ATTACHMENT 7

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For Exelon LaSalle Unit 2," dated May 2004
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Pressure-Temperature Curves
For
Exelon
LaSalle Unit 2

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REPORT REVISION STATUS

Revision	Purpose
0	Initial Issue
1	• Proprietary notations have been updated to meet current requirements. • Revision bars have been provided in the right margin of each paragraph denoting change from the previous report. • Sections 1.0 and 2.0 have been updated to include mention of Appendix G. • Section 4.3.2.1 has been revised for clarification of the transients evaluated for the P-T curves. • 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 G has been added to provide a detailed discussion of the subject analysis and conclusions. • A clarifying statement has been added to Section 4.3.2.2.4 regarding the use of K_{It} in the Beltline Core Not Critical P-T curves. • Section 5.0 Figures 5-5 and 5-11, and Appendix B Tables B-1, B-2, and B-3 have been revised to incorporate changes to the CRD Penetration (Bottom Head) Core Not Critical P-T curve, as defined in Section 4.3.2.1.2 and Appendix G. • Section 5.0 Figures 5-13 and 5-14 have been added to present composite pressure test and core not critical curves for 20 EFPY. Table B-5 has been added to present the tabulated values representing these figures.

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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 curve methodology includes the following: 1) The incorporation of ASME Code Case N-640. 2) The use of the M_m calculation in the 1995 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 SER [14b], and is in compliance with Regulatory Guide 1.190.

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)

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]. 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/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_{Ir}, 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 20 and 32 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 20 and 32 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 20 EFPY.

TABLE OF CONTENTS

TABLE OF APPENDICES

TABLE OF FIGURES

TABLE OF TABLES

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 20 and 32 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. The P-T curves incorporate a fluence [14a] calculated in accordance with the GE Licensing Topical Report NEDC-32983P, which has been approved by the NRC in 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]. 2) The use of the M_m calculation in the 1995 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.

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 beltline material chemistry. The ART calculation, methodology, and ART tables for 20 and 32 EFPY are included in Section 4.2. The 32 EFPY peak ID fluence value of

1.09×10^{18} n/cm^2 used in this report is 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 (other than the LPCI nozzle) are outside the beltline region. Appendix F provides the calculation for equivalent margin analysis (EMA) for upper shelf energy (USE). Finally, Appendix G provides the core not critical calculation for the bottom head (CRD Penetration) P-T curve.

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]. The P-T curves in this report incorporate a fluence [14a] calculated in accordance with the GE Licensing Topical Report NEDC-32983P, which has been approved by the NRC in SER [14b], and is in compliance with Regulatory Guide 1.190. 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. 2) The use of the M_m calculation in the 1995 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 LaSalle Unit 2 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 (other than the LPCI nozzle) are outside the beltline region. Appendix F provides the calculation for equivalent margin analysis (EMA) for upper shelf energy (USE). Finally, Appendix G provides the core not critical calculation for the bottom head (CRD Penetration) P-T curve.

3.0 ANALYSIS ASSUMPTIONS

The following assumptions are made for this analysis:

For end-of-license (32 EFPY) fluence an 80% capacity factor is used to determine the EFPY for a 40-year plant life. The 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).

The shutdown margin is calculated for a water temperature of 68°F, as defined in the LaSalle Unit 2 Technical Specification, Section 1.1.

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 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 LaSalle Unit 2 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, weld, HAZ, and forging, and bolting material LST are summarized in the remainder of this section.

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 LaSalle Unit 2 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 LaSalle Unit 2 beltline plate heat C9404-2 in the lower-intermediate shell course, the lowest Charpy energy and test temperature from the CMTRs is 29 ft-lb at 40°F. The estimated 50 ft-lb longitudinal test temperature is:

$$T_{50L} = 40°\text{F} + [(50 - 29)\ \text{ft-lb} \cdot 2°\text{F/ft-lb}] = 82°\text{F}$$

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

$$T_{50T} = 82°\text{F} + 30°\text{F} = 112°\text{F}$$

The initial RT_{NDT} is the greater of nil-ductility transition temperature (NDT) or (T_{50T}- 60°F). Dropweight testing to establish NDT for plate material is listed in the CMTR; the NDT for the case above is 10°F. Thus, the initial RT_{NDT} for plate heat C9404-2 is 52°F.

For the LaSalle Unit 2 beltline weld heat 3P4966 with flux lot 1214 (contained in the lower-intermediate shell), the CVN results are used to calculate the initial RT_{NDT}. The 50 ft-lb test temperature is applicable to the weld material, but the 30°F adjustment to convert longitudinal data to transverse data is not applicable to weld material. Heat 3P4966 has a lowest Charpy energy of 28 ft-lb at 10°F as recorded in weld qualification records. Therefore,

T_{50T} = 10°F + [(50 – 28) ft-lb · 2°F/ft-lb] = 54°F

The initial RT_{NDT} is the greater of nil-ductility transition temperature (NDT) or (T_{50T} - 60°F). For LaSalle Unit 2, the dropweight testing to establish NDT was not recorded for most weld materials. GE procedure requires that, when no NDT is available for the weld, the resulting RT_{NDT} should be –50°F or higher. The value of (T_{50T} – 60°F) in this example is –6°F; therefore, the initial RT_{NDT} was -6°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 LaSalle Unit 2 (Heat Q2Q25W), the NDT is -20°F and the lowest CVN data is 28 ft-lb at -20°F. The corresponding value of (T_{50T} – 60°F) is:

(T_{50T} - 60°F) = {[-20 + (50 - 28) ft-lb · 2°F/ft-lb] + 30°F} – 60°F = -6°F.

Therefore, the initial RT_{NDT} is the greater of nil-ductility transition temperature (NDT) or (T_{50T}- 60°F), which is -6°F.

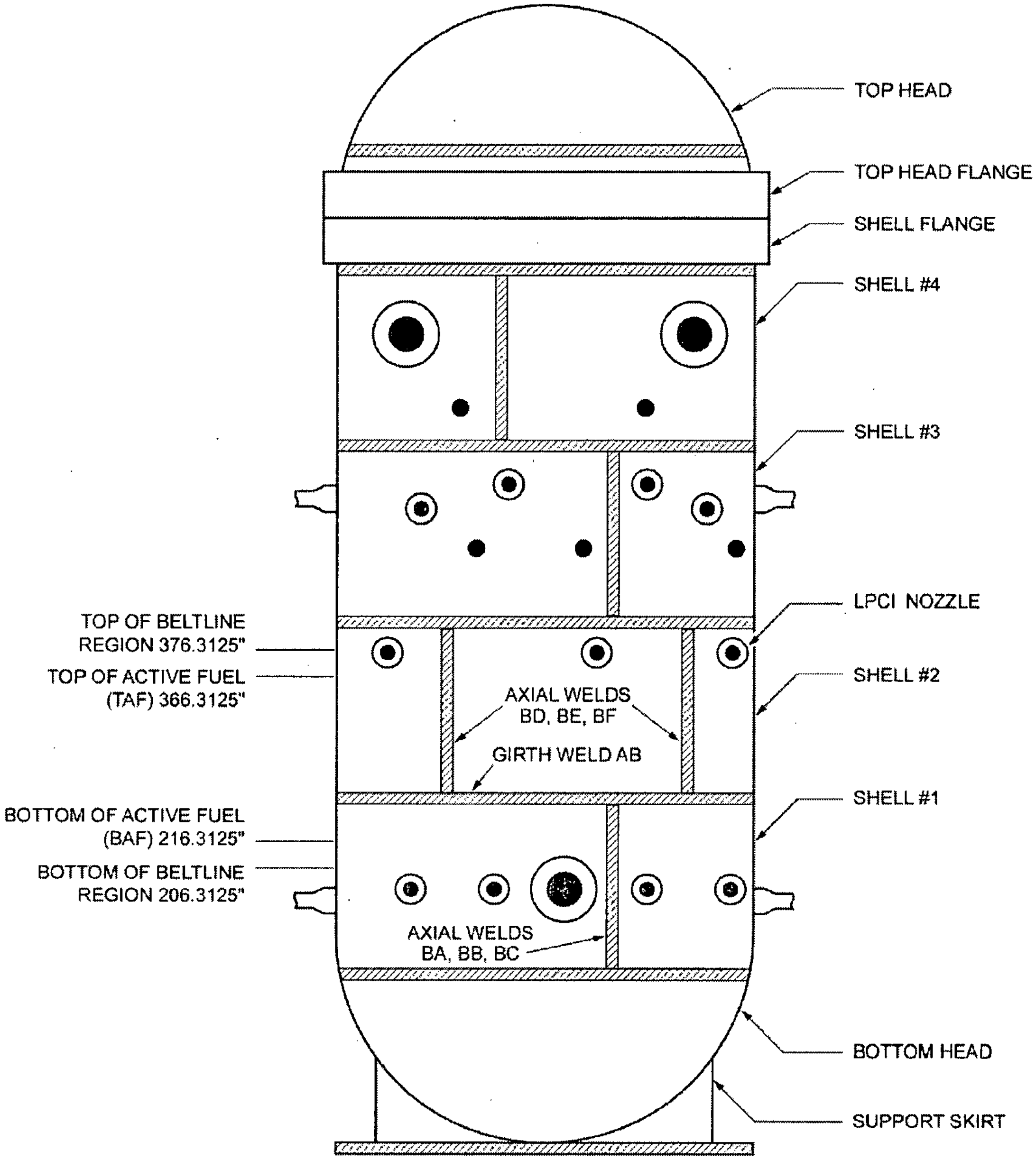
In the bottom head region of the vessel, the vessel plate method is applied for estimating RT_{NDT}. For the lower torus shell of LaSalle Unit 2 (Heat C9306-2), the NDT was not available and the lowest CVN data was 33 ft-lb at 40°F. The corresponding value of (T_{50T} - 60°F) was:

$$(T_{50T} - 60°F) = \{[40°F + (50 – 33) \text{ ft-lb} * 2°F/\text{ft-lb}] + 30°F\} – 60°F = 44°F.$$

Therefore, the initial RT_{NDT} was 44°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°F (as discussed in Section 4.3.2.3) is the LST for the bolting materials. Charpy data for the LaSalle Unit 2 closure studs do not meet the 45 ft-lb, 25 MLE requirement at 10°F. Therefore, the LST for the bolting material is 70°F. The highest RT_{NDT} in the closure flange region is 26°F, for the vessel upper shell materials. Thus, the higher of the LST and the RT_{NDT} +60°F is 86°F, the boltup limit in the closure flange region.

The initial RT_{NDT} values for the LaSalle Unit 2 reactor vessel (refer to Figure 4-1 for LaSalle Unit 2 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.



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 LaSalle Unit 2 RPV Showing Arrangement of Vessel Plates and Welds

Table 4-1: RT_{NDT} Values for LaSalle Unit 2 Vessel Materials

COMPONENT	HEAT	TEST TEMP. (°F)	CHARPY ENERGY (FT-LB)			(T_{50T}-60) (°F)	DROP WEIGHT NDT	RT_{NDT} (°F)
PLATES & FORGINGS:								
Top Head & Flange:								
Top Head: Torus Plate	B3269-1	10	75	72	71	-20	10	10
Torus Plate	B3269-2	10	50	60	50	-20	10	10
Dollar Plate	C9195-3	40	30	30	33	50	50	50
Top Head Flange	BWK-446	10	70	122	142	-20	20	20
Shell Flange	BRC424	10	103	110	105	-20	10	10
Shell Courses:								
Upper Shell	C9678-1	10	47	66	66	-14	10	10
Mk-24	A8453-1	10	44	27	42	26	26	26
	C9507-1	10	51	53	56	-20	10	10
Upper Int. Shell	C9569-1	40	73	69	64	10	40	40
Mk-23	C9481-2	40	46	55	62	18	40	40
	C9602-2	40	56	45	58	20	40	40
Low-Int. Shell	C9404-2	40	48	44	29	52	10	52
Mk-22	C9481-1	40	103	61	85	10	-30	10
	C9601-2	40	85	93	74	10	-30	10
Lower Shell	C9425-1	40	39	43	48	32	0	32
Mk-21	C9425-2	40	44	40	49	30	-30	30
	C9434-2	40	91	58	72	10	-10	10
Bottom Head:	C9306-2	40	36	38	33	44	44	44
	C9514-2	40	50	59	71	10	40	40
	C9621-1	40	63	64	72	10	40	40
	C9245-1	40	61	53	62	10	40	40
Support Skirt:	A8699-3	40	30	31	37	50	50	50
	A8879-1B	40	30	30	33	50	50	50
	A8418-4	40	34	33	30	50	50	50
	C9491-1B	40	77	74	68	10	40	40
STUDS:						LST		
Studs	82552	10	44	45	40	70		
Nuts	10134-48	10	51	52	43	70		

Table 4-2: RT_{NDT} Values for LaSalle Unit 2 Nozzle & Weld Materials

COMPONENT	HEAT	TEST TEMP. (°F)	CHARPY ENERGY (FT-LB)			(T_{50T}-60) (°F)	DROP WEIGHT NDT	RT_{NDT} (°F)
NOZZLES:								
Recirculation Outlet Nozzle, N1	Q2Q32W	40	54	39	40	32	40	40
Recirculation Inlet Nozzle, N2	Q2Q33W	40	54	62	49	12	40	40
	Q2Q25W	40	82	50	77	10	40	40
	Q2Q36W	40	94	87	105	10	40	40
	Q2Q42W	40	82	98	98	10	40	40
Steam Outlet Nozzle, N3	Q2Q30W	40	45	49	48	20	40	40
	Q2Q32W	40	62	49	58	12	40	40
Feedwater Nozzle, N4	Q2Q33W	-20	35	37	43	-20	-20	-20
	Q2Q25W	-20	38	35	28	-6	-20	-6
	Q2Q29W	-20	63	52	38	-26	-20	-20
LP Core Spray Nozzle, N5	Q2Q25W	-20	40	26	36	-2	-20	-2
HP Core Spray Nozzle, N16	Q2Q29W	-20	38	42	53	-26	-20	-20
RHR/LPCI Nozzle, N6	Q2Q36W	-20	44	37	28	-6	-20	-6
	Q2Q42W	-20	57	49	38	-26	-20	-20
Head Spray Nozzle, N7	Q2Q33W	-20	64	70	93	-50	-20	-20
Vent Nozzle, N8	Q2Q19W	40	69	65	58	10	40	40
Jet Pump Instrumentation Nozzle, N9	Q2Q26W	40	29	30	41	52	52	52
CRD Hyd. System Return Nozzle, N10	Q2Q23W	-10	39	30	43	0	-10	0
Drain Nozzle, N15	265M-1	-10	55	34	42	-8	-8	-8
WELDS:								
Vertical Welds:								
BA, BB, BC	3P4000	10	86	87	90	-50	-50	-50
BD, BE, BF	3P4966	10	28	84	63	-6	-50	-6
BG, BJ, BH & BK, BM, BN	4P4784	10	71	73	73.5	-50	-50	-50
Girth Welds:								
AA, AC	3P4966	10	28	84	63	-6	-50	-6
AB	5P6771	10	57	55	42	-34	-50	-34
AD	5P6214B	10	37	54	47	-24	-50	-24
Bottom Head Assembly Welds:								
DA, DB, DC, DD, DE, DF	3P4000	10	86	87	90	-50	-50	-50
Top Head Assembly Welds:								
DM, DN, DP, DH, DJ, DK	3P4966	10	28	84	63	-6	-50	-6
AG	5P6214B	10	37	54	47	-24	-50	-24

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 (Rev 2) provides the methods for determining the ART. The Rev 2 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 welds was made and summarized in Table 4-3 for 20 EFPY and Table 4-4 for 32 EFPY.

4.2.1 Regulatory Guide 1.99, Revision 2 (Rev 2) 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 Rev 2, the SHIFT equation consists of two terms:

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

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

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

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

f = ¼T fluence / 10^{19}

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

σ_I = standard deviation on initial RT_{NDT}, which is taken to be 0°F.

σ_Δ = standard deviation on ΔRT_{NDT}, 28°F for welds and 17°F for base material, except that σ_Δ need not exceed 0.50 times the ΔRT_{NDT} value.

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

The margin term σ_Δ has constant values in Rev 2 of 17°F for plate and 28°F for weld. However, σ_Δ need not be greater than $0.5 \cdot \Delta RT_{NDT}$. Since the GE/BWROG method of 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 σ_I is taken to be 0°F for the vessel plate and weld materials.

4.2.1.1 Chemistry

The vessel beltline chemistries for LaSalle Unit 2 were obtained from several sources. The vessel plate copper values were obtained from the plate manufacturer [5a] and the nickel values were obtained from the CMTRs [12]. Submerged arc weld properties were obtained from separate evaluations [13a, 13b, and 13c]. The copper (Cu) and nickel (Ni) values were used with Tables 1 and 2 of Rev 2, to determine a chemistry factor (CF) per Paragraph 1.1 of Rev 2 for welds and plates, respectively.

4.2.1.2 Fluence

A LaSalle Unit 2 flux for the vessel ID wall [14a] was calculated in accordance with the GE Licensing Topical Report NEDC-32983P, which has been approved by the NRC in SER [14b], and is in compliance with Regulatory Guide 1.190.The flux as documented in [14] is determined for the currently licensed power of 3489 MW_t using a conservative power distribution and is conservatively used from the beginning to the end of the licensing period (32 EFPY).

The peak fast flux for the RPV inner surface from Reference 14 is 1.08e9 n/cm^2-s. The peak fast flux for the RPV inner surface determined from surveillance capsule flux wires removed during the outage following Fuel Cycle 6 at 6.98 EFPY and at a full power of 3323 MW_t is 5.22e8 n/cm^2-s [5b]. Linearly scaling the Reference 5 flux by 1.05 to the currently licensed power of 3489 MW_t results in an estimated flux of 5.48e8 n/cm^2-s. Therefore, the Reference 14 flux bounds the flux determined from the surveillance capsule flux wire results by 197%.

The time period 32 EFPY is 1.01e9 sec, therefore the RPV ID surface fluence is as follows: RPV ID surface fluence = 1.08e9 n/cm^2-s*1.01e9 s = 1.09e18 n/cm^2. This fluence applies to the lower-intermediate plates and welds. The fluence is adjusted for the lower plates and welds and the girth weld based upon a peak / lower shell location ratio of 0.88 (at an elevation of 277" above vessel "0"); hence the peak ID surface fluence for these components is 9.59e17 n/cm^2. Similarly, the fluence is adjusted for the LPCI nozzle based upon a peak / LPCI nozzle location ratio of 0.244 (at an elevation of 355" above vessel "0" and at 45°. 135°, and 225° azimuths); hence the peak ID surface fluence used for this component is 2.66e17 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, Rev 2 was applied to compute ART. For LaSalle Unit 2, the LPCI nozzle is the limiting material for the beltline region for 32 EFPY as discussed in Section 4.3.2.2.2. At 20 EFPY, the P-T curves are not beltline limited. Table 4-3 lists values of beltline ART for 20 EFPY and Table 4-4 lists the values for 32 EFPY. Sections 4.3.2.2.2 and 4.3.2.2.3 provide a discussion of the limiting material.

Table 4-3: LaSalle Unit 2 Beltline ART Values (20 EFPY)

Lower-Intermediate Plates and Welds BD, BE, BF

Thickness in inches = 6.19
Ratio Peak/ Location = 1.00
32 EFPY Peak I.D. fluence = 1.09E+18 n/cm^2
32 EFPY Peak 1/4 T fluence = 7.5E+17 n/cm^2
20 EFPY Peak 1/4 T fluence = 4.7E+17 n/cm^2

Lower Plates and Welds BA, BB, BC, Girth Weld AB

Thickness in inches= 6.19
Ratio Peak/ Location = 0.88
Elevation ~ 277"
32 EFPY Peak I.D. fluence = 9.59E+17 n/cm^2
32 EFPY Peak 1/4 T fluence = 6.6E+17 n/cm^2
20 EFPY Peak 1/4 T fluence = 4.1E+17 n/cm^2

LPCI Nozzle

Thickness in inches= 6.19
Ratio Peak/ Location = 0.244
Elevation ~355"
32 EFPY Peak I.D. fluence = 2.66E+17 n/cm^2
32 EFPY Peak 1/4 T fluence = 1.8E+17 n/cm^2
20 EFPY Peak 1/4 T fluence = 1.1E+17 n/cm^2

COMPONENT	HEAT OR HEAT/LOT	%Cu	%Ni	CF	Initial RT_{NDT} °F	1/4 T Fluence n/cm^2	20 EFPY Δ RT_{NDT} °F	σ_I	σ_Δ	Margin °F	20 EFPY Shift °F	20 EFPY ART °F
PLATES:												
Lower Shell												
21-1	C9425-2	0.120	0.510	81	30	4.1E+17	21	0	11	21	43	73
21-2	C9425-1	0.120	0.510	81	32	4.1E+17	21	0	11	21	43	75
21-3	C9434-2	0.090	0.510	58	10	4.1E+17	15	0	8	15	31	41
Lower-Intermediate Shell												
22-1	C9481-1	0.110	0.500	73	10	4.7E+17	21	0	10	21	41	51
22-2	C9404-2	0.070	0.490	44	52	4.7E+17	12	0	6	12	25	77
22-3	C9601-2	0.120	0.500	81	10	4.7E+17	23	0	11	23	46	56
WELDS:												
Lower Vertical												
BA, BB, BC	3P4000 / 3933	0.020	0.930	27	-50	4.1E+17	7	0	4	7	14	-36
Lower-Intermediate Vertical												
BD, BE, BF	3P4966 / 1214	0.026	0.920	41	-6	4.7E+17	12	0	6	12	23	17
Girth												
AB	5P6771 / 0342	0.040	0.940	54	-34	4.1E+17	14	0	7	14	28	-6
LPCI												
	Q2Q36W	0.220	0.830	177	-6	1.1E+17	21	0	11	21	43	37

Table 4-4: LaSalle Unit 2 Beltline ART Values (32 EFPY)

Lower-Intermediate Plates and Welds BD, BE, BF

Thickness in inches = 6.19 Ratio Peak/ Location = 1.00 32 EFPY Peak I.D. fluence = 1.09E+18 n/cm^2
32 EFPY Peak 1/4 T fluence = 7.5E+17 n/cm^2
32 EFPY Peak 1/4 T fluence = 7.5E+17 n/cm^2

Lower Plates and Welds BA, BB, BC, Girth Weld AB

Thickness in inches= 6.19 Ratio Peak/ Location = 0.88 32 EFPY Peak I.D. fluence = 9.59E+17 n/cm^2
Elevation ~ 277" 32 EFPY Peak 1/4 T fluence = 6.6E+17 n/cm^2
32 EFPY Peak 1/4 T fluence = 6.6E+17 n/cm^2

LPCI Nozzle

Thickness in inches= 6.19 Ratio Peak/ Location = 0.244 32 EFPY Peak I.D. fluence = 2.66E+17 n/cm^2
Elevation ~355" 32 EFPY Peak 1/4 T fluence = 1.8E+17 n/cm^2
32 EFPY Peak 1/4 T fluence = 1.8E+17 n/cm^2

COMPONENT	HEAT OR HEAT/LOT	%Cu	%Ni	CF	Initial RT_{NDT} °F	1/4 T Fluence n/cm^2	32 EFPY Δ RT_{NDT} °F	σ_I	σ_Δ	Margin °F	32 EFPY Shift °F	32 EFPY ART °F
PLATES:												
Lower Shell												
21-1	C9425-2	0.120	0.510	81	30	6.6E+17	27	0	14	27	55	85
21-2	C9425-1	0.120	0.510	81	32	6.6E+17	27	0	14	27	55	87
21-3	C9434-2	0.090	0.510	58	10	6.6E+17	20	0	10	20	39	49
Lower-Intermediate Shell												
22-1	C9481-1	0.110	0.500	73	10	7.5E+17	26	0	13	26	53	63
22-2	C9404-2	0.070	0.490	44	52	7.5E+17	16	0	8	16	32	84
22-3	C9601-2	0.120	0.500	81	10	7.5E+17	29	0	15	29	59	69
WELDS:												
Lower Vertical												
BA, BB, BC	3P4000 / 3933	0.020	0.930	27	-50	6.6E+17	9	0	5	9	18	-32
Lower-Intermediate Vertical												
BD, BE, BF	3P4966 / 1214	0.026	0.920	41	-6	7.5E+17	15	0	7	15	30	24
Girth												
AB	5P6771 / 0342	0.040	0.940	54	-34	6.6E+17	18	0	9	18	37	3
LPCI												
	Q2Q36W	0.220	0.830	177	-6	1.8E+17	29	0	14	29	58	52

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 that a pressure-retaining component may be subjected to 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 portion 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 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:

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 ≤ 20% of preservice hydrotest pressure	Larger of ASME Limits or of highest closure flange region initial RT_{NDT} + 60°F*
2. At > 20% of preservice hydrotest pressure	Larger of ASME Limits or of highest closure flange region initial RT_{NDT} + 90°F
II. Normal operation (heatup and cooldown), including anticipated operational occurrences	
a. Core not critical - Curve B	
1. At ≤ 20% of preservice hydrotest pressure	Larger of ASME Limits or of highest closure flange region initial RT_{NDT} + 60°F*
2. At > 20% of preservice hydrotest pressure	Larger of ASME Limits or of highest closure flange region initial RT_{NDT} + 120°F
b. Core critical - Curve C	
1. At ≤ 20% of preservice hydrotest pressure, with the water level within the normal range for power operation	Larger of ASME Limits + 40°F or of a.1
2. At > 20% of preservice hydrotest pressure	Larger of ASME Limits + 40°F or of a.2 + 40°F or the minimum permissible temperature for the inservice system hydrostatic pressure test

* 60°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^2) to cause any significant shift of RT_{NDT} (see Appendix E). Non-beltline components include nozzles, 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 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.

Table 4-6: Applicable BWR/5 Discontinuity Components for Use With FW (Upper Vessel) Curves A & B

Discontinuity Identification
FW Nozzle
LPCI Nozzle
CRD HYD System Return
Core Spray Nozzle
Recirculation Inlet Nozzle
Steam Outlet Nozzle
Main Closure Flange
Support Skirt
Stabilizer Brackets
Shroud Support Attachments
Core ΔP and Liquid Control Nozzle
Steam Water Interface
Instrumentation Nozzle
Shell
CRD and Bottom Head (B only)
Top Head Nozzles (B only)
Recirculation Outlet Nozzle (B only)

Table 4-7: Applicable BWR/5 Discontinuity Components for Use with CRD (Bottom Head) Curves A&B

Discontinuity Identification
CRD and Bottom Head
Top Head Nozzles
Recirculation Outlet Nozzle
Shell**
Support Skirt**
Shroud Support Attachments**
Core ΔP 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 LaSalle Unit 2 as the plant specific geometric values are bounded by the generic 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 LaSalle Unit 2 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 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:

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

$$\mathbf{M_m} = 0.926 \sqrt{t} \text{ for } 2 \leq \sqrt{t} \leq 3.464 = \mathbf{2.6206}$$

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

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]:

$$K_{Im} = M_m \cdot \sigma_{pm} = [[\quad]] \text{ ksi-in}^{1/2}$$

$$K_{Ib} = (2/3)\, M_m \cdot \sigma_{pb} = [[\quad]] \text{ ksi-in}^{1/2}$$

The total K_I is therefore:

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

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} equation of Paragraph A-4200 in ASME Appendix A [17]:

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

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

$(T - RT_{NDT}) = 84°F$

The generic curve was generated by scaling 143.6 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 44°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:

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

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:

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

The LaSalle Unit 2 specific bottom head dimensions are R = 126.7 inches and t =7.13 inches minimum [19], resulting in:

LaSalle Unit 2 specific: $R\,/\,(t)^{1/2} = 126.7\,/\,(7.13)^{1/2} = 47.5\ \text{inch}^{1/2}$ (4-3)

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

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 $(143.6 / 1.5) \cdot 2.0 = 191.5$ ksi-in$^{1/2}$.

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:

$$(T - RT_{NDT}) = \ln [(K_I - 33.2) / 20.734] / 0.02$$
$$(T - RT_{NDT}) = \ln [(191.5 - 33.2) / 20.734] / 0.02$$
$$(T - RT_{NDT}) = 102°F$$

The generic curve was generated by scaling 192 ksi-in$^{1/2}$ 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$^{1/2}$)	$T - RT_{NDT}$ (°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 44°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 Tables 4-6, 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.

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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 $K_I = 200$ 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: $\sigma = PR / t = 1563$ psig $\cdot$ 126.7 inches / (6.1875 inches) = 32,005 psi. The Dead weight and thermal RFE stress of 2.967 ksi is conservatively added yielding $\sigma = 34.97$ 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 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 $1.5\, \sigma\, (\pi a)^{1/2} \cdot F(a/r_n)$:

Nominal $K_I = 1.5 \quad 34.97 \cdot (\pi \cdot 2.36)^{1/2} \cdot 1.4 = 200$ 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:

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

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

$$(T - RT_{NDT}) = 104.2°F$$

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The generic pressure test P-T curve was generated by scaling 200 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 feedwater nozzle materials is 40°F as described below. The generic pressure test P-T curve is applied to the LaSalle Unit 2 feedwater nozzle curve by shifting the P vs. ($T - RT_{NDT}$) values above to reflect the RT_{NDT} value of 40°F.

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Second, the P-T curve is dependent on the K_I value calculated. The LaSalle Unit 2 specific vessel shell and nozzle dimensions applicable to the feedwater nozzle location [19] and K_I are shown below:

Vessel Radius, R_v	126.7 inches
Vessel Thickness, t_v	6.19 inches
Vessel Pressure, P_v	1563 psig

Pressure stress: σ = PR / t = 1563 psig · 126.7 inches / (6.19 inches) = 31,992 psi. The Dead weight and thermal RFE stress of 2.967 ksi is conservatively added yielding σ = 34.96 ksi. The factor F (a/r_n) from Figure A5-1 of WRC-175 is determined where:

a =	$\frac{1}{4}(t_n^2 + t_v^2)^{1/2}$	=2.36 inches
t_n =	thickness of nozzle	= 7.125 inches
t_v =	thickness of vessel	= 6.19 inches
r_n =	apparent radius of nozzle	= r_i + 0.29 r_c=6.8 inches
r_i =	actual inner radius of nozzle	= 6.0 inches
r_c =	nozzle radius (nozzle corner radius)	= 2.75 inches

Thus, a/r_n = 2.36 / 6.8 = 0.35. The value F(a/r_n), taken from Figure A5-1 of WRC Bulletin 175 for an a/r_n of 0.35, is 1.4. Including the safety factor of 1.5, the stress intensity factor, K_I, is 1.5 σ $(\pi a)^{1/2}$ · F(a/r_n):

Nominal $K_I = 1.5 \cdot 34.96 \cdot (\pi \cdot 2.36)^{1/2} \cdot 1.4 = 199.9$ 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 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, see 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:

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

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

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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, σ_{pm}, and primary bending, σ_{pb}. Secondary membrane, σ_{sm}, and secondary bending, σ_{sb}, stresses are included in the total K_I by using ASME Appendix G [6] methods for secondary portion, K_{Is}:

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

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.

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

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 (σ_{pm}) was adjusted for the actual [[ ]] vessel thickness of 6.1875 inches (i.e., σ_{pm} = 20.49 ksi was revised to 20.49 ksi · 7.5 inches/6.1875 inches = 24.84 ksi). These stresses, and other inputs used in the generic calculations, are shown below:

σ_{pm} = 24.84 ksi σ_{sm} = 16.19 ksi σ_{ys} = 45.0 ksi t_v = 6.1875 inches
σ_{pb} = 0.22 ksi σ_{sb} = 19.04 ksi a = 2.36 inches r_n = 7.09 inches
t_n = 7.125 inches

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

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

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

σ_{pm} = 24.84 ksi σ_{sm} = 9.44 ksi
σ_{pb} = 0.13 ksi σ_{sb} = 11.10 ksi

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:

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

$$M_m = 0.926\sqrt{t} \text{ for } 2 \le \sqrt{t} \le 3.464 = \mathbf{2.845}$$

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

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:

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

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

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

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

The total K_I is, therefore, 238.3 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°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°F water injected into the hot reactor vessel nozzle. In the base case that yielded a K_I value of 238 ksi-in$^{1/2}$, the pressure is 1050 psig and the hot reactor vessel temperature is 551.4°F. Since the reactor vessel temperature follows the saturation temperature curve, the secondary stresses are scaled by $(T_{saturation} - 40) / (551.4 - 40)$. 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$^{1/2}$)	(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 LaSalle Unit 2 is 40°F as shown in Tables 4-1 and 4-2 and previously discussed. The jet pump instrumentation nozzle is not limiting, as previously discussed. The generic curve is applied to the LaSalle Unit 2 upper vessel by shifting the P vs. (T - RT_{NDT}) values above to reflect the RT_{NDT} value of 40°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°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:

$$\sigma_m = PR / t_{min} \tag{4-8}$$

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:

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

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.

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} = Initial RT_{NDT} + Shift	A = 32 + 55 = 87°F (Based on ART values in Section 4.2)
Vessel Height	H = 870.5 inches
Bottom of Active Fuel Height	B = 216.3 inches
Vessel Radius (to inside of clad)	R = 126.5 inches
Minimum Vessel Thickness (without clad)	t = 6.19 inches

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

$$\begin{aligned} P &= 1105 \text{ psi} + (H - B)\ 0.0361 \text{ psi/inch} = P \text{ psig} \qquad (4\text{-}10) \\ &= 1105 + (870.5 - 216.3)\ 0.0361 = 1129 \text{ psig} \end{aligned}$$

Pressure stress:

$$\begin{aligned} \sigma &= PR/t \qquad (4\text{-}11) \\ &= 1.129 \cdot 126.5 / 6.19 = 23.1 \text{ ksi} \end{aligned}$$

The value of M_m for an inside axial postulated surface flaw from Paragraph G-2214.1 [6] was based on a thickness of 6.19 inches (the minimum thickness without cladding); hence, $t^{1/2} = 2.49$. The resulting value obtained was:

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

$$M_m = 0.926 \sqrt{t} \text{ for } 2 \leq \sqrt{t} \leq 3.464 = \mathbf{2.30}$$

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

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.

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} = 53.1, and K_{It} = 2.58 for a 20°F/hr coolant heatup/cooldown rate with a vessel thickness, t, that includes cladding:

$$\begin{aligned}(T - RT_{NDT}) &= \ln[(1.5 \cdot K_{Im} + K_{It} - 33.2) / 20.734] / 0.02 \qquad (4\text{-}12)\\ &= \ln[(1.5 \cdot 53.1 + 2.58 - 33.2) / 20.734] / 0.02\\ &= 43.0°\text{F}\end{aligned}$$

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

T = 43.0 + 87 = 130°F for P = 1105 psig

For LaSalle Unit 2, the LPCI nozzle is the limiting material for the beltline region for 32 EFPY. The beltline pressure test P-T curves provided in Section 5.0 of this report are calculated in the same manner as the Feedwater Nozzle pressure test P-T curves as described in Section 4.3.2.1.3. The initial RT_{NDT} for the LPCI nozzle materials is –6°F as shown in Table 4-2. The generic pressure test P-T curve is applied to the LaSalle Unit 2 Feedwater Nozzle curve by shifting the P vs. ($T - RT_{NDT}$) values in Section 4.3.2.1.3 to reflect the ART value of 52°F. The 20 EFPY beltline pressure test P-T curves are non-beltline limited and the beltline material calculations are performed as described in this section.

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]:

$$K_{IC} = 2.0 \cdot K_{Im} + K_{It} \qquad (4\text{-}13)$$

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 ΔT_w, 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 ΔT_w is based on one-dimensional heat conduction through an insulated flat plate:

$$\partial^2 T(x,t) / \partial x^2 = 1 / \beta \, (\partial T(x,t) / \partial t) \qquad (4\text{-}14)$$

where T(x,t) is temperature of the plate at depth x and time t, and β 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:

$$T = Gx^2 / 2\beta - GCx / \beta + T_0 \tag{4-15}$$

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, ΔT_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.

For LaSalle Unit 2, the LPCI nozzle is the limiting material for the beltline region for 32 EFPY. The beltline core not critical P-T curves provided in Section 5.0 of this report are calculated in the same manner as the Feedwater Nozzle core not critical P-T curves as described in Section 4.3.2.1.4. The initial RT_{NDT} for the LPCI nozzle materials is –6°F as shown in Table 4-2. The generic core not critical P-T curve is applied to the LaSalle Unit 2 Feedwater Nozzle curve by shifting the P vs. $(T - RT_{NDT})$ values in Section 4.3.2.1.4 to reflect the ART value of 52°F. The 20 EFPY beltline core not critical P-T curves are non-beltline limited and the beltline material calculations are performed as described in this section.

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_{Im} 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_{It} term for the thermal stress. The additional inputs used to calculate K_{It} are:

Coolant heatup/cooldown rate, normally 100°F/hr	G = 100 °F/hr
Minimum vessel thickness, including clad thickness (the maximum vessel thickness is conservatively used)	C = 0.552 ft (6.625 inches)
Thermal diffusivity at 550°F (most conservative value)	$\beta = 0.354\ ft^2/hr$ [21]

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

$$\Delta T = GC^2 / 2\beta \qquad (4\text{-}16)$$

$$= 100 \cdot (0.552)^2 / (2 \cdot 0.354) = 43°F$$

The analyzed case for thermal stress is a 1/4T flaw depth with wall thickness of C. The corresponding value of M_t (=0.30) can be interpolated from ASME Appendix G, Figure G-2214-2 [6]. The conservative value for thermal diffusivity at 550°F is used for all calculations; therefore, K_{It} is constant for all pressures. Thus the thermal stress intensity factor, $K_{It} = M_t \cdot \Delta T = 12.9$, can be calculated. K_{Im} has the same value as that calculated in Section 4.3.2.2.2.

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

$$(T - RT_{NDT}) = \ln[((2 \cdot K_{Im} + K_{It}) - 33.2) / 20.734] / 0.02 \qquad (4\text{-}17)$$

$$= \ln[(2 \cdot 53.1 + 12.9 - 33.2) / 20.734] / 0.02$$

$$= 71.1\ °F$$

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

$T = 71.1 + 87 = 158.1$ °F for $P = 1105$ psig

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}. 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 LaSalle Unit 2 at low pressures.

The approach used for LaSalle Unit 2 for the bolt-up temperature was based on a 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 flaw size between 0.1 and 0.24 inches is acceptable. As shown in Tables 4-1 and 4-2, the limiting initial RT_{NDT} for the closure flange region is represented by both the top head and vessel shell flange materials at 26°F, and the LST of the closure studs is 70°F; therefore, the bolt-up temperature value used is 86°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 LaSalle Unit 2 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 86°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 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°F) at pressures below 312 psig. This requirement makes the minimum criticality temperature 86°F, based on an RT_{NDT} of 26°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°F does cause a temperature shift in Curve C at 312 psig.

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_{Ir}, at 1/4T to be less than that at 3/4T for a given metal temperature.

The following P-T curves were generated for LaSalle Unit 2.

- Composite P-T curves were generated for each of the Pressure Test and Core Not Critical conditions at 20 and 32 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 20 and 32 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 20 and 32 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 not beltline limited through 1400 psig for curve A and curve B for 20 EFPY. The P-T curves are beltline (LPCI nozzle) limited above 760 psig for curve A and 550 psig for curve B for 32 EFPY.

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

Table 5-1: 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
Curve A			
	Bottom Head Limits (CRD Nozzle)	Figure 5-1	B-1 & B-3
	Upper Vessel Limits (FW Nozzle)	Figure 5-2	B-1 & B-3
	Beltline Limits for 20 EFPY	Figure 5-3	B-3
	Beltline Limits for 32 EFPY	Figure 5-4	B-1
Curve B			
	Bottom Head Limits (CRD Nozzle)	Figure 5-5	B-1 & B-3
	Upper Vessel Limits (FW Nozzle)	Figure 5-6	B-1 & B-3
	Beltline Limits for 20 EFPY	Figure 5-7	B-3
	Beltline Limits for 32 EFPY	Figure 5-8	B-1
Curve C			
	Composite Curve for 20 EFPY**	Figure 5-9	B-4
A, B, & C	**Composite Curves for 32 EFPY**		
	Bottom Head and Composite Curve A for 32 EFPY*	Figure 5-10	B-2
	Bottom Head and Composite Curve B for 32 EFPY*	Figure 5-11	B-2
	Composite Curve C for 32 EFPY**	Figure 5-12	B-2
A & B	**Composite Curves for 20 EFPY**		
	Bottom Head and Composite Curve A for 20 EFPY*	Figure 5-13	B-5
	Bottom Head and Composite Curve B for 20 EFPY*	Figure 5-14	B-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.

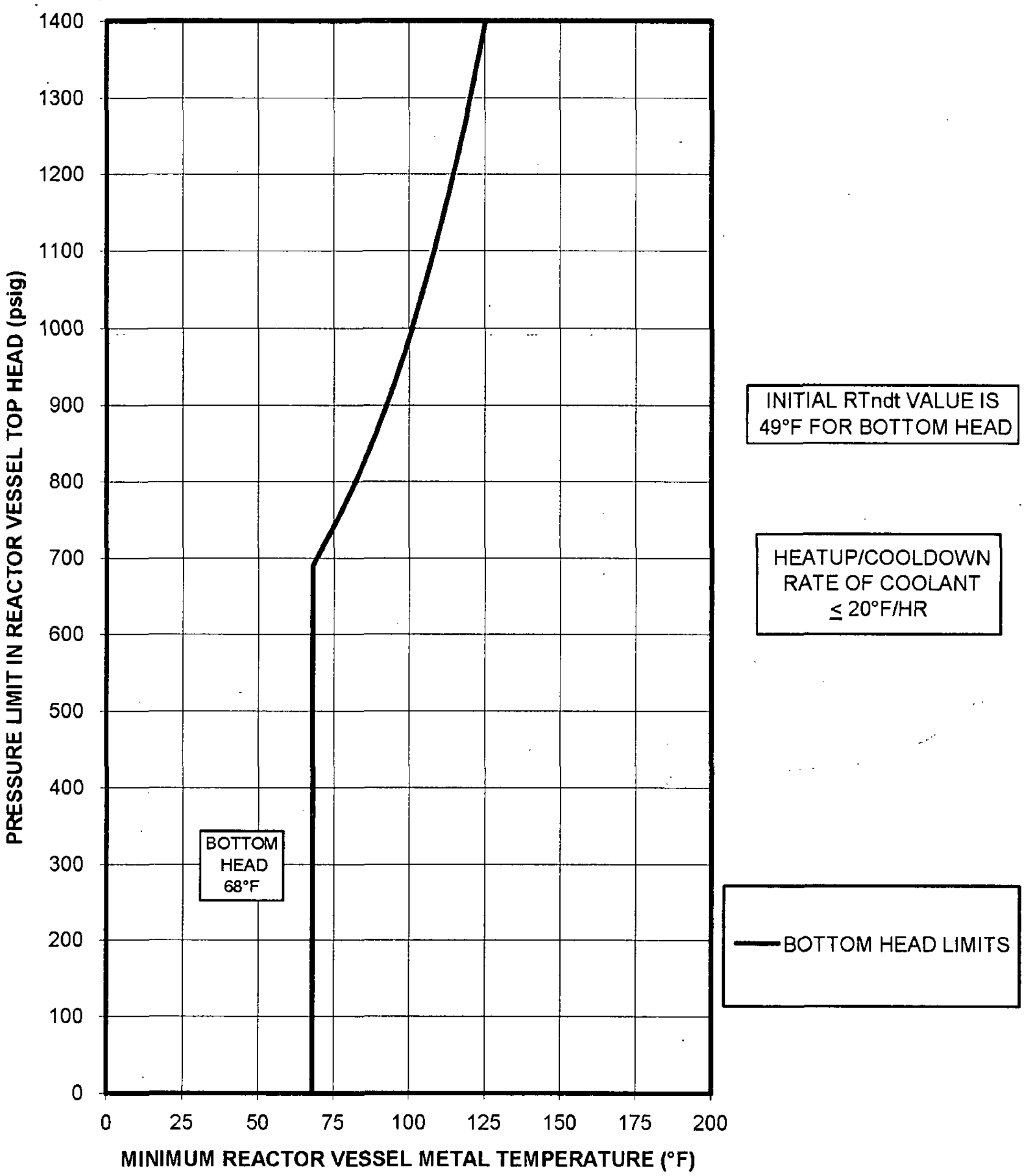

Figure 5-1: Bottom Head P-T Curve for Pressure Test [Curve A]
[20°F/hr or less coolant heatup/cooldown]

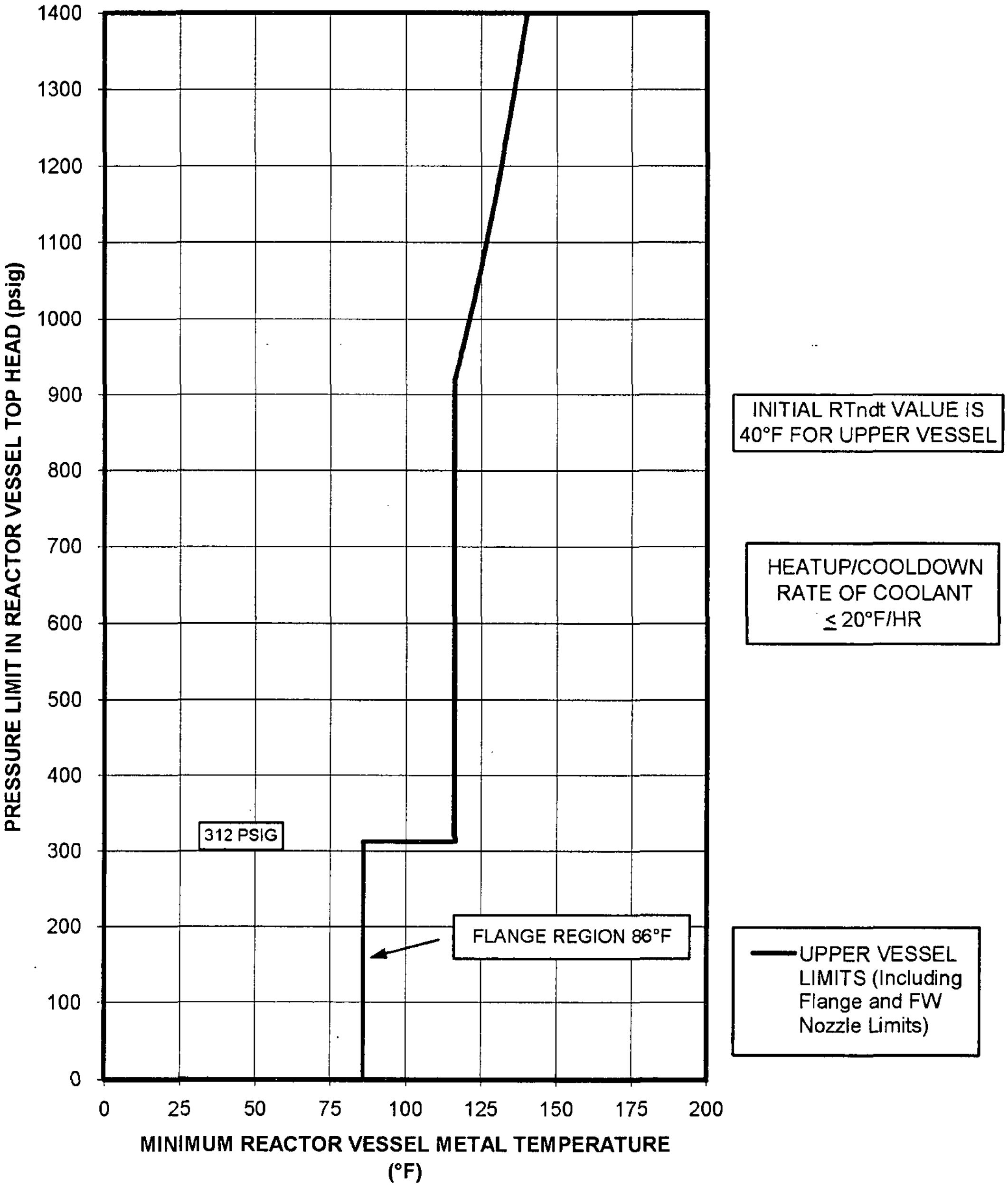

Figure 5-2: Upper Vessel P-T Curve for Pressure Test [Curve A]

[20°F/hr or less coolant heatup/cooldown]

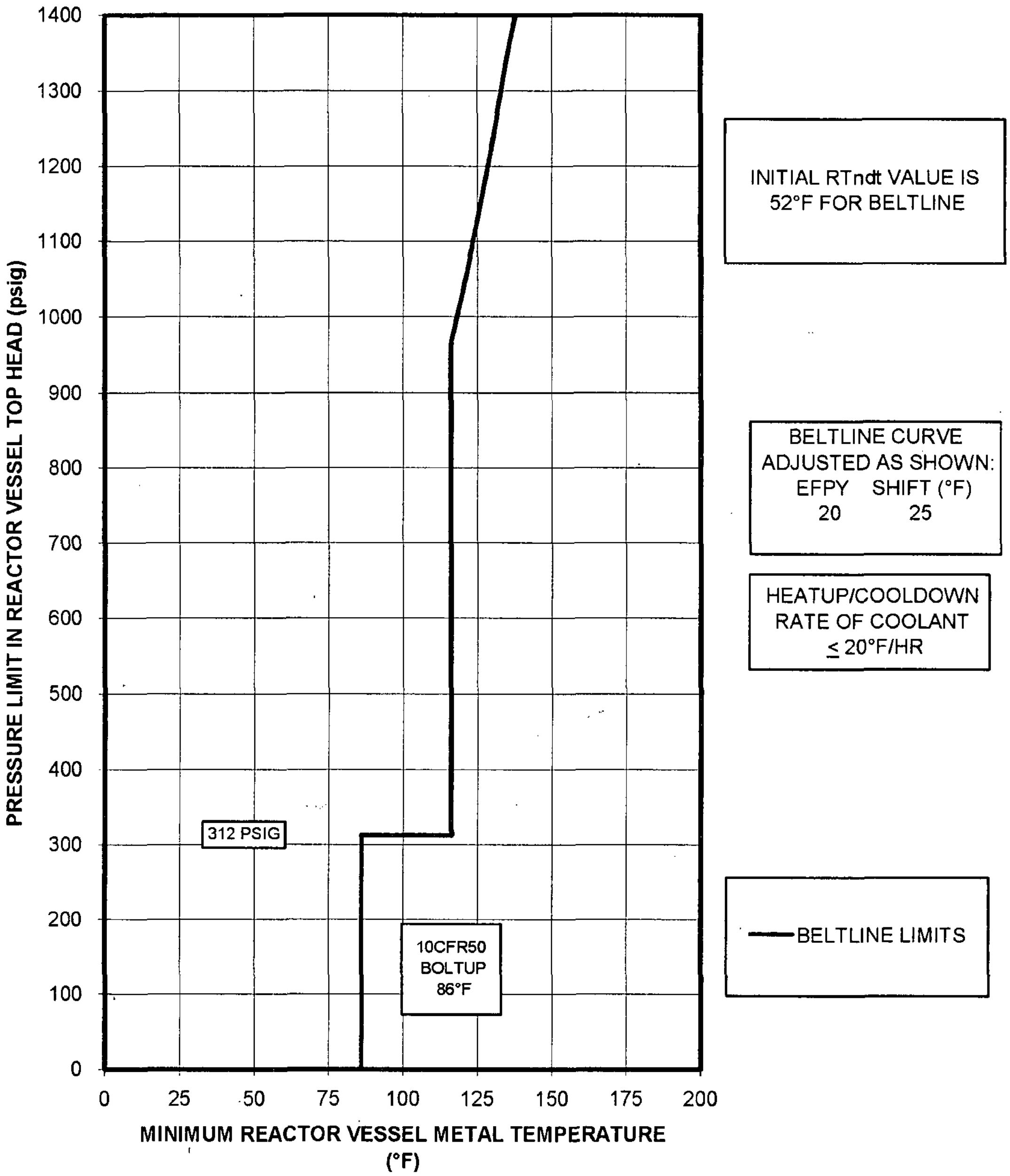

Figure 5-3: Beltline P-T Curve for Pressure Test [Curve A] up to 20 EFPY
[20°F/hr or less coolant heatup/cooldown]

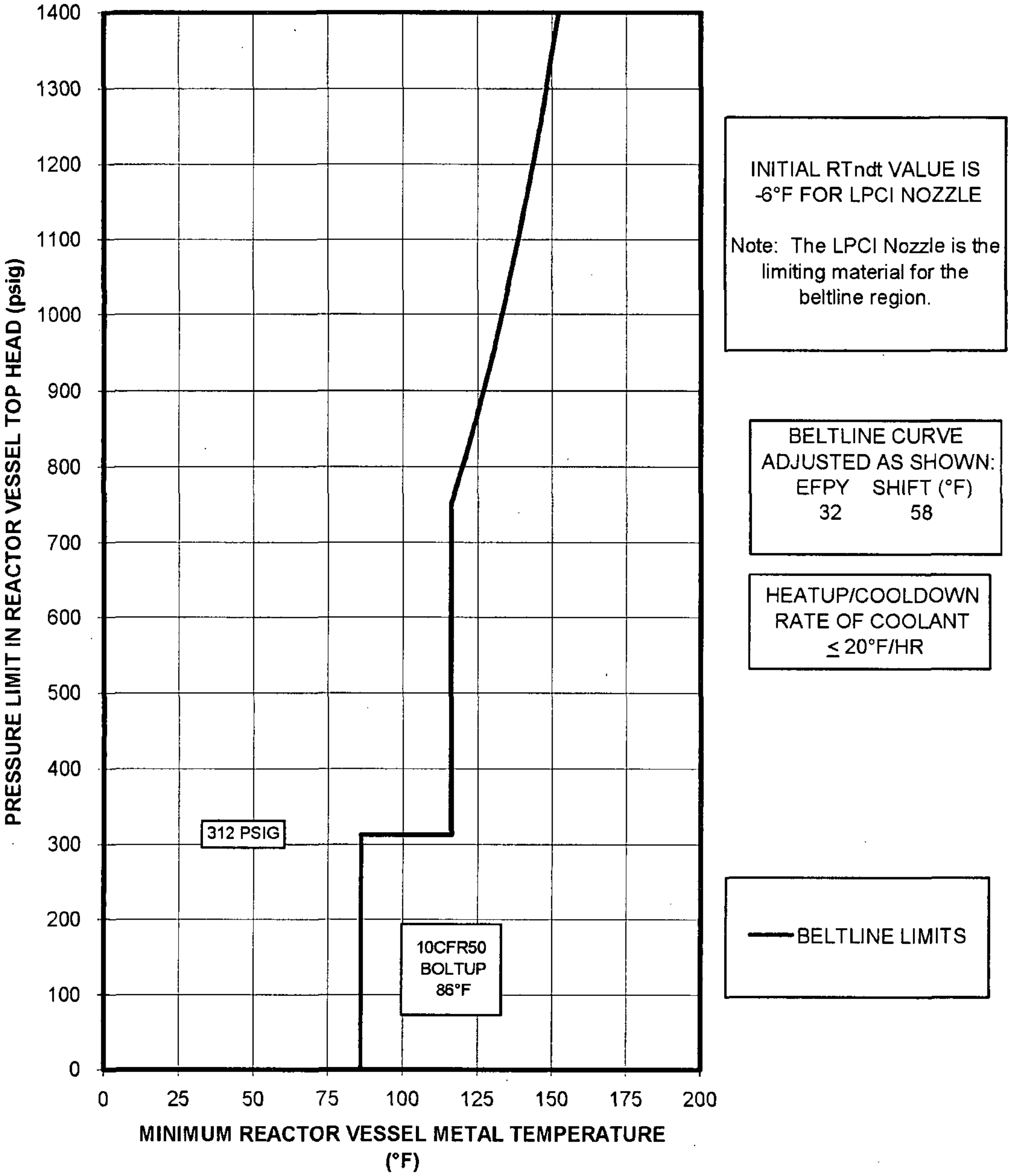

Figure 5-4: Beltline P-T Curve for Pressure Test [Curve A] up to 32 EFPY [20°F/hr or less coolant heatup/cooldown]

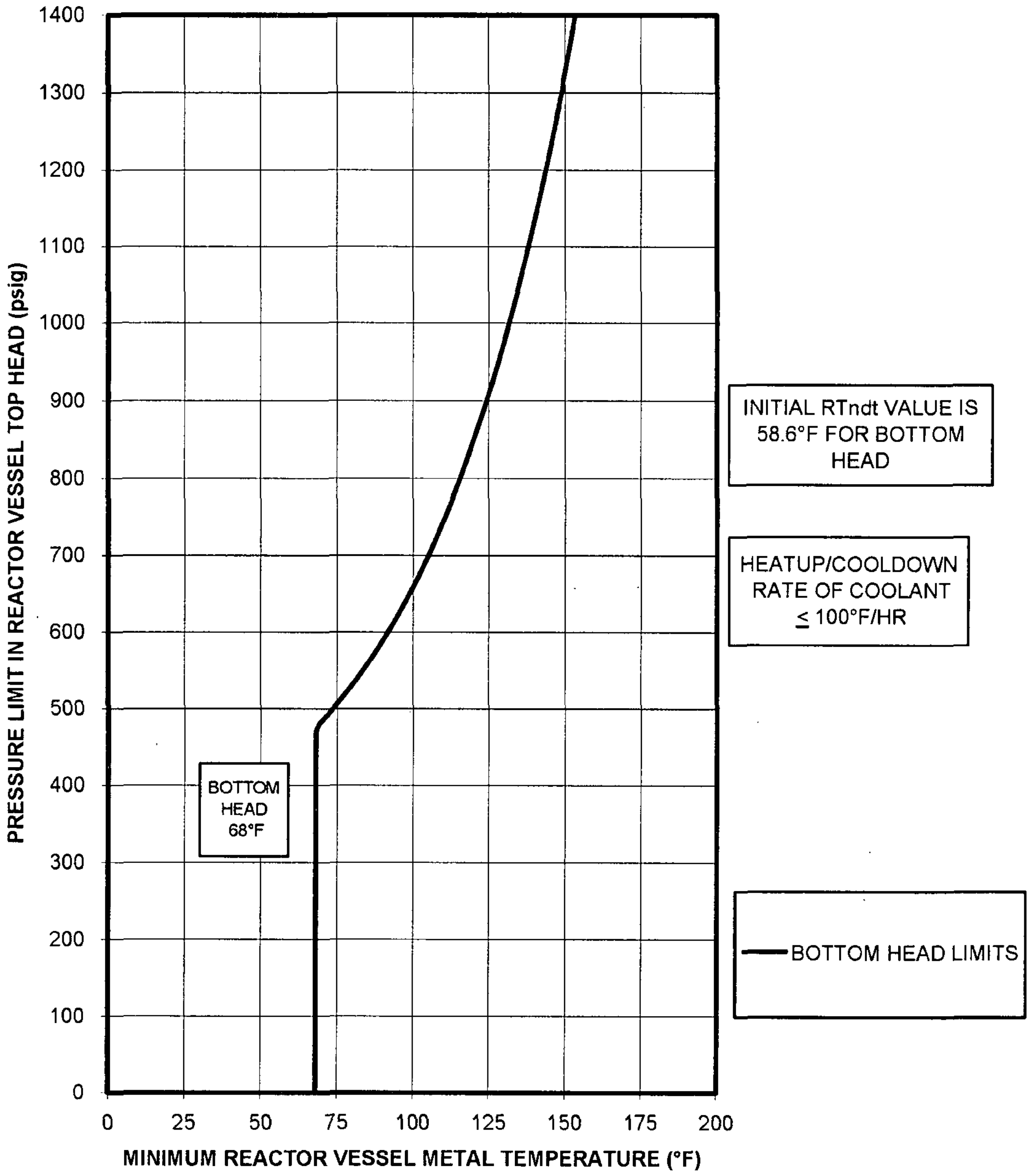

Figure 5-5: Bottom Head P-T Curve for Core Not Critical [Curve B]
[100°F/hr or less coolant heatup/cooldown]

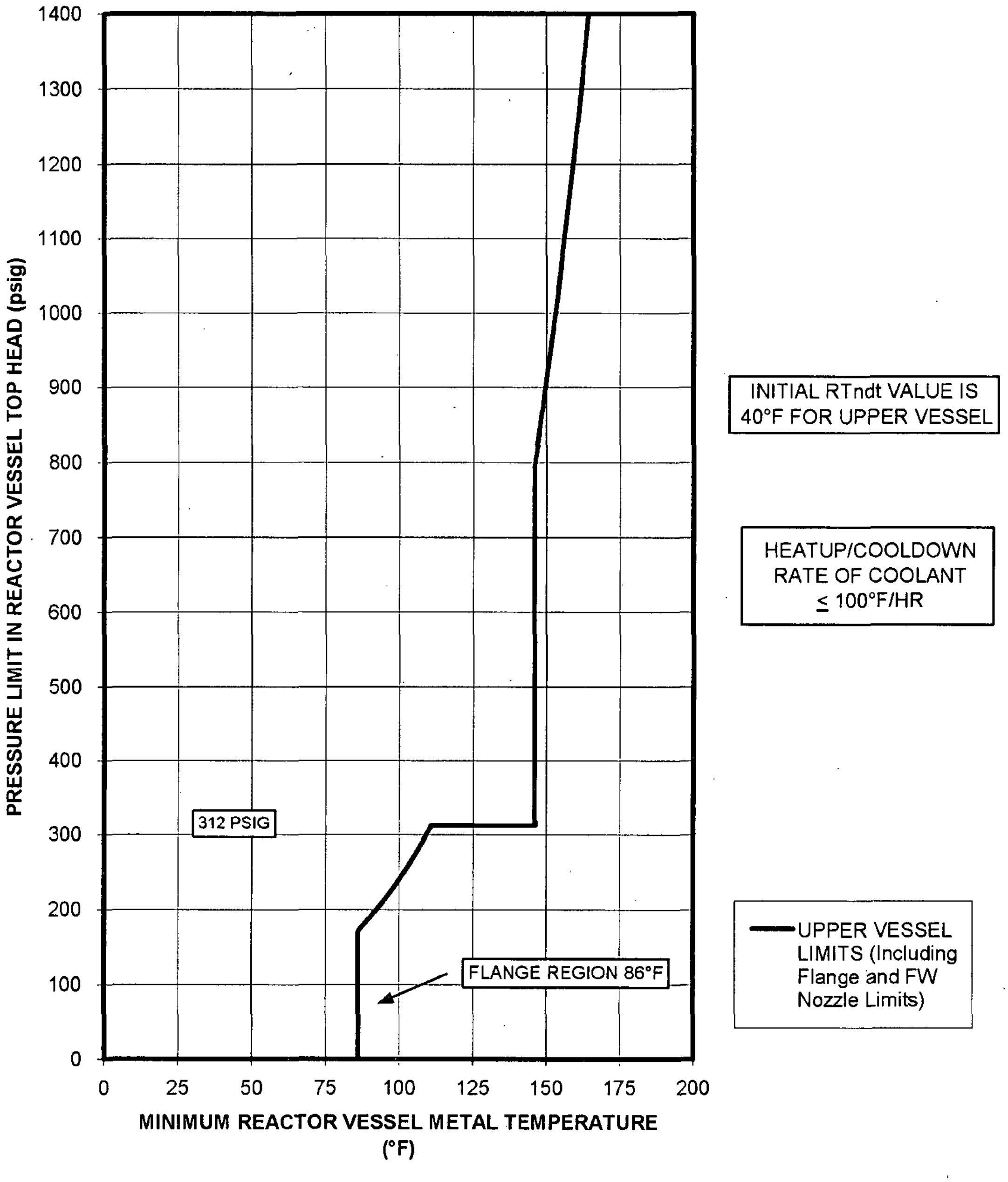

Figure 5-6: Upper Vessel P-T Curve for Core Not Critical [Curve B]

[100°F/hr or less coolant heatup/cooldown]

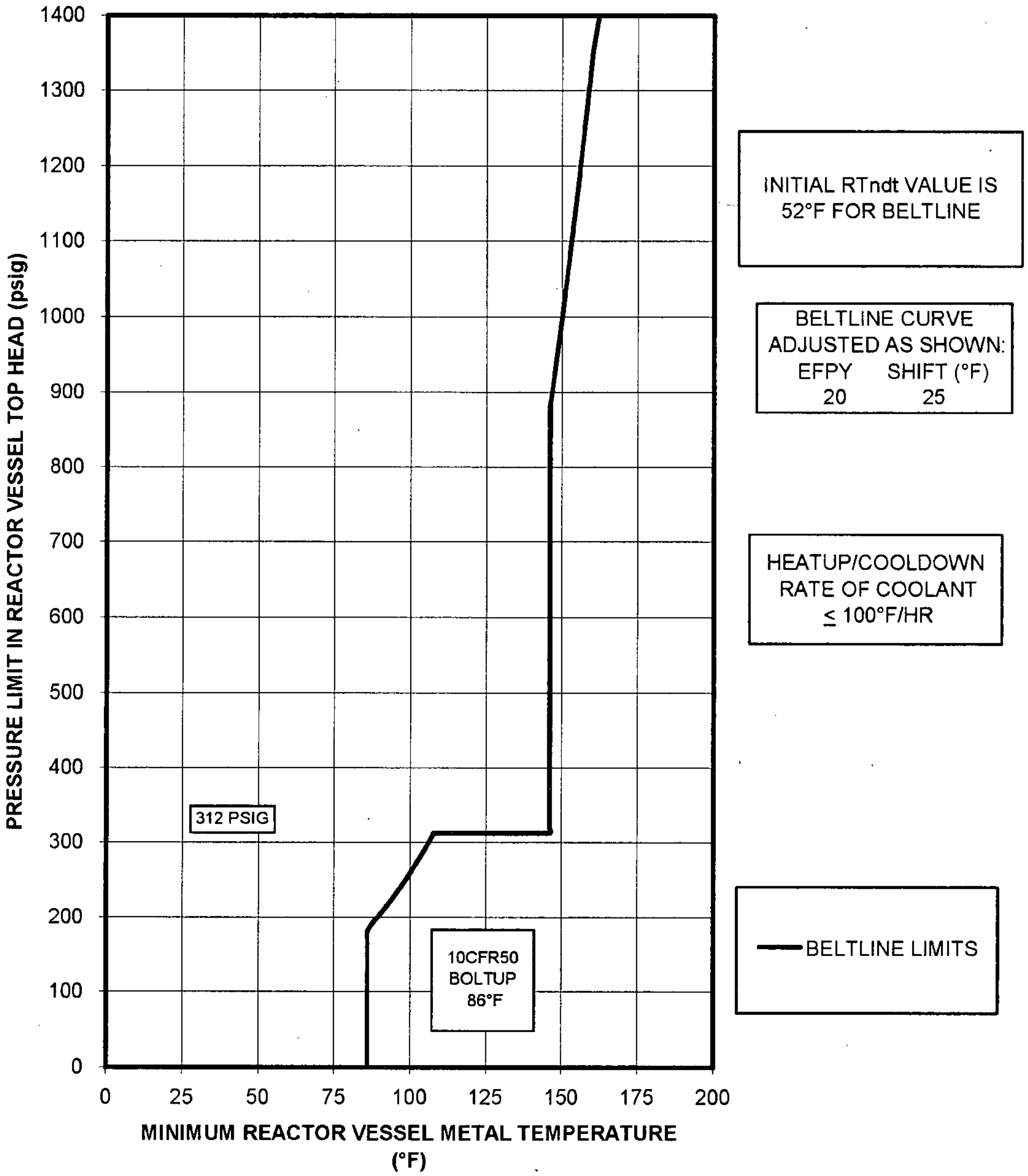

Figure 5-7: Beltline P-T Curve for Core Not Critical [Curve B] up to 20 EFPY
[100°F/hr or less coolant heatup/cooldown]

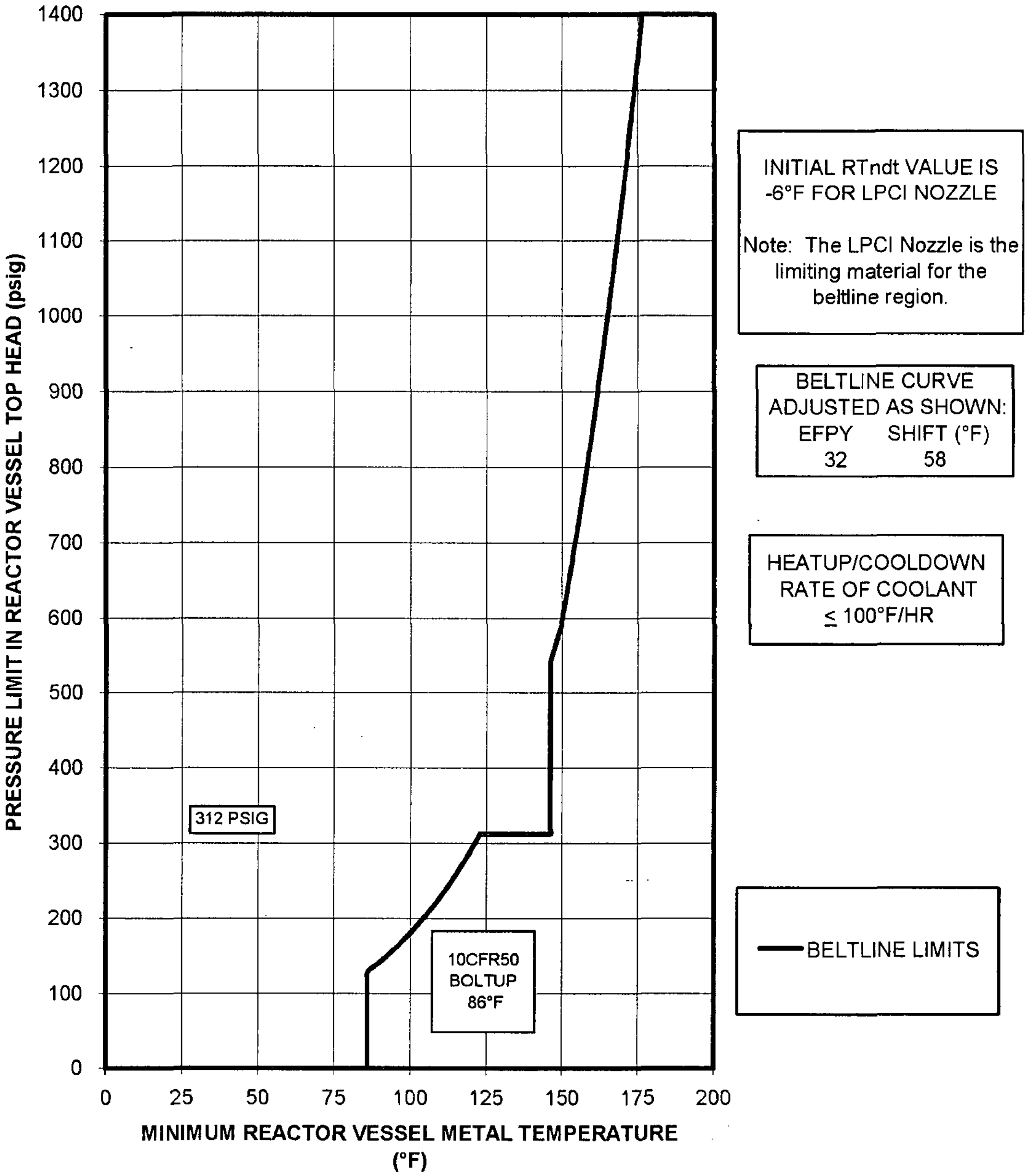

Figure 5-8: Beltline P-T Curves for Core Not Critical [Curve B] up to 32 EFPY
[100°F/hr or less coolant heatup/cooldown]

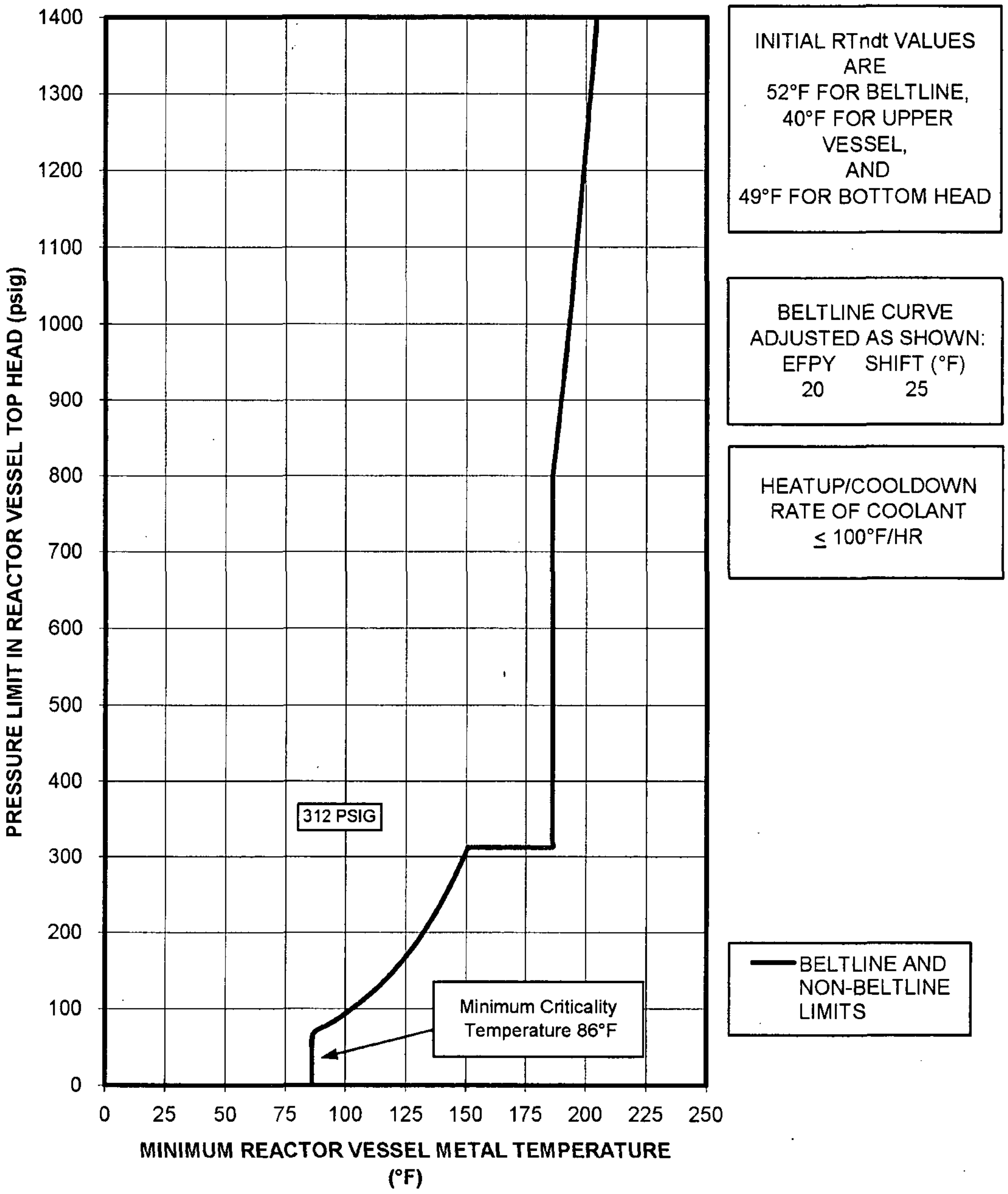

Figure 5-9: Composite Core Critical P-T Curves [Curve C] up to 20 EFPY
[100°F/hr or less coolant heatup/cooldown]

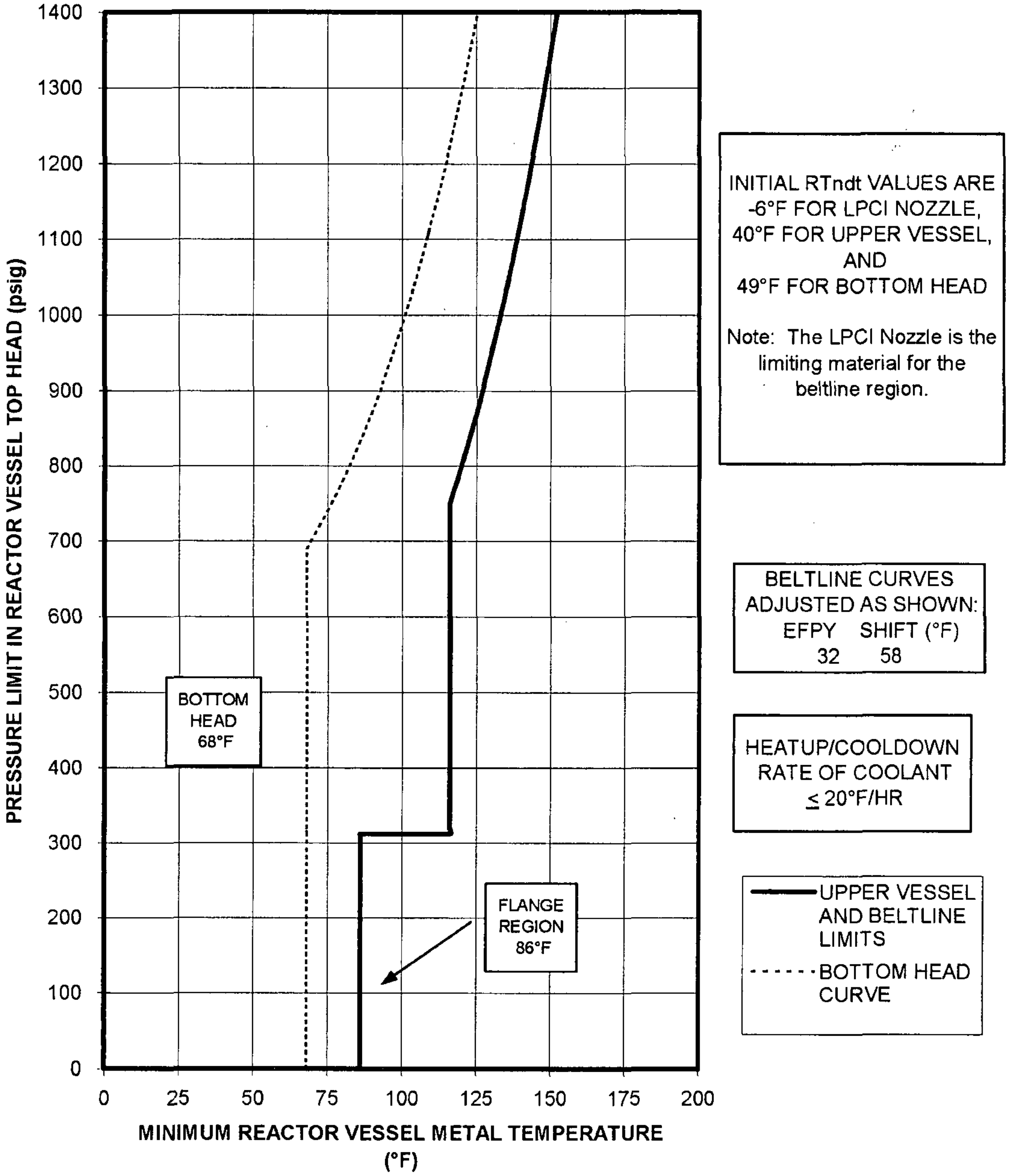

Figure 5-10: Composite Pressure Test P-T Curves [Curve A] up to 32 EFPY [20°F/hr or less coolant heatup/cooldown]

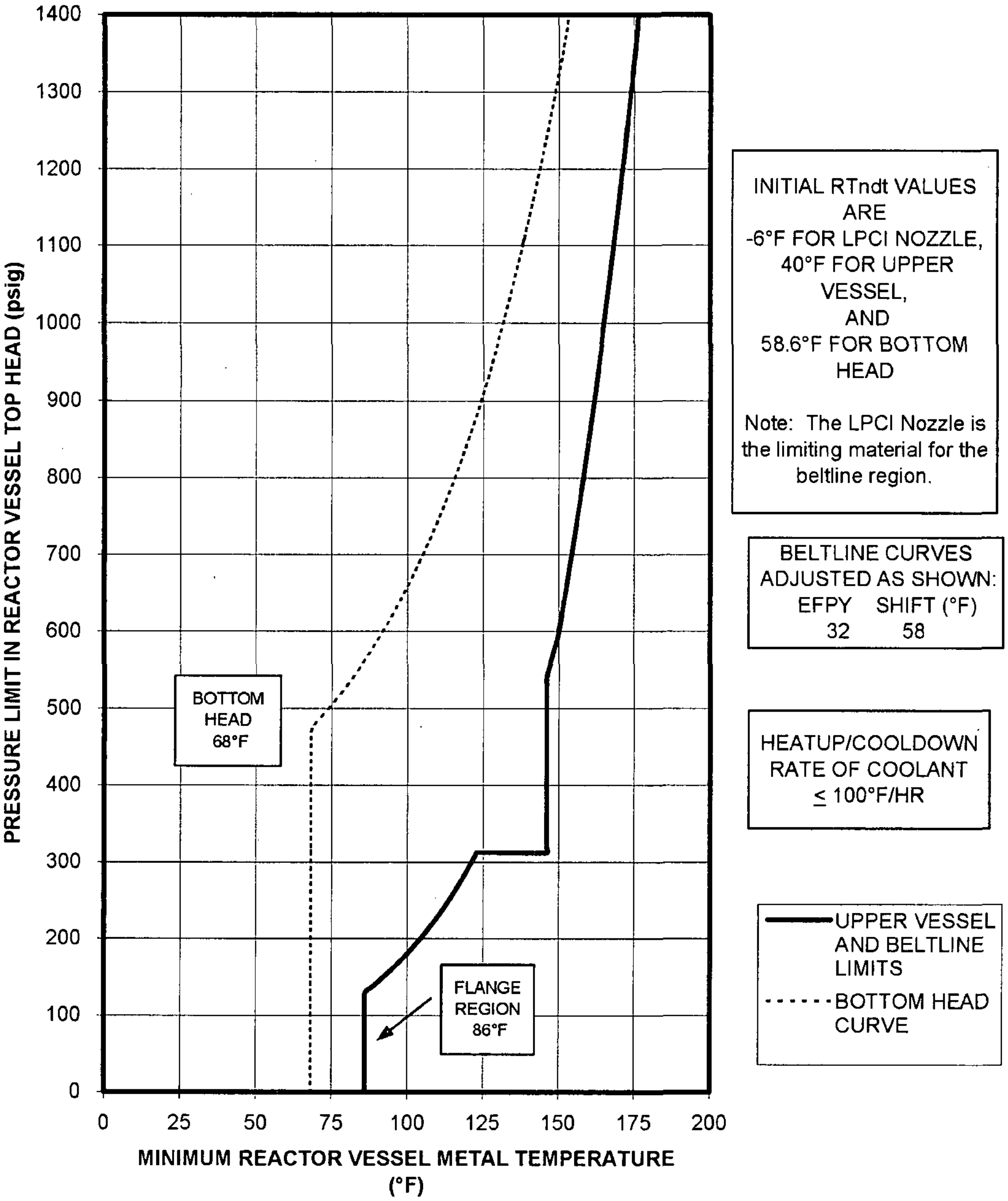

Figure 5-11: Composite Core Not Critical P-T Curves [Curve B] up to 32 EFPY [100°F/hr or less coolant heatup/cooldown]

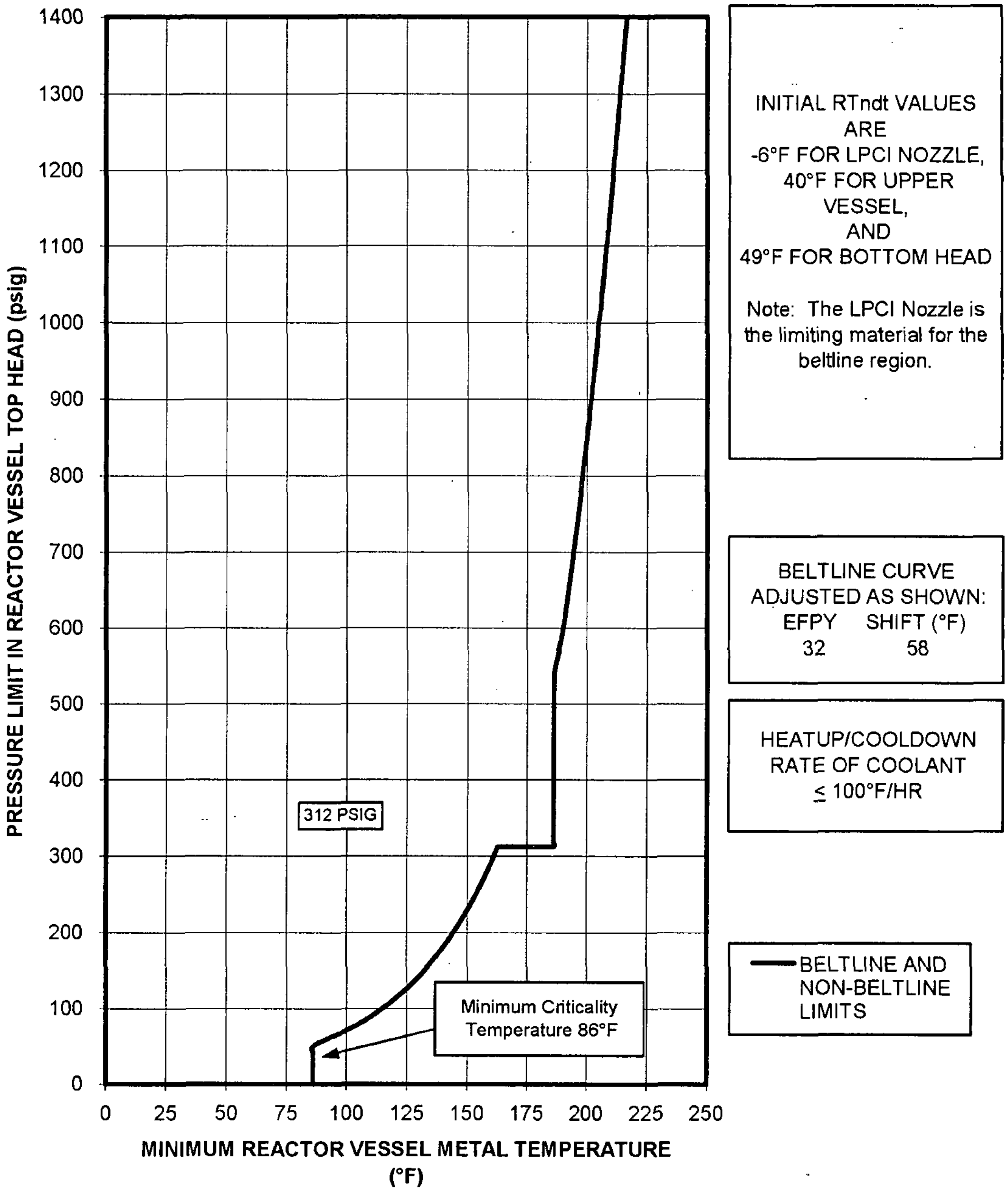

Figure 5-12: Composite Core Critical P-T Curves [Curve C] up to 32 EFPY [100°F/hr or less coolant heatup/cooldown]

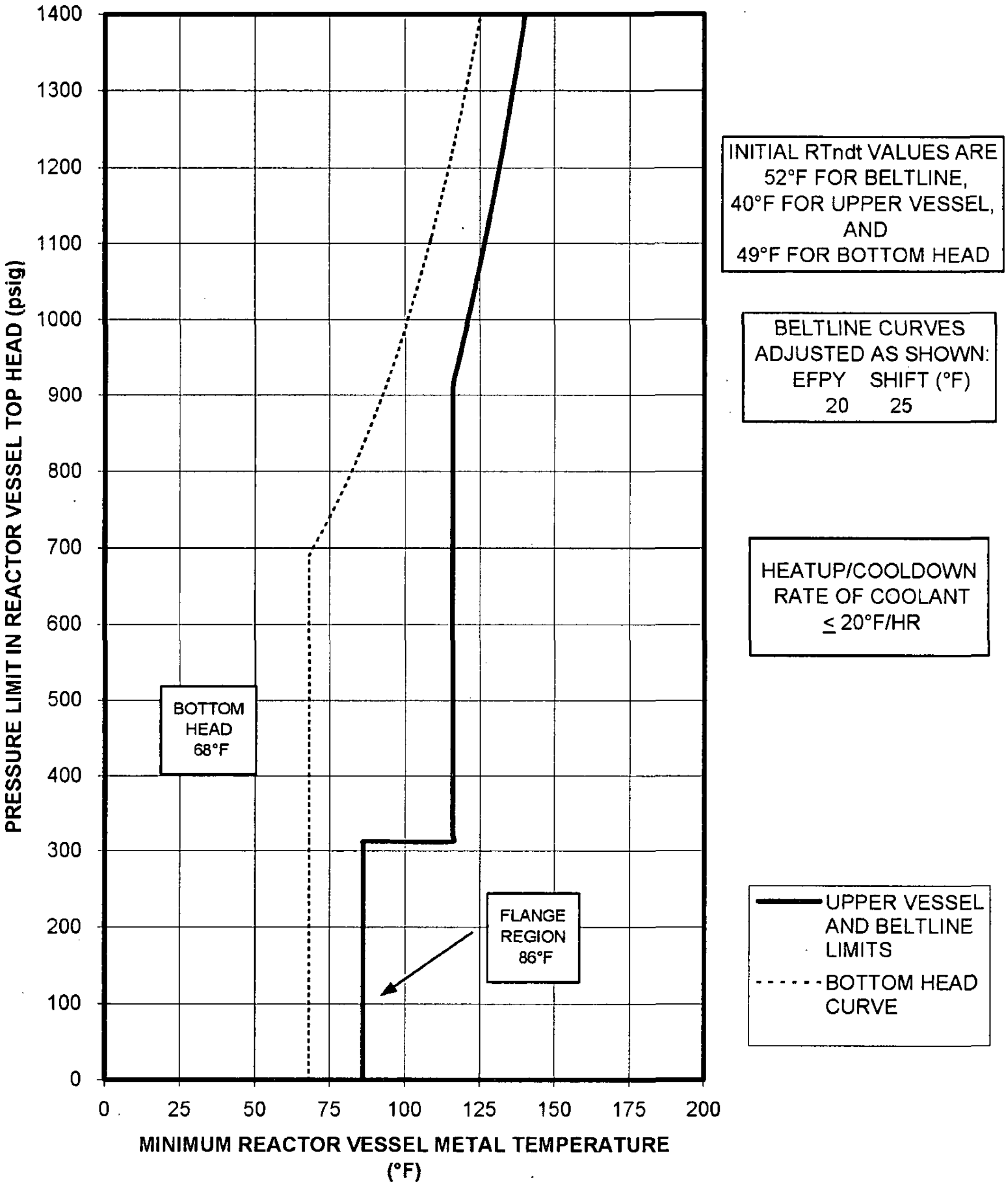

Figure 5-13: Composite Pressure Test P-T Curves [Curve A] up to 20 EFPY [20°F/hr or less coolant heatup/cooldown]

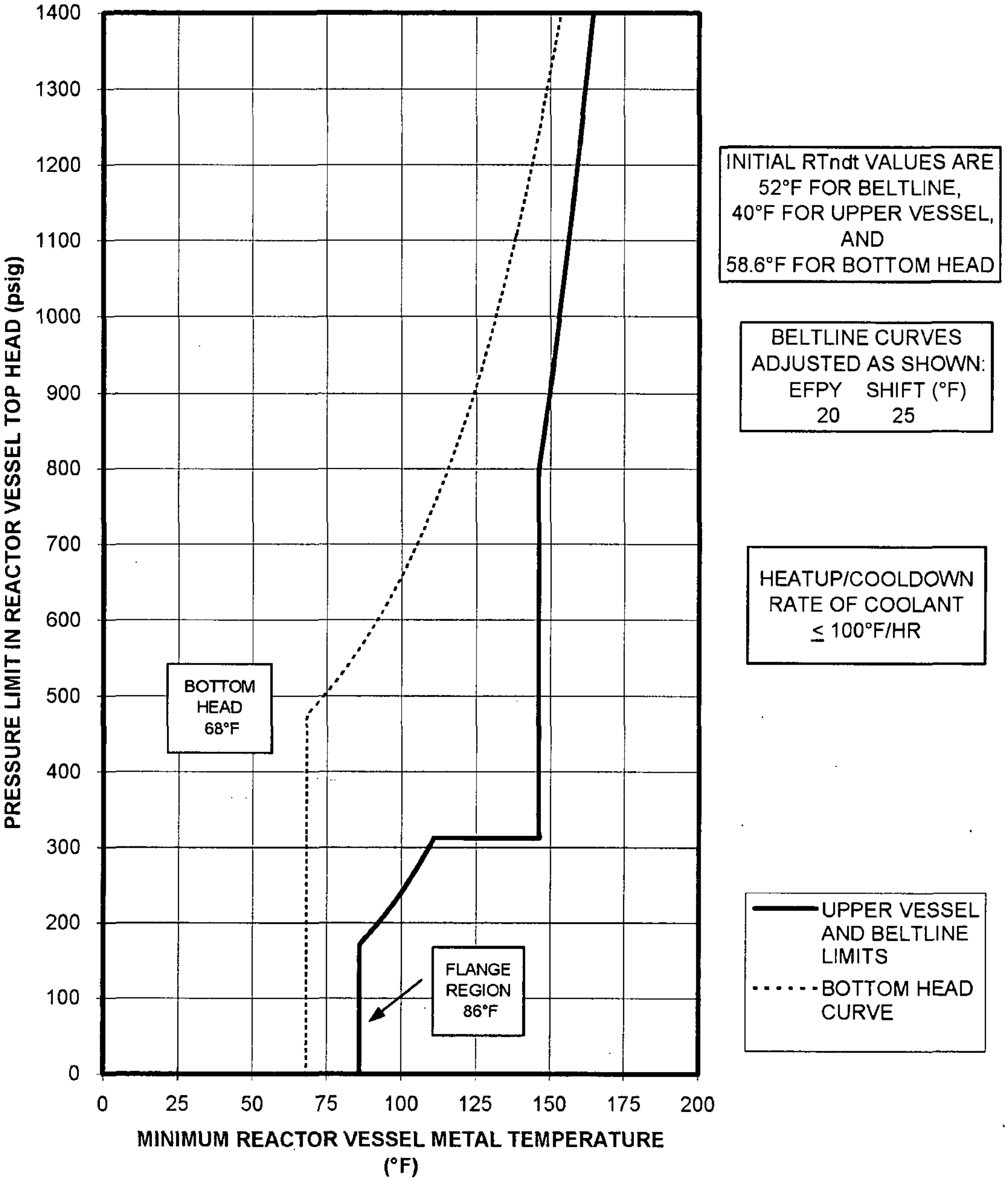

Figure 5-14: Composite Core Not Critical P-T Curves [Curve B] up to 20 EFPY [100°F/hr or less coolant heatup/cooldown]

6.0 REFERENCES

1. Carey, R.G., “Pressure-Temperature Curves for ComEd LaSalle Unit 2”, GE-NE, San Jose, CA, May 2000, (GE-NE-B13-02057-00-05R1, Revision 1)(GE Proprietary).

2. GE Drawing Number 761E581, “Reactor Vessel Thermal Cycles,” GE-NED, San Jose, CA, Revision 1 (GE Proprietary).

3. GE Drawing Number 158B8136, “Reactor Vessel Nozzle Thermal Cycles”, GE-NED, San Jose, CA, Revision 6 (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. a) T.A. Caine, “LaSalle County Station Units 1 and 2 Fracture Toughness Analysis per 10CFR50 Appendix G”, GE-NE, San Jose, CA, March 1988 (SASR 88-10).

   b) E.W. Sleight, “LaSalle Unit 2 RPV surveillance Materials Testing and Analysis,” GE-NE, San Jose, CA, February 1996, (GE-NE-B1301786-01, Revision 0).

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.

10. GE Nuclear Energy, NEDC-32399-P, "Basis for GE RT_{NDT} 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_{NDT} Estimation Method, September 1994", USNRC, December 16, 1994.

12. QA Records & RPV CMTR's:

    LaSalle Unit 2 –QA Records & RPV CMTR's LaSalle Unit 2 GE PO# 205-AE020, Manufactured by CBIN.

13. a) Letter from L. Loflin (Shearon Harris Nuclear Power) to NRC dated September 8, 1989, transmitting BAW-2083, "Analysis of Capsule U, Carolina Power & Light Company, Shearon Harris Unit No. 1, Reactor Vessel Material Surveillance Program", August 1989.

    b) "Carolina Power & Light Company, Shearon Harris Unit No. 1, Reactor Vessel Radiation Surveillance Program", WCAP-10502, May 1984.

    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.

14. a) Wu, Tang, "LaSalle 1&2 Neutron Flux Evaluation," GE-NE, San Jose, CA, May 2002, (GE-NE-0000-0002-5244-01, Rev. 0)(GE Proprietary Information).

    b) Letter, S.A. Richards, 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. [[ ]]

17. "Analysis of Flaws," Appendix A to Section XI of the ASME Boiler & Pressure Vessel Code, 1995 Edition with Addenda through 1996.

18. [[ ]]

19. Bottom Head and Feedwater Nozzle Dimensions:

    a) CBIN Drawing, GE Number VPF 3073-1-7, "Vessel Outline," GE-APED, San Jose, CA, Revision 7.

    b) GE Drawing Number VPF 3073-52, "Feedwater Nozzle", GE-NED, San Jose, CA, Revision 7.

20. [[ ]]

21. "Materials - Properties", Part D to Section II of the ASME Boiler & Pressure Vessel Code, 1995 Edition with Addenda through 1996.

APPENDIX A

DESCRIPTION OF DISCONTINUITIES

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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. Nozzles and appurtenances made from Alloy 600 (Inconel) do not require fracture toughness analysis. Components that do not require a fracture toughness evaluation are listed below:

Nozzle or Appurtenance Identification	Nozzle or Appurtenance	Material	Reference	Remarks
N11	Core Differential Pressure & Liquid Poison – Penetration $\leq$ 2.5"	Alloy 600		Thickness is $\leq$ 2.5" and made of Alloy 600; therefore, no further fracture toughness evaluation is required.
N15	Drain- Penetration $\leq$ 2.5" – Bottom Head	SA-508 Cl. 1 (Heat 265M-1) RT_{NDT}=-8°F	1.5.9 & 1.5.21	The discontinuity of the CRD nozzle listed in Table A-1 bounds this discontinuity; therefore, no further fracture toughness evaluation is required.
N17	Seal Leak Detection – Penetration ~1"	Alloy 600	1.5.9 & 1.5.28	Not a pressure boundary component; therefore, requires no fracture toughness evaluation.
	Top Head Lifting Lugs	SA-533 GR. B CL. 1	1.5.9 & 1.5.14	Not a pressure boundary component and loads only occur on this component when the reactor is shutdown during an outage. Therefore, no fracture toughness evaluation is required.

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

APPENDIX A REFERENCES:

1.5. RPV Drawings

- 1.5.1. CBI #32, Rev. 5, "Top Head Assembly," (GE VPF # 3073-032, Rev. 5)
- 1.5.2. CBI #30, Rev. 3, "Top Head Flange Assembly," (GE VPF # 3073-030, Rev. 3)
- 1.5.3. CBI #26, Rev. 8, "Shell Flange Assembly w/ N17 Nozzle," (GE VPF # 3073-026, Rev. 9)
- 1.5.4. CBI #21, Rev. 2, "#1 Shell Ring Assembly," (GE VPF # 3073-021, Rev. 4)
- 1.5.5. CBI #22, Rev. 3, "#2 Shell Ring Assembly," (GE VPF # 3073-022, Rev. 4)
- 1.5.6. CBI #23, Rev. 2, "#3 Shell Ring Assembly," (GE VPF # 3073-023, Rev. 4)
- 1.5.7. CBI #24, Rev. 3, "#4 Shell Ring Assembly," (GE VPF # 3073-024, Rev. 4)
- 1.5.8. CBI #13, Rev. 5, "Bottom Head Assembly," (GE VPF # 3073-013, Rev. 6)
- 1.5.9. CBI #R13, Rev. 7, "Vessel, Nozzle & Outside Bracket As-Built Dimensions," (GE VPF # 3073-104, Rev. 8)
- 1.5.10. CBI #58, Rev. 5, "RHR/LPCI Mode Nozzle N6," (GE VPF # 3073-058, Rev. 5)
- 1.5.11. CBI #69, Rev. 4, "Instrumentation Nozzle N12," (GE VPF # 3073-069, Rev. 4)
- 1.5.12. CBI #19, Rev. 4, "Shroud Support Assembly," (GE VPF # 3073-019, Rev. 5)
- 1.5.13. CBI #17, Rev. 2, "Shroud Support Stubs," (GE VPF # 3073-017, Rev. 2)
- 1.5.14. CBI #40, Rev. 2, "Top Head Lift Lugs," (GE VPF # 3073-040, Rev. 3)
- 1.5.15. CBI #51, Rev. 8, "N3 Nozzle," (GE VPF # 3073-051, Rev. 8)
- 1.5.16. CBI #52, Rev. 7, "N4 Nozzle," (GE VPF # 3073-052, Rev. 7)
- 1.5.17. CBI #55, Rev. 6, "N5 Nozzle," (GE VPF # 3073-055, Rev. 7)
- 1.5.18. CBI #61, Rev. 2, "N7 Nozzle," (GE VPF # 3073-061, Rev. 3)
- 1.5.19. CBI #63, Rev. 5, "N9 Nozzle," (GE VPF # 3073-063, Rev. 5)
- 1.5.20. CBI #65, Rev. 85, "N10 Nozzle," (GE VPF # 3073-065, Rev. 5)
- 1.5.21. CBI #72, Rev. 4, "N15 Nozzle," (GE VPF # 3073-072, Rev. 4)
- 1.5.22. CBI #51, Rev. 8, "N3 Nozzle," (GE VPF # 3073-051, Rev. 8)
- 1.5.23. CBI #73, Rev. 5, "N16 Nozzle," (GE VPF # 3073-073, Rev. 5)
- 1.5.24. CBI #76, Rev. 2, "N18 Nozzle," (GE VPF # 3073-076, Rev. 3)

1.5.25. CBI #80, Rev. 2, "Stabilizer Brackets," (GE VPF# 3073-080, Rev. 2)

1.5.26. CBI #9, Rev. 7, "Support Skirt Knuckle," (GE VPF # 3073-009, Rev. 7)

1.5.27. CBI #62, Rev. 2, "N8 Nozzle," (GE VPF # 3073-062, Rev. 3)

1.5.28. GE Drawing 732E143, Rev. 16, "Purchase Part, Reactor Vessel," GE-NED, San Jose, CA.

1.5.29. CBI #46, Rev. 5, "N1 Nozzle," (GE VPF # 3073-046, Rev. 5)

1.5.30. CBI #48, Rev. 6, "N2 Nozzle," (GE VPF # 3073-048, Rev. 6)

1.6. Wu, Tang, "LaSalle 1&2 Neutron Flux Evaluation", GE-NE, San Jose, CA, May 2002, (GE-NE-0000-0002-5244-01, Rev. 0) (GE Proprietary).

APPENDIX B

PRESSURE TEMPERATURE CURVE DATA TABULATION

TABLE B-1. LaSalle Unit 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 5-1, 5-2, 5-4, 5-5, 5-6, & 5-8

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	86.0	86.0	68.0	86.0	86.0
10	68.0	86.0	86.0	68.0	86.0	86.0
20	68.0	86.0	86.0	68.0	86.0	86.0
30	68.0	86.0	86.0	68.0	86.0	86.0
40	68.0	86.0	86.0	68.0	86.0	86.0
50	68.0	86.0	86.0	68.0	86.0	86.0
60	68.0	86.0	86.0	68.0	86.0	86.0
70	68.0	86.0	86.0	68.0	86.0	86.0
80	68.0	86.0	86.0	68.0	86.0	86.0
90	68.0	86.0	86.0	68.0	86.0	86.0
100	68.0	86.0	86.0	68.0	86.0	86.0
110	68.0	86.0	86.0	68.0	86.0	86.0
120	68.0	86.0	86.0	68.0	86.0	86.0
130	68.0	86.0	86.0	68.0	86.0	86.2
140	68.0	86.0	86.0	68.0	86.0	89.4
150	68.0	86.0	86.0	68.0	86.0	92.2
160	68.0	86.0	86.0	68.0	86.0	94.9
170	68.0	86.0	86.0	68.0	86.0	97.5
180	68.0	86.0	86.0	68.0	87.9	99.9
190	68.0	86.0	86.0	68.0	90.2	102.2
200	68.0	86.0	86.0	68.0	92.3	104.3
210	68.0	86.0	86.0	68.0	94.3	106.3
220	68.0	86.0	86.0	68.0	96.3	108.3
230	68.0	86.0	86.0	68.0	98.1	110.1
240	68.0	86.0	86.0	68.0	99.9	111.9

TABLE B-1. LaSalle Unit 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 5-1, 5-2, 5-4, 5-5, 5-6, & 5-8

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	86.0	86.0	68.0	101.6	113.6
260	68.0	86.0	86.0	68.0	103.2	115.2
270	68.0	86.0	86.0	68.0	104.8	116.8
280	68.0	86.0	86.0	68.0	106.3	118.3
290	68.0	86.0	86.0	68.0	107.8	119.8
300	68.0	86.0	86.0	68.0	109.2	121.2
310	68.0	86.0	86.0	68.0	110.5	122.5
312.5	68.0	86.0	86.0	68.0	110.9	122.9
312.5	68.0	116.0	116.0	68.0	146.0	146.0
320	68.0	116.0	116.0	68.0	146.0	146.0
330	68.0	116.0	116.0	68.0	146.0	146.0
340	68.0	116.0	116.0	68.0	146.0	146.0
350	68.0	116.0	116.0	68.0	146.0	146.0
360	68.0	116.0	116.0	68.0	146.0	146.0
370	68.0	116.0	116.0	68.0	146.0	146.0
380	68.0	116.0	116.0	68.0	146.0	146.0
390	68.0	116.0	116.0	68.0	146.0	146.0
400	68.0	116.0	116.0	68.0	146.0	146.0
410	68.0	116.0	116.0	68.0	146.0	146.0
420	68.0	116.0	116.0	68.0	146.0	146.0
430	68.0	116.0	116.0	68.0	146.0	146.0
440	68.0	116.0	116.0	68.0	146.0	146.0
450	68.0	116.0	116.0	68.0	146.0	146.0
460	68.0	116.0	116.0	68.0	146.0	146.0
470	68.0	116.0	116.0	68.0	146.0	146.0
480	68.0	116.0	116.0	69.1	146.0	146.0
490	68.0	116.0	116.0	71.4	146.0	146.0

TABLE B-1. LaSalle Unit 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 5-1, 5-2, 5-4, 5-5, 5-6, & 5-8

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	116.0	116.0	73.6	146.0	146.0
510	68.0	116.0	116.0	75.8	146.0	146.0
520	68.0	116.0	116.0	77.8	146.0	146.0
530	68.0	116.0	116.0	79.8	146.0	146.0
540	68.0	116.0	116.0	81.7	146.0	146.0
550	68.0	116.0	116.0	83.5	146.0	146.6
560	68.0	116.0	116.0	85.3	146.0	147.4
570	68.0	116.0	116.0	87.0	146.0	148.1
580	68.0	116.0	116.0	88.6	146.0	148.9
590	68.0	116.0	116.0	90.2	146.0	149.6
600	68.0	116.0	116.0	91.8	146.0	150.1
610	68.0	116.0	116.0	93.3	146.0	150.6
620	68.0	116.0	116.0	94.7	146.0	151.0
630	68.0	116.0	116.0	96.1	146.0	151.4
640	68.0	116.0	116.0	97.5	146.0	151.8
650	68.0	116.0	116.0	98.8	146.0	152.2
660	68.0	116.0	116.0	100.1	146.0	152.7
670	68.0	116.0	116.0	101.4	146.0	153.1
680	68.0	116.0	116.0	102.7	146.0	153.5
690	68.0	116.0	116.0	103.9	146.0	153.9
700	69.2	116.0	116.0	105.0	146.0	154.3
710	70.7	116.0	116.0	106.2	146.0	154.7
720	72.1	116.0	116.0	107.3	146.0	155.1
730	73.5	116.0	116.0	108.4	146.0	155.5
740	74.8	116.0	116.0	109.5	146.0	155.9
750	76.1	116.0	116.0	110.6	146.0	156.2
760	77.4	116.0	116.8	111.6	146.0	156.6

TABLE B-1. LaSalle Unit 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 5-1, 5-2, 5-4, 5-5, 5-6, & 5-8

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	78.6	116.0	117.6	112.6	146.0	157.0
780	79.8	116.0	118.3	113.6	146.0	157.4
790	81.0	116.0	119.1	114.6	146.0	157.8
800	82.2	116.0	119.9	115.5	146.1	158.1
810	83.3	116.0	120.6	116.5	146.5	158.5
820	84.4	116.0	121.4	117.4	146.9	158.9
830	85.5	116.0	122.1	118.3	147.2	159.2
840	86.5	116.0	122.8	119.2	147.6	159.6
850	87.6	116.0	123.5	120.0	147.9	159.9
860	88.6	116.0	124.2	120.9	148.3	160.3
870	89.6	116.0	124.9	121.7	148.6	160.6
880	90.5	116.0	125.6	122.6	149.0	161.0
890	91.5	116.0	126.3	123.4	149.3	161.3
900	92.4	116.0	126.9	124.2	149.7	161.7
910	93.4	116.0	127.6	125.0	150.0	162.0
920	94.3	116.2	128.2	125.7	150.4	162.4
930	95.1	116.9	128.9	126.5	150.7	162.7
940	96.0	117.5	129.5	127.3	151.0	163.0
950	96.9	118.1	130.1	128.0	151.4	163.4
960	97.7	118.7	130.7	128.7	151.7	163.7
970	98.6	119.3	131.3	129.5	152.0	164.0
980	99.4	119.9	131.9	130.2	152.4	164.4
990	100.2	120.5	132.5	130.9	152.7	164.7
1000	101.0	121.1	133.1	131.6	153.0	165.0
1010	101.7	121.7	133.7	132.2	153.3	165.3
1020	102.5	122.2	134.2	132.9	153.6	165.6
1030	103.3	122.8	134.8	133.6	154.0	166.0

TABLE B-1. LaSalle Unit 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 5-1, 5-2, 5-4, 5-5, 5-6, & 5-8

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	104.0	123.4	135.4	134.2	154.3	166.3
1050	104.7	123.9	135.9	134.9	154.6	166.6
1060	105.4	124.5	136.5	135.5	154.9	166.9
1070	106.2	125.0	137.0	136.1	155.2	167.2
1080	106.9	125.5	137.5	136.8	155.5	167.5
1090	107.6	126.1	138.1	137.4	155.8	167.8
1100	108.2	126.6	138.6	138.0	156.1	168.1
1105	108.6	126.8	138.8	138.3	156.3	168.3
1110	108.9	127.1	139.1	138.6	156.4	168.4
1120	109.6	127.6	139.6	139.2	156.7	168.7
1130	110.2	128.1	140.1	139.8	157.0	169.0
1140	110.9	128.6	140.6	140.3	157.3	169.3
1150	111.5	129.1	141.1	140.9	157.6	169.6
1160	112.1	129.6	141.6	141.5	157.9	169.9
1170	112.8	130.1	142.1	142.0	158.2	170.2
1180	113.4	130.6	142.6	142.6	158.5	170.5
1190	114.0	131.1	143.1	143.1	158.7	170.7
1200	114.6	131.5	143.5	143.7	159.0	171.0
1210	115.2	132.0	144.0	144.2	159.3	171.3
1220	115.8	132.5	144.5	144.8	159.6	171.6
1230	116.3	132.9	144.9	145.3	159.9	171.9
1240	116.9	133.4	145.4	145.8	160.2	172.2
1250	117.5	133.8	145.8	146.3	160.4	172.4
1260	118.0	134.3	146.3	146.8	160.7	172.7
1270	118.6	134.7	146.7	147.3	161.0	173.0
1280	119.1	135.2	147.2	147.8	161.2	173.2
1290	119.7	135.6	147.6	148.3	161.5	173.5

TABLE B-1. LaSalle Unit 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 5-1, 5-2, 5-4, 5-5, 5-6, & 5-8

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	120.2	136.0	148.0	148.8	161.8	173.8
1310	120.7	136.5	148.5	149.3	162.1	174.1
1320	121.3	136.9	148.9	149.8	162.3	174.3
1330	121.8	137.3	149.3	150.2	162.6	174.6
1340	122.3	137.7	149.7	150.7	162.8	174.8
1350	122.8	138.1	150.1	151.2	163.1	175.1
1360	123.3	138.6	150.6	151.6	163.4	175.4
1370	123.8	139.0	151.0	152.1	163.6	175.6
1380	124.3	139.4	151.4	152.5	163.9	175.9
1390	124.8	139.8	151.8	153.0	164.1	176.1
1400	125.3	140.2	152.2	153.4	164.4	176.4

TABLE B-2. LaSalle Unit 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 5-10, 5-11 and 5-12

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE B (°F)	NONBELTLINE & BELTLINE 32 EFPY CURVE C (°F)
0	68.0	86.0	68.0	86.0	86.0
10	68.0	86.0	68.0	86.0	86.0
20	68.0	86.0	68.0	86.0	86.0
30	68.0	86.0	68.0	86.0	86.0
40	68.0	86.0	68.0	86.0	86.0
50	68.0	86.0	68.0	86.0	86.0
60	68.0	86.0	68.0	86.0	92.0
70	68.0	86.0	68.0	86.0	99.2
80	68.0	86.0	68.0	86.0	105.2
90	68.0	86.0	68.0	86.0	110.3
100	68.0	86.0	68.0	86.0	114.8
110	68.0	86.0	68.0	86.0	118.9
120	68.0	86.0	68.0	86.0	122.7
130	68.0	86.0	68.0	86.2	126.2
140	68.0	86.0	68.0	89.4	129.4
150	68.0	86.0	68.0	92.2	132.2
160	68.0	86.0	68.0	94.9	134.9
170	68.0	86.0	68.0	97.5	137.5
180	68.0	86.0	68.0	99.9	139.9

TABLE B-2. LaSalle Unit 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 5-10, 5-11 and 5-12

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE B (°F)	NONBELTLINE & BELTLINE 32 EFPY CURVE C (°F)
190	68.0	86.0	68.0	102.2	142.2
200	68.0	86.0	68.0	104.3	144.3
210	68.0	86.0	68.0	106.3	146.3
220	68.0	86.0	68.0	108.3	148.3
230	68.0	86.0	68.0	110.1	150.1
240	68.0	86.0	68.0	111.9	151.9
250	68.0	86.0	68.0	113.6	153.6
260	68.0	86.0	68.0	115.2	155.2
270	68.0	86.0	68.0	116.8	156.8
280	68.0	86.0	68.0	118.3	158.3
290	68.0	86.0	68.0	119.8	159.8
300	68.0	86.0	68.0	121.2	161.2
310	68.0	86.0	68.0	122.5	162.5
312.5	68.0	86.0	68.0	122.9	162.9
312.5	68.0	116.0	68.0	146.0	186.0
320	68.0	116.0	68.0	146.0	186.0
330	68.0	116.0	68.0	146.0	186.0
340	68.0	116.0	68.0	146.0	186.0
350	68.0	116.0	68.0	146.0	186.0
360	68.0	116.0	68.0	146.0	186.0

TABLE B-2. LaSalle Unit 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 5-10, 5-11 and 5-12

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE B (°F)	NONBELTLINE & BELTLINE 32 EFPY CURVE C (°F)
370	68.0	116.0	68.0	146.0	186.0
380	68.0	116.0	68.0	146.0	186.0
390	68.0	116.0	68.0	146.0	186.0
400	68.0	116.0	68.0	146.0	186.0
410	68.0	116.0	68.0	146.0	186.0
420	68.0	116.0	68.0	146.0	186.0
430	68.0	116.0	68.0	146.0	186.0
440	68.0	116.0	68.0	146.0	186.0
450	68.0	116.0	68.0	146.0	186.0
460	68.0	116.0	68.0	146.0	186.0
470	68.0	116.0	68.0	146.0	186.0
480	68.0	116.0	69.1	146.0	186.0
490	68.0	116.0	71.4	146.0	186.0
500	68.0	116.0	73.6	146.0	186.0
510	68.0	116.0	75.8	146.0	186.0
520	68.0	116.0	77.8	146.0	186.0
530	68.0	116.0	79.8	146.0	186.0
540	68.0	116.0	81.7	146.0	186.0
550	68.0	116.0	83.5	146.6	186.6
560	68.0	116.0	85.3	147.4	187.4

TABLE B-2. LaSalle Unit 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 5-10, 5-11 and 5-12

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE B (°F)	NONBELTLINE & BELTLINE 32 EFPY CURVE C (°F)
570	68.0	116.0	87.0	148.1	188.1
580	68.0	116.0	88.6	148.9	188.9
590	68.0	116.0	90.2	149.6	189.6
600	68.0	116.0	91.8	150.1	190.1
610	68.0	116.0	93.3	150.6	190.6
620	68.0	116.0	94.7	151.0	191.0
630	68.0	116.0	96.1	151.4	191.4
640	68.0	116.0	97.5	151.8	191.8
650	68.0	116.0	98.8	152.2	192.2
660	68.0	116.0	100.1	152.7	192.7
670	68.0	116.0	101.4	153.1	193.1
680	68.0	116.0	102.7	153.5	193.5
690	68.0	116.0	103.9	153.9	193.9
700	69.2	116.0	105.0	154.3	194.3
710	70.7	116.0	106.2	154.7	194.7
720	72.1	116.0	107.3	155.1	195.1
730	73.5	116.0	108.4	155.5	195.5
740	74.8	116.0	109.5	155.9	195.9
750	76.1	116.0	110.6	156.2	196.2
760	77.4	116.8	111.6	156.6	196.6

TABLE B-2. LaSalle Unit 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 5-10, 5-11 and 5-12

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE B (°F)	NONBELTLINE & BELTLINE 32 EFPY CURVE C (°F)
770	78.6	117.6	112.6	157.0	197.0
780	79.8	118.3	113.6	157.4	197.4
790	81.0	119.1	114.6	157.8	197.8
800	82.2	119.9	115.5	158.1	198.1
810	83.3	120.6	116.5	158.5	198.5
820	84.4	121.4	117.4	158.9	198.9
830	85.5	122.1	118.3	159.2	199.2
840	86.5	122.8	119.2	159.6	199.6
850	87.6	123.5	120.0	159.9	199.9
860	88.6	124.2	120.9	160.3	200.3
870	89.6	124.9	121.7	160.6	200.6
880	90.5	125.6	122.6	161.0	201.0
890	91.5	126.3	123.4	161.3	201.3
900	92.4	126.9	124.2	161.7	201.7
910	93.4	127.6	125.0	162.0	202.0
920	94.3	128.2	125.7	162.4	202.4
930	95.1	128.9	126.5	162.7	202.7
940	96.0	129.5	127.3	163.0	203.0
950	96.9	130.1	128.0	163.4	203.4
960	97.7	130.7	128.7	163.7	203.7

TABLE B-2. LaSalle Unit 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 5-10, 5-11 and 5-12

	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	BOTTOM HEAD	UPPER RPV & BELTLINE AT 32 EFPY	NONBELTLINE & BELTLINE 32 EFPY
PRESSURE	CURVE A	CURVE A	CURVE B	CURVE B	CURVE C
(PSIG)	(°F)	(°F)	(°F)	(°F)	(°F)
970	98.6	131.3	129.5	164.0	204.0
980	99.4	131.9	130.2	164.4	204.4
990	100.2	132.5	130.9	164.7	204.7
1000	101.0	133.1	131.6	165.0	205.0
1010	101.7	133.7	132.2	165.3	205.3
1020	102.5	134.2	132.9	165.6	205.6
1030	103.3	134.8	133.6	166.0	206.0
1040	104.0	135.4	134.2	166.3	206.3
1050	104.7	135.9	134.9	166.6	206.6
1060	105.4	136.5	135.5	166.9	206.9
1070	106.2	137.0	136.1	167.2	207.2
1080	106.9	137.5	136.8	167.5	207.5
1090	107.6	138.1	137.4	167.8	207.8
1100	108.2	138.6	138.0	168.1	208.1
1105	108.6	138.8	138.3	168.3	208.3
1110	108.9	139.1	138.6	168.4	208.4
1120	109.6	139.6	139.2	168.7	208.7
1130	110.2	140.1	139.8	169.0	209.0
1140	110.9	140.6	140.3	169.3	209.3
1150	111.5	141.1	140.9	169.6	209.6

TABLE B-2. LaSalle Unit 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 5-10, 5-11 and 5-12

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE B (°F)	NONBELTLINE & BELTLINE 32 EFPY CURVE C (°F)
1160	112.1	141.6	141.5	169.9	209.9
1170	112.8	142.1	142.0	170.2	210.2
1180	113.4	142.6	142.6	170.5	210.5
1190	114.0	143.1	143.1	170.7	210.7
1200	114.6	143.5	143.7	171.0	211.0
1210	115.2	144.0	144.2	171.3	211.3
1220	115.8	144.5	144.8	171.6	211.6
1230	116.3	144.9	145.3	171.9	211.9
1240	116.9	145.4	145.8	172.2	212.2
1250	117.5	145.8	146.3	172.4	212.4
1260	118.0	146.3	146.8	172.7	212.7
1270	118.6	146.7	147.3	173.0	213.0
1280	119.1	147.2	147.8	173.2	213.2
1290	119.7	147.6	148.3	173.5	213.5
1300	120.2	148.0	148.8	173.8	213.8
1310	120.7	148.5	149.3	174.1	214.1
1320	121.3	148.9	149.8	174.3	214.3
1330	121.8	149.3	150.2	174.6	214.6
1340	122.3	149.7	150.7	174.8	214.8
1350	122.8	150.1	151.2	175.1	215.1

TABLE B-2. LaSalle Unit 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 5-10, 5-11 and 5-12

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE B (°F)	NONBELTLINE & BELTLINE 32 EFPY CURVE C (°F)
1360	123.3	150.6	151.6	175.4	215.4
1370	123.8	151.0	152.1	175.6	215.6
1380	124.3	151.4	152.5	175.9	215.9
1390	124.8	151.8	153.0	176.1	216.1
1400	125.3	152.2	153.4	176.4	216.4

TABLE B-3. LaSalle Unit 2 P-T Curve Values for 20 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, & 5-7

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	20 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	20 EFPY BELTLINE CURVE B (°F)
0	68.0	86.0	86.0	68.0	86.0	86.0
10	68.0	86.0	86.0	68.0	86.0	86.0
20	68.0	86.0	86.0	68.0	86.0	86.0
30	68.0	86.0	86.0	68.0	86.0	86.0
40	68.0	86.0	86.0	68.0	86.0	86.0
50	68.0	86.0	86.0	68.0	86.0	86.0
60	68.0	86.0	86.0	68.0	86.0	86.0
70	68.0	86.0	86.0	68.0	86.0	86.0
80	68.0	86.0	86.0	68.0	86.0	86.0
90	68.0	86.0	86.0	68.0	86.0	86.0
100	68.0	86.0	86.0	68.0	86.0	86.0
110	68.0	86.0	86.0	68.0	86.0	86.0
120	68.0	86.0	86.0	68.0	86.0	86.0
130	68.0	86.0	86.0	68.0	86.0	86.0
140	68.0	86.0	86.0	68.0	86.0	86.0
150	68.0	86.0	86.0	68.0	86.0	86.0
160	68.0	86.0	86.0	68.0	86.0	86.0
170	68.0	86.0	86.0	68.0	86.0	86.0
180	68.0	86.0	86.0	68.0	87.9	86.0
190	68.0	86.0	86.0	68.0	90.2	87.2
200	68.0	86.0	86.0	68.0	92.3	89.3
210	68.0	86.0	86.0	68.0	94.3	91.3
220	68.0	86.0	86.0	68.0	96.3	93.3
230	68.0	86.0	86.0	68.0	98.1	95.1
240	68.0	86.0	86.0	68.0	99.9	96.9

TABLE B-3. LaSalle Unit 2 P-T Curve Values for 20 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, & 5-7

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	20 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	20 EFPY BELTLINE CURVE B (°F)
250	68.0	86.0	86.0	68.0	101.6	98.6
260	68.0	86.0	86.0	68.0	103.2	100.2
270	68.0	86.0	86.0	68.0	104.8	101.8
280	68.0	86.0	86.0	68.0	106.3	103.3
290	68.0	86.0	86.0	68.0	107.8	104.8
300	68.0	86.0	86.0	68.0	109.2	106.2
310	68.0	86.0	86.0	68.0	110.5	107.5
312.5	68.0	86.0	86.0	68.0	110.9	107.9
312.5	68.0	116.0	116.0	68.0	146.0	146.0
320	68.0	116.0	116.0	68.0	146.0	146.0
330	68.0	116.0	116.0	68.0	146.0	146.0
340	68.0	116.0	116.0	68.0	146.0	146.0
350	68.0	116.0	116.0	68.0	146.0	146.0
360	68.0	116.0	116.0	68.0	146.0	146.0
370	68.0	116.0	116.0	68.0	146.0	146.0
380	68.0	116.0	116.0	68.0	146.0	146.0
390	68.0	116.0	116.0	68.0	146.0	146.0
400	68.0	116.0	116.0	68.0	146.0	146.0
410	68.0	116.0	116.0	68.0	146.0	146.0
420	68.0	116.0	116.0	68.0	146.0	146.0
430	68.0	116.0	116.0	68.0	146.0	146.0
440	68.0	116.0	116.0	68.0	146.0	146.0
450	68.0	116.0	116.0	68.0	146.0	146.0
460	68.0	116.0	116.0	68.0	146.0	146.0
470	68.0	116.0	116.0	68.0	146.0	146.0
480	68.0	116.0	116.0	69.1	146.0	146.0
490	68.0	116.0	116.0	71.4	146.0	146.0

TABLE B-3. LaSalle Unit 2 P-T Curve Values for 20 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, & 5-7

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	20 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	20 EFPY BELTLINE CURVE B (°F)
500	68.0	116.0	116.0	73.6	146.0	146.0
510	68.0	116.0	116.0	75.8	146.0	146.0
520	68.0	116.0	116.0	77.8	146.0	146.0
530	68.0	116.0	116.0	79.8	146.0	146.0
540	68.0	116.0	116.0	81.7	146.0	146.0
550	68.0	116.0	116.0	83.5	146.0	146.0
560	68.0	116.0	116.0	85.3	146.0	146.0
570	68.0	116.0	116.0	87.0	146.0	146.0
580	68.0	116.0	116.0	88.6	146.0	146.0
590	68.0	116.0	116.0	90.2	146.0	146.0
600	68.0	116.0	116.0	91.8	146.0	146.0
610	68.0	116.0	116.0	93.3	146.0	146.0
620	68.0	116.0	116.0	94.7	146.0	146.0
630	68.0	116.0	116.0	96.1	146.0	146.0
640	68.0	116.0	116.0	97.5	146.0	146.0
650	68.0	116.0	116.0	98.8	146.0	146.0
660	68.0	116.0	116.0	100.1	146.0	146.0
670	68.0	116.0	116.0	101.4	146.0	146.0
680	68.0	116.0	116.0	102.7	146.0	146.0
690	68.0	116.0	116.0	103.9	146.0	146.0
700	69.2	116.0	116.0	105.0	146.0	146.0
710	70.7	116.0	116.0	106.2	146.0	146.0
720	72.1	116.0	116.0	107.3	146.0	146.0
730	73.5	116.0	116.0	108.4	146.0	146.0
740	74.8	116.0	116.0	109.5	146.0	146.0
750	76.1	116.0	116.0	110.6	146.0	146.0
760	77.4	116.0	116.0	111.6	146.0	146.0

TABLE B-3. LaSalle Unit 2 P-T Curve Values for 20 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, & 5-7

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	20 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	20 EFPY BELTLINE CURVE B (°F)
770	78.6	116.0	116.0	112.6	146.0	146.0
780	79.8	116.0	116.0	113.6	146.0	146.0
790	81.0	116.0	116.0	114.6	146.0	146.0
800	82.2	116.0	116.0	115.5	146.1	146.0
810	83.3	116.0	116.0	116.5	146.5	146.0
820	84.4	116.0	116.0	117.4	146.9	146.0
830	85.5	116.0	116.0	118.3	147.2	146.0
840	86.5	116.0	116.0	119.2	147.6	146.0
850	87.6	116.0	116.0	120.0	147.9	146.0
860	88.6	116.0	116.0	120.9	148.3	146.0
870	89.6	116.0	116.0	121.7	148.6	146.0
880	90.5	116.0	116.0	122.6	149.0	146.0
890	91.5	116.0	116.0	123.4	149.3	146.3
900	92.4	116.0	116.0	124.2	149.7	146.7
910	93.4	116.0	116.0	125.0	150.0	147.0
920	94.3	116.2	116.0	125.7	150.4	147.4
930	95.1	116.9	116.0	126.5	150.7	147.7
940	96.0	117.5	116.0	127.3	151.0	148.0
950	96.9	118.1	116.0	128.0	151.4	148.4
960	97.7	118.7	116.0	128.7	151.7	148.7
970	98.6	119.3	116.3	129.5	152.0	149.0
980	99.4	119.9	116.9	130.2	152.4	149.4
990	100.2	120.5	117.5	130.9	152.7	149.7
1000	101.0	121.1	118.1	131.6	153.0	150.0
1010	101.7	121.7	118.7	132.2	153.3	150.3
1020	102.5	122.2	119.2	132.9	153.6	150.6
1030	103.3	122.8	119.8	133.6	154.0	151.0

TABLE B-3. LaSalle Unit 2 P-T Curve Values for 20 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, & 5-7

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	20 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	20 EFPY BELTLINE CURVE B (°F)
1040	104.0	123.4	120.4	134.2	154.3	151.3
1050	104.7	123.9	120.9	134.9	154.6	151.6
1060	105.4	124.5	121.5	135.5	154.9	151.9
1070	106.2	125.0	122.0	136.1	155.2	152.2
1080	106.9	125.5	122.5	136.8	155.5	152.5
1090	107.6	126.1	123.1	137.4	155.8	152.8
1100	108.2	126.6	123.6	138.0	156.1	153.1
1105	108.6	126.8	123.8	138.3	156.3	153.3
1110	108.9	127.1	124.1	138.6	156.4	153.4
1120	109.6	127.6	124.6	139.2	156.7	153.7
1130	110.2	128.1	125.1	139.8	157.0	154.0
1140	110.9	128.6	125.6	140.3	157.3	154.3
1150	111.5	129.1	126.1	140.9	157.6	154.6
1160	112.1	129.6	126.6	141.5	157.9	154.9
1170	112.8	130.1	127.1	142.0	158.2	155.2
1180	113.4	130.6	127.6	142.6	158.5	155.5
1190	114.0	131.1	128.1	143.1	158.7	155.7
1200	114.6	131.5	128.5	143.7	159.0	156.0
1210	115.2	132.0	129.0	144.2	159.3	156.3
1220	115.8	132.5	129.5	144.8	159.6	156.6
1230	116.3	132.9	129.9	145.3	159.9	156.9
1240	116.9	133.4	130.4	145.8	160.2	157.2
1250	117.5	133.8	130.8	146.3	160.4	157.4
1260	118.0	134.3	131.3	146.8	160.7	157.7
1270	118.6	134.7	131.7	147.3	161.0	158.0
1280	119.1	135.2	132.2	147.8	161.2	158.2
1290	119.7	135.6	132.6	148.3	161.5	158.5

TABLE B-3. LaSalle Unit 2 P-T Curve Values for 20 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, & 5-7

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	20 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	20 EFPY BELTLINE CURVE B (°F)
1300	120.2	136.0	133.0	148.8	161.8	158.8
1310	120.7	136.5	133.5	149.3	162.1	159.1
1320	121.3	136.9	133.9	149.8	162.3	159.3
1330	121.8	137.3	134.3	150.2	162.6	159.6
1340	122.3	137.7	134.7	150.7	162.8	159.8
1350	122.8	138.1	135.2	151.2	163.1	160.1
1360	123.3	138.6	135.7	151.6	163.4	160.4
1370	123.8	139.0	136.2	152.1	163.6	160.8
1380	124.3	139.4	136.8	152.5	163.9	161.3
1390	124.8	139.8	137.3	153.0	164.1	161.7
1400	125.3	140.2	137.8	153.4	164.4	162.1

TABLE B-4. LaSalle Unit 2 P-T Curve Values for 20 EFPY

Required Coolant Temperatures at 100 °F/hr for Curve C

For Figure 5-9

PRESSURE (PSIG)	UPPER VESSEL CURVE C (°F)	BOTTOM HEAD CURVE C (°F)	20 EFPY BELTLINE CURVE C (°F)
0	86.0	68.0	86.0
10	86.0	68.0	86.0
20	86.0	68.0	86.0
30	86.0	68.0	86.0
40	86.0	68.0	86.0
50	86.0	68.0	86.0
60	86.0	68.0	86.0
70	87.2	68.0	86.0
80	93.2	68.0	86.0
90	98.3	68.0	86.0
100	102.8	68.0	86.0
110	106.9	68.0	86.0
120	110.7	68.0	86.0
130	114.2	68.0	86.0
140	117.4	68.0	86.0
150	120.2	68.0	86.0
160	122.9	68.0	86.0
170	125.5	68.0	86.0
180	127.9	68.0	86.0
190	130.2	68.0	86.0
200	132.3	68.0	86.0
210	134.3	68.0	86.0
220	136.3	68.0	86.0
230	138.1	68.0	86.0
240	139.9	68.0	86.0

TABLE B-4. LaSalle Unit 2 P-T Curve Values for 20 EFPY

Required Coolant Temperatures at 100 °F/hr for Curve C
For Figure 5-9

PRESSURE (PSIG)	UPPER VESSEL CURVE C (°F)	BOTTOM HEAD CURVE C (°F)	20 EFPY BELTLINE CURVE C (°F)
250	141.6	68.0	86.0
260	143.2	68.0	86.0
270	144.8	68.0	86.0
280	146.3	68.0	86.0
290	147.8	68.0	86.0
300	149.2	68.0	86.0
310	150.5	68.0	86.0
312.5	150.9	68.0	86.6
312.5	186.0	68.0	186.0
320	186.0	68.0	186.0
330	186.0	68.0	186.0
340	186.0	68.0	186.0
350	186.0	68.0	186.0
360	186.0	68.0	186.0
370	186.0	68.0	186.0
380	186.0	68.0	186.0
390	186.0	71.3	186.0
400	186.0	75.3	186.0
410	186.0	79.0	186.0
420	186.0	82.5	186.0
430	186.0	85.8	186.0
440	186.0	88.8	186.0
450	186.0	91.7	186.0
460	186.0	94.4	186.0
470	186.0	97.0	186.0
480	186.0	99.5	186.0
490	186.0	101.8	186.0

TABLE B-4. LaSalle Unit 2 P-T Curve Values for 20 EFPY

Required Coolant Temperatures at 100 °F/hr for Curve C
For Figure 5-9

PRESSURE (PSIG)	UPPER VESSEL CURVE C (°F)	BOTTOM HEAD CURVE C (°F)	20 EFPY BELTLINE CURVE C (°F)
500	186.0	104.0	186.0
510	186.0	106.2	186.0
520	186.0	108.2	186.0
530	186.0	110.2	186.0
540	186.0	112.1	186.0
550	186.0	113.9	186.0
560	186.0	115.7	186.0
570	186.0	117.4	186.0
580	186.0	119.0	186.0
590	186.0	120.6	186.0
600	186.0	122.2	186.0
610	186.0	123.7	186.0
620	186.0	125.1	186.0
630	186.0	126.5	186.0
640	186.0	127.9	186.0
650	186.0	129.2	186.0
660	186.0	130.5	186.0
670	186.0	131.8	186.0
680	186.0	133.1	186.0
690	186.0	134.3	186.0
700	186.0	135.4	186.0
710	186.0	136.6	186.0
720	186.0	137.7	186.0
730	186.0	138.8	186.0
740	186.0	139.9	186.0
750	186.0	141.0	186.0
760	186.0	142.0	186.0

TABLE B-4. LaSalle Unit 2 P-T Curve Values for 20 EFPY

Required Coolant Temperatures at 100 °F/hr for Curve C
For Figure 5-9

PRESSURE (PSIG)	UPPER VESSEL CURVE C (°F)	BOTTOM HEAD CURVE C (°F)	20 EFPY BELTLINE CURVE C (°F)
770	186.0	143.0	186.0
780	186.0	144.0	186.0
790	186.0	145.0	186.0
800	186.1	145.9	186.0
810	186.5	146.9	186.0
820	186.9	147.8	186.0
830	187.2	148.7	186.0
840	187.6	149.6	186.0
850	187.9	150.4	186.0
860	188.3	151.3	186.0
870	188.6	152.1	186.0
880	189.0	153.0	186.0
890	189.3	153.8	186.0
900	189.7	154.6	186.0
910	190.0	155.4	186.0
920	190.4	156.1	186.0
930	190.7	156.9	186.0
940	191.0	157.7	186.0
950	191.4	158.4	186.0
960	191.7	159.1	186.0
970	192.0	159.9	186.0
980	192.4	160.6	186.0
990	192.7	161.3	186.0
1000	193.0	162.0	186.0
1010	193.3	162.6	186.0
1020	193.6	163.3	186.0
1030	194.0	164.0	186.0

TABLE B-4. LaSalle Unit 2 P-T Curve Values for 20 EFPY

Required Coolant Temperatures at 100 °F/hr for Curve C
For Figure 5-9

PRESSURE (PSIG)	UPPER VESSEL CURVE C (°F)	BOTTOM HEAD CURVE C (°F)	20 EFPY BELTLINE CURVE C (°F)
1040	194.3	164.6	186.0
1050	194.6	165.3	186.0
1060	194.9	165.9	186.0
1070	195.2	166.5	186.1
1080	195.5	167.2	186.7
1090	195.8	167.8	187.3
1100	196.1	168.4	187.8
1105	196.3	168.7	188.1
1110	196.4	169.0	188.4
1120	196.7	169.6	188.9
1130	197.0	170.2	189.4
1140	197.3	170.7	190.0
1150	197.6	171.3	190.5
1160	197.9	171.9	191.0
1170	198.2	172.4	191.5
1180	198.5	173.0	192.0
1190	198.7	173.5	192.5
1200	199.0	174.1	193.0
1210	199.3	174.6	193.5
1220	199.6	175.2	194.0
1230	199.9	175.7	194.5
1240	200.2	176.2	195.0
1250	200.4	176.7	195.5
1260	200.7	177.2	195.9
1270	201.0	177.7	196.4
1280	201.2	178.2	196.9
1290	201.5	178.7	197.3

TABLE B-4. LaSalle Unit 2 P-T Curve Values for 20 EFPY

Required Coolant Temperatures at 100 °F/hr for Curve C
For Figure 5-9

PRESSURE (PSIG)	UPPER VESSEL CURVE C (°F)	BOTTOM HEAD CURVE C (°F)	20 EFPY BELTLINE CURVE C (°F)
1300	201.8	179.2	197.8
1310	202.1	179.7	198.2
1320	202.3	180.2	198.7
1330	202.6	180.6	199.1
1340	202.8	181.1	199.5
1350	203.1	181.6	200.0
1360	203.4	182.0	200.4
1370	203.6	182.5	200.8
1380	203.9	182.9	201.3
1390	204.1	183.4	201.7
1400	204.4	183.8	202.1

TABLE B-5. LaSalle Unit 2 Composite P-T Curve Values for 20 EFPY

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

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 20 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 20 EFPY CURVE B (°F)
0	68.0	86.0	68.0	86.0
10	68.0	86.0	68.0	86.0
20	68.0	86.0	68.0	86.0
30	68.0	86.0	68.0	86.0
40	68.0	86.0	68.0	86.0
50	68.0	86.0	68.0	86.0
60	68.0	86.0	68.0	86.0
70	68.0	86.0	68.0	86.0
80	68.0	86.0	68.0	86.0
90	68.0	86.0	68.0	86.0
100	68.0	86.0	68.0	86.0
110	68.0	86.0	68.0	86.0
120	68.0	86.0	68.0	86.0
130	68.0	86.0	68.0	86.0
140	68.0	86.0	68.0	86.0
150	68.0	86.0	68.0	86.0
160	68.0	86.0	68.0	86.0
170	68.0	86.0	68.0	86.0
180	68.0	86.0	68.0	87.9
190	68.0	86.0	68.0	90.2
200	68.0	86.0	68.0	92.3
210	68.0	86.0	68.0	94.3
220	68.0	86.0	68.0	96.3
230	68.0	86.0	68.0	98.1

TABLE B-5. LaSalle Unit 2 Composite P-T Curve Values for 20 EFPY

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

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 20 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 20 EFPY CURVE B (°F)
240	68.0	86.0	68.0	99.9
250	68.0	86.0	68.0	101.6
260	68.0	86.0	68.0	103.2
270	68.0	86.0	68.0	104.8
280	68.0	86.0	68.0	106.3
290	68.0	86.0	68.0	107.8
300	68.0	86.0	68.0	109.2
310	68.0	86.0	68.0	110.5
312.5	68.0	86.0	68.0	110.9
312.5	68.0	116.0	68.0	146.0
320	68.0	116.0	68.0	146.0
330	68.0	116.0	68.0	146.0
340	68.0	116.0	68.0	146.0
350	68.0	116.0	68.0	146.0
360	68.0	116.0	68.0	146.0
370	68.0	116.0	68.0	146.0
380	68.0	116.0	68.0	146.0
390	68.0	116.0	68.0	146.0
400	68.0	116.0	68.0	146.0
410	68.0	116.0	68.0	146.0
420	68.0	116.0	68.0	146.0
430	68.0	116.0	68.0	146.0
440	68.0	116.0	68.0	146.0
450	68.0	116.0	68.0	146.0
460	68.0	116.0	68.0	146.0
470	68.0	116.0	68.0	146.0

TABLE B-5. LaSalle Unit 2 Composite P-T Curve Values for 20 EFPY

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

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 20 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 20 EFPY CURVE B (°F)
480	68.0	116.0	69.1	146.0
490	68.0	116.0	71.4	146.0
500	68.0	116.0	73.6	146.0
510	68.0	116.0	75.8	146.0
520	68.0	116.0	77.8	146.0
530	68.0	116.0	79.8	146.0
540	68.0	116.0	81.7	146.0
550	68.0	116.0	83.5	146.0
560	68.0	116.0	85.3	146.0
570	68.0	116.0	87.0	146.0
580	68.0	116.0	88.6	146.0
590	68.0	116.0	90.2	146.0
600	68.0	116.0	91.8	146.0
610	68.0	116.0	93.3	146.0
620	68.0	116.0	94.7	146.0
630	68.0	116.0	96.1	146.0
640	68.0	116.0	97.5	146.0
650	68.0	116.0	98.8	146.0
660	68.0	116.0	100.1	146.0
670	68.0	116.0	101.4	146.0
680	68.0	116.0	102.7	146.0
690	68.0	116.0	103.9	146.0
700	69.2	116.0	105.0	146.0
710	70.7	116.0	106.2	146.0
720	72.1	116.0	107.3	146.0
730	73.5	116.0	108.4	146.0

TABLE B-5. LaSalle Unit 2 Composite P-T Curve Values for 20 EFPY

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

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 20 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 20 EFPY CURVE B (°F)
740	74.8	116.0	109.5	146.0
750	76.1	116.0	110.6	146.0
760	77.4	116.0	111.6	146.0
770	78.6	116.0	112.6	146.0
780	79.8	116.0	113.6	146.0
790	81.0	116.0	114.6	146.0
800	82.2	116.0	115.5	146.1
810	83.3	116.0	116.5	146.5
820	84.4	116.0	117.4	146.9
830	85.5	116.0	118.3	147.2
840	86.5	116.0	119.2	147.6
850	87.6	116.0	120.0	147.9
860	88.6	116.0	120.9	148.3
870	89.6	116.0	121.7	148.6
880	90.5	116.0	122.6	149.0
890	91.5	116.0	123.4	149.3
900	92.4	116.0	124.2	149.7
910	93.4	116.0	125.0	150.0
920	94.3	116.2	125.7	150.4
930	95.1	116.9	126.5	150.7
940	96.0	117.5	127.3	151.0
950	96.9	118.1	128.0	151.4
960	97.7	118.7	128.7	151.7
970	98.6	119.3	129.5	152.0
980	99.4	119.9	130.2	152.4
990	100.2	120.5	130.9	152.7

TABLE B-5. LaSalle Unit 2 Composite P-T Curve Values for 20 EFPY

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

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 20 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 20 EFPY CURVE B (°F)
1000	101.0	121.1	131.6	153.0
1010	101.7	121.7	132.2	153.3
1020	102.5	122.2	132.9	153.6
1030	103.3	122.8	133.6	154.0
1040	104.0	123.4	134.2	154.3
1050	104.7	123.9	134.9	154.6
1060	105.4	124.5	135.5	154.9
1070	106.2	125.0	136.1	155.2
1080	106.9	125.5	136.8	155.5
1090	107.6	126.1	137.4	155.8
1100	108.2	126.6	138.0	156.1
1105	108.6	126.8	138.3	156.3
1110	108.9	127.1	138.6	156.4
1120	109.6	127.6	139.2	156.7
1130	110.2	128.1	139.8	157.0
1140	110.9	128.6	140.3	157.3
1150	111.5	129.1	140.9	157.6
1160	112.1	129.6	141.5	157.9
1170	112.8	130.1	142.0	158.2
1180	113.4	130.6	142.6	158.5
1190	114.0	131.1	143.1	158.7
1200	114.6	131.5	143.7	159.0
1210	115.2	132.0	144.2	159.3
1220	115.8	132.5	144.8	159.6
1230	116.3	132.9	145.3	159.9
1240	116.9	133.4	145.8	160.2

TABLE B-5. LaSalle Unit 2 Composite P-T Curve Values for 20 EFPY

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

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 20 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 20 EFPY CURVE B (°F)
1250	117.5	133.8	146.3	160.4
1260	118.0	134.3	146.8	160.7
1270	118.6	134.7	147.3	161.0
1280	119.1	135.2	147.8	161.2
1290	119.7	135.6	148.3	161.5
1300	120.2	136.0	148.8	161.8
1310	120.7	136.5	149.3	162.1
1320	121.3	136.9	149.8	162.3
1330	121.8	137.3	150.2	162.6
1340	122.3	137.7	150.7	162.8
1350	122.8	138.1	151.2	163.1
1360	123.3	138.6	151.6	163.4
1370	123.8	139.0	152.1	163.6
1380	124.3	139.4	152.5	163.9
1390	124.8	139.8	153.0	164.1
1400	125.3	140.2	153.4	164.4

APPENDIX C

Operating And Temperature Monitoring Requirements

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.

C.2.1 Curve A: Pressure Test

Curve A should be used during pressure tests at times when the coolant temperature is changing by ≤20°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°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.

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)

APPENDIX D

GE SIL 430

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.

TABLE OF RPV TEMPERATURE MONITORING MEASUREMENTS (CONTINUED)

(Typical)

Measurement	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.

TABLE OF RPV TEMPERATURE MONITORING MEASUREMENTS (CONTINUED)

(Typical)

Measurement	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.	Use for metal (not coolant) temperature. Install temporary T/Cs for alternate measurement, if required.
	One of two primary measurements for BWR/6s for hydro test.	
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.	Use for metal (not coolant) temperature. Response faster than closure head flange T/Cs.
	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 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 available on BWR/6s.

TABLE OF RPV TEMPERATURE MONITORING MEASUREMENTS (CONTINUED)

(Typical)

Measurement	Use	Limitations
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.

Product Reference: B21 Nuclear Boiler

Prepared By: A.C. Tsang

Approved for Issue:	**Issued By:**
B.H. Eldridge, Mgr.	D.L. Allred, Manager
Service Information	Customer Service Information
and Analysis	

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APPENDIX E

Determination of Beltline Region and Impact on Fracture Toughness

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 1.0e17 n/cm^2. Therefore, if it can be shown that no nozzles are located where the peak neutron fluence is expected to exceed or equal 1.0e17 n/cm^2, 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): 366.31" (from vessel 0) (Reference 1)
Shell # 1 - Bottom of Active Fuel (BAF): 216.31" (from vessel 0) (Reference 1)
Bottom of LPCI Nozzle in Shell # 2: 355.06" (from vessel 0) (Reference 2)
Center line of LPCI Nozzle in Shell # 2: 372" (from vessel 0) (Reference 3)
Top of Recirculation Outlet Nozzle in Shell # 1: 197.91" (from vessel 0) (Reference 4)
Center line of Recirculation Outlet Nozzle in Shell # 1: 172.5" (from vessel 0) (Reference 3)
Top of Recirculation Inlet Nozzle in Shell # 1: 198.56" (from vessel 0) (Reference 5)
Center line of Recirculation Inlet Nozzle in Shell # 1: 181" (from vessel 0) (Reference 3)

As shown above, the LPCI nozzle is within the core beltline region. This nozzle is bounded by the feedwater pressure-temperature curve as stated in Appendix A.
From [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 ~18" from BAF and the top of the recirculation outlet nozzle is ~18" from BAF), and no other nozzles are within the BAF-TAF region of the reactor vessel. Therefore, if it can be shown that the peak

fluence at this location is less than 1.0E17 n/cm^2, it can be safely concluded that all nozzles are outside the beltline region of the reactor vessel.

Based on the axial flux profile [6], the RPV flux level at ~10" below the BAF dropped to less than 0.1 of the peak flux level at the same radius. Likewise, the RPV flux level at ~10" above the TAF dropped to less than 0.1 of the peak flux at the same radius. Therefore, if the RPV fluence is 1.09E18 n/cm^2 [6], fluence at ~10" below BAF and ~10" above TAF are expected to be less than 1.0E17 n/cm^2 at 32 EFPY. The beltline region considered in the development of the P-T curves is adjusted to include the additional 10" above and below the active fuel region. The adjusted beltline region extends from 206.31" to 376.31" above reactor vessel "0".

Based on the above, it is concluded that none of the LaSalle Unit 2 reactor vessel nozzles, other than the LPCI nozzle, which is considered in the P-T curve evaluation, are in the beltline region.

Appendix E References:

1. Source of Bottom of Beltline Elevation: Figure Q121.7-2, "Welds in Beltline Region of Reactor Vessel – Unit 2", page Q121.7-12.
2. CBIN Drawing #58, Revision 5, "RHR/LPCI Nozzle N6", (GE VPF #3073-58-5).
3. CBIN Drawing #R13, Revision 3, "Vessel, Nozzle, & Outside Bracket As-Built Dimensions" (GE VPF #3073-104-8).
4. CBIN Drawing #46, Revision 5, "Recirculation Outlet Nozzle N1", (GE VPF #3073-46-5).
5. CBIN Drawing #48, Revision 6, "Recirculation Inlet Nozzle N2", (GE VPF #3073-48-6).
6. Wu, Tang, "LaSalle 1&2 Neutron Flux Evaluation", GE-NE, San Jose, CA, May 2002, (GE-NE-0000-0002-5244-01, Rev. 0)(GE Proprietary Information).

APPENDIX F

EVALUATION FOR UPPER SHELF ENERGY (USE)

Paragraph IV.B of 10CFR50 Appendix G [1] sets limits on the upper shelf energy (USE) of the beltline materials. The USE must remain above 50 ft-lb at all times during plant operation, assumed here to be up to 32 EFPY. Calculations of 32 EFPY USE, using Reg. Guide 1.99, Rev. 2 [2] methods, are summarized in Table F-1.

The USE decrease prediction values from Reg. Guide 1.99, Rev. 2 [2] were used for the beltline plates and welds in Table F-1. These calculations are based on the peak 1/4T fluence for all materials other than the LPCI nozzle, for conservatism. Because the Charpy data available for the LPCI nozzle consists of shear energy of 60%, this conservatism is not applied to the 32 EFPY USE calculation for this component; the 1/4T fluence for the LPCI nozzle as provided in Table 4-4 is used. Based on these results, the beltline materials will have USE values above 50 ft-lb at 32 EFPY, as required in 10CFR50 Appendix G [1]. The lowest USE predicted for 32 EFPY is 53 ft-lb (for Lower Shell plate heat C9434-2).

Table F-1: Upper Shelf Energy Evaluation for LaSalle Unit 2 Beltline Materials

Location	Heat	Test Temperature (°F)	Initial Longitudinal USE (ft-lb)	Initial Transverse USE[a] (ft-lb)	%Cu	32 EFPY 1/4T Fluence (n/cm^2)	% Decrease USE[b]	32 EFPY Transverse USE[c] (ft-lb)
Plates:								
Lower	C9425-1	[d]	102	66.3	0.12	7.5E+17	12	58
	C9425-2	[d]	94	61.1	0.12	7.5E+17	12	54
	C9434-2	40	91	59.2	0.09	7.5E+17	10	53
Lower-Intermediate	C9481-1[e]	40	n/a	95.5	0.11	7.5E+17	11	85
	C9404-2	[d]	116	75.4	0.07	7.5E+17	8.5	69
	C9601-2	40	107	69.6	0.12	7.5E+17	12	61
Welds:								
Vertical:								
Lower-Intermediate	3P4000	10	n/a	99	0.02	7.5E+17	8	91
Lower	3P4966	10	n/a	84	0.026	7.5E+17	8.5	77
Girth:								
Lower to Lower-Intermediate	5P6771	10	n/a	61	0.04	7.5E+17	10	55
Nozzles:								
LPCI	Q2Q36W[f]	-10		66	0.22	1.8E+17	12.5	58

a Values obtained from [3]
b Values obtained from Figure 2 of [2] for 32 EFPY 1/4T fluence
c 32 EFPY Transverse USE = Initial Transverse USE * [1 - (% Decrease USE /100)]
d USE values estimated from statistical evaluation in Appendix B of [3]
e Initial Transverse USE value obtained from baseline transverse data set [4]
f Average of Charpy V-Notch data for %Shear = 60

Appendix F References:

1. "Fracture Toughness Requirements", Appendix G to Part 50 of Title 10 of the Code of Federal Regulations, December 1995.
2. "Radiation Embrittlement of Reactor Vessel Materials," USNRC Regulatory Guide 1.99, Revision 2, May 1988.
3. T.A. Caine, "Upper Shelf Energy Evaluation for LaSalle Units 1 and 2", GENE, San Jose, CA, June 1990 (GE Report SASR 90-07).
4. Letter, dated 3/16/94, G.W. Contreras (GE San Jose) to R. Willems (Oak Brook), "LaSalle RPV Archive Material Records Search".

APPENDIX G

CORE NOT CRITICAL CALCULATION FOR BOTTOM HEAD (CRD PENETRATION)

TABLE OF CONTENTS

The following outline describes the contents of this Appendix:

G.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 [Reference 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}. [[

]]

G.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 [Reference 1]. This Appendix discusses the finite element analysis and the Appendix G [Reference 1] calculations separately below.

G.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 [Reference 1] considering the specific bottom head geometry is discussed first followed by a detailed discussion of the finite element analysis and Appendix G evaluation [Reference 1].

G.3.1 Applicability of the ASME Code Appendix G Methods

The methods described in the ASME Code Section XI, Appendix G [Reference 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 ¼ 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 more detailed 3-D 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 [Reference 1].

G.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 done using ANSYS Version 6.1 [Reference 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.

[[

]]

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:

[[

]]

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.

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.

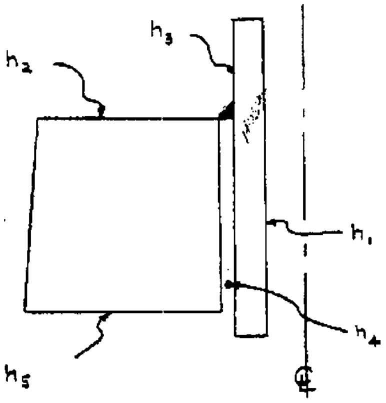

Figure 3. Regions to which thermal loads are applied

a. Region 1: h = 25, T = 60

b. 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.

Crack Configurations

The following four cracks were analyzed:

1. A part through crack, ¼ 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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[[ ]]

[[

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[[ ]]

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[[ ]]

[[

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[[ ]]

Stress Intensity Factor Computation

[[

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[[

]]

[[

]]

[[ ]]

[[

]]

Benchmarking [[ ]] Methodology

[[

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

Pressure Loading Analysis Results

[[

]]

[[

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[[

]]

Benchmarking of Pressure Loading Results

Pressure Loading analyses [[

]]

[[

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[[

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[[

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[[

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[[ ]]

[[

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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.

[[

]]

[[ ]]

[[

]]

[[

]]

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.

[[

]]

[[

]]

G.3.3 ASME Code Appendix G Evaluation

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

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

$$SF_p = 2.0$$

$$SF_t = 1.0$$

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

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$^{1/2}$

G.4 Results

Review of the [[ ]] results above demonstrates that the OD [[ ]] crack exhibits the highest stress intensity for the considered loading. The T-RT$_{NDT}$ 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:

[[

]]

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, [[ ]]

G.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 [[ ]]

G.6 References

I. American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME B&PV Code), Section XI. 1998 Edition with Addenda to 2000.

II. ANSYS User's Manual, Version 6.1.