	68.0	143.1	183.1
380	68.0	113.1	68.0	143.1	183.1
390	68.0	113.1	68.0	143.1	183.1
400	68.0	113.1	68.0	143.1	183.1
410	68.0	113.1	68.0	143.1	183.1
420	68.0	113.1	68.1	143.1	183.1
430	68.0	113.1	71.4	143.1	183.1
440	68.0	113.1	74.4	143.1	183.1
450	68.0	113.1	77.3	143.1	183.1
460	68.0	113.1	80.0	143.1	183.1



## Non-Proprietary Version

TABLE B-4. Quad Cities Unit 1 Composite P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures 5-10, 5-13 and 5-14

PRESSURE (PSIG)	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	UPPER RPV & BELTLINE AT 54 EFPY
	CURVE A	CURVE A	CURVE B	CURVE B	CURVE C
	(°F)	(°F)	(°F)	(°F)	(°F)
470	68.0	113.1	82.6	143.1	183.1
480	68.0	113.1	85.1	143.1	183.1
490	68.0	113.1	87.4	143.1	183.1
500	68.0	113.1	89.6	143.1	183.1
510	68.0	113.1	91.8	143.1	183.1
520	68.0	113.1	93.8	143.1	183.1
530	68.0	113.1	95.8	143.1	183.1
540	68.0	113.1	97.7	143.1	183.1
550	68.0	113.1	99.5	143.1	183.1
560	68.0	113.1	101.3	143.4	183.4
570	68.0	113.1	103.0	144.1	184.1
580	68.0	113.1	104.6	144.9	184.9
590	68.0	113.1	106.2	145.6	185.6
600	68.0	113.1	107.8	146.1	186.1
610	68.0	113.1	109.3	146.6	186.6
620	68.0	113.1	110.7	147.0	187.0
630	68.6	113.1	112.1	147.4	187.4
640	70.5	113.1	113.5	147.8	187.8
650	72.2	113.1	114.8	148.2	188.2
660	73.9	113.1	116.1	148.7	188.7
670	75.6	113.1	117.4	149.1	189.1
680	77.2	113.1	118.7	149.5	189.5
690	78.7	113.1	119.9	149.9	189.9
700	80.2	113.1	121.0	150.3	190.3
710	81.7	113.1	122.2	150.7	190.7
720	83.1	113.1	123.3	151.1	191.1

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TABLE B-4. Quad Cities Unit 1 Composite P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures 5-10, 5-13 and 5-14

	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	UPPER RPV & BELTLINE AT 54 EFPY
PRESSURE (PSIG)	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
730	84.5	113.1	124.4	151.5	191.5
740	85.8	113.1	125.5	151.9	191.9
750	87.1	113.1	126.6	152.2	192.2
760	88.4	113.1	127.6	152.6	192.6
770	89.6	113.6	128.6	153.0	193.0
780	90.8	114.6	129.6	153.4	193.4
790	92.0	116.0	130.6	153.8	193.8
800	93.2	117.3	131.5	154.1	194.1
810	94.3	118.6	132.5	154.5	194.5
820	95.4	119.9	133.4	154.9	194.9
830	96.5	121.1	134.3	155.7	195.7
840	97.5	122.3	135.2	156.5	196.5
850	98.6	123.4	136.0	157.3	197.3
860	99.6	124.6	136.9	158.1	198.1
870	100.6	125.7	137.7	158.8	198.8
880	101.5	126.8	138.6	159.6	199.6
890	102.5	127.9	139.4	160.3	200.3
900	103.4	128.9	140.2	161.1	201.1
910	104.4	129.9	141.0	161.8	201.8
920	105.3	130.9	141.7	162.5	202.5
930	106.1	131.9	142.5	163.2	203.2
940	107.0	132.9	143.3	163.9	203.9
950	107.9	133.8	144.0	164.6	204.6
960	108.7	134.8	144.7	165.2	205.2
970	109.6	135.7	145.5	165.9	205.9
980	110.4	136.6	146.2	166.5	206.5

## Non-Proprietary Version

TABLE B-4. Quad Cities Unit 1 Composite P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures 5-10, 5-13 and 5-14

PRESSURE	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	UPPER RPV & BELTLINE AT 54 EFPY
(PSIG)	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
990	111.2	137.4	146.9	167.2	207.2
1000	112.0	138.3	147.6	167.8	207.8
1010	112.7	139.1	148.2	168.5	208.5
1020	113.5	140.0	148.9	169.1	209.1
1030	114.3	140.8	149.6	169.7	209.7
1040	115.0	141.6	150.2	170.3	210.3
1050	115.7	142.4	150.9	170.9	210.9
1060	116.4	143.2	151.5	171.5	211.5
1070	117.2	144.0	152.1	172.1	212.1
1080	117.9	144.7	152.8	172.7	212.7
1090	118.6	145.5	153.4	173.2	213.2
1100	119.2	146.2	154.0	173.8	213.8
1105	119.6	146.6	154.3	174.1	214.1
1110	119.9	146.9	154.6	174.3	214.3
1120	120.6	147.6	155.2	174.9	214.9
1130	121.2	148.4	155.8	175.4	215.4
1140	121.9	149.1	156.3	176.0	216.0
1150	122.5	149.7	156.9	176.5	216.5
1160	123.1	150.4	157.5	177.0	217.0
1170	123.8	151.1	158.0	177.6	217.6
1180	124.4	151.7	158.6	178.1	218.1
1190	125.0	152.4	159.1	178.6	218.6
1200	125.6	153.0	159.7	179.1	219.1
1210	126.2	153.7	160.2	179.6	219.6
1220	126.8	154.3	160.8	180.1	220.1
1230	127.3	154.9	161.3	180.6	220.6

## Non-Proprietary Version

TABLE B-4. Quad Cities Unit 1 Composite P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures 5-10, 5-13 and 5-14

	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	UPPER RPV & BELTLINE AT 54 EFPY
PRESSURE	CURVE A	CURVE A	CURVE B	CURVE B	CURVE C
(PSIG)	(°F)	(°F)	(°F)	(°F)	(°F)
1240	127.9	155.5	161.8	181.1	221.1
1250	128.5	156.1	162.3	181.6	221.6
1260	129.0	156.7	162.8	182.1	222.1
1270	129.6	157.3	163.3	182.5	222.5
1280	130.1	157.9	163.8	183.0	223.0
1290	130.7	158.5	164.3	183.5	223.5
1300	131.2	159.0	164.8	183.9	223.9
1310	131.7	159.6	165.3	184.4	224.4
1320	132.3	160.2	165.8	184.8	224.8
1330	132.8	160.7	166.2	185.3	225.3
1340	133.3	161.3	166.7	185.7	225.7
1350	133.8	161.8	167.2	186.2	226.2
1360	134.3	162.3	167.6	186.6	226.6
1370	134.8	162.9	168.1	187.0	227.0
1380	135.3	163.4	168.5	187.5	227.5
1390	135.8	163.9	169.0	187.9	227.9
1400	136.3	164.4	169.4	188.3	228.3

## **APPENDIX C**

### **OPERATING AND TEMPERATURE MONITORING REQUIREMENTS**

**Non-Proprietary Version**

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**C.1 NON-BELTLINE MONITORING DURING PRESSURE TESTS**

It is likely that, during leak and hydrostatic pressure testing, the bottom head temperature may be significantly cooler than the beltline. This condition can occur in the bottom head when the recirculation pumps are operating at low speed, or are off, and injection through the control rod drives is used to pressurize the vessel. By using a bottom head curve, the required test temperature at the bottom head could be lower than the required test temperature at the beltline, avoiding the necessity of heating the bottom head to the same requirements of the vessel beltline.

One condition on monitoring the bottom head separately is that it must be demonstrated that the vessel beltline temperature can be accurately monitored during pressure testing. An experiment has been conducted at a BWR-4 that showed that thermocouples on the vessel near the feedwater nozzles, or temperature measurements of water in the recirculation loops provide good estimates of the beltline temperature during pressure testing. Thermocouples on the RPV flange to shell junction outside surface should be used to monitor compliance with upper vessel curve. Thermocouples on the bottom head outside surface should be used to monitor compliance with bottom head curves. A description of these measurements is given in GE SIL 430, attached in Appendix D. First, however, it should be determined whether there are significant temperature differences between the beltline region and the bottom head region.

**C.2 DETERMINING WHICH CURVE TO FOLLOW**

The following subsections outline the criteria needed for determining which curve is governing during different situations. The application of the P-T curves and some of the assumptions inherent in the curves to plant operation is dependent on the proper monitoring of vessel temperatures. A discussion of monitoring of vessel temperatures can be found in Section 4 of the pressure-temperature curve report prepared in 1989 [1].

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**C.2.1 Curve A: Pressure Test**

Curve A should be used during pressure tests at times when the coolant temperature is changing by  $\leq 20^{\circ}\text{F}$  per hour. If the coolant is experiencing a higher heating or cooling rate in preparation for or following a pressure test, Curve B applies.

**C.2.2 Curve B: Non-Nuclear Heatup/Cooldown**

Curve B should be used whenever Curve A or Curve C do not apply. In other words, the operator must follow this curve during times when the coolant is heating or cooling faster than  $20^{\circ}\text{F}$  per hour during a hydrotest and when the core is not critical.

**C.2.3 Curve C: Core Critical Operation**

The operator must comply with this curve whenever the core is critical. An exception to this principle is for low-level physics tests; Curve B must be followed during these situations.

**C.3 REACTOR OPERATION VERSUS OPERATING LIMITS**

For most reactor operating conditions, coolant pressure and temperature are at saturation conditions, which are well into the acceptable operating area (to the right of the P-T curves). The operations where P-T curve compliance is typically monitored closely are planned events, such as vessel boltup, leakage testing and startup/shutdown operations, where operator actions can directly influence vessel pressures and temperatures.

The most severe unplanned transients relative to the P-T curves are those that result from SCRAMs, which sometimes include recirculation pump trips. Depending on operator responses following pump trip, there can be cases where stratification of colder water in the bottom head occurs while the vessel pressure is still relatively high. Experience with such events has shown that operator action is necessary to avoid P-T curve exceedance, but there is adequate time for operators to respond.

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In summary, there are several operating conditions where careful monitoring of P-T conditions against the curves is needed:

- Head flange boltup
- Leakage test (Curve A compliance)
- Startup (coolant temperature change of less than or equal to 100°F in one hour period heatup)
- Shutdown (coolant temperature change of less than or equal to 100°F in one hour period cooldown)
- Recirculation pump trip, bottom head stratification (Curve B compliance)



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**APPENDIX C REFERENCES:**

1. T.A. Caine, "Pressure-Temperature Curves Per Regulatory Guide 1.99, Revision 2 for the Dresden and Quad Cities Nuclear Power Stations", SASR 89-54, Revision 1, August 1989.

## APPENDIX D

### GE SIL 430

## Non-Proprietary Version

September 27, 1985

SIL No. 430

**REACTOR PRESSURE VESSEL TEMPERATURE MONITORING**

Recently, several BWR owners with plants in initial startup have had questions concerning primary and alternate reactor pressure vessel (RPV) temperature monitoring measurements for complying with RPV brittle fracture and thermal stress requirements. As such, the purpose of this Service Information Letter is to provide a summary of RPV temperature monitoring measurements, their primary and alternate uses and their limitations (See the attached table). Of basic concern is temperature monitoring to comply with brittle fracture temperature limits and for vessel thermal stresses during RPV heatup and cooldown. General Electric recommends that BWR owners/operators review this table against their current practices and evaluate any inconsistencies.

**TABLE OF RPV TEMPERATURE MONITORING MEASUREMENTS (Typical)**

Measurement	Use	Limitations
Steam dome saturation temperature as determined from main steam instrument line pressure	Primary measurement above 212°F for Tech Spec 100°F/hr heatup and cooldown rate.	Must convert saturated steam pressure to temperature.
Recirc suction line coolant temperature.	Primary measurement below 212°F for Tech Spec 100°F/hr heatup and cooldown rate.	Must have recirc flow. Must comply with SIL 251 to avoid vessel stratification.
	Alternate measurement above 212°F.	When above 212°F need to allow for temperature variations (up to 10-15°F lower than steam dome saturation temperature) caused primarily by FW flow variations.

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TABLE OF RPV TEMPERATURE MONITORING MEASUREMENTS (CONTINUED)

Measurement	(Typical) Use	Limitations
	Alternate measurement for RPV drain line temperature (can use to comply with delta T limit between steam dome saturation temperature and bottom head drain line temperature).	
RHR heat exchanger inlet coolant temperature	Alternate measurement for Tech Spec 100°F/hr cooldown rate when in shutdown cooling mode.	Must have previously correlated RHR inlet coolant temperature versus RPV coolant temperature.
RPV drain line coolant temperature	Primary measurement to comply with Tech Spec delta T limit between steam dome saturated temp and drain line coolant temperature.	Must have drain line flow. Otherwise, lower than actual temperature and higher delta T's will be indicated. Delta T limit is 100°F for BWR/6s and 145°F for earlier BWRs.
	Primary measurement to comply with Tech Spec brittle fracture limits during cooldown.	Must have drain line flow. Use to verify compliance with Tech Spec minimum metal temperature/reactor pressure curves (using drain line temperature to represent bottom head metal temperature).
	Alternate information only measurement for bottom head inside/outside metal surface temperatures.	Must compensate for outside metal temperature lag during heatup/cooldown. Should have drain line flow.

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TABLE OF RPV TEMPERATURE MONITORING MEASUREMENTS (CONTINUED)

Measurement	(Typical) Use	Limitations
Closure head flanges outside surface T/Cs	Primary measurement for BWR/6s to comply with Tech Spec brittle fracture metal temperature limit for head boltup.  One of two primary measure- ments for BWR/6s for hydro test.	Use for metal (not coolant) temperature. Install temporary T/Cs for alternate measurement, if required.
RPV flange-to-shell junction outside surface T/Cs	Primary measurement for BWRs earlier than 6s to comply with Tech Spec brittle fracture metal temperature limit for head boltup.  One of two primary measurements for BWRs earlier than 6s for hydro test. Preferred in lieu of closure head flange T/Cs if available.	Use for metal (not coolant) temperature. Response faster than closure head flange T/Cs.  Use RPV closure head flange outside surface as alternate measurement.
RPV shell outside surface T/Cs	Information only.	Slow to respond to RPV coolant changes. Not available on BWR/6s.
Top head outside surface T/Cs	Information only.	Very slow to respond to RPV coolant changes. Not avail- able on BWR/6s.

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TABLE OF RPV TEMPERATURE MONITORING MEASUREMENTS (CONTINUED)

Measurement	(Typical)	Limitations
	Use	
Bottom head outside surface T/Cs	1 of 2 primary measurements to comply with Tech Spec brittle fracture metal temperature limit for hydro test.	Should verify that vessel stratification is not present for vessel hydro. (see SIL No. 251).
	Primary measurement to comply with Tech Spec brittle fracture metal temperature limits during heatup.	Use during heatup to verify compliance with Tech Spec metal temperature/reactor pressure curves.

Note: RPV vendor specified metal T limits for vessel heatup and cooldown should be checked during initial plant startup tests when initial RPV vessel heatup and cooldown tests are run.

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**Product Reference: B21 Nuclear Boiler****Prepared By: A.C. Tsang****Approved for Issue:**

B.H. Eldridge, Mgr.

Service Information  
and Analysis**Issued By:**

D.L. Allred, Manager

Customer Service Information

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## **APPENDIX E**

### **DETERMINATION OF BELTLINE REGION AND IMPACT ON FRACTURE TOUGHNESS**



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10CFR50, Appendix G defines the beltline region of the reactor vessel as follows:

“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 establish the value of peak fluence for identification of beltline materials (as discussed above), the 10CFR50 Appendix H fluence value used to determine the need for a surveillance program was used; the value specified is a peak fluence ( $E > 1$  MEV) of  $1.0 \times 10^{17}$  n/cm<sup>2</sup>. Therefore, if it can be shown that no nozzles are located where the peak neutron fluence is expected to exceed or equal  $1.0 \times 10^{17}$  n/cm<sup>2</sup>, then it can be concluded that all reactor vessel nozzles are outside the beltline region of the reactor vessel, and do not need to be considered in the P-T curve evaluation.

The following dimensions are obtained from the referenced drawings:

Shell # 2 - Top of Active Fuel (TAF): 360.3" (from vessel 0) [1]

Shell # 1 - Bottom of Active Fuel (BAF): 216.3" (from vessel 0) [1]

Top of Recirc Outlet Nozzle N1 in Shell # 1: 188" (from vessel 0) [2]

Centerline of Recirc Outlet Nozzle N1 in Shell # 1: 161.5" (from vessel 0) [3]

Top of Recirc Inlet Nozzle N2 in Shell # 1: 193.3" (from vessel 0) [2]

Centerline of Recirc Inlet Nozzle N2 in Shell # 1: 181" (from vessel 0) [3]

Girth Weld between Shell Ring #2 and Shell Ring #3: 391.5" (from vessel 0) [3,4]

From [2 & 3], it is obvious that the recirculation inlet and outlet nozzles are closest to the beltline region (the top of the recirculation inlet nozzle is ~23" below BAF and the top of the recirculation outlet nozzle is ~28" below BAF), and no nozzles are within the BAF-TAF region of the reactor vessel. The girth weld between Shell Rings #2 and #3 is ~31" above TAF. Therefore, if it can be shown that the peak fluence at these locations is less than  $1.0 \times 10^{17}$  n/cm<sup>2</sup>, it can be safely concluded that all nozzles and welds, other than

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those included in Tables 4-3 and 4-4, are outside the beltline region of the reactor vessel.

Based on the bounding 32 and 54 EFPY axial flux profile for pre- and post-EPU [5], the RPV fluence level dropped to less than  $1.0\text{e}17 \text{ n/cm}^2$  at the RPV ID at ~1" below the BAF and at ~6" above TAF. The beltline region considered in the development of the P-T curves is adjusted to include the additional 6" above the active fuel region and the additional 1" below the active fuel region. This adjusted beltline region extends from 215.3" to 366.3" above reactor vessel "0" for both 32 and 54 EFPY.

Based on the above, it is concluded that none of the Quad Cities Unit 1 reactor vessel plates, nozzles or welds, other than those included in Tables 4-3 and 4-4, are in the beltline region.

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**APPENDIX E REFERENCES:**

1. Dresden/Quad Cities LR PT Curves – Design Input Request (DIR), Robert Stachniak (Exelon), 4/26/02.
2. Babcock & Wilcox Co. (B&W) Drawing # 151833E, Revision 1, "Recirculation Nozzles", (GE-NE VPF# 1744-138-3), Quad Cities Units 1&2.
3. Babcock & Wilcox Co. (B&W) Drawing # 26906F, Revision 7, "General Outline", (GE-NE VPF# 1744-145-8), Quad Cities Units 1&2.
4. Babcock & Wilcox Co. (B&W) Drawing # 151825F, Revision 1, "Shell course Sub-Assembly", (GE-NE VPF# 1744-132-4), Quad Cities Units 1&2.
5. S. Sitaraman, "Dresden and Quad Cities Neutron Flux Evaluation", GE-NE, San Jose, CA, March 2003, (GE-NE-0000-0011-0531-R2, Revision 2)(GE Proprietary Information).

## APPENDIX F

### CORE NOT CRITICAL CALCULATION FOR THE BOTTOM HEAD (CRD PENETRATION)

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## TABLE OF CONTENTS

The following outline describes the contents of this Appendix:

- F.1 Executive Summary
- F.2 Scope
- F.3 Analysis Methods
  - F.3.1 Applicability of the ASME Code Appendix G Methods
  - F.3.2 Finite Element Fracture Mechanics Evaluation
  - F.3.3 ASME Code Appendix G Evaluation
- F.4 Results
- F.5 Conclusions
- F.6 References

### F.1 Executive Summary

This Appendix describes the analytical methods used to determine the  $T-RT_{NDT}$  value applicable for the Bottom Head Core Not Critical P-T curves. This evaluation uses new finite element fracture mechanics technology developed by the General Electric Company, which is used to augment the methods described in the ASME Boiler and Pressure Vessel Code [1]. [[

]] This method more

accurately predicts the expected stress intensity [[

]] The peak stress intensities for the pressure and thermal load cases evaluated are used as inputs into the ASME Code Appendix G evaluation methodology to calculate a  $T-RT_{NDT}$ . [[

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**F.2 Scope**

This Appendix describes the analytical methods used to determine the  $T-RT_{NDT}$  value applicable for the Bottom Head Core Not Critical P-T curves. This evaluation uses new finite element fracture mechanics technology developed by the General Electric Company, which is used to augment the methods described in the ASME Boiler and Pressure Vessel Code [1]. This Appendix discusses the finite element analysis and the Appendix G [1] calculations separately below.

**F.3 Analysis Methods**

This section contains technical descriptions of the analytical methods used to perform the BWR Bottom Head fracture mechanics evaluation. The applicability of the current ASME Code, Section XI, Appendix G methods [1] considering the specific bottom head geometry is discussed first, followed by a detailed discussion of the finite element analysis and Appendix G evaluation [1].

***F.3.1 Applicability of the ASME Code Appendix G Methods***

The methods described in the ASME Code Section XI, Appendix G [1] for demonstrating sufficient margin against brittle fracture in the RPV material are based upon flat plate solutions, which consider uniform stress distributions along the crack tip. The method also suggests that a  $\frac{1}{4}$  wall thickness semi-elliptical flaw with an aspect ratio of 6:1 (length to depth) be considered in the evaluation. When the bottom head specific geometry is considered in more detail the following items become evident:

[[

]]

Noting these items, the applicability of the methods suggested in Appendix G [[  
]]. The ASME Code does not preclude using other methods; therefore, a

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more detailed [[ ]] finite element fracture mechanics analysis [[ ]] was performed. The stress intensity obtained from this analysis is used in place of that determined using the Appendix G methods [1].

*F.3.2 Finite Element Fracture Mechanics Evaluation*

An advanced [[ ]] finite element analysis of a BWR bottom head geometry [[ ]] was performed to determine the mode I stress intensity at the tip of a ¼ thickness postulated flaw. [[

]]

Finite Elements [[ ]]

All Finite Element Analyses were performed using ANSYS Version 6.1 [2]. [[

]]

Structural Boundary Conditions

The modeled geometry is one-fourth of the Bottom Head hemisphere, so symmetry boundary conditions are used. [[

]] The mesh is shown in Figure 1.

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**Material Properties**

Two materials are used as per the ASME Code. Material 1 is SA533, which is used to model the vessel. Material 2 [[

]] The ANSYS listing of these materials in (pound-inch-second-°F) units are:



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[[

]]

EX is the Young's Modulus, NUXY is the Poisson's Ratio, ALPX is the Thermal Expansion Coefficient, DENS is the Density, KXX is the Thermal Conductivity and C is the Heat Capacity.

**Loads**

Two loads cases were independently analyzed.

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1. Pressure Loading –

An internal pressure of 1250 psi is applied to the interior of the vessel [[

]] In addition, the thin cylindrical shell stress due to this pressure is applied as a blowoff pressure [[ ]] at the upper extremity of the vertical wall of the BWR. Figure 2 shows these loads. [[

]]

Figure 2. Pressure Loads

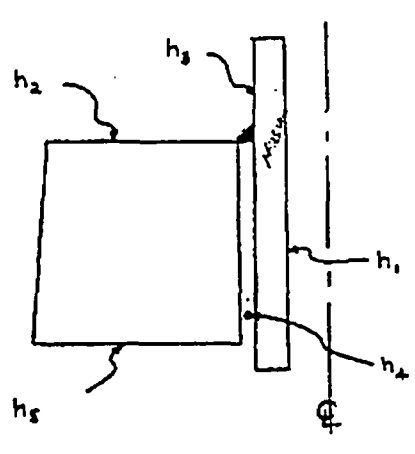
2. [[ ]] Thermal Transient

[[

]]

Thermal loads are applied to the model as time-dependent convection coefficients and bulk temperatures. Referring to the regions identified in Figure 3, the corresponding values follow. Convection coefficients (h) are in units of BTU/(hr-ft-°F) and temperatures (T) are in °F.

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**Figure 3. Regions To Which Thermal Loads Are Applied**

- Region 1:  $h = 25$ ,  $T = 60$
- Regions 2 and 3:

Time (min)	$h_2$	$h_3$	T
0	496	413	[[ ]]
[[ ]]	341	354	[[ ]]
[[ ]]	496	413	[[ ]]
[[ ]]	496	413	[[ ]]

[[ ]]

]]

Temperature Plot vs. Time (min.)

- c. Region 4: Adiabatic (exaggerated in size in drawing)  
d. Region 5:  $h = 0.2$ ,  $T = 100$

The peak thermal gradients were used to compute the thermal stresses based on a uniform reference temperature of 70°F.

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Crack Configurations

The following four cracks were analyzed:

1. A part through crack,  $\frac{1}{4}$  of the vessel wall thickness deep, measured from inside the vessel, [[  
]]
2. Same as 1, but depth is measured from outside the vessel
3. Same as 1, [[  
]]
4. Same as 2, [[  
]]

[[

]]

The cracks considered for this analysis [[

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Stress Intensity Factor Computation

[[

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[[

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Benchmarking [[

]] Methodology

[[



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]] The results of these benchmarking studies have demonstrated the accuracy of this method as used for this evaluation.

Pressure Loading Analysis Results

[[

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Benchmarking Of Pressure Loading Results

Pressure Loading analyses [[

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**Non-Proprietary Version**

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**Non-Proprietary Version**

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Thermal Transients Analysis Results

For the thermal transient considered, the inner diameter of the vessel is hotter than the outer diameter; hence the I.D. cracks, [[ ]], close due to the thermal gradient and result in negative Stress Intensity Factors, which is not critical. However, the O.D. cracks open [[ ]]. All results for the thermal transient will consequently be shown for the O.D. [[ ]] crack.

In order to identify the peak gradient, three locations were chosen. [[ ]]

]]

[[ ]]Thermal Gradients[[ ]]

Figure 10a is a plot of these three gradients vs. time. Figure 10b is zoomed in to the peaking region.

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[[

[[

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|

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Non-Proprietary Version

It can be seen that the peak times and values based on each gradient are:

Gradient	Peak Time (Min.)	Peak Value (°F)
[[		
		]]

Stress analyses were performed using the temperature distributions obtained from the thermal analyses at each of these peak times and the Stress Intensity Factors are shown in Figure 11.

[[

]]

F.3.3 ASME Code Appendix G Evaluation

The peak stress intensities for the pressure and thermal load cases evaluated above are used as inputs to the ASME Code Appendix G evaluation methodology [1] to calculate a T-RT<sub>NDT</sub>. The Core Not Critical Bottom Head P-T curve T-RT<sub>NDT</sub> is calculated using the formulas listed below:

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$$K_I = SF_P \cdot K_{Ip} + SF_T \cdot K_{It}$$

$$SF_P = 2.0$$

$$SF_t = 1.0$$

$$T - RT_{NDT} = \ln \left( \frac{K_I - 33.2}{20.734} \right) \cdot \frac{1}{0.02}$$

Where: KI is the total mode I stress intensity,  
 KIp is the pressure load stress intensity,  
 KIt is the thermal load stress intensity,  
 SFp is the pressure safety factor,  
 SFt is the thermal safety factor,

Note that the stress intensity is defined in units of: ksi\*in<sup>1/2</sup>

#### F.4 Results

Review of the [[ ]] results above demonstrates that the OD [[ ]] crack exhibits the highest stress intensity for the considered loading. The T-RT<sub>NDT</sub> to be used in the Core Not Critical Bottom Head P-T curves shall be calculated using the stress intensities obtained at this location. The calculations are shown below:

[[

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Note that the pressure stress intensity has been adjusted by the factor [[ ]] to account for the vessel pressure at which the maximum thermal stress occurred. The finite element results summarized above were calculated using a vessel pressure [[ ]]

Comparing the  $T-RT_{NDT}$  calculated using the methods described above to that determined using the previous GE methodology, [[ ]]

]]

**F.5 Conclusions**

For the [[ ]] transient, the appropriate  $T-RT_{NDT}$  for use in determining the Bottom Head Core Not Critical P-T curves [[ ]]. Existing Bottom Head Core Not Critical curves developed using the previous GE methodology [[ ]]

**F.6 References**

1. American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME B&PV Code), Section XI, 1998 Edition with Addenda to 2000.
2. ANSYS User's Manual, Version 6.1.

**APPENDIX G**

**BOUNDING P-T CURVES**

**FOR**

**QUAD CITIES UNITS 1 & 2**

**Non-Proprietary Version**

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This appendix contains P-T curves that bound the limiting material characteristics of both Quad Cities Unit 1 and Quad Cities Unit 2. Composite and individual curves are presented for both 32 and 54 EFPY similar to those provided within the main body of this report. Table G-1 provides the figure numbers and the corresponding tabulation for each P-T curve presented in this appendix.

## Non-Proprietary Version

Table G-1: Composite and Individual Curves Used To Construct Composite P-T Curves

Curve	Curve Description	Figure Numbers for Presentation of the P-T Curves	Table Numbers for Presentation of the P-T Curves
<b>Curve A</b>			
	Bottom Head Limits (CRD Nozzle)	Figure G-1	Table G-2 & 4
	Upper Vessel Limits (FW Nozzle)	Figure G-2	Table G-2 & 4
	Beltline Limits for 32 EFPY	Figure G-3	Table G-2
	Beltline Limits for 54 EFPY	Figure G-4	Table G-4
<b>Curve B</b>			
	Bottom Head Limits (CRD Nozzle)	Figure G-5	Table G-2 & 4
	Upper Vessel Limits (FW Nozzle)	Figure G-6	Table G-2 & 4
	Beltline Limits for 32 EFPY	Figure G-7	Table G-2
	Beltline Limits for 54 EFPY	Figure G-8	Table G-4
<b>Curve C</b>			
	Composite Curve for 32 EFPY**	Figure G-9	Table G-3
	Composite Curve for 54 EFPY**	Figure G-10	Table G-5
<b>A &amp; B</b>	<b>Composite Curves for 32 EFPY</b>		
	Bottom Head and Composite Curve A for 32 EFPY*	Figure G-11	Table G-3
	Bottom Head and Composite Curve B for 32 EFPY*	Figure G-12	Table G-3
<b>A &amp; B</b>	<b>Composite Curves for 54 EFPY</b>		
	Bottom Head and Composite Curve A for 54 EFPY*	Figure G-13	Table G-5
	Bottom Head and Composite Curve B for 54 EFPY*	Figure G-14	Table G-5

\* The Composite Curve A & B curve is the more limiting of three limits: 10CFR50 Bolt-up Limits, Upper Vessel Limits (FW Nozzle), and Beltline Limits. A separate Bottom Head Limits (CRD Nozzle) curve is individually included on this figure.

\*\* The Composite Curve C curve is the more limiting of four limits: 10CFR50 Bolt-up Limits, Bottom Head Limits (CRD Nozzle), Upper Vessel Limits (FW Nozzle), and Beltline Limits.

## Non-Proprietary Version

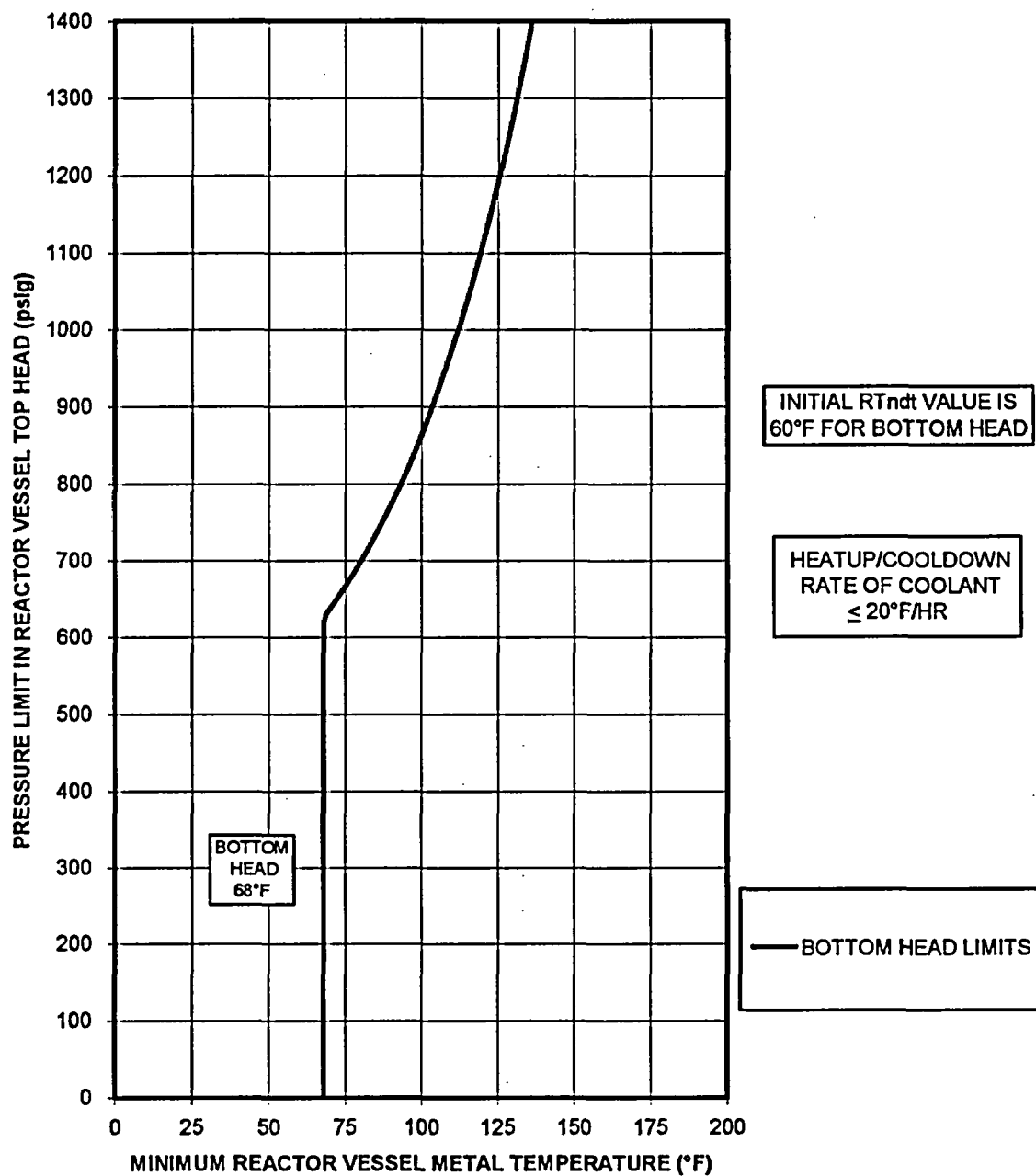


Figure G-1: Bounding Quad Cities 1&2 Bottom Head P-T Curve  
for Pressure Test [Curve A] [20°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

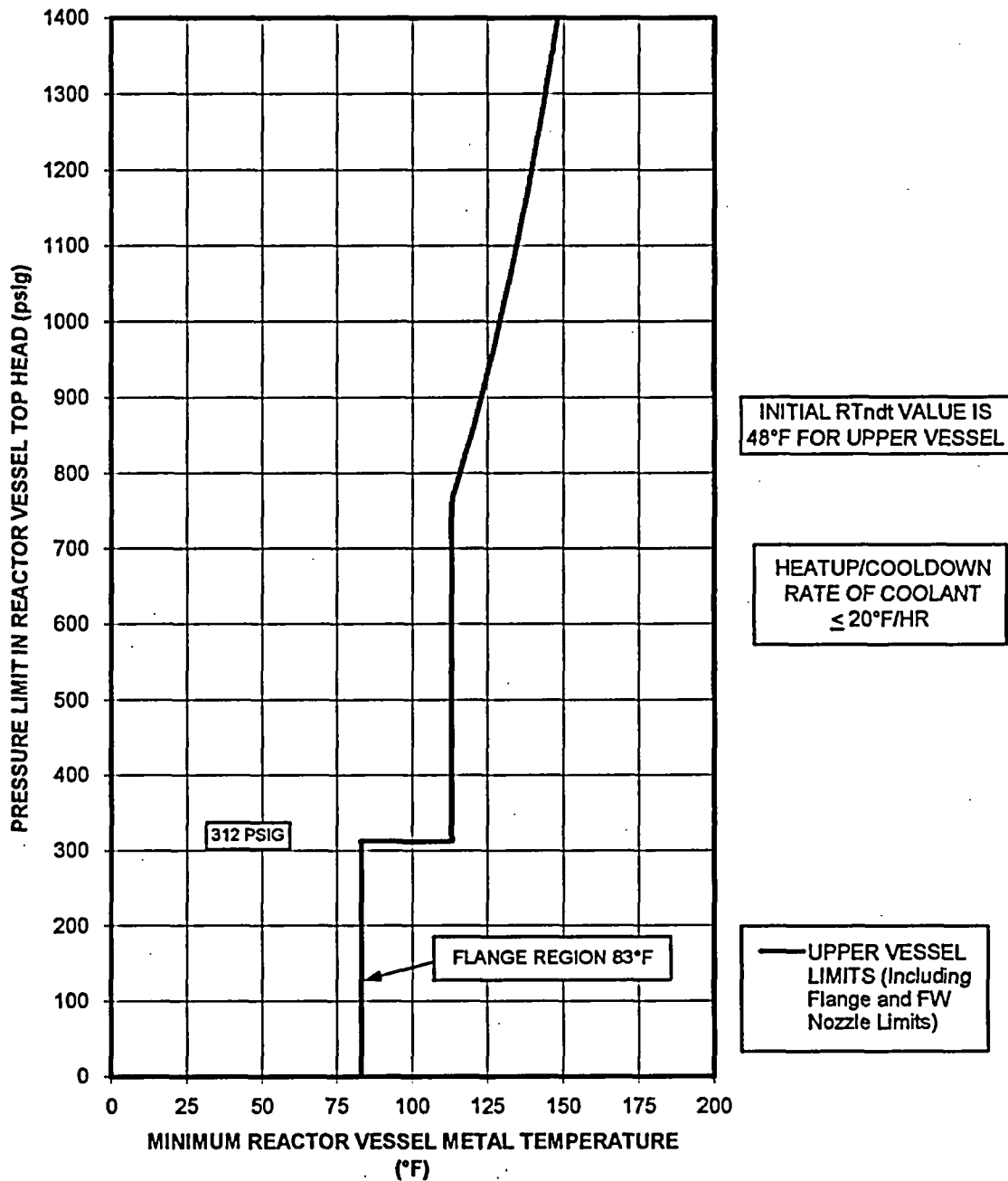


Figure G-2: Bounding Quad Cities 1&2 Upper Vessel P-T Curve for Pressure Test [Curve A]  
[20°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

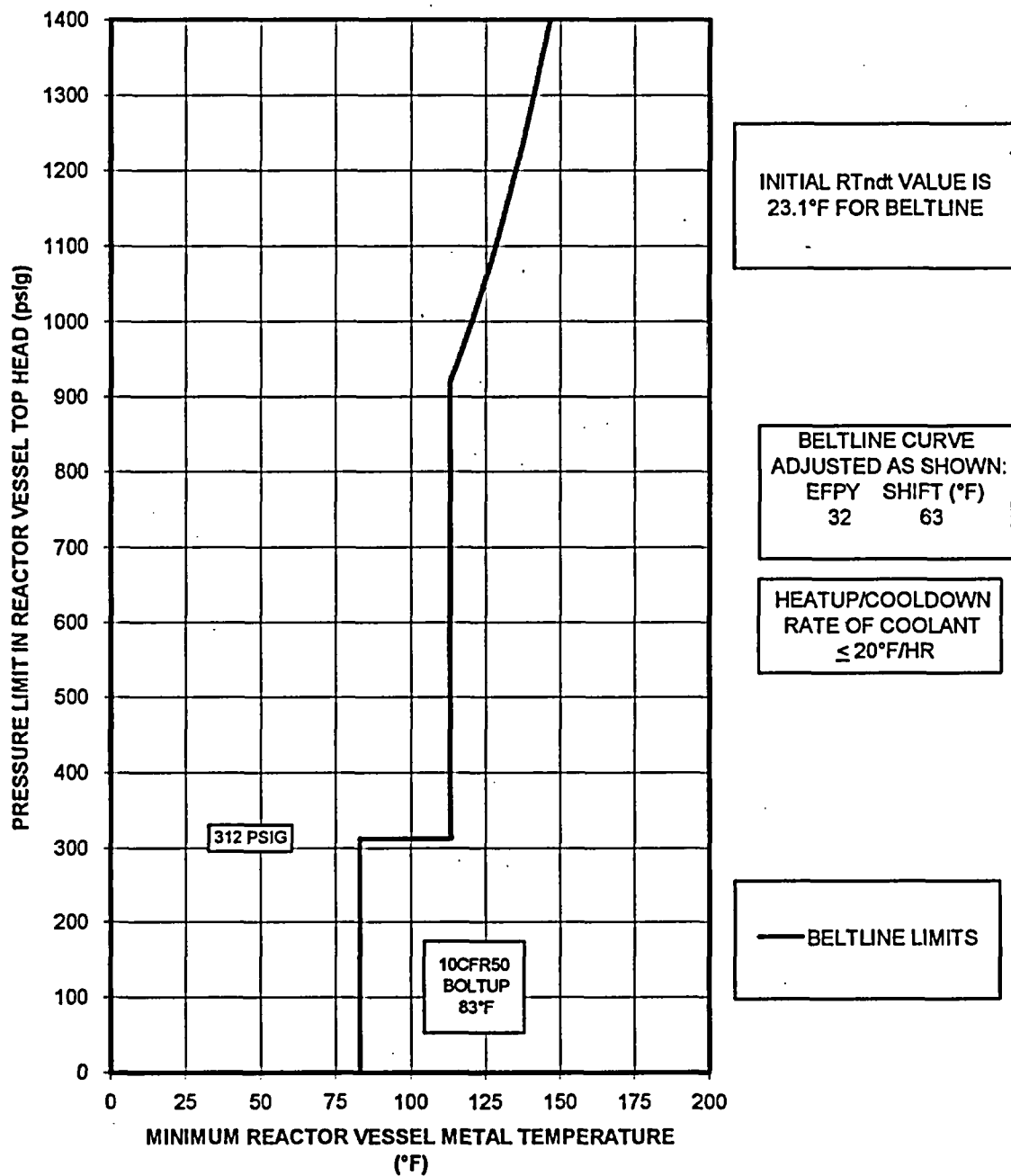


Figure G-3: Bounding Quad Cities 1&2 Beltline P-T Curve  
for Pressure Test [Curve A] up to 32 EFPY [20°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

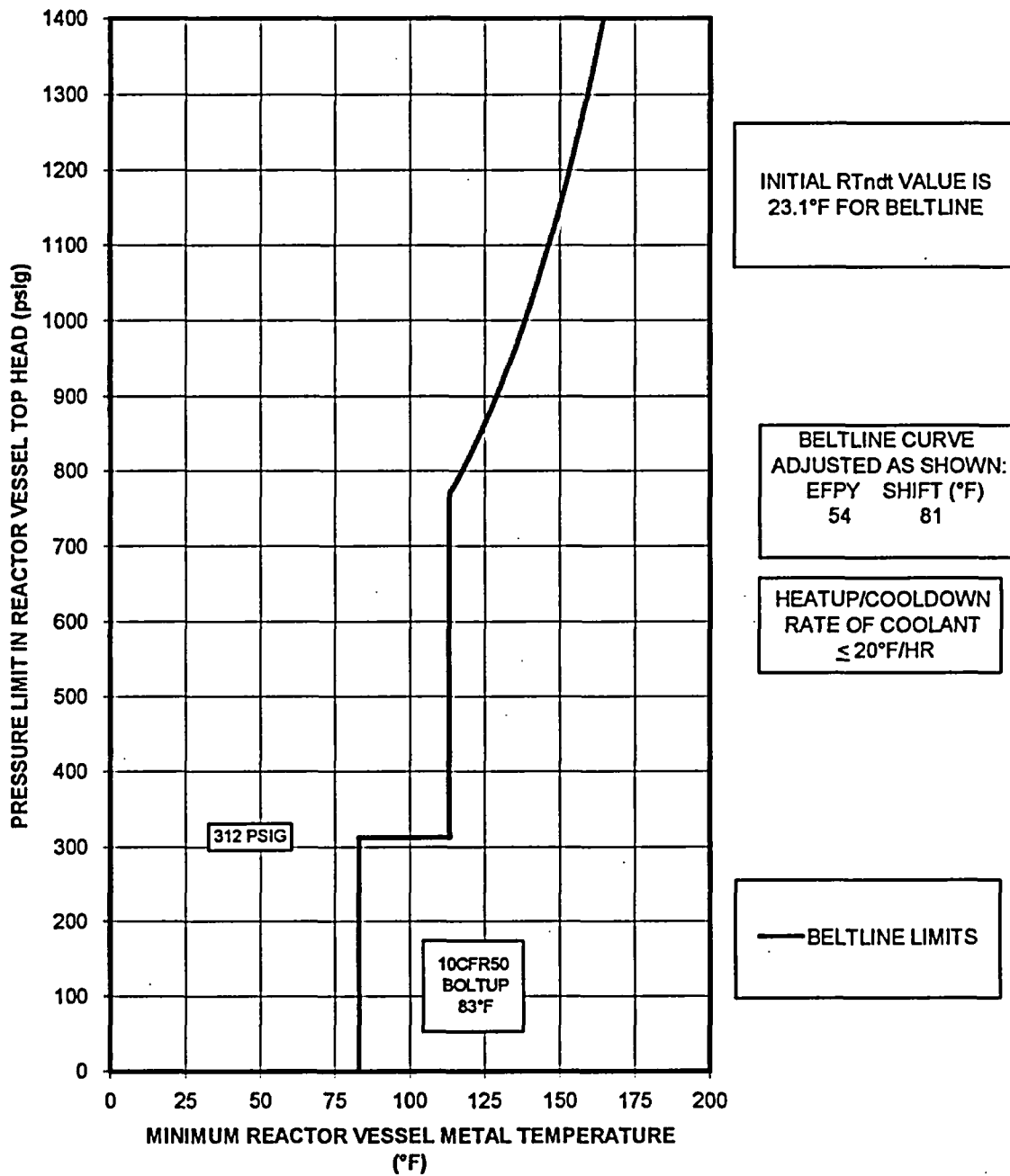


Figure G-4: Bounding Quad Cities 1&2 Beltline P-T Curve  
for Pressure Test [Curve A] up to 54 EFPY [20°F/hr or less coolant heatup/cooldown]



## Non-Proprietary Version

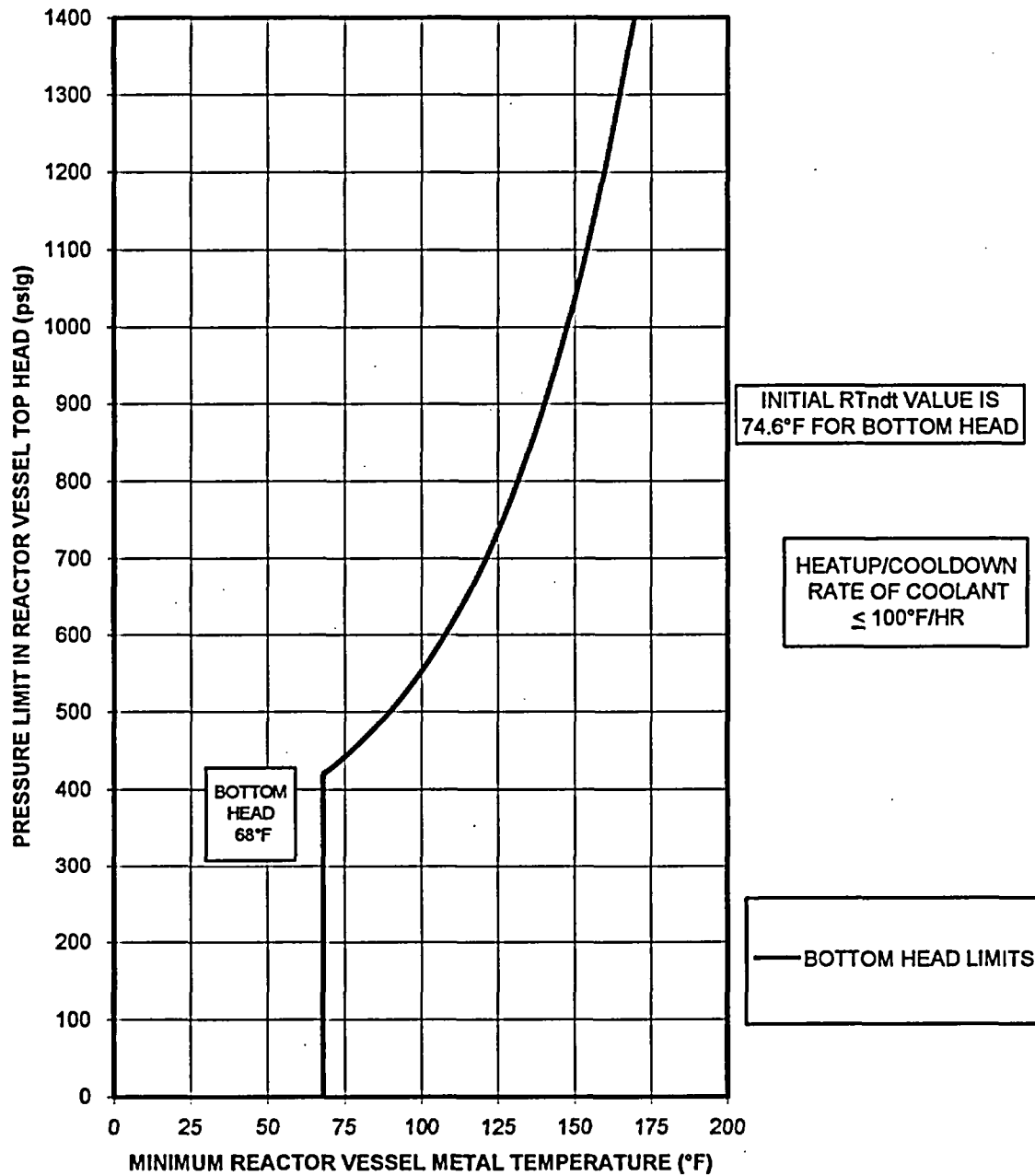


Figure G-5: Bounding Quad Cities 1&2 Bottom Head P-T Curve for Core Not Critical [Curve B]  
[100°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

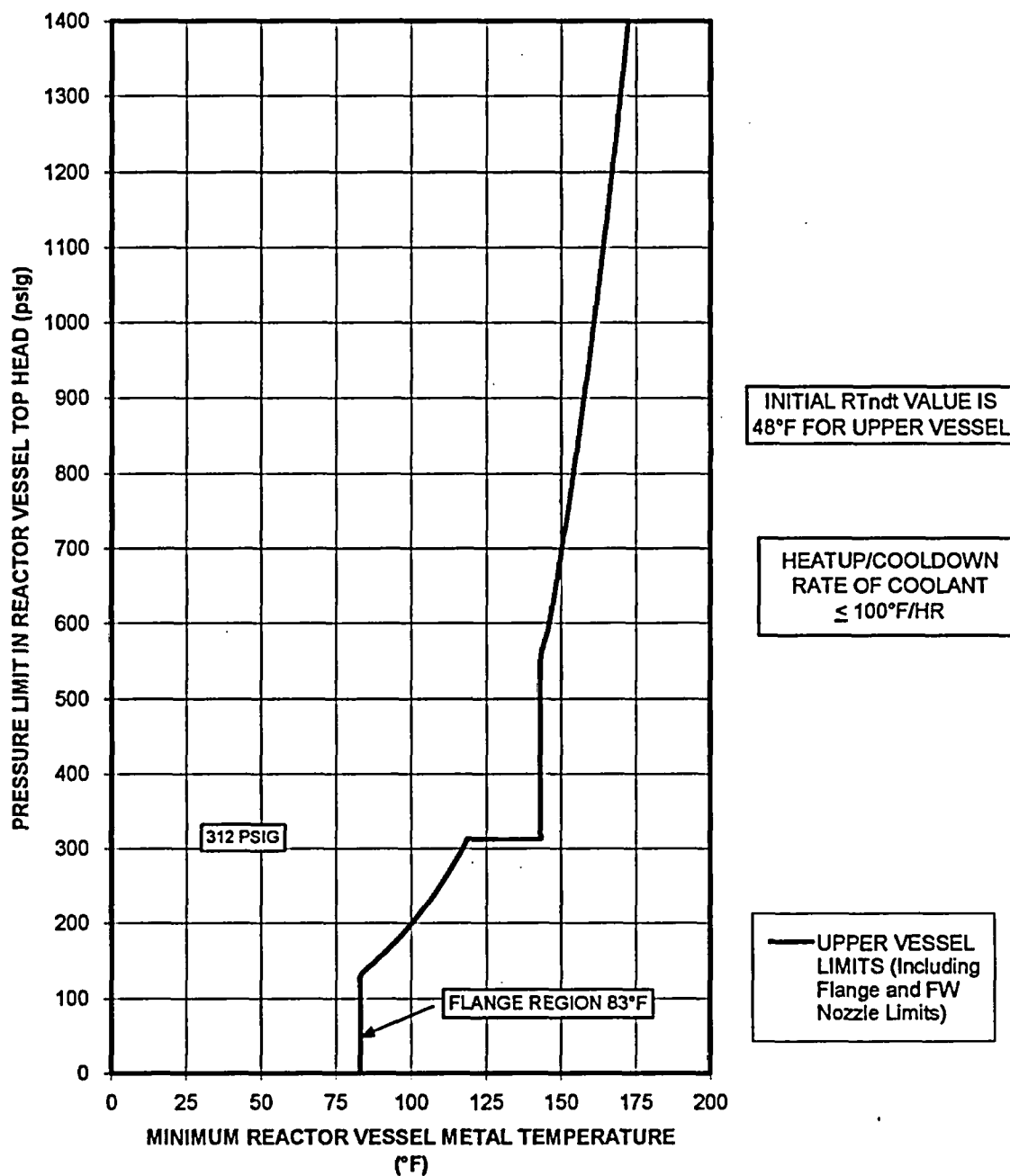


Figure G-6: Bounding Quad Cities 1&2 Upper Vessel P-T Curve for Core Not Critical [Curve B]  
[100°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

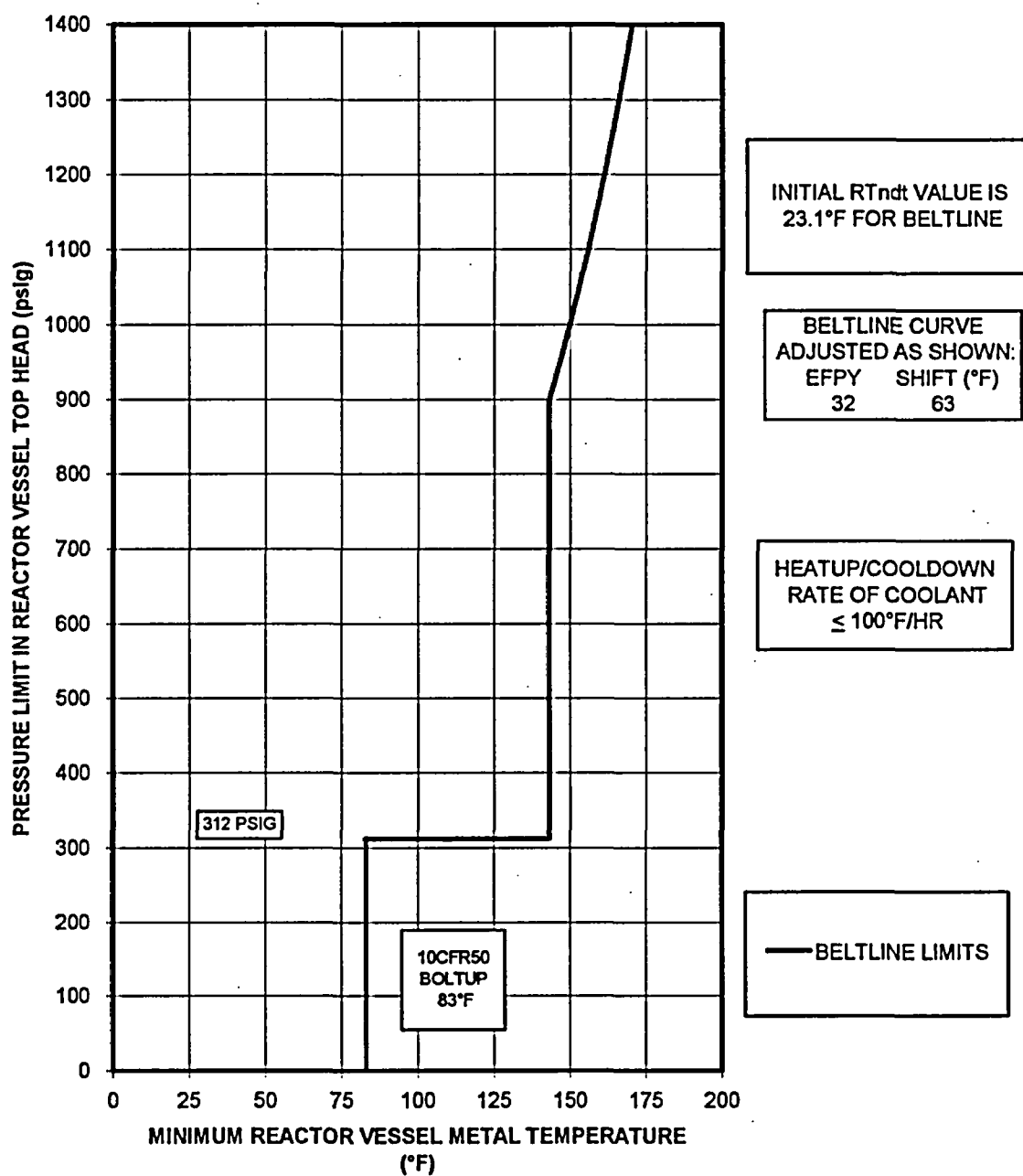


Figure G-7: Bounding Quad Cities 1&2 Beltline P-T Curve  
for Core Not Critical [Curve B] up to 32 EFPY  
[100°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

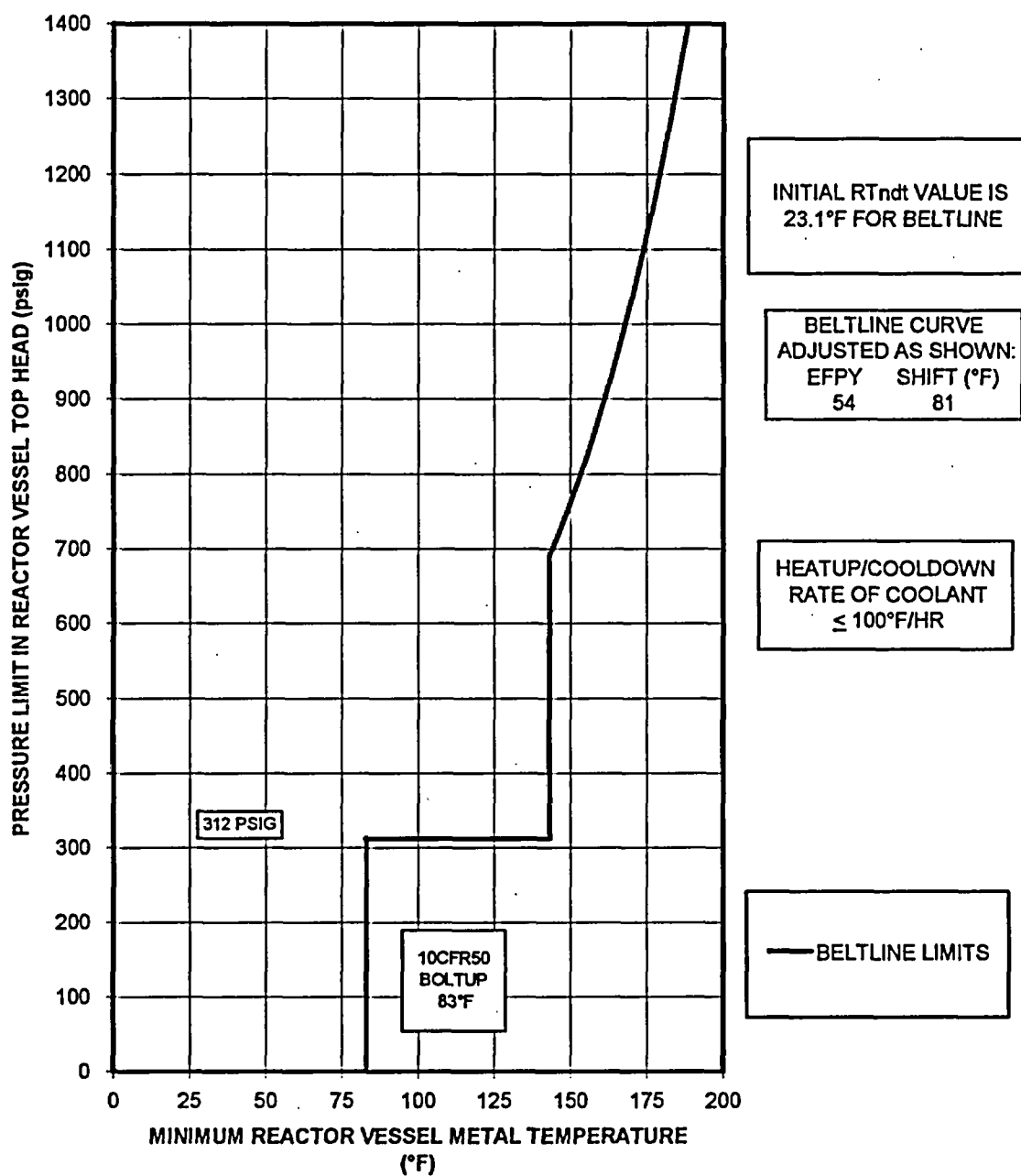


Figure G-8: Bounding Quad Cities 1&2 Beltline P-T Curve  
for Core Not Critical [Curve B] up to 54 EFPY  
[100°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

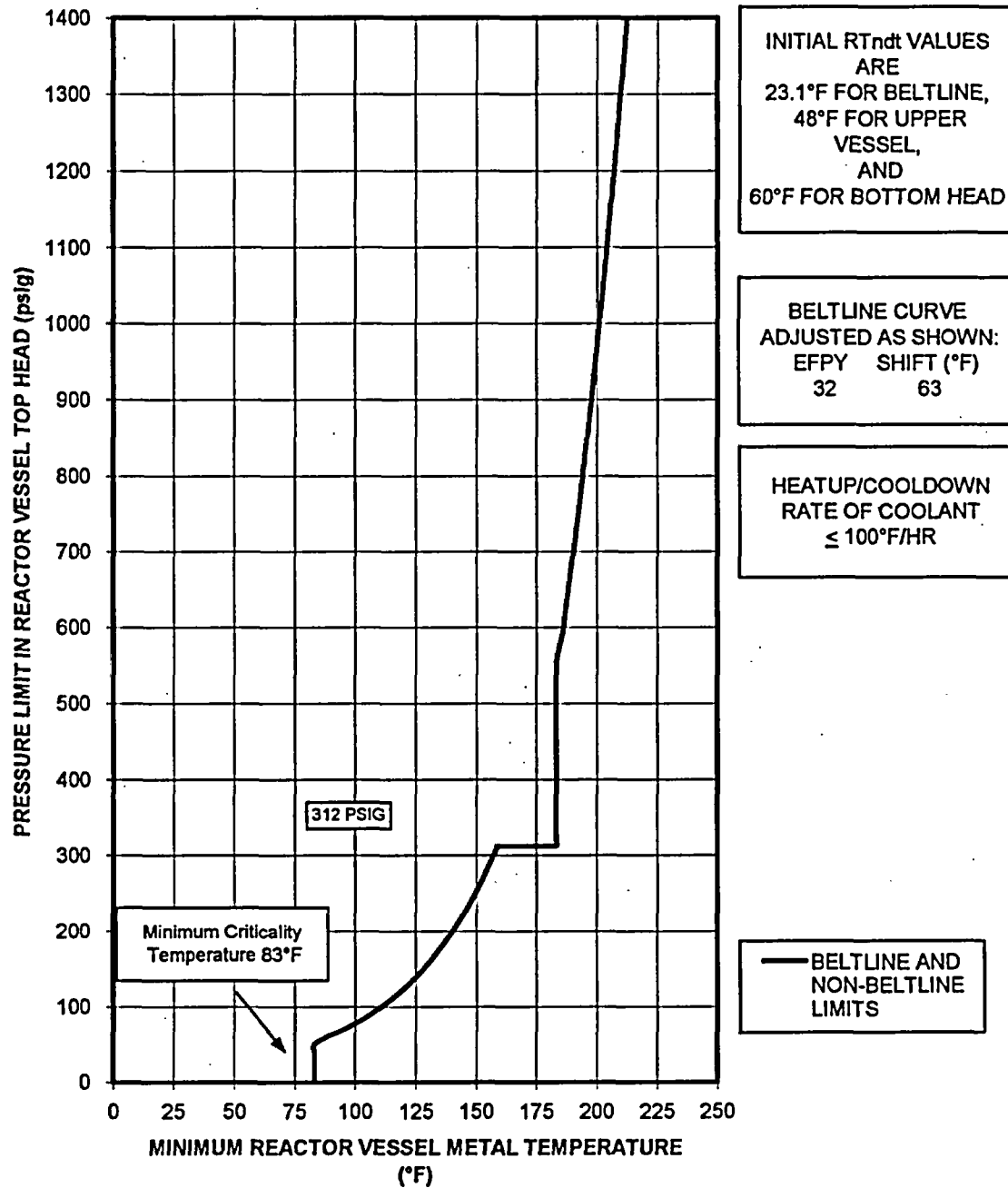


Figure G-9: Bounding Quad Cities 1&2 Core Critical P-T Curves [Curve C]  
up to 32 EFPY [100°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

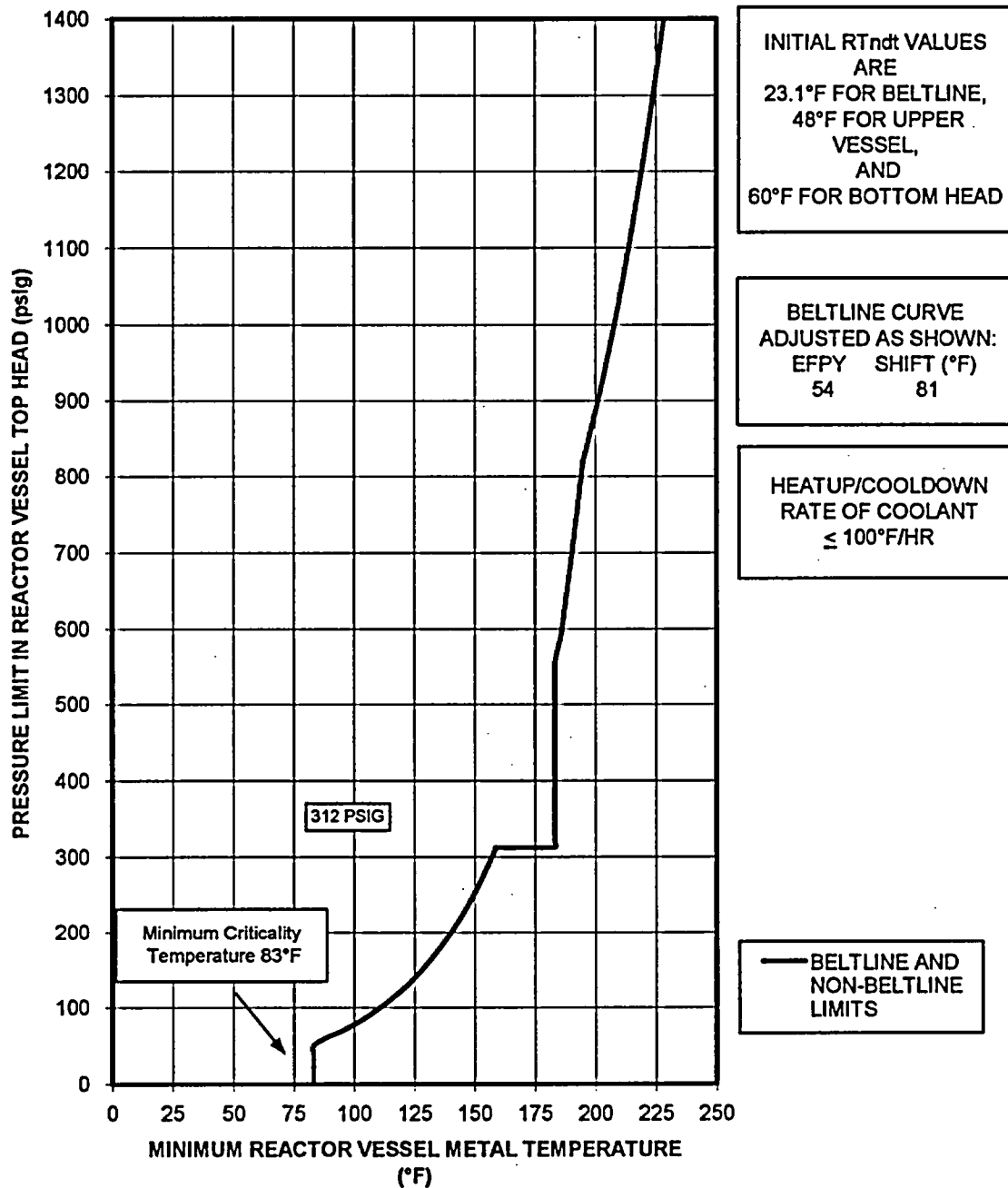


Figure G-10: Bounding Quad Cities 1&2 Core Critical P-T Curves [Curve C]  
up to 54 EFPY [100°F/hr or less coolant heatup/cooldown]

Non-Proprietary Version

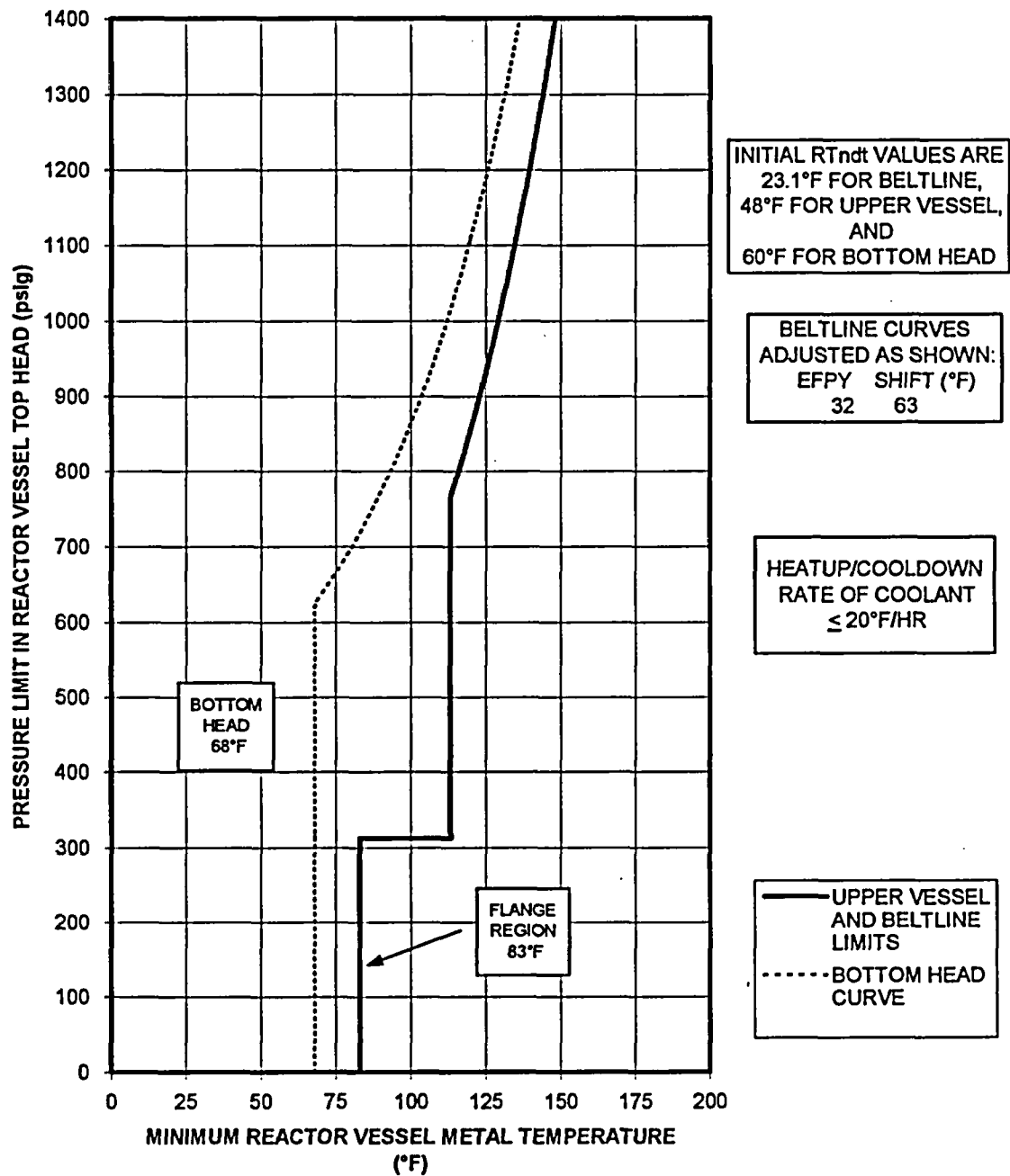


Figure G-11: Bounding Quad Cities 1&2 Composite Pressure Test P-T Curves [Curve A]  
 up to 32 EFPY [20°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

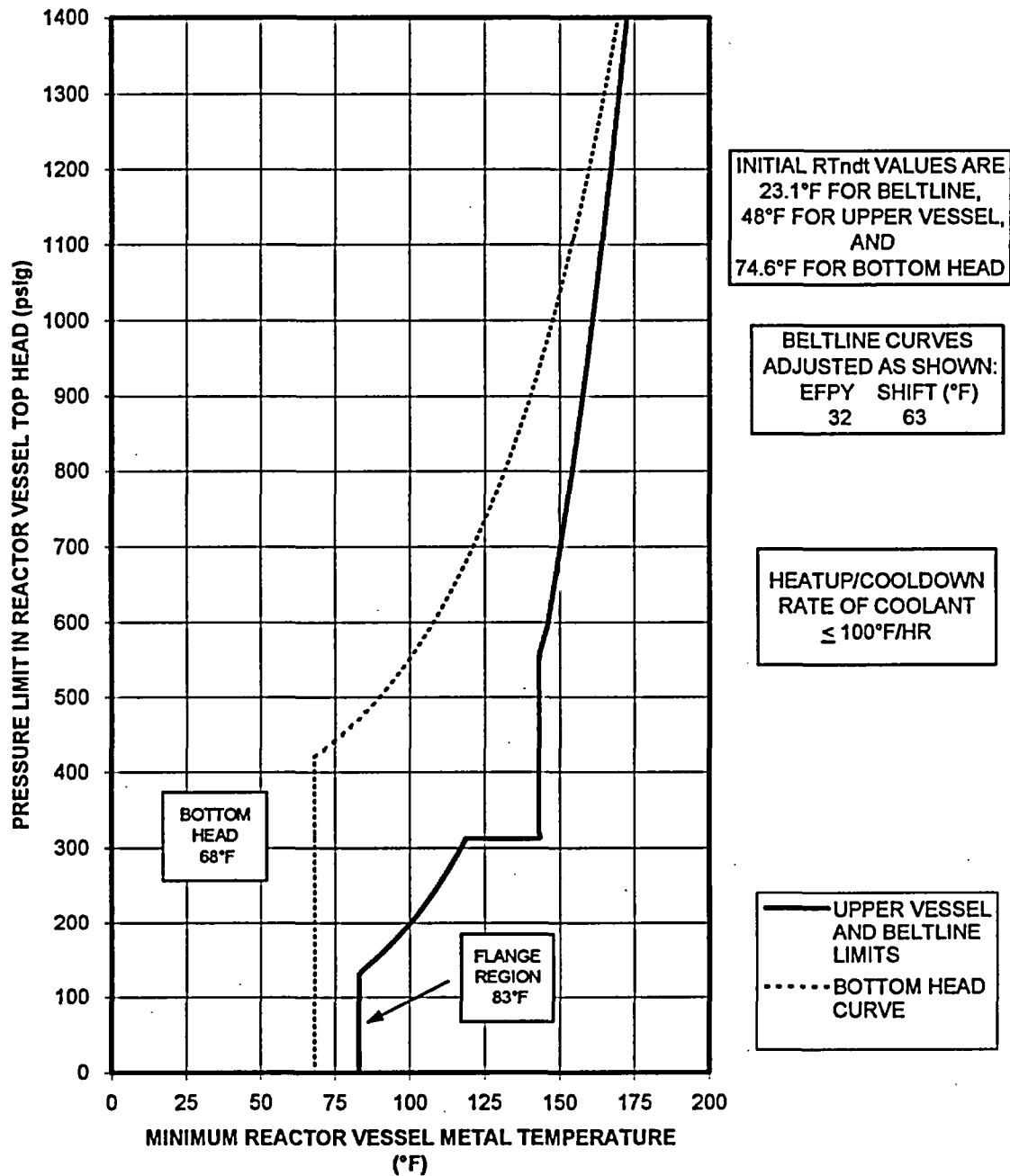


Figure G-12: Bounding Quad Cities 1&2 Composite Core Not Critical P-T Curves [Curve B]  
 up to 32 EPFY [100°F/hr or less coolant heatup/cooldown]



## Non-Proprietary Version

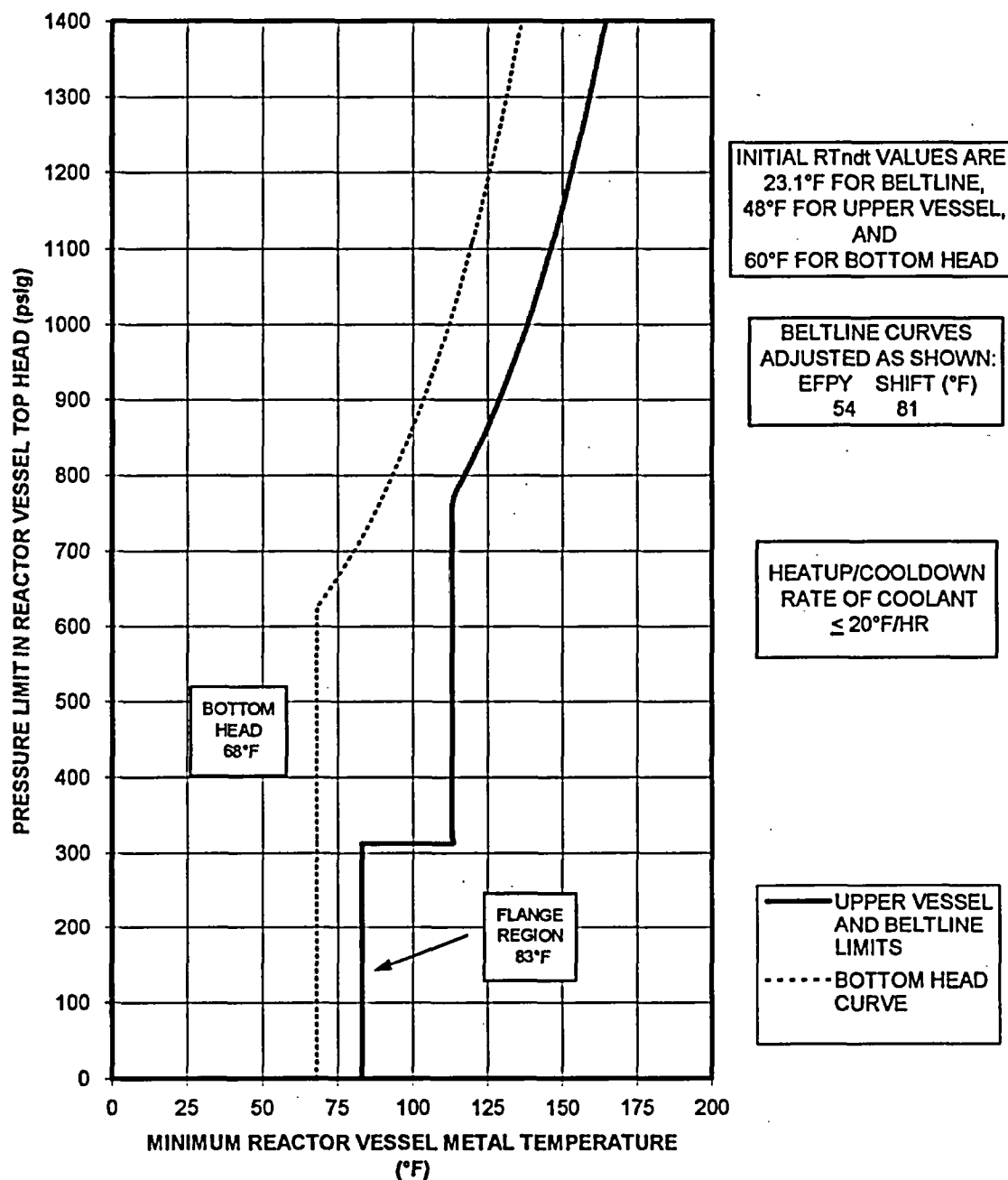


Figure G-13: Bounding Quad Cities 1&2 Composite Pressure Test P-T Curves [Curve A]  
 up to 54 EPFY [20°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

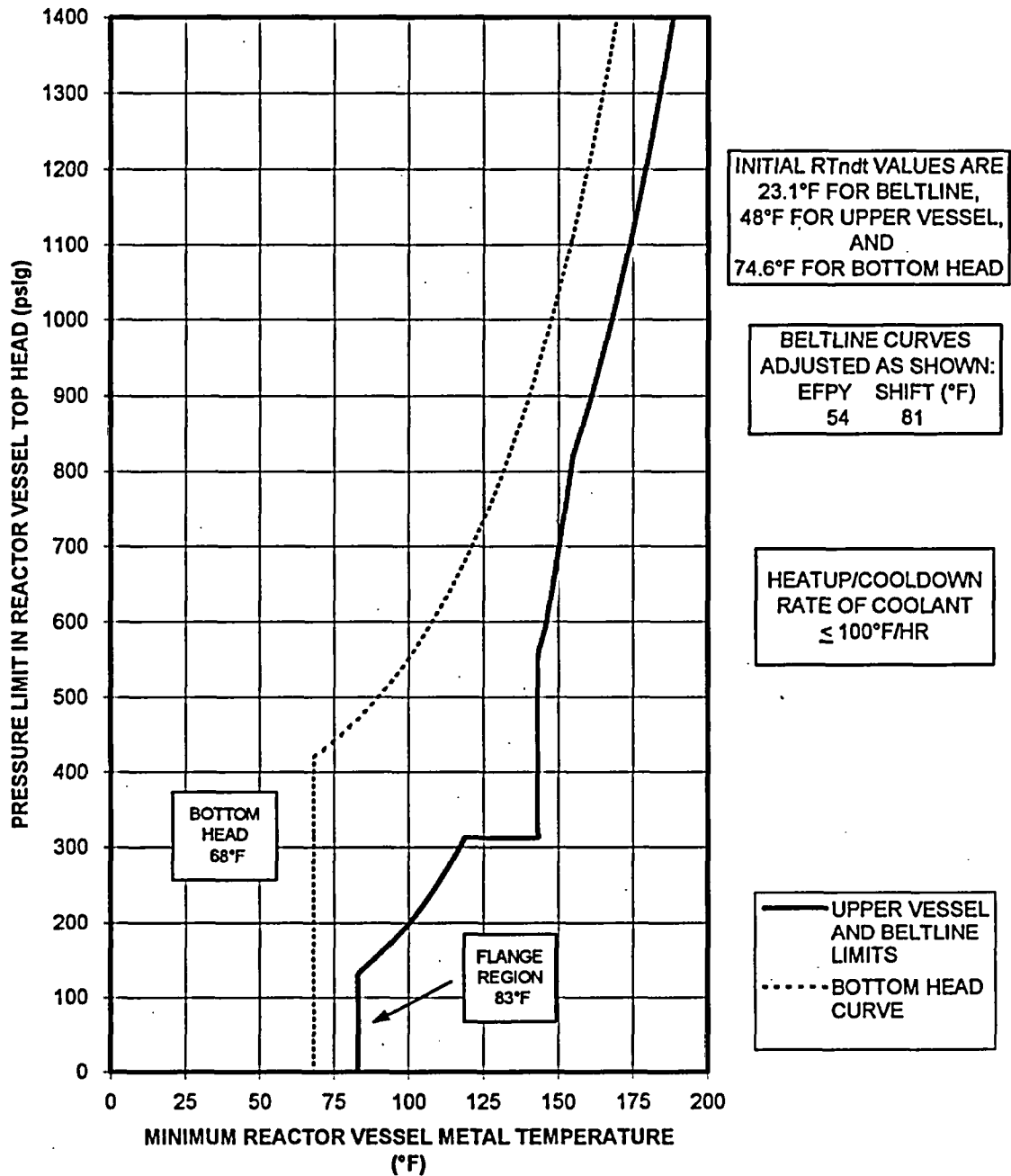


Figure G-14: Bounding Quad Cities 1&2 Composite Core Not Critical P-T Curves [Curve B]  
up to 54 EFPY [100°F/hr or less coolant heatup/cooldown]

## Non-Proprietary Version

TABLE G-2. Bounding Quad Cities 1&amp;2 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-1, G-2, G-3, G-5, G-6 and G-7

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	32 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	32 EFPY BELTLINE CURVE B (°F)
0	68.0	83.1	83.1	68.0	83.1	83.1
10	68.0	83.1	83.1	68.0	83.1	83.1
20	68.0	83.1	83.1	68.0	83.1	83.1
30	68.0	83.1	83.1	68.0	83.1	83.1
40	68.0	83.1	83.1	68.0	83.1	83.1
50	68.0	83.1	83.1	68.0	83.1	83.1
60	68.0	83.1	83.1	68.0	83.1	83.1
70	68.0	83.1	83.1	68.0	83.1	83.1
80	68.0	83.1	83.1	68.0	83.1	83.1
90	68.0	83.1	83.1	68.0	83.1	83.1
100	68.0	83.1	83.1	68.0	83.1	83.1
110	68.0	83.1	83.1	68.0	83.1	83.1
120	68.0	83.1	83.1	68.0	83.1	83.1
130	68.0	83.1	83.1	68.0	83.1	83.1
140	68.0	83.1	83.1	68.0	85.4	83.1
150	68.0	83.1	83.1	68.0	88.2	83.1
160	68.0	83.1	83.1	68.0	90.9	83.1
170	68.0	83.1	83.1	68.0	93.5	83.1
180	68.0	83.1	83.1	68.0	95.9	83.1
190	68.0	83.1	83.1	68.0	98.2	83.1
200	68.0	83.1	83.1	68.0	100.3	83.1
210	68.0	83.1	83.1	68.0	102.3	83.1
220	68.0	83.1	83.1	68.0	104.3	83.1
230	68.0	83.1	83.1	68.0	106.1	83.1
240	68.0	83.1	83.1	68.0	107.9	83.1

## Non-Proprietary Version

TABLE G-2. Bounding Quad Cities 1&amp;2 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-1, G-2, G-3, G-5, G-6 and G-7

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	32 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	32 EFPY BELTLINE CURVE B (°F)
250	68.0	83.1	83.1	68.0	109.6	83.1
260	68.0	83.1	83.1	68.0	111.2	83.1
270	68.0	83.1	83.1	68.0	112.8	83.1
280	68.0	83.1	83.1	68.0	114.3	83.1
290	68.0	83.1	83.1	68.0	115.8	83.1
300	68.0	83.1	83.1	68.0	117.2	83.1
310	68.0	83.1	83.1	68.0	118.5	83.1
312.5	68.0	83.1	83.1	68.0	118.9	83.1
312.5	68.0	113.1	113.1	68.0	143.1	143.1
320	68.0	113.1	113.1	68.0	143.1	143.1
330	68.0	113.1	113.1	68.0	143.1	143.1
340	68.0	113.1	113.1	68.0	143.1	143.1
350	68.0	113.1	113.1	68.0	143.1	143.1
360	68.0	113.1	113.1	68.0	143.1	143.1
370	68.0	113.1	113.1	68.0	143.1	143.1
380	68.0	113.1	113.1	68.0	143.1	143.1
390	68.0	113.1	113.1	68.0	143.1	143.1
400	68.0	113.1	113.1	68.0	143.1	143.1
410	68.0	113.1	113.1	68.0	143.1	143.1
420	68.0	113.1	113.1	68.1	143.1	143.1
430	68.0	113.1	113.1	71.4	143.1	143.1
440	68.0	113.1	113.1	74.4	143.1	143.1
450	68.0	113.1	113.1	77.3	143.1	143.1
460	68.0	113.1	113.1	80.0	143.1	143.1
470	68.0	113.1	113.1	82.6	143.1	143.1
480	68.0	113.1	113.1	85.1	143.1	143.1
490	68.0	113.1	113.1	87.4	143.1	143.1

## Non-Proprietary Version

TABLE G-2. Bounding Quad Cities 1&amp;2 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-1, G-2, G-3, G-5, G-6 and G-7

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	32 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	32 EFPY BELTLINE CURVE B (°F)
500	68.0	113.1	113.1	89.6	143.1	143.1
510	68.0	113.1	113.1	91.8	143.1	143.1
520	68.0	113.1	113.1	93.8	143.1	143.1
530	68.0	113.1	113.1	95.8	143.1	143.1
540	68.0	113.1	113.1	97.7	143.1	143.1
550	68.0	113.1	113.1	99.5	143.1	143.1
560	68.0	113.1	113.1	101.3	143.4	143.1
570	68.0	113.1	113.1	103.0	144.1	143.1
580	68.0	113.1	113.1	104.6	144.9	143.1
590	68.0	113.1	113.1	106.2	145.6	143.1
600	68.0	113.1	113.1	107.8	146.1	143.1
610	68.0	113.1	113.1	109.3	146.6	143.1
620	68.0	113.1	113.1	110.7	147.0	143.1
630	68.6	113.1	113.1	112.1	147.4	143.1
640	70.5	113.1	113.1	113.5	147.8	143.1
650	72.2	113.1	113.1	114.8	148.2	143.1
660	73.9	113.1	113.1	116.1	148.7	143.1
670	75.6	113.1	113.1	117.4	149.1	143.1
680	77.2	113.1	113.1	118.7	149.5	143.1
690	78.7	113.1	113.1	119.9	149.9	143.1
700	80.2	113.1	113.1	121.0	150.3	143.1
710	81.7	113.1	113.1	122.2	150.7	143.1
720	83.1	113.1	113.1	123.3	151.1	143.1
730	84.5	113.1	113.1	124.4	151.5	143.1
740	85.8	113.1	113.1	125.5	151.9	143.1
750	87.1	113.1	113.1	126.6	152.2	143.1
760	88.4	113.1	113.1	127.6	152.6	143.1

## Non-Proprietary Version

TABLE G-2. Bounding Quad Cities 1&amp;2 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-1, G-2, G-3, G-5, G-6 and G-7

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	32 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	32 EFPY BELTLINE CURVE B (°F)
770	89.6	113.6	113.1	128.6	153.0	143.1
780	90.8	114.3	113.1	129.6	153.4	143.1
790	92.0	115.1	113.1	130.6	153.8	143.1
800	93.2	115.9	113.1	131.5	154.1	143.1
810	94.3	116.6	113.1	132.5	154.5	143.1
820	95.4	117.4	113.1	133.4	154.9	143.1
830	96.5	118.1	113.1	134.3	155.2	143.1
840	97.5	118.8	113.1	135.2	155.6	143.1
850	98.6	119.5	113.1	136.0	155.9	143.1
860	99.6	120.2	113.1	136.9	156.3	143.1
870	100.6	120.9	113.1	137.7	156.6	143.1
880	101.5	121.6	113.1	138.6	157.0	143.1
890	102.5	122.3	113.1	139.4	157.3	143.1
900	103.4	122.9	113.1	140.2	157.7	143.1
910	104.4	123.6	113.1	141.0	158.0	143.8
920	105.3	124.2	113.1	141.7	158.4	144.5
930	106.1	124.9	113.9	142.5	158.7	145.2
940	107.0	125.5	114.9	143.3	159.0	145.9
950	107.9	126.1	115.8	144.0	159.4	146.6
960	108.7	126.7	116.8	144.7	159.7	147.2
970	109.6	127.3	117.7	145.5	160.0	147.9
980	110.4	127.9	118.6	146.2	160.4	148.5
990	111.2	128.5	119.4	146.9	160.7	149.2
1000	112.0	129.1	120.3	147.6	161.0	149.8
1010	112.7	129.7	121.1	148.2	161.3	150.5
1020	113.5	130.2	122.0	148.9	161.6	151.1
1030	114.3	130.8	122.8	149.6	162.0	151.7

## Non-Proprietary Version

TABLE G-2. Bounding Quad Cities 1&amp;2 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-1, G-2, G-3, G-5, G-6 and G-7

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	32 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	32 EFPY BELTLINE CURVE B (°F)
1040	115.0	131.4	123.6	150.2	162.3	152.3
1050	115.7	131.9	124.4	150.9	162.6	152.9
1060	116.4	132.5	125.2	151.5	162.9	153.5
1070	117.2	133.0	126.0	152.1	163.2	154.1
1080	117.9	133.5	126.7	152.8	163.5	154.7
1090	118.6	134.1	127.5	153.4	163.8	155.2
1100	119.2	134.6	128.2	154.0	164.1	155.8
1105	119.6	134.8	128.6	154.3	164.3	156.1
1110	119.9	135.1	128.9	154.6	164.4	156.3
1120	120.6	135.6	129.6	155.2	164.7	156.9
1130	121.2	136.1	130.4	155.8	165.0	157.4
1140	121.9	136.6	131.1	156.3	165.3	158.0
1150	122.5	137.1	131.7	156.9	165.6	158.5
1160	123.1	137.6	132.4	157.5	165.9	159.0
1170	123.8	138.1	133.1	158.0	166.2	159.6
1180	124.4	138.6	133.7	158.6	166.5	160.1
1190	125.0	139.1	134.4	159.1	166.7	160.6
1200	125.6	139.5	135.0	159.7	167.0	161.1
1210	126.2	140.0	135.7	160.2	167.3	161.6
1220	126.8	140.5	136.3	160.8	167.6	162.1
1230	127.3	140.9	136.9	161.3	167.9	162.6
1240	127.9	141.4	137.5	161.8	168.2	163.1
1250	128.5	141.8	138.1	162.3	168.4	163.6
1260	129.0	142.3	138.7	162.8	168.7	164.1
1270	129.6	142.7	139.3	163.3	169.0	164.5
1280	130.1	143.2	139.9	163.8	169.2	165.0
1290	130.7	143.6	140.5	164.3	169.5	165.5

## Non-Proprietary Version

TABLE G-2. Bounding Quad Cities 1&amp;2 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-1, G-2, G-3, G-5, G-6 and G-7

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	32 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	32 EFPY BELTLINE CURVE B (°F)
1300	131.2	144.0	141.0	164.8	169.8	165.9
1310	131.7	144.5	141.6	165.3	170.1	166.4
1320	132.3	144.9	142.2	165.8	170.3	166.8
1330	132.8	145.3	142.7	166.2	170.6	167.3
1340	133.3	145.7	143.3	166.7	170.8	167.7
1350	133.8	146.1	143.8	167.2	171.1	168.2
1360	134.3	146.6	144.3	167.6	171.4	168.6
1370	134.8	147.0	144.9	168.1	171.6	169.0
1380	135.3	147.4	145.4	168.5	171.9	169.5
1390	135.8	147.8	145.9	169.0	172.1	169.9
1400	136.3	148.2	146.4	169.4	172.4	170.3



## Non-Proprietary Version

TABLE G-3. Bounding Quad Cities 1&2  
Composite P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-9, G-11 and G-12

PRESSURE (PSIG)	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	UPPER RPV & BELTLINE AT 32 EFPY
	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
0	68.0	83.1	68.0	83.1	83.1
10	68.0	83.1	68.0	83.1	83.1
20	68.0	83.1	68.0	83.1	83.1
30	68.0	83.1	68.0	83.1	83.1
40	68.0	83.1	68.0	83.1	83.1
50	68.0	83.1	68.0	83.1	83.1
60	68.0	83.1	68.0	83.1	88.0
70	68.0	83.1	68.0	83.1	95.2
80	68.0	83.1	68.0	83.1	101.2
90	68.0	83.1	68.0	83.1	106.3
100	68.0	83.1	68.0	83.1	110.8
110	68.0	83.1	68.0	83.1	114.9
120	68.0	83.1	68.0	83.1	118.7
130	68.0	83.1	68.0	83.1	122.2
140	68.0	83.1	68.0	85.4	125.4
150	68.0	83.1	68.0	88.2	128.2
160	68.0	83.1	68.0	90.9	130.9
170	68.0	83.1	68.0	93.5	133.5
180	68.0	83.1	68.0	95.9	135.9
190	68.0	83.1	68.0	98.2	138.2
200	68.0	83.1	68.0	100.3	140.3
210	68.0	83.1	68.0	102.3	142.3

## Non-Proprietary Version

TABLE G-3. Bounding Quad Cities 1&2  
Composite P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-9, G-11 and G-12

PRESSURE (PSIG)	BOTTOM HEAD CURVE A	UPPER RPV & BELTLINE AT 32 EFPY CURVE A	BOTTOM HEAD CURVE B	UPPER RPV & BELTLINE AT 32 EFPY CURVE B	UPPER RPV & BELTLINE AT 32 EFPY CURVE C
	(°F)	(°F)	(°F)	(°F)	(°F)
220	68.0	83.1	68.0	104.3	144.3
230	68.0	83.1	68.0	106.1	146.1
240	68.0	83.1	68.0	107.9	147.9
250	68.0	83.1	68.0	109.6	149.6
260	68.0	83.1	68.0	111.2	151.2
270	68.0	83.1	68.0	112.8	152.8
280	68.0	83.1	68.0	114.3	154.3
290	68.0	83.1	68.0	115.8	155.8
300	68.0	83.1	68.0	117.2	157.2
310	68.0	83.1	68.0	118.5	158.5
312.5	68.0	83.1	68.0	118.9	158.9
312.5	68.0	113.1	68.0	143.1	183.1
320	68.0	113.1	68.0	143.1	183.1
330	68.0	113.1	68.0	143.1	183.1
340	68.0	113.1	68.0	143.1	183.1
350	68.0	113.1	68.0	143.1	183.1
360	68.0	113.1	68.0	143.1	183.1
370	68.0	113.1	68.0	143.1	183.1
380	68.0	113.1	68.0	143.1	183.1
390	68.0	113.1	68.0	143.1	183.1
400	68.0	113.1	68.0	143.1	183.1
410	68.0	113.1	68.0	143.1	183.1
420	68.0	113.1	68.1	143.1	183.1

## Non-Proprietary Version

TABLE G-3. Bounding Quad Cities 1&2  
Composite P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-9, G-11 and G-12

PRESSURE (PSIG)	BOTTOM HEAD CURVE A	UPPER RPV & BELTLINE AT 32 EFPY CURVE A	BOTTOM HEAD CURVE B	UPPER RPV & BELTLINE AT 32 EFPY CURVE B	UPPER RPV & BELTLINE AT 32 EFPY CURVE C
	(°F)	(°F)	(°F)	(°F)	(°F)
430	68.0	113.1	71.4	143.1	183.1
440	68.0	113.1	74.4	143.1	183.1
450	68.0	113.1	77.3	143.1	183.1
460	68.0	113.1	80.0	143.1	183.1
470	68.0	113.1	82.6	143.1	183.1
480	68.0	113.1	85.1	143.1	183.1
490	68.0	113.1	87.4	143.1	183.1
500	68.0	113.1	89.6	143.1	183.1
510	68.0	113.1	91.8	143.1	183.1
520	68.0	113.1	93.8	143.1	183.1
530	68.0	113.1	95.8	143.1	183.1
540	68.0	113.1	97.7	143.1	183.1
550	68.0	113.1	99.5	143.1	183.1
560	68.0	113.1	101.3	143.4	183.4
570	68.0	113.1	103.0	144.1	184.1
580	68.0	113.1	104.6	144.9	184.9
590	68.0	113.1	106.2	145.6	185.6
600	68.0	113.1	107.8	146.1	186.1
610	68.0	113.1	109.3	146.6	186.6
620	68.0	113.1	110.7	147.0	187.0
630	68.6	113.1	112.1	147.4	187.4
640	70.5	113.1	113.5	147.8	187.8
650	72.2	113.1	114.8	148.2	188.2

## Non-Proprietary Version

TABLE G-3. Bounding Quad Cities 1&2  
Composite P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-9, G-11 and G-12

PRESSURE (PSIG)	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	UPPER RPV & BELTLINE AT 32 EFPY
	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
660	73.9	113.1	116.1	148.7	188.7
670	75.6	113.1	117.4	149.1	189.1
680	77.2	113.1	118.7	149.5	189.5
690	78.7	113.1	119.9	149.9	189.9
700	80.2	113.1	121.0	150.3	190.3
710	81.7	113.1	122.2	150.7	190.7
720	83.1	113.1	123.3	151.1	191.1
730	84.5	113.1	124.4	151.5	191.5
740	85.8	113.1	125.5	151.9	191.9
750	87.1	113.1	126.6	152.2	192.2
760	88.4	113.1	127.6	152.6	192.6
770	89.6	113.6	128.6	153.0	193.0
780	90.8	114.3	129.6	153.4	193.4
790	92.0	115.1	130.6	153.8	193.8
800	93.2	115.9	131.5	154.1	194.1
810	94.3	116.6	132.5	154.5	194.5
820	95.4	117.4	133.4	154.9	194.9
830	96.5	118.1	134.3	155.2	195.2
840	97.5	118.8	135.2	155.6	195.6
850	98.6	119.5	136.0	155.9	195.9
860	99.6	120.2	136.9	156.3	196.3
870	100.6	120.9	137.7	156.6	196.6
880	101.5	121.6	138.6	157.0	197.0

## Non-Proprietary Version

TABLE G-3. Bounding Quad Cities 1&2  
Composite P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-9, G-11 and G-12

PRESSURE (PSIG)	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	UPPER RPV & BELTLINE AT 32 EFPY
	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
890	102.5	122.3	139.4	157.3	197.3
900	103.4	122.9	140.2	157.7	197.7
910	104.4	123.6	141.0	158.0	198.0
920	105.3	124.2	141.7	158.4	198.4
930	106.1	124.9	142.5	158.7	198.7
940	107.0	125.5	143.3	159.0	199.0
950	107.9	126.1	144.0	159.4	199.4
960	108.7	126.7	144.7	159.7	199.7
970	109.6	127.3	145.5	160.0	200.0
980	110.4	127.9	146.2	160.4	200.4
990	111.2	128.5	146.9	160.7	200.7
1000	112.0	129.1	147.6	161.0	201.0
1010	112.7	129.7	148.2	161.3	201.3
1020	113.5	130.2	148.9	161.6	201.6
1030	114.3	130.8	149.6	162.0	202.0
1040	115.0	131.4	150.2	162.3	202.3
1050	115.7	131.9	150.9	162.6	202.6
1060	116.4	132.5	151.5	162.9	202.9
1070	117.2	133.0	152.1	163.2	203.2
1080	117.9	133.5	152.8	163.5	203.5
1090	118.6	134.1	153.4	163.8	203.8
1100	119.2	134.6	154.0	164.1	204.1
1105	119.6	134.8	154.3	164.3	204.3

## Non-Proprietary Version

TABLE G-3. Bounding Quad Cities 1&2  
Composite P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-9, G-11 and G-12

PRESSURE (PSIG)	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	UPPER RPV & BELTLINE AT 32 EFPY
	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
1110	119.9	135.1	154.6	164.4	204.4
1120	120.6	135.6	155.2	164.7	204.7
1130	121.2	136.1	155.8	165.0	205.0
1140	121.9	136.6	156.3	165.3	205.3
1150	122.5	137.1	156.9	165.6	205.6
1160	123.1	137.6	157.5	165.9	205.9
1170	123.8	138.1	158.0	166.2	206.2
1180	124.4	138.6	158.6	166.5	206.5
1190	125.0	139.1	159.1	166.7	206.7
1200	125.6	139.5	159.7	167.0	207.0
1210	126.2	140.0	160.2	167.3	207.3
1220	126.8	140.5	160.8	167.6	207.6
1230	127.3	140.9	161.3	167.9	207.9
1240	127.9	141.4	161.8	168.2	208.2
1250	128.5	141.8	162.3	168.4	208.4
1260	129.0	142.3	162.8	168.7	208.7
1270	129.6	142.7	163.3	169.0	209.0
1280	130.1	143.2	163.8	169.2	209.2
1290	130.7	143.6	164.3	169.5	209.5
1300	131.2	144.0	164.8	169.8	209.8
1310	131.7	144.5	165.3	170.1	210.1
1320	132.3	144.9	165.8	170.3	210.3
1330	132.8	145.3	166.2	170.6	210.6

## Non-Proprietary Version

**TABLE G-3. Bounding Quad Cities 1&2  
Composite P-T Curve Values for 32 EFPY**

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-9, G-11 and G-12

PRESSURE (PSIG)	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	UPPER RPV & BELTLINE AT 32 EFPY
	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
1340	133.3	145.7	166.7	170.8	210.8
1350	133.8	146.1	167.2	171.1	211.1
1360	134.3	146.6	167.6	171.4	211.4
1370	134.8	147.0	168.1	171.6	211.6
1380	135.3	147.4	168.5	171.9	211.9
1390	135.8	147.8	169.0	172.1	212.1
1400	136.3	148.2	169.4	172.4	212.4

## Non-Proprietary Version

TABLE G-4. Bounding Quad Cities 1&amp;2 P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-1, G-2, G-4, G-5, G-6 and G-8

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	54 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	54 EFPY BELTLINE CURVE B (°F)
0	68.0	83.1	83.1	68.0	83.1	83.1
10	68.0	83.1	83.1	68.0	83.1	83.1
20	68.0	83.1	83.1	68.0	83.1	83.1
30	68.0	83.1	83.1	68.0	83.1	83.1
40	68.0	83.1	83.1	68.0	83.1	83.1
50	68.0	83.1	83.1	68.0	83.1	83.1
60	68.0	83.1	83.1	68.0	83.1	83.1
70	68.0	83.1	83.1	68.0	83.1	83.1
80	68.0	83.1	83.1	68.0	83.1	83.1
90	68.0	83.1	83.1	68.0	83.1	83.1
100	68.0	83.1	83.1	68.0	83.1	83.1
110	68.0	83.1	83.1	68.0	83.1	83.1
120	68.0	83.1	83.1	68.0	83.1	83.1
130	68.0	83.1	83.1	68.0	83.1	83.1
140	68.0	83.1	83.1	68.0	85.4	83.1
150	68.0	83.1	83.1	68.0	88.2	83.1
160	68.0	83.1	83.1	68.0	90.9	83.1
170	68.0	83.1	83.1	68.0	93.5	83.1
180	68.0	83.1	83.1	68.0	95.9	83.1
190	68.0	83.1	83.1	68.0	98.2	83.1
200	68.0	83.1	83.1	68.0	100.3	83.1
210	68.0	83.1	83.1	68.0	102.3	83.1
220	68.0	83.1	83.1	68.0	104.3	83.1
230	68.0	83.1	83.1	68.0	106.1	83.1
240	68.0	83.1	83.1	68.0	107.9	83.1



## Non-Proprietary Version

TABLE G-4. Bounding Quad Cities 1&amp;2 P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-1, G-2, G-4, G-5, G-6 and G-8

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	54 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	54 EFPY BELTLINE CURVE B (°F)
250	68.0	83.1	83.1	68.0	109.6	83.1
260	68.0	83.1	83.1	68.0	111.2	83.1
270	68.0	83.1	83.1	68.0	112.8	83.1
280	68.0	83.1	83.1	68.0	114.3	83.1
290	68.0	83.1	83.1	68.0	115.8	83.1
300	68.0	83.1	83.1	68.0	117.2	83.1
310	68.0	83.1	83.1	68.0	118.5	83.1
312.5	68.0	83.1	83.1	68.0	118.9	83.1
312.5	68.0	113.1	113.1	68.0	143.1	143.1
320	68.0	113.1	113.1	68.0	143.1	143.1
330	68.0	113.1	113.1	68.0	143.1	143.1
340	68.0	113.1	113.1	68.0	143.1	143.1
350	68.0	113.1	113.1	68.0	143.1	143.1
360	68.0	113.1	113.1	68.0	143.1	143.1
370	68.0	113.1	113.1	68.0	143.1	143.1
380	68.0	113.1	113.1	68.0	143.1	143.1
390	68.0	113.1	113.1	68.0	143.1	143.1
400	68.0	113.1	113.1	68.0	143.1	143.1
410	68.0	113.1	113.1	68.0	143.1	143.1
420	68.0	113.1	113.1	68.1	143.1	143.1
430	68.0	113.1	113.1	71.4	143.1	143.1
440	68.0	113.1	113.1	74.4	143.1	143.1
450	68.0	113.1	113.1	77.3	143.1	143.1
460	68.0	113.1	113.1	80.0	143.1	143.1
470	68.0	113.1	113.1	82.6	143.1	143.1
480	68.0	113.1	113.1	85.1	143.1	143.1
490	68.0	113.1	113.1	87.4	143.1	143.1

## Non-Proprietary Version

TABLE G-4. Bounding Quad Cities 1&amp;2 P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-1, G-2, G-4, G-5, G-6 and G-8

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	54 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	54 EFPY BELTLINE CURVE B (°F)
500	68.0	113.1	113.1	89.6	143.1	143.1
510	68.0	113.1	113.1	91.8	143.1	143.1
520	68.0	113.1	113.1	93.8	143.1	143.1
530	68.0	113.1	113.1	95.8	143.1	143.1
540	68.0	113.1	113.1	97.7	143.1	143.1
550	68.0	113.1	113.1	99.5	143.1	143.1
560	68.0	113.1	113.1	101.3	143.4	143.1
570	68.0	113.1	113.1	103.0	144.1	143.1
580	68.0	113.1	113.1	104.6	144.9	143.1
590	68.0	113.1	113.1	106.2	145.6	143.1
600	68.0	113.1	113.1	107.8	146.1	143.1
610	68.0	113.1	113.1	109.3	146.6	143.1
620	68.0	113.1	113.1	110.7	147.0	143.1
630	68.6	113.1	113.1	112.1	147.4	143.1
640	70.5	113.1	113.1	113.5	147.8	143.1
650	72.2	113.1	113.1	114.8	148.2	143.1
660	73.9	113.1	113.1	116.1	148.7	143.1
670	75.6	113.1	113.1	117.4	149.1	143.1
680	77.2	113.1	113.1	118.7	149.5	143.1
690	78.7	113.1	113.1	119.9	149.9	143.1
700	80.2	113.1	113.1	121.0	150.3	144.0
710	81.7	113.1	113.1	122.2	150.7	145.0
720	83.1	113.1	113.1	123.3	151.1	146.0
730	84.5	113.1	113.1	124.4	151.5	146.9
740	85.8	113.1	113.1	125.5	151.9	147.9
750	87.1	113.1	113.1	126.6	152.2	148.8
760	88.4	113.1	113.1	127.6	152.6	149.7

## Non-Proprietary Version

TABLE G-4. Bounding Quad Cities 1&amp;2 P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-1, G-2, G-4, G-5, G-6 and G-8

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	54 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	54 EFPY BELTLINE CURVE B (°F)
770	89.6	113.6	113.2	128.6	153.0	150.6
780	90.8	114.3	114.6	129.6	153.4	151.5
790	92.0	115.1	116.0	130.6	153.8	152.4
800	93.2	115.9	117.3	131.5	154.1	153.2
810	94.3	116.6	118.6	132.5	154.5	154.1
820	95.4	117.4	119.9	133.4	154.9	154.9
830	96.5	118.1	121.1	134.3	155.2	155.7
840	97.5	118.8	122.3	135.2	155.6	156.5
850	98.6	119.5	123.4	136.0	155.9	157.3
860	99.6	120.2	124.6	136.9	156.3	158.1
870	100.6	120.9	125.7	137.7	156.6	158.8
880	101.5	121.6	126.8	138.6	157.0	159.6
890	102.5	122.3	127.9	139.4	157.3	160.3
900	103.4	122.9	128.9	140.2	157.7	161.1
910	104.4	123.6	129.9	141.0	158.0	161.8
920	105.3	124.2	130.9	141.7	158.4	162.5
930	106.1	124.9	131.9	142.5	158.7	163.2
940	107.0	125.5	132.9	143.3	159.0	163.9
950	107.9	126.1	133.8	144.0	159.4	164.6
960	108.7	126.7	134.8	144.7	159.7	165.2
970	109.6	127.3	135.7	145.5	160.0	165.9
980	110.4	127.9	136.6	146.2	160.4	166.5
990	111.2	128.5	137.4	146.9	160.7	167.2
1000	112.0	129.1	138.3	147.6	161.0	167.8
1010	112.7	129.7	139.1	148.2	161.3	168.5
1020	113.5	130.2	140.0	148.9	161.6	169.1
1030	114.3	130.8	140.8	149.6	162.0	169.7

## Non-Proprietary Version

TABLE G-4. Bounding Quad Cities 1&amp;2 P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-1, G-2, G-4, G-5, G-6 and G-8

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	54 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	54 EFPY BELTLINE CURVE B (°F)
1040	115.0	131.4	141.6	150.2	162.3	170.3
1050	115.7	131.9	142.4	150.9	162.6	170.9
1060	116.4	132.5	143.2	151.5	162.9	171.5
1070	117.2	133.0	144.0	152.1	163.2	172.1
1080	117.9	133.5	144.7	152.8	163.5	172.7
1090	118.6	134.1	145.5	153.4	163.8	173.2
1100	119.2	134.6	146.2	154.0	164.1	173.8
1105	119.6	134.8	146.6	154.3	164.3	174.1
1110	119.9	135.1	146.9	154.6	164.4	174.3
1120	120.6	135.6	147.6	155.2	164.7	174.9
1130	121.2	136.1	148.4	155.8	165.0	175.4
1140	121.9	136.6	149.1	156.3	165.3	176.0
1150	122.5	137.1	149.7	156.9	165.6	176.5
1160	123.1	137.6	150.4	157.5	165.9	177.0
1170	123.8	138.1	151.1	158.0	166.2	177.6
1180	124.4	138.6	151.7	158.6	166.5	178.1
1190	125.0	139.1	152.4	159.1	166.7	178.6
1200	125.6	139.5	153.0	159.7	167.0	179.1
1210	126.2	140.0	153.7	160.2	167.3	179.6
1220	126.8	140.5	154.3	160.8	167.6	180.1
1230	127.3	140.9	154.9	161.3	167.9	180.6
1240	127.9	141.4	155.5	161.8	168.2	181.1
1250	128.5	141.8	156.1	162.3	168.4	181.6
1260	129.0	142.3	156.7	162.8	168.7	182.1
1270	129.6	142.7	157.3	163.3	169.0	182.5
1280	130.1	143.2	157.9	163.8	169.2	183.0
1290	130.7	143.6	158.5	164.3	169.5	183.5

## Non-Proprietary Version

TABLE G-4. Bounding Quad Cities 1&amp;2 P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-1, G-2, G-4, G-5, G-6 and G-8

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	54 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	54 EFPY BELTLINE CURVE B (°F)
1300	131.2	144.0	159.0	164.8	169.8	183.9
1310	131.7	144.5	159.6	165.3	170.1	184.4
1320	132.3	144.9	160.2	165.8	170.3	184.8
1330	132.8	145.3	160.7	166.2	170.6	185.3
1340	133.3	145.7	161.3	166.7	170.8	185.7
1350	133.8	146.1	161.8	167.2	171.1	186.2
1360	134.3	146.6	162.3	167.6	171.4	186.6
1370	134.8	147.0	162.9	168.1	171.6	187.0
1380	135.3	147.4	163.4	168.5	171.9	187.5
1390	135.8	147.8	163.9	169.0	172.1	187.9
1400	136.3	148.2	164.4	169.4	172.4	188.3

## Non-Proprietary Version

TABLE G-5. Bounding Quad Cities 1&2  
Composite P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-10, G-13 and G-14

PRESSURE (PSIG)	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	UPPER RPV & BELTLINE AT 54 EFPY
	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
0	68.0	83.1	68.0	83.1	83.1
10	68.0	83.1	68.0	83.1	83.1
20	68.0	83.1	68.0	83.1	83.1
30	68.0	83.1	68.0	83.1	83.1
40	68.0	83.1	68.0	83.1	83.1
50	68.0	83.1	68.0	83.1	83.1
60	68.0	83.1	68.0	83.1	88.0
70	68.0	83.1	68.0	83.1	95.2
80	68.0	83.1	68.0	83.1	101.2
90	68.0	83.1	68.0	83.1	106.3
100	68.0	83.1	68.0	83.1	110.8
110	68.0	83.1	68.0	83.1	114.9
120	68.0	83.1	68.0	83.1	118.7
130	68.0	83.1	68.0	83.1	122.2
140	68.0	83.1	68.0	85.4	125.4
150	68.0	83.1	68.0	88.2	128.2
160	68.0	83.1	68.0	90.9	130.9
170	68.0	83.1	68.0	93.5	133.5
180	68.0	83.1	68.0	95.9	135.9
190	68.0	83.1	68.0	98.2	138.2
200	68.0	83.1	68.0	100.3	140.3
210	68.0	83.1	68.0	102.3	142.3

## Non-Proprietary Version

TABLE G-5. Bounding Quad Cities 1&2  
Composite P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-10, G-13 and G-14

PRESSURE (PSIG)	BOTTOM HEAD CURVE A	UPPER RPV & BELTLINE AT 54 EFPY CURVE A	BOTTOM HEAD CURVE B	UPPER RPV & BELTLINE AT 54 EFPY CURVE B	UPPER RPV & BELTLINE AT 54 EFPY CURVE C
	(°F)	(°F)	(°F)	(°F)	(°F)
220	68.0	83.1	68.0	104.3	144.3
230	68.0	83.1	68.0	106.1	146.1
240	68.0	83.1	68.0	107.9	147.9
250	68.0	83.1	68.0	109.6	149.6
260	68.0	83.1	68.0	111.2	151.2
270	68.0	83.1	68.0	112.8	152.8
280	68.0	83.1	68.0	114.3	154.3
290	68.0	83.1	68.0	115.8	155.8
300	68.0	83.1	68.0	117.2	157.2
310	68.0	83.1	68.0	118.5	158.5
312.5	68.0	83.1	68.0	118.9	158.9
312.5	68.0	113.1	68.0	143.1	183.1
320	68.0	113.1	68.0	143.1	183.1
330	68.0	113.1	68.0	143.1	183.1
340	68.0	113.1	68.0	143.1	183.1
350	68.0	113.1	68.0	143.1	183.1
360	68.0	113.1	68.0	143.1	183.1
370	68.0	113.1	68.0	143.1	183.1
380	68.0	113.1	68.0	143.1	183.1
390	68.0	113.1	68.0	143.1	183.1
400	68.0	113.1	68.0	143.1	183.1
410	68.0	113.1	68.0	143.1	183.1
420	68.0	113.1	68.1	143.1	183.1

## Non-Proprietary Version

TABLE G-5. Bounding Quad Cities 1&2  
Composite P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-10, G-13 and G-14

PRESSURE (PSIG)	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	UPPER RPV & BELTLINE AT 54 EFPY
	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
430	68.0	113.1	71.4	143.1	183.1
440	68.0	113.1	74.4	143.1	183.1
450	68.0	113.1	77.3	143.1	183.1
460	68.0	113.1	80.0	143.1	183.1
470	68.0	113.1	82.6	143.1	183.1
480	68.0	113.1	85.1	143.1	183.1
490	68.0	113.1	87.4	143.1	183.1
500	68.0	113.1	89.6	143.1	183.1
510	68.0	113.1	91.8	143.1	183.1
520	68.0	113.1	93.8	143.1	183.1
530	68.0	113.1	95.8	143.1	183.1
540	68.0	113.1	97.7	143.1	183.1
550	68.0	113.1	99.5	143.1	183.1
560	68.0	113.1	101.3	143.4	183.4
570	68.0	113.1	103.0	144.1	184.1
580	68.0	113.1	104.6	144.9	184.9
590	68.0	113.1	106.2	145.6	185.6
600	68.0	113.1	107.8	146.1	186.1
610	68.0	113.1	109.3	146.6	186.6
620	68.0	113.1	110.7	147.0	187.0
630	68.6	113.1	112.1	147.4	187.4
640	70.5	113.1	113.5	147.8	187.8
650	72.2	113.1	114.8	148.2	188.2



## Non-Proprietary Version

TABLE G-5. Bounding Quad Cities 1&2  
Composite P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-10, G-13 and G-14

PRESSURE (PSIG)	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	UPPER RPV & BELTLINE AT 54 EFPY
	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
660	73.9	113.1	116.1	148.7	188.7
670	75.6	113.1	117.4	149.1	189.1
680	77.2	113.1	118.7	149.5	189.5
690	78.7	113.1	119.9	149.9	189.9
700	80.2	113.1	121.0	150.3	190.3
710	81.7	113.1	122.2	150.7	190.7
720	83.1	113.1	123.3	151.1	191.1
730	84.5	113.1	124.4	151.5	191.5
740	85.8	113.1	125.5	151.9	191.9
750	87.1	113.1	126.6	152.2	192.2
760	88.4	113.1	127.6	152.6	192.6
770	89.6	113.6	128.6	153.0	193.0
780	90.8	114.6	129.6	153.4	193.4
790	92.0	116.0	130.6	153.8	193.8
800	93.2	117.3	131.5	154.1	194.1
810	94.3	118.6	132.5	154.5	194.5
820	95.4	119.9	133.4	154.9	194.9
830	96.5	121.1	134.3	155.7	195.7
840	97.5	122.3	135.2	156.5	196.5
850	98.6	123.4	136.0	157.3	197.3
860	99.6	124.6	136.9	158.1	198.1
870	100.6	125.7	137.7	158.8	198.8
880	101.5	126.8	138.6	159.6	199.6

## Non-Proprietary Version

TABLE G-5. Bounding Quad Cities 1&2  
Composite P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-10, G-13 and G-14

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 54 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 54 EFPY CURVE B (°F)	UPPER RPV & BELTLINE AT 54 EFPY CURVE C (°F)
890	102.5	127.9	139.4	160.3	200.3
900	103.4	128.9	140.2	161.1	201.1
910	104.4	129.9	141.0	161.8	201.8
920	105.3	130.9	141.7	162.5	202.5
930	106.1	131.9	142.5	163.2	203.2
940	107.0	132.9	143.3	163.9	203.9
950	107.9	133.8	144.0	164.6	204.6
960	108.7	134.8	144.7	165.2	205.2
970	109.6	135.7	145.5	165.9	205.9
980	110.4	136.6	146.2	166.5	206.5
990	111.2	137.4	146.9	167.2	207.2
1000	112.0	138.3	147.6	167.8	207.8
1010	112.7	139.1	148.2	168.5	208.5
1020	113.5	140.0	148.9	169.1	209.1
1030	114.3	140.8	149.6	169.7	209.7
1040	115.0	141.6	150.2	170.3	210.3
1050	115.7	142.4	150.9	170.9	210.9
1060	116.4	143.2	151.5	171.5	211.5
1070	117.2	144.0	152.1	172.1	212.1
1080	117.9	144.7	152.8	172.7	212.7
1090	118.6	145.5	153.4	173.2	213.2
1100	119.2	146.2	154.0	173.8	213.8
1105	119.6	146.6	154.3	174.1	214.1

## Non-Proprietary Version

TABLE G-5. Bounding Quad Cities 1&2  
Composite P-T Curve Values for 54 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-10, G-13 and G-14

PRESSURE (PSIG)	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	UPPER RPV & BELTLINE AT 54 EFPY
	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
1110	119.9	146.9	154.6	174.3	214.3
1120	120.6	147.6	155.2	174.9	214.9
1130	121.2	148.4	155.8	175.4	215.4
1140	121.9	149.1	156.3	176.0	216.0
1150	122.5	149.7	156.9	176.5	216.5
1160	123.1	150.4	157.5	177.0	217.0
1170	123.8	151.1	158.0	177.6	217.6
1180	124.4	151.7	158.6	178.1	218.1
1190	125.0	152.4	159.1	178.6	218.6
1200	125.6	153.0	159.7	179.1	219.1
1210	126.2	153.7	160.2	179.6	219.6
1220	126.8	154.3	160.8	180.1	220.1
1230	127.3	154.9	161.3	180.6	220.6
1240	127.9	155.5	161.8	181.1	221.1
1250	128.5	156.1	162.3	181.6	221.6
1260	129.0	156.7	162.8	182.1	222.1
1270	129.6	157.3	163.3	182.5	222.5
1280	130.1	157.9	163.8	183.0	223.0
1290	130.7	158.5	164.3	183.5	223.5
1300	131.2	159.0	164.8	183.9	223.9
1310	131.7	159.6	165.3	184.4	224.4
1320	132.3	160.2	165.8	184.8	224.8
1330	132.8	160.7	166.2	185.3	225.3

## Non-Proprietary Version

**TABLE G-5. Bounding Quad Cities 1&2  
Composite P-T Curve Values for 54 EFPY**

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A  
for Figures G-10, G-13 and G-14

PRESSURE (PSIG)	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 54 EFPY	UPPER RPV & BELTLINE AT 54 EFPY
	CURVE A (°F)	CURVE A (°F)	CURVE B (°F)	CURVE B (°F)	CURVE C (°F)
1340	133.3	161.3	166.7	185.7	225.7
1350	133.8	161.8	167.2	186.2	226.2
1360	134.3	162.3	167.6	186.6	226.6
1370	134.8	162.9	168.1	187.0	227.0
1380	135.3	163.4	168.5	187.5	227.5
1390	135.8	163.9	169.0	187.9	227.9
1400	136.3	164.4	169.4	188.3	228.3