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Pressure-Temperature Curves

For

ComEd

LaSalle Unit 1

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REPORT REVISION STATUS

Revision	Purpose
1	The report was revised to modify the proprietary markings per agreement with the NRC

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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 1988 [1]. Several improvements were made to the P-T curve methodology; the improvements include, but are not limited to, the incorporation of ASME Code Cases N-640 and N-588. ASME Code Case N-640 allows the use of K_{IC} rather than K_{Ia} to determine T-RT_{NDT}. ASME Code Case N-588 allows the use of an alternative procedure for calculating the applied stress intensity factors of Appendix G for axial and circumferential welds. Descriptions of other improvements are included in the P-T curve methodology section.

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 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.

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1.0 INTRODUCTION

The pressure-temperature (P-T) curves included in this report have been developed to present steam dome pressure versus minimum vessel metal temperature incorporating appropriate non-beltline limits and irradiation embrittlement effects in the beltline. Complete P-T curves were developed for 20 and 32 effective full power years (EFPY). The P-T curves are given in Section 5.0 and a tabulation of the curves is included in Appendix B.

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 1988 [1]. Several improvements were made to the P-T curve methodology; the improvements include, but are not limited to, the incorporation of ASME Code Cases N-640 [4] and N-588 [5]. ASME Code Case N-640 allows the use of K_{IC} rather than K_{Ia} to determine T-RT_{NDT}. ASME Code Case N-588 allows the use of an alternative procedure for calculating the applied stress intensity factors of Appendix G for axial and circumferential welds. Descriptions of other improvements are included in the P-T curve methodology section. 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 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 were tabulated from the Certified Material Test Report (CMTR's). 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 fluence values of

5.0×10^{17} n/cm^2 for LaSalle Unit 1 is used in this report and takes into account power uprate. A discussion of fluence is included in Section 4.2.1.2. Beltline chemistry values were updated to include the current data available from the vessel fabricator. The chemistry data is 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 to document 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. Finally, Appendix E contains an evaluation of the vessel wall thickness discontinuity in the beltline region.

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 1988 [1]. A detailed description of the P-T curve bases is included in Section 4.3. Several improvements were made to the P-T curve methodology; the improvements included the incorporation of ASME Code Cases N-640 [4] and N-588 [5]. ASME Code Case N-640 allows the use of K_{IC} rather than K_{Ia} to determine T-RT_{NDT}. ASME Code Case N-588 allows the use of an alternative procedure for calculating the applied stress intensity factors to consider attenuation to reference flaw orientation of Appendix G for circumferential welds. This code case also provides an alternative procedure for calculating the applied stress intensity factor for axial welds. Other improvements include, but are not limited to the following:

- 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 [6] 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 1 vessel components. The non-beltline limits are discussed in Section 4.3 and are also governed by requirements in [6].

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.

3.0 ANALYSIS ASSUMPTIONS

The following assumption is 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).

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; the requirements are summarized as follows:

a. Test specimens shall be longitudinally oriented CVN specimens.

b. At the qualification test temperature (specified in 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 are 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 [6] 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 [11] 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 [12], and approved by the NRC for generic use [13].

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

To establish the initial RT_{NDT} temperatures for the LaSalle Unit 1 vessel per the current requirements, calculations were performed in accordance with the GE method for determining RT_{NDT}. Example RT_{NDT} calculations for vessel plate, 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, CMTR's). For LaSalle Unit 1 CMTR's, 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 plate heat C5978-2 in the lower shell course of LaSalle Unit 1, the lowest Charpy energy and test temperature from the CMTR's is 41.0 ft-lb. at 40°F. The estimated 50 ft-lb. longitudinal test temperature is:

T_{50L} = 40°F + [(50 - 41.0) ft-lb. * 2°F/ft-lb.] = 58°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} = 58°F + 30°F = 88°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 was listed in the

CMTR; the NDT for the case above was -10°F and the value of (T_{50T}-60°F) is 28°F. Thus, the initial RT_{NDT} for plate heat C5978-2 would be 28°F; however, a semi curve-fit approach using CMTR data was performed [1] that resulted in a RT_{NDT} for plate heat C5978-2 of 23°F.

For the LaSalle Unit 1 middle shell weld, the CVN results were used to calculate the 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 1P3571 with flux lot 3958 has a lowest Charpy energy of 40 ft-lb. at 10°F as recorded in weld qualification records. Therefore,

T_{50T} = 10°F + [(50 - 40.0) ft-lb. * 2°F/ft-lb.] = 30°F

The initial RT_{NDT} is the greater of nil-ductility transition temperature (NDT) or (T_{50T}-60°F). For LaSalle Unit 1, the dropweight testing to establish -30°F. The value of (T_{50T}-60°F) in this example is -30°F; therefore, the initial RT_{NDT} was -30°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 1, the NDT was 40°F and the lowest CVN data was 48 ft-lb. at 10°F. The corresponding value of (T_{50T}-60°F) was:

(T_{50T} - 60°F) = {[10 + (50-48) ft-lb. * 2°F/ft-lb.] + 30°F} – 60°F = -16°F.

Therefore, the initial RT_{NDT} was 40°F.

In the bottom head region of the vessel, the full Charpy longitudinal test data was fit using a hyperbolic tangent fit to determine the 50 ft-lb transition temperature. For the bottom head dome piece of LaSalle Unit 1 (Heat C6003-3), the NDT was 40°F and the 50 ft-lb longitudinal transition temperature 77°F. The corresponding value of (T_{50T}-60°F) was:

(T_{50T} - 60°F) = {77°F + 30°F} – 60°F = 47°F.
Therefore, the initial RT_{NDT} was 47°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 is the LST for the bolting materials. Charpy data for the LaSalle Unit 1 closure studs meet the 45 ft-lb., 25 MLE requirement at 10°F. Therefore, the LST for the bolting material was 10°F. However, the highest RT_{NDT} in the flange region is 12°F, for the vessel flange. Thus, the higher of the LST and the RT_{NDT} +60°F is 72°F, the boltup limit in the closure flange region.

The initial RT_{NDT} values for the LaSalle Unit 1 reactor vessel materials are listed in Tables 4-1 and 4-2a&b. This tabulation includes beltline, closure flange, feedwater nozzle, and bottom head materials that were considered in generating the P-T curves.

Table 4-1: RT_{NDT} Values for LaSalle Unit 1 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:								
Vessel Flange, 308-02	2V-659 ATF-112	10	70	68	97	-20	10	10
Closure Flange, 319-02	ACT-USS-4P-1997 Ser.118	10	92	110	91	-20	10	10
Dome, 319-05	C7434-1	10	65	76	67	-20	-10	-10
Upper Torus, 319-04	C7434-1	10	65	76	67	-20	-10	-10
Lower Torus, 319-03	C7376-2	10	65	74	73	-20	-10	-10
Shell Courses:								
Upper Shell 305-04	C5987-1	10	63	55	35	10	-10	10
	C5987-2	10	76	79	51	-20	-10	-10
	C6003-2	40	65	49	50	12	10	12
Upper Int. Shell 305-04	C5996-2	10	62	71	66	-20	-10	-10
	C5979-2	10	64	63	49	-18	-10	-10
	C5996-1	10	65	60	77	-20	-10	-10
Middle Shell 305-03	A5333-1	10	56	67	53	-20	-10	-10
	B0078-1	10	73	49	70	-18	-10	-10
	C6123-2	10	77	60	73	-20	-10	-10
Low-Int. Shell 305-02	C6345-1	10	109	88	77	-20	-40	-20
	C6318-1	10	80	66	72	-20	-20	-20
	C6345-2	10	93	94	67	-20	-40	-20
Lower Shell 305-01	C5978-1	40	53	48	48	14	10	14
	C5978-2	40	62	60	41	28	-10	23*
	C5979-1	40	73	92	65	10	-10	10
Bottom Head:								
Bottom Head Dome, 306-17	C6003-3	40	36	39	40	38	40	47**
Lower Torus 306-18	C5540-1	10	54	78	82	-20	-10	-10
	C5328-1	40	64	51	51	10	-10	10
	C5328-2	40	55	62	59	10	-10	10
Upper Torus 306-19	C5505-2	10	63	96	73	-20	-10	-10
	C5445-3	10	70	67	70	-20	-10	-10
Support Skirt:								
309-08	5P2003 Ser.201	10	81	74	103	-20	40	40
309-06	B1042-3	10	70	61	68	-20	10	10
309-04	C7159-4	40	28	25	34	60	60	60
STUDS:						LST		
Closure Head Studs, 32-01	14716	10	45	43	43	70		
Closure Nut/Washers, 326-02/03	24632	10	38	36	39	70		

* Value of RT_{NDT} was obtained from semi curve-fit calculation using CMTR data.

** Value of RT_{NDT} is obtained from curve-fit of CMTR data.

Table 4-2a: RT_{NDT} Values for LaSalle Unit 1 Nozzle Materials.

COMPONENT	HEAT	TEST TEMP. (°F)	CHARPY ENERGY (FT-LB)			(T_{50T}-60) (°F)	DROP WEIGHT NDT	RT_{NDT} (°F)
NOZZLES:								
Recirc. Outlet Nozzle	AV5840-OK9380	10	73	84	65	-20	0	0
314-02	AV5840-OK9381	10	56	84	80	-20	10	10
Recirc. Inlet Nozzle	Q2Q14VW-175W	10	30	30	43	20	40	40
314-07	Q2Q6VW-175W	10	34	36	39	12	40	40
Steam Outlet Nozzles	AV4276-9I9074	10	44	62	42	-4	30	30
316-07	AV4279-9I9236	10	84	55	80	-20	30	30
	AV4442-9J9176	10	93	97	82	-20	30	30
	AV4274-9H9176	10	69	100	71	-20	30	30
Feedwater Nozzle, 316-02	Q2Q14VW-174W-1/6	10	48	72	60	-16	40	40
Core Spray Nozzle	AV4067-9H9168	10	79	70	71	-20	30	30
316-12	AV4068-9H9169	10	45	35	76	10	30	30
RHR/LPC1 Nozzles, 316-17	Q2Q22W-569F-1/3	10	44	44	37	6	10	10
CDR Hydro Return Nozzle, 315-10	AV3142-9G9640	10	34	30	44	20	30	30
Jet Pump Nozzles, 314-12	AV3138-9F-9231B/C	10	116	90	96	-20	30	30
Closure Head Inst. Nozzle, 318-07	Q2Q23W-346J-1A	10	35	47	31	18	30	30
Vent Nozzle, 318-02	Q2Q24W-345J	10	78	109	122	-20	10	10
Drain Nozzle, 315-14	Q1Q1VW-738T	10	39	25	32	30	30	30
Stabilizer Bracket, 324-19	C4943-3	10	36	35	36	10	10	10

Table 4-2b: RT_{NDT} Values for LaSalle Unit 1 Weld Materials.

COMPONENT	HEAT	TEST TEMP. (°F)	CHARPY ENERGY (FT-LB)			(T_{50T}-60) (°F)	DROP WEIGHT NDT	RT_{NDT} (°F)
WELDS:								
Vertical Welds:								
2-307 Bottom Shell Long Seams 1-308 Upper Shell Long Seams 2-308 Upper Inter. Shell Long Seams	21935-1092-3889	10	97	90	83	-50	-50	-50
1-308 Upper Shell Long Seams 2-307 Bottom Shell Long Seams	12008-1092-3889	10	97	90	83	-50	-50	-50
1-308 Upper Shell Long Seams 3-308 Middle Shell Long Seams	305424-1092-3889	10	82	87	92	-50	-50	-50
3-308 Middle Shell Long Seams	IP3571-1092-3958	10	40	46	46	-30	-50	-30
4-308 Lower Inter. Shell Long Seams	305414-1092-3947	10	82	66	80	-50	-50	-50
4-308 Lower Inter. Shell Long Seams	12008-1092-3947	10	92	91	92	-50	-50	-50
1-319 Closure Head Seg. Lower Torus 2-319 Closure Head Seg. Upper Torus	FOAA	10	125	124	130	-50	-50	-50
1-319 Closure Head Seg. Lower Torus	EAIB	10	118	129	107	-50	-50	-50
Girth Welds:								
3-306 Bottom Hd. Build up for sup. Skirt 5-306 Bottom Hd. Dome to Side Seg, 6-306 Bottom Hd. Low. To Up Side Seg.	305414-1092-3951	10	66	61	62	-50	-50	-50
6-306 Bottom Hd. Low. To Up Side Seg. 4-307 Inlay in Bot. Sd for Core Sup Attch.	305424-1092-3889	10	82	87	92	-50	-50	-50
9-307 Bottom Head to Lower Shell 3-319 Close. Hd. Torus to Close. Hd. Flg.	10120-0091-3458	10	124	130	122	-50	-50	-50
9-307 Bottom Head to Lower Shell 3-319 Close. Hd. Torus to Close. Hd. Flg. 6-308 Upper Vessel Shell Girth Seam	51874-0091-3458	10	89	64	87	-50	-50	-50
9-307 Bottom Head to Lower Shell	51912-0091-3490	10	93	84	92	-50	-50	-50
6-308 Upper Vessel Shell Girth Seam 15-308 Flange to Upper Shell	10137-0091-3999	10	101	108	107	-50	-50	-50
6-308 Upper Vessel Shell Girth Seam	5P5622-0091-0831	-20	95	87	86	-80	-80	-80
6-308 Upper Vessel Shell Girth Seam	2P5755-0091-0831	-10	81	80	82	-70	-70	-70
6-308 Upper Vessel Shell Girth Seam	6329637-0091-3458	10	103	65	88	-50	-50	-50
6-308 Upper Vessel Shell Girth Seam 15-308 Flange to Upper Shell 5-319 Closure Hd. Upper Torus to Dome	6329637-0091-3999	10	101	108	103	-50	-50	-50
4-309 Support Skirt Forging to Bot. Hd.	90099-0091-3977	10	96	97	89	-50	-50	-50
4-309 Support Skirt Forging to Bot. Hd.	90136-0091-3998	10	110	109	107	-50	-50	-50
1-313 Up. Assy to Lower Closing Seams	4P6519-0091-0145	0	98	101	102	-60	-60	-60
1-313 Up. Assy to Lower Closing Seams	4P6519-0091-0842	0	46	59	48	-52	-80	-52
1-313 Up. Assy to Lower Closing Seams	4P6519-0091-0653	-40	57	63	73	-100	-60	-60
4-319 Close. Hd. Upper Torus to Lower	606L40-0091-3489	10	96	95	77	-50	-50	-50

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 several beltline welds were 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:

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

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

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

$f = 1/4\ T\ fluence / 10^{19}$

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

4.2.1.1 Chemistry

The vessel beltline chemistries were obtained from the LaSalle 1 RAI [29]. 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. 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 $0.5*\Delta RT_{NDT}$. 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 [19] for the vessel plate and weld materials.

4.2.1.2 Fluence

The 32 EFPY fluence at the 1/4T depth of vessel wall for the 251" LaSalle Unit 1 vessel was obtained from surveillance capsule results. The surveillance capsule results were adjusted for power uprate conditions [16]. The value of 32 EFPY peak surface fluence, considering power uprate, used in this report for LaSalle Unit 1 was 5.0×10^{17} n/cm^2. Therefore, a fluence of 5.0×10^{17} n/cm^2 was used for the LaSalle Unit 1 beltline plate and weld embrittlement calculations.

The value of fluence at the LPCI nozzle (elevation of approximately 372 inches) was determined by reduction of the peak fluence by a factor of 0.145 [1]. Therefore, a fluence of 7.3×10^{16} n/cm^2 was used for the LaSalle Unit 1 LPCI nozzle located in the beltline for embrittlement calculations.

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 [7] was applied to compute ART. Table 4-3 lists values of beltline ART for 20 EFPY and Table 4-4 lists the values for 32 EFPY.

Table 4-3: LaSalle Unit 1 Beltline ART Values (20 EFPY)

Middle & Lower-Intermediate Plates and Welds 3-308, 4-308, 6-308 & 1-313

Thickness =	6.13	inches	Ratio Peak/ Location = 1.00	32 EFPY Peak I.D. fluence =	5.04E+17	n/cm^2
				32 EFPY Peak 1/4 T fluence =	3.5E+17	n/cm^2
				20 EFPY Peak 1/4 T fluence =	2.2E+17	n/cm^2

Lower Plate and Welds 2-307

Thickness =	7.13	inches	Ratio Peak/ Location = 0.66	32 EFPY Peak I.D. fluence =	3.3E+17	n/cm^2
			Location = 229 7/8" Elevation	32 EFPY Peak 1/4 T fluence =	2.2E+17	n/cm^2
				20 EFPY Peak 1/4 T fluence =	1.3E+17	n/cm^2

LPCI Nozzle

Thickness =	6.13	inches	Ratio Peak/ Location = 0.145	32 EFPY Peak I.D. fluence =	7.3E+16	n/cm^2
			Location = ~372" Elevation	32 EFPY Peak 1/4 T fluence =	5.1E+16	n/cm^2
				20 EFPY Peak 1/4 T fluence =	3.2E+16	n/cm^2

COMPONENT	SHELL ASSEM.	HEAT OR HEAT/LOT	%Cu	%Ni	CF	Initial RTndt °F	20 EFPY Δ RTndt °F	σ_I	σ_Δ	Margin °F	20 EFPY Shift °F	20 EFPY ART °F
PLATES:												
Lower	307-04											
G-5603-1		C5978-1	0.11	0.58	74	14	10	0	5	10	20	34
G-5603-2		C5978-2	0.11	0.59	74	23	10	0	5	10	20	43
G-5603-3		C5979-1	0.12	0.66	84	10	11	0	6	11	22	32
Lower-Intmed	308-06											
G5604-1		C6345-1	0.15	0.49	104	-20	19	0	9	19	38	18
G5604-2		C6318-1	0.12	0.51	81	-20	15	0	7	15	29	9
G5604-3		C6345-2	0.15	0.51	105	-20	19	0	10	19	38	18
Middle	308-05											
G5605-1		A5333-1	0.12	0.54	82	-10	15	0	7	15	30	20
G5605-2		B0078-1	0.15	0.50	105	-10	19	0	10	19	38	28
G5605-3		C6123-2	0.13	0.68	93	-10	17	0	8	17	34	24
WELDS:												
Middle												
3-308 A,B,C		305424/3889	0.273	0.629	189.5	-50	34	0	17	34	69	19
		1P3571/3958	0.283	0.755	212	-30	38	0	19	38	77	47
Lower-Intmed												
4-308 A,B,C		305414/3947	0.337	0.609	209	-50	38	0	19	38	76	26
		12008/3947	0.235	0.975	233	-50	42	0	21	42	85	35
		305414&12008 tandem	0.286	0.792	219	-50	40	0	20	40	79	29
Lower												
2-307 A,B,C		21935/3889	0.183	0.704	172	-50	23	0	11	23	46	-4
		12008/3889	0.235	0.975	233	-50	31	0	16	31	62	12
		21935&12008 tandem	0.213	0.867	209	-50	28	0	14	28	56	6
Girth												
6-308		6329637	0.205	0.105	98	-50	18	0	9	18	36	-14
1-313		4P6519	0.131	0.060	64	-52	12	0	6	12	23	-29
LPCI												
		Q2Q22W	0.100	0.820	67	10	3	0	2	3	6	16

Table 4-4: LaSalle Unit 1 Beltline ART Values (32 EFPY)

Middle & Lower-Intermediate Plates and Welds 3-308, 4-308, 6-308 & 1-313

Thickness = 6.13 inches
Ratio Peak/Location = 1.00
32 EFPY Peak I.D. fluence = 5.04E+17 n/cm^2
32 EFPY Peak 1/4 T fluence = 3.5E+17 n/cm^2
32 EFPY Peak 1/4 T fluence = 3.5E+17 n/cm^2

Lower Plate and Welds 2-307

Thickness = 7.13 inches
Ratio Peak/Location = 0.66
Location = 229 7/8" Elevation
32 EFPY Peak I.D. fluence = 3.3E+17 n/cm^2
32 EFPY Peak 1/4 T fluence = 2.2E+17 n/cm^2
32 EFPY Peak 1/4 T fluence = 2.2E+17 n/cm^2

LPCI Nozzle

Thickness = 6.13 inches
Ratio Peak/Location = 0.145
Location = ~372" Elevation
32 EFPY Peak I.D. fluence = 7.3E+16 n/cm^2
32 EFPY Peak 1/4 T fluence = 5.1E+16 n/cm^2
32 EFPY Peak 1/4 T fluence = 5.1E+16 n/cm^2

COMPONENT	SHELL ASSEM.	HEAT OR HEAT/LOT	%Cu	%Ni	CF	Initial RTndt °F	32 EFPY Δ RTndt °F	σ_I	σ_Δ	Margin °F	32 EFPY Shift °F	32 EFPY ART °F
PLATES:												
Lower	307-04											
G-5603-1		C5978-1	0.11	0.58	74	14	13	0	7	13	27	41
G-5603-2		C5978-2	0.11	0.59	74	23	13	0	7	13	27	50
G-5603-3		C5979-1	0.12	0.66	84	10	15	0	8	15	30	40
Lower-Intmed	308-06											
G5604-1		C6345-1	0.15	0.49	104	-20	25	0	12	25	50	30
G5604-2		C6318-1	0.12	0.51	81	-20	19	0	10	19	39	19
G5604-3		C6345-2	0.15	0.51	105	-20	25	0	13	25	50	30
Middle	308-05											
G5605-1		A5333-1	0.12	0.54	82	-10	20	0	10	20	39	29
G5605-2		B0078-1	0.15	0.50	105	-10	25	0	13	25	50	40
G5605-3		C6123-2	0.13	0.68	93	-10	22	0	11	22	45	35
WELDS:												
Middle												
3-308 A,B,C		305424/3889	0.273	0.629	189.5	-50	45	0	23	45	91	41
		1P3571/3958	0.283	0.755	212	-30	51	0	25	51	102	72
Lower-Intmed												
4-308 A,B,C		305414/3947	0.337	0.609	209	-50	50	0	25	50	100	50
		12008/3947	0.235	0.975	233	-50	56	0	28	56	112	62
		305414&12008 tandem	0.286	0.792	219	-50	52	0	26	52	105	55
Lower												
2-307 A,B,C		21935/3889	0.183	0.704	172	-50	31	0	15	31	62	12
		12008/3889	0.235	0.975	233	-50	42	0	21	42	84	34
		21935&12008 tandem	0.213	0.867	209	-50	38	0	19	38	75	25
Girth												
6-308		6329637	0.205	0.105	98	-50	23	0	12	23	47	-3
1-313		4P6519	0.131	0.060	64	-52	15	0	8	15	31	-21
LPCI												
		Q2Q22W	0.100	0.820	67	10	5	0	2	5	9	19

4.3 PRESSURE-TEMPERATURE CURVE METHODOLOGY

4.3.1 Background

Nuclear Regulatory Commission (NRC) 10CFR50 Appendix G [6] 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 [9]) 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 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 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 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 and 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 4.4

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 [6] requirements. The non-beltline and beltline region operating limits are evaluated according to procedures in 10CFR50 Appendix G [6], ASME Code Appendix G [9], and Welding Research Council (WRC) Bulletin 175 [10]. 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 to cause any significant shift of RT_{NDT}. Non-beltline components include most 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, loss of recirculation pump flow, and all transients involving emergency core cooling injections. 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 [9] 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 Curves A & B

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

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

Discontinuity Identification
CRD and Bottom Head
Top Head Nozzles
Recirculation Outlet Nozzle

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 1 as the plant specific geometric values are bounded by the generic analysis for a large BWR/6, as determined from 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 1 by using plant specific RT_{NDT} values for the reactor pressure vessel (RPV). The presence of nozzles and CRD penetration holes of the upper vessel and bottom head, respectively, has made the analysis different from a shell analysis such as the beltline. This was the result of the stress concentrations and higher thermal stress for certain transient conditions experienced by the upper vessel and the bottom head.

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 Case N-588 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.

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

The CRD penetration region limits were established primarily for consideration of bottom head discontinuity stresses during pressure testing.

The value of M_m for an inside axial postulated surface flaw from Paragraph 2214-1 [5] was based on a thickness of 8.0 inches; hence, $t^{1/2}$ = 2.83. The resulting value obtained was:

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

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

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

K_{Im} is calculated from the equation in Paragraph G-2214.1 [5] and K_{Ib} is calculated from the equation in Paragraph G-2214.2 [5]:

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

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

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} the equation of Paragraph A-4200 in ASME Appendix A [8]:

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

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

$(T - RT_{NDT}) = 84°F$

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

Pressure Test 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	144	84
1400	129	77
1200	111	66
1000	92	52
800	74	33
600	55	3
400	37	-88

The highest RT_{NDT} for the bottom head plates and welds is 47°F, as shown in Table 4-1.

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:

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

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

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

The LaSalle Unit 1 specific bottom head dimensions are R = 127.4 inches to base metal [26] and t = 7.38 inches minimum [26], resulting in:

LaSalle Unit 1 specific:

$$R / (t)^{1/2} = 127.4 / (7.38)^{1/2} = 46.9 \text{ inch}^{1/2} \tag{4-3}$$

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

The calculated value of K_I for pressure test is multiplied by a safety factor (SF) of 1.5, per ASME Appendix G [9] 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 [8] 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 47°F, as shown in Table 4-1.

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 that are bounded. Therefore, for heatup/cooldown conditions, the CRD penetration provides bounding limits.

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 [10] 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.

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

Nominal $K_I = 1.5 \cdot 34.97 \cdot (\pi \cdot 2.36)^{1/2} \cdot 1.4 = 200$ 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 [8] for the pressure test condition:

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

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

$$(T - RT_{NDT}) = 104.2°F$$

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}).

The highest RT_{NDT} for the nozzle materials is 40°F as described below. The generic pressure test P-T curve is applied to the LaSalle Unit 1 feedwater nozzle curve by shifting the P vs. (T - RT_{NDT}) values above to reflect the RT_{NDT} value of 40°F.

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

Vessel Radius, R_v (to base metal)	127 inches
Vessel Thickness, t_v	6.69 inches
Vessel Pressure, P_v	1563 psig

Pressure stress: $\sigma = PR / t$ = 1563 psig · 127 inches / (6.69 inches) = 29,671 psi. The Dead weight and thermal RFE stress of 2.967 ksi is conservatively added yielding σ = 32.64 ksi. The factor F (a/r_n) from Figure A5-1 of WRC-175 is 1.4 where :

a =	$\frac{1}{4} (t_n^2 + t_v^2)^{1/2}$	=2.31 inches
t_n =	thickness of nozzle	= 6.38 inches [22]
t_v =	thickness of vessel	= 6.69 inches
r_n =	apparent radius of nozzle	= r_i + 0.29 r_c=7.29 inches
r_i =	actual inner radius of nozzle	= 6.13 inches [22]
r_c =	nozzle radius (nozzle corner radius)	= 4.0 inches [22]

Thus, a/r_n = 2.31 / 7.29 = 0.32. The value $F(a/r_n)$, taken from Figure A5-1 of WRC Bulletin 175 for an a/r_n of 0.32, is 1.5. 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 $K_I = 1.5 \cdot 32.64 \cdot (\pi \cdot 2.31)^{1/2} \cdot 1.5 = 197.9$ ksi-in$^{1/2}$

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.

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 [10].

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:

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

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

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 [10].

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 [9] 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 [10]. However, the correction was not applied to primary membrane stresses because stresses that are based on equilibrium considerations (i.e., primary membrane) are not displacement controlled and are not reduced or changed by deformation of the component. 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 [8]. 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 inch was used in the evaluation. However, a thickness of 7.5 inch is not conservative for the pressure stress evaluation. Therefore, the pressure stress (σ_{pm}) was adjusted for the actual vessel thickness of 6.1875 inch (i.e., σ_{pm}=20.49 ksi was revised to 20.49 ksi *7.5 inch/6.1875 inch = 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 inch
σ_{pb} = 0.22 ksi	σ_{sb} = 19.04 ksi	a = 2.36 inch	r_n = 7.08 inch
t_n = 7.125 inch			

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 [10]. (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 2214-1 [5] was based on the 4a thickness ; hence, $t^{1/2}$ = 3.072. The resulting value obtained was:

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

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

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

The value $F(a/r_n)$, taken from Figure A5-1 of WRC Bulletin 175 for an a/r_n of 0.33, 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: 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 region components of LaSalle Unit 1 is 40°F as shown in Tables 4-1 and 4-2a&b and discussed previously. The generic curve is applied to the LaSalle Unit 1 upper vessel by shifting the P vs. $(T - RT_{NDT})$ values above to reflect the RT_{NDT} value of 40°F.

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 [9], 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.

An evaluation was performed [20, Appendix C] for the vessel wall thickness transition discontinuity located between the lower and lower-intermediate shells in the beltline region. Appendix E of this report contains an update of the evaluation.

4.3.2.2.1 Beltline Region - Pressure Test

The methods of ASME Code Section XI, Appendix G [9] 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:

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

The stress intensity factor, K_{Im}, is calculated using Paragraph 2214-1 of the ASME Code Case N-588 [5].

The calculated value of K_{Im} for pressure test is multiplied by a safety factor (SF) of 1.5, per ASME Appendix G [9] 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 [8] for the pressure test condition:

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

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 = -30 + 102 = 72 °F (Based on ART values in Section 4.2)
Vessel Height	H = 863.3 inches
Bottom of Active Fuel Height	B = 216 inches
Vessel Radius (to inside of clad)	R = 126.7 inches
Minimum Vessel Thickness (without clad)	t = 6.13 inches
Limiting Beltline Material Yield Strength	σ_y = 42.6 ksi

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

$$P = 1105 \text{ psi} + (H - B)\ 0.0361 \text{ psi/inch} = P \text{ psig} \quad (4\text{-}10)$$
$$= 1105 + (863.3 - 216)\ 0.0361 = 1128 \text{ psig}$$

Pressure stress:

$$\sigma = PR/t \quad (4\text{-}11)$$
$$= 1.128 \cdot 126.7 / 6.13 = 23.3 \text{ ksi}$$

The value of M_m for an inside axial postulated surface flaw from Paragraph 2214-1 [5] was based on a thickness of 6.13 inches (the minimum thickness without cladding); hence, $t^{1/2} = 2.48$. The resulting value obtained was:

$$M_m = 1.85 \text{ for } \sqrt{t} \leq 2$$
$$M_m = 0.926 \sqrt{t} \text{ for } 2 \leq \sqrt{t} \leq 3.464 = 2.29$$
$$M_m = 3.21 \text{ for } \sqrt{t} > 3.464$$

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

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 [8], K_{Im} = 53.4, and K_{It} = 3.01 for a 20°F/hr coolant heatup/cooldown rate with a vessel thickness, t, that includes cladding:

$$(T - RT_{NDT}) = \ln[(1.5 \cdot K_{Im} + K_{It} - 33.2) / 20.734] / 0.02 \qquad (4\text{-}12)$$

$$= \ln[(1.5 \cdot 53.4 + 3.01 - 33.2) / 20.734] / 0.02$$

$$= 43.9°F$$

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

$$T = 43.9 + 72 = 115.9°F \qquad \text{for } P = 1105 \text{ psig}$$

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 [9]:

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

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-2214-2 of ASME Appendix G [9] 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-2214-3 of ASME Appendix G [9]. 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:

$$T = Gx^2 / 2\beta - GCx / \beta + T_0 \qquad (4\text{-}15)$$

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-2214-3 of ASME Appendix G [9]. Therefore, ΔT_w calculated from Equation 4-15 is used with the appropriate M_t of Figure G-2214-2 of ASME Appendix G [9] to compute K_{It} for heatup and cooldown.

The M_t relationships were derived in the Welding Research Council (WRC) Bulletin 175 [10] 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.

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

This sample calculation is for a pressure of 1105 psi 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, C = 0.588 ft (7.06 inches)
Thermal diffusivity at 550°F (most conservative value), β = 0.354 ft^2/ hr [28]

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:

$$\Delta T = GC^2 / 2\beta \qquad (4\text{-}16)$$
$$= 100 \cdot (0.588)^2 / (2 \cdot 0.354) = 49°F$$

The analyzed case for thermal stress is a 1/4T flaw depth with wall thickness of C. The corresponding value of M_t (=0.308) can be interpolated from ASME Appendix G, Figure G-2214-2 [9]. Thus the thermal stress intensity factor, $K_{It} = M_t \cdot \Delta T = 15.1$, 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 ($T-RT_{NDT}$):

$$(T - RT_{NDT}) = \ln[((2 \cdot K_{Im} + K_{It}) - 33.2) / 20.734] / 0.2 \quad (4\text{-}17)$$
$$= \ln[(2 \cdot 53.4 + 15.1 - 33.2) / 20.734] / 0.02$$
$$= 72.7°F$$

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

T = 72.7 + 72 = 144.7°F for P = 1105 psig

4.3.2.3 CLOSURE FLANGE REGION

10CFR50 Appendix G [6] 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 1 at low pressures.

The original ASME Code requirement for bolt-up was at qualification temperature (T_{30L}) plus 60°F. The ASME Code requirements state in Paragraph G-2222(c) that, for application of full bolt preload and reactor pressure up to 20% of hydrostatic test pressure, the RPV metal temperature must be at RT_{NDT} or greater. The approach used for LaSalle Unit 1 for the bolt-up temperature was based on a more 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 Table 4-1, the limiting initial RT_{NDT} for the closure flange region was the upper shell at 12°F, and the LST of the closure studs was 10°F; therefore, the bolt-up temperature value used was 72°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 [6] 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 [9] 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 1 Technical Specification, is calculated for a water temperature of 68°F. Shutdown margin is the quantity of reactivity needed for a reactor core to reach criticality with the strongest-worth control rod fully withdrawn and all other control rods fully inserted. Although it may be possible to safely allow the water temperature to fall below this 68°F limit, further extensive calculations would be required to justify a lower temperature. The 72°F limit applies when the head is on and tensioned and the 68°F limit for the bottom head curve 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 [6] 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 [6], Table 1. Table 1 of [6] 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 [6] 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 72°F, based on an RT_{NDT} of 12°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). However, the hydrostatic pressure test requirement does not 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 1.

- Composite P-T curves were generated for each of the Pressure Test and Core Not Critical conditions at 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.

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 AT 32 EFPY

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

* 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.

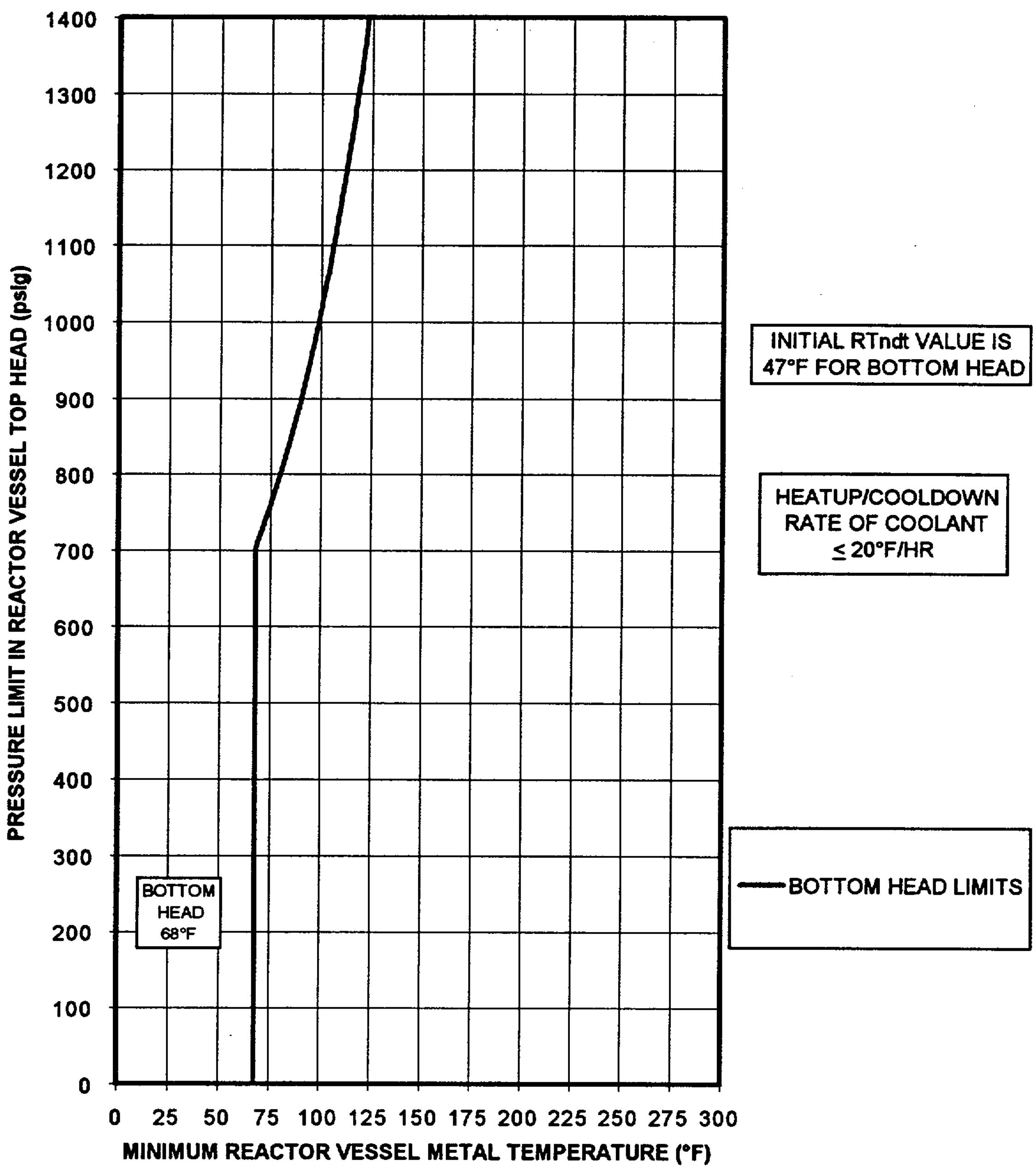

Figure 5-1: Bottom Head P-T Curve for Pressure Test [Curve A]
[20°F/hr or less coolant heatup/cooldown]

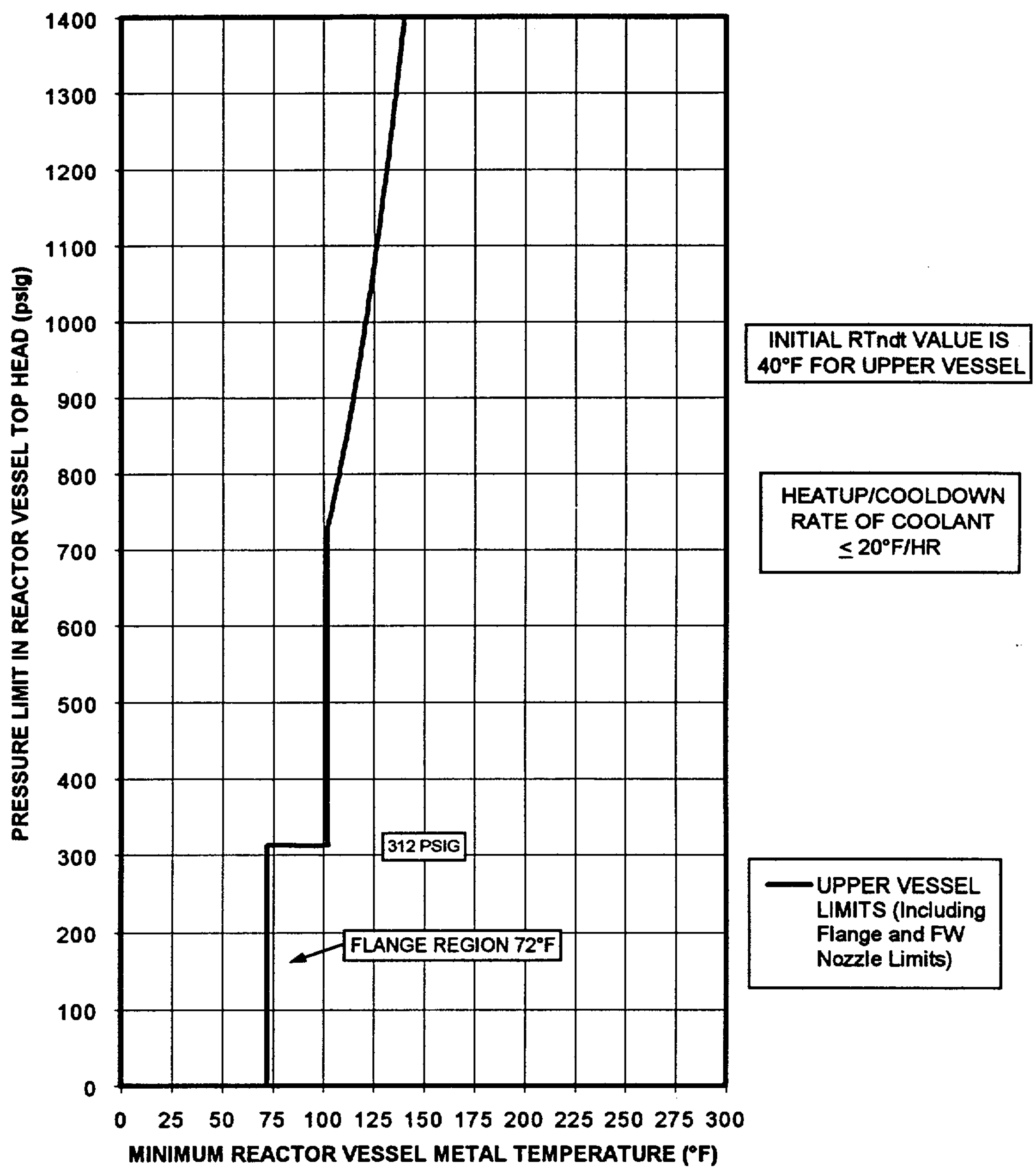

Figure 5-2: Upper Vessel P-T Curve for Pressure Test [Curve A]

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

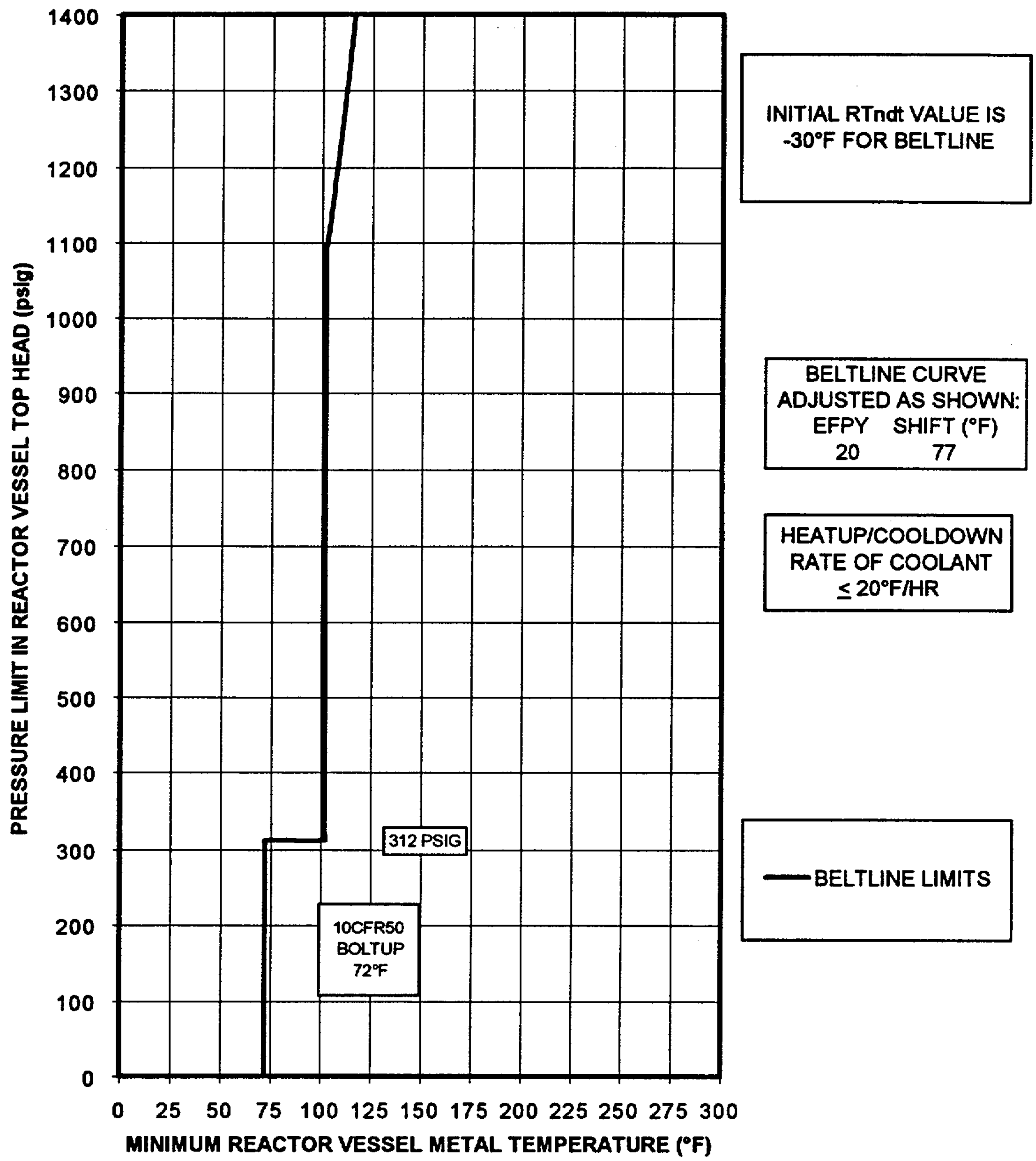

Figure 5-3: Beltline P-T Curve for Pressure Test [Curve A] up to 20 EFPY

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

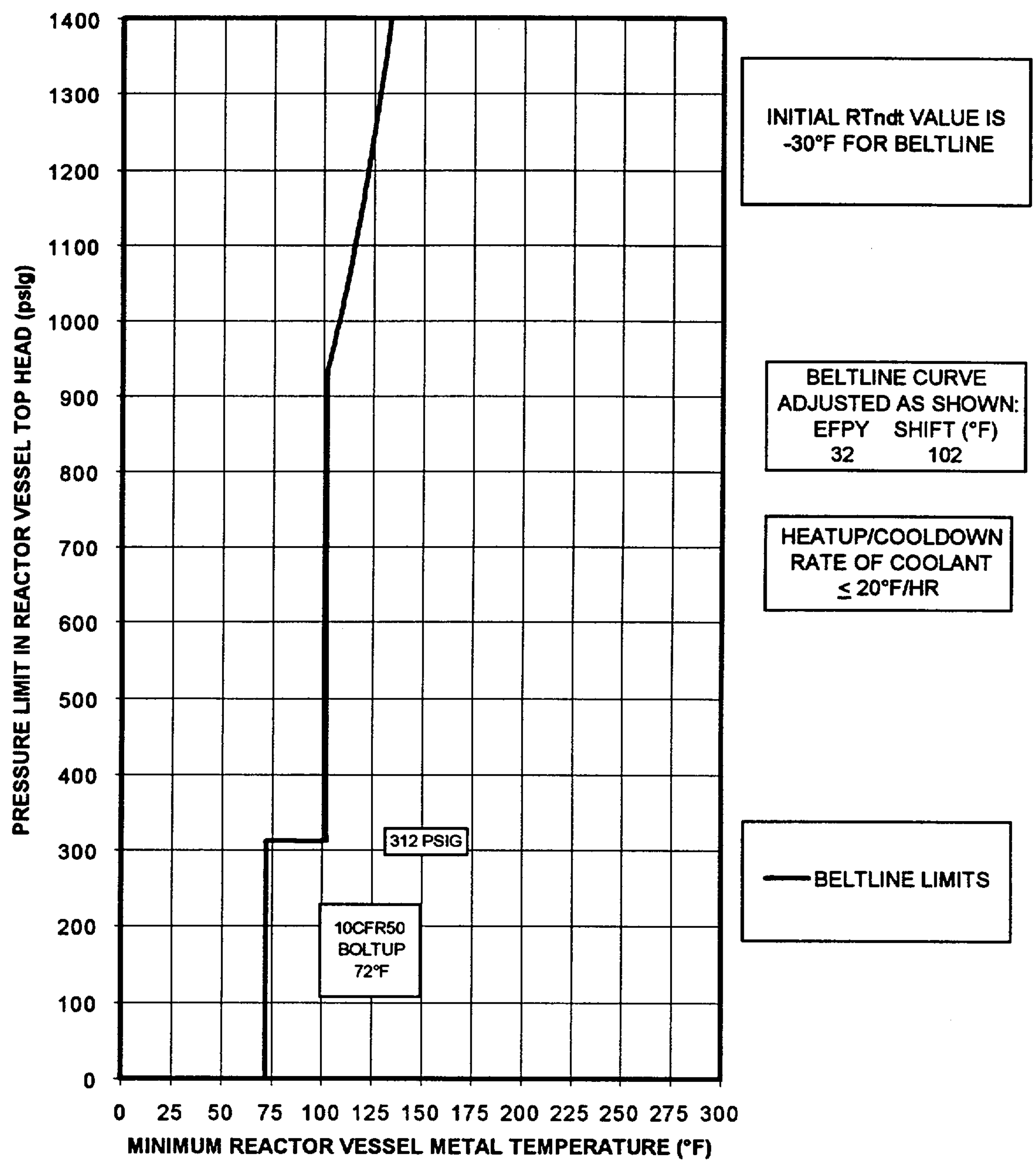

Figure 5-4: Beltline P-T Curve for Pressure Test [Curve A] up to 32 EFPY
[20°F/hr or less coolant heatup/cooldown]

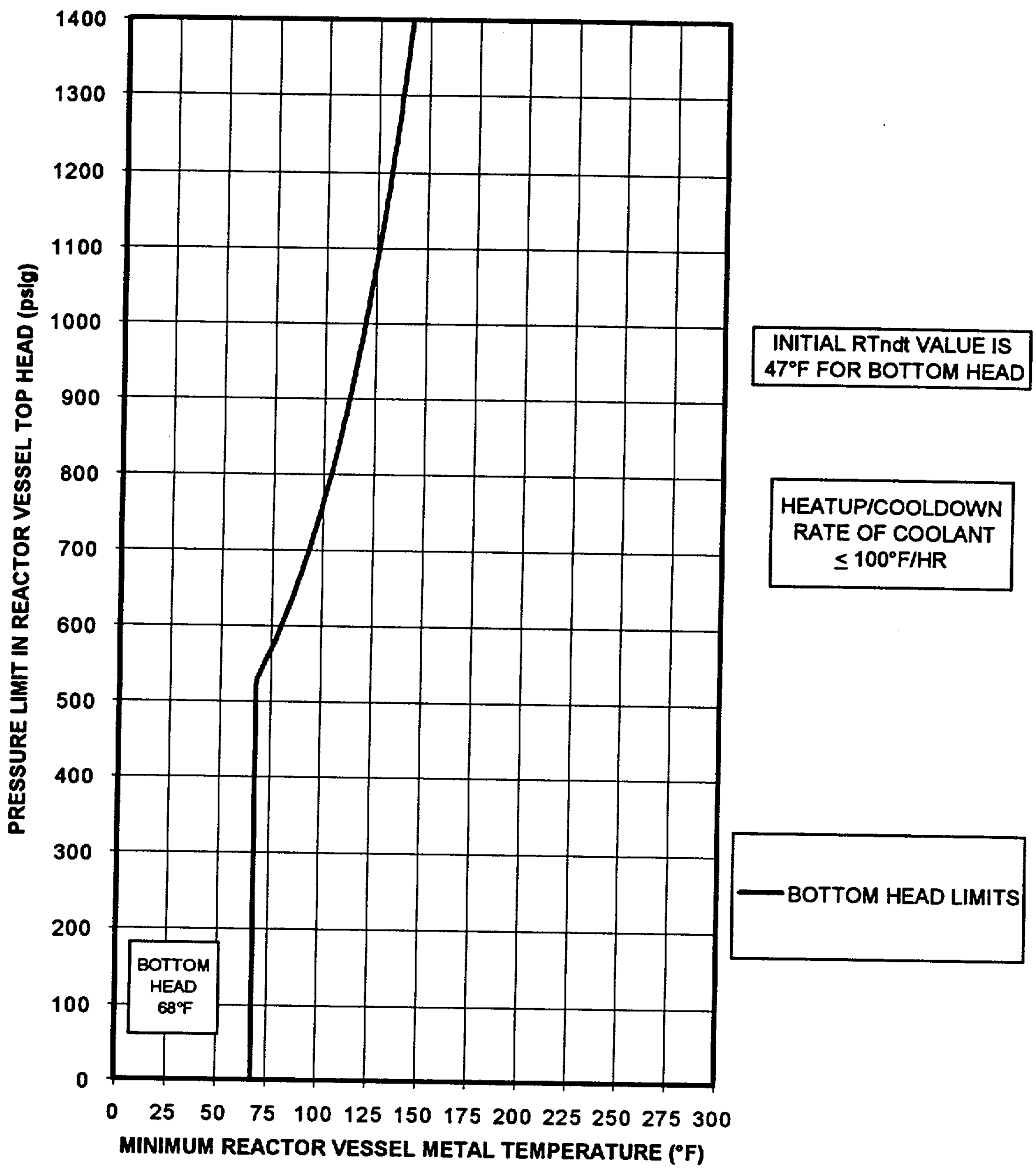

Figure 5-5: Bottom Head P-T Curve for Core Not Critical [Curve B]
[100°F/hr or less coolant heatup/cooldown]

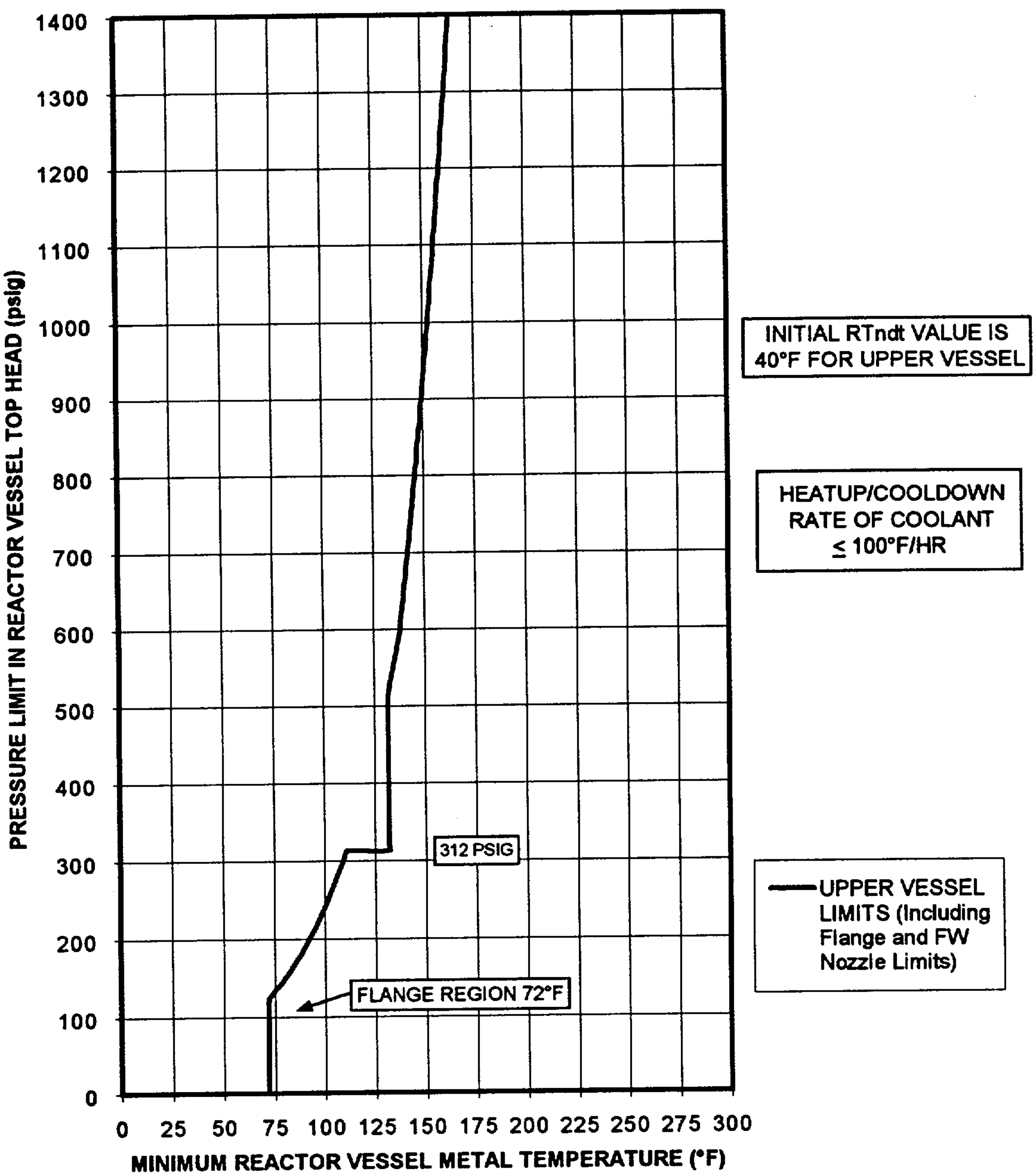

Figure 5-6: Upper Vessel P-T Curve for Core Not Critical [Curve B]

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

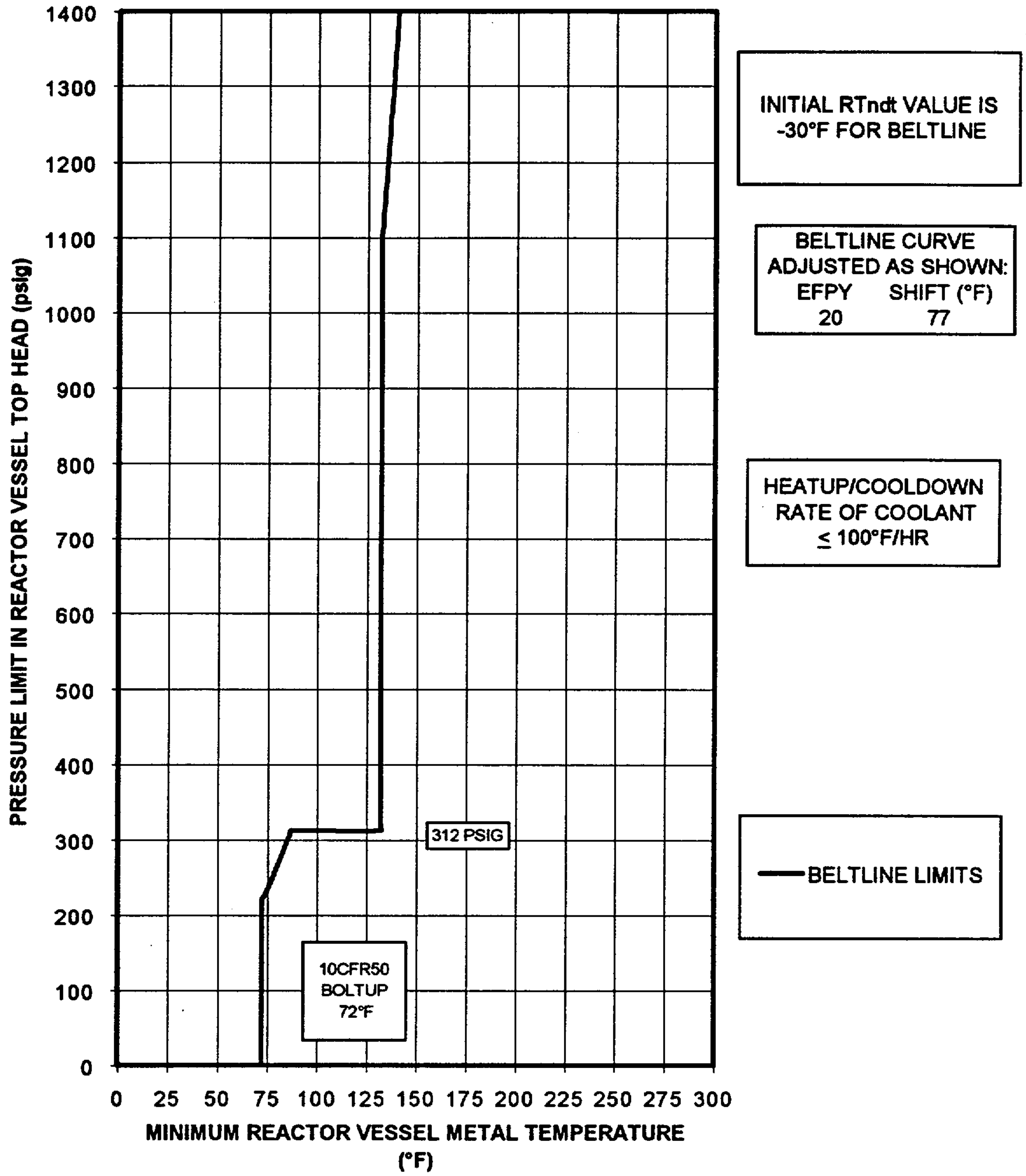

Figure 5-7: Beltline P-T Curve for Core Not Critical [Curve B] up to 20 EFPY

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

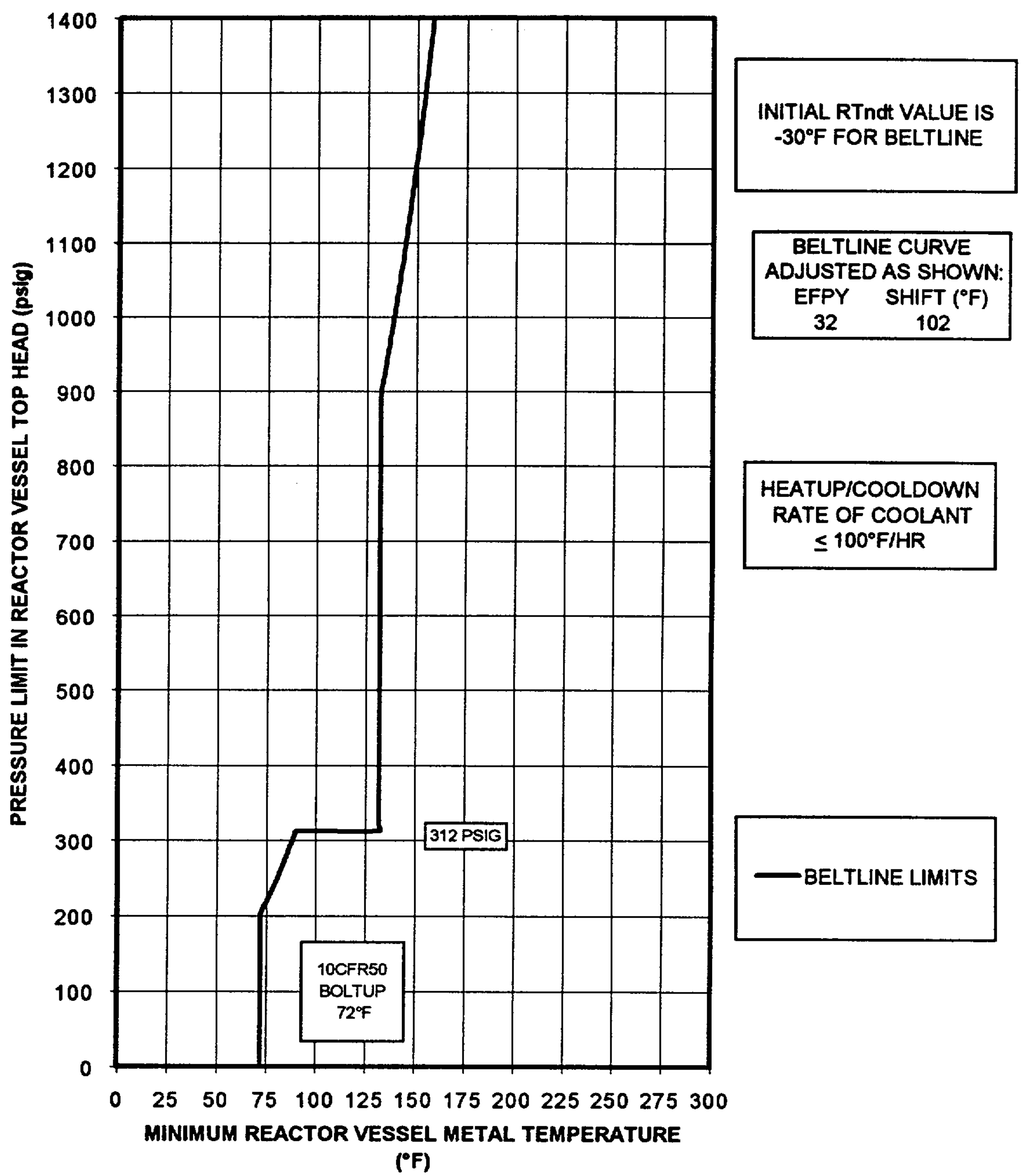

Figure 5-8: Beltline P-T Curves for Core Not Critical [Curve B] up to 32 EFPY [100°F/hr or less coolant heatup/cooldown]

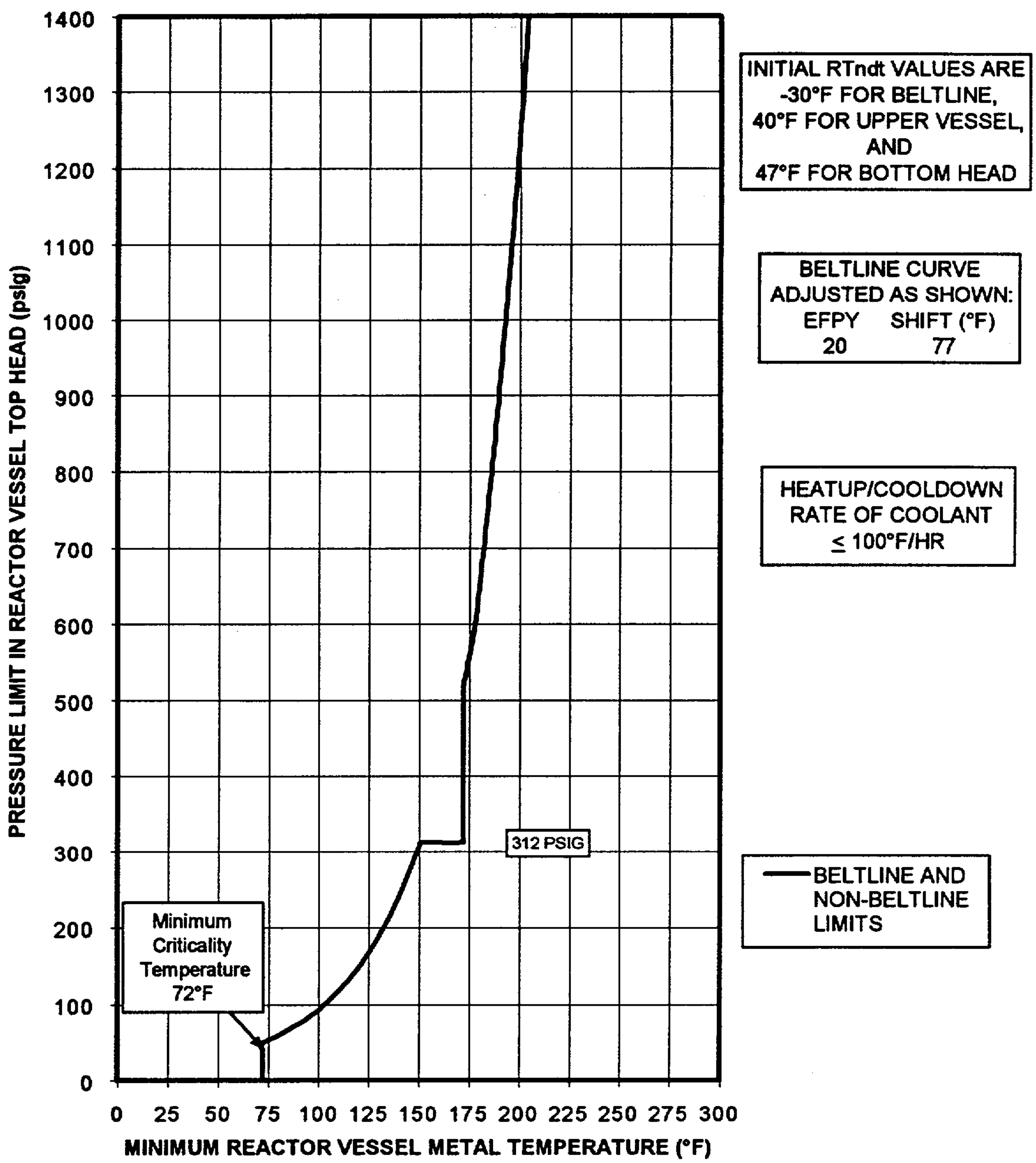

Figure 5-9: Core Critical P-T Curves [Curve C] up to 20 EFPY

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

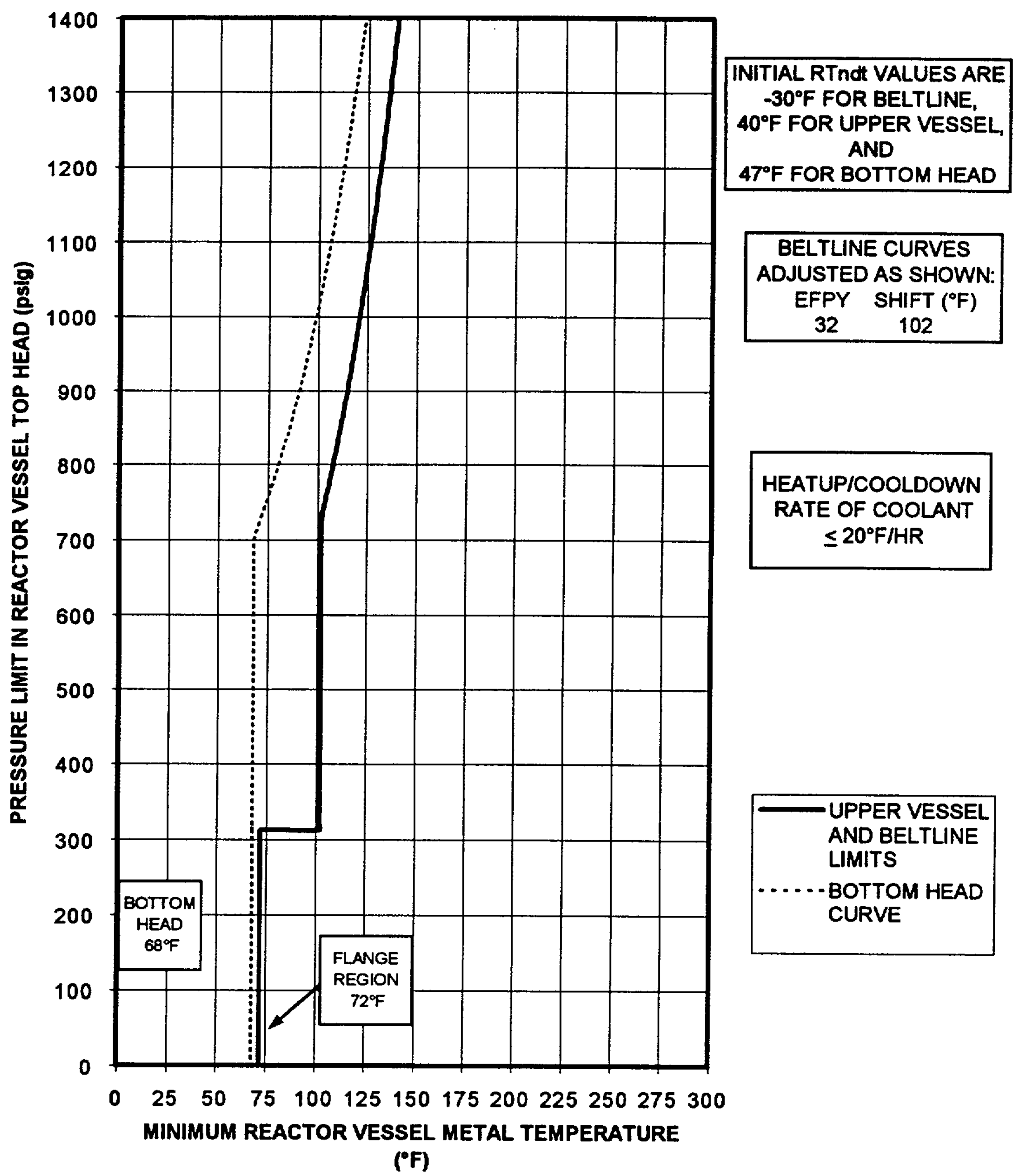

Figure 5-10: Pressure Test P-T Curves [Curve A] up to 32 EFPY

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

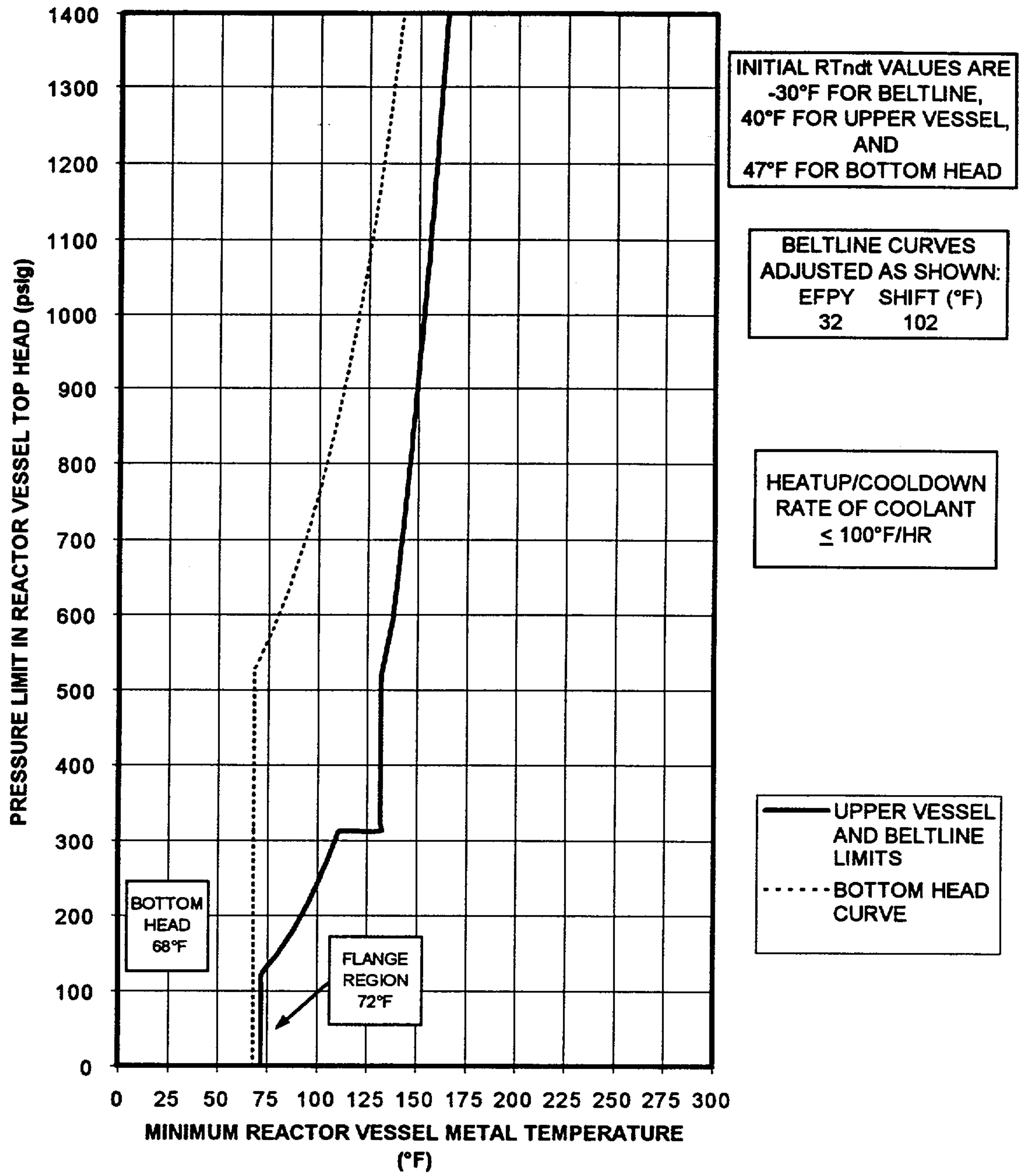

Figure 5-11: Core Not Critical P-T Curves [Curve B] up to 32 EFPY [100°F/hr or less coolant heatup/cooldown

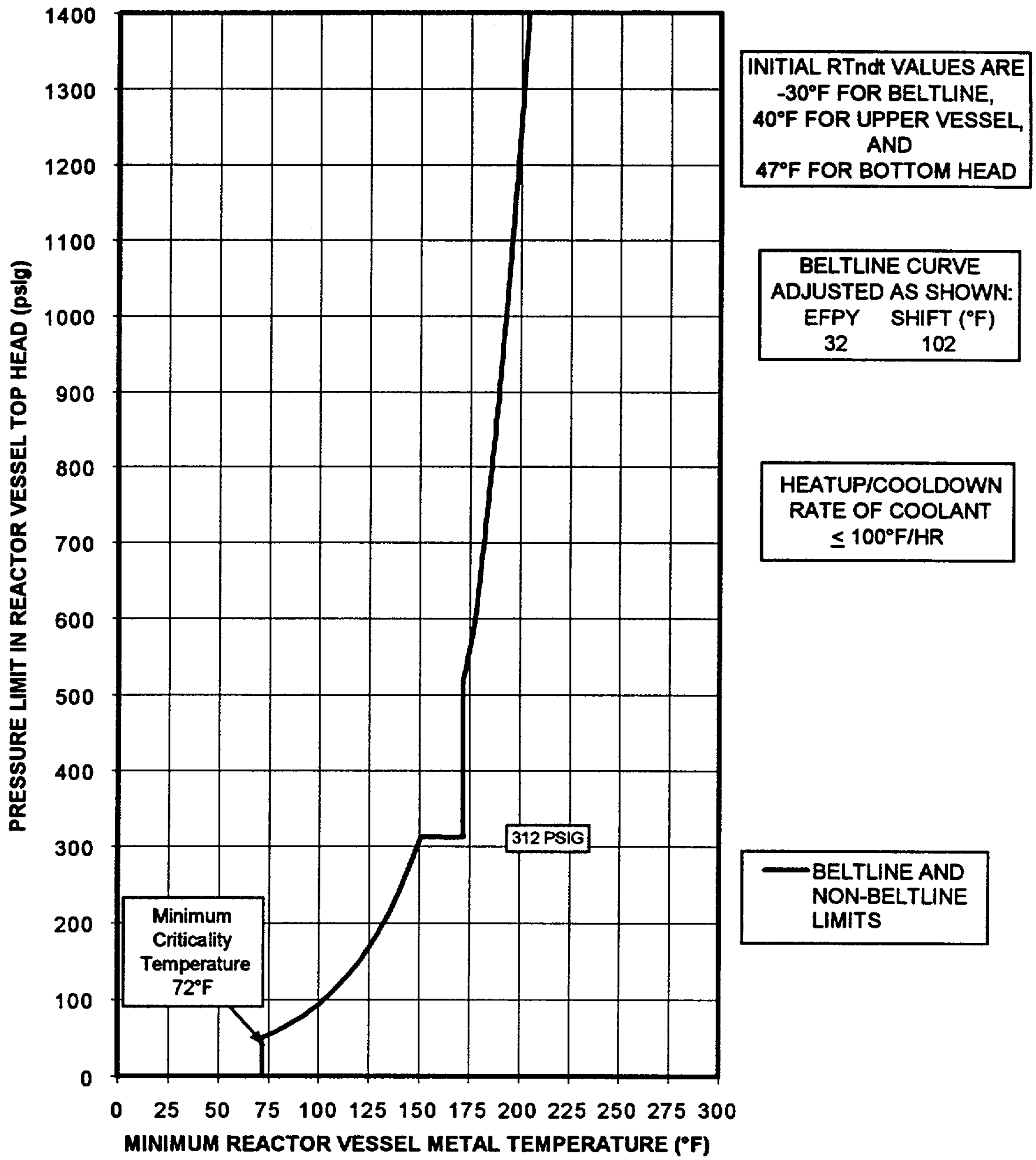

Figure 5-12: Core Critical P-T Curves [Curve C] up to 32 EFPY

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

6.0 REFERENCES

1. 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). Source Document for P-T Curves Section 5. Source Document for ART Chemistry Section 4.2.1.1. Source Document for LPCI fluence reduction Section 4.2.1.2.

2. GE Drawing Number 731E776, "Reactor Vessel Thermal Cycles," GE-NED, San Jose, CA, Revision 3. (GE Proprietary)

3. GE Drawing Number 158B8316, "Reactor Vessel Nozzle Thermal Cycles," GE-NED, San Jose, CA, Revision 7. (GE Proprietary)

4. Alternative to Reference Alternative Reference Fracture Toughness for Development of P-T Limit Curves Section XI, Division 1," Code Case N-640 of the ASME Boiler & Pressure Vessel Code, Approval Date February 26, 1999.

5. "Alternative to Reference Flaw Orientation of Appendix G for Circumferential Welds in Reactor Vessels Section XI, Division 1," Code Case N-588 of the ASME Boiler & Pressure Vessel Code, Approval Date December 12, 1997.

6. "Fracture toughness Requirements," Appendix G to Part 50 of Title 10 of the Code of Federal Regulations, December 1995.

7. "Radiation Embrittlement of Reactor Vessel Materials," USNRC Regulatory Guide 1.99, Revision 2, May 1988.

8. "Analysis of Flaws," Appendix A to Section XI of the ASME Boiler & Pressure Vessel Code, 1992 Edition.

9. "Fracture Toughness Criteria for Protection Against Failure," Appendix G to Section III or XI of the ASME Boiler & Pressure Vessel Code, 1989 Edition.

10. "PVRC Recommendations on Toughness Requirements for Ferritic Materials," Welding Research Council Bulletin 175, August 1972.

11. Hodge, J. M., "Properties of Heavy Section Nuclear Reactor Steels," Welding Research Council Bulletin 217, July 1976.

12. 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).

13. 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.

14. This reference not used.

15. This reference not used.

16. L.J. Tilly, "Project Task Report LaSalle Nuclear Power Plant Asset Improvement Project Task 301: RPV Fracture Toughness Evaluation," GE-NE-A1300384-23-01, May 1999.

17. This reference not used.

18. This reference not used.

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

20. B.J. Branlund, "Plant LaSalle Units 1 and 2 RPV Shell Thickness Transition and Other Geometric Discontinuities," (GE-NE-B1301969-01), June 1998.

21. This reference not used.

22. CE Drawing # E-232-863, Rev. 4, "Nozzle Details for 251" ID BWR," (GE VPF 2029-099, Rev. 7).

23. This reference not used.

26. CE Drawing # E232-842, Rev. 2, "Bottom Head Machining and Welding for 251" ID BWR," (GE VPF # 2029-107, Rev. 4).

28. "Appendix I – Design Stress Intensity Values, Allowable Stresses, Material Properties, and Design Fatigue Curves," Mandatory Appendices to Section III of the ASME Boiler & Pressure Vessel Code, 1989 Edition.

29. 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.

30. "Reactor Vessel Purchase Specification, Reactor Pressure Vessel," (21A9242AF, Revision 9), December 1975.

31. T.A. Caine, "LaSalle Unit 1 RPV Surveillance Materials Testing and Analysis," (GE-NE-523-A166-1294, Revision 1), June 1995.

APPENDIX A

DESCRIPTION OF DISCONTINUITIES

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
317-01	Core Differential Pressure & Liquid Poison – Penetration ≤ 2.5" Bottom Head	SB 166	1.5.12 & 1.6	Thickness is ≤ 2.5" and made of Alloy 600; therefore, no further fracture toughness evaluation is required.
315-14	Drain- Penetration ≤ 2.5" – Bottom Head	SA-508 Cl. 1	1.5.1, 1.5.15 & 1.6	The discontinuity of the CRD nozzle listed in Table A-1 bounds this discontinuity; therefore, no further fracture toughness evaluation is required.
321-05	Seal Leak Detection – Penetration ~1" Flange		1.5.1	Not a pressure boundary component; therefore, requires no fracture toughness evaluation.
319-06	Top Head Lifting Lugs Attachment to Top Head	SA-533 GR. B CL. 1	1.5.1 & 1.5.13, 1.6	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 REFERENCE:

1.5. RPV Drawings

1.5.1. CE Drawing # 232-788, Rev. 3, "General Arrangement Elevation for 251" I.D. BWR," (GE VPF #2029-117, Rev. 4).

1.5.2. CE Drawing # 232-790, Rev. 8, "Lower Vessel Shell Assembly Machining & Welding for 251" I.D. BWR," (GE VPF #2029-036, Rev. 8).

1.5.3. CE Drawing # 232-791, Rev. 15, "Upper Vessel Shell Assembly Machining & Welding for 251" I.D. BWR," (GE VPF #2029-037, Rev. 14).

1.5.4. CE Drawing # 232-792, Rev. 7, "Vessel Machining for 251" I.D. BWR," (GE VPF #2029-054, Rev. 8).

1.5.5. CE Drawing # 232-796, Rev. 9, "Vessel External Attachments for 251" I.D. BWR," (GE VPF #2029-085, Rev. 10).

1.5.6. CE Drawing # 232-801, Rev. 0, "Closure Head Final Machining for 251" I.D. BWR," (GE VPF #2029-114, Rev. 2).

1.5.7. CE Drawing # 232-839, Rev. 4, "Closure Head Nozzle Details for 251" I.D. BWR," (GE VPF #2029-108, Rev. 6).

1.5.8. CE Drawing # 232-842, Rev. 2, "Bottom Head Machining & Welding for 251" I.D. BWR," (GE VPF #2029-107, Rev. 4).

1.5.9. CE Drawing # 232-861, Rev. 0, "Vessel Support Skirt Assembly and Details for 251" I.D. BWR," (GE VPF #2029-121, Rev. 2).

1.5.10. CE Drawing # 232-862, Rev. 0, "Bottom Head Penetrations for 251" I.D. BWR," (GE VPF #2029-120, Rev. 2).

1.5.11. CE Drawing # 232-863, Rev. 4, "Nozzle Details for 251" I.D. BWR," (GE VPF #2029-099, Rev. 7).

1.5.12. CE Drawing # 232-880, Rev. 1, "Nozzle Details for 251" I.D. BWR," (GE VPF #2029-115, Rev. 3).

1.5.13. CE Drawing # 232-911, Rev. 4, "Closure Head Machining & Welding for 251" I.D. BWR," (GE VPF #2029-083, Rev. 6).

1.5.14. CE Drawing # 232-937, Rev. 3, "Shroud Support Details and Assembly for 251" I.D. BWR," (GE VPF #2029-082, Rev. 5).

1.5.15. CE Drawing # 232-938, Rev. 6, "Nozzle Details for 251" I.D. BWR," (GE VPF #2029-084, Rev. 8)

1.6. CE Stress Report, "Analytical Report for LaSalle County Station Unit 1 for Commonwealth Edison Company," CE Power Systems, Combustion Engineering, Inc, Chattanooga, TN, (Report No CENC-1250.)

APPENDIX B

PRESSURE TEMPERATURE CURVE DATA TABULATION

TABLE B-1. LaSalle 1 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

FOR FIGURES 5-1, 5-2, 5-4, 5-5, 5-6, AND 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	72.0	72.0	68.0	72.0	72.0
10	68.0	72.0	72.0	68.0	72.0	72.0
20	68.0	72.0	72.0	68.0	72.0	72.0
30	68.0	72.0	72.0	68.0	72.0	72.0
40	68.0	72.0	72.0	68.0	72.0	72.0
50	68.0	72.0	72.0	68.0	72.0	72.0
60	68.0	72.0	72.0	68.0	72.0	72.0
70	68.0	72.0	72.0	68.0	72.0	72.0
80	68.0	72.0	72.0	68.0	72.0	72.0
90	68.0	72.0	72.0	68.0	72.0	72.0
100	68.0	72.0	72.0	68.0	72.0	72.0
110	68.0	72.0	72.0	68.0	72.0	72.0
120	68.0	72.0	72.0	68.0	72.0	72.0
130	68.0	72.0	72.0	68.0	74.2	72.0
140	68.0	72.0	72.0	68.0	77.4	72.0
150	68.0	72.0	72.0	68.0	80.2	72.0
160	68.0	72.0	72.0	68.0	82.9	72.0
170	68.0	72.0	72.0	68.0	85.5	72.0
180	68.0	72.0	72.0	68.0	87.9	72.0
190	68.0	72.0	72.0	68.0	90.2	72.0
200	68.0	72.0	72.0	68.0	92.3	72.0
210	68.0	72.0	72.0	68.0	94.3	73.3
220	68.0	72.0	72.0	68.0	96.3	75.3
230	68.0	72.0	72.0	68.0	98.1	77.1
240	68.0	72.0	72.0	68.0	99.9	78.9
250	68.0	72.0	72.0	68.0	101.6	80.6
260	68.0	72.0	72.0	68.0	103.2	82.2
270	68.0	72.0	72.0	68.0	104.8	83.8
280	68.0	72.0	72.0	68.0	106.3	85.3
290	68.0	72.0	72.0	68.0	107.8	86.8
300	68.0	72.0	72.0	68.0	109.2	88.2
310	68.0	72.0	72.0	68.0	110.5	89.5
312.5	68.0	72.0	72.0	68.0	110.9	89.9
312.5	68.0	102.0	102.0	68.0	132.0	132.0
320	68.0	102.0	102.0	68.0	132.0	132.0
330	68.0	102.0	102.0	68.0	132.0	132.0

TABLE B-1. LaSalle 1 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

FOR FIGURES 5-1, 5-2, 5-4, 5-5, 5-6, AND 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)
340	68.0	102.0	102.0	68.0	132.0	132.0
350	68.0	102.0	102.0	68.0	132.0	132.0
360	68.0	102.0	102.0	68.0	132.0	132.0
370	68.0	102.0	102.0	68.0	132.0	132.0
380	68.0	102.0	102.0	68.0	132.0	132.0
390	68.0	102.0	102.0	68.0	132.0	132.0
400	68.0	102.0	102.0	68.0	132.0	132.0
410	68.0	102.0	102.0	68.0	132.0	132.0
420	68.0	102.0	102.0	68.0	132.0	132.0
430	68.0	102.0	102.0	68.0	132.0	132.0
440	68.0	102.0	102.0	68.0	132.0	132.0
450	68.0	102.0	102.0	68.0	132.0	132.0
460	68.0	102.0	102.0	68.0	132.0	132.0
470	68.0	102.0	102.0	68.0	132.0	132.0
480	68.0	102.0	102.0	68.0	132.0	132.0
490	68.0	102.0	102.0	68.0	132.0	132.0
500	68.0	102.0	102.0	68.0	132.0	132.0
510	68.0	102.0	102.0	68.0	132.0	132.0
520	68.0	102.0	102.0	68.0	132.2	132.0
530	68.0	102.0	102.0	68.2	133.0	132.0
540	68.0	102.0	102.0	70.1	133.8	132.0
550	68.0	102.0	102.0	71.9	134.6	132.0
560	68.0	102.0	102.0	73.7	135.4	132.0
570	68.0	102.0	102.0	75.4	136.1	132.0
580	68.0	102.0	102.0	77.0	136.9	132.0
590	68.0	102.0	102.0	78.6	137.6	132.0
600	68.0	102.0	102.0	80.2	138.1	132.0
610	68.0	102.0	102.0	81.7	138.6	132.0
620	68.0	102.0	102.0	83.1	139.0	132.0
630	68.0	102.0	102.0	84.5	139.4	132.0
640	68.0	102.0	102.0	85.9	139.8	132.0
650	68.0	102.0	102.0	87.2	140.2	132.0
660	68.0	102.0	102.0	88.5	140.7	132.0
670	68.0	102.0	102.0	89.8	141.1	132.0
680	68.0	102.0	102.0	91.1	141.5	132.0
690	68.0	102.0	102.0	92.3	141.9	132.0
700	68.0	102.0	102.0	93.4	142.3	132.0

TABLE B-1. LaSalle 1 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

FOR FIGURES 5-1, 5-2, 5-4, 5-5, 5-6, AND 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)
710	68.7	102.0	102.0	94.6	142.7	132.0
720	70.1	102.0	102.0	95.7	143.1	132.0
730	71.5	102.3	102.0	96.8	143.5	132.0
740	72.8	103.1	102.0	97.9	143.9	132.0
750	74.1	104.0	102.0	99.0	144.2	132.0
760	75.4	104.8	102.0	100.0	144.6	132.0
770	76.6	105.6	102.0	101.0	145.0	132.0
780	77.8	106.3	102.0	102.0	145.4	132.0
790	79.0	107.1	102.0	103.0	145.8	132.0
800	80.2	107.9	102.0	103.9	146.1	132.0
810	81.3	108.6	102.0	104.9	146.5	132.0
820	82.4	109.4	102.0	105.8	146.9	132.0
830	83.5	110.1	102.0	106.7	147.2	132.0
840	84.5	110.8	102.0	107.6	147.6	132.0
850	85.6	111.5	102.0	108.4	147.9	132.0
860	86.6	112.2	102.0	109.3	148.3	132.0
870	87.6	112.9	102.0	110.1	148.6	132.0
880	88.5	113.6	102.0	111.0	149.0	132.0
890	89.5	114.3	102.0	111.8	149.3	132.0
900	90.4	114.9	102.0	112.6	149.7	132.4
910	91.4	115.6	102.0	113.4	150.0	133.1
920	92.3	116.2	102.0	114.1	150.4	133.7
930	93.1	116.9	102.0	114.9	150.7	134.4
940	94.0	117.5	102.7	115.7	151.0	135.0
950	94.9	118.1	103.6	116.4	151.4	135.7
960	95.7	118.7	104.5	117.1	151.7	136.3
970	96.6	119.3	105.4	117.9	152.0	137.0
980	97.4	119.9	106.3	118.6	152.4	137.6
990	98.2	120.5	107.1	119.3	152.7	138.2
1000	99.0	121.1	108.0	120.0	153.0	138.8
1010	99.7	121.7	108.8	120.6	153.3	139.4
1020	100.5	122.2	109.6	121.3	153.6	140.0
1030	101.3	122.8	110.4	122.0	154.0	140.6
1040	102.0	123.4	111.2	122.6	154.3	141.1
1050	102.7	123.9	112.0	123.3	154.6	141.7
1060	103.4	124.5	112.7	123.9	154.9	142.3
1070	104.2	125.0	113.5	124.5	155.2	142.8

TABLE B-1. LaSalle 1 P-T Curve Values for 32 EFPY

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

FOR FIGURES 5-1, 5-2, 5-4, 5-5, 5-6, AND 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)
1080	104.9	125.5	114.2	125.2	155.5	143.4
1090	105.6	126.1	115.0	125.8	155.8	143.9
1100	106.2	126.6	115.7	126.4	156.1	144.5
1110	106.9	127.1	116.4	127.0	156.4	145.0
1120	107.6	127.6	117.1	127.6	156.7	145.5
1130	108.2	128.1	117.8	128.2	157.0	146.1
1140	108.9	128.6	118.5	128.7	157.3	146.6
1150	109.5	129.1	119.1	129.3	157.6	147.1
1160	110.1	129.6	119.8	129.9	157.9	147.6
1170	110.8	130.1	120.4	130.4	158.2	148.1
1180	111.4	130.6	121.1	131.0	158.5	148.6
1190	112.0	131.1	121.7	131.5	158.7	149.1
1200	112.6	131.5	122.4	132.1	159.0	149.6
1210	113.2	132.0	123.0	132.6	159.3	150.0
1220	113.8	132.5	123.6	133.2	159.6	150.5
1230	114.3	132.9	124.2	133.7	159.9	151.0
1240	114.9	133.4	124.8	134.2	160.2	151.5
1250	115.5	133.8	125.4	134.7	160.4	151.9
1260	116.0	134.3	126.0	135.2	160.7	152.4
1270	116.6	134.7	126.6	135.7	161.0	152.8
1280	117.1	135.2	127.1	136.2	161.2	153.3
1290	117.7	135.6	127.7	136.7	161.5	153.7
1300	118.2	136.0	128.3	137.2	161.8	154.2
1310	118.7	136.5	128.8	137.7	162.1	154.6
1320	119.3	136.9	129.4	138.2	162.3	155.1
1330	119.8	137.3	129.9	138.6	162.6	155.5
1340	120.3	137.7	130.4	139.1	162.8	155.9
1350	120.8	138.1	131.0	139.6	163.1	156.3
1360	121.3	138.6	131.5	140.0	163.4	156.8
1370	121.8	139.0	132.0	140.5	163.6	157.2
1380	122.3	139.4	132.5	140.9	163.9	157.6
1390	122.8	139.8	133.0	141.4	164.1	158.0
1400	123.3	140.2	133.5	141.8	164.4	158.4

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

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

FOR FIGURES 5-10, 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)	NON-BELTLINE AND BELTLINE AT 32 EFPY CURVE C (°F)
0	68.0	72.0	68.0	72.0	72.0
10	68.0	72.0	68.0	72.0	72.0
20	68.0	72.0	68.0	72.0	72.0
30	68.0	72.0	68.0	72.0	72.0
40	68.0	72.0	68.0	72.0	72.0
50	68.0	72.0	68.0	72.0	72.0
60	68.0	72.0	68.0	72.0	80.0
70	68.0	72.0	68.0	72.0	87.2
80	68.0	72.0	68.0	72.0	93.2
90	68.0	72.0	68.0	72.0	98.3
100	68.0	72.0	68.0	72.0	102.8
110	68.0	72.0	68.0	72.0	106.9
120	68.0	72.0	68.0	72.0	110.7
130	68.0	72.0	68.0	74.2	114.2
140	68.0	72.0	68.0	77.4	117.4
150	68.0	72.0	68.0	80.2	120.2
160	68.0	72.0	68.0	82.9	122.9
170	68.0	72.0	68.0	85.5	125.5
180	68.0	72.0	68.0	87.9	127.9
190	68.0	72.0	68.0	90.2	130.2
200	68.0	72.0	68.0	92.3	132.3
210	68.0	72.0	68.0	94.3	134.3
220	68.0	72.0	68.0	96.3	136.3
230	68.0	72.0	68.0	98.1	138.1
240	68.0	72.0	68.0	99.9	139.9
250	68.0	72.0	68.0	101.6	141.6
260	68.0	72.0	68.0	103.2	143.2
270	68.0	72.0	68.0	104.8	144.8
280	68.0	72.0	68.0	106.3	146.3
290	68.0	72.0	68.0	107.8	147.8
300	68.0	72.0	68.0	109.2	149.2
310	68.0	72.0	68.0	110.5	150.5
312.5	68.0	72.0	68.0	110.9	150.9
312.5	68.0	102.0	68.0	132.0	172.0
320	68.0	102.0	68.0	132.0	172.0
330	68.0	102.0	68.0	132.0	172.0
340	68.0	102.0	68.0	132.0	172.0
350	68.0	102.0	68.0	132.0	172.0
360	68.0	102.0	68.0	132.0	172.0
370	68.0	102.0	68.0	132.0	172.0

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

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

FOR FIGURES 5-10, 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)	NON-BELTLINE AND BELTLINE AT 32 EFPY CURVE C (°F)
380	68.0	102.0	68.0	132.0	172.0
390	68.0	102.0	68.0	132.0	172.0
400	68.0	102.0	68.0	132.0	172.0
410	68.0	102.0	68.0	132.0	172.0
420	68.0	102.0	68.0	132.0	172.0
430	68.0	102.0	68.0	132.0	172.0
440	68.0	102.0	68.0	132.0	172.0
450	68.0	102.0	68.0	132.0	172.0
460	68.0	102.0	68.0	132.0	172.0
470	68.0	102.0	68.0	132.0	172.0
480	68.0	102.0	68.0	132.0	172.0
490	68.0	102.0	68.0	132.0	172.0
500	68.0	102.0	68.0	132.0	172.0
510	68.0	102.0	68.0	132.0	172.0
520	68.0	102.0	68.0	132.2	172.2
530	68.0	102.0	68.2	133.0	173.0
540	68.0	102.0	70.1	133.8	173.8
550	68.0	102.0	71.9	134.6	174.6
560	68.0	102.0	73.7	135.4	175.4
570	68.0	102.0	75.4	136.1	176.1
580	68.0	102.0	77.0	136.9	176.9
590	68.0	102.0	78.6	137.6	177.6
600	68.0	102.0	80.2	138.1	178.1
610	68.0	102.0	81.7	138.6	178.6
620	68.0	102.0	83.1	139.0	179.0
630	68.0	102.0	84.5	139.4	179.4
640	68.0	102.0	85.9	139.8	179.8
650	68.0	102.0	87.2	140.2	180.2
660	68.0	102.0	88.5	140.7	180.7
670	68.0	102.0	89.8	141.1	181.1
680	68.0	102.0	91.1	141.5	181.5
690	68.0	102.0	92.3	141.9	181.9
700	68.0	102.0	93.4	142.3	182.3
710	68.7	102.0	94.6	142.7	182.7
720	70.1	102.0	95.7	143.1	183.1
730	71.5	102.3	96.8	143.5	183.5
740	72.8	103.1	97.9	143.9	183.9

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

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

FOR FIGURES 5-10, 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)	NON-BELTLINE AND BELTLINE AT 32 EFPY CURVE C (°F)
750	74.1	104.0	99.0	144.2	184.2
760	75.4	104.8	100.0	144.6	184.6
770	76.6	105.6	101.0	145.0	185.0
780	77.8	106.3	102.0	145.4	185.4
790	79.0	107.1	103.0	145.8	185.8
800	80.2	107.9	103.9	146.1	186.1
810	81.3	108.6	104.9	146.5	186.5
820	82.4	109.4	105.8	146.9	186.9
830	83.5	110.1	106.7	147.2	187.2
840	84.5	110.8	107.6	147.6	187.6
850	85.6	111.5	108.4	147.9	187.9
860	86.6	112.2	109.3	148.3	188.3
870	87.6	112.9	110.1	148.6	188.6
880	88.5	113.6	111.0	149.0	189.0
890	89.5	114.3	111.8	149.3	189.3
900	90.4	114.9	112.6	149.7	189.7
910	91.4	115.6	113.4	150.0	190.0
920	92.3	116.2	114.1	150.4	190.4
930	93.1	116.9	114.9	150.7	190.7
940	94.0	117.5	115.7	151.0	191.0
950	94.9	118.1	116.4	151.4	191.4
960	95.7	118.7	117.1	151.7	191.7
970	96.6	119.3	117.9	152.0	192.0
980	97.4	119.9	118.6	152.4	192.4
990	98.2	120.5	119.3	152.7	192.7
1000	99.0	121.1	120.0	153.0	193.0
1010	99.7	121.7	120.6	153.3	193.3
1020	100.5	122.2	121.3	153.6	193.6
1030	101.3	122.8	122.0	154.0	194.0
1040	102.0	123.4	122.6	154.3	194.3
1050	102.7	123.9	123.3	154.6	194.6
1060	103.4	124.5	123.9	154.9	194.9
1070	104.2	125.0	124.5	155.2	195.2
1080	104.9	125.5	125.2	155.5	195.5
1090	105.6	126.1	125.8	155.8	195.8
1100	106.2	126.6	126.4	156.1	196.1
1110	106.9	127.1	127.0	156.4	196.4

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

Required Coolant Temperatures at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

FOR FIGURES 5-10, 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)	NON-BELTLINE AND BELTLINE AT 32 EFPY CURVE C (°F)
1120	107.6	127.6	127.6	156.7	196.7
1130	108.2	128.1	128.2	157.0	197.0
1140	108.9	128.6	128.7	157.3	197.3
1150	109.5	129.1	129.3	157.6	197.6
1160	110.1	129.6	129.9	157.9	197.9
1170	110.8	130.1	130.4	158.2	198.2
1180	111.4	130.6	131.0	158.5	198.5
1190	112.0	131.1	131.5	158.7	198.7
1200	112.6	131.5	132.1	159.0	199.0
1210	113.2	132.0	132.6	159.3	199.3
1220	113.8	132.5	133.2	159.6	199.6
1230	114.3	132.9	133.7	159.9	199.9
1240	114.9	133.4	134.2	160.2	200.2
1250	115.5	133.8	134.7	160.4	200.4
1260	116.0	134.3	135.2	160.7	200.7
1270	116.6	134.7	135.7	161.0	201.0
1280	117.1	135.2	136.2	161.2	201.2
1290	117.7	135.6	136.7	161.5	201.5
1300	118.2	136.0	137.2	161.8	201.8
1310	118.7	136.5	137.7	162.1	202.1
1320	119.3	136.9	138.2	162.3	202.3
1330	119.8	137.3	138.6	162.6	202.6
1340	120.3	137.7	139.1	162.8	202.8
1350	120.8	138.1	139.6	163.1	203.1
1360	121.3	138.6	140.0	163.4	203.4
1370	121.8	139.0	140.5	163.6	203.6
1380	122.3	139.4	140.9	163.9	203.9
1390	122.8	139.8	141.4	164.1	204.1
1400	123.3	140.2	141.8	164.4	204.4

TABLE B-3. LaSalle 1 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, AND 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	72.0	72.0	68.0	72.0	72.0
10	68.0	72.0	72.0	68.0	72.0	72.0
20	68.0	72.0	72.0	68.0	72.0	72.0
30	68.0	72.0	72.0	68.0	72.0	72.0
40	68.0	72.0	72.0	68.0	72.0	72.0
50	68.0	72.0	72.0	68.0	72.0	72.0
60	68.0	72.0	72.0	68.0	72.0	72.0
70	68.0	72.0	72.0	68.0	72.0	72.0
80	68.0	72.0	72.0	68.0	72.0	72.0
90	68.0	72.0	72.0	68.0	72.0	72.0
100	68.0	72.0	72.0	68.0	72.0	72.0
110	68.0	72.0	72.0	68.0	72.0	72.0
120	68.0	72.0	72.0	68.0	72.0	72.0
130	68.0	72.0	72.0	68.0	74.2	72.0
140	68.0	72.0	72.0	68.0	77.4	72.0
150	68.0	72.0	72.0	68.0	80.2	72.0
160	68.0	72.0	72.0	68.0	82.9	72.0
170	68.0	72.0	72.0	68.0	85.5	72.0
180	68.0	72.0	72.0	68.0	87.9	72.0
190	68.0	72.0	72.0	68.0	90.2	72.0
200	68.0	72.0	72.0	68.0	92.3	72.0
210	68.0	72.0	72.0	68.0	94.3	72.0
220	68.0	72.0	72.0	68.0	96.3	72.3
230	68.0	72.0	72.0	68.0	98.1	74.1
240	68.0	72.0	72.0	68.0	99.9	75.9
250	68.0	72.0	72.0	68.0	101.6	77.6
260	68.0	72.0	72.0	68.0	103.2	79.2
270	68.0	72.0	72.0	68.0	104.8	80.8
280	68.0	72.0	72.0	68.0	106.3	82.3
290	68.0	72.0	72.0	68.0	107.8	83.8
300	68.0	72.0	72.0	68.0	109.2	85.2
310	68.0	72.0	72.0	68.0	110.5	86.5
312.5	68.0	72.0	72.0	68.0	110.9	86.9
312.5	68.0	102.0	102.0	68.0	132.0	132.0
320	68.0	102.0	102.0	68.0	132.0	132.0
330	68.0	102.0	102.0	68.0	132.0	132.0

TABLE B-3. LaSalle 1 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, AND 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)
340	68.0	102.0	102.0	68.0	132.0	132.0
350	68.0	102.0	102.0	68.0	132.0	132.0
360	68.0	102.0	102.0	68.0	132.0	132.0
370	68.0	102.0	102.0	68.0	132.0	132.0
380	68.0	102.0	102.0	68.0	132.0	132.0
390	68.0	102.0	102.0	68.0	132.0	132.0
400	68.0	102.0	102.0	68.0	132.0	132.0
410	68.0	102.0	102.0	68.0	132.0	132.0
420	68.0	102.0	102.0	68.0	132.0	132.0
430	68.0	102.0	102.0	68.0	132.0	132.0
440	68.0	102.0	102.0	68.0	132.0	132.0
450	68.0	102.0	102.0	68.0	132.0	132.0
460	68.0	102.0	102.0	68.0	132.0	132.0
470	68.0	102.0	102.0	68.0	132.0	132.0
480	68.0	102.0	102.0	68.0	132.0	132.0
490	68.0	102.0	102.0	68.0	132.0	132.0
500	68.0	102.0	102.0	68.0	132.0	132.0
510	68.0	102.0	102.0	68.0	132.0	132.0
520	68.0	102.0	102.0	68.0	132.2	132.0
530	68.0	102.0	102.0	68.2	133.0	132.0
540	68.0	102.0	102.0	70.1	133.8	132.0
550	68.0	102.0	102.0	71.9	134.6	132.0
560	68.0	102.0	102.0	73.7	135.4	132.0
570	68.0	102.0	102.0	75.4	136.1	132.0
580	68.0	102.0	102.0	77.0	136.9	132.0
590	68.0	102.0	102.0	78.6	137.6	132.0
600	68.0	102.0	102.0	80.2	138.1	132.0
610	68.0	102.0	102.0	81.7	138.6	132.0
620	68.0	102.0	102.0	83.1	139.0	132.0
630	68.0	102.0	102.0	84.5	139.4	132.0
640	68.0	102.0	102.0	85.9	139.8	132.0
650	68.0	102.0	102.0	87.2	140.2	132.0
660	68.0	102.0	102.0	88.5	140.7	132.0
670	68.0	102.0	102.0	89.8	141.1	132.0
680	68.0	102.0	102.0	91.1	141.5	132.0
690	68.0	102.0	102.0	92.3	141.9	132.0
700	68.0	102.0	102.0	93.4	142.3	132.0

TABLE B-3. LaSalle 1 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, AND 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)
710	68.7	102.0	102.0	94.6	142.7	132.0
720	70.1	102.0	102.0	95.7	143.1	132.0
730	71.5	102.3	102.0	96.8	143.5	132.0
740	72.8	103.1	102.0	97.9	143.9	132.0
750	74.1	104.0	102.0	99.0	144.2	132.0
760	75.4	104.8	102.0	100.0	144.6	132.0
770	76.6	105.6	102.0	101.0	145.0	132.0
780	77.8	106.3	102.0	102.0	145.4	132.0
790	79.0	107.1	102.0	103.0	145.8	132.0
800	80.2	107.9	102.0	103.9	146.1	132.0
810	81.3	108.6	102.0	104.9	146.5	132.0
820	82.4	109.4	102.0	105.8	146.9	132.0
830	83.5	110.1	102.0	106.7	147.2	132.0
840	84.5	110.8	102.0	107.6	147.6	132.0
850	85.6	111.5	102.0	108.4	147.9	132.0
860	86.6	112.2	102.0	109.3	148.3	132.0
870	87.6	112.9	102.0	110.1	148.6	132.0
880	88.5	113.6	102.0	111.0	149.0	132.0
890	89.5	114.3	102.0	111.8	149.3	132.0
900	90.4	114.9	102.0	112.6	149.7	132.0
910	91.4	115.6	102.0	113.4	150.0	132.0
920	92.3	116.2	102.0	114.1	150.4	132.0
930	93.1	116.9	102.0	114.9	150.7	132.0
940	94.0	117.5	102.0	115.7	151.0	132.0
950	94.9	118.1	102.0	116.4	151.4	132.0
960	95.7	118.7	102.0	117.1	151.7	132.0
970	96.6	119.3	102.0	117.9	152.0	132.0
980	97.4	119.9	102.0	118.6	152.4	132.0
990	98.2	120.5	102.0	119.3	152.7	132.0
1000	99.0	121.1	102.0	120.0	153.0	132.0
1010	99.7	121.7	102.0	120.6	153.3	132.0
1020	100.5	122.2	102.0	121.3	153.6	132.0
1030	101.3	122.8	102.0	122.0	154.0	132.0
1040	102.0	123.4	102.0	122.6	154.3	132.0
1050	102.7	123.9	102.0	123.3	154.6	132.0
1060	103.4	124.5	102.0	123.9	154.9	132.0
1070	104.2	125.0	102.0	124.5	155.2	132.0

TABLE B-3. LaSalle 1 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, AND 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)
1080	104.9	125.5	102.0	125.2	155.5	132.0
1090	105.6	126.1	102.1	125.8	155.8	132.0
1100	106.2	126.6	102.6	126.4	156.1	132.1
1110	106.9	127.1	103.1	127.0	156.4	132.4
1120	107.6	127.6	103.6	127.6	156.7	132.7
1130	108.2	128.1	104.1	128.2	157.0	133.0
1140	108.9	128.6	104.6	128.7	157.3	133.3
1150	109.5	129.1	105.1	129.3	157.6	133.6
1160	110.1	129.6	105.6	129.9	157.9	133.9
1170	110.8	130.1	106.1	130.4	158.2	134.2
1180	111.4	130.6	106.6	131.0	158.5	134.5
1190	112.0	131.1	107.1	131.5	158.7	134.7
1200	112.6	131.5	107.5	132.1	159.0	135.0
1210	113.2	132.0	108.0	132.6	159.3	135.3
1220	113.8	132.5	108.5	133.2	159.6	135.6
1230	114.3	132.9	108.9	133.7	159.9	135.9
1240	114.9	133.4	109.4	134.2	160.2	136.2
1250	115.5	133.8	109.8	134.7	160.4	136.4
1260	116.0	134.3	110.3	135.2	160.7	136.7
1270	116.6	134.7	110.7	135.7	161.0	137.0
1280	117.1	135.2	111.2	136.2	161.2	137.2
1290	117.7	135.6	111.6	136.7	161.5	137.5
1300	118.2	136.0	112.0	137.2	161.8	137.8
1310	118.7	136.5	112.5	137.7	162.1	138.1
1320	119.3	136.9	112.9	138.2	162.3	138.3
1330	119.8	137.3	113.3	138.6	162.6	138.6
1340	120.3	137.7	113.7	139.1	162.8	138.8
1350	120.8	138.1	114.1	139.6	163.1	139.1
1360	121.3	138.6	114.6	140.0	163.4	139.4
1370	121.8	139.0	115.0	140.5	163.6	139.6
1380	122.3	139.4	115.4	140.9	163.9	139.9
1390	122.8	139.8	115.8	141.4	164.1	140.1
1400	123.3	140.2	116.2	141.8	164.4	140.4

TABLE B-4. LaSalle Unit 1 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 5-9

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)	NON-BELTLINE AND BELTLINE AT 20 EFPY CURVE C (°F)
0	68.0	72.0	68.0	72.0	72.0
10	68.0	72.0	68.0	72.0	72.0
20	68.0	72.0	68.0	72.0	72.0
30	68.0	72.0	68.0	72.0	72.0
40	68.0	72.0	68.0	72.0	72.0
50	68.0	72.0	68.0	72.0	72.0
60	68.0	72.0	68.0	72.0	80.0
70	68.0	72.0	68.0	72.0	87.2
80	68.0	72.0	68.0	72.0	93.2
90	68.0	72.0	68.0	72.0	98.3
100	68.0	72.0	68.0	72.0	102.8
110	68.0	72.0	68.0	72.0	106.9
120	68.0	72.0	68.0	72.0	110.7
130	68.0	72.0	68.0	74.2	114.2
140	68.0	72.0	68.0	77.4	117.4
150	68.0	72.0	68.0	80.2	120.2
160	68.0	72.0	68.0	82.9	122.9
170	68.0	72.0	68.0	85.5	125.5
180	68.0	72.0	68.0	87.9	127.9
190	68.0	72.0	68.0	90.2	130.2
200	68.0	72.0	68.0	92.3	132.3
210	68.0	72.0	68.0	94.3	134.3
220	68.0	72.0	68.0	96.3	136.3
230	68.0	72.0	68.0	98.1	138.1
240	68.0	72.0	68.0	99.9	139.9
250	68.0	72.0	68.0	101.6	141.6
260	68.0	72.0	68.0	103.2	143.2
270	68.0	72.0	68.0	104.8	144.8
280	68.0	72.0	68.0	106.3	146.3
290	68.0	72.0	68.0	107.8	147.8
300	68.0	72.0	68.0	109.2	149.2
310	68.0	72.0	68.0	110.5	150.5
312.5	68.0	72.0	68.0	110.9	150.9
312.5	68.0	102.0	68.0	132.0	172.0
320	68.0	102.0	68.0	132.0	172.0

TABLE B-4. LaSalle Unit 1 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 5-9

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)	NON-BELTLINE AND BELTLINE AT 20 EFPY CURVE C (°F)
330	68.0	102.0	68.0	132.0	172.0
340	68.0	102.0	68.0	132.0	172.0
350	68.0	102.0	68.0	132.0	172.0
360	68.0	102.0	68.0	132.0	172.0
370	68.0	102.0	68.0	132.0	172.0
380	68.0	102.0	68.0	132.0	172.0
390	68.0	102.0	68.0	132.0	172.0
400	68.0	102.0	68.0	132.0	172.0
410	68.0	102.0	68.0	132.0	172.0
420	68.0	102.0	68.0	132.0	172.0
430	68.0	102.0	68.0	132.0	172.0
440	68.0	102.0	68.0	132.0	172.0
450	68.0	102.0	68.0	132.0	172.0
460	68.0	102.0	68.0	132.0	172.0
470	68.0	102.0	68.0	132.0	172.0
480	68.0	102.0	68.0	132.0	172.0
490	68.0	102.0	68.0	132.0	172.0
500	68.0	102.0	68.0	132.0	172.0
510	68.0	102.0	68.0	132.0	172.0
520	68.0	102.0	68.0	132.2	172.2
530	68.0	102.0	68.2	133.0	173.0
540	68.0	102.0	70.1	133.8	173.8
550	68.0	102.0	71.9	134.6	174.6
560	68.0	102.0	73.7	135.4	175.4
570	68.0	102.0	75.4	136.1	176.1
580	68.0	102.0	77.0	136.9	176.9
590	68.0	102.0	78.6	137.6	177.6
600	68.0	102.0	80.2	138.1	178.1
610	68.0	102.0	81.7	138.6	178.6
620	68.0	102.0	83.1	139.0	179.0
630	68.0	102.0	84.5	139.4	179.4
640	68.0	102.0	85.9	139.8	179.8
650	68.0	102.0	87.2	140.2	180.2
660	68.0	102.0	88.5	140.7	180.7
670	68.0	102.0	89.8	141.1	181.1
680	68.0	102.0	91.1	141.5	181.5

TABLE B-4. LaSalle Unit 1 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 5-9

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)	NON-BELTLINE AND BELTLINE AT 20 EFPY CURVE C (°F)
690	68.0	102.0	92.3	141.9	181.9
700	68.0	102.0	93.4	142.3	182.3
710	68.7	102.0	94.6	142.7	182.7
720	70.1	102.0	95.7	143.1	183.1
730	71.5	102.3	96.8	143.5	183.5
740	72.8	103.1	97.9	143.9	183.9
750	74.1	104.0	99.0	144.2	184.2
760	75.4	104.8	100.0	144.6	184.6
770	76.6	105.6	101.0	145.0	185.0
780	77.8	106.3	102.0	145.4	185.4
790	79.0	107.1	103.0	145.8	185.8
800	80.2	107.9	103.9	146.1	186.1
810	81.3	108.6	104.9	146.5	186.5
820	82.4	109.4	105.8	146.9	186.9
830	83.5	110.1	106.7	147.2	187.2
840	84.5	110.8	107.6	147.6	187.6
850	85.6	111.5	108.4	147.9	187.9
860	86.6	112.2	109.3	148.3	188.3
870	87.6	112.9	110.1	148.6	188.6
880	88.5	113.6	111.0	149.0	189.0
890	89.5	114.3	111.8	149.3	189.3
900	90.4	114.9	112.6	149.7	189.7
910	91.4	115.6	113.4	150.0	190.0
920	92.3	116.2	114.1	150.4	190.4
930	93.1	116.9	114.9	150.7	190.7
940	94.0	117.5	115.7	151.0	191.0
950	94.9	118.1	116.4	151.4	191.4
960	95.7	118.7	117.1	151.7	191.7
970	96.6	119.3	117.9	152.0	192.0
980	97.4	119.9	118.6	152.4	192.4
990	98.2	120.5	119.3	152.7	192.7
1000	99.0	121.1	120.0	153.0	193.0
1010	99.7	121.7	120.6	153.3	193.3
1020	100.5	122.2	121.3	153.6	193.6
1030	101.3	122.8	122.0	154.0	194.0
1040	102.0	123.4	122.6	154.3	194.3

TABLE B-4. LaSalle Unit 1 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 5-9

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)	NON-BELTLINE AND BELTLINE AT 20 EFPY CURVE C (°F)
1050	102.7	123.9	123.3	154.6	194.6
1060	103.4	124.5	123.9	154.9	194.9
1070	104.2	125.0	124.5	155.2	195.2
1080	104.9	125.5	125.2	155.5	195.5
1090	105.6	126.1	125.8	155.8	195.8
1100	106.2	126.6	126.4	156.1	196.1
1110	106.9	127.1	127.0	156.4	196.4
1120	107.6	127.6	127.6	156.7	196.7
1130	108.2	128.1	128.2	157.0	197.0
1140	108.9	128.6	128.7	157.3	197.3
1150	109.5	129.1	129.3	157.6	197.6
1160	110.1	129.6	129.9	157.9	197.9
1170	110.8	130.1	130.4	158.2	198.2
1180	111.4	130.6	131.0	158.5	198.5
1190	112.0	131.1	131.5	158.7	198.7
1200	112.6	131.5	132.1	159.0	199.0
1210	113.2	132.0	132.6	159.3	199.3
1220	113.8	132.5	133.2	159.6	199.6
1230	114.3	132.9	133.7	159.9	199.9
1240	114.9	133.4	134.2	160.2	200.2
1250	115.5	133.8	134.7	160.4	200.4
1260	116.0	134.3	135.2	160.7	200.7
1270	116.6	134.7	135.7	161.0	201.0
1280	117.1	135.2	136.2	161.2	201.2
1290	117.7	135.6	136.7	161.5	201.5
1300	118.2	136.0	137.2	161.8	201.8
1310	118.7	136.5	137.7	162.1	202.1
1320	119.3	136.9	138.2	162.3	202.3
1330	119.8	137.3	138.6	162.6	202.6
1340	120.3	137.7	139.1	162.8	202.8
1350	120.8	138.1	139.6	163.1	203.1
1360	121.3	138.6	140.0	163.4	203.4
1370	121.8	139.0	140.5	163.6	203.6
1380	122.3	139.4	140.9	163.9	203.9
1390	122.8	139.8	141.4	164.1	204.1
1400	123.3	140.2	141.8	164.4	204.4

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. A discussion of monitoring of vessel temperatures can be found in Section 4 of the pressure-temperature curve report prepared in 1989 [19].

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 does 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 which 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 temps.	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:
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Service Information
and Analysis

Issued By:
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Customer Service Information

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APPENDIX E

THICKNESS TRANSITION DISCONTINUITY EVALUATION

Objectives:

The purpose of the following evaluations is to determine the hydrotest and the heat-up/cool-down temperature (T) for the shell thickness transition discontinuity and to demonstrate that the temperature is bounded by the feedwater (FW) nozzle hydrotest and heat-up/cool-down temperature.

Methods and Assumptions:

An ANSYS finite element analysis was performed for the thickness discontinuity in the beltline region of LaSalle Unit 1. The purpose of this evaluation was to determine the RPV discontinuity stresses (hoop and axial) that result from a thickness transition discontinuity in the beltline region. The transition is modeled as a transition from 6 1/8" minimum thickness to 7 1/8" minimum thickness. (References 1.5.1, 1.5.2 & 1.5.3 in Appendix A)

Three load cases were evaluated for the beltline shell discontinuity: 1) hydrostatic test pressure at 1563 psig, 2) a cool-down transient of 100°F/hr, starting at 550°F and decreasing to 70°F on the inside surface wall [2] and with an initial operating pressure of 1050 psig, and 3) a heat-up transient of 100°F/hr, starting at 70°F and increasing to 550°F on the inside surface wall [2] and with a final operating pressure of 1050 psig. For both transient cases it was assumed that the outside RPV wall surface is insulated with a heat transfer coefficient of 0.2 BTU/hr-ft^2 °F [30] and that the ambient temperature is 100°F. These are the bounding beltline transients of those described in Table 5.2-4 of the LaSalle Unit 1 and 2 UFSAR and Region B of the thermal cycle diagram [2] at temperatures for which brittle fracture could occur. Material properties were used from the code of construction for the RPV Materials: Shell Plate Materials are ASME SA533, Grade B, Class 1, low alloy steel (LAS) [31].

Methods consistent with those described in Section 4.3 were used to calculate the T-RT_{NDT} for the shell discontinuity for a hydrotest pressure of 1563 psig and the two transient cases. The adjusted reference temperature values shown in Table 4-4 were added to the T-RT_{NDT}

to determine the temperature "T". The value of "T" was compared to that of the FW/LPCI nozzle for the same condition as described in Sections 4.3.2.1.3 for the hydrotest pressure case and 4.3.2.1.4 for the transients cases.

As shown below the stresses that result from the transition discontinuity are not significantly greater than those remote from the discontinuity (the difference in stress is less than 1 ksi for the pressure case and less than 2 ksi for the thermal cases). Therefore, the shell transition discontinuity stresses are also bounded by the beltline shell calculation.

The methods of ASME Code Section XI, Appendix G [9] are used to calculate the pressure test and thermal limits. The membrane and bending stress were determined from the finite element analysis and are shown below. The hoop stresses were more limiting than the axial stresses.

The stress intensity factors, K_{Im} and K_{Ib}, are calculated using Code Cases N-640 [4] and N-588 [5], and ASME Code Section XI Appendix A [8] and Appendix G [9]. Therefore, $K_{Im} = M_m * \sigma_m$ and $K_{Ib} = M_b * \sigma_b$. The values of M_m and M_b were determined from the Code Case N-588 [5]. The stress intensity is based on a 1/4 T radial flaw with a six-to-one aspect ratio (length of 1.5T). The flaw is oriented normal to the maximum stress direction, in this case a vertically oriented flaw since the hoop stress was limiting.

The calculated value of $K_{Im} + K_{Ib}$ is multiplied by a safety factor (SF) (1.5 for pressure test and 2.0 for the transient cases), per ASME Appendix G [9] for comparison with K_{IR}, the material fracture toughness expressed as K_{IC}.

The relationship between K_{IC} and temperature relative to reference temperature ($T - RT_{NDT}$) is provided in ASME Code Section XI Appendix A [8] Paragraph A-4200, represented by the relationship (K_1 units ksi-in $^{0.5}$):

$$K_{IC} = 33.2 + 20.734 \exp[0.02 (T - RT_{NDT})]$$; therefore,

$$T\text{-}RT_{NDT} = \ln[(K_{IC}-33.2)/20.734]/0.02,$$

where $K_{IC} = SF * (K_{Im} + K_{Ib})$ for pressure test

and $K_{IC} = (SF * K_{IP}) + K_{IS}$ for transient case.

This relationship is derived in the Welding Research Council (WRC) Bulletin 175 [10] as the lower bound of all dynamic fracture toughness data. This relationship provides values of pressure versus temperature (from K_{IR} and $(T - RT_{NDT})$, respectively).

The RT_{NDT} is added to the $(T\text{-}RT_{NDT})$ to determine the hydrotest, heat-up, and cool-down temperatures.

Analysis Information:

Thin Section Thickness

t_{min} = 6.13 inch

$\sqrt{(t)}$ = 2.47 $inch^{0.5}$

Thick Section Thickness

t_{min} = 7.13 inch

$\sqrt{(t)}$ = 2.67 $inch^{0.5}$

Analysis and Results for the Hydrotest Pressure (Case 1):

Pressure (psig)	Primary membrane Pm (psi)	Primary bending Pb (psi)	Mm	Km = Mm*Pm (psi $in^{0.5}$)	Mb = 2/3 Mm	Kb = Mb*Pb (psi $in^{0.5}$)	T-RTndt (°F)
Maximum Hoop Stress - Adjacent to the discontinuity in thin section (6.125")							
1000	20920	475					
1563	32698	743	2.29	74966	1.53	1136	68.1
Thin section remote from the discontinuity (t = 6.125")							
1000	20740	534					
1563	32417	835	2.29	74321	1.53	1276	67.6
Thick section remote from the discontinuity (t = 7.125")							
1000	17820	460					
1563	27853	719	2.47	68870	1.65	1185	62.2

Note that the axial stress is approximately 1/2 of the hoop stress.

Results and Conclusions:

The maximum T-RT_{NDT} for the thickness discontinuity is 68°F. The limiting beltline material RT_{NDT} is 72°F (see Table 4-4), so T = 140°F.

The limiting beltline plate RT_{NDT} is 55°F (see Table 4-4), so T = 123°F.

The T- RT_{NDT} for the FW nozzle is 106°F (see Section 4.3.2.1.3) at 1563 psig. The limiting RT_{NDT} for the FW nozzle region is 40°F (see Section 4.3.2.1.3), so T = 146°F

The FW nozzle pressure test temperature "T" bounds the thickness discontinuity for the case with the limiting ART value. Therefore, the thickness discontinuity remains bounded by the FW nozzle.

Analysis and Results for Cool-down (CD - Case 2) and Heat-up (HU - Case 3):

Hoop Stress

Location and Case	Pressure (psig)	Primary membrane Pm (psi)	Primary bending Pb (psi)	Secondary membrane Sm (psi)	Secondary bending Sb (psi)	Mm	Mb = 2/3 Mm	K_{IP} (psi in$^{0.5}$)	K_{IS} (psi in$^{0.5}$)	T-RTndt (°F)
Maximum Hoop Stress from Discontinuity in thick section adjacent to discontinuity										
	1000	20920	475							
ID - CD	1050	21966	499	135	6040	2.47	1.65	55136	10290	71.9
OD - HU	1050	21966	-499	-161	7253	2.47	1.65	53491	11558	70.7
Thin section remote from the discontinuity (t = 6.125")										
	1000	20740	534							
ID - CD	1050	21777	561	0	3671	2.29	1.53	50785	5611	63.6
OD - HU	1050	21777	-561	1	5506	2.29	1.53	49070	8418	63.2
Thick section remote from the discontinuity (t = 7.125")										
	1000	17820	460							
ID - CD	1050	18711	483	-1	6122	2.47	1.65	47061	10089	61.6
OD - HU	1050	18711	-483	1	7351	2.47	1.65	45470	12120	60.7

Results and Conclusions:

The maximum T-RT_{NDT} for the thickness discontinuity is 72°F. The limiting beltline material RT_{NDT} is 72°F (see Table 4-4), so T = 144°F.

The limiting beltline plate RT_{NDT} is 55°F (see Table 4-4), so T = 127°F.

The T- RT_{NDT} for the FW nozzle for core not critical heat-up/cool-down is 115°F at 1050 psig (see Section 4.3.2.1.4). The limiting RT_{NDT} for the FW nozzle region is 40°F (see Section 4.3.2.1.4), so T = 155°F

The FW nozzle pressure test temperature "T" bounds the thickness discontinuity for the case with the limiting ART value. Therefore, the thickness discontinuity remains bounded by the FW nozzle.

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