GE Nuclear Energy

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

GE-NE-B13-02057-00-03a-R1
Revision 1
Class I
May 2000

Pressure-Temperature Curves

For

ComEd

Dresden Unit 3

Prepared by: T A Caine for

R. G. Carey, Engineer

Structural Assessment and Mitigation

Verified by: B D Frew

B. D. Frew, Senior Engineer

Structural Assessment and Mitigation

Approved by: B. J. Branlund

B. J. Branlund, Principal Engineer

Structural Assessment and Mitigation

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 1997 [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 $T\text{-}RT_{NDT}$. 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 22 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 22 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 22 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 1997 [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. 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 22 and 32 EFPY are included in Section 4.2. The 32 EFPY fluence value of

5.1×10^{17} n/cm^2 used in this report was determined to be the maximum of the fluence values from each of the Dresden and Quad Cities vessels. 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. Finally, GE SIL 430, a GE service information letter regarding Reactor Pressure Vessel Temperature Monitoring is included in Appendix D.

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 1997 [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 Dresden Unit 3 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 and 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 Dresden Unit 3 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, HAZ, and forging, and bolting material LST are summarized in the remainder of this section.

The RT_{NDT} values for the vessel weld materials were not calculated; these values were obtained from other sources (see Section 4.2, Tables 4.3 and 4.4).

For vessel plate material, the first step in calculating RT_{NDT} is to establish the 50 ft-lb. transverse test temperature from longitudinal test specimen data (obtained from certified material test reports, CMTR's). For Dresden Unit 3 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 C1290-2 in the lower-intermediate shell course of Dresden Unit 3, the lowest Charpy energy and test temperature from the CMTR's is 45.0 ft-lb. at 10°F. The estimated 50 ft-lb. longitudinal test temperature is:

T_{50L} = 10°F + [(50 - 45.0) ft-lb. * 2°F/ft-lb.] = 20°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} = 20°F + 30°F = 50°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. Thus, the initial RT_{NDT} for plate heat C1290-2 was 10°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 Dresden Unit 3, the NDT was 30°F and the lowest CVN data was 32 ft-lb. at 40°F (transverse charpy data). The corresponding value of (T_{50T} – 60°F) was:

(T_{50T} - 60°F) = [40 + (50-32) ft-lb. * 3°F/ft-lb.] – 60°F = 34°F.

Therefore, the initial RT_{NDT} was 34°F.

In the bottom head region of the vessel, the vessel plate method is applied for estimating RT_{NDT}. For the bottom head center of Dresden Unit 3 (Heat C1173-2), the NDT was 40°F and the lowest CVN data was 33 ft-lb. at 40°F. The corresponding value of (T_{50T} – 60°F) was:

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

Therefore, the initial RT_{NDT} was 44°F.

For bolting material, the current ASME Code requirements define the lowest service temperature (LST) as the temperature at which transverse CVN energy of 45 ft-lb. and 25 mils lateral expansion (MLE) were achieved. If the required Charpy results are not met, or are not reported, but the CVN energy reported is above 30 ft-lb., the requirements of the ASME Code Section III, Subsection NB-2300 at construction are applied. Namely that the 30 ft-lb. test temperature plus 60°F is the LST for the bolting materials. Charpy data for the Dresden Unit 3 closure studs do not meet the 45 ft-lb., 25 MLE requirement at 10°F. Therefore, the LST for the bolting material is 70°F. However, the highest RT_{NDT} in the closure flange region is 23.1°F, for the vertical electroslag weld. Thus, the higher of the LST and the RT_{NDT} +60°F is 83.1°F, the boltup limit in the closure flange region.

The initial RT_{NDT} values for the Dresden Unit 3 reactor vessel materials are listed in Tables 4-1 and 4-2. 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 Dresden Unit 3 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								
Dollar Plate MK201	C1177-4	40	73	72	74	10	40	40
Top Head Torus	A0458-2	10	54	60	73	-20	10	10
MK 202	C1173-4	10	70	51	74	-20	10	10
	C1177-3	10	54	69	70	-20	10	10
Top Head Flange								
MK209	5P1127	10	43	75.04	71.92	-6	10	10
MK48	5P1114	10	57	108	106	-20	-10	-10
Shell Courses								
Upper Shell	C1191-1	10	50	43	55	-6	10	10
MK60	C1191-2	10	40	49	52	0	10	10
	B5144-1	10	64	51	62	-20	10	10
Upper Int. Shell	B5144-2	10	65	66	40	0	10	10
MK59	C1516-1	10	39	43	49	2	10	10
	B5159-1	10	83	57	65	-20	10	10
Low-Int. Shell	C1290-2	10	45	60	62	-10	10	10
MK58	A0237-1	10	71	70	59	-20	10	10
	B5118-1	10	66	67	66	-20	10	10
Lower Shell	C1256-2	10	75	70	90	-20	-10	-10
MK57	C1182-2	10	70	61	64	-20	10	10
	B5159-2	10	55	50	65	-20	0	0
Bottom Head								
Dollar Plate MK1	A0284-2	40	54	65	60	10	40	40
Btm Head Torus, Btm Head	A0237-2	40	92	91	109	10	40	40
MK2	C1177-1	40	49	62	74	12	40	40
	C1177-2	40	66	64	83	10	40	40
	C1485-1*							40
Bottom Center, Btm Head	C1173-2	40	49	33	47	44	40	44
MK4	C1173-1	40	41	45	74	28	40	40

*CMTR not available-40F RTndt assumed per purchase specification 21A1109

Table 4-2: RT_{NDT} values for Dresden Unit 3 Nozzle and Weld Materials.

COMPONENT	HEAT	TEST TEMP. (°F)	CHARPY ENERGY (FT-LB)			(T_{50T}-60) (°F)	DROP WEIGHT NDT	RT_{NDT} (°F)
NOZZLES								
Recirc. Outlet Nozzle MK8 (Transverse data)	ZT2405-1	40	65	74.5	74.5	-20	40	40
Recirc Inlet Nozzle	ZT2405-4	40	72.5	65	84	-20	40	40
MK7 (Transverse data)	ZT2405-3	40	78.5	64	60.5	-20	40	40
(Longitudinal)	ZT2869	40	31	37.5	39	48	30	48
Steam Outlet Nozzle MK14 (Transverse data)	ZT2405-2	40	52.5	42	49	4	40	40
Feedwater Nozzle	ZT2405-5	40	52.5	61.5	70.5	-20	40	40
MK10 (Transverse data)	ZT2885-6	40	32	34	36.5	34	30	34
Core Spray Nozzle	ZT2869-5	40	39	36	44.5	38	30	38
MK11	ZT2782	40	43	42	34	42	30	42
6" Instrumentation, Vent & CRD HSR Nozzle MK206 & 204 & 13	ZT3043	40	102	130	117	10	40	40
Jet Pump Nozzle MK19	EV8446	40	68.5	64	49	12	40	40
Core Diff. Press & Liq. Con. Noz Penetration	C1173-2	40	49	33	47	44	40	44
Drain Penetration	A0284-2	40	54	65	60	10	40	40
CRD Penetration	A0284-2	40	54	65	60	10	40	40
Isolation Cond. Nozzle MK15 (Transverse data)	ZT2405-3	40	67	47.5	53.5	-12.5	40	40
WELDS:								
Vertical Welds	ESW							23.1
Girth Welds	299L44/ 8650							-5
STUDS:						**LST**		
Studs MK61	6720372	10	53	35	58	70	OK	

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 22 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 several sources, as detailed below:

- Vessel Plate: Copper- plate manufacturer [14]; Nickel- highest value from CMTR.
- Submerged arc welds: Copper and nickel from separate evaluation [15 & 29].
- Electroslag welds: Copper and nickel from separate evaluations [17 & 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 for the vessel plate materials [1]. The σ_I for the submerged arc welds was 20°F [16] and for the electroslag welds was 13°F [17].

4.2.1.2 Fluence

The 32 EFPY fluence at the 1/4T depth of vessel wall for the Dresden Unit 3 vessels was obtained from surveillance capsule results. Since the Dresden and Quad Cities vessels are 251" diameter vessels with similar low density fuel configurations and characteristics, the 32 EFPY fluence values used in this evaluation was determined to be the maximum of the fluence values from each of the Dresden and Quad Cities vessels. The currently licensed, 32 EFPY, fluence values for each vessel [1, 18 & 19] are as follows:

Dresden 2:	3.6×10^{17} n/cm^2 [20]
Dresden 3:	5.1×10^{17} n/cm^2 [21]
Quad Cities 1:	3.5×10^{17} n/cm^2 [22]
Quad Cities 2:	4.9×10^{17} n/cm^2 [23]

Therefore a fluence of 5.1×10^{17} n/cm^2 was used for the Dresden Unit 3 beltline embrittlement calculation. This is the same fluence used in the 1997 pressure-temperature curves report for Dresden and Quad Cities [1], that was reviewed and accepted by the NRC in 1997 [18].

4.2.2 Limiting Beltline Material

The limiting beltline material signifies the material that is estimated to receive the greatest embrittlement due to irradiation effects combined with initial RT_{NDT}. Using initial RT_{NDT}, chemistry, and fluence as inputs, Rev 2 was applied to compute ART. Table 4-3 lists values of beltline ART for 22 EFPY and Table 4-4 lists the values for 32 EFPY.

BELTLINE ART VALUES FOR DRESDEN 3
FOR 22 EFPY

Plate
Thickness = 6.13 inches

Weld
Thickness = 6.13 inches

Plate

32 EFPY Peak I.D. fluence	=	5.10E+17 n/cm^2
32 EFPY Peak 1/4 T fluence	=	3.53E+17 n/cm^2
22 EFPY Peak I.D. fluence	=	3.51E+17 n/cm^2
22 EFPY Peak 1/4 T fluence	=	2.43E+17 n/cm^2

Weld

32 EFPY Peak I.D. fluence	=	5.10E+17 n/cm^2
32 EFPY Peak 1/4 T fluence	=	3.53E+17 n/cm^2
22 EFPY Peak I.D. fluence	=	3.51E+17 n/cm^2
22 EFPY Peak 1/4 T fluence	=	2.43E+17 n/cm^2

COMPONENT	WELD TYPE	# OF VERTICAL WELD SEAMS	HEAT OR HEAT/LOT	%Cu	%Ni	CF	INITIAL RTndt °F	22 EFPY Δ RTndt °F	σ_I °F	σ_Δ °F	MARGIN °F	22 EFPY SHIFT °F	22 EFPY ART °F
PLATES:													
Lower													
6-111-2			C1256-2	0.11	0.5	73	-10.0	14.1	0.0	7.1	14.1	28.3	18.3
6-111-6			B5159-2	0.24	0.47	153	0.0	29.6	0.0	14.8	29.6	59.3	59.3
6-111-7			C1182-2	0.22	0.5	148	10.0	28.7	0.0	14.3	28.7	57.3	67.3
Lower-Intmed													
6-111-3			A0237-1	0.23	0.49	151	10.0	29.2	0.0	14.6	29.2	58.5	68.5
6-111-10			B5118-1	0.22	0.49	146	10.0	28.3	0.0	14.1	28.3	56.5	66.5
6-111-11			C1290-2	0.15	0.49	104	10.0	20.1	0.0	10.1	20.1	40.3	50.3
VERTICAL WELDS:													
Lower-Intmed	ES *	3		0.24	0.37	141	23.1	27.3	13.0	13.7	37.7	65.0	88.1
Lower	ES *	3		0.24	0.37	141	23.1	27.3	13.0	13.7	37.7	65.0	88.1
GIRTH WELD:													
Lower to Lower-Intmed	SAW		299L44/8650**	0.34	0.68	221	-5.0	42.8	20.0	21.4	58.6	101.4	96.4

* Chemistry values are based on data from BAW-2258, dated January 1996, but adjusted. Values of Initial RTndt and σ_I are obtained from the same document.

** Chemistry values from BAW-2325, dated May 1998, and initial RTndt and σ_I values from BAW-1803-1, dated May 1991.

Table 4-3: Dresden Unit 3 Beltline ART Values (22 EFPY)

BELTLINE ART VALUES FOR DRESDEN 3
FOR 32 EFPY

Plate				**Plate**		
Thickness	=	6.13 inches		32 EFPY Peak I.D. fluence	=	5.10E+17 n/cm^2
				32 EFPY Peak 1/4 T fluence	=	3.53E+17 n/cm^2
Weld				**Weld**		
Thickness	=	6.13 inches		32 EFPY Peak I.D. fluence	=	5.10E+17 n/cm^2
				32 EFPY Peak 1/4 T fluence	=	3.53E+17 n/cm^2

COMPONENT	WELD TYPE	# OF VERTICAL WELD SEAMS	HEAT OR HEAT/LOT	%Cu	%Ni	CF	INITIAL RTndt °F	32 EFPY Δ RTndt °F	σ_I °F	σ_Δ °F	MARGIN °F	32 EFPY SHIFT °F	32 EFPY ART °F
PLATES:													
Lower													
6-111-2			C1256-2	0.11	0.5	73	-10.0	17.6	0.0	8.8	17.6	35.2	25.2
6-111-6			B5159-2	0.24	0.47	153	0.0	36.9	0.0	17.0	34.0	70.9	70.9
6-111-7			C1182-2	0.22	0.5	148	10.0	35.7	0.0	17.0	34.0	69.7	79.7
Lower-Intmed													
6-111-3			A0237-1	0.23	0.49	151	10.0	36.4	0.0	17.0	34.0	70.4	80.4
6-111-10			B5118-1	0.22	0.49	146	10.0	35.2	0.0	17.0	34.0	69.2	79.2
6-111-11			C1290-2	0.15	0.49	104	10.0	25.1	0.0	12.5	25.1	50.2	60.2
VERTICAL WELDS:													
Lower-Intmed	ES *	3		0.24	0.37	141	23.1	34.0	13.0	17.0	42.8	76.8	99.9
Lower	ES *	3		0.24	0.37	141	23.1	34.0	13.0	17.0	42.8	76.8	99.9
GIRTH WELD:													
Lower to Lower-Intmed	SAW		299L44/8650**	0.34	0.68	221	-5.0	53.3	20.0	26.7	66.7	120.0	115.0

* Chemistry values are based on data from BAW-2258, dated January 1996, but adjusted. Values of Initial RTndt and σ_I are obtained from the same document.

** Chemistry values from BAW-2325, dated May 1998, and initial RTndt and σ_I values from BAW-1803-1, dated May 1991.

Table 4-4: Dresden Unit 3 Beltline ART Values (32 EFPY)

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 4.3.2.3

There are four vessel regions that affect the operating limits: the closure flange region, the core beltline region, and the two regions in the remainder of the vessel (i.e., the upper vessel and lower vessel non-beltline regions). The closure flange region limits are controlling at lower pressures primarily because of 10CFR50 Appendix G [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/3 Discontinuity Components FOR USE WITH FW CURVES A & B

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

Table 4-7: Applicable BWR/3 Discontinuity Components for Use with CRD Curves A&B

Discontinuity Identification
CRD and Bottom Head
Top Head Nozzle
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 Dresden Unit 3 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 Dresden Unit 3 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 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]:

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

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

The total K_I is therefore:

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

This equation includes a safety factor of 1.5 on primary stress. The method to solve for $(T - RT_{NDT})$ for a specific K_I is based on the K_{Ic} 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 44°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:

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

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

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

The Dresden Unit 3 specific bottom head dimensions are R = 125.7 inches and t = 8 inches minimum [26], resulting in:

Dresden Unit 3 specific:

$R / (t)^{1/2} = 125.7 / (8.0)^{1/2} = 44 \text{ inch}^{1/2}$ (4-3)

Since the generic value of $R/(t)^{1/2}$ is larger, the generic P-T curve is conservative when applied to the Dresden Unit 3 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 44°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 being 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 $1.5\ \sigma\ (\pi a)^{1/2} \cdot F(a/r_n)$:

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

The method to solve for $(T - RT_{NDT})$ for a specific K_I is based on the K_{Ic} equation of Paragraph A-4200 in ASME Appendix A [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 Dresden Unit 3 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 Dresden Unit 3 specific vessel shell and nozzle dimensions applicable to the feedwater nozzle location and K_I are shown below:

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

Pressure stress: $\sigma = PR / t$ = 1563 psig · 125.7 inches / (6.125 inches) = 32,073 psi. The Dead weight and thermal RFE stress of 2.967 ksi is conservatively added yielding σ = 35.04 ksi. The factor F (a/r_n) from Figure A5-1 of WRC-175 is 1.39 where :

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

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

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

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

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

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}:

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

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.

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

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.)

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

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 component at Dresden Unit 3 is 40°F as shown in Table 4-2. The generic curve is applied to the Dresden Unit 3 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.

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 $(T\text{-}RT_{NDT})$, 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 = 23.1 + 76.8 = 100 °F * (Based on ART values in Section 4.2)*
Vessel Height	H = 823 inches
Bottom of Active Fuel Height	B = 216.3 inches
Vessel Radius (to inside of clad)	R = 125.7 inches
Minimum Vessel Thickness (without clad)	t = 6.125 inches
Limiting Beltline Material Yield Strength	σ_y = 42.5 ksi

* The most limiting ART is that of the girth weld. However, because the calculated value of K_{Im} is reduced for a girth weld due to implementing ASME Code Case N-588 (circumferentially oriented defect for circumferential welds), the vertical electroslag weld (the next limiting material) bounds P-T curve beltline region requirements.

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

$$P = 1105 \text{ psi} + (H - B)\, 0.0361 \text{ psi/inch} = P \text{ psig} \quad (4\text{-}10)$$
$$= 1105 + (823 - 216.3)\, 0.0361 = 1127 \text{ psig}$$

Pressure stress:

$$\sigma = PR/t \quad (4\text{-}11)$$
$$= 1.127 \cdot 125.7 / 6.125 = 23.1 \text{ ksi}$$

Since the most limiting ART is for a girth weld, the stress intensity calculations for both the axial and girth welds are shown below. The axial weld calculation has the most limiting temperature for the P-T curve in the beltline region. Even though the most limiting ART is for a girth weld, the 15 °F difference in temperature is not as significant as the difference between the stress intensity factors for the axial and girth welds.

Axial Weld Calculation:

The value of M_m for an inside axial postulated surface flaw from Paragraph 2214-1 [5] was based on a thickness of 6.125 inches (the minimum thickness without cladding); hence, $t^{1/2} = 2.47$. The resulting value obtained was:

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

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

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

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} = 52.9, and K_{It} = 2.28 for a 20°F/hr coolant heatup/cooldown rate with a vessel thickness, t, that includes cladding:

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

$$= \ln[(1.5 \cdot 52.9 + 2.28 - 33.2) / 20.734] / 0.02$$

$$= 42°F$$

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

T = 42 + 100 = 142°F for P = 1105 psig

Girth Weld Calculation:

The value of M_m for an inside circumferencial postulated surface flaw from Paragraph 2214-1 [5] was based on a thickness of 6.125 inches (the minimum thickness without cladding); hence, $t^{1/2} = 2.47$. The resulting value obtained was:

$$M_m = 0.89 \text{ for } \sqrt{t} \leq 2$$

$$M_m = 0.443 \sqrt{t} \text{ for } 2 \leq \sqrt{t} \leq 3.464 = 1.10$$

$$M_m = 1.53 \text{ for } \sqrt{t} > 3.464$$

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], $K_{Im} = 25.4$, and $K_{It} = 2.28$ for a 20°F/hr coolant heatup/cooldown rate with a vessel thickness, t, that includes cladding:

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

$$= \ln[(1.5 \cdot 25.4 + 2.28 - 33.2) / 20.734] / 0.02$$

$$= -53°F$$

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

T = -53 + 115 = 62°F for P = 1105 psig

As stated above, based on the applied pressure and temperature stress intensity factors, the axial weld flaw bounds the P-T curve in the beltline region.

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]:

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

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

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

The thermal stresses in the vessel wall are caused by a radial thermal gradient that is created by changes in the adjacent reactor coolant temperature in heatup or cooldown conditions. The stress intensity factor is computed by multiplying the coefficient M_t from Figure G-2214-2 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:

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

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 = 0.526 ft (6.313 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:

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

$$= 100 \cdot (0.526)^2 / (2 \cdot 0.354) = 39°F$$

The analyzed case for thermal stress is a 1/4T flaw depth with wall thickness of C. The corresponding value of M_t (=0.2914) can be interpolated from ASME Appendix G, Figure G-2214-2 [9]. Thus the thermal stress intensity factor, $K_{It} = M_t \cdot \Delta T = 11.39$, 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 $(T - RT_{NDT})$:

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

$$= \ln[(2 \cdot 52.9 + 11.39 - 33.2) / 20.734] / 0.02$$

$$= 70\ °F$$

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

T = 70 + 100 = 170 °F for P = 1105 psig

As previously concluded, based on the applied pressure and temperature stress intensity factors, the axial weld flaw bounds the P-T curve in the beltline region.

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 Dresden Unit 3 at low pressures.

The original ASME Code requirement for bolt-up was at qualification temperature (T_{30L}) plus 60°F. The ASME Code used for the currently licensed P-T curves is the 1989 ASME Code [19]. 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 Dresden Unit 3 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 4-2, the limiting initial RT_{NDT} for the closure flange region was the electroslag weld in the upper shell at 23.1°F, and the LST of the closure studs was 70°F; therefore, the bolt-up temperature value used was 83°F. This conservatism is appropriate because bolt-up is one of the more limiting operating conditions (high stress and low temperature) for brittle fracture.

10CFR50 Appendix G, paragraph IV.A.2 [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 Dresden Unit 3 Technical Specification, is calculated for a water temperature of 68°F. Shutdown margin is the quantity of reactivity needed for a reactor core to reach criticality with the strongest-worth control rod fully withdrawn and all other control rods fully inserted. Although it may be possible to safely allow the water temperature to fall below this 68°F limit, further extensive calculations would be required to justify a lower temperature. The 83°F limit 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 83.1°F, based on an RT_{NDT} of 23.1°F. In addition, above 312 psig the Curve C temperature must be at least the greater of RT_{NDT}

of the closure region + 160°F or the temperature required for the hydrostatic pressure test (Curve A at 1105 psig). The requirement of closure region RT_{NDT} + 160°F does cause a temperature shift in Curve C at 312 psig.

5.0 CONCLUSIONS AND RECOMMENDATIONS

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

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

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

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

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

The following P-T curves were generated for Dresden Unit 3.

- 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 22 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 22 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	Tables B-1 & 3
	Upper Vessel Limits (FW Nozzle)	Figure 5-2	Tables B-1 & 3
	Beltline Limits for 22 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	Tables B-1 & 3
	Upper Vessel Limits (FW Nozzle)	Figure 5-6	Tables B-1 & 3
	Beltline Limits for 22 EFPY	Figure 5-7	Table B-3
	Beltline Limits for 32 EFPY	Figure 5-8	Table B-1
Curve C			
	Composite Curve for 22 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.

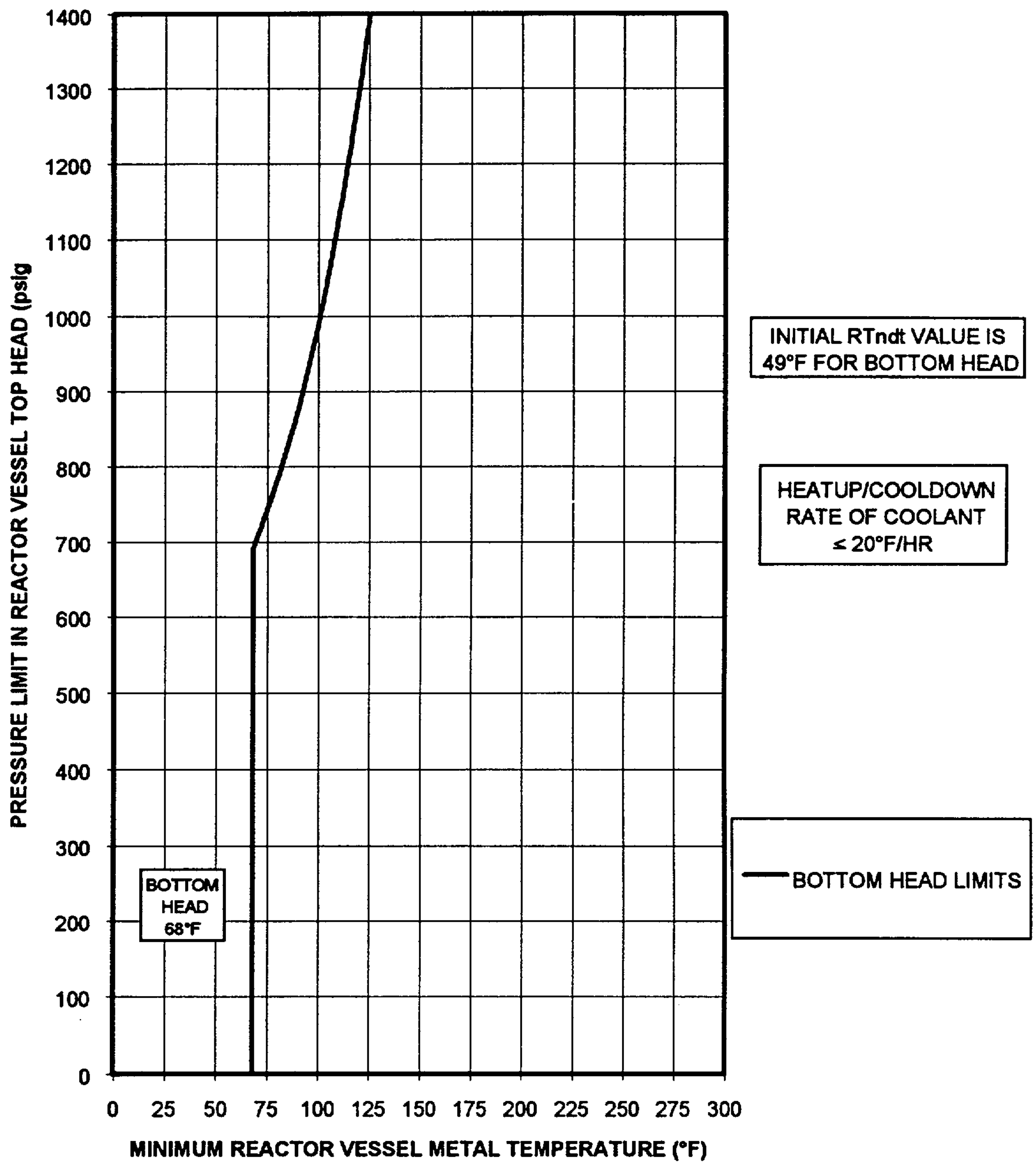

Figure 5-1: Bottom Head P-T Curve for Pressure Test [Curve A]

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

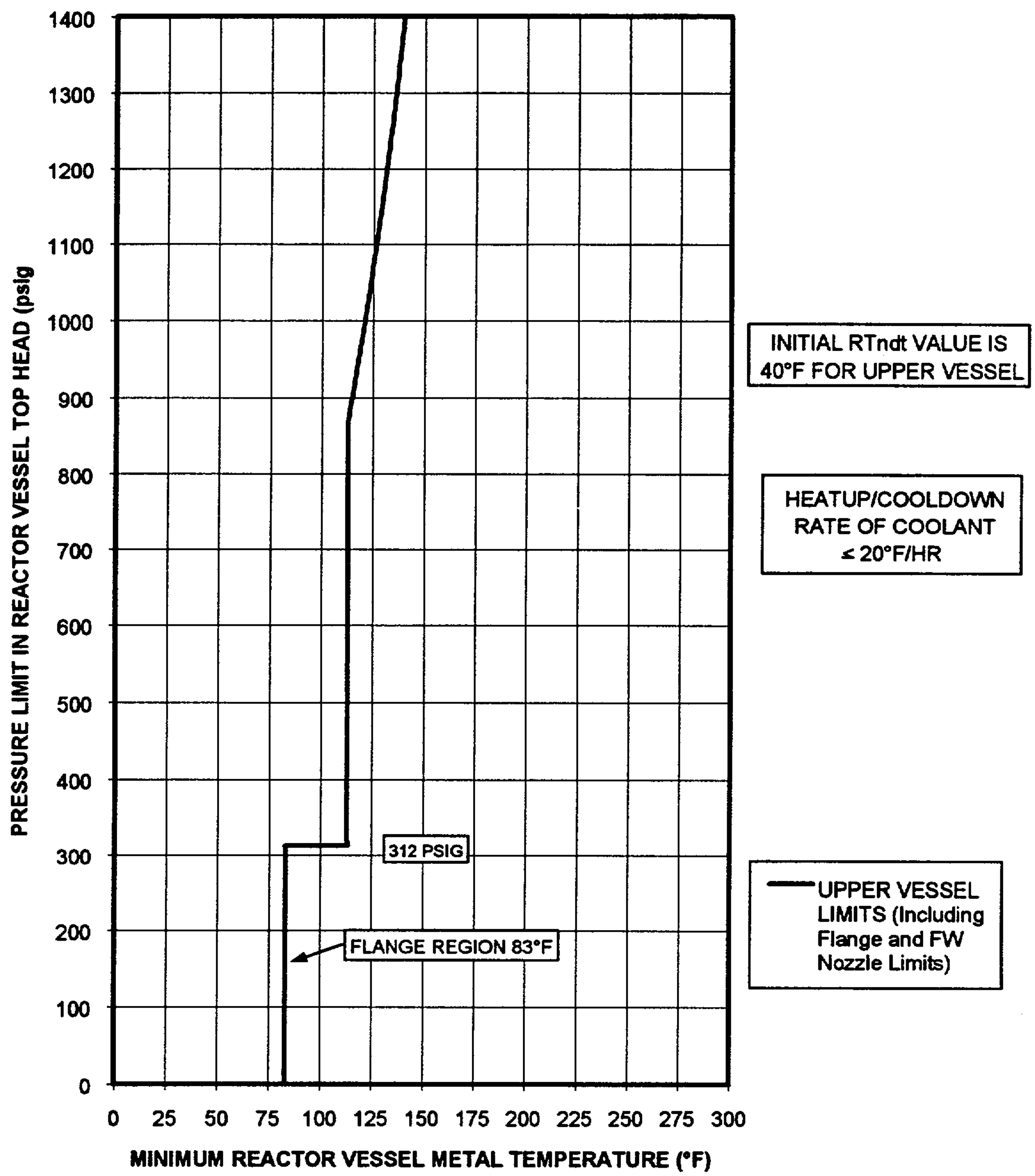

Figure 5-2: Upper Vessel P-T Curve for Pressure Test [Curve A]

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

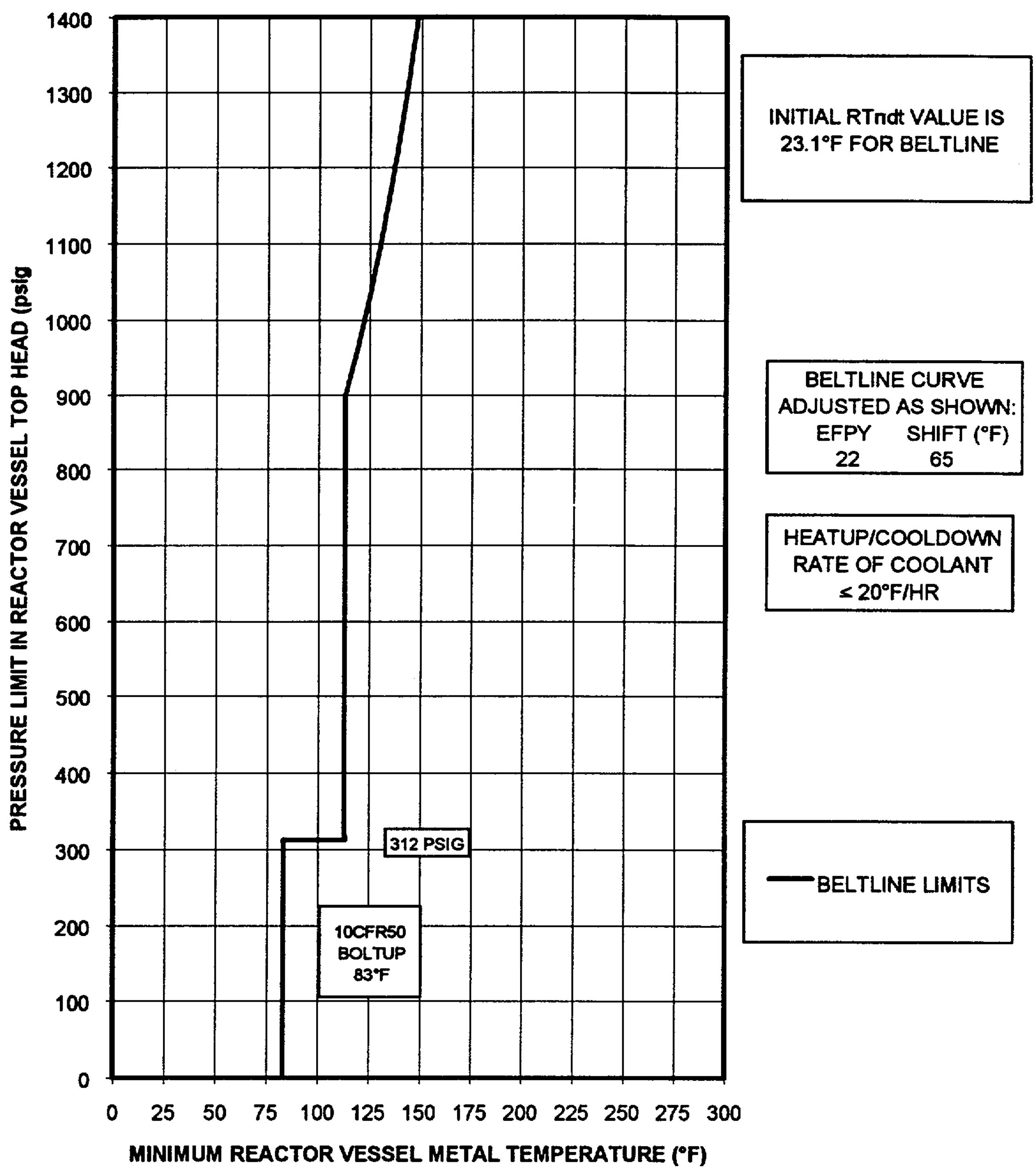

Figure 5-3: Beltline P-T Curve for Pressure Test [Curve A] up to 22 EFPY
[20°F/hr or less coolant heatup/cooldown]

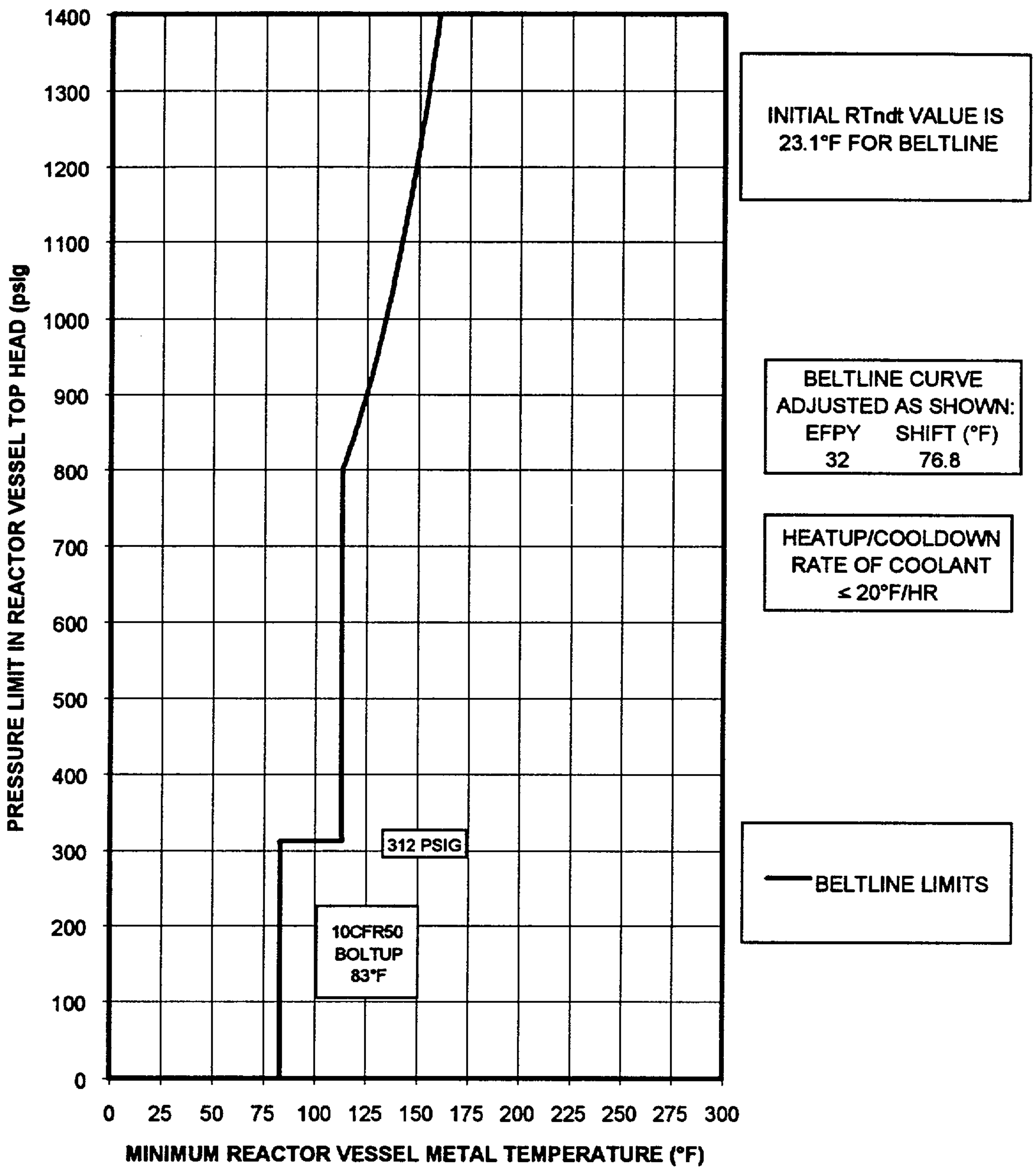

Figure 5-4: Beltline P-T Curve for Pressure Test [Curve A] up to 32 EFPY
[20°F/hr or less coolant heatup/cooldown]

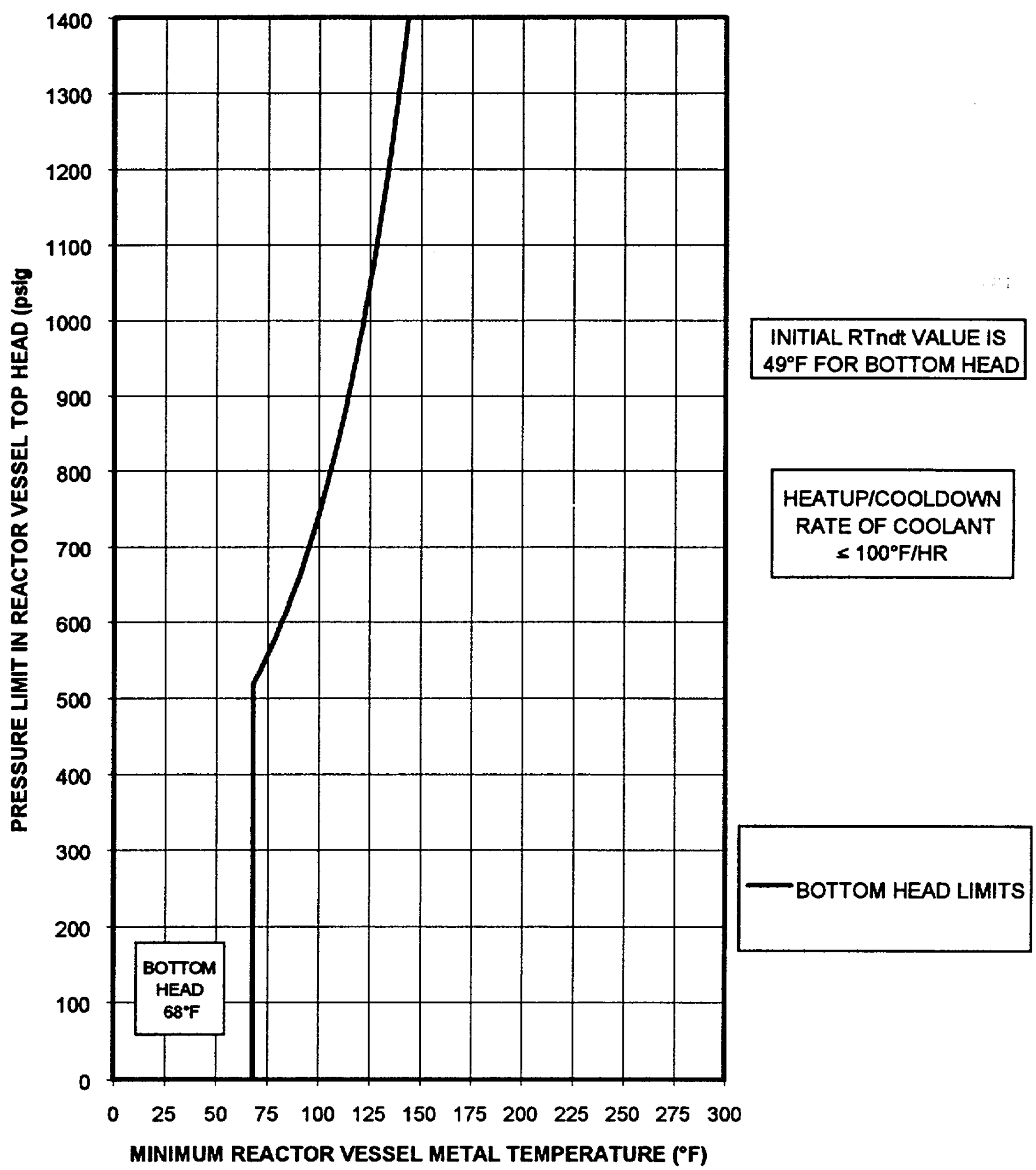

Figure 5-5: Bottom Head P-T Curve for Core Not Critical [Curve B]

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

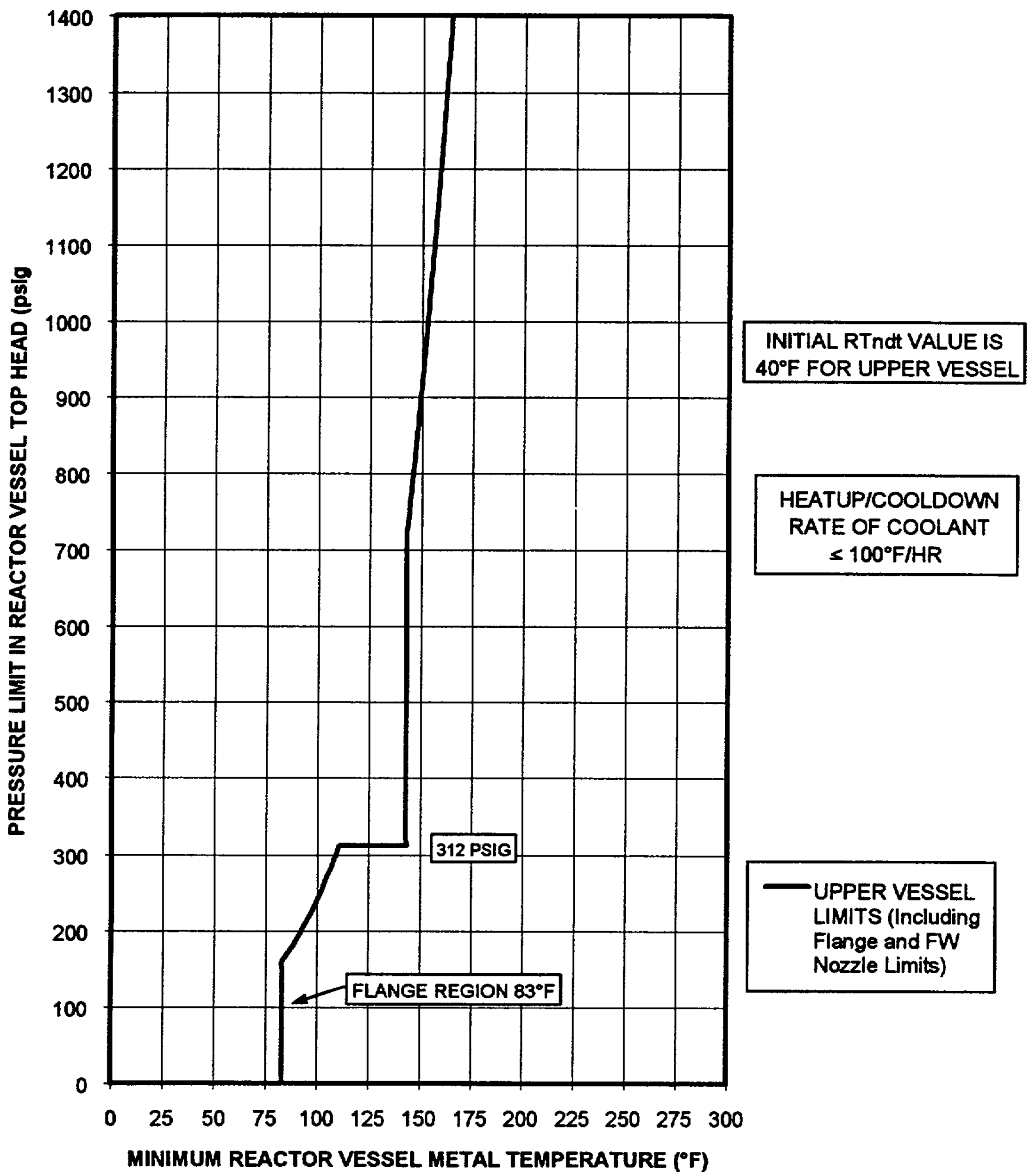

Figure 5-6: Upper Vessel P-T Curve for Core Not Critical [Curve B]

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

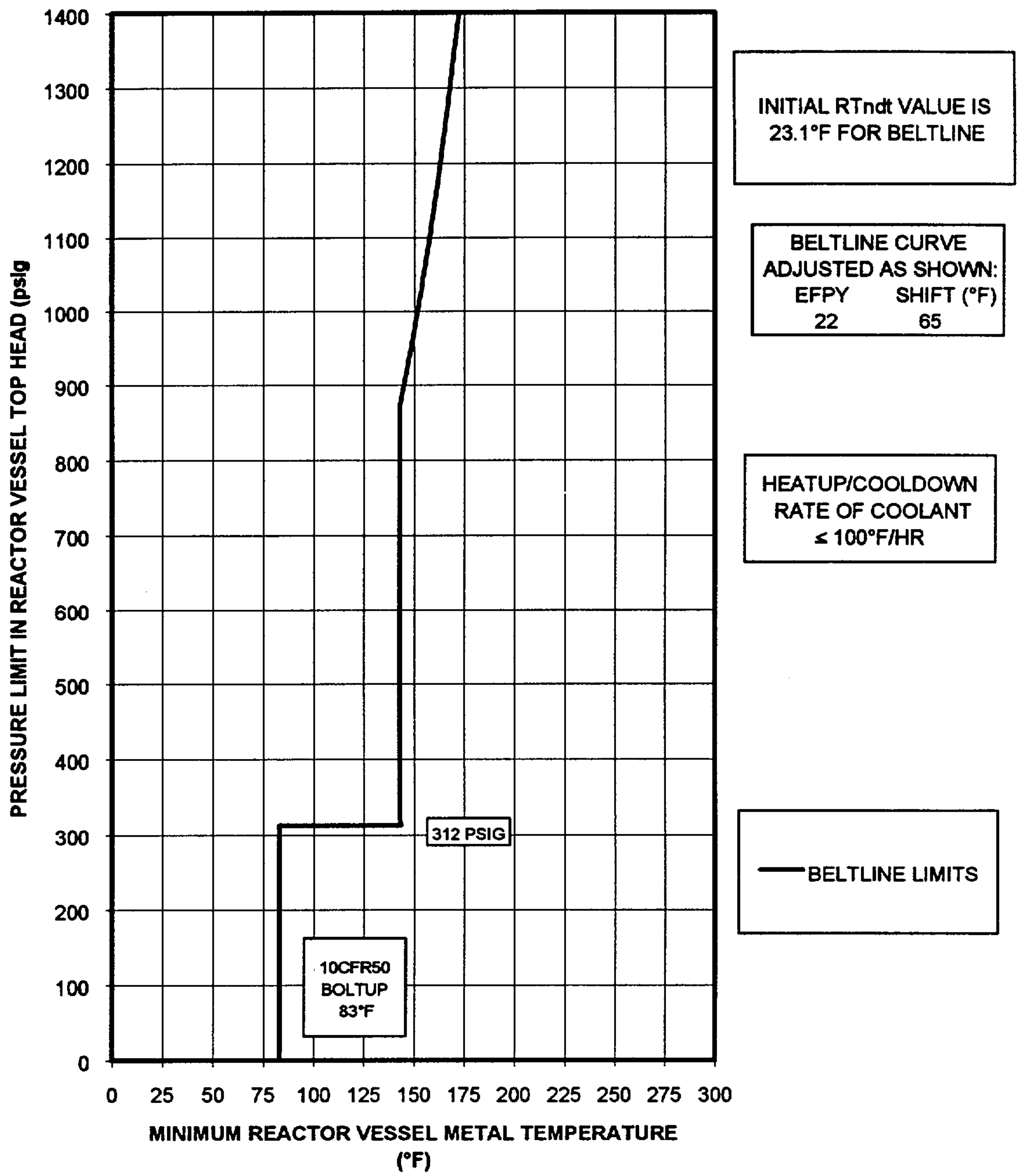

Figure 5-7: Beltline P-T Curve for Core Not Critical [Curve B] up to 22 EFPY [100°F/hr or less coolant heatup/cooldown]

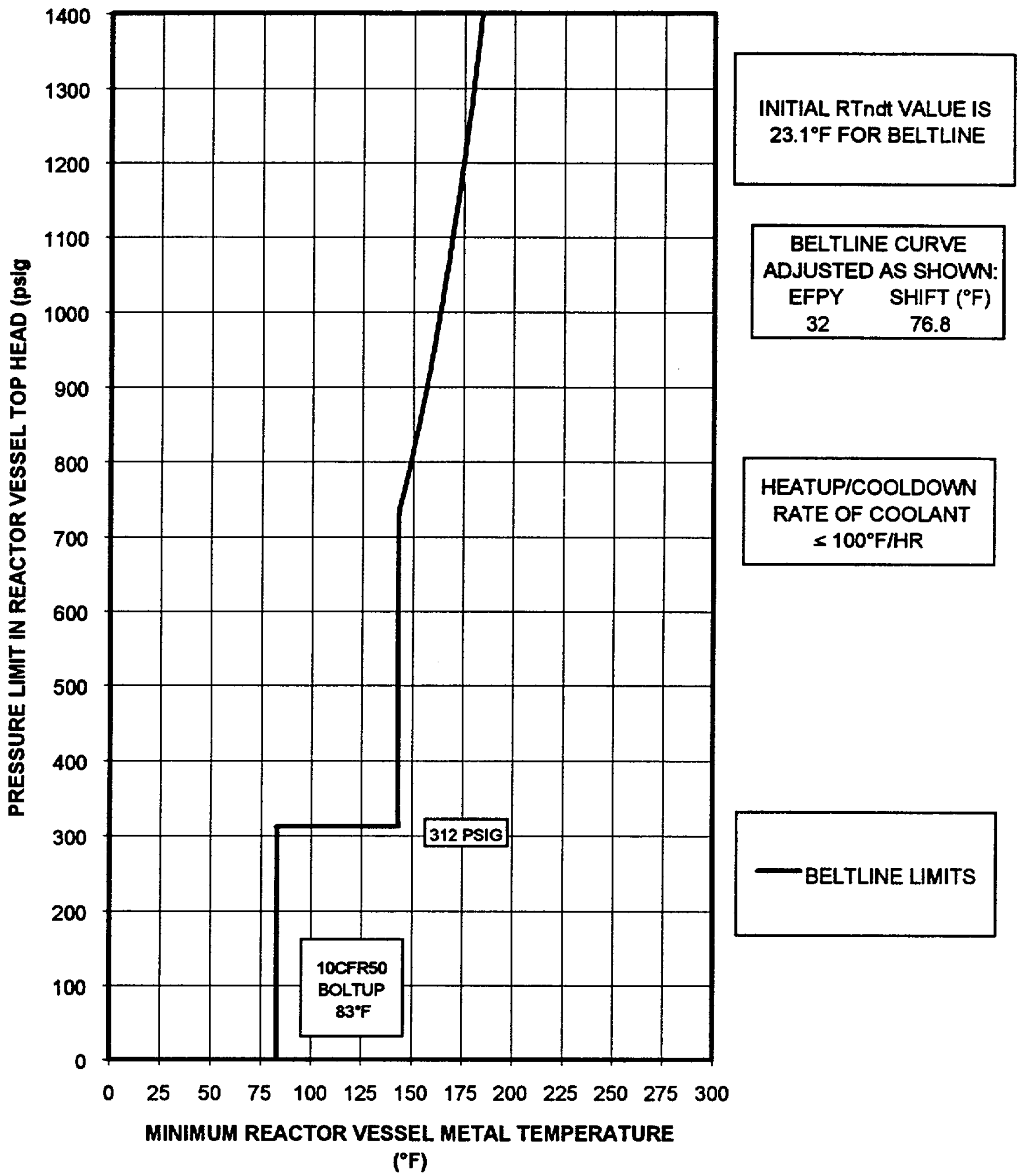

Figure 5-8: Beltline P-T Curves for Core Not Critical [Curve B] up to 32 EFPY [100°F/hr or less coolant heatup/cooldown]

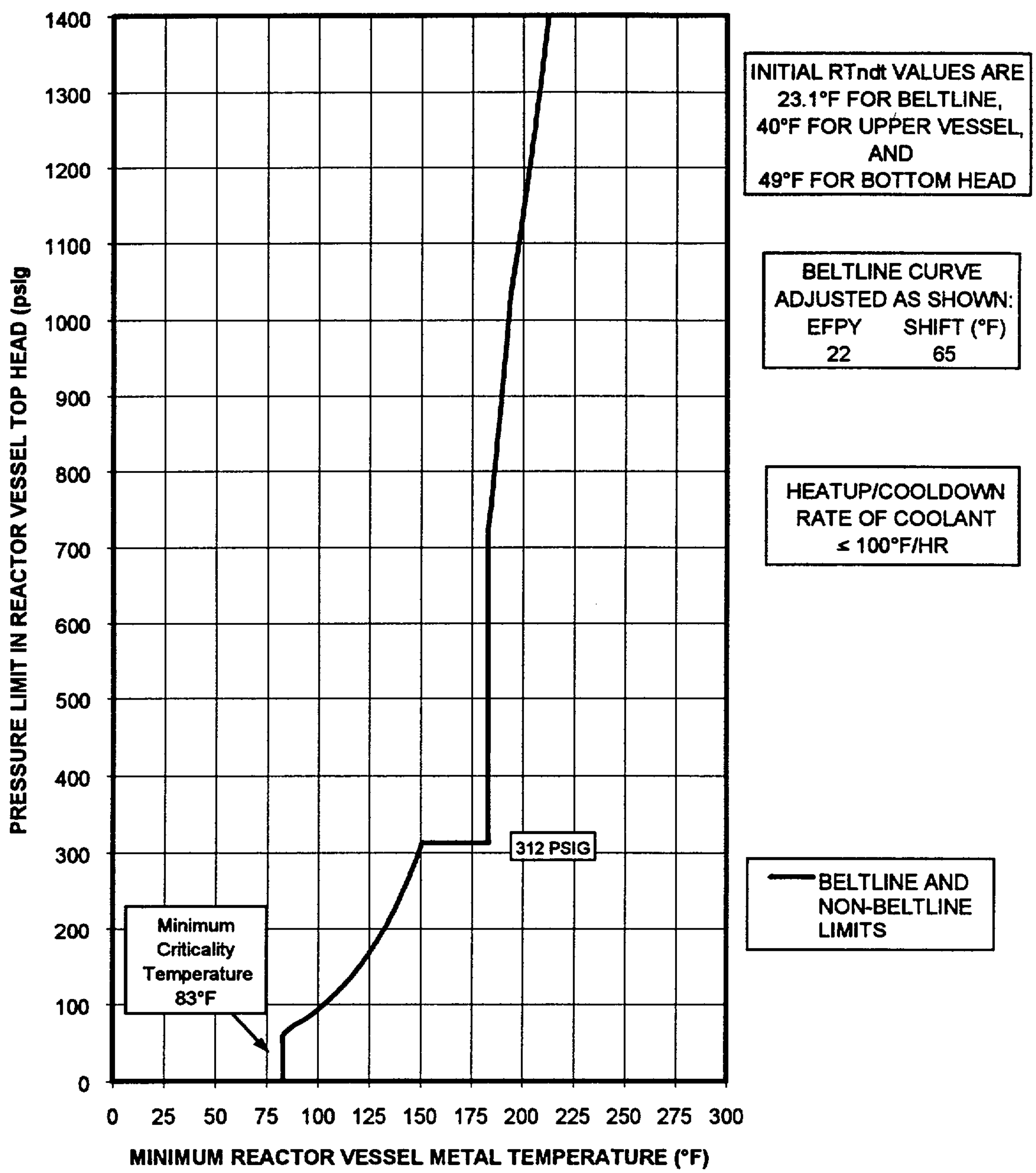

Figure 5-9: Core Critical P-T Curves [Curve C] up to 22 EFPY
[100°F/hr or less coolant heatup/cooldown]

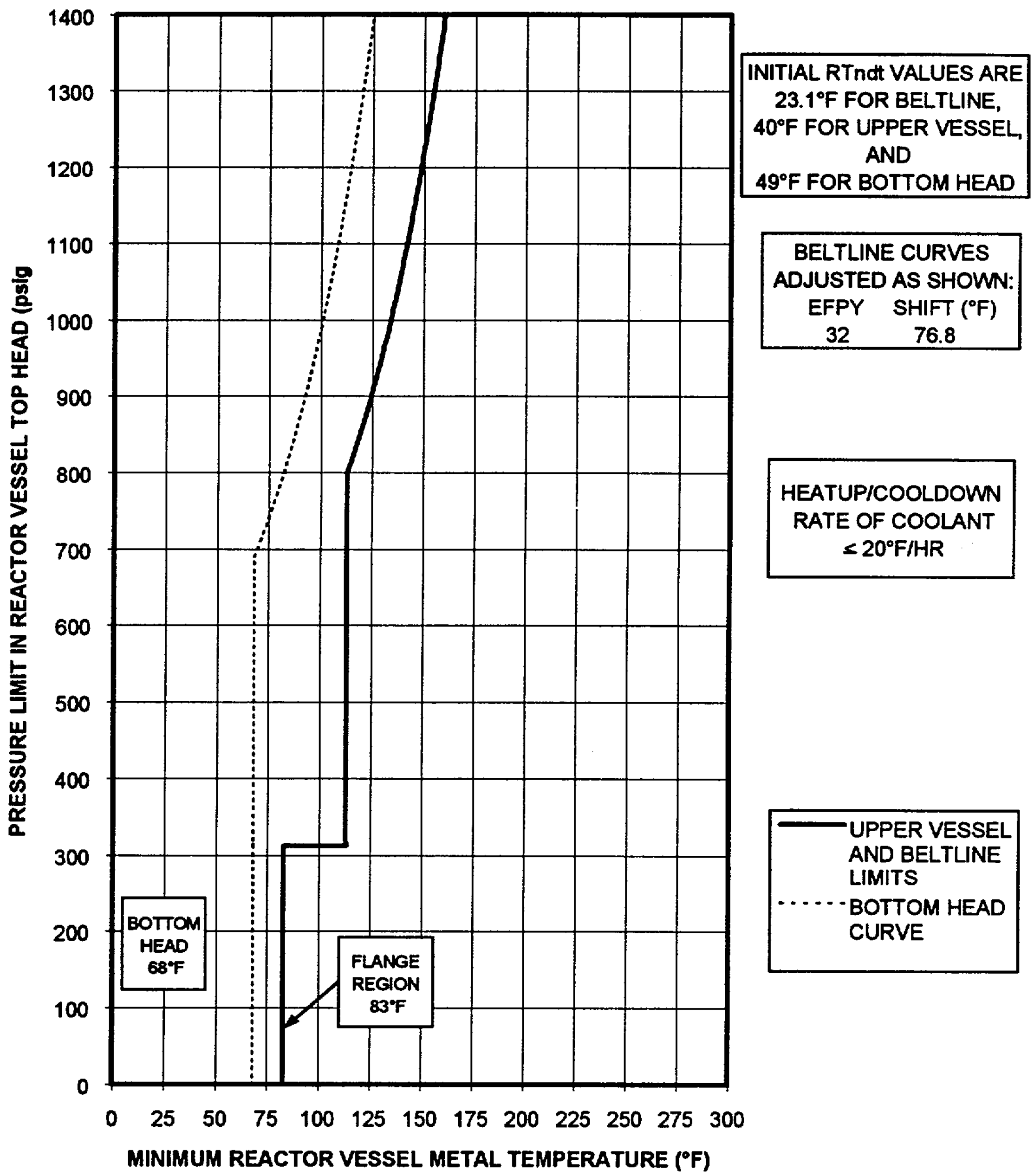

Figure 5-10: Pressure Test P-T Curves [Curve A] up to 32 EFPY

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

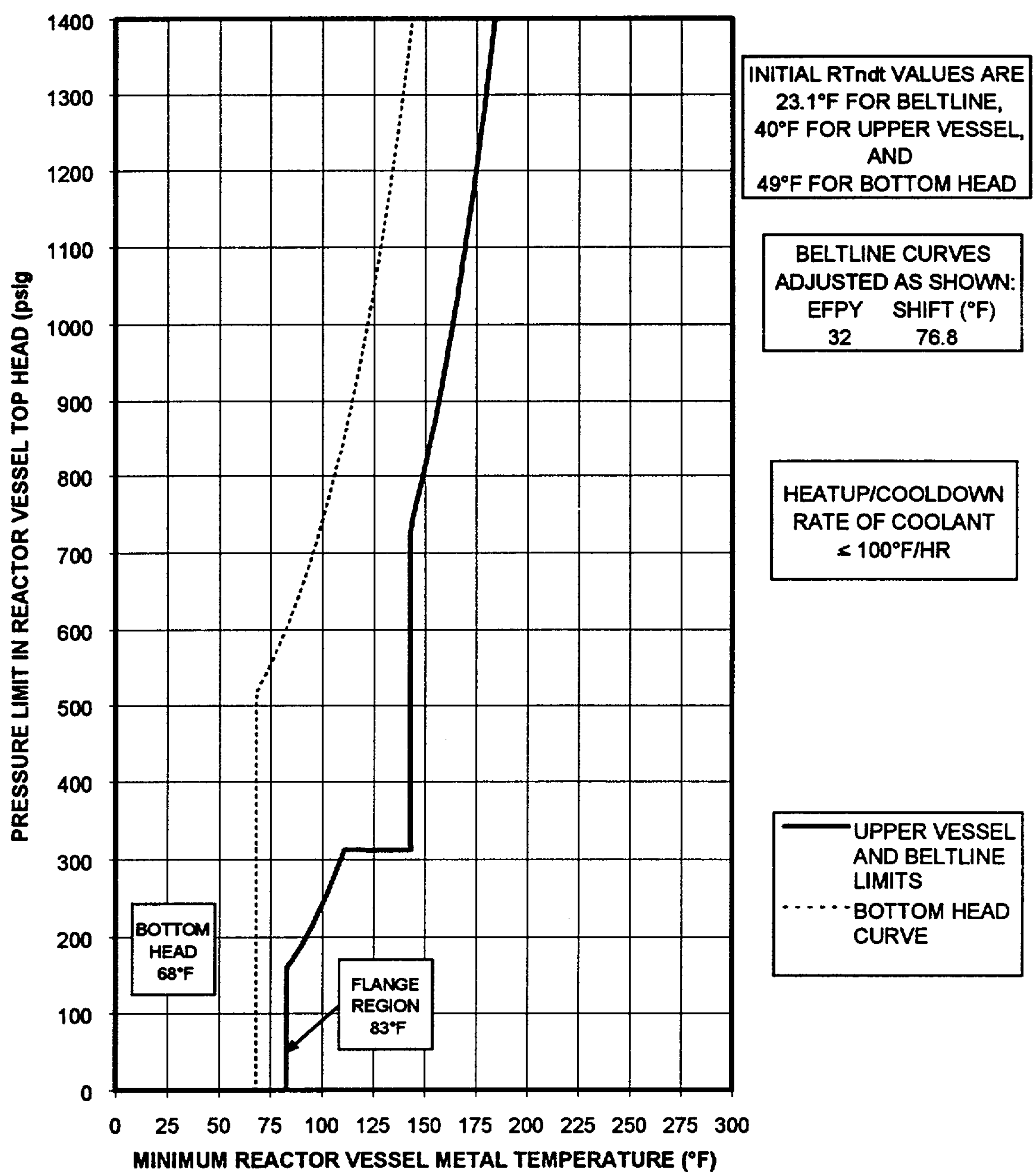

Figure 5-11: Core Not Critical P-T Curves [Curve B] up to 32 EFPY
[100°F/hr or less coolant heatup/cooldown

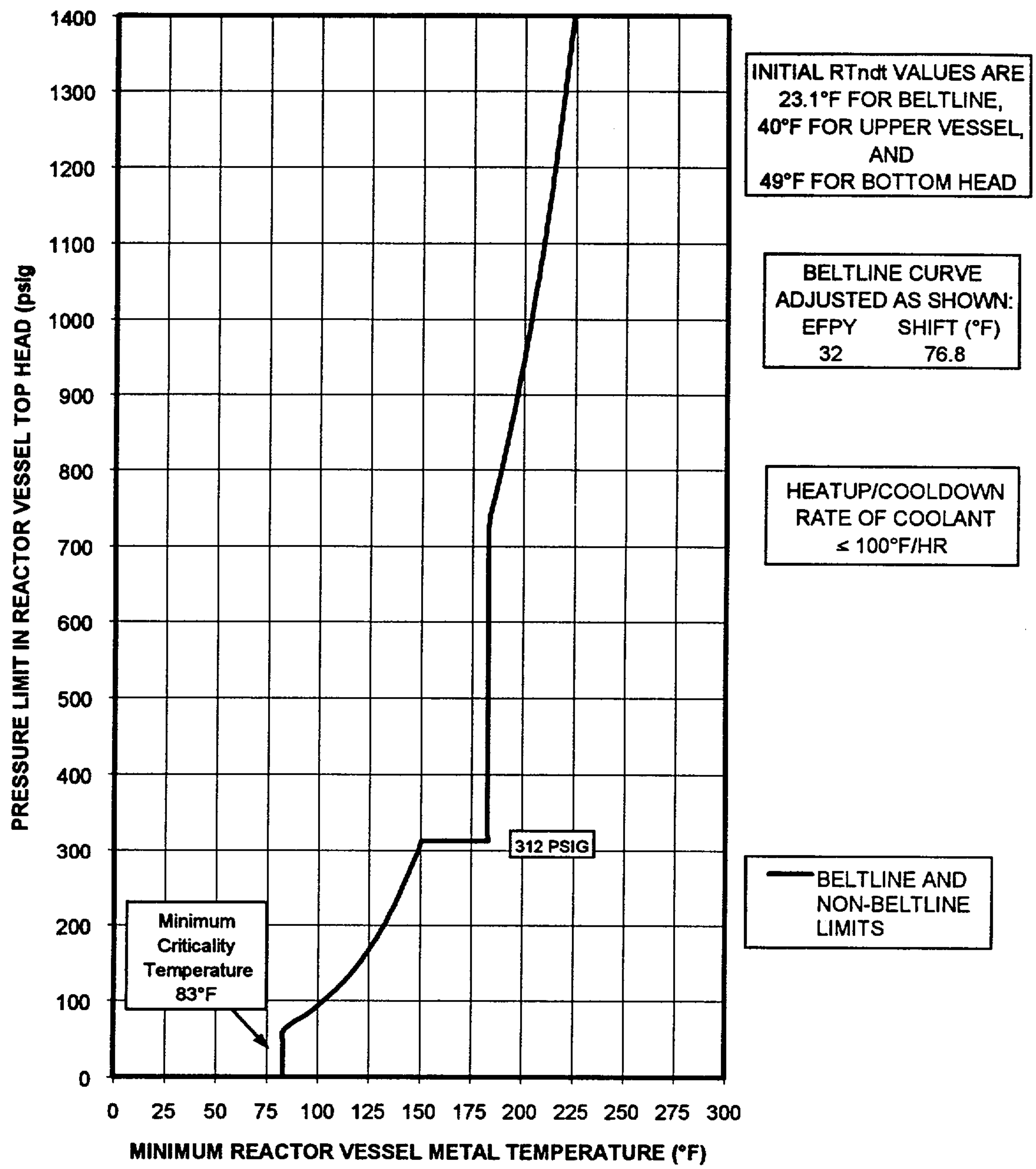

Figure 5-12: Core Critical P-T Curves [Curve C] up to 32 EFPY

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

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23. "Quad Cities Nuclear Power Station Unit 2 Reactor Vessel Irradiation Surveillance Program Analysis of Capsule No. 18," SwRI No. 06-7484-002, March 1984.

26. "Final Design Report for General Electric - NED Dresden III", Babcock & Wilcox Co., Mt. Vernon, Indiana, August 1970, (GE VPF 2252-181-1)

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.

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. Also Inconel discontinuities require no fracture toughness evaluations. The RPV penetrations of the nozzles listed in Tables 1 and 2 bound the RPV penetration for the nozzles listed below, therefore, no further fracture toughness evaluation is performed for these nozzles. Nozzles and appurtenances ≤ 2.5" or made from Inconel are not included in Tables1 and 2 and are listed below. The Top Head Lifting Lugs are also not included in Tables 1 and 2 because the loads only occur on these components when the reactor is shutdown during an outage. Components not requiring a fracture toughness evaluation are listed below:

Nozzle or Appurtenance Identification	Nozzle or Appurtenance	Material	Reference	RT_{NDT} (°F)	LST (°F)
MK 12	2" Instrumentation ≤ 2.5" Penetration in RPV Shell	Alloy 600 Low Alloy	1, 2 & 7	N/A 10	N/A 70
MK 17, 43	Core Differential Pressure & Liquid Poison – Penetration ≤ 2.5" – Bottom Head	Low Alloy	1, 2 & 7	44	104
MK 22	Drain- Penetration ≤ 2.5" – Bottom Head Penetrating in Dollar Plate	SA105-GR 2 Low Alloy	1, 2 & 7	N/A 40	N/A 100
MK 51 - 54	Shroud Support Attachment to RPV Wall Attachment to Bottom Head	Alloy 600 Low Alloy	1, 2 & 7	N/A 44	N/A 104
MK 74, 75 & 77-84	Insulation Brackets – Shells and Bottom Head Attachment to RPV Shells Attachment to Dollar Plate and RPV Shells	Carbon Steel Low Alloy Low Alloy	1, 2 & 7	N/A 10 44	N/A 70 100
MK 101-127	Control Rod Drive Stub Tubes – Bottom Head Penetration in Dollar Plate	Alloy 600 Low Alloy	2 & 7	N/A 44	N/A 100
Mk 139, 141 & 142	High and Low Pressure Seal Leak Detection- Penetration ~ 1" * - Flange	Low Alloy	1 & 7	N/A 10	N/A 70

Mk 210	Top Head Lifting Lugs (only loads at outage) Attachment to Torus	Low Alloy	1, 2 & 7	10	70

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

APPENDIX A REFERENCES:

1. RPV Outline or As-Built
   - Babcock & Wilcox Co. Drawing # 26903F, Revision 2, "General Outline," Babcock & Wilcox Co, Mt. Vernon, Indiana, (GE-NE VPF# 2252-139-4) - Dresden Unit 3
   - Babcock & Wilcox Co. Drawing # 26904F, Revision 3, "Outline Sections," Babcock & Wilcox Co, Mt. Vernon, Indiana, (GE-NE VPF# 2252-140-3) - Dresden Unit 3

2. Certified Stress Report
   - "Certified Design Document for Dresden Unit 3" B&W contract No. 610-0111, GE Order No. 205-55579," Babcock & Wilcox Co, Mt. Vernon, Indiana, August, 1970, (GE-NE VPF# 2252-181-1) - Dresden Unit 3

3. Babcock & Wilcox Co. Drawing # 151810E, Revision 2, "Support Skirt Assy & Details," Babcock & Wilcox Co, Mt. Vernon, Indiana, (GE-NE VPF# 2252-133-4) - Dresden Unit 3

4. GE Drawing # 104R861, Revision 5, "Reactor Assembly, Nuclear Boiler," GE-NED, San Jose, CA.) - Dresden Unit 2 & 3

5. Fax Transmittal of NDIT No. SEC-DB-99-163 from Bob Geier to Ray Carey, "Pressure – Temperature (P-T) Curve Limit Re-evaluation for Dresden Units 2 and 3," Commonwealth Edison Company – Dresden Nuclear Station, Morris, IL, 11/2/99. – Dresden Unit 2

6. Babcock & Wilcox Co. Drawing &151808E, Revision 1, "Shroud Support," Babcock & Wilcox Co, Mt. Vernon, Indiana, (GE-NE VPF# 2252-131-03) - Dresden Unit 3.

7. QA Records & RPV CMTR's
   Dresden 3 - (QA Records & RPV CMTR's Dresden Unit 3 GE PO# 205-55579, Mfg by B&W)"General Electric Company Atomic Power Equipment Department (APED) Quality Control - Procured Equipment, RPV QC" Project: Dresden 3, Purchase Order: 205-55579, Vendor: Babcock & Wilcox, Location: Mt. Vernon, Indiana.

APPENDIX B

PRESSURE TEMPERATURE CURVE DATA TABULATION

TABLE B-1. Dresden Unit 3 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	83.1	83.1	68.0	83.1	83.1
10	68.0	83.1	83.1	68.0	83.1	83.1
20	68.0	83.1	83.1	68.0	83.1	83.1
30	68.0	83.1	83.1	68.0	83.1	83.1
40	68.0	83.1	83.1	68.0	83.1	83.1
50	68.0	83.1	83.1	68.0	83.1	83.1
60	68.0	83.1	83.1	68.0	83.1	83.1
70	68.0	83.1	83.1	68.0	83.1	83.1
80	68.0	83.1	83.1	68.0	83.1	83.1
90	68.0	83.1	83.1	68.0	83.1	83.1
100	68.0	83.1	83.1	68.0	83.1	83.1
110	68.0	83.1	83.1	68.0	83.1	83.1
120	68.0	83.1	83.1	68.0	83.1	83.1
130	68.0	83.1	83.1	68.0	83.1	83.1
140	68.0	83.1	83.1	68.0	83.1	83.1
150	68.0	83.1	83.1	68.0	83.1	83.1
160	68.0	83.1	83.1	68.0	83.1	83.1
170	68.0	83.1	83.1	68.0	85.5	83.1
180	68.0	83.1	83.1	68.0	87.9	83.1
190	68.0	83.1	83.1	68.0	90.2	83.1
200	68.0	83.1	83.1	68.0	92.3	83.1
210	68.0	83.1	83.1	68.0	94.3	83.1
220	68.0	83.1	83.1	68.0	96.3	83.1
230	68.0	83.1	83.1	68.0	98.1	83.1
240	68.0	83.1	83.1	68.0	99.9	83.1
250	68.0	83.1	83.1	68.0	101.6	83.1
260	68.0	83.1	83.1	68.0	103.2	83.1
270	68.0	83.1	83.1	68.0	104.8	83.1
280	68.0	83.1	83.1	68.0	106.3	83.1
290	68.0	83.1	83.1	68.0	107.8	83.1
300	68.0	83.1	83.1	68.0	109.2	83.1
310	68.0	83.1	83.1	68.0	110.5	83.1
312.5	68.0	83.1	83.1	68.0	110.9	83.1
312.5	68.0	113.1	113.1	68.0	143.1	143.1
320	68.0	113.1	113.1	68.0	143.1	143.1
330	68.0	113.1	113.1	68.0	143.1	143.1
340	68.0	113.1	113.1	68.0	143.1	143.1
350	68.0	113.1	113.1	68.0	143.1	143.1
360	68.0	113.1	113.1	68.0	143.1	143.1
370	68.0	113.1	113.1	68.0	143.1	143.1
380	68.0	113.1	113.1	68.0	143.1	143.1

TABLE B-1. Dresden Unit 3 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)
390	68.0	113.1	113.1	68.0	143.1	143.1
400	68.0	113.1	113.1	68.0	143.1	143.1
410	68.0	113.1	113.1	68.0	143.1	143.1
420	68.0	113.1	113.1	68.0	143.1	143.1
430	68.0	113.1	113.1	68.0	143.1	143.1
440	68.0	113.1	113.1	68.0	143.1	143.1
450	68.0	113.1	113.1	68.0	143.1	143.1
460	68.0	113.1	113.1	68.0	143.1	143.1
470	68.0	113.1	113.1	68.0	143.1	143.1
480	68.0	113.1	113.1	68.0	143.1	143.1
490	68.0	113.1	113.1	68.0	143.1	143.1
500	68.0	113.1	113.1	68.0	143.1	143.1
510	68.0	113.1	113.1	68.0	143.1	143.1
520	68.0	113.1	113.1	68.2	143.1	143.1
530	68.0	113.1	113.1	70.2	143.1	143.1
540	68.0	113.1	113.1	72.1	143.1	143.1
550	68.0	113.1	113.1	73.9	143.1	143.1
560	68.0	113.1	113.1	75.7	143.1	143.1
570	68.0	113.1	113.1	77.4	143.1	143.1
580	68.0	113.1	113.1	79.0	143.1	143.1
590	68.0	113.1	113.1	80.6	143.1	143.1
600	68.0	113.1	113.1	82.2	143.1	143.1
610	68.0	113.1	113.1	83.7	143.1	143.1
620	68.0	113.1	113.1	85.1	143.1	143.1
630	68.0	113.1	113.1	86.5	143.1	143.1
640	68.0	113.1	113.1	87.9	143.1	143.1
650	68.0	113.1	113.1	89.2	143.1	143.1
660	68.0	113.1	113.1	90.5	143.1	143.1
670	68.0	113.1	113.1	91.8	143.1	143.1
680	68.0	113.1	113.1	93.1	143.1	143.1
690	68.0	113.1	113.1	94.3	143.1	143.1
700	69.2	113.1	113.1	95.4	143.1	143.1
710	70.7	113.1	113.1	96.6	143.1	143.1
720	72.1	113.1	113.1	97.7	143.1	143.1
730	73.5	113.1	113.1	98.8	143.5	143.1
740	74.8	113.1	113.1	99.9	143.9	143.8
750	76.1	113.1	113.1	101.0	144.2	144.7
760	77.4	113.1	113.1	102.0	144.6	145.6
770	78.6	113.1	113.1	103.0	145.0	146.5
780	79.8	113.1	113.1	104.0	145.4	147.4
790	81.0	113.1	113.1	105.0	145.8	148.3
800	82.2	113.1	113.2	105.9	146.1	149.1
810	83.3	113.1	114.5	106.9	146.5	150.0

TABLE B-1. Dresden Unit 3 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)
820	84.4	113.1	115.8	107.8	146.9	150.8
830	85.5	113.1	117.0	108.7	147.2	151.6
840	86.5	113.1	118.2	109.6	147.6	152.4
850	87.6	113.1	119.3	110.4	147.9	153.2
860	88.6	113.1	120.5	111.3	148.3	154.0
870	89.6	113.1	121.6	112.1	148.6	154.7
880	90.5	113.6	122.7	113.0	149.0	155.5
890	91.5	114.3	123.8	113.8	149.3	156.2
900	92.4	114.9	124.8	114.6	149.7	157.0
910	93.4	115.6	125.8	115.4	150.0	157.7
920	94.3	116.2	126.8	116.1	150.4	158.4
930	95.1	116.9	127.8	116.9	150.7	159.1
940	96.0	117.5	128.8	117.7	151.0	159.8
950	96.9	118.1	129.7	118.4	151.4	160.5
960	97.7	118.7	130.6	119.1	151.7	161.1
970	98.6	119.3	131.6	119.9	152.0	161.8
980	99.4	119.9	132.5	120.6	152.4	162.4
990	100.2	120.5	133.3	121.3	152.7	163.1
1000	101.0	121.1	134.2	122.0	153.0	163.7
1010	101.7	121.7	135.0	122.6	153.3	164.4
1020	102.5	122.2	135.9	123.3	153.6	165.0
1030	103.3	122.8	136.7	124.0	154.0	165.6
1040	104.0	123.4	137.5	124.6	154.3	166.2
1050	104.7	123.9	138.3	125.3	154.6	166.8
1060	105.4	124.5	139.1	125.9	154.9	167.4
1070	106.2	125.0	139.9	126.5	155.2	168.0
1080	106.9	125.5	140.6	127.2	155.5	168.6
1090	107.6	126.1	141.4	127.8	155.8	169.1
1100	108.2	126.6	142.1	128.4	156.1	169.7
1110	108.9	127.1	142.8	129.0	156.4	170.2
1120	109.6	127.6	143.5	129.6	156.7	170.8
1130	110.2	128.1	144.3	130.2	157.0	171.3
1140	110.9	128.6	145.0	130.7	157.3	171.9
1150	111.5	129.1	145.6	131.3	157.6	172.4
1160	112.1	129.6	146.3	131.9	157.9	172.9
1170	112.8	130.1	147.0	132.4	158.2	173.5
1180	113.4	130.6	147.6	133.0	158.5	174.0
1190	114.0	131.1	148.3	133.5	158.7	174.5
1200	114.6	131.5	148.9	134.1	159.0	175.0
1210	115.2	132.0	149.6	134.6	159.3	175.5
1220	115.8	132.5	150.2	135.2	159.6	176.0
1230	116.3	132.9	150.8	135.7	159.9	176.5
1240	116.9	133.4	151.4	136.2	160.2	177.0

TABLE B-1. Dresden Unit 3 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)
1250	117.5	133.8	152.0	136.7	160.4	177.5
1260	118.0	134.3	152.6	137.2	160.7	178.0
1270	118.6	134.7	153.2	137.7	161.0	178.4
1280	119.1	135.2	153.8	138.2	161.2	178.9
1290	119.7	135.6	154.4	138.7	161.5	179.4
1300	120.2	136.0	154.9	139.2	161.8	179.8
1310	120.7	136.5	155.5	139.7	162.1	180.3
1320	121.3	136.9	156.1	140.2	162.3	180.7
1330	121.8	137.3	156.6	140.6	162.6	181.2
1340	122.3	137.7	157.2	141.1	162.8	181.6
1350	122.8	138.1	157.7	141.6	163.1	182.1
1360	123.3	138.6	158.2	142.0	163.4	182.5
1370	123.8	139.0	158.8	142.5	163.6	182.9
1380	124.3	139.4	159.3	142.9	163.9	183.4
1390	124.8	139.8	159.8	143.4	164.1	183.8
1400	125.3	140.2	160.3	143.8	164.4	184.2

TABLE B-2: Dresden Unit 3 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	83.1	68.0	83.1	83.1
10	68.0	83.1	68.0	83.1	83.1
20	68.0	83.1	68.0	83.1	83.1
30	68.0	83.1	68.0	83.1	83.1
40	68.0	83.1	68.0	83.1	83.1
50	68.0	83.1	68.0	83.1	83.1
60	68.0	83.1	68.0	83.1	83.1
70	68.0	83.1	68.0	83.1	87.2
80	68.0	83.1	68.0	83.1	93.2
90	68.0	83.1	68.0	83.1	98.3
100	68.0	83.1	68.0	83.1	102.8
110	68.0	83.1	68.0	83.1	106.9
120	68.0	83.1	68.0	83.1	110.7
130	68.0	83.1	68.0	83.1	114.2
140	68.0	83.1	68.0	83.1	117.4
150	68.0	83.1	68.0	83.1	120.2
160	68.0	83.1	68.0	83.1	122.9
170	68.0	83.1	68.0	85.5	125.5
180	68.0	83.1	68.0	87.9	127.9
190	68.0	83.1	68.0	90.2	130.2
200	68.0	83.1	68.0	92.3	132.3
210	68.0	83.1	68.0	94.3	134.3
220	68.0	83.1	68.0	96.3	136.3
230	68.0	83.1	68.0	98.1	138.1
240	68.0	83.1	68.0	99.9	139.9
250	68.0	83.1	68.0	101.6	141.6
260	68.0	83.1	68.0	103.2	143.2
270	68.0	83.1	68.0	104.8	144.8
280	68.0	83.1	68.0	106.3	146.3
290	68.0	83.1	68.0	107.8	147.8
300	68.0	83.1	68.0	109.2	149.2
310	68.0	83.1	68.0	110.5	150.5
312.5	68.0	83.1	68.0	110.9	150.9
312.5	68.0	113.1	68.0	143.1	183.1
320	68.0	113.1	68.0	143.1	183.1
330	68.0	113.1	68.0	143.1	183.1
340	68.0	113.1	68.0	143.1	183.1
350	68.0	113.1	68.0	143.1	183.1
360	68.0	113.1	68.0	143.1	183.1
370	68.0	113.1	68.0	143.1	183.1

TABLE B-2. Dresden Unit 3 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	113.1	68.0	143.1	183.1
390	68.0	113.1	68.0	143.1	183.1
400	68.0	113.1	68.0	143.1	183.1
410	68.0	113.1	68.0	143.1	183.1
420	68.0	113.1	68.0	143.1	183.1
430	68.0	113.1	68.0	143.1	183.1
440	68.0	113.1	68.0	143.1	183.1
450	68.0	113.1	68.0	143.1	183.1
460	68.0	113.1	68.0	143.1	183.1
470	68.0	113.1	68.0	143.1	183.1
480	68.0	113.1	68.0	143.1	183.1
490	68.0	113.1	68.0	143.1	183.1
500	68.0	113.1	68.0	143.1	183.1
510	68.0	113.1	68.0	143.1	183.1
520	68.0	113.1	68.2	143.1	183.1
530	68.0	113.1	70.2	143.1	183.1
540	68.0	113.1	72.1	143.1	183.1
550	68.0	113.1	73.9	143.1	183.1
560	68.0	113.1	75.7	143.1	183.1
570	68.0	113.1	77.4	143.1	183.1
580	68.0	113.1	79.0	143.1	183.1
590	68.0	113.1	80.6	143.1	183.1
600	68.0	113.1	82.2	143.1	183.1
610	68.0	113.1	83.7	143.1	183.1
620	68.0	113.1	85.1	143.1	183.1
630	68.0	113.1	86.5	143.1	183.1
640	68.0	113.1	87.9	143.1	183.1
650	68.0	113.1	89.2	143.1	183.1
660	68.0	113.1	90.5	143.1	183.1
670	68.0	113.1	91.8	143.1	183.1
680	68.0	113.1	93.1	143.1	183.1
690	68.0	113.1	94.3	143.1	183.1
700	69.2	113.1	95.4	143.1	183.1
710	70.7	113.1	96.6	143.1	183.1
720	72.1	113.1	97.7	143.1	183.1
730	73.5	113.1	98.8	143.5	183.5
740	74.8	113.1	99.9	143.9	183.9
750	76.1	113.1	101.0	144.7	184.7
760	77.4	113.1	102.0	145.6	185.6
770	78.6	113.1	103.0	146.5	186.5
780	79.8	113.1	104.0	147.4	187.4
790	81.0	113.1	105.0	148.3	188.3

TABLE B-2. Dresden Unit 3 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)
800	82.2	113.2	105.9	149.1	189.1
810	83.3	114.5	106.9	150.0	190.0
820	84.4	115.8	107.8	150.8	190.8
830	85.5	117.0	108.7	151.6	191.6
840	86.5	118.2	109.6	152.4	192.4
850	87.6	119.3	110.4	153.2	193.2
860	88.6	120.5	111.3	154.0	194.0
870	89.6	121.6	112.1	154.7	194.7
880	90.5	122.7	113.0	155.5	195.5
890	91.5	123.8	113.8	156.2	196.2
900	92.4	124.8	114.6	157.0	197.0
910	93.4	125.8	115.4	157.7	197.7
920	94.3	126.8	116.1	158.4	198.4
930	95.1	127.8	116.9	159.1	199.1
940	96.0	128.8	117.7	159.8	199.8
950	96.9	129.7	118.4	160.5	200.5
960	97.7	130.6	119.1	161.1	201.1
970	98.6	131.6	119.9	161.8	201.8
980	99.4	132.5	120.6	162.4	202.4
990	100.2	133.3	121.3	163.1	203.1
1000	101.0	134.2	122.0	163.7	203.7
1010	101.7	135.0	122.6	164.4	204.4
1020	102.5	135.9	123.3	165.0	205.0
1030	103.3	136.7	124.0	165.6	205.6
1040	104.0	137.5	124.6	166.2	206.2
1050	104.7	138.3	125.3	166.8	206.8
1060	105.4	139.1	125.9	167.4	207.4
1070	106.2	139.9	126.5	168.0	208.0
1080	106.9	140.6	127.2	168.6	208.6
1090	107.6	141.4	127.8	169.1	209.1
1100	108.2	142.1	128.4	169.7	209.7
1110	108.9	142.8	129.0	170.2	210.2
1120	109.6	143.5	129.6	170.8	210.8
1130	110.2	144.3	130.2	171.3	211.3
1140	110.9	145.0	130.7	171.9	211.9
1150	111.5	145.6	131.3	172.4	212.4
1160	112.1	146.3	131.9	172.9	212.9
1170	112.8	147.0	132.4	173.5	213.5
1180	113.4	147.6	133.0	174.0	214.0
1190	114.0	148.3	133.5	174.5	214.5
1200	114.6	148.9	134.1	175.0	215.0
1210	115.2	149.6	134.6	175.5	215.5

TABLE B-2. Dresden Unit 3 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)
1220	115.8	150.2	135.2	176.0	216.0
1230	116.3	150.8	135.7	176.5	216.5
1240	116.9	151.4	136.2	177.0	217.0
1250	117.5	152.0	136.7	177.5	217.5
1260	118.0	152.6	137.2	178.0	218.0
1270	118.6	153.2	137.7	178.4	218.4
1280	119.1	153.8	138.2	178.9	218.9
1290	119.7	154.4	138.7	179.4	219.4
1300	120.2	154.9	139.2	179.8	219.8
1310	120.7	155.5	139.7	180.3	220.3
1320	121.3	156.1	140.2	180.7	220.7
1330	121.8	156.6	140.6	181.2	221.2
1340	122.3	157.2	141.1	181.6	221.6
1350	122.8	157.7	141.6	182.1	222.1
1360	123.3	158.2	142.0	182.5	222.5
1370	123.8	158.8	142.5	182.9	222.9
1380	124.3	159.3	142.9	183.4	223.4
1390	124.8	159.8	143.4	183.8	223.8
1400	125.3	160.3	143.8	184.2	224.2

TABLE B-3. Dresden Unit 3 P-T Curve Values for 22 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)	22 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	22 EFPY BELTLINE CURVE B (°F)
0	68.0	83.1	83.1	68.0	83.1	83.1
10	68.0	83.1	83.1	68.0	83.1	83.1
20	68.0	83.1	83.1	68.0	83.1	83.1
30	68.0	83.1	83.1	68.0	83.1	83.1
40	68.0	83.1	83.1	68.0	83.1	83.1
50	68.0	83.1	83.1	68.0	83.1	83.1
60	68.0	83.1	83.1	68.0	83.1	83.1
70	68.0	83.1	83.1	68.0	83.1	83.1
80	68.0	83.1	83.1	68.0	83.1	83.1
90	68.0	83.1	83.1	68.0	83.1	83.1
100	68.0	83.1	83.1	68.0	83.1	83.1
110	68.0	83.1	83.1	68.0	83.1	83.1
120	68.0	83.1	83.1	68.0	83.1	83.1
130	68.0	83.1	83.1	68.0	83.1	83.1
140	68.0	83.1	83.1	68.0	83.1	83.1
150	68.0	83.1	83.1	68.0	83.1	83.1
160	68.0	83.1	83.1	68.0	83.1	83.1
170	68.0	83.1	83.1	68.0	85.5	83.1
180	68.0	83.1	83.1	68.0	87.9	83.1
190	68.0	83.1	83.1	68.0	90.2	83.1
200	68.0	83.1	83.1	68.0	92.3	83.1
210	68.0	83.1	83.1	68.0	94.3	83.1
220	68.0	83.1	83.1	68.0	96.3	83.1
230	68.0	83.1	83.1	68.0	98.1	83.1
240	68.0	83.1	83.1	68.0	99.9	83.1
250	68.0	83.1	83.1	68.0	101.6	83.1
260	68.0	83.1	83.1	68.0	103.2	83.1
270	68.0	83.1	83.1	68.0	104.8	83.1
280	68.0	83.1	83.1	68.0	106.3	83.1
290	68.0	83.1	83.1	68.0	107.8	83.1
300	68.0	83.1	83.1	68.0	109.2	83.1
310	68.0	83.1	83.1	68.0	110.5	83.1
312.5	68.0	83.1	83.1	68.0	110.9	83.1
312.5	68.0	113.1	113.1	68.0	143.1	143.1
320	68.0	113.1	113.1	68.0	143.1	143.1
330	68.0	113.1	113.1	68.0	143.1	143.1

TABLE B-3. Dresden Unit 3 P-T Curve Values for 22 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)	22 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	22 EFPY BELTLINE CURVE B (°F)
340	68.0	113.1	113.1	68.0	143.1	143.1
350	68.0	113.1	113.1	68.0	143.1	143.1
360	68.0	113.1	113.1	68.0	143.1	143.1
370	68.0	113.1	113.1	68.0	143.1	143.1
380	68.0	113.1	113.1	68.0	143.1	143.1
390	68.0	113.1	113.1	68.0	143.1	143.1
400	68.0	113.1	113.1	68.0	143.1	143.1
410	68.0	113.1	113.1	68.0	143.1	143.1
420	68.0	113.1	113.1	68.0	143.1	143.1
430	68.0	113.1	113.1	68.0	143.1	143.1
440	68.0	113.1	113.1	68.0	143.1	143.1
450	68.0	113.1	113.1	68.0	143.1	143.1
460	68.0	113.1	113.1	68.0	143.1	143.1
470	68.0	113.1	113.1	68.0	143.1	143.1
480	68.0	113.1	113.1	68.0	143.1	143.1
490	68.0	113.1	113.1	68.0	143.1	143.1
500	68.0	113.1	113.1	68.0	143.1	143.1
510	68.0	113.1	113.1	68.0	143.1	143.1
520	68.0	113.1	113.1	68.2	143.1	143.1
530	68.0	113.1	113.1	70.2	143.1	143.1
540	68.0	113.1	113.1	72.1	143.1	143.1
550	68.0	113.1	113.1	73.9	143.1	143.1
560	68.0	113.1	113.1	75.7	143.1	143.1
570	68.0	113.1	113.1	77.4	143.1	143.1
580	68.0	113.1	113.1	79.0	143.1	143.1
590	68.0	113.1	113.1	80.6	143.1	143.1
600	68.0	113.1	113.1	82.2	143.1	143.1
610	68.0	113.1	113.1	83.7	143.1	143.1
620	68.0	113.1	113.1	85.1	143.1	143.1
630	68.0	113.1	113.1	86.5	143.1	143.1
640	68.0	113.1	113.1	87.9	143.1	143.1
650	68.0	113.1	113.1	89.2	143.1	143.1
660	68.0	113.1	113.1	90.5	143.1	143.1
670	68.0	113.1	113.1	91.8	143.1	143.1
680	68.0	113.1	113.1	93.1	143.1	143.1
690	68.0	113.1	113.1	94.3	143.1	143.1
700	69.2	113.1	113.1	95.4	143.1	143.1
710	70.7	113.1	113.1	96.6	143.1	143.1
720	72.1	113.1	113.1	97.7	143.1	143.1
730	73.5	113.1	113.1	98.8	143.5	143.1
740	74.8	113.1	113.1	99.9	143.9	143.1
750	76.1	113.1	113.1	101.0	144.2	143.1
760	77.4	113.1	113.1	102.0	144.6	143.1

TABLE B-3. Dresden Unit 3 P-T Curve Values for 22 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)	22 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	22 EFPY BELTLINE CURVE B (°F)
770	78.6	113.1	113.1	103.0	145.0	143.1
780	79.8	113.1	113.1	104.0	145.4	143.1
790	81.0	113.1	113.1	105.0	145.8	143.1
800	82.2	113.1	113.1	105.9	146.1	143.1
810	83.3	113.1	113.1	106.9	146.5	143.1
820	84.4	113.1	113.1	107.8	146.9	143.1
830	85.5	113.1	113.1	108.7	147.2	143.1
840	86.5	113.1	113.1	109.6	147.6	143.1
850	87.6	113.1	113.1	110.4	147.9	143.1
860	88.6	113.1	113.1	111.3	148.3	143.1
870	89.6	113.1	113.1	112.1	148.6	143.1
880	90.5	113.6	113.1	113.0	149.0	143.7
890	91.5	114.3	113.1	113.8	149.3	144.4
900	92.4	114.9	113.1	114.6	149.7	145.2
910	93.4	115.6	114.0	115.4	150.0	145.9
920	94.3	116.2	115.0	116.1	150.4	146.6
930	95.1	116.9	116.0	116.9	150.7	147.3
940	96.0	117.5	117.0	117.7	151.0	148.0
950	96.9	118.1	117.9	118.4	151.4	148.7
960	97.7	118.7	118.9	119.1	151.7	149.3
970	98.6	119.3	119.8	119.9	152.0	150.0
980	99.4	119.9	120.7	120.6	152.4	150.6
990	100.2	120.5	121.5	121.3	152.7	151.3
1000	101.0	121.1	122.4	122.0	153.0	151.9
1010	101.7	121.7	123.2	122.6	153.3	152.6
1020	102.5	122.2	124.1	123.3	153.6	153.2
1030	103.3	122.8	124.9	124.0	154.0	153.8
1040	104.0	123.4	125.7	124.6	154.3	154.4
1050	104.7	123.9	126.5	125.3	154.6	155.0
1060	105.4	124.5	127.3	125.9	154.9	155.6
1070	106.2	125.0	128.1	126.5	155.2	156.2
1080	106.9	125.5	128.8	127.2	155.5	156.8
1090	107.6	126.1	129.6	127.8	155.8	157.3
1100	108.2	126.6	130.3	128.4	156.1	157.9
1110	108.9	127.1	131.0	129.0	156.4	158.4
1120	109.6	127.6	131.7	129.6	156.7	159.0
1130	110.2	128.1	132.5	130.2	157.0	159.5
1140	110.9	128.6	133.2	130.7	157.3	160.1
1150	111.5	129.1	133.8	131.3	157.6	160.6
1160	112.1	129.6	134.5	131.9	157.9	161.1
1170	112.8	130.1	135.2	132.4	158.2	161.7
1180	113.4	130.6	135.8	133.0	158.5	162.2
1190	114.0	131.1	136.5	133.5	158.7	162.7

TABLE B-3. Dresden Unit 3 P-T Curve Values for 22 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)	22 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	22 EFPY BELTLINE CURVE B (°F)
1200	114.6	131.5	137.1	134.1	159.0	163.2
1210	115.2	132.0	137.8	134.6	159.3	163.7
1220	115.8	132.5	138.4	135.2	159.6	164.2
1230	116.3	132.9	139.0	135.7	159.9	164.7
1240	116.9	133.4	139.6	136.2	160.2	165.2
1250	117.5	133.8	140.2	136.7	160.4	165.7
1260	118.0	134.3	140.8	137.2	160.7	166.2
1270	118.6	134.7	141.4	137.7	161.0	166.6
1280	119.1	135.2	142.0	138.2	161.2	167.1
1290	119.7	135.6	142.6	138.7	161.5	167.6
1300	120.2	136.0	143.1	139.2	161.8	168.0
1310	120.7	136.5	143.7	139.7	162.1	168.5
1320	121.3	136.9	144.3	140.2	162.3	168.9
1330	121.8	137.3	144.8	140.6	162.6	169.4
1340	122.3	137.7	145.4	141.1	162.8	169.8
1350	122.8	138.1	145.9	141.6	163.1	170.3
1360	123.3	138.6	146.4	142.0	163.4	170.7
1370	123.8	139.0	147.0	142.5	163.6	171.1
1380	124.3	139.4	147.5	142.9	163.9	171.6
1390	124.8	139.8	148.0	143.4	164.1	172.0
1400	125.3	140.2	148.5	143.8	164.4	172.4

TABLE B-4. Dresden Unit 3 Composite P-T Curve Values for 22 EFPY

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

FOR FIGURE 5-9

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 22 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 22 EFPY CURVE B (°F)	NON-BELTLINE AND BELTLINE AT 22 EFPY CURVE C (°F)
0	68.0	83.1	68.0	83.1	83.1
10	68.0	83.1	68.0	83.1	83.1
20	68.0	83.1	68.0	83.1	83.1
30	68.0	83.1	68.0	83.1	83.1
40	68.0	83.1	68.0	83.1	83.1
50	68.0	83.1	68.0	83.1	83.1
60	68.0	83.1	68.0	83.1	83.1
70	68.0	83.1	68.0	83.1	87.2
80	68.0	83.1	68.0	83.1	93.2
90	68.0	83.1	68.0	83.1	98.3
100	68.0	83.1	68.0	83.1	102.8
110	68.0	83.1	68.0	83.1	106.9
120	68.0	83.1	68.0	83.1	110.7
130	68.0	83.1	68.0	83.1	114.2
140	68.0	83.1	68.0	83.1	117.4
150	68.0	83.1	68.0	83.1	120.2
160	68.0	83.1	68.0	83.1	122.9
170	68.0	83.1	68.0	85.5	125.5
180	68.0	83.1	68.0	87.9	127.9
190	68.0	83.1	68.0	90.2	130.2
200	68.0	83.1	68.0	92.3	132.3
210	68.0	83.1	68.0	94.3	134.3
220	68.0	83.1	68.0	96.3	136.3
230	68.0	83.1	68.0	98.1	138.1
240	68.0	83.1	68.0	99.9	139.9
250	68.0	83.1	68.0	101.6	141.6
260	68.0	83.1	68.0	103.2	143.2
270	68.0	83.1	68.0	104.8	144.8
280	68.0	83.1	68.0	106.3	146.3
290	68.0	83.1	68.0	107.8	147.8
300	68.0	83.1	68.0	109.2	149.2
310	68.0	83.1	68.0	110.5	150.5
312.5	68.0	83.1	68.0	110.9	150.9
312.5	68.0	113.1	68.0	143.1	183.1
320	68.0	113.1	68.0	143.1	183.1
330	68.0	113.1	68.0	143.1	183.1
340	68.0	113.1	68.0	143.1	183.1
350	68.0	113.1	68.0	143.1	183.1
360	68.0	113.1	68.0	143.1	183.1
370	68.0	113.1	68.0	143.1	183.1

TABLE B-4. Dresden Unit 3 Composite P-T Curve Values for 22 EFPY

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

FOR FIGURE 5-9

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 22 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 22 EFPY CURVE B (°F)	NON-BELTLINE AND BELTLINE AT 22 EFPY CURVE C (°F)
380	68.0	113.1	68.0	143.1	183.1
390	68.0	113.1	68.0	143.1	183.1
400	68.0	113.1	68.0	143.1	183.1
410	68.0	113.1	68.0	143.1	183.1
420	68.0	113.1	68.0	143.1	183.1
430	68.0	113.1	68.0	143.1	183.1
440	68.0	113.1	68.0	143.1	183.1
450	68.0	113.1	68.0	143.1	183.1
460	68.0	113.1	68.0	143.1	183.1
470	68.0	113.1	68.0	143.1	183.1
480	68.0	113.1	68.0	143.1	183.1
490	68.0	113.1	68.0	143.1	183.1
500	68.0	113.1	68.0	143.1	183.1
510	68.0	113.1	68.0	143.1	183.1
520	68.0	113.1	68.2	143.1	183.1
530	68.0	113.1	70.2	143.1	183.1
540	68.0	113.1	72.1	143.1	183.1
550	68.0	113.1	73.9	143.1	183.1
560	68.0	113.1	75.7	143.1	183.1
570	68.0	113.1	77.4	143.1	183.1
580	68.0	113.1	79.0	143.1	183.1
590	68.0	113.1	80.6	143.1	183.1
600	68.0	113.1	82.2	143.1	183.1
610	68.0	113.1	83.7	143.1	183.1
620	68.0	113.1	85.1	143.1	183.1
630	68.0	113.1	86.5	143.1	183.1
640	68.0	113.1	87.9	143.1	183.1
650	68.0	113.1	89.2	143.1	183.1
660	68.0	113.1	90.5	143.1	183.1
670	68.0	113.1	91.8	143.1	183.1
680	68.0	113.1	93.1	143.1	183.1
690	68.0	113.1	94.3	143.1	183.1
700	69.2	113.1	95.4	143.1	183.1
710	70.7	113.1	96.6	143.1	183.1
720	72.1	113.1	97.7	143.1	183.1
730	73.5	113.1	98.8	143.5	183.5
740	74.8	113.1	99.9	143.9	183.9
750	76.1	113.1	101.0	144.2	184.2
760	77.4	113.1	102.0	144.6	184.6
770	78.6	113.1	103.0	145.0	185.0
780	79.8	113.1	104.0	145.4	185.4
790	81.0	113.1	105.0	145.8	185.8

TABLE B-4. Dresden Unit 3 Composite P-T Curve Values for 22 EFPY

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

FOR FIGURE 5-9

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 22 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 22 EFPY CURVE B (°F)	NON-BELTLINE AND BELTLINE AT 22 EFPY CURVE C (°F)
800	82.2	113.1	105.9	146.1	186.1
810	83.3	113.1	106.9	146.5	186.5
820	84.4	113.1	107.8	146.9	186.9
830	85.5	113.1	108.7	147.2	187.2
840	86.5	113.1	109.6	147.6	187.6
850	87.6	113.1	110.4	147.9	187.9
860	88.6	113.1	111.3	148.3	188.3
870	89.6	113.1	112.1	148.6	188.6
880	90.5	113.6	113.0	149.0	189.0
890	91.5	114.3	113.8	149.3	189.3
900	92.4	114.9	114.6	149.7	189.7
910	93.4	115.6	115.4	150.0	190.0
920	94.3	116.2	116.1	150.4	190.4
930	95.1	116.9	116.9	150.7	190.7
940	96.0	117.5	117.7	151.0	191.0
950	96.9	118.1	118.4	151.4	191.4
960	97.7	118.9	119.1	151.7	191.7
970	98.6	119.8	119.9	152.0	192.0
980	99.4	120.7	120.6	152.4	192.4
990	100.2	121.5	121.3	152.7	192.7
1000	101.0	122.4	122.0	153.0	193.0
1010	101.7	123.2	122.6	153.3	193.3
1020	102.5	124.1	123.3	153.6	193.6
1030	103.3	124.9	124.0	154.0	194.0
1040	104.0	125.7	124.6	154.4	194.4
1050	104.7	126.5	125.3	155.0	195.0
1060	105.4	127.3	125.9	155.6	195.6
1070	106.2	128.1	126.5	156.2	196.2
1080	106.9	128.8	127.2	156.8	196.8
1090	107.6	129.6	127.8	157.3	197.3
1100	108.2	130.3	128.4	157.9	197.9
1110	108.9	131.0	129.0	158.4	198.4
1120	109.6	131.7	129.6	159.0	199.0
1130	110.2	132.5	130.2	159.5	199.5
1140	110.9	133.2	130.7	160.1	200.1
1150	111.5	133.8	131.3	160.6	200.6
1160	112.1	134.5	131.9	161.1	201.1
1170	112.8	135.2	132.4	161.7	201.7
1180	113.4	135.8	133.0	162.2	202.2
1190	114.0	136.5	133.5	162.7	202.7
1200	114.6	137.1	134.1	163.2	203.2
1210	115.2	137.8	134.6	163.7	203.7

TABLE B-4. Dresden Unit 3 Composite P-T Curve Values for 22 EFPY

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

FOR FIGURE 5-9

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 22 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 22 EFPY CURVE B (°F)	NON-BELTLINE AND BELTLINE AT 22 EFPY CURVE C (°F)
1220	115.8	138.4	135.2	164.2	204.2
1230	116.3	139.0	135.7	164.7	204.7
1240	116.9	139.6	136.2	165.2	205.2
1250	117.5	140.2	136.7	165.7	205.7
1260	118.0	140.8	137.2	166.2	206.2
1270	118.6	141.4	137.7	166.6	206.6
1280	119.1	142.0	138.2	167.1	207.1
1290	119.7	142.6	138.7	167.6	207.6
1300	120.2	143.1	139.2	168.0	208.0
1310	120.7	143.7	139.7	168.5	208.5
1320	121.3	144.3	140.2	168.9	208.9
1330	121.8	144.8	140.6	169.4	209.4
1340	122.3	145.4	141.1	169.8	209.8
1350	122.8	145.9	141.6	170.3	210.3
1360	123.3	146.4	142.0	170.7	210.7
1370	123.8	147.0	142.5	171.1	211.1
1380	124.3	147.5	142.9	171.6	211.6
1390	124.8	148.0	143.4	172.0	212.0
1400	125.3	148.5	143.8	172.4	212.4

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 E. 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 do not apply. In other words, the operator must follow this curve during times when the coolant is heating or cooling faster than 20°F per hour during a hydrotest and when the core is not critical.

C.2.3 Curve C: Core Critical Operation

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

C.3 REACTOR OPERATION VERSUS OPERATING LIMITS

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

The most severe unplanned transients relative to the P-T curves are those 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 temperatures.	Must compensate for outside metal temperature lag during heatup/cooldown. Should have drain line flow.

TABLE OF RPV TEMPERATURE MONITORING MEASUREMENTS (CONTINUED)

(Typical)

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

TABLE OF RPV TEMPERATURE MONITORING MEASUREMENTS (CONTINUED)

(Typical)

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

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

Product Reference: B21 Nuclear Boiler

Prepared By: A.C. Tsang

Approved for Issue:

B.H. Eldridge, Mgr.

Service Information

and Analysis

Issued By:

D.L. Allred, Manager

Customer Service Information

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