ENCLOSURE 2

BWROG-06020

GE Licensing Topical Report NEDO-33178, Revision 0, "General Electric Methodology for Development of Reactor Pressure Vessel Pressure-Temperature Curves"

Non-Proprietary Version

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GE Nuclear Energy

NEDO-33178
Revision 0
DRF 0000-0036-1049
Class I
July 2006

Licensing Topical Report

General Electric Methodology for Development of Reactor Pressure Vessel Pressure-Temperature Curves

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Non-Proprietary Version

Licensing Topical Report
General Electric Methodology for Development of Reactor Pressure Vessel Pressure-Temperature Curves

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REPORT REVISION STATUS

Revision	Purpose
0	Initial Issue

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IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT

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The information contained in this document is furnished for the purpose of obtaining NRC approval of a calculation process for Pressure-Temperature (P-T) curve for BWRs. The only undertakings of General Electric Company respecting information in this document are contained in the contracts between General Electric Company and the participating utilities in effect at the time this report is issued, and nothing contained in this document shall be construed as changing those contracts. The use of this information by anyone other than that for which it is intended is not authorized; and with respect to **any unauthorized use**, General Electric Company makes no representation or warranty, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document.

ABSTRACT

This document presents the methodology developed by the General Electric Company (GE) for the determination of reactor pressure vessel pressure-temperature curves. The adequacy of the GE methodology is demonstrated through a detailed description of the calculation procedures and examples showing agreement between GE practices and the standards and Code requirements set forth in 10CFR50 Appendix G.

This report does not include development or licensing of vessel fluence methods, which are covered by other LTRs. It is assumed that such fluence methods would be utilized to develop the necessary and appropriate inputs for use in the P-T curve development methodology outlined in this report.

This document is presented in the following manner. The main body of the report provides the methodology and selected examples. An example template for the plant-specific report that will be provided to the Utility is appended and denoted as Attachment 1. This plant-specific report maintains the same numbering system as the main body of this topical report, thereby allowing direct correlation between sections of the main body (which presents the methodology) and the plant-specific report (which presents only plant-specific data and calculations). Throughout this topical report, reference is made to the plant-specific data that is contained in the Attachment 1; in all cases, example information is provided in Attachment 1 to this report. An example PTLR (Pressure-Temperature Limits Report) prepared for NRC review is contained in Attachment 2.

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1.0 INTRODUCTION

The methodology for the pressure-temperature (P-T) curves included in this report has been developed to present steam dome pressure versus minimum vessel metal temperature incorporating appropriate non-beltline limits and irradiation embrittlement effects in the beltline. P-T curves are provided 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. The ASME Boiler and Pressure Vessel Code was used in this evaluation; the Edition and Addenda used in the plant-specific evaluation are specified in Attachment 1 (the plant-specific report provided to the Utility) and Attachment 2 (hereinafter referred to as the PTLR). The P-T curve methodology includes the following: 1) the use of K_{Ic} from Figure A-4200-1 of Appendix A to determine T-RT_{NDT}, and 2) the use of the M_m calculation in the ASME Code paragraph G-2214.1 [6] for a postulated defect normal to the direction of maximum stress. P-T curves are developed using geometry of the RPV shells and discontinuities, the initial RT_{NDT} of the RPV materials, and the adjusted reference temperature (ART) for the beltline materials.

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

Section 4.2; plant-specific calculations are provided in Section 4.2 of Attachment 1 and Appendix B of the PTLR. Beltline chemistry values are discussed in Section 4.2.1.1; plant-specific chemistry values are provided in Section 4.2.1.1 of Attachment 1 and Appendix B of the PTLR. The peak ID fluence used in the plant-specific evaluation is provided in Section 4.2.1.2 of Attachment 1 and Appendix B of the PTLR. It is noted that this report does not include development or licensing of vessel fluence methods, which are covered by other LTRs. It is assumed that such fluence methods would be utilized to develop the necessary and appropriate inputs for use in the P-T curve development methodology outlined in this report.

Appendix A includes comprehensive documentation of the RPV discontinuities. This appendix also documents the non-beltline discontinuity curve that is used to protect each discontinuity. Appendix A of Attachment 1 provides the plant-specific documentation.

Guidelines and requirements for operating and temperature monitoring are included in Appendix C. Temperature monitoring requirements and methods are available in GE Services Information Letter (SIL) 430 contained in Appendix D. Appendix E documents components that have a fluence ≥ 1.0e17 n/cm^2, thus extending the beltline region beyond the core, and demonstrates that all components requiring fracture toughness evaluation are either included in the development of the P-T curves or are outside the beltline region; Appendix E of Attachment 1 documents the plant-specific application, which is also included in Appendix B of the PTLR. Appendix F provides an example calculation for a beltline curve where a nozzle is the limiting material. Appendix G contains an example evaluation of the vessel wall thickness discontinuities in the beltline and bottom head regions; Appendix G of Attachment 1 provides the plant-specific evaluation where applicable. Appendix H provides a core-not-critical calculation for the bottom head (CRD penetration). Finally, Appendix I presents guidance for the use of ISP surveillance data, which has been provided by EPRI.

Attachment 1 of this report provides an example of the plant-specific Pressure-Temperature Curve Report prepared for presentation to the Utility, which complements the Licensing Topical Report. Attachment 2 contains the Pressure-Temperature Limits Report (PTLR) prepared for presentation to the NRC.

2.0 SCOPE OF THE ANALYSIS

A detailed description of the P-T curve bases is included in Section 4.3. The ASME Boiler and Pressure Vessel Code was used in this evaluation; the Edition and Addenda used in the plant-specific evaluation are specified in the Attachment 1 Utility report and the PTLR. The P-T curve methodology includes the following: 1) the use of K_{Ic} from Figure A-4200-1 of Appendix A to determine $T-RT_{NDT}$, and 2) the use of the M_m calculation in the ASME Code paragraph G-2214.1 for a postulated defect normal to the direction of maximum stress. Other features presented are:

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

The pressure-temperature (P-T) curves are established to the requirements of 10CFR50, Appendix G [8] to assure that brittle fracture of the reactor vessel is prevented. Part of the analysis involved in developing the P-T curves is to account for irradiation embrittlement effects in the core region, or beltline. The method used to account for irradiation embrittlement is described in Regulatory Guide 1.99, Rev. 2 [7]. It is noted that this report does not include development or licensing of vessel fluence methods, which are covered by other LTRs. It is assumed that such fluence methods would be utilized to develop the necessary and appropriate inputs for use in the P-T curve development methodology outlined in this report.

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 vessel components. The non-beltline limits are discussed in Section 4.3 and are also governed by requirements in [8].

Furthermore, curves are included to allow monitoring of the vessel bottom head region separate from the upper vessel/beltline region. This refinement could minimize heating requirements prior to pressure testing. Operating and temperature monitoring requirements are found in Appendix C. Temperature monitoring requirements and methods are available in GE Services Information Letter (SIL) 430 contained in Appendix D. Appendix E documents components that have a fluence ≥ 1.0e17 n/cm^2, thus extending the beltline region beyond the core, and demonstrates that all components requiring fracture toughness evaluation are either included in the development of the P-T curves or are outside the beltline region; Appendix E of the PTLR documents the plant-specific application. Appendix F provides an example calculation for a beltline curve where a nozzle is the limiting material. Appendix G contains an example evaluation of the vessel wall thickness discontinuities in the beltline and bottom head regions; Appendix G of Attachment 1 provides the plant-specific evaluation where applicable. Appendix H provides a core-not-critical calculation for the bottom head (CRD penetration). Finally, Appendix I presents guidance for the use of ISP surveillance data, which has been provided by EPRI.

Attachment 1 of this report provides an example of the plant-specific Pressure-Temperature Curve Report prepared for presentation to the Utility, which complements the Licensing Topical Report. Attachment 2 contains the Pressure-Temperature Limits Report (PTLR) prepared for presentation to the NRC.

3.0 ANALYSIS ASSUMPTIONS

Assumptions made for this analysis include the plant-specific hydrostatic pressure test and the fuel shutdown margin. All assumptions are described in Section 3 of the plant-specific Utility P-T curve report in Attachment 1.

4.0 ANALYSIS

4.1 INITIAL REFERENCE TEMPERATURE

4.1.1 Background

The initial RT_{NDT} values for the low alloy steel vessel components are needed to develop the vessel P-T limits. The applicable ASME Code of Construction for the plant-specific RPV is specified in Section 4.1 of Attachment 1.

4.1.1.1 The requirements for establishing the vessel component toughness prior to 1972 were per the ASME Code Section III, Subsection NB-2300 and are summarized as follows:

a. Test specimens shall be longitudinally oriented CVN specimens.

b. At the qualification test temperature (specified in the vessel purchase specification), no impact test result shall be less than 25 ft-lb, and the average of three test results shall be at least 30 ft-lb.

c. Pressure tests shall be conducted at a temperature at least 60°F above the qualification test temperature for the vessel materials.

4.1.1.2 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.

4.1.1.3 10CFR50 Appendix G [8] states that for vessels constructed to a version of the ASME Code prior to the Summer 1972 Addendum, fracture toughness data and data analyses must be supplemented in an approved manner. GE developed methods for analytically converting fracture toughness data for vessels constructed before 1972 to comply with current requirements. These methods were developed from data in WRC Bulletin 217 [9] and from data collected to respond to NRC questions on FSAR submittals in the late 1970s. In 1994, these methods of estimating RT_{NDT} were submitted for generic approval by the BWR Owners' Group [10], and approved by the NRC for generic use [11].

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

To establish the initial RT_{NDT} temperatures for the plant-specific vessel per the current requirements, calculations are performed in accordance with the GE method for determining RT_{NDT}. Example RT_{NDT} calculations for vessel plate, forging, weld, and for bolting material LST are summarized in the remainder of this section. Non-beltline weld material values are not available for all plants. The plate or forging materials typically bound the weld materials, and as such, the plate or forging material initial RT_{NDT} shall be used in these cases.

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 all available sources such as certified material test reports, CMTRs, the Integrated Surveillance Program (ISP), best-estimates, etc.). For most CMTRs, typically six energy values were listed at a given test temperature, corresponding to two sets of Charpy tests. Where the lowest energy Charpy value is less than 50 ft-lb, it is adjusted by adding 2°F per ft-lb energy difference from 50 ft-lb. If the test specimens are transverse and the lowest energy Charpy value is less than 50 ft-lb, it is adjusted by adding 3°F per ft-lb energy difference from 50 ft-lbs.

As an example, for a plate heat in the cylindrical shell course, the lowest Charpy energy and test temperature from the CMTRs is 45 ft-lb at 10°F for a longitudinal test specimen. The estimated 50 ft-lb longitudinal test temperature is:

$$T_{50L} = 10°F + [\,(50 - 45)\text{ ft-lb} \cdot 2°F/\text{ft-lb}\,] = 20°F$$

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

$$T_{50T} = 20°F + 30°F = 50°F.$$

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

$$T_{50T} - 60°F = 50°F - 60°F = -10°F.$$

Dropweight testing to establish NDT for plate material is listed in the CMTR; the NDT for the example case above is –20°F. Thus, the initial RT_{NDT} for the plate heat is –10°F.

For vessel forging material, such as nozzles and closure flanges, the method for establishing RT_{NDT} is the same as for vessel plate material.

As an example, for a weld heat in the cylindrical shell, the CVN results are used to calculate the initial RT_{NDT}. The 50 ft-lb test temperature is applicable to the weld material, but the 30°F adjustment to convert longitudinal data to transverse data is not applicable to weld material. The example heat has a lowest Charpy energy of 47 ft-lb at 10°F. Therefore,

$$T_{50T} = 10°F + [\,(50 - 47) \cdot 2°F/\text{ft-lb}\,] = 16°F$$

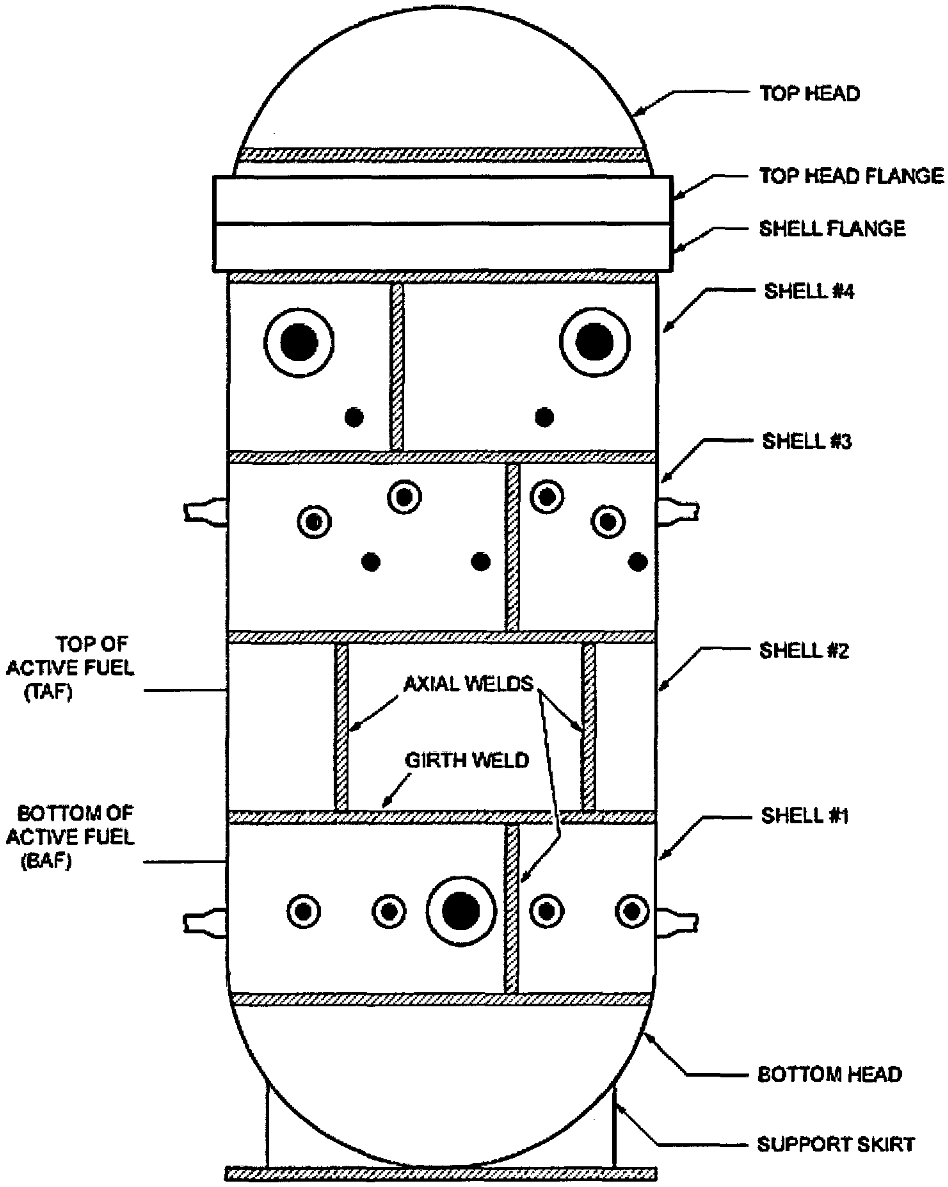
The initial RT_{NDT} is the greater of nil-ductility transition temperature (NDT) or (T_{50T} - 60°F). T_{50T} - 60°F = 16°F - 60°F = -44°F.

For the example case, the dropweight testing to establish NDT was -50°F. The value of (T_{50T} - 60°F) in this example is -44°F; therefore, the initial RT_{NDT} was -44°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 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. If all of the requirements are met, the LST is considered to be the temperature at which the tests were performed. Thus, the higher of the LST and the RT_{NDT} +60°F is the bolt-up limit in the closure flange region.

The initial RT_{NDT} values for the reactor vessel (refer to Figure 4-1 of Attachment 1 and Appendix B of the PTLR for the plant-specific schematic) materials are listed in Table 4-1 of Attachment 1 and Appendix B of the PTLR. This tabulation includes beltline, closure flange, feedwater nozzle, and bottom head materials that are considered in generating the P-T curves. The values presented in these tables and used to determine the initial RT_{NDT} are typically obtained from the plant-specific vessel CMTRs [12]. Non-plant-specific information regarding Initial RT_{NDT} may be obtained from the BWRVIP ISP in accordance with Appendix I.



Notes: (1) Refer to Tables 4-1, 4-2, 4-3 and 4-4 for reactor vessel components and their heat identifications.
(2) See Appendix E for the definition of the beltline region.

Figure 4-1: Example Schematic of a Plant-Specific RPV Showing Arrangement of Vessel Plates and Welds

The following table is included in the plant-specific P-T curve report (Attachment 1):

Table 4-1: RT_{NDT} Values for Plant-Specific Materials

This information is also included in Appendix B of the PTLR.

4.2 *ADJUSTED REFERENCE TEMPERATURE FOR BELTLINE*

The adjusted reference temperature (ART) of the limiting beltline material is used to adjust the beltline P-T curves to account for irradiation effects. Regulatory Guide 1.99, Revision 2 (RG1.99) provides the methods for determining the ART. The RG1.99 methods for determining the limiting material and adjusting the P-T curves using ART are discussed in this section. P-T curves are typically provided for two unique periods in time (an intermediate and an end of license EFPY). An evaluation of ART for all beltline plates and welds is performed and summarized in Table 4-2 of Attachment 1 and is provided in Appendix B of the PTLR.

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

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

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

where,

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

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

CF = chemistry factor from Tables 1 or 2 of RG1.99

f = ¼T fluence / 10^{19}

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

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

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

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

The margin term σ_Δ as described above, is defined in RG1.99; this methodology is used except when Integrated Surveillance Program data from BWRVIP-135 [5] is available, and BWRVIP-102 [5] methods are applied. Since the GE/BWROG method of estimating RT_{NDT} operates on the lowest Charpy energy value (as described in Section 4.1.2) and provides a conservative adjustment to the 50 ft-lb level, the value of σ_I is taken to be 0°F for the vessel plate and weld materials, unless otherwise specified (e.g., the ISP data).

4.2.1.1 Chemistry

The vessel beltline chemistries are obtained from all available plant-specific references (e.g., CMTRs, Integrated Surveillance Program, best-estimates). The chemistry used for the beltline region is presented in Table 4-2 of Attachment 1 and Appendix B of the PTLR.

The copper (Cu) and nickel (Ni) values were used with Tables 1 and 2 of RG1.99, to determine a chemistry factor (CF) per Paragraph 1.1 of RG1.99 for welds and plates, respectively.

For any materials where Integrated Surveillance Program (ISP) data is available, both the chemistry for the plant-specific vessel and the chemistry from the ISP are presented. The adjusted CF is used to calculate the adjusted reference temperature following the methods defined by BWRVIP-102 [5]. Appendix I contains guidance for the use of BWRVIP ISP surveillance data.

4.2.1.2 Fluence

The peak fluence for the RPV inner surface is determined using an approved methodology consistent with Regulatory Guide 1.190 [13]. This fluence is defined in Section 4.2.1.2 of Attachment 1 and Appendix B of the PTLR. Calculations for 1/4T fluence are performed in accordance with RG1.99 [7].

It is noted that this report does not include development or licensing of vessel fluence methods, which are covered by other LTRs. It is assumed that such fluence methods would be utilized to develop the necessary and appropriate inputs for use in the P-T curve development methodology outlined in this report.

4.2.2 Limiting Beltline Material

The limiting beltline material signifies the material that is estimated to receive the greatest embrittlement due to irradiation effects combined with initial RT_{NDT}. Using initial RT_{NDT}, chemistry, and fluence as inputs, RG1.99 was applied to compute ART. Table 4-2 of Attachment 1 and Appendix B of the PTLR list values of beltline ART.

All Integrated Surveillance Program (ISP) capsule material data [5] applicable to each BWR is used to represent each BWR vessel. These materials are included in the ART calculations provided in Table 4-2 of Attachment 1 and Appendix B of the PTLR, and in the determination of the limiting material that is represented in the beltline P-T curves.

The following tables are included in the plant-specific P-T curve report (Attachment 1) and Appendix B of the PTLR:

Table 4-2a: Plant-Specific Beltline ART Values (Intermediate EFPY)

Table 4-2b: Plant-Specific Beltline ART Values (End of License EFPY)

4.3 *PRESSURE-TEMPERATURE CURVE METHODOLOGY*

4.3.1 Background

Nuclear Regulatory Commission (NRC) 10CFR50 Appendix G [8] specifies fracture toughness requirements to provide adequate margins of safety during the operating conditions to which a pressure-retaining component may be subjected over its service lifetime. The ASME Code (Appendix G of Section XI [6]) forms the basis for the requirements of 10CFR50 Appendix G. The operating limits for pressure and temperature are required for three categories of operation: (a) hydrostatic pressure tests and leak tests, referred to as Curve A; (b) non-nuclear heatup/cooldown (core not critical), 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 plant-specific 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} (>1.0e17 n/cm^2; see Appendix E). The remaining portions of the vessel (i.e., upper vessel, lower vessel) include shells, components like the nozzles, the support skirt, and stabilizer brackets; these regions will also be called the non-beltline region.

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

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

The applicable temperature is the greater of the 10CFR50 Appendix G minimum temperature requirement or the ASME Appendix G limits. A summary of the requirements is provided in Table 4-3.

Table 4-3: Summary of the 10CFR50 Appendix G Requirements

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

* 60°F adder is included by GE as an additional conservatism as discussed in Section 4.3.2.3.

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

Welding Research Council (WRC) Bulletin 175 [15]. The beltline region minimum temperature limits are adjusted to account for vessel irradiation.

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4.3.2 P-T Curve Methodology

4.3.2.1 Non-Beltline Regions

Non-beltline regions are defined as the vessel locations that are remote from the active fuel and where the neutron fluence is not sufficient ($<1.0e17$ n/cm^2) to cause any significant shift of RT_{NDT}. Non-beltline components include nozzles (see Appendix E), closure flanges, some shell plates, the top and bottom head plates, and the control rod drive (CRD) penetrations.

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

Table 4-4a: Applicable BWR/2-5 Discontinuity Components for Use with FW (Upper Vessel) 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	
Water Level Instrumentation Nozzle	
Jet Pump Instrumentation Nozzle	
Shell	
CRD and Bottom Head	
Top Head Nozzle	
Recirculation Outlet Nozzle	]]

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

Discontinuity Identification	[[
FW Nozzle	
LPCI Nozzle	
CRD HYD System Return	
Core Spray Nozzle	
Recirculation Inlet Nozzle	
Steam Outlet Nozzle	
Support Skirt and Bottom Head	
Jet Pump Instrumentation Nozzle	
Shroud Support Attachments	
Stabilizer Bracket	
Shell Discontinuities	
Water Level Instrumentation Nozzle	]]

Table 4-5a: Applicable BWR/2-5 Discontinuity Components for Use with CRD (Bottom Head) Curves A&B

Discontinuity Identification	[[
CRD and Bottom Head	
Top Head Nozzles	
Recirculation Outlet Nozzle	
Shell*	
Support Skirt*	
Shroud Support Attachments*	
Core ΔP and Liquid Control Nozzle*	]]

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

Table 4-5b: Applicable BWR/6 Discontinuity Components for Use with CRD (Bottom Head) Curves A&B

Discontinuity Identification	[[
CRD and Bottom Head	
Vibration Instrumentation Nozzle	
Core ΔP and Liquid Control Nozzle	
Top Head Nozzles	
Recirculation Outlet Nozzle	
Main Closure Flange	
Steam Water Interface	
Shell Discontinuities	
Support Skirt*	
Shroud Support Attachments*	]]

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

The P-T curves for the non-beltline region were conservatively developed for a large BWR/6 (nominal inside diameter of 251 inches). The analysis is considered appropriate for application to each BWR vessel as the plant-specific geometric values are comparable to the generic analysis for a large BWR/6, as determined in Section 4.3.2.1.1 through Section 4.3.2.1.4 of Attachment 1. The generic value is adapted to the conditions at each plant by using plant-specific RT_{NDT} values for the reactor pressure vessel (RPV). The presence of nozzles and CRD penetration holes in the upper vessel and bottom head, respectively, has made the analysis different from a shell analysis such as the beltline. This was the result of the stress concentrations and higher thermal stress for certain transient conditions experienced by the upper vessel and the bottom head.

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Thickness discontinuities exist between various shells in some vessels. An example evaluation is provided for wall thickness transition discontinuities located between the bottom head lower torus and upper torus and also between a bottom head torus and Shell #1. Appendix G of this report contains a detailed description of this evaluation. For this sample evaluation, it was concluded that the discontinuities are bounded by the bottom head P-T curve developed in the following sections, and no further adjustment was required. Each vessel is reviewed for such discontinuities. Where these discontinuities exist, a plant-specific evaluation similar to that provided in Appendix G of Attachment 1 is performed. The results of the discontinuity evaluation are compared to the plant-specific curves generated using the methods presented in the following sections, in order to determine whether the curves bound the discontinuity. Should the discontinuity bound the curve, the curve is shifted sufficiently in order to assure that the discontinuities are bounded.

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

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

was 84°F. [[

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

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

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

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

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

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

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

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

The total K_I is therefore:

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

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

$$(T - RT_{NDT}) = \ln[(K_I - 33.2) / 20.734] / 0.02$$
$$(T - RT_{NDT}) = \ln[(144 - 33.2) / 20.734] / 0.02$$
$$(T - RT_{NDT}) = 84°F$$

The generic curve was generated by scaling 143.6 ksi-in$^{1/2}$ by the nominal pressures and calculating the associated $(T - RT_{NDT})$ as shown in Table 4-6.

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The highest RT_{NDT} for the bottom head plates and welds is obtained from Table 4-1 of Attachment 1 and Appendix B of the PTLR. [[

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

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

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 plant-specific bottom head dimensions are applied to Equation 4-2 as demonstrated in Section 4.3.2.1.1 of Attachment 1.

Plant-specific: $R / (t)^{1/2}$ (4-3)

When the generic value of $R/(t)^{1/2}$ is larger, the generic P-T curve is conservative when applied to the plant-specific bottom head. Should the generic value be smaller, a plant-specific evaluation is performed. It is noted that for all plants evaluated to-date, the generic case bounds the plant-specific case.

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

As discussed previously, the CRD penetration region limits were established primarily for consideration of bottom head discontinuity stresses during pressure testing.

Heatup/cooldown limits were calculated by increasing the safety factor in the pressure testing stresses (Section 4.3.2.1.1) from 1.5 to 2.0. [[

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

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

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

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

$(T - RT_{NDT}) = 102°F$

The generic curve was generated by scaling 192 ksi-in$^{1/2}$ by the nominal pressures and calculating the associated $(T - RT_{NDT})$ as shown in Table 4-7.

Table 4-7: 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 obtained from Table 4-1 of Attachment 1 and Appendix B of the PTLR. [[

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As discussed in Section 4.3.2.1.1 an evaluation is performed to assure that the CRD discontinuity bounds the other discontinuities that are to be protected by the CRD curve with respect to pressure stresses (see Table 4-5 and Appendix A of Attachment 1). With respect to thermal stresses, the transients evaluated for the CRD are similar to or more severe than those of the other components being bounded. Therefore, for heatup/cooldown conditions, the CRD penetration provides bounding limits.

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

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

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

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

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

Pressure stress: $\sigma = PR / t$

σ = 1563 psig · 126.7 inches / (6.1875 inches)

σ = 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 $1.5\ \sigma\ (\pi a)^{1/2} \cdot F(a/r_n)$:

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

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

$$(T - RT_{NDT}) = \ln [(K_I - 33.2) / 20.734] / 0.02$$
$$(T - RT_{NDT}) = \ln [(200 - 33.2) / 20.734] / 0.02$$
$$(T - RT_{NDT}) = 104.2°F$$

[[

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

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[[

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The highest RT_{NDT} for the feedwater nozzle materials is obtained from Table 4-1 of Attachment 1 and Appendix B of the PTLR. [[

]] The generic curve is applied to the plant-specific feedwater nozzle curve by shifting the P vs. (T - RT_{NDT}) values above to reflect the RT_{NDT} value obtained from Table 4-1 [[

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Second, the P-T curve is dependent on the K_I value calculated. The plant-specific vessel shell and nozzle dimensions applicable to the feedwater nozzle location [19] and K_I are obtained from plant-specific drawings and provided in Section 4.3.2.1.3 of Attachment 1.

Vessel Radius to base metal, R_v
Vessel Thickness, t_v
Vessel Pressure, P_v

Pressure stress is calculated based on these values as shown in Section 4.3.2.1.3 of Attachment 1. The dead weight and thermal RFE stress of 2.967 ksi is conservatively added. The factor $F(a/r_n)$ from Figure A5-1 of WRC 175 is determined using plant-specific dimensions as shown in Section 4.3.2.1.3 of Attachment 1:

$a = ¼ (t_n{}^2 + t_v{}^2)^{1/2}$
t_n = thickness of nozzle
t_v = thickness of vessel
r_n = apparent radius of nozzle
r_i = actual inner radius of nozzle
r_c = nozzle radius (nozzle corner radius)

The value of a/r_n is determined and the value $F(a/r_n)$ is obtained from Figure A5-1 of WRC Bulletin 175. Including the safety factor of 1.5, the stress intensity factor, K_I, is $1.5\ \sigma\ (\pi a)^{1/2} \cdot F(a/r_n)$ as shown in Section 4.3.2.1.3 of Attachment 1.

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

The feedwater nozzle was selected to represent non-beltline components for fracture toughness analyses because the stress conditions are the most severe experienced in the vessel. In addition to the pressure and piping load stresses resulting from the nozzle discontinuity, the feedwater nozzle region experiences feedwater flow that is colder relative to the vessel coolant.

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

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

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

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

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

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

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

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

The thermal stresses are proportional to the thickness in which a larger thickness produces a larger thermal stress. The equation for thermal stress is $E\alpha\Delta T/(2^*(1-\mu))$ where ΔT is greater for a shell with a larger thickness. E is defined as the Modulus of Elasticity, α is the coefficient of thermal expansion, ΔT is the through-wall temperature difference, and μ is Poissons Ratio. Therefore, thermal stress is bounding for the [[ ]]. The thermal stress in the K_I solution has a safety factor of 1.0.

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

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

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

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

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

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

In this case the total stress, 60.29 ksi, exceeds the yield stress, σ_{ys}, so the correction factor, R, is calculated to consider the nonlinear effects in the plastic region according to the following equation based on the assumptions and recommendation of WRC Bulletin 175 [15]. (The value of specified yield stress is for the material at the temperature under consideration. For conservatism, the inside surface temperature is used.)

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

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 G-2214.1 [6] was based on the 4*a* 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, is therefore,

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

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

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

$$K_{IP} = 190.4 \text{ ksi-in}^{1/2}$$

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

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

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

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 as shown in Table 4-9.

Table 4-9: Core Not Critical Feedwater Nozzle K_I and $(T - RT_{NDT})$ as a Function of Pressure

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

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

The highest non-beltline RT_{NDT} for the feedwater nozzle is obtained from Table 4-1 of Attachment 1 or Appendix B of the PTLR. [[

]] The generic curve is

applied to the plant-specific upper vessel by shifting the P vs. (T - RT_{NDT}) values above to reflect the RT_{NDT} value as discussed in Section 4.3.2.1.3.

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4.3.2.2 CORE BELTLINE REGION

The pressure-temperature (P-T) operating limits for the beltline region are determined according to the ASME Code [6]. As the beltline fluence increases with the increase in operating life, the P-T curves shift to a higher temperature.

The stress intensity factors (K_I), calculated for the beltline region according to ASME Code Appendix G procedures [6], were based on a combination of pressure and thermal stresses for a 1/4T flaw in a flat plate. The pressure stresses were calculated using thin-walled cylinder equations. Thermal stresses were calculated assuming the through-wall temperature distribution of a flat plate; values were calculated for 100°F/hr coolant thermal gradient. The shift value of the most limiting ART material was used to adjust the RT_{NDT} values for the P-T limits. Thermal stresses are calculated including clad thickness as defined by the ASME Code. As demonstrated in Table 4-2 of Attachment 1 or Appendix B of the PTLR, the ART is conservatively calculated using minimum wall thickness excluding clad thickness.

Thickness discontinuities exist between various shells in some vessels. An example evaluation was performed for the vessel wall thickness transition discontinuity located between the lower and lower-intermediate shells in the beltline region. Appendix G of this report contains a detailed description of this evaluation. For this sample evaluation, it was concluded that the discontinuity is bounded by the beltline P-T curve developed in the following sections, and no further adjustment was required. Each plant-specific vessel is reviewed for such discontinuities. Where these discontinuities exist, an evaluation similar to that provided in Appendix G is performed. The results of the discontinuity evaluation are compared to the plant-specific curves generated using the methods presented in the following section, in order to determine whether the curves bound the discontinuity. Should the discontinuity bound the curve, the curve is shifted sufficiently in order to assure that the discontinuities are bounded.

For some plants, the definition of the extended beltline region as discussed in Appendix E causes other components such as nozzles to be considered as part of the beltline region. In these cases, the materials are included in the ART calculations presented in Table 4-2 of Attachment 1 or Appendix B of the PTLR. Where the nozzle ART is the limiting beltline component, the P-T curves are evaluated using the basis for the FW nozzle evaluation presented in Sections 4.3.2.1.3 and/or 4.3.2.1.4, as appropriate. Plant-specific nozzle dimensions are used in these calculations. Additional discussion and an example are provided in the sections below.

4.3.2.2.1 Beltline Region - Pressure Test

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

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

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

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

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

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

This relationship provides values of pressure versus temperature (from K_{Ic} 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, specified as 20°F/hr for the plant-specific example, 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

A calculation is performed for a plant-specific pressure test pressure at a given EFPY. The plant-specific inputs used in the beltline limit calculation are presented in Section 4.3.2.2.2 of Attachment 1 or Appendix B of the PTLR.

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

$$P = \text{hydrotest pressure (psi)} + (H - B)\ 0.0361\ \text{psi/inch} = P\ \text{psig} \qquad (4\text{-}10)$$

Where,

H = vessel height (inches), and

B = bottom of active fuel height (inches).

Pressure stress:

$$\sigma = PR/t \qquad (4\text{-}11)$$

The value of M_m for an inside axial postulated surface flaw from Paragraph G-2214.1 [6] was based on the plant-specific thickness (the minimum thickness without cladding). The resulting value is obtained using the following equations:

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

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

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

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

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

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

T is calculated by adding the adjusted RT_{NDT} to the T - RT_{NDT} obtained from Equation 4-12.

Nozzles in the Beltline Region

In the event that a nozzle is the limiting material for the beltline region, the beltline P-T curves are calculated in the same manner as for the Feedwater nozzle pressure test P-T curves, using the plant-specific nozzle dimensions, as described in Section 4.3.2.1.3. The generic feedwater pressure test P-T curve is applied to the plant-specific Feedwater Nozzle curve by shifting the P vs. $(T-RT_{NDT})$ values in Section 4.3.2.1.3 to reflect the appropriate ART value from Table 4-2 of Attachment 1 or Appendix B of the PTLR. Appendix F provides a sample calculation demonstrating the procedure used to evaluate a nozzle that occurs in the beltline region.

Girth Weld Limiting ART in the Beltline Region

Most plants are limited by the ART for either a plate material or axial weld in the beltline region. However, for plants where the limiting material is a circumferential weld, the calculated value of K_{Im} is reduced as defined by ASME Code paragraph G-2214.1 [6] for a postulated defect normal to the direction of maximum stress. To demonstrate that, by using this method, the axial weld has the most limiting temperature for the P-T curves in the beltline region, an example of the stress intensity calculations for both the axial and circumferential welds at a given EFPY are presented.

Axial Weld Calculation

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

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

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

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

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

Equation 4-9 can be rearranged, and 1.5 K_{Im} substituted for K_{Ic}, to solve for $(T-RT_{NDT})$. Using the K_{Ic} equation of Paragraph A-4200 in ASME Appendix A [17], $K_{Im} = 51.2$, and $K_{It} = 2.39$ for a 20°F/hr coolant heatup/cooldown rate with a vessel thickness, t, that includes cladding:

$$\begin{aligned}(T - RT_{NDT}) &= \ln [(1.5 \cdot K_{Im} + K_{It} - 33.2) / 20.734] / 0.02 \qquad (4\text{-}12)\\ &= \ln [(1.5 \cdot 51.2 + 2.39 - 33.2) / 20.734] / 0.02\\ &= 39.8°F\end{aligned}$$

T is calculated by adding the adjusted RT_{NDT}.

Girth Weld Calculation

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

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

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

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

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 [17], $K_{Im} = 24.6$, and $K_{It} = 2.39$ for a 20°F/hr coolant heatup/cooldown rate with a vessel thickness, t, that includes cladding:

$$\begin{aligned} (T - RT_{NDT}) &= \ln[(1.5 \cdot K_{Im} + K_{It} - 33.2) / 20.734] / 0.02 \qquad (4\text{-}12) \\ &= \ln[(1.5 \cdot 24.6 + 2.39 - 33.2) / 20.734] / 0.02 \\ &= -61°F \end{aligned}$$

T is calculated by adding the adjusted RT_{NDT}.

It can be seen that the difference between the T-RT_{NDT} for the axial weld calculation is sufficiently higher than that for the circumferential weld calculation in this example. 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. Should the girth weld T - RT_{NDT} bound the axial weld T – RT_{NDT}, the beltline P-T curves are based upon the girth weld ART.

4.3.2.2.3 Beltline Region - Core Not Critical Heatup/Cooldown

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

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

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

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

The thermal stresses in the vessel wall are caused by a radial thermal gradient that is created by changes in the adjacent reactor coolant temperature in heatup or cooldown conditions. The stress intensity factor is computed by multiplying the coefficient M_t from Figure G-2214-1 of ASME Appendix G [6] by the through-wall temperature gradient ΔT_w, given that the temperature gradient has a through-wall shape similar to that shown in Figure G-2214-2 of ASME Appendix G [6]. The relationship used to compute the through-wall ΔT_w is based on one-dimensional heat conduction through an insulated flat plate:

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

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

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

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

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

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

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-2214-2 of ASME Appendix G [6]. Therefore, ΔT_w calculated from Equation 4-15 is used with the appropriate M_t of Figure G-2214-1 of ASME Appendix G [6] to compute K_{It} for heatup and cooldown.

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

Nozzles in the Beltline Region

In the event that a nozzle is the limiting material for the beltline region, the beltline core not critical P-T curves are calculated in the same manner as the Feedwater Nozzle core not critical P-T curves as described in Section 4.3.2.1.4. The generic feedwater core not critical P-T curve is applied to the plant-specific Feedwater Nozzle curve by shifting the P vs. ($T-RT_{NDT}$) values in Section 4.3.2.1.4 to reflect the appropriate ART value from Table 4-2 of Attachment 1 or Appendix B of the PTLR. An example calculation is presented in Appendix F.

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

The core not critical heatup/cooldown curve at a given pressure uses the same K_{Im} calculation 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 condition rather than a test condition; the operational condition necessitates the use of 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 = plant-specific value shown in Section 4.3.2.2.4 of Attachment 1
Thermal diffusivity at 550°F (most conservative value)	β = 0.354 ft²/ hr [21]

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

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

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

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

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

T is calculated by adding the adjusted RT_{NDT} to the $T - RT_{NDT}$ obtained using Equation 4-17.

4.3.2.3 CLOSURE FLANGE REGION

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

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

The approach used for the plant-specific case for the bolt-up temperature is based on the conservative value of (RT_{NDT} + 60°F), or the LST of the bolting materials, whichever is greater. The 60°F adder is included by GE for two reasons: 1) the pre-1971 requirements of the ASME Code Section III, Subsection NA, Appendix G included the 60°F adder, and 2) inclusion of the additional 60°F requirement above the RT_{NDT} provides the additional assurance that a 1/4T flaw size is acceptable. The limiting initial RT_{NDT} for the closure flange region is obtained from Table 4-1 of Attachment 1 or Appendix B of the PTLR, as is the LST of the closure studs. The bolt-up temperature value used is the more conservative of these values. This conservatism is appropriate because bolt-up is one of the more limiting operating conditions (high stress and low temperature) for brittle fracture.

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

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

The shutdown margin, provided in the plant-specific Technical Specification, is typically 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 limit for the upper vessel and beltline region and the 68°F limit for the bottom head curve apply when the head is on and tensioned and when the head is off while fuel is in the vessel. When the head is not tensioned and fuel is not in the vessel, the requirements of

10CFR50 Appendix G [8] do not apply, and there are no limits on the vessel temperatures.

4.3.2.4 CORE CRITICAL OPERATION REQUIREMENTS OF 10CFR50, APPENDIX G

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

Table 1 of 10CFR50 Appendix G [8] indicates that for a BWR with water level within normal range for power operation, the allowed temperature for initial criticality at the closure flange region is (RT_{NDT} + 60°F) at pressures below 312 psig. This minimum criticality requirement is demonstrated in Section 4.3.2.4 of Attachment 1. 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). The requirement of closure region RT_{NDT} + 160°F typically causes 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 curves, the P-T curves specify a coolant heatup and cooldown temperature rate of 100°F/hr or less for which the curves are applicable. However, the core not critical and the core critical curves were also developed to bound transients defined on the plant-specific RPV thermal cycle diagram [2] and 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 and cooldown and for both the 1/4T and 3/4T locations because the maximum tensile stress for either heatup or cooldown is applied at the 1/4T location. For beltline curves this approach has added conservatism because irradiation effects cause the allowable toughness, K_{Ir}, at 1/4T to be less than that at 3/4T for a given metal temperature.

The following P-T curves are generated for the plant-specific case as seen in Attachment 1 and the PTLR:

- Composite P-T curves are generated for each of the pressure test and core not critical conditions. The composite curves are 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 penetration) curve is also individually included with the composite curve for the pressure test and core not critical condition.
- Separate P-T curves are developed for the upper vessel, beltline, and bottom head for the pressure test and core not critical conditions.
- A composite P-T curve is also generated for the core critical condition. The composite curves are 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 of Attachment 1 shows the figure numbers for each P-T curve. A tabulation of the curves is presented in Appendix B of Attachment 1 and the PTLR.

The following table is included in the plant-specific P-T curve report (Attachment 1):

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

The following figures are included in Attachment 1. The figures noted in this list are typical of those provided on a plant-specific basis. On occasion, variations are requested by different Utilities; in these cases, the methods used to develop the various curves are consistent with the methods described in this report, and are presented in the manner requested by the Utility.

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

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

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

Figure 5-6: Composite Pressure Test P-T Curves [Curve A] up to End of License EFPY [20°F/hr or less coolant heatup/cooldown]

Figures are provided for the PTLR in the manner requested by the Utility.

6.0 REFERENCES

1. Currently Licensed Plant-Specific P-T Curves.

2. GE Drawing of Plant-Specific Reactor Vessel Thermal Cycles (GE Proprietary).

3. GE Drawing of Plant-Specific Reactor Vessel Nozzle Thermal Cycles (GE Proprietary).

4. Plant-Specific Fluence Calculation (GE Proprietary) or other approved Fluence Calculation.

5. a) "BWR Vessel and Internals Project BWR Integrated Surveillance Program Implementation Guidelines", BWRVIP-102, EPRI, Palo Alto, CA (EPRI Proprietary).
b) "BWR Vessel and Internals Project Integrated Surveillance Program (ISP) Data Source Book and Plant Evaluations", BWRVIP-135, EPRI, Palo Alto, CA, (EPRI Proprietary).

6. "Fracture Toughness Criteria for Protection Against Failure", Appendix G to Section XI of the ASME Boiler & Pressure Vessel Code.

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

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

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

10. GE Nuclear Energy, NEDC-32399-P, "Basis for GE RT_{NDT} Estimation Method", Report for BWR Owners' Group, San Jose, California, September 1994 (GE Proprietary).

11. Letter from B. Sheron to R.A. Pinelli, "Safety Assessment of Report NEDC-32399-P, Basis for GE RT_{NDT} Estimation Method, September 1994", USNRC, December 16, 1994.

12. Plant-Specific QA Records and RPV CMTRs.

13. "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence", USNRC Regulatory Guide 1.190, April 2001.

14. Plant-Specific Fluence Input using an NRC-Approved Method.

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

16. [[ ]]

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

18. [[ ]]

19. Bottom Head and Feedwater Nozzle Dimensions:
    a. Plant-Specific Bottom Head Drawing.
    b. Plant-Specific Feedwater Nozzle Drawing.

20. [[ ]]

21. "Materials - Properties", Part D to Section II of the ASME Boiler & Pressure Vessel Code.

APPENDIX A

DESCRIPTION OF DISCONTINUITIES

The following tables are provided in Appendix A of Attachment 1.

[[ ]]

Table A-2 – Example Geometric Discontinuities Not Requiring Fracture Toughness Evaluations

APPENDIX B

PRESSURE-TEMPERATURE CURVE DATA TABULATION

The following tables are provided in Appendix B of Attachment 1 and the PTLR:

APPENDIX C

OPERATING AND TEMPERATURE MONITORING REQUIREMENTS

C.1 NON-BELTLINE MONITORING DURING PRESSURE TESTS

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

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

C.2 DETERMINING WHICH CURVE TO FOLLOW

The following subsections outline the criteria needed for determining which curve is governing during different situations. The application of the P-T curves and some of the assumptions inherent in the curves to plant operation is dependent on the proper monitoring of vessel temperatures.

C.2.1 Curve A: Pressure Test

Curve A should be used during pressure tests at times when the coolant temperature is changing by ≤20°F per hour. If the coolant is experiencing a higher heating or cooling rate in preparation for or following a pressure test, Curve B applies.

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

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

C.2.3 Curve C: Core Critical Operation

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

C.3 REACTOR OPERATION VERSUS OPERATING LIMITS

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

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

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

- Head flange bolt-up
- 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 bolt-up.	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 bolt-up.	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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APPENDIX E

DETERMINATION OF BELTLINE REGION AND IMPACT ON FRACTURE TOUGHNESS

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

"The region of the reactor vessel (shell material including welds, heat affected zones, and plates or forgings) that directly surrounds the effective height of the active core and adjacent regions of the reactor vessel that are predicted to experience sufficient neutron radiation damage."

To establish the value of peak fluence for identification of beltline materials (as discussed above), the 10CFR50 Appendix H fluence value used to determine the need for a surveillance program was used; the value specified is a peak fluence (E>1 MeV) of 1.0e17 n/cm^2. Therefore, if it can be shown that no discontinuities are located where the peak neutron fluence is expected to exceed or equal 1.0e17 n/cm^2, then it can be concluded that all reactor vessel discontinuities, other than those shown in Table 4-2 of Attachment 1 or Appendix B of the PTLR, are outside the beltline region of the reactor vessel, and do not need to be considered in the P-T curve evaluation.

Plant-specific dimensions are obtained from referenced drawings for the locations of the beltline and components closest to this region as demonstrated in Table E-1 in Attachment 1 and Appendix B of the PTLR.

The following table is provided in Appendix E of Attachment 1 and Appendix B of the PTLR:

Table E-1 Determination of Discontinuities in Extended Beltline Region

From this comparison, it becomes obvious which plant-specific discontinuities are closest to the beltline region. If it is determined that any of these discontinuities sees a fluence greater than 1.0e17 n/cm^2, they are included in Table 4-2 of Attachment 1 and Appendix B of the PTLR, and considered in development of the beltline region P-T curves. If it can be shown that the peak fluence at these locations is less than 1.0e17 n/cm^2, it can be safely concluded that all discontinuities, other than those included in Table 4-2 of Attachment 1 or Appendix B of the PTLR, are outside the beltline region of the reactor vessel.

APPENDIX F

EXAMPLE CALCULATION FOR LIMITING NOZZLE
IN THE BELTLINE REGION

Pressure Test Procedure

As noted in Section 4.3.2.2.2 of this report, in the event that a nozzle is the limiting material for the beltline region, the beltline P-T curves are calculated in the same manner as for the Feedwater Nozzle pressure test P-T curves, using the plant-specific nozzle dimensions as described in Section 4.3.2.1.3. The generic Feedwater pressure test P-T curve is applied to the plant-specific Feedwater Nozzle curve by shifting the P vs. ($T-RT_{NDT}$) values in Section 4.3.2.1.3 to reflect the appropriate ART value from Table 4-2.

Example of Core Not Critical Beltline Calculation Using a Nozzle at 1055 psig and a Given EFPY

As an example using a Recirculation Inlet nozzle, the primary membrane stresses are scaled using the plant-specific nozzle geometry. The secondary thermal stresses for the FW nozzle are conservatively used for this nozzle. These stresses are then adjusted for stresses above yield. From these stresses, K_I can be determined. The stresses are scaled for various pressures and temperatures, similar to the scaling used for the FW nozzle core not critical curve in Section 4.3.2.1.4. The primary stresses are scaled by the nominal pressures, while the secondary stresses are scaled by the temperature difference of the cold FW nozzle (40°F) water injected into the hot reactor vessel nozzle. The base case is a pressure of 1050 psig and reactor vessel temperature of 551.4°F; this yields a K_I value of 305.6 ksi-in$^{1/2}$. Since the reactor vessel temperature follows the saturation temperature curve, the secondary stresses are scaled by ($T_{saturation}$ - 40°F) / (551°F - 40°F). From K_I, the associated $T - RT_{NDT}$ can be calculated.

FW Nozzle t_v = 6.1875 inches
Recirculation Inlet Nozzle t_v = 5.25 inches, however, t_v = 4.875 is conservatively used
$F(a/r_n)$ = 1.5

The FW nozzle stresses are used for the Recirculation Inlet nozzle; only the primary membrane stress is scaled for the plant-specific vessel thickness, t_v. At a pressure of 1050 psig and a temperature of 551.4°F, the stresses are:

σ_{pm} = 24.84 ksi * (6.1875 inches / 4.875 inches) = 31.53 ksi
σ_{pb} = 0.22 ksi
σ_{sm} = 16.19 ksi
σ_{sb} = 19.04 ksi

K_I is calculated:

$t^{1/2}$ = $(4a)^{1/2}$ = $(4 \cdot 1.89)^{1/2}$ = 2.75
M_m = $0.926 \cdot 2.75$ = 2.546

K_{IP} is calculated using Equation 4-4 as shown in Section 4.3.2.1.4:
K_{IP} = 2.0 * (31.53 + 0.22) * $(\pi \cdot 1.89)^{1/2}$ * 1.5 = 232.1 ksi-in$^{1/2}$

K_{Is} is calculated using Equation 4-5 as shown in Section 4.3.2.1.4:

K_{Is} = $2.546 \cdot (16.19 + 2/3 \cdot 19.04)$ = 73.5 ksi-in$^{1/2}$

K_I = $K_{IP} + K_{Is}$
K_I = 232.1 ksi-in$^{1/2}$ + 73.5 ksi-in$^{1/2}$ = 305.6 ksi-in$^{1/2}$

T-RT_{NDT} is further calculated:

T-RT_{NDT} = ln [(305.6 – 33.2) / 20.734] / 0.02 = 128.8°F

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

APPENDIX G

THICKNESS TRANSITION DISCONTINUITY EVALUATION

G.1 OBJECTIVE

The purpose of the following example evaluation is to determine the hydrotest, heatup/cooldown, and transient temperatures (T) for shell thickness transition discontinuities in the beltline and the bottom head upper to lower torus, to demonstrate the methods used to determine that these temperatures are bounded by the appropriate P-T curves.

G.2 METHODS AND ASSUMPTIONS

ANSYS finite element analyses are performed for any thickness discontinuities in the plant-specific vessel. The purpose of this example evaluation is to determine the RPV discontinuity stresses (hoop and axial) that result from the thickness transition discontinuity in the beltline and bottom head regions. The transitions are modeled as specified in Section G.2 of Attachment 1.

Load cases defined on the plant-specific vessel thermal cycle diagram [3] are evaluated for the transition region discontinuities, including the bounding beltline transients of those described in Region B of the plant-specific vessel thermal cycle diagram at temperatures for which brittle fracture could occur.

Additionally, the bottom head is analyzed for

1) [[ ]], and
2) [[ ]] [3].

As discussed in Section 4.3.2.1.2 of this report, these transients represent [[ ]]. The limiting Normal/Upset transient is also analyzed. It was determined that the [[ ]] transients for this example case bound this operating condition for the bottom head region; results for the bounding conditions are presented in Appendix G of Attachment 1.

Material properties are used from the Code of construction for the plant-specific RPV materials as defined in Section G.2 of Attachment 1.

Methods consistent with those described in Section 4.3 are used to calculate the $T - RT_{NDT}$ for the shell discontinuity for a plant-specific hydrotest pressure and the two bottom head region transient cases. For the beltline region, the adjusted reference temperature values shown in Table 4-2 of Attachment 1 and Appendix B of the PTLR are added to the $T - RT_{NDT}$ to determine the temperature, T. The value of T is compared to that of the beltline region for the same condition as described in Sections 4.3.2.2.1 for the hydrotest pressure case and 4.3.2.2.4 for the transient cases. Similarly, the value of T for the bottom head region is compared to that of the curve defined in Sections 4.3.2.1.1 for the hydrotest pressure case and 4.3.2.1.2 for the transient cases.

The Control Rod Drive Penetrations in the bottom head are not evaluated as a part of this discontinuity analysis; detailed analysis of the penetrations is provided in Appendix H. The stub tubes provide sufficient stiffness that the deletion of these penetrations from this analysis is acceptable.

It is demonstrated in the Attachment 1 example case that Curve A for the bottom head (CRD) and beltline regions (Figures 5-1 and 5-4 of Attachment 1, respectively) bound the temperatures found for the hydrostatic pressure test temperatures from the FEA analysis. It is also shown that Curve B for the bottom head and beltline regions (Figures 5-7 and 5-10 of Attachment 1, respectively) bound the temperatures found for transient pressures from the stresses obtained in the FEA analysis. Therefore, the transition discontinuity stresses in the beltline and bottom head upper to lower torus are bounded by the P-T curves.

The locations of maximum stress are evaluated for the beltline shell and bottom head torus locations as shown in Figure G-1 of Attachment 1.

The methods of ASME Code Section XI, Appendix G [6] are used to calculate the pressure test and thermal limits. The membrane and bending stresses are determined from the finite element analysis and are shown in Appendix G of Attachment 1. The hoop stresses are more limiting than the axial stresses, and are provided in Tables G-1 through G-5 of Appendix G in Attachment 1.

The stress intensity factors, K_{Im} and K_{Ib}, are calculated using ASME Code Section XI Appendix A [7] and Appendix G [6], as shown in Section 4.3.2.2.2 of this report. Therefore,
$K_{Im} = M_m \cdot \sigma_m$ and $K_{Ib} = M_b \cdot \sigma_b$. The values of M_m and M_b are determined from the ASME Code Appendix G [6]. The stress intensity is based on a 1/4 T radial flaw with a six-to-one aspect ratio (length of 1.5T). The flaw is oriented normal to the maximum stress direction, in this case a vertically oriented flaw since the hoop stress is limiting.

The calculated value of $K_{Im} + K_{Ib}$ is multiplied by a safety factor (SF) (1.5 for pressure test and 2.0 for the transient cases), per ASME Appendix G [6] for comparison with K_{IR}, the material fracture toughness expressed as K_{Ic}.

The relationship between K_{Ic} and temperature relative to reference temperature ($T - RT_{NDT}$) is provided in ASME Code Section XI Appendix A [7] Paragraph A-4200, represented by the relationship (K_I units ksi-in$^{1/2}$):

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

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

$$\text{where } K_{Ic} = SF * (K_{Im} + K_{Ib}) \quad \text{for the pressure test,}$$

$$\text{and } K_{Ic} = (SF * K_{IP}) + K_{IS} \quad \text{for transient cases.}$$

This relationship is derived in the Welding Research Council (WRC) Bulletin 175 [8] as the lower bound of all dynamic fracture toughness data. This relationship provides values of pressure versus temperature (from K_{IR} and $(T - RT_{NDT})$, respectively).

The RT_{NDT} is added to the $(T - RT_{NDT})$ to determine the hydrotest, heatup, cooldown, and additional transient temperatures.

Analysis Information:

The values used for t_{min}, t_{max}, and $\sqrt{(t)}$ are provided in Section G.1 of Attachment 1.

The following figure is provided in Appendix G of Attachment 1:

> Figure G-1: Location and Wall Thickness of Evaluation Discontinuities in the Beltline and Bottom Head Regions

The following tables are provided in Appendix G of Attachment 1:

> Table G-1: Analysis Results for Hydrostatic Pressure Test for the Beltline Shell Discontinuity
> Table G-2: Analysis Results for Hydrostatic Pressure Test for the Bottom Head Discontinuity

G.3 Results and Conclusions for Hydrostatic Pressure Test

The results of this example analysis demonstrate that Curve A remains bounding for the bottom head torus (Figure 5-1 of Attachment 1) and beltline shell (Figure 5-4 of Attachment 1) discontinuities.

Beltline

The maximum plant-specific T - RT_{NDT} calculated with the linearized stresses from the Finite Element Analysis (FEA) for the beltline thickness discontinuity is obtained from Table G-1 of Attachment 1. The limiting beltline plate and weld material RT_{NDT} (ART) at the region of the discontinuity is obtained from Table 4-2 of Attachment 1 and Appendix B of the PTLR. The required T for the beltline curve is determined by adding T – RT_{NDT} and ART.

The values obtained from the FEA are compared to the T - RT_{NDT} for the beltline region Curve A obtained from Section 4.3.2.2.2 of Attachment 1. If the beltline region hydrostatic pressure test temperature T is greater than the T obtained with the FEA analysis results, the thickness discontinuity remains bounded by the beltline curve. Should the FEA analysis T exceed the P-T curve T, the P-T curve is adjusted such that it bounds the discontinuity.

Bottom Head Lower Torus to Upper Torus

The maximum T - RT_{NDT} calculated with the Finite Element Analysis results for the bottom head lower torus to upper torus region is obtained from Table G-2 of Attachment 1. The maximum RT_{NDT} for the bottom head lower torus to upper torus materials is obtained from Table 4-1 of Attachment 1 and Appendix B of the PTLR.

The values obtained from the FEA are compared to the T - RT_{NDT} for the bottom head region Curve A obtained from Section 4.3.2.1.2 of Attachment 1. If the bottom head region hydrostatic pressure test temperature T is greater than the T obtained with the FEA analysis results, the thickness discontinuity remains bounded by the bottom head curve. Should the FEA analysis T exceed the P-T curve T, the P-T curve is adjusted such that it bounds the discontinuity.

The following tables are included in Appendix G of Attachment 1:

Table G-3: Beltline Analysis and Results for Heatup and Cooldown

Table G-4: Bottom Head Analysis and Results for Heatup and Cooldown

Table G-5: Bottom Head Analysis and Results for [[
]]

G.4 Results and Conclusions for Transient Cases

The results of the discontinuity analysis demonstrate that the linearized stresses in the bottom head torus, and beltline regions are bounded by the bottom head (CRD) Curve B, and the beltline Curve B (Figures 5-7 and 5-10, respectively, from Attachment 1).

<u>Beltline</u>

The maximum plant-specific T - RT_{NDT} calculated with the linearized stresses from the Finite Element Analysis (FEA) for the beltline thickness discontinuity is obtained from Table G-3 of Attachment 1. The limiting beltline weld material RT_{NDT} (ART) at the region of the discontinuity is obtained from Table 4-2 of Attachment 1 and Appendix B of the PTLR. The limiting beltline plate RT_{NDT} (ART) at the region of the discontinuity is also obtained from Table 4-2.

The values obtained from the FEA are compared to the T - RT_{NDT} for the beltline region Curve B. If the beltline region T is greater than the T obtained with the FEA analysis results, the thickness discontinuity remains bounded by the beltline curve. Should the FEA analysis T exceed the P-T curve T, the P-T curve is adjusted such that it bounds the discontinuity.

<u>Bottom Head Lower Torus to Upper Torus</u>

The maximum plant-specific T - RT_{NDT} for the thickness discontinuity in the bottom head lower to upper torus region is obtained from Tables G-4 and G-5 of Attachment 1. The maximum RT_{NDT} for the materials in this region is obtained from Table 4-1 of Attachment 1 and Appendix B of the PTLR.

The values obtained from the FEA are compared to the T - RT_{NDT} for the bottom head region Curve B obtained from Section 4.3.2.1.2 of Attachment 1. If the bottom head region T is greater than the T obtained with the FEA analysis results, the thickness discontinuity remains bounded by the bottom head curve. Should the FEA analysis T exceed the P-T curve T, the P-T curve is adjusted such that it bounds the discontinuity.

Appendix G References:

1. Plant-Specific Vessel Drawings.
2. Plant-Specific Vessel Drawings.
3. Plant-Specific Vessel Drawings.
4. Plant-Specific Vessel Drawings.
5. Plant-Specific QA Records and RPV CMTRs.
6. "Fracture Toughness Criteria for Protection Against Failure", Appendix G to Section XI of the ASME Boiler and Pressure Vessel Code.
7. "Analysis of Flaws", Appendix A to Section XI of the ASME Boiler and Pressure Vessel Code.
8. "PVRC Recommendations on Toughness Requirements for Ferritic Materials", Welding Research Council Bulletin 175, August 1972.

APPENDIX H

CORE NOT CRITICAL CALCULATION

FOR THE BOTTOM HEAD CRD PENETRATION

TABLE OF CONTENTS

The following outline describes the contents of this Appendix:

H.1 Executive Summary

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

]] This method more accurately predicts the expected stress intensity [[

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

]]

H.2 Scope

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

H.3 Analysis Methods

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

H.3.1 Applicability of the ASME Code Appendix G Methods

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

[[

]]

Noting these items, the applicability of the methods suggested in Appendix G [[ ]] The ASME Code does not preclude using other methods; therefore, a more detailed [[ ]] finite element fracture mechanics analysis [[

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

H.3.2 Finite Element Fracture Mechanics Evaluation

An advanced [[ ]] finite element analysis of a BWR bottom head geometry [[

]] was performed to determine the Mode I stress intensity at the tip of a 1/4T postulated flaw. [[

]]

<u>Finite Elements</u> [[ ]]

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

]]

Structural Boundary Conditions

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

]] The mesh is shown in Figure H-1.

[[

]]

Material Properties

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

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

[[

]]

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

Loads

Two loads cases were independently analyzed.

1. Pressure Loading –

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

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

   ]]

   Figure H-2. Pressure Loads

2. [[ ]] Thermal Transient

   [[

   ]]

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

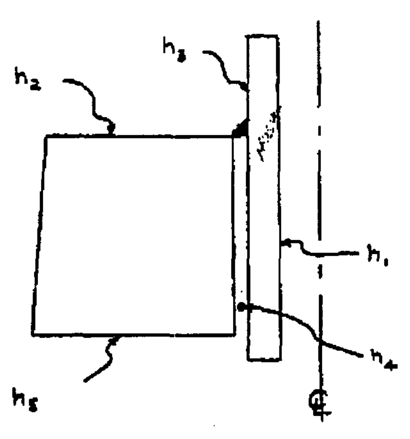

Figure H-3. Regions To Which Thermal Loads Are Applied

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

b. Regions 2 and 3:

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

[[

]]

Temperature Plot vs. Time (min.)

c. Region 4: Adiabatic (exaggerated in size in drawing)

d. Region 5: h = 0.2, T = 100

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

Crack Configurations

The following four cracks were analyzed:

1. A part through crack, ¼ of the vessel wall thickness deep, measured from inside the vessel, [[ ]]
2. Same as 1, but depth is measured from outside the vessel
3. Same as 1, [[ ]]
4. Same as 2, [[ ]]

[[ ]]

The cracks considered for this analysis [[ ]]

[[

Stress Intensity Factor Computation

[[

]]

[[

]]

Benchmarking [[ ]] Methodology

[[

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

Pressure Loading Analysis Results

[[

]]

Benchmarking of Pressure Loading Results

Pressure Loading analyses [[

]]

Thermal Transients Analysis Results

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

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

]]

[[ ]] Thermal Gradients [[ ]]

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

[[

]]

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

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

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

[[

]]

H.3.3 ASME Code Appendix G Evaluation

The peak stress intensities for the pressure and thermal load cases evaluated above are used as inputs to the ASME Code Appendix G evaluation methodology [1] to calculate a $T - RT_{NDT}$. The core not critical bottom head P-T curve $T - RT_{NDT}$ is calculated using the formulas listed below:

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

$$SF_p = 2.0$$

$$SF_t = 1.0$$

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

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

Note that the stress intensity is defined in units of: $ksi*in^{1/2}$.

H.4 Results

Review of the [[ ]] results above demonstrates that the OD [[ ]] crack exhibits the highest stress intensity for the considered loading. The $T - RT_{NDT}$ to be used in the core not critical bottom head P-T curves shall be calculated using the stress intensities obtained at this location. The calculations are shown below:

[[

]]

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

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

]]

H.5 Conclusions

For the [[ ]] transient, the appropriate T-RT_{NDT} for use in determining the bottom head core not critical P-T curves [[ ]]. Existing bottom head core not critical curves developed using the previous GE methodology [[
]]

H.6 References

1. American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME B&PV Code), Section XI.

2. ANSYS User's Manual, Version 6.1.

APPENDIX I

GUIDANCE FOR THE USE OF BWRVIP ISP SURVEILLANCE DATA

THIS APPENDIX WAS PROVIDED BY THE EPRI BWRVIP PROGRAM

This section provides guidance for the use of BWR surveillance data for developing pressure temperature limit curves and other vessel integrity evaluations.

I.1 Introduction

The BWRVIP Integrated Surveillance Program (ISP) replaces individual plant reactor pressure vessel surveillance capsule programs with representative weld and base materials data from host reactors [1]. A representative material is a plate or weld material that is selected from among all the existing plant surveillance programs or the Supplemental Surveillance Program (SSP) [2] to represent one or more limiting plate or weld materials in a plant. The BWRVIP ISP is responsible to provide each BWR plant with surveillance data for the materials assigned to represent that plant's limiting vessel weld and base materials. Plant owners, in turn are responsible to evaluate the data using the methods in Regulatory Guide 1.99, Revision 2 [3], in accordance with 10CFR50, Appendix G, for determination of Adjusted Reference Temperature (ART) values.

Surveillance and chemistry data for all representative materials in the ISP have been evaluated by BWRVIP. For each material that has been designated as an ISP representative material, a comprehensive material summary has been developed. All baseline and irradiated Charpy data for ISP surveillance materials have been obtained from past surveillance program and capsule reports. The data were reanalyzed, using consistent analysis standards and protocols. Best estimate chemistry values were also calculated in a manner consistent with USNRC guidance [4].

The BWRVIP ISP has been generically approved by NRC and is documented in a safety evaluation [5]. Owners incorporate the ISP on a plant-specific basis via license amendment.

I.2 Guidance for Processing Surveillance Data

The following process is recommended for evaluating surveillance data:

1. If there is new surveillance data for any heat that is located in the vessel beltline (e.g., heat numbers match), then Procedure #1 can be used as a guide for evaluating the new information. A new Adjusted Reference Temperature (ART) should be calculated for the vessel material to determine whether plant vessel integrity evaluations are affected.

2. If there is new information but that same heat number is not contained in the vessel beltline, then Procedure #2 can be used as a guide for evaluating the new information.

I.3 Reporting

The following information should be reported to the BWRVIP following an evaluation of the ISP surveillance data applied to a specific BWR vessel.

1. After vessel integrity evaluations (e.g., ART tables) are updated, the plant should provide an information copy of the revised ART tables for the beltline materials to the BWRVIP ISP Project Manager. This will assist the BWRVIP during its annual ISP program review to revalidate the ISP Test Matrix.

2. As an ongoing "maintenance" activity, all plants should inform the BWRVIP ISP Project Manager whenever its fluence calculations are updated. It is essential that the following information be promptly reported to the BWRVIP ISP Project Manager:

    a. Updated fluence values for the beltline region inside surface and 1/4T positions;

    b. Revised capsule fluence estimates and revised lead or lag factors;

    c. Revised ART calculations for beltline materials resulting from the revised fluence, with fluence, CF and margin clearly specified for each material.

    This information is particularly vital to the BWRVIP ISP, because any revisions to capsule fluence estimates can affect RT_{NDT} shift calculations for that material – with a direct effect on any other plants using that data for an updated CF value.

Procedure #1

Recommended Guidance for the Use of ISP Surveillance Data when Vessel Material and Surveillance Material Heat Numbers Are Identical

Prerequisites

This procedure provides recommended guidance for the use of BWRVIP ISP surveillance data only when the following condition is met:

1. *The heat number of the vessel beltline material being evaluated and the heat number of the surveillance material (e.g., the ISP Representative Material or other material) are identical.*

Objective

The objective of this procedure is to determine the Adjusted Reference Temperature (ART) for the vessel material as determined by the following expression:

$$\text{ART} = \text{Initial } RT_{NDT} + \Delta RT_{NDT} + \text{Margin} \qquad (1)$$

This procedure is designed to determine the "ΔRT_{NDT}" and "Margin" terms of the ART equation. The "Initial RT_{NDT}" is established by the plant according to the definition below.

Definitions and Background

The guidance provided by this procedure is based on Regulatory Guide 1.99, Rev. 2, with clarifications as noted by References 4 (1998 NRC Presentation) and 5 (10CFR50.61, PTS Rule).

Initial RT_{NDT} is the reference temperature for the unirradiated material as defined in Paragraph NB-2331 of Section III of the ASME Boiler and Pressure Vessel Code. Some plants have measured values of Initial RT_{NDT}; other plants use generic values. For generic values of weld metal, the following generic mean values must be used unless justification for different values is provided: 0°F for welds made with Linde 80 flux, and -56°F for welds made with Linde 0091, 1092, and 124 and ARCOS B-5 weld fluxes [6].

ΔRT_{NDT} is the mean value of the adjustment in reference temperature caused by irradiation, as calculated by the equation:

$$\Delta RT_{NDT} = (CF)\, f^{(0.28 - 0.1 \log f)} \qquad (2)$$

where CF (°F) is the chemistry factor. The CF can either be a function of copper and nickel content, as given in Reg. Guide 1.99 Rev. 2 Table 1 (welds) or 2 (base metal), or a factor based on the "best fit" of two or more surveillance test data.

The neutron fluence at any depth in the vessel wall, f (10^{19} n/cm^2, E > 1 MeV), is determined as follows:

$$f = f_{surf}\,(e^{-0.24x}) \qquad (3)$$

where f_{surf} (10^{19} n/cm^2, E > 1 MeV) is the calculated value of the neutron fluence at the vessel inner surface, and x (in inches) is the depth into the vessel wall measured from the vessel inner surface. The depth of interest for this calculation is the 1/4T position in the vessel wall.

The fluence factor, $f^{(0.28 - 0.1 \log f)}$, is determined by calculation from the fluence.

"Margin" is the quantity, °F, that is to be added to obtain conservative upper-bound values of adjusted reference temperature required by Appendix G to 10CFR, Part 50,

$$\text{Margin} = 2\sqrt{\sigma_I^2 + \sigma_\Delta^2} \qquad (4)$$

where σ_I is the standard deviation for the initial RT_{NDT}. If a measured value of initial RT_{NDT} for the material in question is available, σ_I is to be estimated from the precision of the test method (and it is normally taken to be 0°F). If not, and generic mean values for the class of material are used, σ_I is the standard deviation obtained from the set of data used to establish the mean. If the generic mean Initial RT_{NDT} value of a Linde 80, 0091, 1092 and 124 or ARCOS B-5 weld is used, then σ_I is 17°F [6]. The standard deviation for ΔRT_{NDT}, σ_Δ , is 28°F for welds and 17°F for base metal, except that σ_Δ need not exceed 0.50 times the mean value of ΔRT_{NDT}.

Procedural Steps

1. Verify Heat Number Match

This recommended procedure is applicable only in the case that the heat number of the vessel beltline material being evaluated and the heat number of the surveillance material (e.g., the ISP Representative Material or other material) are identical. If not, then Procedure #2, "Recommended Guidance for the Use of ISP Surveillance Data When the Vessel Material and Surveillance Material Heat Numbers Do Not Match", should be used.

2. Identify Available Surveillance Data for this Heat

Review the ISP surveillance data for this heat. Are there 2 or more reported surveillance data points for this material? If YES, proceed to Step 3. If NO, then skip to Step 5.

3. Determine Credibility of Surveillance Data

The objective of this step is to verify that there are two or more valid, credible surveillance data points for this heat.

The BWRVIP analysis of the surveillance data for this heat should be reviewed.

a. Confirm that the vessel wall temperature at the cladding/base metal interface (in the beltline region) is within +/- 25°F of the BWR capsule irradiation temperature range of 525°F to 535°F.

b. If the vessel wall temperature is an outlier appropriate temperature adjustments to the surveillance data may be required.

c. If the vessel temperature credibility criterion is confirmed, then the plant should declare the surveillance data to be "credible" or "not credible" for its vessel, depending on the BWRVIP evaluation of the data scatter criterion.

Note: Classification of the surveillance data as "credible" or "not credible" does not determine whether or not the data will be *used. Under certain circumstances, the NRC requires the Chemistry Factor to be based on non-credible surveillance data, if the Table CF is non-conservative in comparison [4]. Those circumstances will be explained in detail in the following steps.*

4. Determine Chemistry Factor (2 or more Surveillance Data)

This step applies only when there are 2 or more surveillance data points available. If there is only one surveillance data point, or no data, then skip to Step 5.

The CF is based either on the Reg. Guide 1.99 Rev. 2 tables, or on the best fit of the surveillance data, according to the guidance below.

If the material being evaluated is a plate, determine the Chemistry Factor according to Step 4.a. If the material is a weld, determine Chemistry Factor according to Step 4.b.

4.a.Determine CF for a Plate Material

1) Determine the Table CF (that is, the CF given in Table 2 of Reg. Guide 1.99 Rev. 2) for the best estimate chemistry of the vessel plate.

2) Compare this Table CF to the surveillance CF (e.g., the CF determined by a best fit to the surveillance data) reported by the BWRVIP.

3) If the fitted data give a higher value of CF than the tables, then surveillance data CF should be used. This is true even if the surveillance data were not credible (Ref. 4, Case 3).

4) If the fitted results give a lower value, and the surveillance data are credible, then either the Table CF or the surveillance CF value may be used. If the fitted results give a lower value, and the surveillance data are not credible, then the higher (e.g., Table CF) must be used (Ref. 4, Case 2).

5) Skip to Step 6.

4.b.Determine CF for a Weld Material

If the measured copper or nickel content of the surveillance weld differs from that of the vessel weld of the same heat, (i.e., the surveillance weld best estimate chemistry differs from the vessel weld best estimate chemistry), the fitted CF from the surveillance data should be adjusted by multiplying it by the ratio of the Reg. Guide 1.99 Rev. 2 table chemistry factor for the vessel weld to that for the surveillance weld. The following steps incorporate this adjustment:

1) Determine the Table CF (that is, the CF given in Table 1 of Reg. Guide 1.99 Rev. 2) for the best estimate chemistry of the vessel weld.

   Note: Revised best estimate chemistries for selected BWR welds and plates have been calculated by the BWRVIP. Calculation of the best estimate chemistries for all other vessel materials is the responsibility of the plant.

2) Determine the Table CF for the best estimate chemistry of the surveillance weld (Table $CF_{Surv.\ Chem}$).

3) Calculate an Adjusted Surveillance CF by the following equation:

$$\text{Adjusted Surv. CF} = \left(\frac{\text{Table } CF_{\text{Vessel Chem.}}}{\text{Table } CF_{\text{Surv. Chem.}}}\right) * CF_{\text{Fitted Data}} \qquad (5)$$

4) Compare the Adjusted Surveillance CF to the Table $CF_{Vessel\ Chem}$.

5) If the Adjusted Surveillance CF is higher than the Table $CF_{Vessel\ Chem}$, then the Adjusted Surveillance CF should be used as the CF in Step 6 (calculation of ΔRT_{NDT}). This is true even if the surveillance data were not credible because of excessive scatter.

6) If the Adjusted Surveillance CF is less than the Table $CF_{Vessel\ Chem}$, and the surveillance data are credible, then either the Table CF or the Adjusted Surv. CF value may be used. If the Adjusted Surveillance CF is less than the Table $CF_{Vessel\ Chem}$, and the

surveillance data are not credible, then the higher (e.g., Table $CF_{Vessel\ Chem}$) must be used.

7) Skip to Step 6.

5. *Determine Chemistry Factor (No Surveillance Data, or 1 Data Point)*

This step applies only when there is only one, or less, surveillance data points available. If there are two or more surveillance data points, do not use Step 5; go back to Step 4.

The CF for the vessel material should be determined from the Reg. Guide 1.99 Rev. 2 tables, based on the best estimate chemistry of the vessel material.

Note: Revised best estimate chemistries for selected BWR welds and plates have been calculated by the BWRVIP. Calculation of the best estimate chemistries for all other vessel materials is the responsibility of the plant.

After the CF associated with the best estimate chemistry of the vessel heat is determined from Reg. Guide 1.99 Rev. 2 Table 1 (Welds) or Table 2 (Plates), proceed to Step 6.

6. *Calculate ΔRT_{NDT}*

Calculate the transition temperature shift at the 1/4T position in the vessel, $\Delta RT_{NDT\ 1/4T}$, using the appropriate CF value determined in Step 4 or 5 and the projected fluence at the 1/4T location, $f_{1/4T}$, using equation (6):

$$\Delta RT_{NDT_{1/4T}} = CF * f_{1/4T}^{(0.28 - 0.1 \log f_{1/4T})} \tag{6}$$

7. *Determine Margin*

The margin term is calculated by Equation (4). If the surveillance data are credible, the values given there for σ_Δ may be cut in half. Therefore:

a) For credible surveillance data, σ_Δ is the lower of the following:

a) 14°F for welds, 8.5°F for base metal, <u>or</u>

b) 0.50 times the mean value of ΔRT_{NDT}.

b) If the surveillance data are not credible, then σ_{Δ} is the lower of the following:

a) 28°F for welds, 17°F for base metal, or

b) 0.50 times the mean value of ΔRT_{NDT}.

8. *Calculate the ART for the Vessel Material*

Calculate the ART for the vessel material using Equation (1) and the values for ΔRT_{NDT} and Margin determined above.

Procedure #2

Recommended Guidance for the Use of ISP Surveillance Data when Vessel Material and Surveillance Material Heat Numbers Do Not Match

Prerequisites

This procedure provides recommended guidance for the use of BWRVIP ISP surveillance data only when the heat number of the vessel beltline material being evaluated and the heat number of the surveillance material (e.g., the ISP Representative Material) do not match.

Objective

The objective of this procedure is to determine the Adjusted Reference Temperature (ART) for the vessel material as determined by the following expression:

$$ART = \text{Initial } RT_{NDT} + \Delta RT_{NDT} + \text{Margin} \quad (1)$$

This procedure is designed to assist the plants in using the ISP surveillance data to determine the "ΔRT_{NDT}" and "Margin" terms of the ART equation. The "Initial RT_{NDT}" is established by the plant according to the definition below.

Definitions and Background

Initial RT_{NDT} is the reference temperature for the unirradiated material as defined in Paragraph NB-2331 of Section III of the ASME Boiler and Pressure Vessel Code. Some plants have measured values of Initial RT_{NDT}; other plants use generic values. For generic values of weld metal, the following generic mean values must be used unless justification for different values is provided: 0°F for welds made with Linde 80 flux, and -56°F for welds made with Linde 0091, 1092, and 124 and ARCOS B-5 weld fluxes.

ΔRT_{NDT} is the mean value of the adjustment in reference temperature caused by irradiation, as calculated by the equation:

$$\Delta RT_{NDT} = (CF)\, f^{(0.28 - 0.1 \log f)} \qquad (2)$$

where CF (°F) is the chemistry factor. The CF can either be a function of copper and nickel content, as given in Reg. Guide 1.99 Rev. 2 Table 1 (welds) or 2 (base metal), or a factor based on the "best fit" of two or more surveillance test data. For the materials being evaluated by this procedure, only the Reg. Guide tables will be used.

The neutron fluence at any depth in the vessel wall, f (10^{19} n/cm^2, E > 1 MeV), is determined as follows:

$$f = f_{surf}\,(e^{-0.24x}) \qquad (3)$$

where f_{surf} (10^{19} n/cm^2, E > 1 MeV) is the calculated value of the neutron fluence at the vessel inner surface, and x (in inches) is the depth into the vessel wall measured from the vessel inner surface. The depth of interest for this calculation is the 1/4T position in the vessel wall.

The fluence factor, $f^{(0.28 - 0.1 \log f)}$, is determined by calculation from the fluence.

"Margin" is the quantity, °F, that is to be added to obtain conservative upper-bound values of adjusted reference temperature required by Appendix G to 10CFR, Part 50,

$$\text{Margin} = 2\sqrt{\sigma_I^2 + \sigma_\Delta^2} \qquad (4)$$

where σ_I is the standard deviation for the initial RT_{NDT}. If a measured value of initial RT_{NDT} for the material in question is available, σ_I is to be estimated from the precision of the test method (and it is normally taken to be 0°F). If not, and generic mean values for the class of material are used, σ_I is the standard deviation obtained from the set of data used to establish the mean. If the generic mean Initial RT_{NDT} value of a Linde 80, 0091, 1092 and 124 or ARCOS B-5 weld is used, then σ_I is 17°F. The standard deviation for ΔRT_{NDT}, σ_Δ , is 28°F for welds and

17°F for base metal, except that σ_{Δ} need not exceed 0.50 times the mean value of ΔRT_{NDT}.

Procedural Steps

1. *Verify Heat Numbers Do Not Match*

This recommended procedure is applicable only in the case that the heat number of the vessel beltline material being evaluated and the heat number of the surveillance material (e.g., the ISP Representative Material or other material) do not match. If they do match, then Procedure #1, "Recommended Guidance for the Use of ISP Surveillance Data When Vessel Material and Surveillance Material Heat Numbers Are Identical" should be used.

2. *Review Surveillance Data for the Assigned ISP Representative Material*

All surveillance data for the ISP representative materials have been analyzed by the BWRVIP.

3. *Determine Chemistry Factor*

The CF for the vessel material should be determined from the Reg. Guide 1.99 Rev. 2 Table 1 (Welds) or Table 2 (Plates), based on the best estimate chemistry of the vessel material.

> *Note: Revised best estimate chemistries for selected BWR welds and plates have been calculated by the BWRVIP. Calculation of the best estimate chemistries for all other vessel materials is the responsibility of the plant.*

4. *Calculate ΔRT_{NDT}*

Calculate the transition temperature shift at the 1/4T position in the vessel, $\Delta RT_{NDT\ 1/4T}$, using the CF value determined in Step 3 and the projected fluence at the 1/4T location, $f_{1/4T}$, using equation (6):

$$\Delta RT_{NDT_{1/4T}} = CF * f_{1/4T}^{(0.28 - 0.1 \log f_{1/4T})} \qquad (6)$$

5. *Determine Margin*

The margin term is calculated by Equation (4).

σ_Δ is the lower of the following:

a. 28°F for welds, 17°F for base metal, <u>or</u>

b. 0.50 times the mean value of ΔRT_{NDT}.

6. *Calculate the ART for the Vessel Material*

Calculate the ART for the vessel material using Equation (1) and the values for ΔRT_{NDT} and Margin determined above.

Table 6-1

Chemistry Factor for Welds, °F

Copper Wt-%	Nickel, Wt-% 0	0.20	0.40	0.60	0.80	1.00	1.20
0	20	20	20	20	20	20	20
0.01	20	20	20	20	20	20	20
0.02	21	26	27	27	27	27	27
0.03	22	35	41	41	41	41	41
0.04	24	43	54	54	54	54	54
0.05	26	49	67	68	68	68	68
0.06	29	52	77	82	82	82	82
0.07	32	55	85	95	95	95	95
0.08	36	58	90	106	108	108	108
0.09	40	61	94	115	122	122	122
0.10	44	65	97	122	133	135	135
0.11	49	68	101	130	144	148	148
0.12	52	72	103	135	153	161	161
0.13	58	76	106	139	162	172	176
0.14	61	79	109	142	168	182	188
0.15	66	84	112	146	175	191	200
0.16	70	88	115	149	178	199	211
0.17	75	92	119	151	184	207	221
0.18	79	95	122	154	187	214	230
0.19	83	100	126	157	191	220	238
0.20	88	104	129	160	194	223	245
0.21	92	108	133	164	197	229	252
0.22	97	112	137	167	200	232	257
0.23	101	117	140	169	203	236	263
0.24	105	121	144	173	206	239	268
0.25	110	126	148	176	209	243	272

Copper Wt-%	Nickel, Wt-% 0	0.20	0.40	0.60	0.80	1.00	1.20
0.26	113	130	151	180	212	246	276
0.27	119	134	155	184	216	249	280
0.28	122	138	160	187	218	251	284
0.29	128	142	164	191	222	254	287
0.30	131	146	167	194	225	257	290
0.31	136	151	172	198	228	260	293
0.32	140	155	175	202	231	263	296
0.33	144	160	180	205	234	266	299
0.34	149	164	184	209	238	269	302
0.35	153	168	187	212	241	272	305
0.36	158	172	191	216	245	275	308
0.37	162	177	196	220	248	278	311
0.38	166	182	200	223	250	281	314
0.39	171	185	203	227	254	285	317
0.40	175	189	207	231	257	288	320

Table 6-2
Chemistry Factor for Base Metal, °F

Copper Wt-%	Nickel, Wt-% 0	0.20	0.40	0.60	0.80	1.00	1.20
0	20	20	20	20	20	20	20
0.01	20	20	20	20	20	20	20
0.02	20	20	20	20	20	20	20
0.03	20	20	20	20	20	20	20
0.04	22	26	26	26	26	26	26
0.05	25	31	31	31	31	31	31
0.06	28	37	37	37	37	37	37
0.07	31	43	44	44	44	44	44
0.08	34	48	51	51	51	51	51
0.09	37	53	58	58	58	58	58
0.10	41	58	65	65	67	67	67
0.11	45	62	72	74	77	77	77
0.12	49	67	79	83	86	86	86
0.13	53	71	85	91	96	96	96
0.14	57	75	91	100	105	106	106
0.15	61	80	99	110	115	117	117
0.16	65	84	104	118	123	125	125
0.17	69	88	110	127	132	135	135
0.18	73	92	115	134	141	144	144
0.19	78	97	120	142	150	154	154
0.20	82	102	125	149	159	164	165
0.21	86	107	129	155	167	172	174
0.22	91	112	134	161	176	181	184
0.23	95	117	138	167	184	190	194
0.24	100	121	143	172	191	199	204
0.25	104	126	148	176	199	208	214
0.26	109	130	151	180	205	216	221
0.27	114	134	155	184	211	225	230

Copper Wt-%	Nickel, Wt-% 0	0.20	0.40	0.60	0.80	1.00	1.20
0.28	119	138	160	187	216	233	239
0.29	124	142	164	191	221	241	248
0.30	129	146	167	194	225	249	257
0.31	134	151	172	198	228	255	266
0.32	139	155	175	202	231	260	274
0.33	144	160	180	205	234	264	282
0.34	149	164	184	209	238	268	290
0.35	153	168	187	212	241	272	298
0.36	158	173	191	216	245	275	303
0.37	162	177	196	220	248	278	308
0.38	166	182	200	223	250	281	313
0.39	171	185	203	227	254	285	317
0.40	175	189	207	231	257	288	320

I.4 References

1. BWRVIP-86-A: BWR Vessel and Internal Project, Updated BWR Integrated Surveillance Program (ISP) Implementation Plan, EPRI, Palo Alto, CA: 2002, 1003346.

2. "Progress Report on Phase 2 of the BWR Owners' Group Supplemental Surveillance Program," T.A. Caine, S. Ranganath, and S.J. Stark, GE Nuclear Energy, GE-NE-523-99-0792, January 1992.

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

4. USNRC, Generic Letter 92-01 and RPV Integrity Workshop Handouts, K. Wichman, M. Mitchell, and A. Hiser, NRC/Industry Workshop on RPV Integrity Issues, February 12, 1998.

5. Letter from William H. Bateman (NRC) to Carl Terry (BWRVIP Chairman), Safety Evaluation Regarding EPRI Proprietary Reports "BWR Vessel and Internals Project, BWR Integrated Surveillance Program Plan (BWRVIP-78)" and "BWRVIP-86: BWR Vessel and Internals Project, BWR Integrated Surveillance Program Implementation Plan," dated February 1, 2002.

6. 10 CFR 50.61, Fracture toughness requirements for protection against pressurized thermal shock events, Federal Register, Volume 60, No. 243, dated December 19, 1995.

ATTACHMENT 1

P-T Curve Report Template

EXAMPLE TEMPLATE OF PLANT-SPECIFIC
PRESSURE-TEMPERATURE LIMITS REPORT
BASED UPON
GE LICENSING TOPICAL REPORT
NEDC-33178P

This attachment is not intended to represent any BWR, and is provided only as an example of the content of a typical P-T curve report.

P-T Curve Report Template
For Utility/Plant

Author

GE PROPRIETARY INFORMATION

Pressure-Temperature Limits Report
For
Utility
Plant

Prepared by: Responsible Engineer
Mechanical Design & Analysis CoE
Mechanics & Seismic Engineering

Verified by: Responsible Verifier
Mechanical Design & Analysis CoE
Mechanics & Seismic Engineering

Approved by: Responsible Manager
Mechanical Design & Analysis CoE
Mechanics & Seismic Engineering

REPORT REVISION STATUS

Revision	Purpose
0	Initial Issue

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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. PLANT is currently licensed to P-T curves for 32 EFPY [1]; the P-T curves in this report represent both an intermediate and an end-of-license effective full power years (EFPY). The 1998 Edition of the ASME Boiler and Pressure Vessel Code including 2000 Addenda was used in this evaluation. The P-T curve methodology includes the following: 1) the use of K_{Ic} from Figure A-4200-1 of Appendix A to determine T-RT_{NDT}, and 2) the use of the M_m calculation in the ASME Code paragraph G-2214.1 for a postulated defect normal to the direction of maximum stress. This report incorporates a fluence [4] calculated in accordance with the GE Licensing Topical Report NEDC-32983P, which has been approved by the NRC in a SER [14], and is in compliance with Regulatory Guide 1.190. The latest information from the BWRVIP Integrated Surveillance Program that is applicable to PLANT has been utilized.

The P-T curves presented in this report reflect changes from those currently licensed [1]. These P-T curves have been generated to incorporate a revised fluence [4].

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

The P-T curves apply for both heatup and cooldown and for both the 1/4T and 3/4T locations because the maximum tensile stress for either heatup or cooldown is applied at the 1/4T location. For beltline curves this approach has added conservatism because irradiation effects cause the allowable toughness, K_{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 an intermediate and end of license 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 an intermediate and end of license EFPY), and bottom head for the Pressure Test and Core Not Critical conditions.

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1.0 INTRODUCTION

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

The P-T curves presented in this report reflect changes from those currently licensed [1]. These P-T curves have been generated to incorporate a revised fluence [4].

The methodology used to generate the P-T curves in this report is presented in Section 4.3. The 1998 Edition of the ASME Boiler and Pressure Vessel Code including 2000 Addenda was used in this evaluation. The P-T curve methodology includes the following: 1) the use of K_{Ic} from Figure A-4200-1 of Appendix A to determine T-RT_{NDT}, and 2) the use of the M_m calculation in the ASME Code paragraph G-2214.1 [6] for a postulated defect normal to the direction of maximum stress. P-T curves are developed using geometry of the RPV shells and discontinuities, the initial RT_{NDT} of the RPV materials, and the adjusted reference temperature (ART) for the beltline materials.

The initial RT_{NDT} is the reference temperature for the unirradiated material as defined in Paragraph NB-2331 of Section III of the ASME Boiler and Pressure Vessel Code. The Charpy energy data used to determine the initial RT_{NDT} values are tabulated from the

Certified Material Test Report (CMTRs). The data and methodology used to determine initial RT_{NDT} are 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 an intermediate and end of license EFPY are included in Section 4.2. Beltline chemistry values are discussed in Section 4.2.1.1. The peak ID fluence values of 7.13e17 n/cm^2 (intermediate EFPY) and 9.68e17 n/cm^2 (end of license EFPY) used in this report are discussed in Section 4.2.1.2.

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

Guidelines and requirements for operating and temperature monitoring are included in Appendix C. Temperature monitoring requirements and methods are available in GE Services Information Letter (SIL) 430 contained in Appendix D. Appendix E documents components that have a fluence $\geq$ 1.0e17 n/cm^2, thus extending the beltline region beyond the core, and demonstrates that all components requiring fracture toughness evaluation are either included in the development of the P-T curves or are outside the beltline region. Appendix F provides an example calculation for a beltline curve where a nozzle is the limiting material. Appendix G contains an evaluation of the vessel wall thickness discontinuities in the beltline and bottom head regions. Appendix H provides a core-not-critical calculation for the bottom head (CRD penetration). Finally, Appendix I presents guidance for the use of ISP surveillance data, which has been provided by EPRI.

2.0 SCOPE OF THE ANALYSIS

A detailed description of the P-T curve bases is included in Section 4.3. The 1998 Edition of the ASME Boiler and Pressure Vessel Code including 2000 Addenda was used in this evaluation. The P-T curve methodology includes the following: 1) the use of K_{Ic} from Figure A-4200-1 of Appendix A to determine T-RT_{NDT}, and 2) the use of the M_m calculation in the ASME Code paragraph G-2214.1 for a postulated defect normal to the direction of maximum stress. Other features presented are:

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

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

The beltline region in the PLANT vessel includes a thickness discontinuity between the lower and lower-intermediate shells. This discontinuity is noted in Appendix A and evaluated in Appendix G. 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 plant-specific vessel components. The non-beltline limits are discussed in Section 4.3 and are also governed by requirements in [8]. In addition, there are thickness discontinuities in the bottom head, which are also noted in Appendix A and evaluated in Appendix G.

Furthermore, curves are included to allow monitoring of the vessel bottom head and upper vessel regions separate from the beltline region. This refinement could minimize heating requirements prior to pressure testing. Operating and temperature monitoring requirements are found in Appendix C. Temperature monitoring requirements and methods are available in GE Services Information Letter (SIL) 430 contained in Appendix D. Appendix E documents components that have a fluence ≥ 1.0e17 n/cm^2, thus extending the beltline region beyond the core, and demonstrates that all components requiring fracture toughness evaluation are either included in the development of the P-T curves or are outside the beltline region. Appendix F provides an example calculation for a beltline curve where a nozzle is the limiting material. Appendix G contains an evaluation of the vessel wall thickness discontinuities in the beltline and bottom head regions. Appendix H provides a core-not-critical calculation for the bottom head (CRD penetration). Finally, Appendix I presents guidance for the use of ISP surveillance data, which has been provided by EPRI.

3.0 ANALYSIS ASSUMPTIONS

The following assumptions are made for this analysis:

The hydrostatic pressure test will be conducted at a maximum pressure of 1055 psig [13].

The shutdown margin, provided in the Definitions Section of the plant-specific Technical Specification [13], is calculated for a water temperature of 68°F.

4.0 ANALYSIS

4.1 *INITIAL REFERENCE TEMPERATURE*

4.1.1 Background

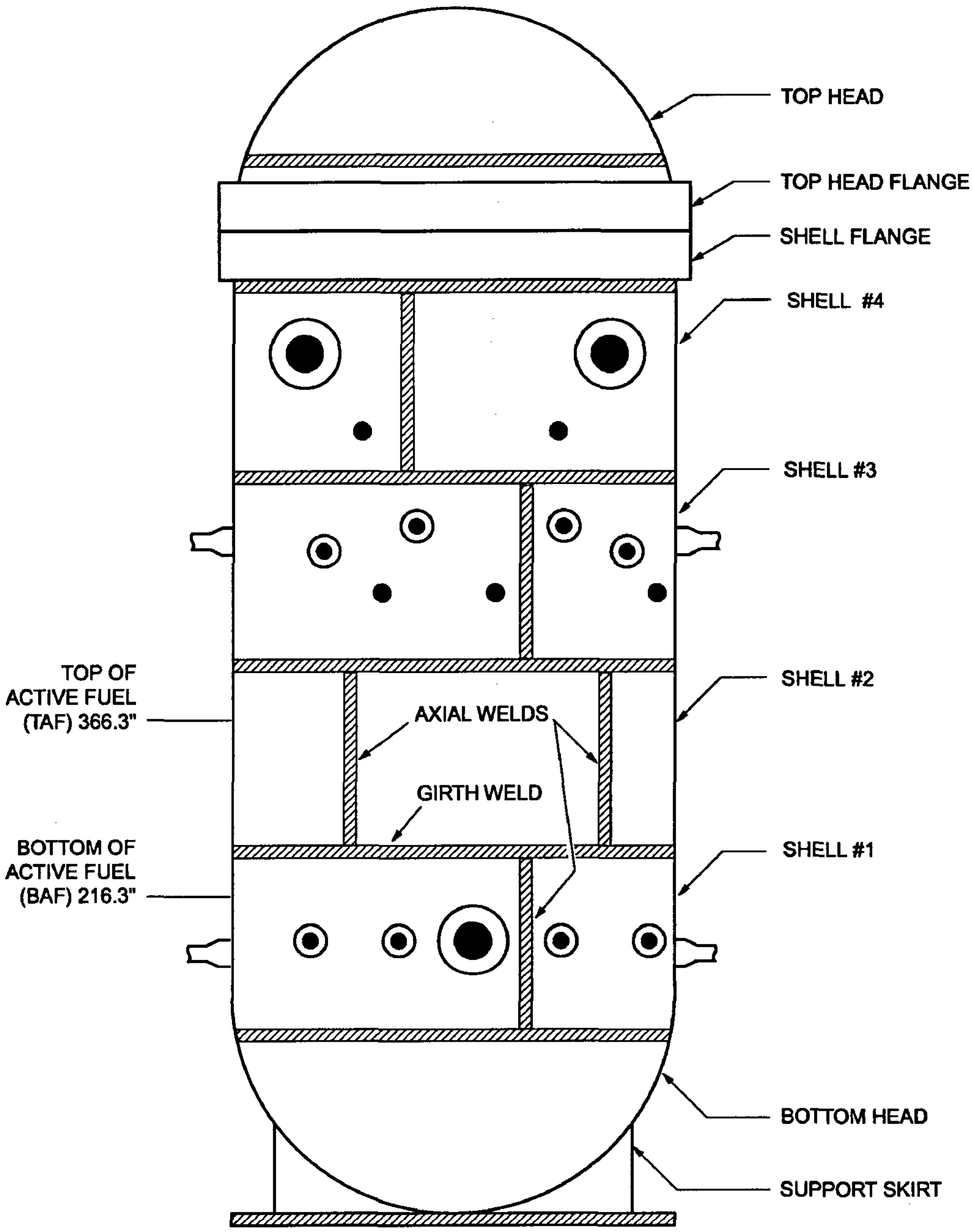
The applicable plant-specific ASME Code of Construction is 1968 Edition with Summer 1969 Addenda. Therefore, the methods defined in Section 4.1.1.1 of NEDC-33178P [22] (hereinafter referred to as the Topical Report) are applied.

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

To establish the initial RT_{NDT} temperatures for the plant-specific vessel per the current requirements, calculations were performed in accordance with the GE method for determining RT_{NDT} as described in Section 4.1 of the Topical Report.

All of the available reported Charpy data for the plant-specific closure studs met the 45 ft-lb requirements at 10°F. However, MLE data was not reported and information for all stud materials was not available. Therefore, the limiting LST for the bolting material is 70°F. The highest RT_{NDT} in the closure flange region is 12°F, for the upper shell. Thus, the higher of the LST and the RT_{NDT} +60°F is 72°F, the bolt-up limit in the closure flange region.

The initial RT_{NDT} values for the plant-specific reactor vessel (refer to Figure 4-1 for the plant-specific schematic) materials are listed in Table 4-1. This tabulation includes beltline, closure flange, feedwater nozzle, and bottom head materials that are considered in generating the P-T curves. The values presented in these tables and used to determine the initial RT_{NDT} were obtained from the plant-specific vessel CMTRs [12].



Notes: (1) Refer to Tables 4-1, 4-2, 4-3 and 4-4 for reactor vessel components and their heat identifications.
(2) See Appendix E for the definition of the beltline region.

Figure 4-1: Schematic of the Plant-Specific RPV Showing Arrangement of Vessel Plates and Welds

Table 4-1a: RT_{NDT} Values for PLANT Plate and Flange Materials

Component	Heat	Test Temp (°F)	Charpy Energy (ft-lb)			(T_{50T}-60) (°F)	Drop Weight NDT (°F)	RT_{NDT} (°F)
Top Head & Flange								
Shell Flange		10	85	80	90	-20	10	10
Top Head Flange		10	100	111	101	-20	10	10
Top Head Dollar		10	70	86	70	-20	-10	-10
Top Head Lower Torus Plates		10	80	91	92	-20	-10	-10
		10	85	96	88	-20	-10	-10
Top Head Upper Torus Plates		10	102	85	100	-20	-10	-10
Shell Courses								
Upper Shell Plates		40	62	60	56	10	-10	10
		40	61	49	55	12	-10	12
		10	55	63	53	-20	-10	-10
		40	70	75	88	10	-10	10
Upper Intermediate Plates		10	70	62	66	-20	-10	-10
		10	57	45	52	-10	-10	-10
		10	44	55	58	-8	-10	-8
Lower-Intermediate Plates		10	61	45	58	-10	-20	-10
		10	65	64	54	-20	-20	-20
		10	48	49	63	-16	-30	-16
		10	46	65	60	-12	-30	-12
Lower Shell Plates		10	60	75	74	-20	-10	-10
		10	80	79	92	-20	-10	-10
		10	57	66	68	-20	-10	-10
Bottom Head								
Bottom Head Dollar		10	41	48	52	-2	-10	-2
Bottom Head Upper Torus Plates		-40	55	61	55	-70	-10	-10
		-40	66	64	54	-70	-10	-10
Bottom Head Lower Torus Plates		10	57	70	80	-20	-10	-10
		10	71	70	72	-20	-10	-10
		40	40	48	42	30	10	30

NOTE: These are minimum Charpy values.

Table 4-1b: RT_{NDT} Values for PLANT Nozzle Materials

Component	Heat or Heat / Flux / Lot	Test Temp (°F)	Charpy Energy (ft-lb)			$(T_{50T}-60)$ (°F)	Drop Weight NDT (°F)	RT_{NDT} (°F)
Recirculation Outlet Nozzle		10	70	92	59	-20	-20	-20
		10	90.0	89	80	-20	-30	-20
Recirculation Inlet Nozzle		10	51	45	38	4	0	4
		10	33	32	40	16	-10	16
		10	67	32	37	16	20	20
		10	43	36	55	8	-30	8
		10	48	40	45	0	-30	0
		10	55	28	39	24	-40	24
		10	50	32	48	16	20	20
		10	47	66	54	-14	10	10
		10	75	46	55	-12	10	10
		10	47	58	85	-14	40	40
Steam Outlet Nozzle		10	60	36	80	8	10	10
		10	70	70	36	8	0	8
		10	40	35	32	16	10	16
		10	55	32	44	16	10	16
Feedwater Nozzle		10	80	90	57	-20	0	0
		10	60	55	50	-20	0	0
		10	60	55	76	-20	-30	-20
		10	60	42	66	-4	-10	-4
		10	38	55	51	4	0	4
		10	41	44	34	12	-10	12
Core Spray Nozzle		10	66	52	85	-20	-10	-10
		10	65	80	82	-20	-10	-10
Instrumentation Nozzle		10	54	60	70	-20	10	10
		10	54	59	72	-20	10	10
Top Head Vent Nozzle		10	90	90	88	-20	10	10
Jet Pump Nozzle		10	80	101	105	-20	-20	-20
		10	82	105	105	-20	-20	-20
CRD HYD Return Nozzle		10	44	40	46	0	10	10
Core ΔP Nozzle	Alloy 600							(2)
Replacement Instrument Nozzles		10	38	42	30	20	40	40
		10	230	230	247	-20	40	40
High Pressure Leak Detector Nozzle								10 (1)
Drain Nozzle		10	40	25	33	30	40	40
CRD Stub Tubes	Alloy 600							(2)

(1) Information for this heat is not available; the purchase specification requirements are used for evaluation of this component.
(2) Alloy 600 components do not require fracture toughness evaluation; see Appendix A for additional information.

NOTE: These are minimum Charpy values.

Table 4-1c: RT_{NDT} Values for PLANT Weld Materials

Component	Heat or Heat / Flux / Lot	Test Temp (°F)	Charpy Energy (ft-lb)			$(T_{50T}$-60) (°F)	Drop Weight NDT (°F)	RT_{NDT} (°F)
Beltline - Axial								
Lower Shell		10	70	75	82	-50	-	-50
		10	60	47	61	-44	-	-44
Lower-Intermediate Shell		10	80	90	87	-50	-	-50
Beltline - Girth								
Lower-Intermediate Shell to Lower Shell		10	99	105	107	-50	-	-50
Non-Beltline - Axial								
Upper-Intermediate Shell		10	60	47	62	-44	-	-44
		10	109	110	111	-50	-	-50
		10	153	130	135	-50	-	-50
Upper Shell		10	54	60	57	-50	-	-50
		10	65	70	60	-50	-	-50
Bottom Head Upper Torus Meridional Welds		10	111	110	113	-50	-	-50
Bottom Head Lower Torus Meridional Welds		10	120	108	119	-50	-	-50
		10	111	110	112	-50	-	-50
Top Head Upper Torus Meridional Welds		10	130	165	150	-50	-	-50
Top Head Lower Torus Meridional Welds		10	167	142	154	-50	-	-50
		10	109	105	112	-50	-	-50
		10	130	168	151	-50	-	-50
Non-Beltline - Girth								
Top Head Assembly		10	111	105	111	-50	-	-50
		10	57	30	51	-10	-	-10
Shell Flange to Upper Shell		10	51	72	70	-50	-	-50
Upper Shell to Upper-Intermediate Shell		10	80	85	91	-50	-	-50
Upper-Intermediate Shell to Lower-Intermediate Shell		10	77	65	63	-50	-	-50
		10	40	47	48	-30	-	-30
Lower Shell to Bottom Head		10	57	30	51	-10	-	-10
		10	111	109	105	-50	-	-50
Bottom Head Assembly		10	101	105	103	-50	-	-50
Support Skirt to Bottom Head		10	63	57	59	-50	-	-50

Note: These are minimum Charpy values.

Table 4-1d: RT_{NDT} Values for PLANT Appurtenance and Bolting Materials

Component	Heat	Test Temp (°F)	Charpy Energy (ft-lb)			$(T_{50T}-60)$ (°F)	Drop Weight NDT (°F)	RT_{NDT} (°F)
Misc Appurtenances:								
Support Skirt Forging		10	75	85	102	-20	30	30
Shroud Support	Alloy 600							(1)
Stabilizer Brackets		40 10	57 55	49 45	52 50	12 -10	10 -30	12 -10
Guide Rod Brackets	Stainless Steel							(1)
Steam Dryer Support Lugs	Stainless Steel							(1)
Steam Dryer Hold Down Brackets		10 10	121 82	125 65	108 60	-20 -20	- -	-20 -20
Core Spray Brackets	Stainless Steel							(1)
Basin Seal Skirt								10 (2) 10 (2)
Surveillance Specimen Brackets	Stainless Steel Stainless Steel							(1) (1)
Feedwater Sparger Brackets	Stainless Steel							(1)
Top Head Lifting Lugs								40 (2)

Component	Heat	Test Temp (°F)	Charpy Energy (ft-lb)			Min Lat Exp (mils)	LST (°F)
Closure Studs							
	(3)	10 10 10	50 52 -	50 54 -	50 52 -	- - -	70 70 70
Closure Nuts							
	(3)	10 10	57 -	59 -	53 -	- -	70 70

(1) Information for this heat is not available; the purchase specification requirements are used for evaluation of this component.
(2) Alloy 600 and Stainless Steel components do not require fracture toughness evaluation; see Appendix A for additional information
(3) Information for this component is not available; ASME Code requirements are applied as defined in Section 4.1.2 of this report.

NOTE: These are minimum Charpy values.

4.2 ADJUSTED REFERENCE TEMPERATURE FOR BELTLINE

An evaluation of ART for all beltline plates and welds was performed using the methods described in Section 4.2 of the Topical Report, and is summarized in Tables 4-2a and 4-2b for an intermediate and end of license EFPY, respectively.

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

4.2.1.1 Chemistry

The vessel beltline chemistries were obtained from [13] and are consistent with all known available sources of data for the beltline materials, including the Certified Material Test Reports (CMTR) [12], and the currently licensed P-T curve report [1]. Chemistries for the surveillance materials evaluated in Table 4-2 were obtained from the Integrated Surveillance Program (ISP) [13].

For a weld heat that occurs in the ISP and the plant-specific vessel, both the plant-specific chemistry and the chemistry from the ISP are presented. This heat is the surveillance weld material as defined by the ISP; chemistry and adjusted CF information defined by this program were provided by [13]. For this material, an adjusted CF used in calculating the adjusted reference temperature for an intermediate and end of license EFPY was obtained by multiplying the ISP least-squares fit CF developed in accordance with RG1.99 as defined by BWRVIP-102 [5] by the ratio of the RG1.99 CF for the vessel weld chemistry to the RG1.99 CF for the ISP surveillance chemistry. This results in an adjusted CF of: 326.96 • (224 / 206.6) = 354.5.

4.2.1.2 Fluence

The peak fluence for the RPV inner surface, used for determination of the P-T curves, is 9.68e17 n/cm^2 for the end of license EFPY. For the intermediate EFPY, the peak fluence for the RPV inner surface is 7.13e17 n/cm^2. The basis for all fluence values used in this report is contained in [4]. Calculations for 1/4T fluence are performed in accordance with RG1.99 [7] as specified in Section 4.2.1.3 of the Topical Report.

The peak fluence for the elevation of the girth weld between the lower and lower-intermediate shell plates is also provided in [4]. This fluence is applied to the girth weld and all plates and welds in the lower shell. Axial fluence distribution factors of 0.64 and 0.65 are applied for the end of license and intermediate EFPY fluences, respectively. The slight difference is due to the amount of time that PLANT will operate at the EPU power level.

4.2.2 Limiting Beltline Material

Tables 4-2a and 4-2b list values of beltline ART for an intermediate and end of license EFPY, respectively.

Surveillance capsule material data is available from the Integrated Surveillance Program (ISP) to represent the plant-specific vessel. These materials are included in the ART calculations provided in Table 4-2, and in the determination of the limiting material that is represented in the beltline P-T curves. All methods are defined in Section 4.2 of the Topical Report.

Table 4-2a: Plant-Specific Beltline ART Values (Intermediate EFPY)

Lower-Intermediate Shell Plates and Axial Welds

Thickness in inches= 6.125

End of License EFPY Peak I.D. fluence = 7.50E+17 n/cm^2
Intermediate EFPY Peak I.D. fluence = 5.63E+17 n/cm^2
Intermediate EFPY Peak 1/4T fluence = 3.90E+17 n/cm^2

Lower Shell Plates and Axial Welds & Lower to Lower-Intermediate Girth Weld

Thickness in inches= 7.125

Axial Distribution Factor at Elevation of Girth Weld = 0.65

End of License EFPY Peak I.D. fluence = 4.88E+17 n/cm^2
Intermediate EFPY Peak I.D. fluence = 3.66E+17 n/cm^2
Intermediate EFPY Peak 1/4T fluence = 2.38E+17 n/cm^2

COMPONENT	HEAT OR HEAT/LOT	%Cu	%Ni	CF	Adjusted CF (1)	Initial RTndt °F	1/4 T Fluence n/cm^2	Intermediate EFPY Δ RTndt °F	σ_I	σ_Δ	Margin °F	Intermediate EFPY Shift °F	Intermediate EFPY ART °F
PLATES:													
Lower Shell		0.08	0.62	51		-10	2.38E+17	10	0	5	10	20	10
Lower-Intermediate Shell		0.12	0.61	83		-12	3.90E+17	21	0	11	21	42	30
WELDS:													
Lower Shell Axial		0.26	0.87	224		-44	2.38E+17	43	0	21	43	86	42
Lower-Intermediate Shell Axial		0.32	0.50	188.5		-50	3.90E+17	48	0	24	48	96	46
Lower to Lower-Intermediate Girth		0.23	1.00	236		-50	2.38E+17	45	0	23	45	90	40
INTEGRATED SURVEILLANCE PROGRAM (2):													
Plate (3)		0.12	0.69	84		-12	3.90E+17	21	0	11	21	43	31
Weld (4)		0.21	0.86	207	354	-44	2.38E+17	68	0	28	28	96	52

(1) Adjusted CF calculated per RG1.99 Position 2.1 as shown in Section 4.2.1.1 of this report.
(2) Procedures defined in BWRVIP-102 are applied to determine the ART considering the Integrated Surveillance Program.
(3) The ISP plate is not the identical heat and is presented using the ISP chemistry and CF and applied to the limiting plant-specific plate.
(4) The ISP weld is the identical heat and is presented using the ISP chemistry and adjusted CF with the vessel weld Initial RT_{NDT} and fluence. σ_Δ is presented as calculated, but is multiplied by 0.5 for the Margin calculation as defined in RG1.99, Position 2.1.

Table 4-2b: Plant-Specific Beltline ART Values (End of License EFPY)

Lower-Intermediate Shell Plates and Axial Welds

Thickness in inches= 6.125

End of License EFPY Peak I.D. fluence =	9.68E+17	n/cm^2
Intermediate EFPY Peak I.D. fluence =	6.70E+17	n/cm^2
Intermediate EFPY Peak 1/4T fluence =	6.70E+17	n/cm^2

Lower Shell Plates and Axial Welds & Lower to Lower-Intermediate Girth Weld

Thickness in inches= 7.125

Axial Distribution Factor at Elevation of Girth Weld = 0.64

End of License EFPY Peak I.D. fluence =	6.23E+17	n/cm^2
Intermediate EFPY Peak I.D. fluence =	4.07E+17	n/cm^2
Intermediate EFPY Peak 1/4T fluence =	4.07E+17	n/cm^2

COMPONENT	HEAT OR HEAT/ LOT	%Cu	%Ni	CF	Adjusted CF (1)	Initial RTndt °F	1/4 T Fluence n/cm^2	End of License EFPY Δ RTndt °F	σ_I	σ_Δ	Margin °F	End of License EFPY Shift °F	End of License EFPY ART °F
PLATES:													
Lower Shell		0.08	0.62	51		-10	4.07E+17	13	0	7	13	27	17
Lower-Intermediate Shell		0.12	0.61	83		-12	6.70E+17	28	0	14	28	57	45
WELDS:													
Lower Shell Axial		0.26	0.87	224		-44	4.07E+17	59	0	28	56	115	71
Lower-Intermediate Shell Axial		0.32	0.50	188.5		-50	6.70E+17	64	0	28	56	120	70
Lower to Lower-Intermediate Girth		0.23	1.00	236		-50	4.07E+17	62	0	28	56	118	68
INTEGRATED SURVEILLANCE PROGRAM (2):													
Plate (3)		0.12	0.69	84		-12	6.70E+17	29	0	14	29	57	45
Weld (4)		0.21	0.86	207	354	-44	4.07E+17	93	0	28	28	121	77

(1) Adjusted CF calculated per RG1.99 Position 2.1 as shown in Section 4.2.1.1 of this report.
(2) Procedures defined in BWRVIP-102 are applied to determine the ART considering the Integrated Surveillance Program.
(3) The ISP plate is not the identical heat and is presented using the ISP chemistry and CF and applied to the limiting plant-specific plate.
(4) The ISP weld is the identical heat and is presented using the ISP chemistry and adjusted CF with the vessel weld Initial RT_{NDT} and fluence. σ_Δ is presented as calculated, but is multiplied by 0.5 for the Margin calculation as defined in RG1.99, Position 2.1.

4.3 *PRESSURE-TEMPERATURE CURVE METHODOLOGY*

4.3.1 Background

Methods used to develop the P-T curves are described in Section 4.3 of the Topical Report (NEDC-33178P) [22].

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].

4.3.2 P-T Curve Methodology

4.3.2.1 Non-Beltline Regions

An evaluation was performed for the bottom head wall thickness transition discontinuity located between the bottom head lower torus and upper torus. Appendix G of this report contains a detailed description of this evaluation. It was concluded that the discontinuity is bounded by the bottom head P-T curve developed in the following sections, and no further adjustment was required.

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

The highest RT_{NDT} for the bottom head plates and welds is 30°F, as shown in Tables 4-1a and 4-1c. [[

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The plant-specific bottom head dimensions are R = 127.38 inches and t =7.38 inches minimum [19], resulting in:

Plant-Specific: $R / (t)^{1/2} = 127.38 / (7.38)^{1/2} = 47 \text{ inch}^{1/2}$ (4-3)

Since the generic value of $R/(t)^{1/2} = 49 \text{ inch}^{1/2}$ [22] is larger, the generic P-T curve is conservative when applied to the plant-specific bottom head.

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

The highest RT_{NDT} for the bottom head plates and welds is 30°F, as shown in Tables 4-1a and 4-1c. [[

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

The highest RT_{NDT} for the feedwater nozzle materials is 12°F as shown in Table 4-1b. However, the RT_{NDT} was increased to 25°F to consider the stresses in the bottom head/CRD together with the initial RT_{NDT} as described below. The generic pressure test P-T curve is applied to the plant-specific feedwater nozzle curve by shifting the P vs. (T - RT_{NDT}) values above to reflect the RT_{NDT} value of 25°F.

[[

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

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

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

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

Thus, a/r_n = 2.31 / 7.29 = 0.32. The value $F(a/r_n)$, taken from Figure A5-1 of WRC Bulletin 175 for an a/r_n of 0.32, is 1.5. Including the safety factor of 1.5, the stress intensity factor, K_I, is $1.5\ \sigma\ (\pi a)^{1/2} \cdot F\ (a/r_n)$:

Nominal $K_I = 1.5 \cdot 32.64 \cdot (\pi \cdot 2.31)^{1/2} \cdot 1.5 = 197.9$ ksi-in$^{1/2}$

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

The highest plant-specific non-beltline RT_{NDT} for the feedwater nozzle is 12°F as shown in Table 4-1b. However, the RT_{NDT} was increased to 25°F to consider the stresses in the bottom head/CRD as previously discussed. The generic curve is applied to the PLANT upper vessel by shifting the P vs. (T - RT_{NDT}) values above to reflect the RT_{NDT} value of 25°F as discussed in Section 4.3.2.1.3.

4.3.2.2 CORE BELTLINE REGION

An evaluation was performed for the vessel wall thickness transition discontinuity located between the lower and lower-intermediate shells in the beltline region. Appendix G of this report contains a detailed description of this evaluation. It was concluded that the discontinuity is bounded by the beltline P-T curve developed in the following sections, and no further adjustment was required.

4.3.2.2.1 Beltline Region - Pressure Test

The methodology for determining the beltline region pressure test P-T curve is defined in Section 4.3.2.2.1 of the Topical Report [22].

4.3.2.2.2 Calculations for the Beltline Region - Pressure Test

This sample calculation, following the methods defined in the Topical Report, is for a pressure test pressure of 1055 psig at the end of license EFPY. The following inputs were used in the beltline limit calculation:

Adjusted RT_{NDT} = Initial RT_{NDT} + Shift	A = -44 + 121 = 77°F (Based on ART values in Table 4-2b)
Vessel Height	H = 861.6 inches
Bottom of Active Fuel Height	B = 216.3 inches
Vessel Radius (to base metal)	R = 127 inches
Minimum Vessel Thickness (without clad)	t = 6.125 inches

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

$$P = 1055 \text{ psi} + (H - B)\, 0.0361 \text{ psi/inch} = P \text{ psig} \qquad (4\text{-}10)$$
$$= 1055 + (861.6 - 216.3)\, 0.0361 = 1078 \text{ psig}$$

Pressure stress:

$$\sigma = PR/t \qquad (4\text{-}11)$$
$$= 1.078 \cdot 127 / 6.125 = 22.35 \text{ ksi}$$

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

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

Equation 4-9 can be rearranged, and 1.5 K_{Im} substituted for K_{Ic}, to solve for (T - RT_{NDT}). Using the K_{Ic} equation of Paragraph A-4200 in ASME Appendix A [17], K_{Im} = 51.2, and

K_{It}= 2.39 for a 20°F/hr coolant heatup/cooldown rate with a vessel thickness, t, that includes cladding:

$$(T - RT_{NDT}) = \ln[(1.5 \cdot K_{Im} + K_{It} - 33.2) / 20.734] / 0.02 \quad (4\text{-}12)$$
$$= \ln[(1.5 \cdot 51.2 + 2.39 - 33.2) / 20.734] / 0.02$$
$$= 39.8°F$$

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

$T = 39.8 + 77 = 116.8°F$ for P = 1055 psig at the end of license EFPY

4.3.2.2.3 Beltline Region - Core Not Critical Heatup/Cooldown

The methodology for determining the beltline region core not critical heatup/cooldown P-T curve is defined in Section 4.3.2.2.3 of the Topical Report.

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

This plant-specific sample calculation is for a pressure of 1055 psig for the end of license EFPY and follows the methodology described in Section 4.3.2.2.4 of the Topical Report.

Coolant heatup/cooldown rate, normally 100°F/hr	G = 100 °F/hr
Minimum vessel thickness, including clad thickness	C = 0.5365 ft (6.125" + 0.3125" = 6.4375")
Thermal diffusivity at 550°F (most conservative value)	$\beta = 0.354\ ft^2/hr$ [21]

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

$$\Delta T = GC^2 / 2\beta \tag{4-16}$$
$$= 100 \cdot (0.5365)^2 / (2 \cdot 0.354) = 41°F$$

The corresponding value of M_t (=0.2942) can be interpolated from ASME Appendix G, Figure G-2214-2 [6]. Thus the thermal stress intensity factor, $K_{It} = M_t \cdot \Delta T = 11.96$, can be calculated.

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

$$(T - RT_{NDT}) = \ln[((2 \cdot K_{Im} + K_{It}) - 33.2) / 20.734] / 0.02 \tag{4-17}$$
$$= \ln[(2 \cdot 51.2 + 11.96 - 33.2) / 20.734] / 0.02$$
$$= 68.2\ °F$$

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

$T = 68.2 + 77 = 145.2\ °F$ for P = 1055 psig at the end of license EFPY

4.3.2.3 CLOSURE FLANGE REGION

As shown in Tables 4-1a, 4-1b, and 4-1c, the limiting initial RT_{NDT} for the closure flange region is represented by Shell #4 at 12°F, and the LST of the closure studs is 70°F; therefore, the bolt-up temperature value used is the more conservative value of 72°F.

The shutdown margin, provided in the plant-specific Technical Specification, is calculated for a water temperature of 68°F. The 72°F limit for the upper vessel and beltline region and the 68°F limit for the bottom head curve apply when the head is on and tensioned and when the head is off while fuel is in the vessel.

4.3.2.4 CORE CRITICAL OPERATION REQUIREMENTS OF 10CFR50, APPENDIX G

Using the methods described in Section 4.3.2.4 of the Topical Report [22], this requirement makes the minimum criticality temperature 72°F, based on an RT_{NDT} of 12°F. In addition, above 312 psig the Curve C temperature must be at least the greater of RT_{NDT} of the closure region + 160°F or the temperature required for the hydrostatic pressure test (Curve A at 1055 psig). The requirement of closure region RT_{NDT} + 160°F causes a temperature shift in Curve C at 312 psig.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The following P-T curves were generated:

- Composite P-T curves were generated for each of the Pressure Test and Core Not Critical conditions at an intermediate and end of license 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 and intermediate and end of license 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 an intermediate and end of license EFPY. The composite curves were generated by enveloping the most restrictive P-T limits from the separate beltline, upper vessel, bottom head, and closure assembly P-T limits.

Using the fluence from Section 4.2.1.2, the P-T curves are beltline limited above 900 psig for Curve A and above 820 psig for Curve B for the intermediate EFPY. The end of license EFPY P-T curves are beltline limited above 840 psig for Curve A and upper vessel limited between 820 and 890 psig and beltline limited above 890 psig for Curve B.

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

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

Curve	Curve Description	Figure Numbers for Presentation of the P-T Curves	Table Numbers for Presentation of the P-T Curves
A	Bottom Head Limits (CRD Nozzle)	Figure 5-1	Tables B-1 & B-3
A	Upper Vessel Limits (FW Nozzle)	Figure 5-2	Tables B-1 & B-3
A	Beltline Limits - Intermediate EFPY	Figure 5-3	Table B-1
A	Beltline Limits – End of License EFPY	Figure 5-4	Table B-3
A	Bottom Head and Composite Curve A – Intermediate EFPY*	Figure 5-5	Table B-2
A	Bottom Head and Composite Curve A – End of License EFPY*	Figure 5-6	Table B-4
B	Bottom Head Limits (CRD Nozzle)	Figure 5-7	Tables B-1 & B-3
B	Upper Vessel Limits (FW Nozzle)	Figure 5-8	Tables B-1 & B-3
B	Beltline Limits - Intermediate EFPY	Figure 5-9	Table B-1
B	Beltline Limits – End of License EFPY	Figure 5-10	Table B-3
B	Bottom Head and Composite Curve B – Intermediate EFPY*	Figure 5-11	Table B-2
B	Bottom Head and Composite Curve B – End of License EFPY*	Figure 5-12	Table B-4
C	Composite Curve C – Intermediate EFPY**	Figure 5-13	Table B-2
C	Composite Curve C - End of License EFPY**	Figure 5-14	Table B-4

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

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

*** The Limiting curves are the more limiting of four limits: 10CFR50 Bolt-up Limits, Bottom Head Limits (CRD Nozzle), Upper Vessel Limits (FW Nozzle), and Beltline Limits.

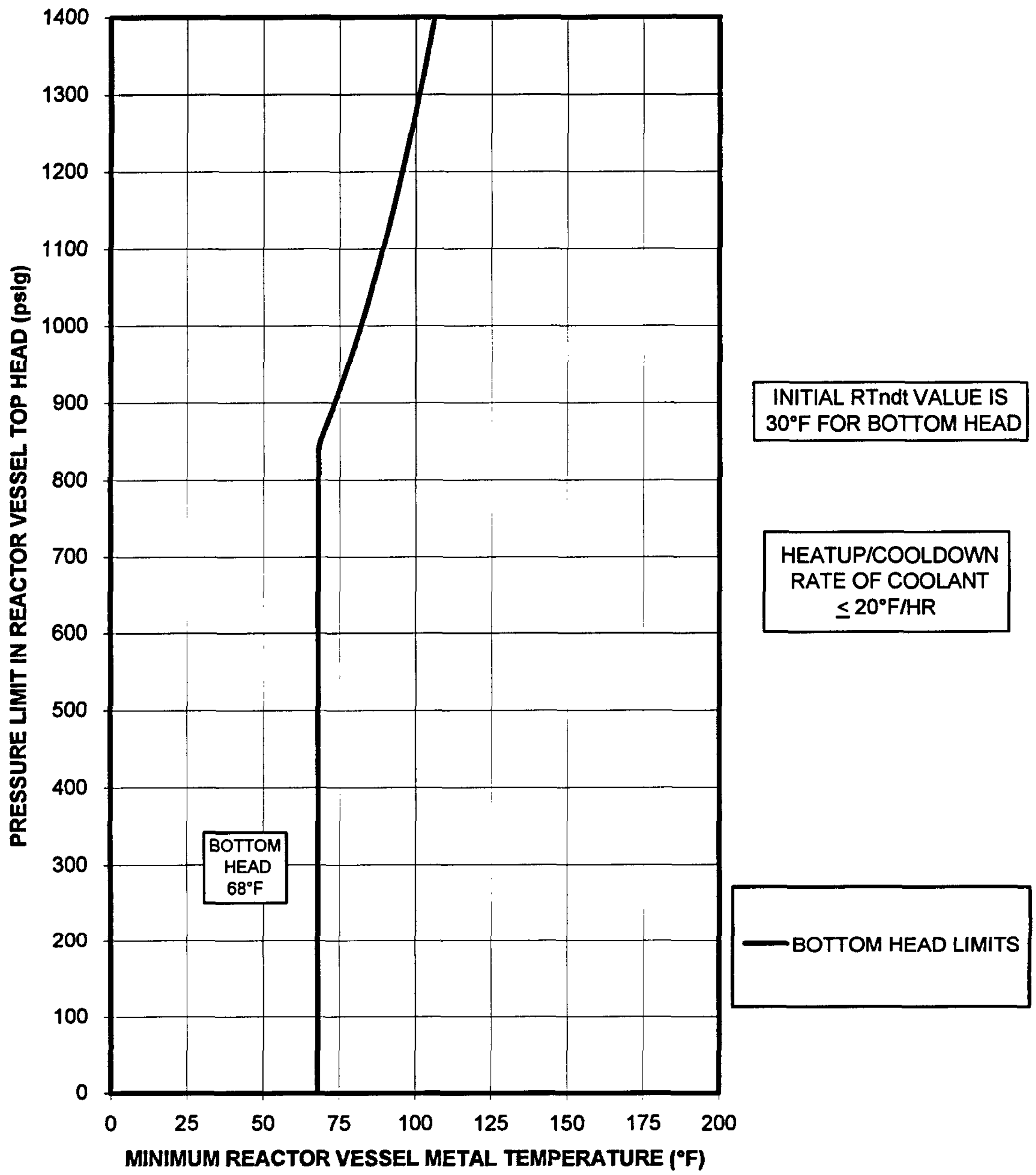

Figure 5-1: Bottom Head P-T Curve for Pressure Test [Curve A]

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

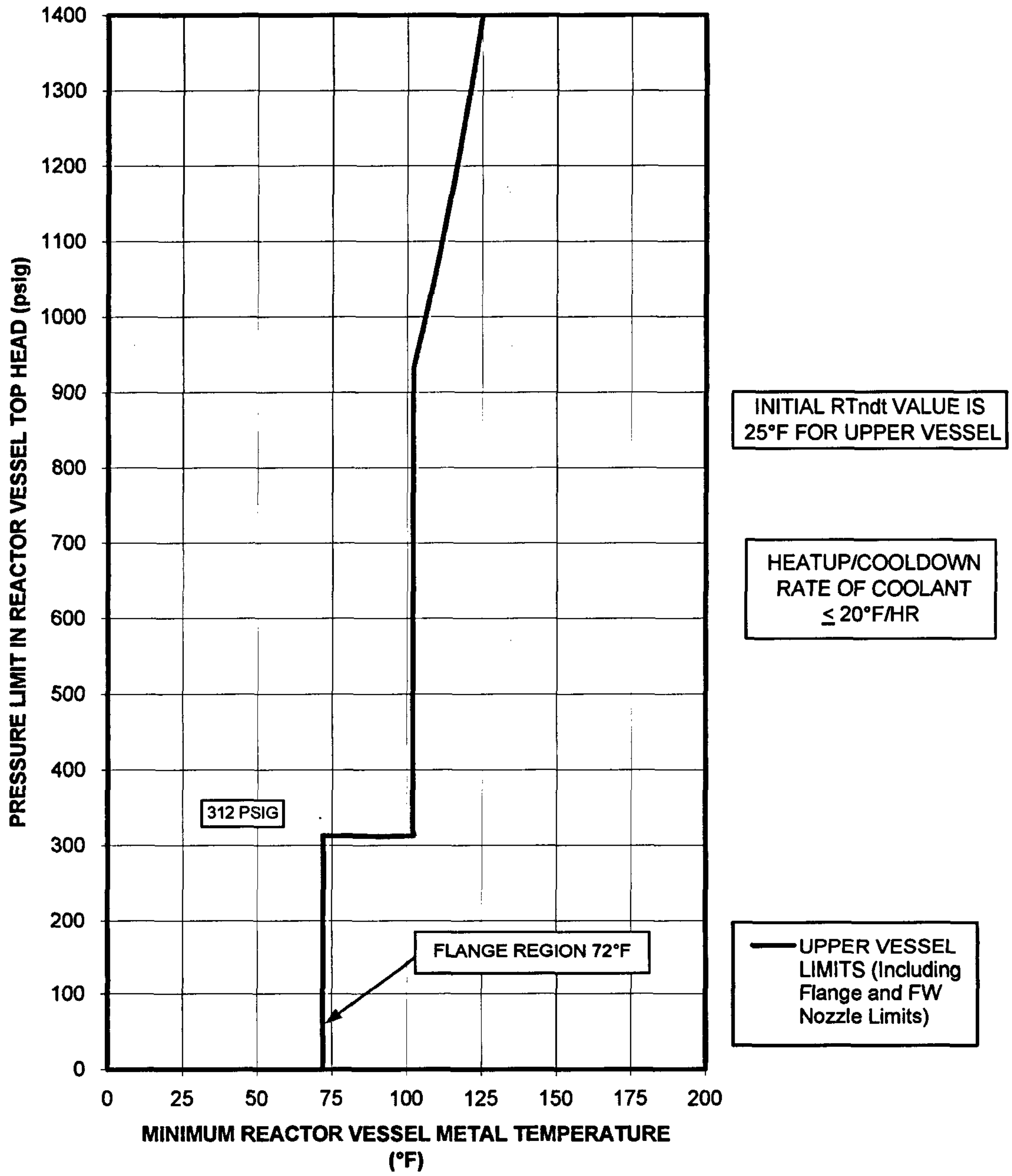

Figure 5-2: Upper Vessel P-T Curve for Pressure Test [Curve A]

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

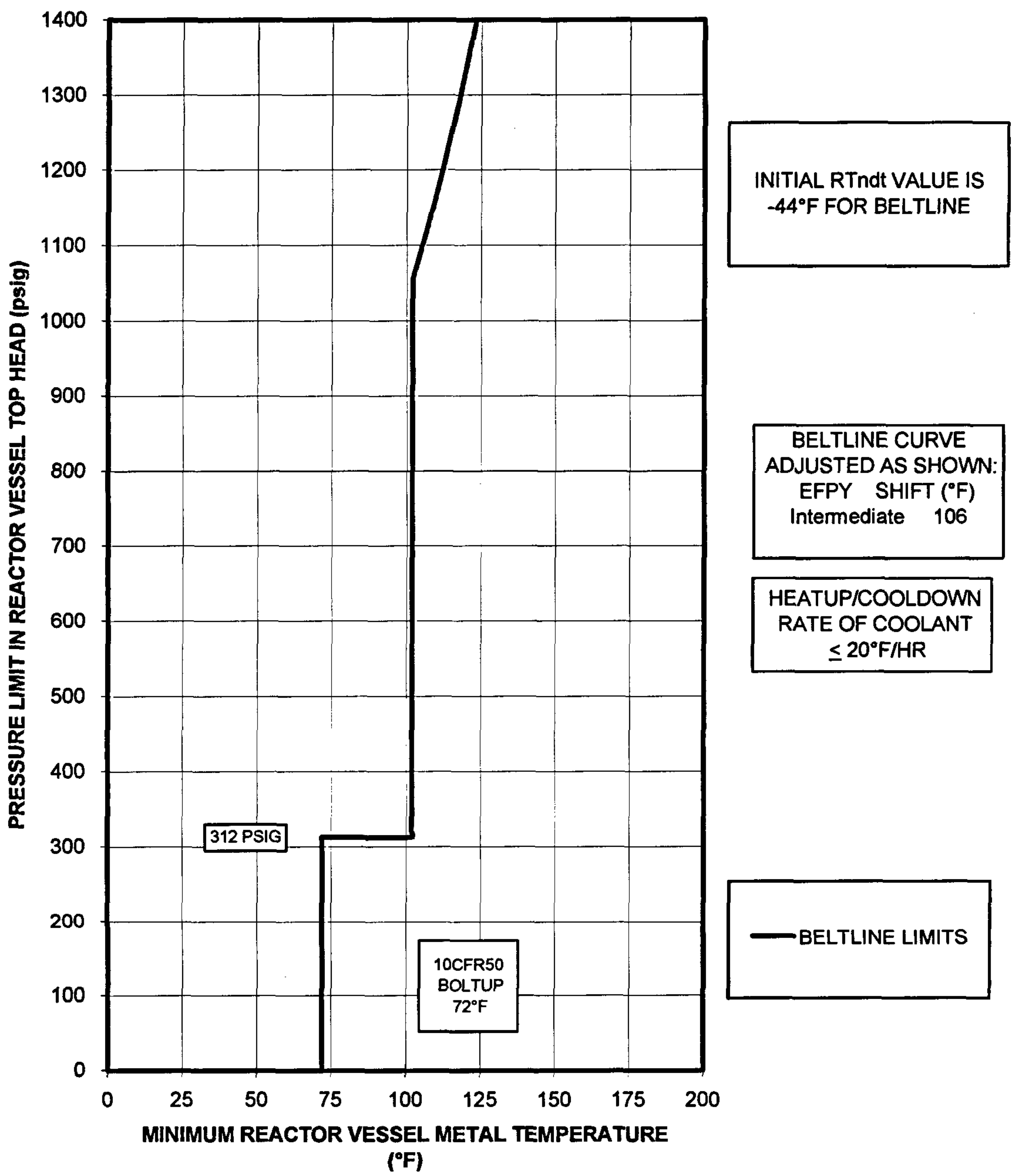

Figure 5-3: Beltline P-T Curve for Pressure Test [Curve A] up to Intermediate EFPY [20°F/hr or less coolant heatup/cooldown]

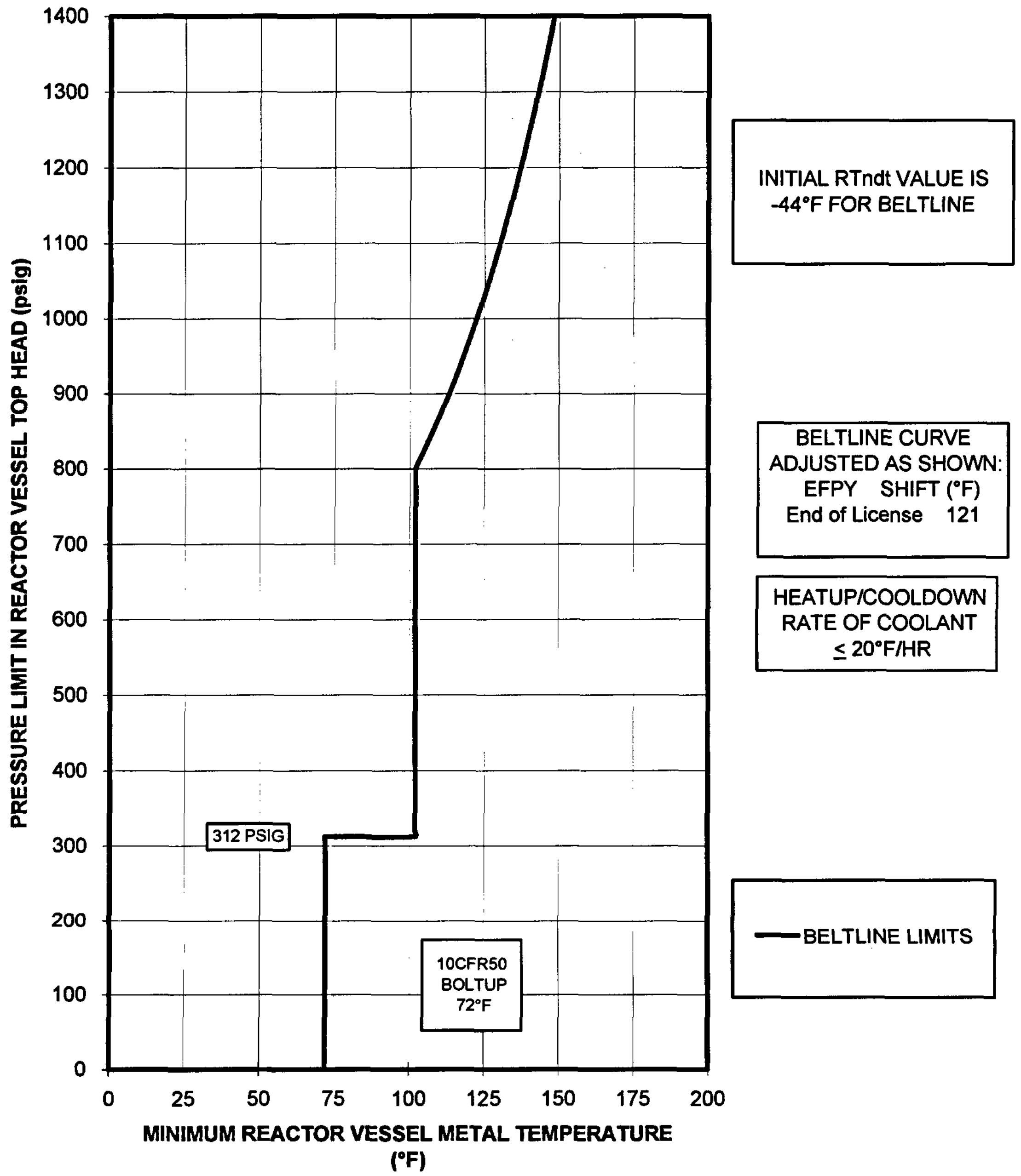

Figure 5-4: Beltline P-T Curve for Pressure Test [Curve A] up to End of License EFPY [20°F/hr or less coolant heatup/cooldown]

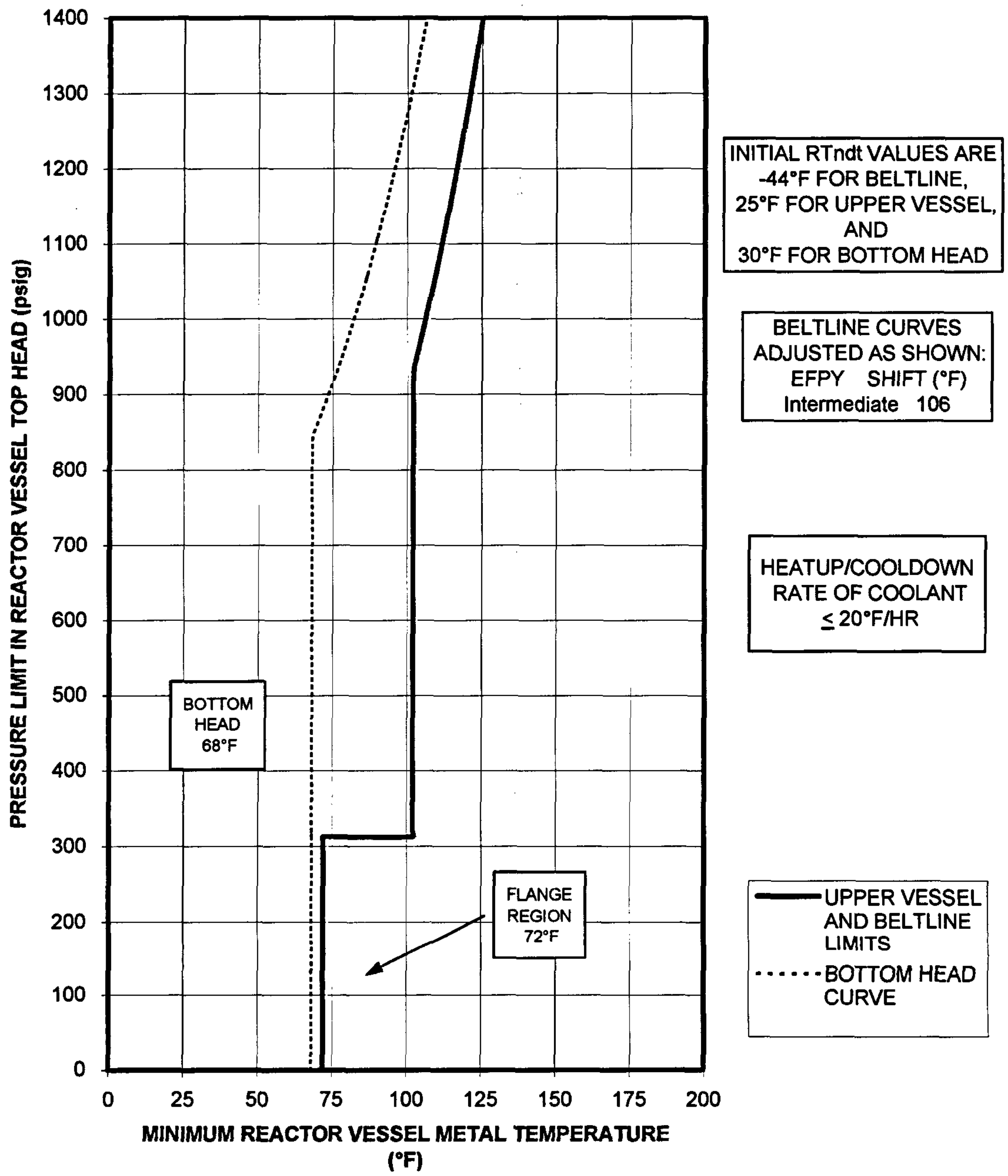

Figure 5-5: Composite Pressure Test P-T Curves [Curve A] up to Intermediate EFPY [20°F/hr or less coolant heatup/cooldown]

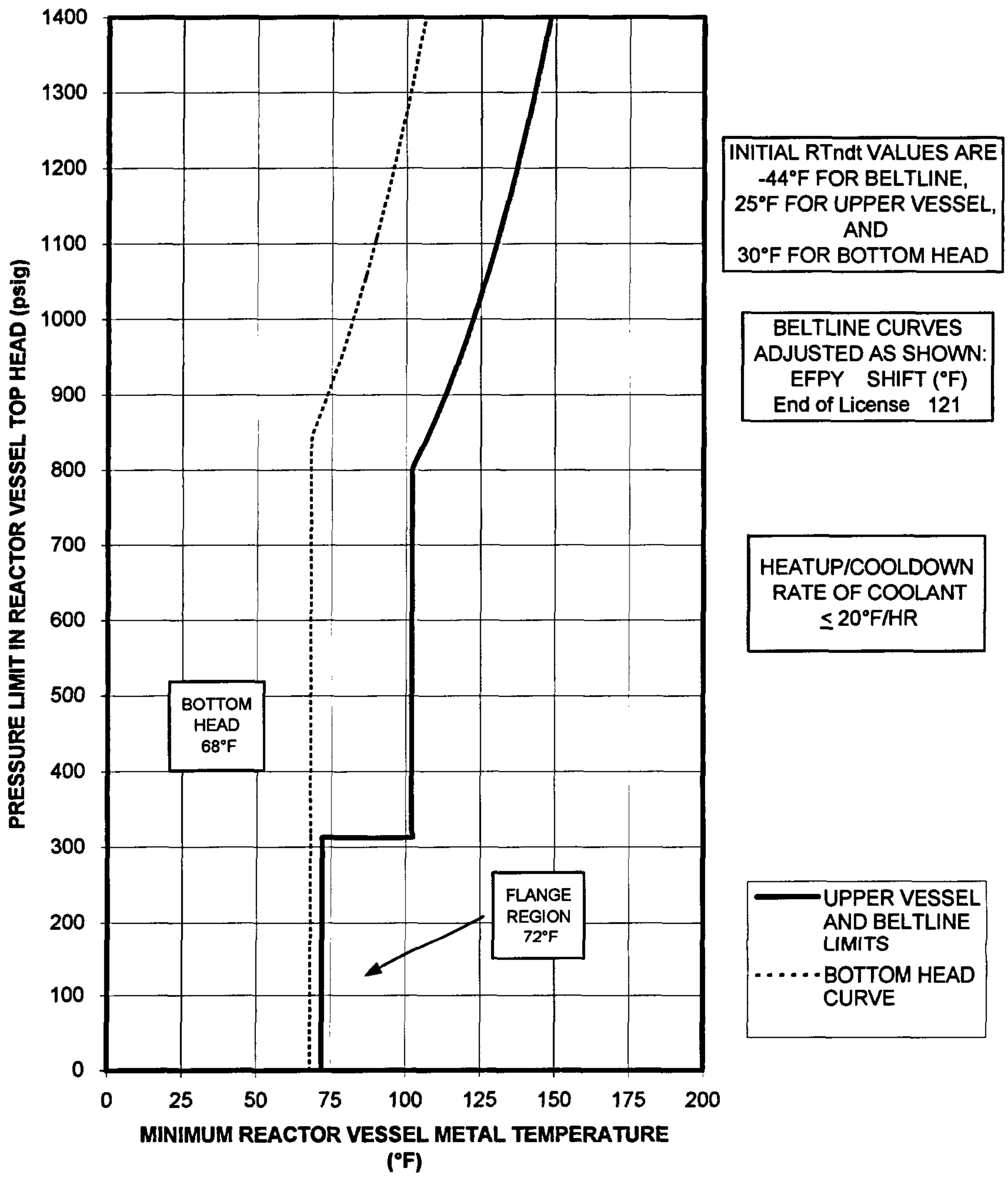

Figure 5-6: Composite Pressure Test P-T Curves [Curve A] up to End of License EFPY [20°F/hr or less coolant heatup/cooldown]

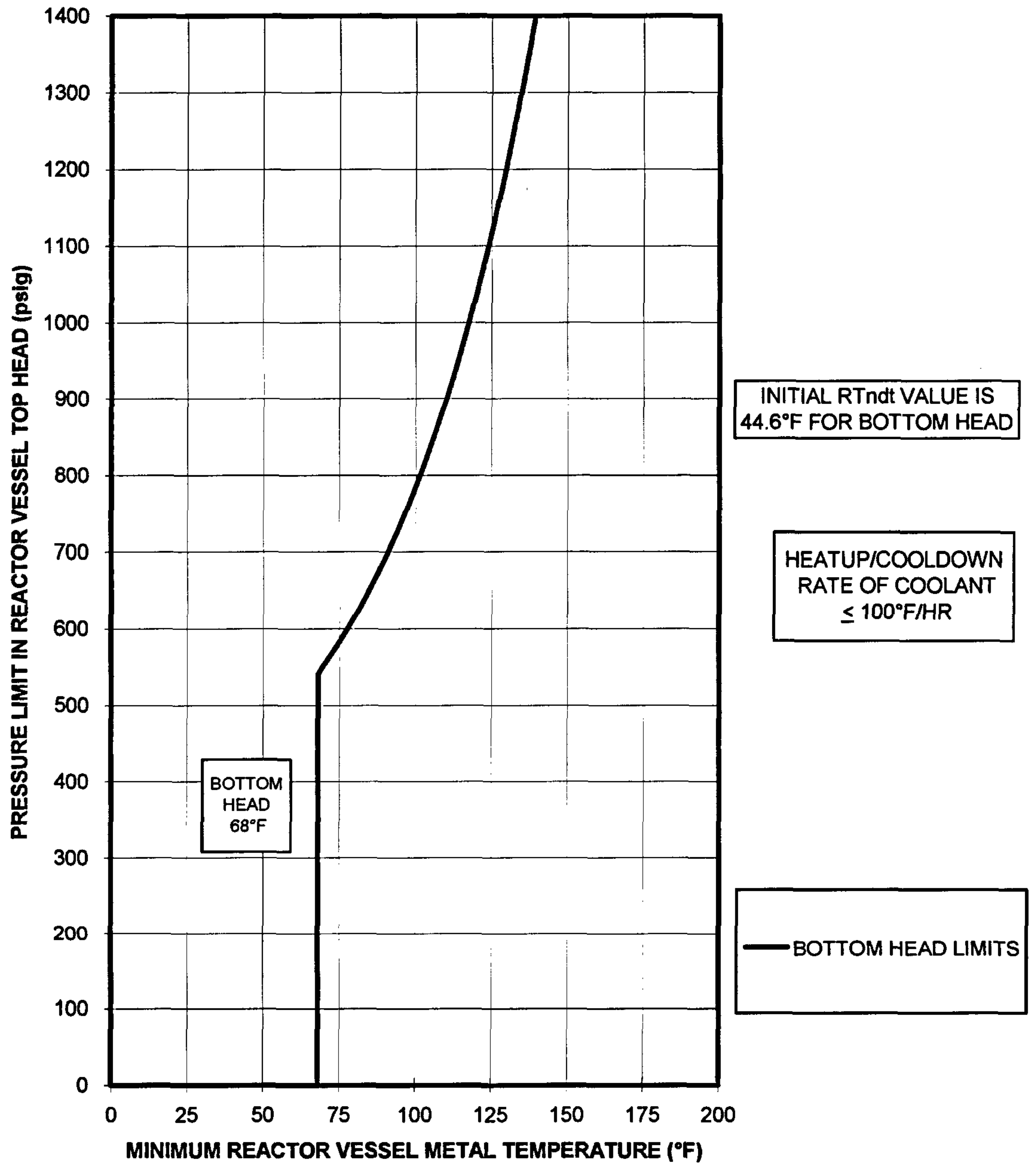

Figure 5-7: Bottom Head P-T Curve for Core Not Critical [Curve B]
[100°F/hr or less coolant heatup/cooldown]

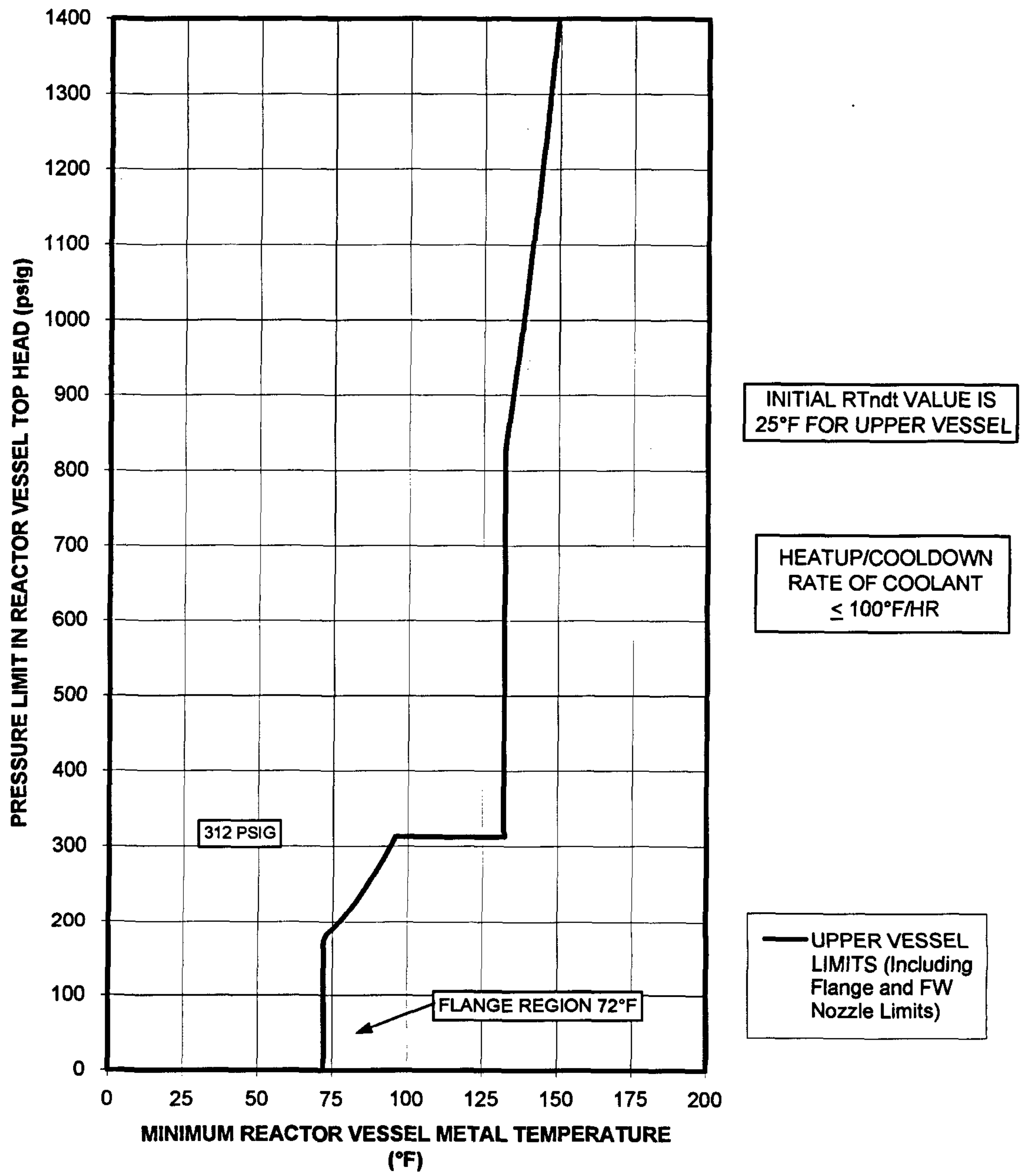

Figure 5-8: Upper Vessel P-T Curve for Core Not Critical [Curve B]

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

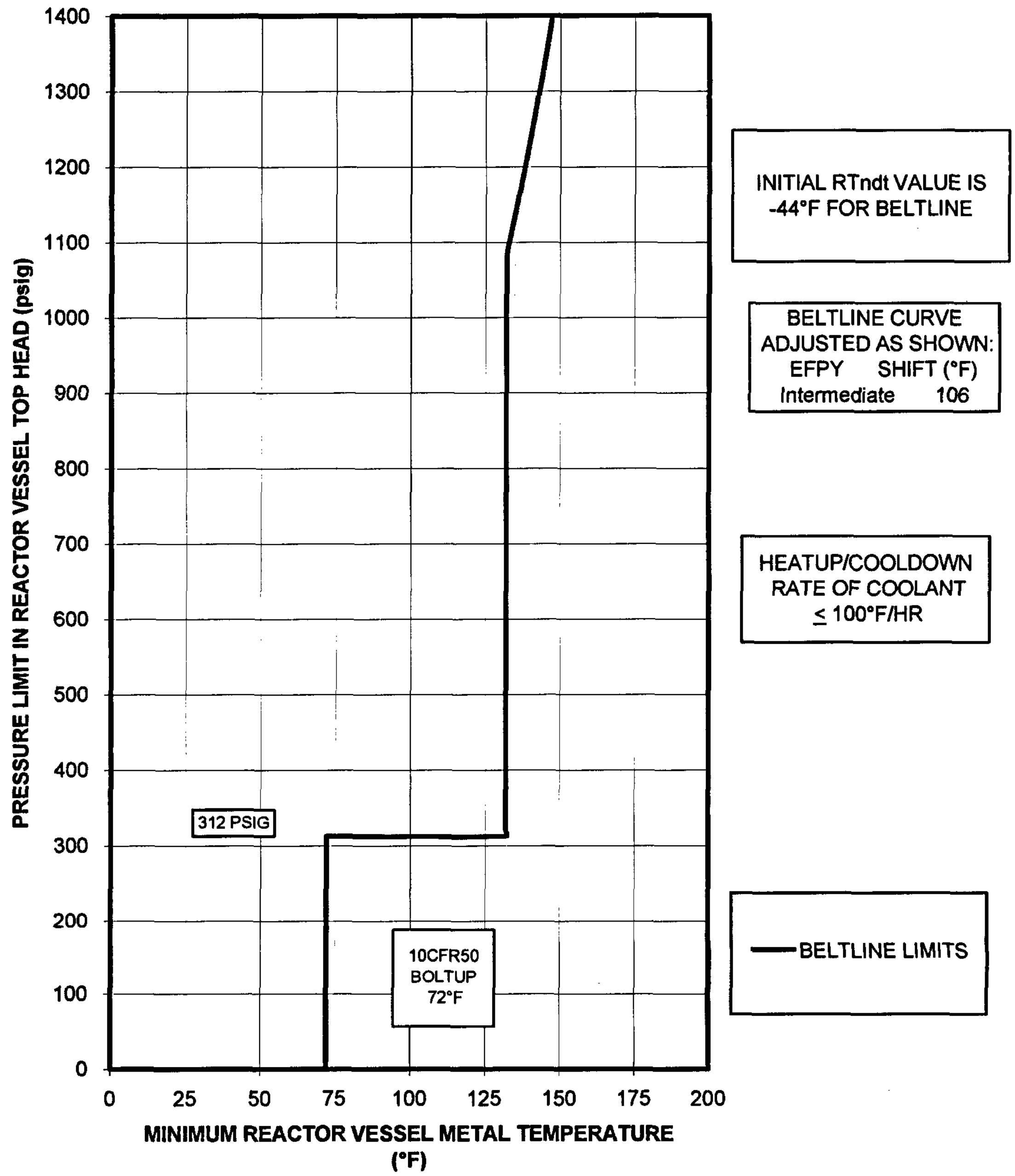

Figure 5-9: Beltline P-T Curve for Core Not Critical [Curve B] up to Intermediate EFPY [100°F/hr or less coolant heatup/cooldown]

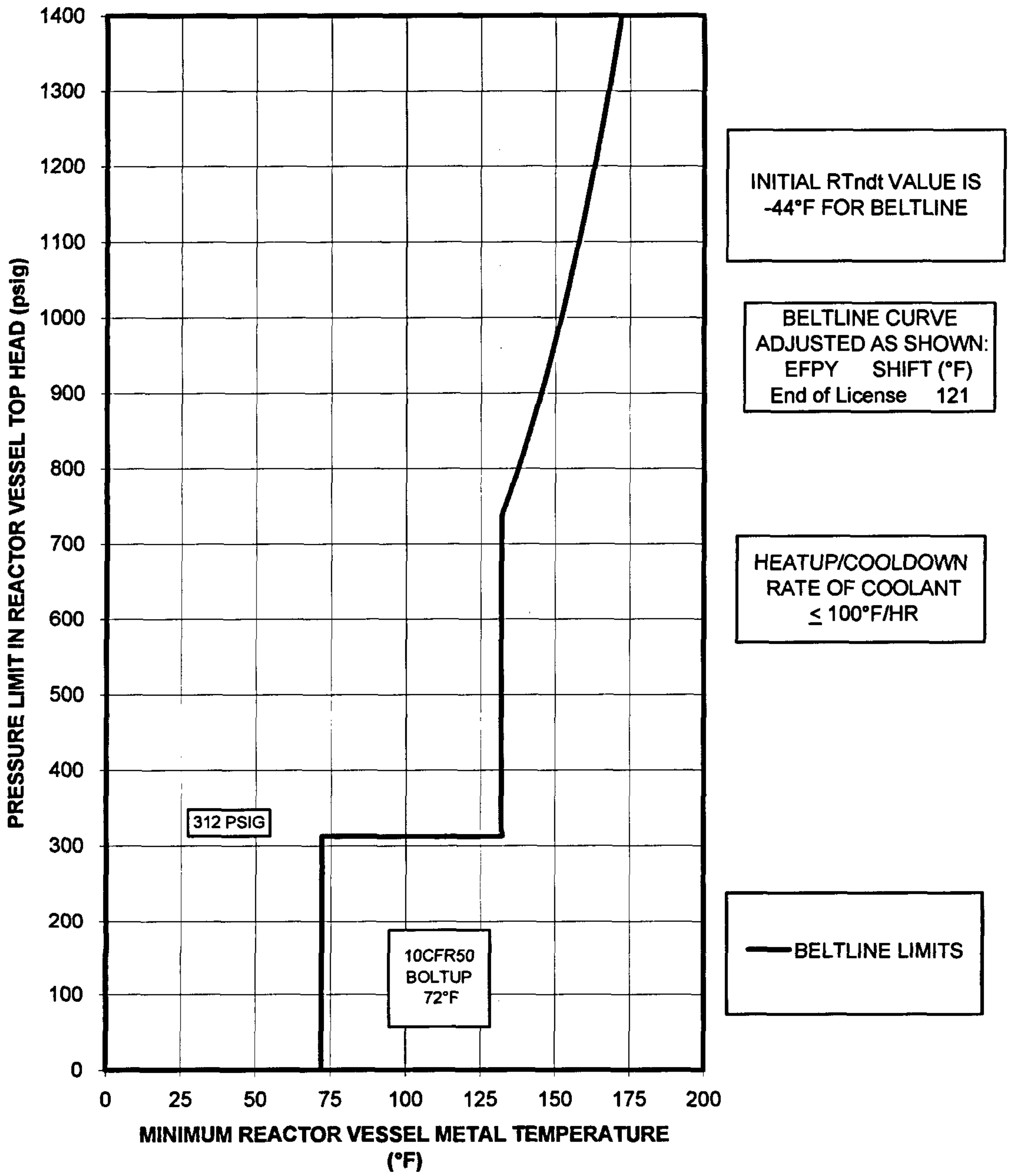

Figure 5-10: Beltline P-T Curve for Core Not Critical [Curve B] up to End of License EFPY [100°F/hr or less coolant heatup/cooldown]

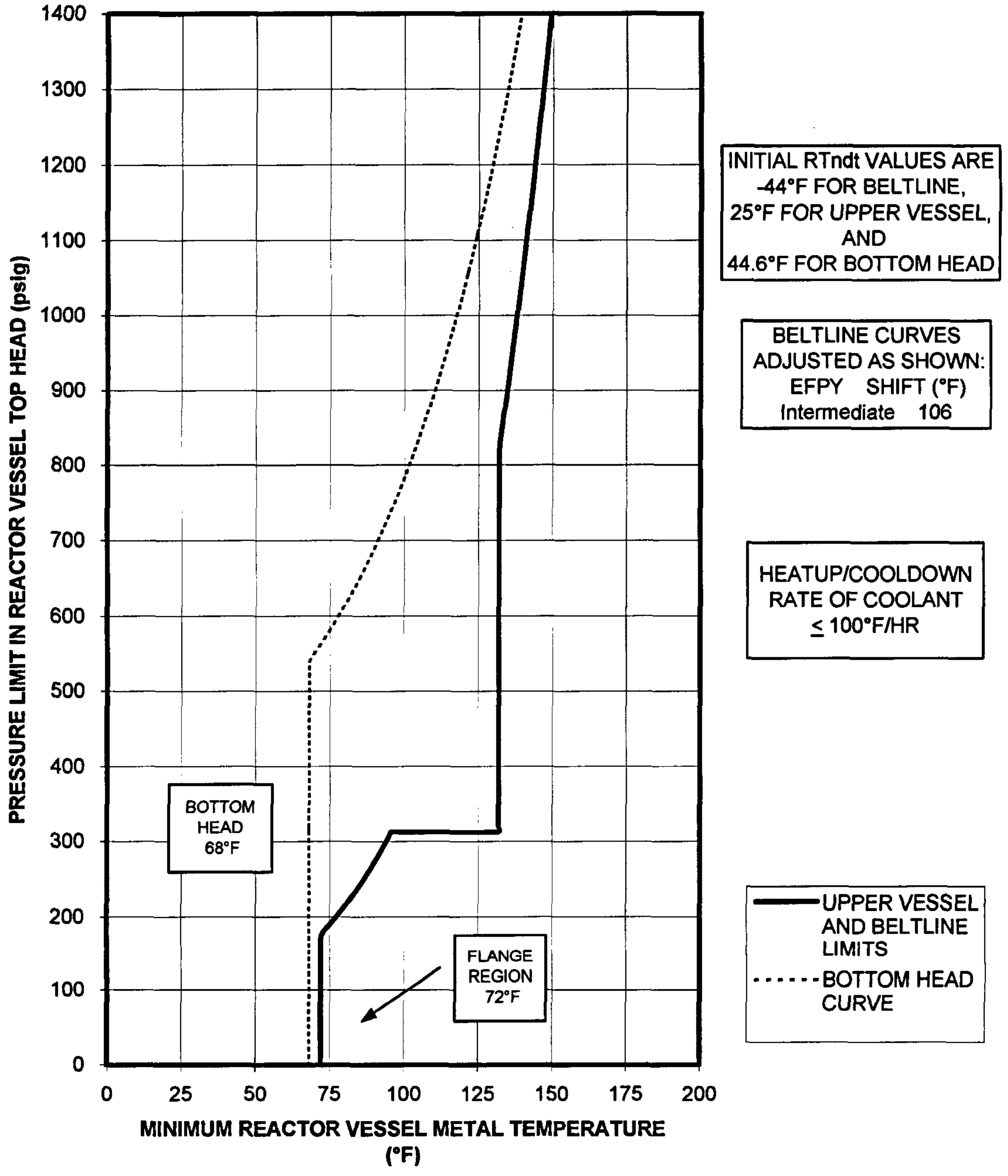

Figure 5-11: Composite Core Not Critical P-T Curves [Curve B] up to Intermediate EFPY [100°F/hr or less coolant heatup/cooldown]

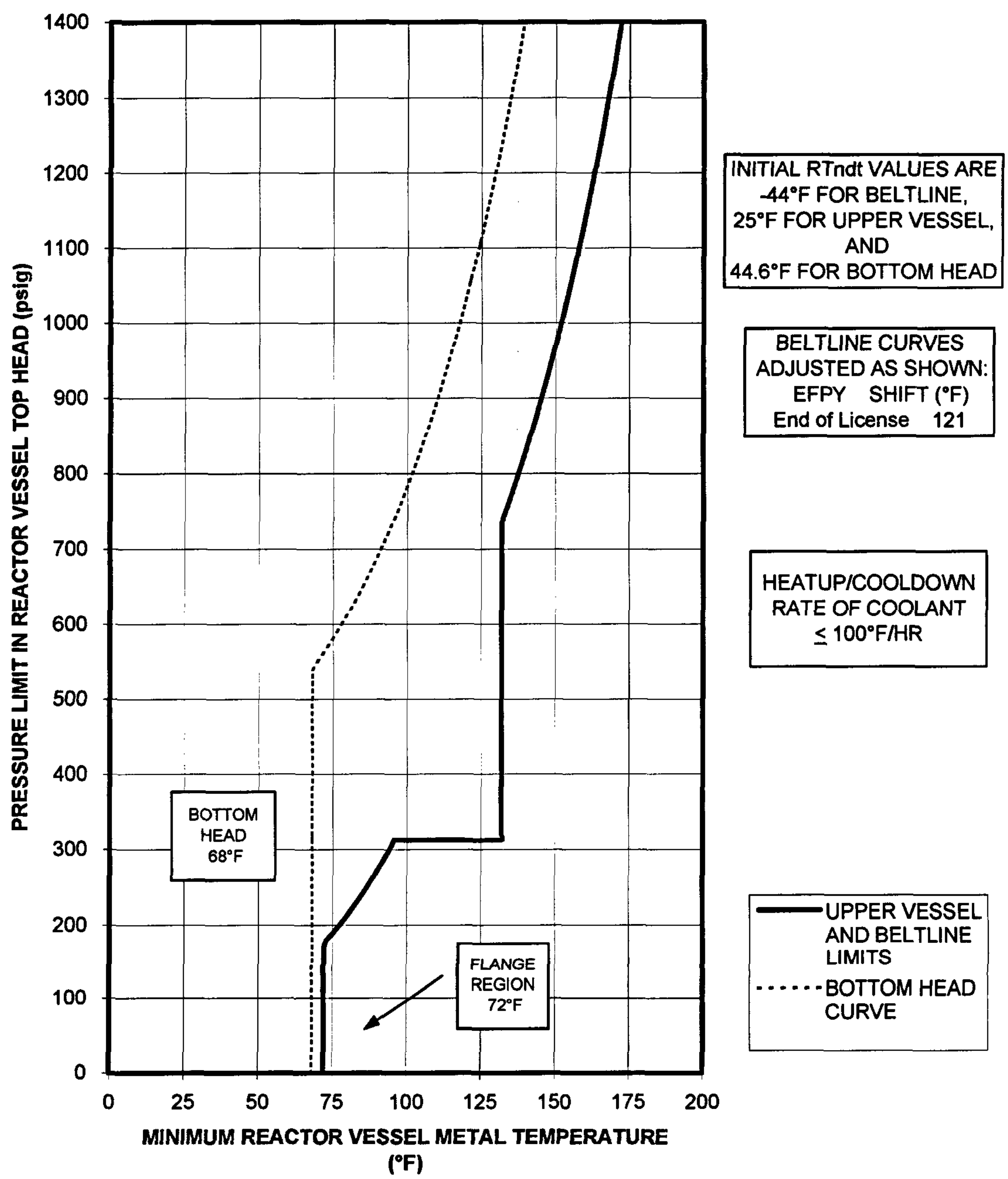

Figure 5-12: Composite Core Not Critical P-T Curves [Curve B] up to End of License EFPY [100°F/hr or less coolant heatup/cooldown]

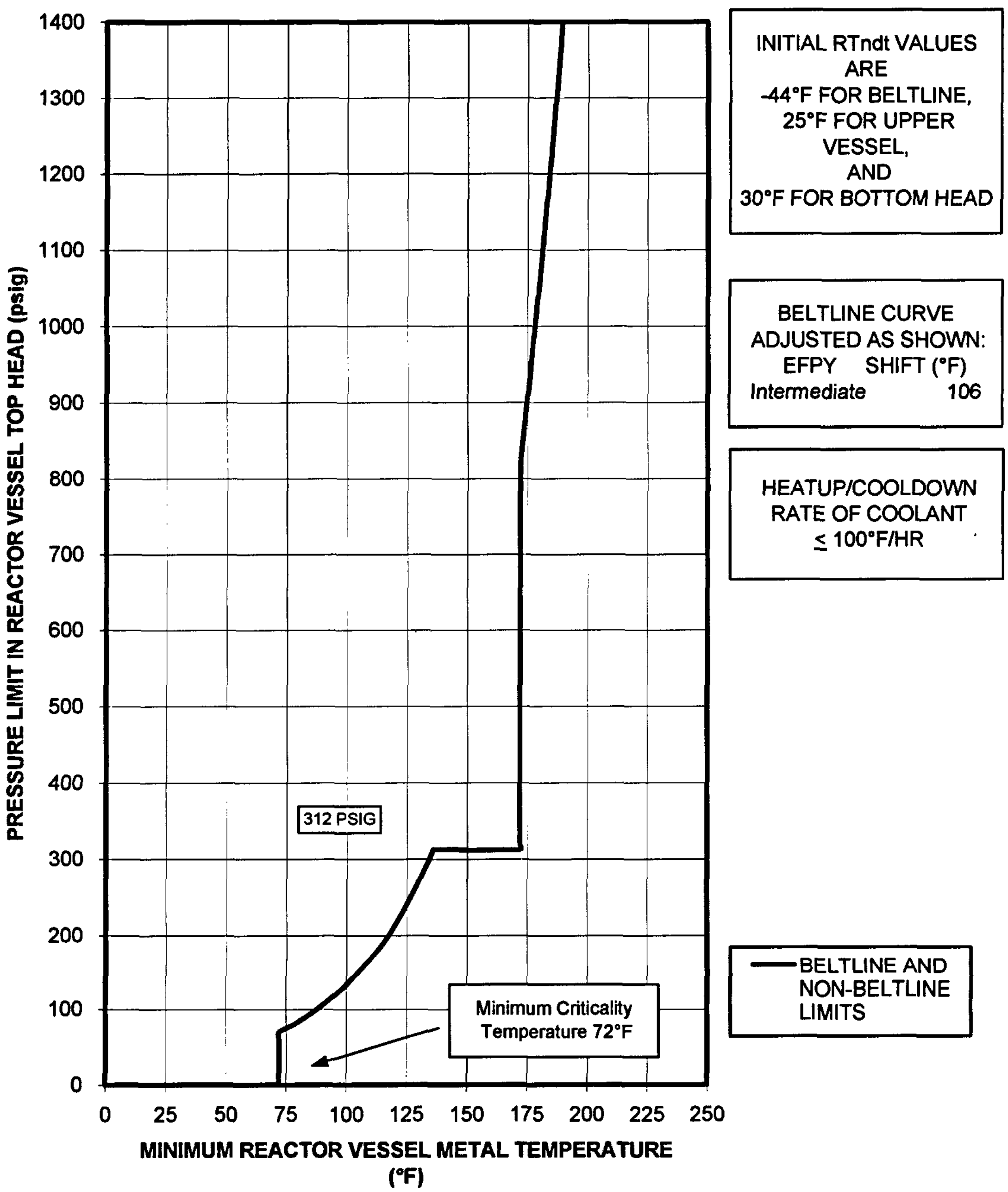

Figure 5-13: Composite Core Critical P-T Curves [Curve C] up to Intermediate EFPY [100°F/hr or less coolant heatup/cooldown]

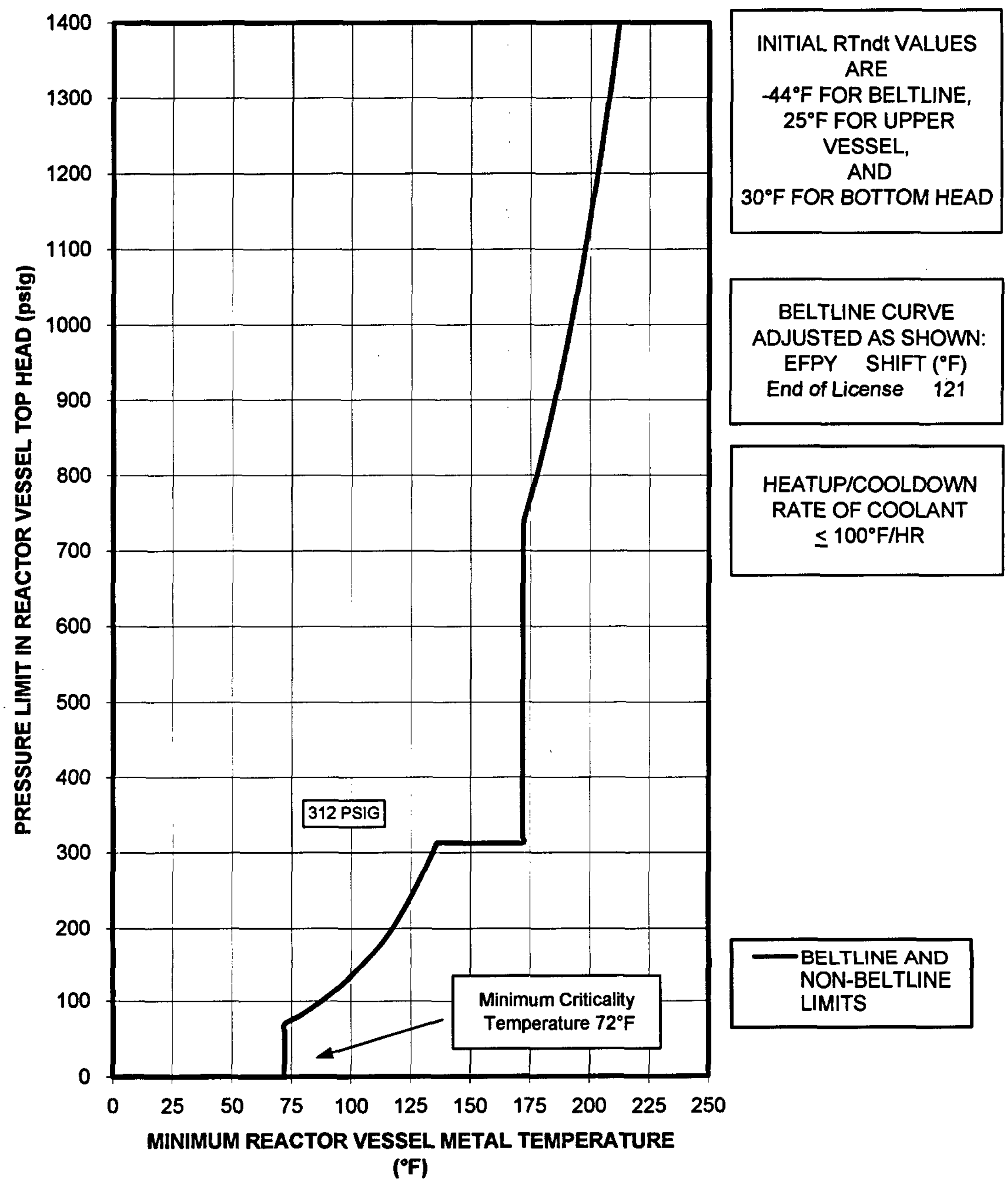

Figure 5-14: Composite Core Critical P-T Curves [Curve C] up to End of License EFPY [100°F/hr or less coolant heatup/cooldown]

6.0 REFERENCES

1. Plant-Specific Report Defining Currently Licensed P-T Curves.

2. Plant-Specific Reactor Vessel Thermal Cycle Drawing (GE Proprietary).

3. Plant-Specific Reactor Vessel Nozzle Thermal Cycle Drawing (GE Proprietary).

4. Plant-Specific Fluence Calculation (GE Proprietary) or other approved Fluence Calculation.

5. a) "BWR Vessel and Internals Project BWR Integrated Surveillance Program Implementation Guidelines", BWRVIP-102, EPRI, Palo Alto, CA, (EPRI Proprietary).
b) "BWR Vessel and Internals Project Integrated Surveillance Program (ISP) Data Source Book and Plant Evaluations", BWRVIP-135, EPRI, Palo Alto, CA, (EPRI Proprietary).

6. "Fracture Toughness Criteria for Protection Against Failure", Appendix G to Section XI of the ASME Boiler & Pressure Vessel Code, 1998 Edition with Addenda through 2000.

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

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

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

10. GE Nuclear Energy, NEDC-32399-P, "Basis for GE RT_{NDT} Estimation Method", Report for BWR Owners' Group, San Jose, California, September 1994 (GE Proprietary).

11. Letter from B. Sheron to R.A. Pinelli, "Safety Assessment of Report NEDC-32399-P, Basis for GE RT_{NDT} Estimation Method, September 1994", USNRC, December 16, 1994.

12. Plant-Specific QA Records and RPV CMTRs.

13. Plant-Specific Design Input.

14. Letter, S.A. Richard, USNRC to J.F. Klapproth, GE-NE, "Safety Evaluation for NEDC-32983P, General Electric Methodology for Reactor Pressure Vessel Fast Neutron Flux Evaluation (TAC No. MA9891)", MFN 01-050, September 14, 2001.

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

16. [[ ]]

17. "Analysis of Flaws", Appendix A to Section XI of the ASME Boiler & Pressure Vessel Code, 1998 Edition with Addenda through 2000.

18. [[ ]]

19. Bottom Head and Feedwater Nozzle Dimensions:
    a. Plant-Specific Drawing for the Bottom Head.
    b. Plant-Specific Drawing for the Feedwater Nozzle.

20. [[ ]]

21. "Materials - Properties", Part D to Section II of the ASME Boiler & Pressure Vessel Code, 1998 Edition with Addenda through 2000.

22. GE Nuclear Energy, NEDC-33178P, Revision 0, "General Electric Methodology for Development of Reactor Pressure Vessel Pressure-Temperature Curves", Report for BWR Owners' Group, Sunol, California, July 2006 (GE Proprietary).

APPENDIX A

DESCRIPTION OF DISCONTINUITIES

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

Per ASME Code Appendix G, Section G2223 (c), fracture toughness analysis to demonstrate protection against non-ductile failure is not required for portions of nozzles and appurtenances having a thickness of 2.5" or less provided the lowest service temperature is not lower than RT_{NDT} plus 60°F. Inconel (or Alloy 600) and stainless steel discontinuities require no fracture toughness evaluations.

Nozzle or Appurtenance	Material	Reference	Remarks
High Pressure Seal Leak Detector Nozzle (attached to Shell Flange)	SA 106 Gr B		Nozzles less than 2.5" require no fracture toughness evaluation.
Core ΔP and Liquid Control Nozzle (See Table A-1 for Penetration in the Bottom Head Dollar Plate)	Inconel		Nozzles made from Inconel require no fracture toughness evaluation.
Instrumentation Nozzles	SA 508 CL 1		Nozzles less than 2.5" in thickness require no fracture toughness evaluation.
Drain Nozzle	SA 508 CL 1		Nozzles less than 2.5" in thickness require no fracture toughness evaluation.
Shroud Support	SB-166 Inconel		Components made from Inconel require no fracture toughness evaluation.
Basin Seal Skirt	SA 515 GR 70		Not a pressure boundary component; therefore requires no fracture toughness evaluation.
Thermocouple Pad	A 36 Carbon Steel		Not a pressure boundary component; therefore requires no fracture toughness evaluation.
CRD Stub Tubes (in Bottom Head Dollar Plate and Lower Torus)	SB-167 Alloy 600		Components made from Alloy 600 and less than 2.5" require no fracture toughness evaluation.
Surveillance Brackets	SA351 Gr CF8M		Appurtenances made from Stainless Steel require no fracture toughness evaluation.
Core Spray Brackets	SA351 Gr CF8M		Appurtenances made from Stainless Steel require no fracture toughness evaluation.
Feedwater Sparger Brackets	SA351 Gr CF8M		Appurtenances made from Stainless Steel require no fracture toughness evaluation.

Table A-2 - Geometric Discontinuities Not Requiring Fracture Toughness Evaluations, Continued

Nozzle or Appurtenance	Material	Reference	Remarks
Steam Dryer Support Lug	SA351 Gr CF8M		Appurtenances made from Stainless Steel require no fracture toughness evaluation.
Guide Rod Bracket	SA351 Gr CF8M		Appurtenances made from Stainless Steel require no fracture toughness evaluation
Top Head Lifting Lugs	SA 533 Gr B CL 1		Loading only occurs during outages. Not a pressure boundary component; therefore requires no fracture toughness evaluation.
Steam Dryer Hold Down Bracket	SA 533 Gr B CL 1		Not a pressure boundary component; therefore requires no fracture toughness evaluation.

APPENDIX A REFERENCES:

1. Plant-Specific Vessel Drawings.
2. Plant-Specific Design Input.
3. Plant-Specific Fluence Calculation (GE Proprietary) or other approved Fluence Calculation.
4. Plant-Specific Component Drawings.

APPENDIX B

PRESSURE TEMPERATURE CURVE DATA TABULATION

TABLE B-1. PLANT P-T Curve Values for Intermediate EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-1, 5-2, 5-3, 5-7, 5-8 & 5-9

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	BELTLINE CURVE B (°F)
0	68.0	72.0	72.0	68.0	72.0	72.0
10	68.0	72.0	72.0	68.0	72.0	72.0
20	68.0	72.0	72.0	68.0	72.0	72.0
30	68.0	72.0	72.0	68.0	72.0	72.0
40	68.0	72.0	72.0	68.0	72.0	72.0
50	68.0	72.0	72.0	68.0	72.0	72.0
60	68.0	72.0	72.0	68.0	72.0	72.0
70	68.0	72.0	72.0	68.0	72.0	72.0
80	68.0	72.0	72.0	68.0	72.0	72.0
90	68.0	72.0	72.0	68.0	72.0	72.0
100	68.0	72.0	72.0	68.0	72.0	72.0
110	68.0	72.0	72.0	68.0	72.0	72.0
120	68.0	72.0	72.0	68.0	72.0	72.0
130	68.0	72.0	72.0	68.0	72.0	72.0
140	68.0	72.0	72.0	68.0	72.0	72.0
150	68.0	72.0	72.0	68.0	72.0	72.0
160	68.0	72.0	72.0	68.0	72.0	72.0
170	68.0	72.0	72.0	68.0	72.0	72.0
180	68.0	72.0	72.0	68.0	72.9	72.0
190	68.0	72.0	72.0	68.0	75.2	72.0

TABLE B-1. PLANT P-T Curve Values for Intermediate EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-1, 5-2, 5-3, 5-7, 5-8 & 5-9

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	BELTLINE CURVE B (°F)
200	68.0	72.0	72.0	68.0	77.3	72.0
210	68.0	72.0	72.0	68.0	79.3	72.0
220	68.0	72.0	72.0	68.0	81.3	72.0
230	68.0	72.0	72.0	68.0	83.1	72.0
240	68.0	72.0	72.0	68.0	84.9	72.0
250	68.0	72.0	72.0	68.0	86.6	72.0
260	68.0	72.0	72.0	68.0	88.2	72.0
270	68.0	72.0	72.0	68.0	89.8	72.0
280	68.0	72.0	72.0	68.0	91.3	72.0
290	68.0	72.0	72.0	68.0	92.8	72.0
300	68.0	72.0	72.0	68.0	94.2	72.0
310	68.0	72.0	72.0	68.0	95.5	72.0
312.5	68.0	72.0	72.0	68.0	95.9	72.0
312.5	68.0	102.0	102.0	68.0	132.0	132.0
320	68.0	102.0	102.0	68.0	132.0	132.0
330	68.0	102.0	102.0	68.0	132.0	132.0
340	68.0	102.0	102.0	68.0	132.0	132.0
350	68.0	102.0	102.0	68.0	132.0	132.0
360	68.0	102.0	102.0	68.0	132.0	132.0
370	68.0	102.0	102.0	68.0	132.0	132.0
380	68.0	102.0	102.0	68.0	132.0	132.0
390	68.0	102.0	102.0	68.0	132.0	132.0

TABLE B-1. PLANT P-T Curve Values for Intermediate EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-1, 5-2, 5-3, 5-7, 5-8 & 5-9

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	BELTLINE CURVE B (°F)
400	68.0	102.0	102.0	68.0	132.0	132.0
410	68.0	102.0	102.0	68.0	132.0	132.0
420	68.0	102.0	102.0	68.0	132.0	132.0
430	68.0	102.0	102.0	68.0	132.0	132.0
440	68.0	102.0	102.0	68.0	132.0	132.0
450	68.0	102.0	102.0	68.0	132.0	132.0
460	68.0	102.0	102.0	68.0	132.0	132.0
470	68.0	102.0	102.0	68.0	132.0	132.0
480	68.0	102.0	102.0	68.0	132.0	132.0
490	68.0	102.0	102.0	68.0	132.0	132.0
500	68.0	102.0	102.0	68.0	132.0	132.0
510	68.0	102.0	102.0	68.0	132.0	132.0
520	68.0	102.0	102.0	68.0	132.0	132.0
530	68.0	102.0	102.0	68.0	132.0	132.0
540	68.0	102.0	102.0	68.0	132.0	132.0
550	68.0	102.0	102.0	69.5	132.0	132.0
560	68.0	102.0	102.0	71.3	132.0	132.0
570	68.0	102.0	102.0	73.0	132.0	132.0
580	68.0	102.0	102.0	74.6	132.0	132.0
590	68.0	102.0	102.0	76.2	132.0	132.0
600	68.0	102.0	102.0	77.8	132.0	132.0
610	68.0	102.0	102.0	79.3	132.0	132.0

TABLE B-1. PLANT P-T Curve Values for Intermediate EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-1, 5-2, 5-3, 5-7, 5-8 & 5-9

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	BELTLINE CURVE B (°F)
620	68.0	102.0	102.0	80.7	132.0	132.0
630	68.0	102.0	102.0	82.1	132.0	132.0
640	68.0	102.0	102.0	83.5	132.0	132.0
650	68.0	102.0	102.0	84.8	132.0	132.0
660	68.0	102.0	102.0	86.1	132.0	132.0
670	68.0	102.0	102.0	87.4	132.0	132.0
680	68.0	102.0	102.0	88.7	132.0	132.0
690	68.0	102.0	102.0	89.9	132.0	132.0
700	68.0	102.0	102.0	91.0	132.0	132.0
710	68.0	102.0	102.0	92.2	132.0	132.0
720	68.0	102.0	102.0	93.3	132.0	132.0
730	68.0	102.0	102.0	94.4	132.0	132.0
740	68.0	102.0	102.0	95.5	132.0	132.0
750	68.0	102.0	102.0	96.6	132.0	132.0
760	68.0	102.0	102.0	97.6	132.0	132.0
770	68.0	102.0	102.0	98.6	132.0	132.0
780	68.0	102.0	102.0	99.6	132.0	132.0
790	68.0	102.0	102.0	100.6	132.0	132.0
800	68.0	102.0	102.0	101.5	132.0	132.0
810	68.0	102.0	102.0	102.5	132.0	132.0
820	68.0	102.0	102.0	103.4	132.0	132.0
830	68.0	102.0	102.0	104.3	132.2	132.0

TABLE B-1. PLANT P-T Curve Values for Intermediate EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-1, 5-2, 5-3, 5-7, 5-8 & 5-9

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	BELTLINE CURVE B (°F)
840	68.0	102.0	102.0	105.2	132.6	132.0
850	68.6	102.0	102.0	106.0	132.9	132.0
860	69.6	102.0	102.0	106.9	133.3	132.0
870	70.6	102.0	102.0	107.7	133.6	132.0
880	71.5	102.0	102.0	108.6	134.0	132.0
890	72.5	102.0	102.0	109.4	134.3	132.0
900	73.4	102.0	102.0	110.2	134.7	132.0
910	74.4	102.0	102.2	111.0	135.0	132.0
920	75.3	102.0	103.2	111.7	135.4	132.0
930	76.1	102.0	104.1	112.5	135.7	132.0
940	77.0	102.5	105.1	113.3	136.0	132.0
950	77.9	103.1	106.0	114.0	136.4	132.0
960	78.7	103.7	106.9	114.7	136.7	132.0
970	79.6	104.3	107.8	115.5	137.0	132.0
980	80.4	104.9	108.7	116.2	137.4	132.0
990	81.2	105.5	109.6	116.9	137.7	132.0
1000	82.0	106.1	110.4	117.6	138.0	132.0
1010	82.7	106.7	111.3	118.2	138.3	132.0
1020	83.5	107.2	112.1	118.9	138.6	132.0
1030	84.3	107.8	112.9	119.6	139.0	132.0
1040	85.0	108.4	113.7	120.2	139.3	132.0
1050	85.7	108.9	114.5	120.9	139.6	132.0

TABLE B-1. PLANT P-T Curve Values for Intermediate EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-1, 5-2, 5-3, 5-7, 5-8 & 5-9

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	BELTLINE CURVE B (°F)
1055	86.1	109.2	114.9	121.2	139.7	132.0
1060	86.4	109.5	115.3	121.5	139.9	132.0
1070	87.2	110.0	116.0	122.1	140.2	132.0
1080	87.9	110.5	116.8	122.8	140.5	132.0
1090	88.6	111.1	117.5	123.4	140.8	132.3
1100	89.2	111.6	118.3	124.0	141.1	132.8
1105	89.6	111.8	118.6	124.3	141.3	133.1
1110	89.9	112.1	119.0	124.6	141.4	133.4
1120	90.6	112.6	119.7	125.2	141.7	133.9
1130	91.2	113.1	120.4	125.8	142.0	134.5
1140	91.9	113.6	121.1	126.3	142.3	135.0
1150	92.5	114.1	121.8	126.9	142.6	135.5
1160	93.1	114.6	122.4	127.5	142.9	136.1
1170	93.8	115.1	123.1	128.0	143.2	136.6
1180	94.4	115.6	123.7	128.6	143.5	137.1
1190	95.0	116.1	124.4	129.1	143.7	137.6
1200	95.6	116.5	125.0	129.7	144.0	138.1
1210	96.2	117.0	125.7	130.2	144.3	138.6
1220	96.8	117.5	126.3	130.8	144.6	139.1
1230	97.3	117.9	126.9	131.3	144.9	139.6
1240	97.9	118.4	127.5	131.8	145.2	140.1
1250	98.5	118.8	128.1	132.3	145.4	140.6

TABLE B-1. PLANT P-T Curve Values for Intermediate EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-1, 5-2, 5-3, 5-7, 5-8 & 5-9

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	BELTLINE CURVE B (°F)
1260	99.0	119.3	128.7	132.8	145.7	141.0
1270	99.6	119.7	129.3	133.3	146.0	141.5
1280	100.1	120.2	129.8	133.8	146.2	142.0
1290	100.7	120.6	130.4	134.3	146.5	142.4
1300	101.2	121.0	131.0	134.8	146.8	142.9
1310	101.7	121.5	131.5	135.3	147.1	143.3
1320	102.3	121.9	132.1	135.8	147.3	143.8
1330	102.8	122.3	132.6	136.2	147.6	144.2
1340	103.3	122.7	133.2	136.7	147.8	144.7
1350	103.8	123.1	133.7	137.2	148.1	145.1
1360	104.3	123.6	134.2	137.6	148.4	145.5
1370	104.8	124.0	134.8	138.1	148.6	146.0
1380	105.3	124.4	135.3	138.5	148.9	146.4
1390	105.8	124.8	135.8	139.0	149.1	146.8
1400	106.3	125.2	136.3	139.4	149.4	147.2

TABLE B-2. PLANT Composite P-T Curve Values for Intermediate EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-5, 5-11 & 5-13

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE CURVE B (°F)	LIMITING CURVE C (°F)
0	68.0	72.0	68.0	72.0	72.0
10	68.0	72.0	68.0	72.0	72.0
20	68.0	72.0	68.0	72.0	72.0
30	68.0	72.0	68.0	72.0	72.0
40	68.0	72.0	68.0	72.0	72.0
50	68.0	72.0	68.0	72.0	72.0
60	68.0	72.0	68.0	72.0	72.0
70	68.0	72.0	68.0	72.0	72.2
80	68.0	72.0	68.0	72.0	78.2
90	68.0	72.0	68.0	72.0	83.3
100	68.0	72.0	68.0	72.0	87.8
110	68.0	72.0	68.0	72.0	91.9
120	68.0	72.0	68.0	72.0	95.7
130	68.0	72.0	68.0	72.0	99.2
140	68.0	72.0	68.0	72.0	102.4
150	68.0	72.0	68.0	72.0	105.2
160	68.0	72.0	68.0	72.0	107.9
170	68.0	72.0	68.0	72.0	110.5
180	68.0	72.0	68.0	72.9	112.9
190	68.0	72.0	68.0	75.2	115.2
200	68.0	72.0	68.0	77.3	117.3

TABLE B-2. PLANT Composite P-T Curve Values for Intermediate EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-5, 5-11 & 5-13

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE CURVE B (°F)	LIMITING CURVE C (°F)
210	68.0	72.0	68.0	79.3	119.3
220	68.0	72.0	68.0	81.3	121.3
230	68.0	72.0	68.0	83.1	123.1
240	68.0	72.0	68.0	84.9	124.9
250	68.0	72.0	68.0	86.6	126.6
260	68.0	72.0	68.0	88.2	128.2
270	68.0	72.0	68.0	89.8	129.8
280	68.0	72.0	68.0	91.3	131.3
290	68.0	72.0	68.0	92.8	132.8
300	68.0	72.0	68.0	94.2	134.2
310	68.0	72.0	68.0	95.5	135.5
312.5	68.0	72.0	68.0	95.9	135.9
312.5	68.0	102.0	68.0	132.0	172.0
320	68.0	102.0	68.0	132.0	172.0
330	68.0	102.0	68.0	132.0	172.0
340	68.0	102.0	68.0	132.0	172.0
350	68.0	102.0	68.0	132.0	172.0
360	68.0	102.0	68.0	132.0	172.0
370	68.0	102.0	68.0	132.0	172.0
380	68.0	102.0	68.0	132.0	172.0
390	68.0	102.0	68.0	132.0	172.0
400	68.0	102.0	68.0	132.0	172.0
410	68.0	102.0	68.0	132.0	172.0

TABLE B-2. PLANT Composite P-T Curve Values for Intermediate EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-5, 5-11 & 5-13

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE CURVE B (°F)	LIMITING CURVE C (°F)
420	68.0	102.0	68.0	132.0	172.0
430	68.0	102.0	68.0	132.0	172.0
440	68.0	102.0	68.0	132.0	172.0
450	68.0	102.0	68.0	132.0	172.0
460	68.0	102.0	68.0	132.0	172.0
470	68.0	102.0	68.0	132.0	172.0
480	68.0	102.0	68.0	132.0	172.0
490	68.0	102.0	68.0	132.0	172.0
500	68.0	102.0	68.0	132.0	172.0
510	68.0	102.0	68.0	132.0	172.0
520	68.0	102.0	68.0	132.0	172.0
530	68.0	102.0	68.0	132.0	172.0
540	68.0	102.0	68.0	132.0	172.0
550	68.0	102.0	69.5	132.0	172.0
560	68.0	102.0	71.3	132.0	172.0
570	68.0	102.0	73.0	132.0	172.0
580	68.0	102.0	74.6	132.0	172.0
590	68.0	102.0	76.2	132.0	172.0
600	68.0	102.0	77.8	132.0	172.0
610	68.0	102.0	79.3	132.0	172.0
620	68.0	102.0	80.7	132.0	172.0
630	68.0	102.0	82.1	132.0	172.0
640	68.0	102.0	83.5	132.0	172.0

TABLE B-2. PLANT Composite P-T Curve Values for Intermediate EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-5, 5-11 & 5-13

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE CURVE B (°F)	LIMITING CURVE C (°F)
650	68.0	102.0	84.8	132.0	172.0
660	68.0	102.0	86.1	132.0	172.0
670	68.0	102.0	87.4	132.0	172.0
680	68.0	102.0	88.7	132.0	172.0
690	68.0	102.0	89.9	132.0	172.0
700	68.0	102.0	91.0	132.0	172.0
710	68.0	102.0	92.2	132.0	172.0
720	68.0	102.0	93.3	132.0	172.0
730	68.0	102.0	94.4	132.0	172.0
740	68.0	102.0	95.5	132.0	172.0
750	68.0	102.0	96.6	132.0	172.0
760	68.0	102.0	97.6	132.0	172.0
770	68.0	102.0	98.6	132.0	172.0
780	68.0	102.0	99.6	132.0	172.0
790	68.0	102.0	100.6	132.0	172.0
800	68.0	102.0	101.5	132.0	172.0
810	68.0	102.0	102.5	132.0	172.0
820	68.0	102.0	103.4	132.0	172.0
830	68.0	102.0	104.3	132.2	172.2
840	68.0	102.0	105.2	132.6	172.6
850	68.6	102.0	106.0	132.9	172.9
860	69.6	102.0	106.9	133.3	173.3
870	70.6	102.0	107.7	133.6	173.6

TABLE B-2. PLANT Composite P-T Curve Values for Intermediate EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-5, 5-11 & 5-13

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE CURVE B (°F)	LIMITING CURVE C (°F)
880	71.5	102.0	108.6	134.0	174.0
890	72.5	102.0	109.4	134.3	174.3
900	73.4	102.0	110.2	134.7	174.7
910	74.4	102.2	111.0	135.0	175.0
920	75.3	103.2	111.7	135.4	175.4
930	76.1	104.1	112.5	135.7	175.7
940	77.0	105.1	113.3	136.0	176.0
950	77.9	106.0	114.0	136.4	176.4
960	78.7	106.9	114.7	136.7	176.7
970	79.6	107.8	115.5	137.0	177.0
980	80.4	108.7	116.2	137.4	177.4
990	81.2	109.6	116.9	137.7	177.7
1000	82.0	110.4	117.6	138.0	178.0
1010	82.7	111.3	118.2	138.3	178.3
1020	83.5	112.1	118.9	138.6	178.6
1030	84.3	112.9	119.6	139.0	179.0
1040	85.0	113.7	120.2	139.3	179.3
1050	85.7	114.5	120.9	139.6	179.6
1055	86.1	114.9	121.2	139.7	179.7
1060	86.4	115.3	121.5	139.9	179.9
1070	87.2	116.0	122.1	140.2	180.2
1080	87.9	116.8	122.8	140.5	180.5
1090	88.6	117.5	123.4	140.8	180.8

TABLE B-2. PLANT Composite P-T Curve Values for Intermediate EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-5, 5-11 & 5-13

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE CURVE B (°F)	LIMITING CURVE C (°F)
1100	89.2	118.3	124.0	141.1	181.1
1105	89.6	118.6	124.3	141.3	181.3
1110	89.9	119.0	124.6	141.4	181.4
1120	90.6	119.7	125.2	141.7	181.7
1130	91.2	120.4	125.8	142.0	182.0
1140	91.9	121.1	126.3	142.3	182.3
1150	92.5	121.8	126.9	142.6	182.6
1160	93.1	122.4	127.5	142.9	182.9
1170	93.8	123.1	128.0	143.2	183.2
1180	94.4	123.7	128.6	143.5	183.5
1190	95.0	124.4	129.1	143.7	183.7
1200	95.6	125.0	129.7	144.0	184.0
1210	96.2	125.7	130.2	144.3	184.3
1220	96.8	126.3	130.8	144.6	184.6
1230	97.3	126.9	131.3	144.9	184.9
1240	97.9	127.5	131.8	145.2	185.2
1250	98.5	128.1	132.3	145.4	185.4
1260	99.0	128.7	132.8	145.7	185.7
1270	99.6	129.3	133.3	146.0	186.0
1280	100.1	129.8	133.8	146.2	186.2
1290	100.7	130.4	134.3	146.5	186.5
1300	101.2	131.0	134.8	146.8	186.8
1310	101.7	131.5	135.3	147.1	187.1

TABLE B-2. PLANT Composite P-T Curve Values for Intermediate EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-5, 5-11 & 5-13

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE CURVE B (°F)	LIMITING CURVE C (°F)
1320	102.3	132.1	135.8	147.3	187.3
1330	102.8	132.6	136.2	147.6	187.6
1340	103.3	133.2	136.7	147.8	187.8
1350	103.8	133.7	137.2	148.1	188.1
1360	104.3	134.2	137.6	148.4	188.4
1370	104.8	134.8	138.1	148.6	188.6
1380	105.3	135.3	138.5	148.9	188.9
1390	105.8	135.8	139.0	149.1	189.1
1400	106.3	136.3	139.4	149.4	189.4

TABLE B-3. PLANT P-T Curve Values for End of License EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-1, 5-2, 5-4, 5-7, 5-8 & 5-10

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	BELTLINE CURVE B (°F)
0	68.0	72.0	72.0	68.0	72.0	72.0
10	68.0	72.0	72.0	68.0	72.0	72.0
20	68.0	72.0	72.0	68.0	72.0	72.0
30	68.0	72.0	72.0	68.0	72.0	72.0
40	68.0	72.0	72.0	68.0	72.0	72.0
50	68.0	72.0	72.0	68.0	72.0	72.0
60	68.0	72.0	72.0	68.0	72.0	72.0
70	68.0	72.0	72.0	68.0	72.0	72.0
80	68.0	72.0	72.0	68.0	72.0	72.0
90	68.0	72.0	72.0	68.0	72.0	72.0
100	68.0	72.0	72.0	68.0	72.0	72.0
110	68.0	72.0	72.0	68.0	72.0	72.0
120	68.0	72.0	72.0	68.0	72.0	72.0
130	68.0	72.0	72.0	68.0	72.0	72.0
140	68.0	72.0	72.0	68.0	72.0	72.0
150	68.0	72.0	72.0	68.0	72.0	72.0
160	68.0	72.0	72.0	68.0	72.0	72.0
170	68.0	72.0	72.0	68.0	72.0	72.0
180	68.0	72.0	72.0	68.0	72.9	72.0
190	68.0	72.0	72.0	68.0	75.2	72.0

TABLE B-3. PLANT P-T Curve Values for End of License EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-1, 5-2, 5-4, 5-7, 5-8 & 5-10

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	BELTLINE CURVE B (°F)
200	68.0	72.0	72.0	68.0	77.3	72.0
210	68.0	72.0	72.0	68.0	79.3	72.0
220	68.0	72.0	72.0	68.0	81.3	72.0
230	68.0	72.0	72.0	68.0	83.1	72.0
240	68.0	72.0	72.0	68.0	84.9	72.0
250	68.0	72.0	72.0	68.0	86.6	72.0
260	68.0	72.0	72.0	68.0	88.2	72.0
270	68.0	72.0	72.0	68.0	89.8	72.0
280	68.0	72.0	72.0	68.0	91.3	72.0
290	68.0	72.0	72.0	68.0	92.8	72.0
300	68.0	72.0	72.0	68.0	94.2	72.0
310	68.0	72.0	72.0	68.0	95.5	72.0
312.5	68.0	72.0	72.0	68.0	95.9	72.0
312.5	68.0	102.0	102.0	68.0	132.0	132.0
320	68.0	102.0	102.0	68.0	132.0	132.0
330	68.0	102.0	102.0	68.0	132.0	132.0
340	68.0	102.0	102.0	68.0	132.0	132.0
350	68.0	102.0	102.0	68.0	132.0	132.0
360	68.0	102.0	102.0	68.0	132.0	132.0
370	68.0	102.0	102.0	68.0	132.0	132.0
380	68.0	102.0	102.0	68.0	132.0	132.0
390	68.0	102.0	102.0	68.0	132.0	132.0

TABLE B-3. PLANT P-T Curve Values for End of License EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-1, 5-2, 5-4, 5-7, 5-8 & 5-10

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	BELTLINE CURVE B (°F)
400	68.0	102.0	102.0	68.0	132.0	132.0
410	68.0	102.0	102.0	68.0	132.0	132.0
420	68.0	102.0	102.0	68.0	132.0	132.0
430	68.0	102.0	102.0	68.0	132.0	132.0
440	68.0	102.0	102.0	68.0	132.0	132.0
450	68.0	102.0	102.0	68.0	132.0	132.0
460	68.0	102.0	102.0	68.0	132.0	132.0
470	68.0	102.0	102.0	68.0	132.0	132.0
480	68.0	102.0	102.0	68.0	132.0	132.0
490	68.0	102.0	102.0	68.0	132.0	132.0
500	68.0	102.0	102.0	68.0	132.0	132.0
510	68.0	102.0	102.0	68.0	132.0	132.0
520	68.0	102.0	102.0	68.0	132.0	132.0
530	68.0	102.0	102.0	68.0	132.0	132.0
540	68.0	102.0	102.0	68.0	132.0	132.0
550	68.0	102.0	102.0	69.5	132.0	132.0
560	68.0	102.0	102.0	71.3	132.0	132.0
570	68.0	102.0	102.0	73.0	132.0	132.0
580	68.0	102.0	102.0	74.6	132.0	132.0
590	68.0	102.0	102.0	76.2	132.0	132.0
600	68.0	102.0	102.0	77.8	132.0	132.0
610	68.0	102.0	102.0	79.3	132.0	132.0

TABLE B-3. PLANT P-T Curve Values for End of License EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-1, 5-2, 5-4, 5-7, 5-8 & 5-10

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	BELTLINE CURVE B (°F)
620	68.0	102.0	102.0	80.7	132.0	132.0
630	68.0	102.0	102.0	82.1	132.0	132.0
640	68.0	102.0	102.0	83.5	132.0	132.0
650	68.0	102.0	102.0	84.8	132.0	132.0
660	68.0	102.0	102.0	86.1	132.0	132.0
670	68.0	102.0	102.0	87.4	132.0	132.0
680	68.0	102.0	102.0	88.7	132.0	132.0
690	68.0	102.0	102.0	89.9	132.0	132.0
700	68.0	102.0	102.0	91.0	132.0	132.0
710	68.0	102.0	102.0	92.2	132.0	132.0
720	68.0	102.0	102.0	93.3	132.0	132.0
730	68.0	102.0	102.0	94.4	132.0	132.0
740	68.0	102.0	102.0	95.5	132.0	132.0
750	68.0	102.0	102.0	96.6	132.0	132.0
760	68.0	102.0	102.0	97.6	132.0	132.0
770	68.0	102.0	102.0	98.6	132.0	132.0
780	68.0	102.0	102.0	99.6	132.0	132.0
790	68.0	102.0	102.0	100.6	132.0	132.0
800	68.0	102.0	102.0	101.5	132.0	132.0
810	68.0	102.0	102.0	102.5	132.0	132.0
820	68.0	102.0	102.0	103.4	132.0	132.0
830	68.0	102.0	102.0	104.3	132.2	132.0

TABLE B-3. PLANT P-T Curve Values for End of License EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-1, 5-2, 5-4, 5-7, 5-8 & 5-10

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	BELTLINE CURVE B (°F)
840	68.0	102.0	102.0	105.2	132.6	132.0
850	68.6	102.0	102.8	106.0	132.9	132.0
860	69.6	102.0	103.9	106.9	133.3	132.3
870	70.6	102.0	105.0	107.7	133.6	133.1
880	71.5	102.0	106.1	108.6	134.0	133.8
890	72.5	102.0	107.2	109.4	134.3	134.6
900	73.4	102.0	108.2	110.2	134.7	135.3
910	74.4	102.0	109.2	111.0	135.0	136.0
920	75.3	102.0	110.2	111.7	135.4	136.7
930	76.1	102.0	111.1	112.5	135.7	137.4
940	77.0	102.5	112.1	113.3	136.0	138.1
950	77.9	103.1	113.0	114.0	136.4	138.7
960	78.7	103.7	113.9	114.7	136.7	139.4
970	79.6	104.3	114.8	115.5	137.0	140.0
980	80.4	104.9	115.7	116.2	137.4	140.7
990	81.2	105.5	116.6	116.9	137.7	141.3
1000	82.0	106.1	117.4	117.6	138.0	142.0
1010	82.7	106.7	118.3	118.2	138.3	142.6
1020	83.5	107.2	119.1	118.9	138.6	143.2
1030	84.3	107.8	119.9	119.6	139.0	143.8
1040	85.0	108.4	120.7	120.2	139.3	144.4
1050	85.7	108.9	121.5	120.9	139.6	145.0

TABLE B-3. PLANT P-T Curve Values for End of License EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-1, 5-2, 5-4, 5-7, 5-8 & 5-10

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	BELTLINE CURVE B (°F)
1055	86.1	109.2	121.9	121.2	139.7	145.3
1060	86.4	109.5	122.3	121.5	139.9	145.6
1070	87.2	110.0	123.0	122.1	140.2	146.2
1080	87.9	110.5	123.8	122.8	140.5	146.7
1090	88.6	111.1	124.5	123.4	140.8	147.3
1100	89.2	111.6	125.3	124.0	141.1	147.8
1105	89.6	111.8	125.6	124.3	141.3	148.1
1110	89.9	112.1	126.0	124.6	141.4	148.4
1120	90.6	112.6	126.7	125.2	141.7	148.9
1130	91.2	113.1	127.4	125.8	142.0	149.5
1140	91.9	113.6	128.1	126.3	142.3	150.0
1150	92.5	114.1	128.8	126.9	142.6	150.5
1160	93.1	114.6	129.4	127.5	142.9	151.1
1170	93.8	115.1	130.1	128.0	143.2	151.6
1180	94.4	115.6	130.7	128.6	143.5	152.1
1190	95.0	116.1	131.4	129.1	143.7	152.6
1200	95.6	116.5	132.0	129.7	144.0	153.1
1210	96.2	117.0	132.7	130.2	144.3	153.6
1220	96.8	117.5	133.3	130.8	144.6	154.1
1230	97.3	117.9	133.9	131.3	144.9	154.6
1240	97.9	118.4	134.5	131.8	145.2	155.1
1250	98.5	118.8	135.1	132.3	145.4	155.6

TABLE B-3. PLANT P-T Curve Values for End of License EFPY

Required Metal Temperature with Required Coolant Temperature Rate
at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A
for Figures 5-1, 5-2, 5-4, 5-7, 5-8 & 5-10

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER VESSEL CURVE A (°F)	BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	BELTLINE CURVE B (°F)
1260	99.0	119.3	135.7	132.8	145.7	156.0
1270	99.6	119.7	136.3	133.3	146.0	156.5
1280	100.1	120.2	136.8	133.8	146.2	157.0
1290	100.7	120.6	137.4	134.3	146.5	157.4
1300	101.2	121.0	138.0	134.8	146.8	157.9
1310	101.7	121.5	138.5	135.3	147.1	158.3
1320	102.3	121.9	139.1	135.8	147.3	158.8
1330	102.8	122.3	139.6	136.2	147.6	159.2
1340	103.3	122.7	140.2	136.7	147.8	159.7
1350	103.8	123.1	140.7	137.2	148.1	160.1
1360	104.3	123.6	141.2	137.6	148.4	160.5
1370	104.8	124.0	141.8	138.1	148.6	161.0
1380	105.3	124.4	142.3	138.5	148.9	161.4
1390	105.8	124.8	142.8	139.0	149.1	161.8
1400	106.3	125.2	143.3	139.4	149.4	162.2

TABLE B-4. PLANT Composite P-T Curve Values for End of License EFPY

Required Metal Temperature with Required Coolant Temperature Rate at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

for Figures 5-6, 5-12 & 5-14

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE CURVE B (°F)	LIMITING CURVE C (°F)
0	68.0	72.0	68.0	72.0	72.0
10	68.0	72.0	68.0	72.0	72.0
20	68.0	72.0	68.0	72.0	72.0
30	68.0	72.0	68.0	72.0	72.0
40	68.0	72.0	68.0	72.0	72.0
50	68.0	72.0	68.0	72.0	72.0
60	68.0	72.0	68.0	72.0	72.0
70	68.0	72.0	68.0	72.0	72.2
80	68.0	72.0	68.0	72.0	78.2
90	68.0	72.0	68.0	72.0	83.3
100	68.0	72.0	68.0	72.0	87.8
110	68.0	72.0	68.0	72.0	91.9
120	68.0	72.0	68.0	72.0	95.7
130	68.0	72.0	68.0	72.0	99.2
140	68.0	72.0	68.0	72.0	102.4
150	68.0	72.0	68.0	72.0	105.2
160	68.0	72.0	68.0	72.0	107.9
170	68.0	72.0	68.0	72.0	110.5
180	68.0	72.0	68.0	72.9	112.9
190	68.0	72.0	68.0	75.2	115.2
200	68.0	72.0	68.0	77.3	117.3

TABLE B-4. PLANT Composite P-T Curve Values for End of License EFPY

Required Metal Temperature with Required Coolant Temperature Rate at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

for Figures 5-6, 5-12 & 5-14

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE CURVE B (°F)	LIMITING CURVE C (°F)
210	68.0	72.0	68.0	79.3	119.3
220	68.0	72.0	68.0	81.3	121.3
230	68.0	72.0	68.0	83.1	123.1
240	68.0	72.0	68.0	84.9	124.9
250	68.0	72.0	68.0	86.6	126.6
260	68.0	72.0	68.0	88.2	128.2
270	68.0	72.0	68.0	89.8	129.8
280	68.0	72.0	68.0	91.3	131.3
290	68.0	72.0	68.0	92.8	132.8
300	68.0	72.0	68.0	94.2	134.2
310	68.0	72.0	68.0	95.5	135.5
312.5	68.0	72.0	68.0	95.9	135.9
312.5	68.0	102.0	68.0	132.0	172.0
320	68.0	102.0	68.0	132.0	172.0
330	68.0	102.0	68.0	132.0	172.0
340	68.0	102.0	68.0	132.0	172.0
350	68.0	102.0	68.0	132.0	172.0
360	68.0	102.0	68.0	132.0	172.0
370	68.0	102.0	68.0	132.0	172.0
380	68.0	102.0	68.0	132.0	172.0
390	68.0	102.0	68.0	132.0	172.0
400	68.0	102.0	68.0	132.0	172.0
410	68.0	102.0	68.0	132.0	172.0

TABLE B-4. PLANT Composite P-T Curve Values for End of License EFPY

Required Metal Temperature with Required Coolant Temperature Rate at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

for Figures 5-6, 5-12 & 5-14

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE CURVE B (°F)	LIMITING CURVE C (°F)
420	68.0	102.0	68.0	132.0	172.0
430	68.0	102.0	68.0	132.0	172.0
440	68.0	102.0	68.0	132.0	172.0
450	68.0	102.0	68.0	132.0	172.0
460	68.0	102.0	68.0	132.0	172.0
470	68.0	102.0	68.0	132.0	172.0
480	68.0	102.0	68.0	132.0	172.0
490	68.0	102.0	68.0	132.0	172.0
500	68.0	102.0	68.0	132.0	172.0
510	68.0	102.0	68.0	132.0	172.0
520	68.0	102.0	68.0	132.0	172.0
530	68.0	102.0	68.0	132.0	172.0
540	68.0	102.0	68.0	132.0	172.0
550	68.0	102.0	69.5	132.0	172.0
560	68.0	102.0	71.3	132.0	172.0
570	68.0	102.0	73.0	132.0	172.0
580	68.0	102.0	74.6	132.0	172.0
590	68.0	102.0	76.2	132.0	172.0
600	68.0	102.0	77.8	132.0	172.0
610	68.0	102.0	79.3	132.0	172.0
620	68.0	102.0	80.7	132.0	172.0
630	68.0	102.0	82.1	132.0	172.0
640	68.0	102.0	83.5	132.0	172.0

TABLE B-4. PLANT Composite P-T Curve Values for End of License EFPY

Required Metal Temperature with Required Coolant Temperature Rate at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

for Figures 5-6, 5-12 & 5-14

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE CURVE B (°F)	LIMITING CURVE C (°F)
650	68.0	102.0	84.8	132.0	172.0
660	68.0	102.0	86.1	132.0	172.0
670	68.0	102.0	87.4	132.0	172.0
680	68.0	102.0	88.7	132.0	172.0
690	68.0	102.0	89.9	132.0	172.0
700	68.0	102.0	91.0	132.0	172.0
710	68.0	102.0	92.2	132.0	172.0
720	68.0	102.0	93.3	132.0	172.0
730	68.0	102.0	94.4	132.0	172.0
740	68.0	102.0	95.5	132.0	172.0
750	68.0	102.0	96.6	132.0	172.0
760	68.0	102.0	97.6	132.0	172.0
770	68.0	102.0	98.6	132.0	172.0
780	68.0	102.0	99.6	132.0	172.0
790	68.0	102.0	100.6	132.0	172.0
800	68.0	102.0	101.5	132.0	172.0
810	68.0	102.0	102.5	132.0	172.0
820	68.0	102.0	103.4	132.0	172.0
830	68.0	102.0	104.3	132.2	172.2
840	68.0	102.0	105.2	132.6	172.6
850	68.6	102.8	106.0	132.9	172.9
860	69.6	103.9	106.9	133.3	173.3
870	70.6	105.0	107.7	133.6	173.6

TABLE B-4. PLANT Composite P-T Curve Values for End of License EFPY

Required Metal Temperature with Required Coolant Temperature Rate at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

for Figures 5-6, 5-12 & 5-14

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE CURVE B (°F)	LIMITING CURVE C (°F)
880	71.5	106.1	108.6	134.0	174.0
890	72.5	107.2	109.4	134.6	174.6
900	73.4	108.2	110.2	135.3	175.3
910	74.4	109.2	111.0	136.0	176.0
920	75.3	110.2	111.7	136.7	176.7
930	76.1	111.1	112.5	137.4	177.4
940	77.0	112.1	113.3	138.1	178.1
950	77.9	113.0	114.0	138.7	178.7
960	78.7	113.9	114.7	139.4	179.4
970	79.6	114.8	115.5	140.0	180.0
980	80.4	115.7	116.2	140.7	180.7
990	81.2	116.6	116.9	141.3	181.3
1000	82.0	117.4	117.6	142.0	182.0
1010	82.7	118.3	118.2	142.6	182.6
1020	83.5	119.1	118.9	143.2	183.2
1030	84.3	119.9	119.6	143.8	183.8
1040	85.0	120.7	120.2	144.4	184.4
1050	85.7	121.5	120.9	145.0	185.0
1055	86.1	121.9	121.2	145.3	185.3
1060	86.4	122.3	121.5	145.6	185.6
1070	87.2	123.0	122.1	146.2	186.2
1080	87.9	123.8	122.8	146.7	186.7
1090	88.6	124.5	123.4	147.3	187.3

TABLE B-4. PLANT Composite P-T Curve Values for End of License EFPY

Required Metal Temperature with Required Coolant Temperature Rate at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

for Figures 5-6, 5-12 & 5-14

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE CURVE B (°F)	LIMITING CURVE C (°F)
1100	89.2	125.3	124.0	147.8	187.8
1105	89.6	125.6	124.3	148.1	188.1
1110	89.9	126.0	124.6	148.4	188.4
1120	90.6	126.7	125.2	148.9	188.9
1130	91.2	127.4	125.8	149.5	189.5
1140	91.9	128.1	126.3	150.0	190.0
1150	92.5	128.8	126.9	150.5	190.5
1160	93.1	129.4	127.5	151.1	191.1
1170	93.8	130.1	128.0	151.6	191.6
1180	94.4	130.7	128.6	152.1	192.1
1190	95.0	131.4	129.1	152.6	192.6
1200	95.6	132.0	129.7	153.1	193.1
1210	96.2	132.7	130.2	153.6	193.6
1220	96.8	133.3	130.8	154.1	194.1
1230	97.3	133.9	131.3	154.6	194.6
1240	97.9	134.5	131.8	155.1	195.1
1250	98.5	135.1	132.3	155.6	195.6
1260	99.0	135.7	132.8	156.0	196.0
1270	99.6	136.3	133.3	156.5	196.5
1280	100.1	136.8	133.8	157.0	197.0
1290	100.7	137.4	134.3	157.4	197.4
1300	101.2	138.0	134.8	157.9	197.9
1310	101.7	138.5	135.3	158.3	198.3

TABLE B-4. PLANT Composite P-T Curve Values for End of License EFPY

Required Metal Temperature with Required Coolant Temperature Rate at 100 °F/hr for Curves B & C and 20 °F/hr for Curve A

for Figures 5-6, 5-12 & 5-14

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE CURVE B (°F)	LIMITING CURVE C (°F)
1320	102.3	139.1	135.8	158.8	198.8
1330	102.8	139.6	136.2	159.2	199.2
1340	103.3	140.2	136.7	159.7	199.7
1350	103.8	140.7	137.2	160.1	200.1
1360	104.3	141.2	137.6	160.5	200.5
1370	104.8	141.8	138.1	161.0	201.0
1380	105.3	142.3	138.5	161.4	201.4
1390	105.8	142.8	139.0	161.8	201.8
1400	106.3	143.3	139.4	162.2	202.2

APPENDIX C

OPERATING AND TEMPERATURE MONITORING REQUIREMENTS

All relevant information is contained in Appendix C of the Topical Report (NEDC-33178P) [22].

APPENDIX D

GE SIL 430

All relevant information is contained in Appendix D of the Topical Report (NEDC-33178P) [22].

APPENDIX E

DETERMINATION OF BELTLINE REGION AND IMPACT ON FRACTURE TOUGHNESS

This evaluation uses the methods defined in Appendix E of the Topical Report (NEDC-33178P) [4]. The following dimensions are obtained from the referenced drawings:

Component	Elevation (inches from RPV "0")	Reference
Shell # 2 - Top of Active Fuel (TAF)*	366.3"	3
Shell # 1 - Bottom of Active Fuel (BAF)	216.3"	3
Shell # 2 – Top of Extended Beltline Region	374.7"	3
Shell # 1 – Bottom of Extended Beltline Region	210.5"	3
Centerline of Recirculation Outlet Nozzle in Shell # 1	161.5"	3
Top of Recirculation Outlet Nozzle N1 in Shell # 1	193.7"	3
Centerline of Recirculation Inlet Nozzle N2 in Shell # 1	181.0"	3
Top of Recirculation Inlet Nozzle N2 in Shell # 1	197.5"	3
Centerline of 2" Instrumentation Nozzle in Shell # 2	366.0"	3

From the fluence report [2], it is obvious that the recirculation inlet and outlet nozzles are closest to the beltline region (the top of the recirculation inlet nozzle is ~19" below BAF and the top of the recirculation outlet nozzle is ~23" below BAF). Therefore, if it can be shown that the peak fluence at these locations is less than 1.0e17 n/cm^2, it can be safely concluded that all nozzles and welds, other than those included in Table 4-2, are outside the beltline region of the reactor vessel.

Based on the axial fluence profile, the RPV fluence at the end of license EFPY drops to less than 1.0e17 n/cm^2 at ~6" below the BAF and at ~9" above TAF. The beltline region considered in the development of the P-T curves is adjusted to include the region from 210.5" to 374.7" above reactor vessel "0" for the end of license EFPY.

Based on the above, it is concluded that none of the PLANT reactor vessel plates, nozzles, or welds, other than those included in Table 4-2, are in the beltline region.

APPENDIX E REFERENCES:

1. Plant-Specific Design Input.
2. Plant-Specific Fluence Calculation (GE Proprietary) or other approved Fluence Calculation.
3. Plant-Specific Drawings.
4. GE Nuclear Energy, NEDC-33178P, Revision 0, "General Electric Methodology for Development of Reactor Pressure Vessel Pressure-Temperature Curves", Report for BWR Owners' Group, Sunol, California, July 2006 (GE Proprietary).

APPENDIX F

EXAMPLE CALCULATION FOR LIMITING NOZZLE

IN THE BELTLINE REGION

Pressure Test Procedure

As noted in Section 4.3.2.2.2 of this report, in the event that a nozzle is the limiting material for the beltline region, the beltline P-T curves are calculated in the same manner as for the Feedwater Nozzle pressure test P-T curves, using the plant-specific nozzle dimensions as described in Section 4.3.2.1.3. The generic Feedwater pressure test P-T curve is applied to the plant-specific Feedwater Nozzle curve by shifting the P vs. (T-RT_{NDT}) values in Section 4.3.2.1.3 to reflect the appropriate ART value from Table 4-2.

Core Not Critical Beltline Calculation Using a Nozzle at 1055 psig and a Given EFPY

As an example using a Recirculation Inlet nozzle, the primary membrane stresses are scaled using the plant-specific nozzle geometry. The secondary thermal stresses for the FW nozzle are conservatively used for this nozzle. These stresses are then adjusted for stresses above yield. From these stresses, K_I can be determined. The stresses are scaled for various pressures and temperatures, similar to the scaling used for the FW nozzle core not critical curve in Section 4.3.2.1.4. The primary stresses are scaled by the nominal pressures, while the secondary stresses are scaled by the temperature difference of the cold FW nozzle (40°F) water injected into the hot reactor vessel nozzle. The base case is a pressure of 1050 psig and reactor vessel temperature of 551.4°F; this yields a K_I value of 305.6 ksi-in$^{1/2}$. Since the reactor vessel temperature follows the saturation temperature curve, the secondary stresses are scaled by ($T_{saturation}$ – 40°F) / (551°F – 40°F). From K_I, the associated T - RT_{NDT} can be calculated.

FW Nozzle t_v = 6.1875 inches
Recirculation Inlet Nozzle t_v = 5.25 inches, however, t_v = 4.875 is conservatively used
$F(a/r_n)$ = 1.5

The FW nozzle stresses are used for the Recirculation Inlet nozzle; only the primary membrane stress is scaled for the plant-specific vessel thickness, t_v. At a pressure of 1050 psig and a temperature of 551.4°F, the stresses are:

σ_{pm} = 24.84 ksi * (6.1875 inches / 4.875 inches) = 31.53 ksi
σ_{pb} = 0.22 ksi
σ_{sm} = 16.19 ksi
σ_{sb} = 19.04 ksi

K_I is calculated:

$t^{1/2}$ = $(4a)^{1/2}$ = $(4 \cdot 1.89)^{1/2}$ = 2.75
M_m = $0.926 \cdot 2.75$ = 2.546

K_{IP} is calculated using Equation 4-4 as shown in Section 4.3.2.1.4:
K_{IP} = $2.0 * (31.53 + 0.22) * (\pi \cdot 1.89)^{1/2} * 1.5$ = 232.1 ksi-in$^{1/2}$

K_{Is} is calculated using Equation 4-5 as shown in Section 4.3.2.1.4:

K_{Is} = $2.546 \cdot (16.19 + 2/3 \cdot 19.04)$ = 73.5 ksi-in$^{1/2}$

K_I = $K_{IP} + K_{Is}$
K_I = 232.1 ksi-in$^{1/2}$ + 73.5 ksi-in$^{1/2}$ = 305.6 ksi-in$^{1/2}$

T-RT_{NDT} is further calculated:

T-RT_{NDT} = ln [(305.6 – 33.2) / 20.734] / 0.02 = 128.8°F

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

APPENDIX G

THICKNESS TRANSITION DISCONTINUITY EVALUATION

G.1 OBJECTIVE

The purpose of the following evaluation is to determine the hydrotest, heatup/cooldown, and transient temperatures (T) for the shell thickness transition discontinuities in the beltline and the bottom head upper to lower torus, and to demonstrate that these temperatures are bounded by the appropriate P-T curves.

G.2 METHODS AND ASSUMPTIONS

ANSYS finite element analyses were performed for the thickness discontinuities in the beltline and bottom head regions of the plant-specific vessel. The purpose of this evaluation was to determine the RPV discontinuity stresses (hoop and axial) that result from the thickness transition discontinuity in the beltline and bottom head regions. The transition in the beltline is modeled as a transition from 7.125 inches minimum thickness (lower shell) to 6.125 inches minimum thickness (lower-intermediate shell) [1]. The bottom head lower torus to upper torus is modeled as a transition from 7.375 inches minimum thickness to 3.4375 inches minimum thickness, respectively [2].

Four (4) load cases defined on the plant-specific vessel thermal cycle diagram [3] were evaluated for the beltline and bottom head shell discontinuity:

1) hydrostatic test pressure at 1055 psig,
2) cooldown transient of 100°F/hr, starting at 546°F and decreasing to 70°F on the inside surface wall and with an initial operating pressure of 1000 psig, and 3) a heatup transient of 100°F/hr, starting at 70°F and increasing to 546°F on the inside surface wall and with a final operating pressure of 1000 psig. For both transient cases it was assumed that the outside RPV wall surface is insulated with a heat transfer coefficient of 0.2 BTU/hr-ft^2 °F [4] and that the ambient temperature is 100°F.

These are the bounding beltline transients of those described in Region B of the plant-specific vessel thermal cycle diagram at temperatures for which brittle fracture could occur.

Additionally, the bottom head was analyzed for

3) [[ ]], and

4) [[ ]] [3].

As discussed in Section 4.3.2.1.2 of the Topical Report (NEDC-33178P) [9], these transients represent [[ ]]. The Normal/Upset transient "Loss of AC Power Natural Circulation Restart" was also analyzed. It was determined that the [[ ]] transients bound this operating condition for the bottom head region; results for the bounding conditions are presented in this appendix.

Material properties were used from the Code of construction for the RPV Materials: shell and bottom head plate materials are ASME SA533, Grade B, Class 1 low alloy steel (LAS) and support skirt materials are ASME SA508 Class 2 [5].

Methods consistent with those described in Section 4.3 of the Topical Report were used to calculate the T - RT_{NDT} for the shell discontinuity for a hydrotest pressure of 1055 psig and the two transient cases. The adjusted reference temperature values shown in Table 4-2b were added to the T - RT_{NDT} to determine the temperature, T. The value of T was compared to that of the beltline region for the same condition as described in Sections 4.3.2.2.1 for the hydrotest pressure case and 4.3.2.2.4 for the transient cases.

It is demonstrated in this analysis that Curve A for the bottom head (CRD) and beltline regions (Figures 5-1 and 5-4) bound the temperatures found for the hydrostatic test pressure temperatures from the FEA analysis. It is also shown that Curve B for the bottom head (CRD) beltline regions (Figures 5-7 and 5-10) bound the temperatures found for transient pressures from the stresses obtained in the FEA analysis. Therefore, the transition discontinuity stresses in the beltline and bottom head upper to lower torus are bounded by the P-T curves.

The locations of maximum stress were evaluated in the beltline shell and bottom head torus locations as shown in Figure G-1.

The methods of ASME Code Section XI, Appendix G [6] are used to calculate the pressure test and thermal limits. The membrane and bending stresses were determined from the finite element analysis and are shown below. The hoop stresses were more limiting than the axial stresses, and are provided in Tables G-1 through G-5 of this appendix.

The stress intensity factors, K_{Im} and K_{Ib}, are calculated using 1998 ASME Code with Addenda through 2000 Section XI Appendix A [7] and Appendix G [6], as shown in Section 4.3.2.2.2 of this report. Therefore, $K_{Im} = M_m \cdot \sigma_m$ and $K_{Ib} = M_b \cdot \sigma_b$. The values of M_m and M_b were determined from the ASME Code Appendix G [6]. The stress intensity is based on a 1/4T radial flaw with a six-to-one aspect ratio (length of 1.5T). The flaw is oriented normal to the maximum stress direction, in this case a vertically oriented flaw since the hoop stress was limiting.

The calculated value of $K_{Im} + K_{Ib}$ is multiplied by a safety factor (SF) (1.5 for pressure test and 2.0 for the transient cases), per ASME Appendix G [6] for comparison with K_{IR}, the material fracture toughness expressed as K_{Ic}.

The relationship between K_{Ic} and temperature relative to reference temperature ($T - RT_{NDT}$) is provided in ASME Code Section XI Appendix A [7] Paragraph A-4200, represented by the relationship (K_I units ksi-in$^{0.5}$):

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

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

$$\text{where } K_{Ic} = SF * (K_{Im} + K_{Ib}) \quad \text{for the pressure test,}$$

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

This relationship is derived in the Welding Research Council (WRC) Bulletin 175 [8] as the lower bound of all dynamic fracture toughness data. This relationship provides values of pressure versus temperature (from K_{IR} and $(T - RT_{NDT})$, respectively).

The RT_{NDT} is added to the $(T - RT_{NDT})$ to determine the hydrotest, heatup, cooldown, and additional transient temperatures.

Analysis Information:

Beltline

Thin Section Thickness:	t_{min} = 6.125 inches
	$\sqrt{(t)}$ = 2.47 $inch^{0.5}$
Thick Section Thickness:	t_{max} = 7.125 inches
	$\sqrt{(t)}$ = 2.67 $inch^{0.5}$

Bottom Head Upper Torus to Lower Torus

Thin Section Thickness:	t_{min} = 3.438 inches
	$\sqrt{(t)}$ = 1.85 $inch^{0.5}$
Thick Section Thickness:	t_{max} = 7.375 inches
	$\sqrt{(t)}$ = 2.72 $inch^{0.5}$

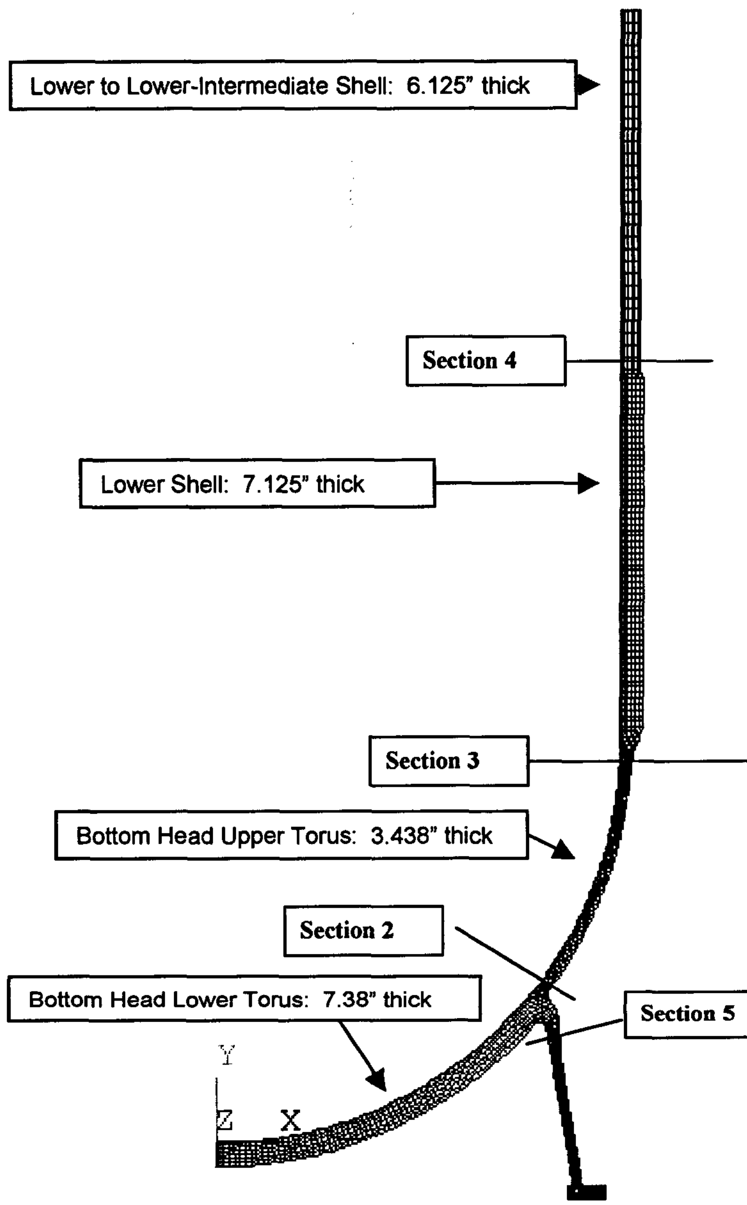

Figure G-1: Location and Wall Thickness of Evaluation Discontinuities in the Beltline and Bottom Head Regions

Table G-1: Analysis Results for Hydrostatic Pressure Test for the Beltline Shell Discontinuity

Pressure (psig)	Surface	Primary Membrane P_m (psi)	Primary Bending P_b (psi)	M_m	$K_{Im} = M_m*P_m$ (psi in$^{1/2}$)	$M_b = 2/3\ M_m$	K_{Ib}	K_I	T-RT_{NDT} (°F)
1000	Inside	19860	-24	2.29	45514	1.53	-36	68.22	26.20
1000	Outside	19860	24	2.29	45514	1.53	36	68.32	26.36
1055	Inside	20952	-25	2.29	48017	1.53	-38	71.97	31.29
1055	Outside	20952	25	2.29	48017	1.53	38	72.08	**31.44**

Table G-2: Analysis Results for Hydrostatic Pressure Test for the Bottom Head Discontinuities

Pressure	Section	Surface	Primary Membrane P_m (psi)	Primary Bending P_b (psi)	M_m	$K_m = M_m*P_b$ (psi in$^{1/2}$)	M_b = 2/3 M_m	K_b	K_I	T-RT_{NDT} (°F)
1000	2	Inside	18000	-2363	1.85	33300	1.23	-2914	45.58	-25.79
1000	2	Outside	18000	2363	1.85	33300	1.23	2914	54.32	0.93
1055	2	Inside	18990	-2493	1.85	35132	1.23	-3075	48.09	-16.57
1055	2	Outside	18990	2493	1.85	35132	1.23	3075	57.31	**7.54**
1000	5	Inside	5247	424	1.85	9707	1.23	523	15.34	-
1000	5	Outside	5247	-424	1.85	9707	1.23	-523	13.78	-
1055	5	Inside	5536	447	1.85	10241	1.23	551	16.19	-
1055	5	Outside	5536	-447	1.85	10241	1.23	-551	14.53	-

G.3 Results and Conclusions for Hydrostatic Pressure Test

The results of this analysis demonstrate that Curve A remains bounding for the bottom head torus (Figure 5-1) and beltline shell (Figure 5-4) discontinuities.

<u>Beltline</u>

The maximum plant-specific T-RT_{NDT} calculated with the linearized stresses from the Finite Element Analysis (FEA) for the beltline thickness discontinuity is 31.44°F as shown in Table G-1. The limiting beltline weld material RT_{NDT} (ART) at the region of the discontinuity is 77°F (see Table 4-2b) at end of license EFPY, resulting in T = 108.44°F. The limiting beltline plate RT_{NDT} (ART) at the region of the discontinuity is 45°F (see Table 4-2b) at end of license EFPY, resulting in T = 76.44°F.

At 1055 psig, representing the end of license EFPY plant-specific hydrostatic pressure test, the T - RT_{NDT} for the beltline region Curve A is 39.8°F (see Section 4.3.2.2.2), and T = 116.8°F (see Section 4.3.2.2.2).

Because the end of license EFPY beltline region hydrostatic pressure test temperature "T" of 116.8°F is greater than the T = 108.44°F obtained with the FEA analysis results, the thickness discontinuity remains bounded by the beltline curve.

Similarly, the limiting beltline material RT_{NDT} (ART) at the region of discontinuity at the intermediate EFPY is the beltline weld at 62°F (see Table 4-2a), resulting in T = 93.44°F. At 1055 psig, the T for the intermediate EFPY beltline region Curve A is 102°F. Because the intermediate EFPY beltline region hydrostatic pressure test curve is greater than the T obtained by FEA, the thickness discontinuity remains bounded by the beltline curve.

Bottom Head Lower Torus to Upper Torus

The maximum T - RT_{NDT} calculated with the Finite Element Analysis results for the bottom head lower torus to upper torus region is 7.54°F, as shown for Sections 2 and 5 (see Figure G-1 for location of these sections) in Table G-2. The maximum RT_{NDT} for the bottom head lower torus to upper torus is 30°F for the plates (see Table 4-1a) and –50°F for the welds (see Table 4-1c). Thus a limiting value of T = 37.54°F is obtained from the linearized stresses obtained in the FEA analysis. From Tables B-1 and B-3, the bottom head T (appropriate for this location) used in the analysis is 86.1°F at 1055 psig. This value bounds the maximum value of T = 37.54°F, obtained using the linearized stresses from the FEA analysis.

Table G-3: Beltline Analysis and Results for Heatup and Cooldown at 1030 psig

Case	Surface	Primary Membrane P_m (psi)	Primary Bending P_b (psi)	Secondary Membrane S_m (psi)	Secondary Bending S_b (psi)	M_m	M_b = 2/3 M_m	K_{IP} (psi in$^{1/2}$)	K_{IS} (psi in$^{1/2}$)	K_I Total (psi in$^{1/2}$)	T-RT_{NDT} (°F)
Heatup	Inside	20462	-25	-163	-6469	2.29	1.53	46819	-10248	83391	44.20
Heatup	Outside	20462	25	-163	6469	2.29	1.53	46895	9504	103294	60.90
Cooldown	Inside	20462	-25	1	9785	2.29	1.53	46819	14940	108579	**64.54**
Cooldown	Outside	20462	25	1	-9633	2.29	1.53	46895	-14705	79086	39.72

Table G-4: Bottom Head Analysis and Results for Heatup and Cooldown at 1030 psig

Case	Location	Surface	Primary Membrane P_m (psi)	Primary Bending P_b (psi)	Secondary Membrane S_m (psi)	Secondary Bending S_b (psi)	M_m	M_b = 2/3 M_m	K_{IP} (psi in$^{1/2}$)	K_{IS} (psi in$^{1/2}$)	K_I Total (psi in$^{1/2}$)	T-RT_{NDT} (°F)
Heatup	2	Inside	18545	-2493	-5529	-4959	1.85	1.23	31234	-16345	46124	-23.63
Heatup	2	Outside	18990	2493	-5529	4959	1.85	1.23	38206	-4113	72300	31.72
Cooldown	2	Inside	18990	-2493	688	3255	1.85	1.23	32057	5287	69401	27.87
Cooldown	2	Outside	18990	2493	688	-3255	1.85	1.23	38206	-2742	73671	33.44
Heatup	5	Inside	5406	447	27020	-14010	1.85	1.23	10553	32708	53813	-0.29
Heatup	5	Outside	5406	-447	27020	14010	1.85	1.23	9450	67266	86165	**46.89**
Cooldown	5	Inside	5406	447	-49	-24810	1.85	1.23	10553	-30690	-9585	-
Cooldown	5	Outside	5406	-447	-49	24520	1.85	1.23	9450	30150	49049	-13.43

Table G-5: Bottom Head Analysis and Results for [[ ]] at 1030 psig*

Case*	Location	Surface	Primary Membrane P_m (psi)	Primary Bending P_b (psi)	Secondary Membrane S_m (psi)	Secondary Bending S_b (psi)	M_m	M_b = 2/3 M_m	K_{IP} (psi in$^{1/2}$)	K_{IS} (psi in$^{1/2}$)	K_I Total (psi in$^{1/2}$)	T-RT_{NDT} (°F)
[[ ]]	2	Inside	18545	-2493	-410	-39260	1.85	1.23	31234	-49180	13289	-
[[ ]]	2	Outside	18990	2493	-410	38890	1.85	1.23	38206	47205	123617	**73.63**
[[ ]]	2	Inside	18990	-2493	-3241	12120	1.85	1.23	32057	8952	73066	32.69
[[ ]]	2	Outside	18990	2493	-3241	-12120	1.85	1.23	38206	-20944	55468	3.57
[[ ]]	5	Inside	5406	447	-23	-10350	1.85	1.23	10553	-12807	8298	-
[[ ]]	5	Outside	5406	-447	-23	10210	1.85	1.23	9450	12551	31450	-
[[ ]]	5	Inside	5406	447	-55	-40660	1.85	1.23	10553	-50249	-29144	26.41
[[ ]]	5	Outside	5406	-447	-55	40190	1.85	1.23	9450	49466	68365	

* See Section 4.3.2.1.2 and Appendix H of NEDC-33178P [9] for more information regarding these transients.

[[

]]

G.4 Results and Conclusions for Transient Cases:

The results of the discontinuity analysis demonstrate that the linearized stresses in the bottom head torus and beltline regions are bounded by the bottom head (CRD) Curve B, and the beltline Curve B (Figures 5-7 and 5-9, respectively).

Beltline

The maximum plant-specific T - RT_{NDT} calculated with the linearized stresses from the Finite Element Analysis (FEA) for the beltline thickness discontinuity is 64.54°F as shown in Table G-3. The limiting beltline weld material RT_{NDT} (ART) at the region of the discontinuity is 77°F (see Table 4-2b) at end of license EFPY, resulting in T = 141.54°F. The limiting beltline plate RT_{NDT} (ART) at the region of the discontinuity is 45°F (see Table 4-2b) at end of license EFPY, resulting in T = 109.54°F.

At 1030 psig, the end of license EFPY beltline Curve B temperature T = 143.8°F (see Table B-3). Because the beltline region temperature, T, of 143.8°F is greater than the T = 109.54°F obtained with the FEA analysis result, the thickness discontinuity remains bounded by the beltline curve.

Similarly, the limiting beltline material RT_{NDT} (ART) at the region of discontinuity at the intermediate EFPY is the beltline weld at 62°F (see Table 4-2a), resulting in T = 126.54°F. At 1030 psig, the "T" for the intermediate EFPY beltline region Curve B is 132°F. Because the intermediate EFPY beltline region Curve B is greater than the T obtained by FEA, the thickness discontinuity remains bounded by the beltline curve.

Bottom Head Lower Torus to Upper Torus

The maximum plant-specific T - RT_{NDT} for the thickness discontinuity in the bottom head lower to upper torus region at 1030 psig is 73.63°F as shown for Sections 2 and 5 (see Figure G-1 for location of these sections) in Tables G-4 and G-5. The maximum

RT_{NDT} for this region is 30°F for the plates (see Table 4-1a) and -50°F for the welds (see Table 4-1c). This yields a maximum value of T= 103.63°F.

From Tables B-1 and B-3, the bottom head T (appropriate for this location) used in the analysis is 119.6°F at 1030 psig. This value bounds the maximum value of T = 103.63°F, obtained using the linearized stresses from the FEA analysis.

It has been demonstrated in this analysis that Curve A for the bottom head (CRD) and beltline regions (Figures 5-1 and 5-4, respectively) bound the temperatures found for the hydrostatic test pressure temperatures from the FEA analysis. It has also been shown that Curve B for the bottom head (CRD) beltline regions (Figures 5-7 and 5-10, respectively) bound the temperatures found for the applicable transient pressures from the stresses obtained in the FEA analysis. Therefore, the transition discontinuity stresses in the beltline and bottom head upper to lower torus are bounded by the P-T curves provided in Section 5 of this report.

Appendix G References:

1. Plant-Specific Vessel Drawings.
2. Plant-Specific Vessel Drawings.
3. Plant-Specific Reactor Vessel Thermal Cycles Drawing (GE Proprietary Information).
4. Plant-Specific Vessel Drawings.
5. Plant-Specific QA Records and RPV CMTRs.
6. "Fracture Toughness Criteria for Protection Against Failure", Appendix G to Section XI of the ASME Boiler and Pressure Vessel Code, 1998 Edition with Addenda through 2000.
7. "Analysis of Flaws", Appendix A to Section XI of the ASME Boiler and Pressure Vessel Code, 1998 Edition with Addenda through 2000.
8. "PVRC Recommendations on Toughness Requirements for Ferritic Materials", Welding Research Council Bulletin 175, August 1972.
9. GE Nuclear Energy, NEDC-33178P, Revision 0, "General Electric Methodology for Development of Reactor Pressure Vessel Pressure-Temperature Curves", Report for BWR Owners' Group, Sunol, California, July 2006 (GE Proprietary).

APPENDIX H

CORE NOT CRITICAL CALCULATION

FOR THE BOTTOM HEAD CRD PENETRATION

All relevant information is contained in Appendix H of the Topical Report (NEDC-33178P) [22].

APPENDIX I

GUIDANCE FOR THE USE OF BWRVIP ISP SURVEILLANCE DATA

THIS APPENDIX WAS PROVIDED BY THE EPRI BWRVIP PROGRAM

All relevant information is contained in Appendix I of the Topical Report (NEDC-33178P) [22].

ATTACHMENT 2

Pressure-Temperature Limits Report (PTLR)

[LICENSEE/PLANT NAME]

Pressure And Temperature Limits Report (PTLR)

up to [32] Effective Full-Power Years (EFPY)

Revision [#]

Prepared by: ______________________________ Date: _______

Reviewed by: ______________________________ Date: _______

Approved by: ______________________________ Date: _______
[Director, Engineering]

Concurred by: ______________________________ Date: _______
[Manager, Licensing]

[PLANT NAME] PTLR
Rev. [0]
[EFFECTIVE DATE]

Table of Contents

[PLANT NAME] PTLR
Rev. [0]
[EFFECTIVE DATE]

1.0 Purpose

The purpose of the [PLANT NAME] Pressure and Temperature Limits Report (PTLR) is to present operating limits relating to:

1. Reactor Coolant System (RCS) Pressure versus Temperature limits during Heatup, Cooldown and Hydrostatic/Class 1 Leak Testing;
2. RCS Heatup and Cooldown rates;
3. Reactor Pressure Vessel (RPV) to RCS coolant ΔT requirements during Recirculation Pump startups;
4. RPV bottom head coolant temperature to RPV coolant temperature ΔT requirements during Recirculation Pump startups;
5. RPV head flange bolt-up temperature limits.

This report has been prepared in accordance with the requirements of Technical Specification (TS) 5.6.6, "Reactor Coolant System (RCS) PRESSURE AND TEMPERATURE LIMITS REPORT (PTLR)".

2.0 Applicability

This report is applicable to the [PLANT NAME] RPV for up to [32] Effective Full-Power Years (EFPY).

The following TS is affected by the information contained in this report:

TS 3.4.10 RCS Pressure and Temperature (P/T) Limits;

3.0 Methodology

The limits in this report were derived from the NRC-approved methods listed in TS 5.6.6, using the specific revisions listed below:

1. The neutron fluence was calculated per [Topical Report Name, Report Number, Rev. #, Date], approved in Reference 6.1.

[PLANT NAME] PTLR
Rev. [0]
[EFFECTIVE DATE]

2. The pressure and temperature limits were calculated per [Topical Report Name, Report Number, Rev. #, Date]. The methodology used was previously approved in Reference 6.2.

3. This revision of the pressure and temperature limits is to incorporate the following changes:

[List changes in methods, input assumptions, etc. made since the previous revision of the PTLR.]

Changes to the curves, limits, or parameters within this PTLR, based upon new irradiation fluence data of the RPV, or other plant design assumptions in the Updated Final Safety Analysis Report (UFSAR), can be made pursuant to 10 CFR 50.59, provided the above methodologies are utilized. The revised PTLR shall be submitted to the NRC upon issuance.

Changes to the curves, limits, or parameters within this PTLR, based upon new surveillance capsule data of the RPV, cannot be made without prior NRC approval. Such analysis and revisions shall be submitted to the NRC for review prior to incorporation into the PTLR.

4.0 Operating Limits

The pressure-temperature (P-T) curves included in this report represent steam dome pressure versus minimum vessel metal temperature and incorporate the appropriate non-beltline limits and irradiation embrittlement effects in the beltline region.

Complete P-T curves were developed for [25 and 32] EFPY. The P-T curves are provided in Figure 1 and a tabulation of the curves is included in Table 1 ([25] EFPY) and Table 2 ([32] EFPY).

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 (core not critical), referred to as Curve B; and (c) core critical operation, referred to as Curve C.

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Normal Operating Heatup and Cooldown rate limit (Figure 1: Curve B - Non-Nuclear Heating and Curve C - Nuclear Heating): ≤ 100 °F/hour.

Heatup and Cooldown rate limit during Hydrostatic and Class 1 Leak Testing (Figure 1: Curve A): ≤ 20 °F/hour.

RPV bottom head coolant temperature to RPV coolant temperature ΔT limit during Recirculation Pump startup: ≤ [145] °F.

Recirculation loop coolant temperature to RPV coolant temperature ΔT limit during Recirculation Pump startup: ≤ [50] °F.

RPV flange and adjacent shell temperature limit: [≥ 74 °F].

5.0 Discussion

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 (RG 1.99) provides the methods for determining the ART. The RG 1.99 methods for determining the limiting material and adjusting the P-T curves using ART are discussed in this section.

The vessel beltline copper and nickel values [(except for the N2 and N16 nozzles)] were obtained from the evaluation presented in the [Integrated Surveillance Program (Reference 6.3). For the N2 and N16 nozzles, a bounding value of 0.18% was assumed for copper, and the nickel values for N16 and N2 of 0.85% and 0.84%, respectively, were obtained from a Certified Material Test Report.] The copper (Cu) and nickel (Ni) values were used with Tables 1 and 2 of RG 1.99, to determine a chemistry factor (CF) per Paragraph 1.1 of RG 1.99 for welds and plates, respectively.

The P-T curves for the non-beltline region were conservatively developed for a Boiling-Water Reactor Product Line 6 (BWR/6) with nominal inside diameter of 251 inches. The analysis is considered appropriate for [PLANT NAME], since the plant specific geometric values are bounded by the generic analysis for a large BWR/6. The generic value was adapted to the conditions at [PLANT NAME] using plant-specific RT_{NDT} values for the reactor pressure vessel.

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The peak RPV ID fluence used in the P-T curve evaluation for [32] EFPY is [#] n/cm^2, which was calculated using methods that comply with the guidelines of RG 1.190, (Reference 6.1).

This fluence applies to the [lower-intermediate] plates and associated longitudinal welds. The fluence is adjusted for the lower plates and associated longitudinal welds and the girth weld based upon an attenuation factor of [#]; hence, the peak ID surface fluence for these components is [#] n/cm2. [Similarly, the fluence is adjusted for the N2 nozzle based upon an attenuation factor of [#]; hence the peak ID surface fluence used for this component is [#] n/cm^2.] [The same method is applied to the N16 nozzle, which has an attenuation factor of [#], resulting in a peak ID surface fluence of [#] n/cm^2.]

The P-T curves for the heatup and cooldown operating conditions 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 the outer wall during heatup. However, as a conservative simplification, the thermal gradient stress at the 1/4T location is assumed to be tensile for both heatup and cooldown. This results in the approach of applying the maximum tensile stress at the 1/4T location. This approach is conservative because irradiation effects cause the allowable toughness, K_{Ir}, at 1/4T to be less than that at 3/4T for a given metal temperature. This approach causes no operational difficulties, since the BWR is at steam saturation conditions during normal operation, well above the heatup/cooldown curve limits.

For the core not critical curve (Curve B) and the core critical curve (Curve C), the P-T curves specify a coolant heatup and cooldown temperature rate of ≤ 100°F/hr 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 and the nozzle thermal cycle diagrams. For the hydrostatic pressure and leak test curve (Curve A), a coolant heatup and cooldown temperature rate of

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≤ 20°F/hr must be maintained. The P/T limits and corresponding heatup/cooldown rates of either Curve A or B may be applied while achieving or recovering from test conditions. Curve A applies during pressure testing and when the limits of Curve B cannot be maintained.

For [PLANT NAME], the [N2 Recirculation Inlet nozzle] is the limiting material for the beltline region for [32] EFPY. The beltline pressure test P-T curves provided in this report are calculated in the same manner as the [Feedwater Nozzle pressure test P-T curves, using the N2-specific geometry.] The initial RT_{NDT} for the [N2 Recirculation Inlet nozzle] materials is [#]°F. The generic pressure test P-T curve is applied to the [PLANT NAME] [N2 Nozzle] curve by shifting the P vs. (T - RT_{NDT}) values to reflect the ART value of [#]°F. Similarly, the generic pressure test P-T curve is applied to the [PLANT NAME] [N2 Nozzle] curve by shifting the P vs. (T-RT_{NDT}) values to reflect the [25] EFPY ART value of [#]°F. Using the fluence discussed above, the P-T curves are beltline ([N2 Recirculation Inlet nozzle]) limited above [#] and [#] psig for Curve A for [25] and [32] EFPY, respectively, and above [#] psig for Curve B for both [25] and [32] EFPY.

6.0 References

6.1 [List NRC approval letter for Fluence Topical Report used in the PTLR]

6.2 [List NRC approval letter for P/T Curve Topical Report used in the PTLR]

6.3 [Integrated Surveillance Program Report]

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Figure 1 – Composite P-T Curves Effective for up to [25] EFPY

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Figure 2 – Composite P-T Curves Effective for up to [32] EFPY

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Table 1 – Tabulation Of Curves – [25] EFPY

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Table 2 – Tabulation Of Curves – [32] EFPY

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Appendix A

Reactor Vessel Material Surveillance Program

In accordance with 10 CFR 50, Appendix H, Reactor Vessel Material Surveillance Program Requirements, the [second] surveillance capsule was removed from the [PLANT NAME] reactor vessel on [Date], during refueling outage (RFO) [#]. The surveillance capsule contained flux wires for neutron fluence measurement, Charpy V-Notch impact test specimens and uniaxial tensile test specimens fabricated using materials from the vessel materials within the core beltline region. The flux wires and test specimens removed from the capsule were tested according to ASTM E185-82. The methods and results of testing are presented in Reference 6.5, as required by 10 CFR 50, Appendices G and H.

As described in [PLANT NAME] Updated Final Safety Analysis Report (UFSAR) Section [5.3.16, Material Surveillance], the remaining surveillance capsule(s) is(are) slated to be removed as defined by the Integrated Surveillance Program.

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Appendix B

[PLANT NAME] Reactor Pressure Vessel P-T Curve Supporting Plant-Specific Information

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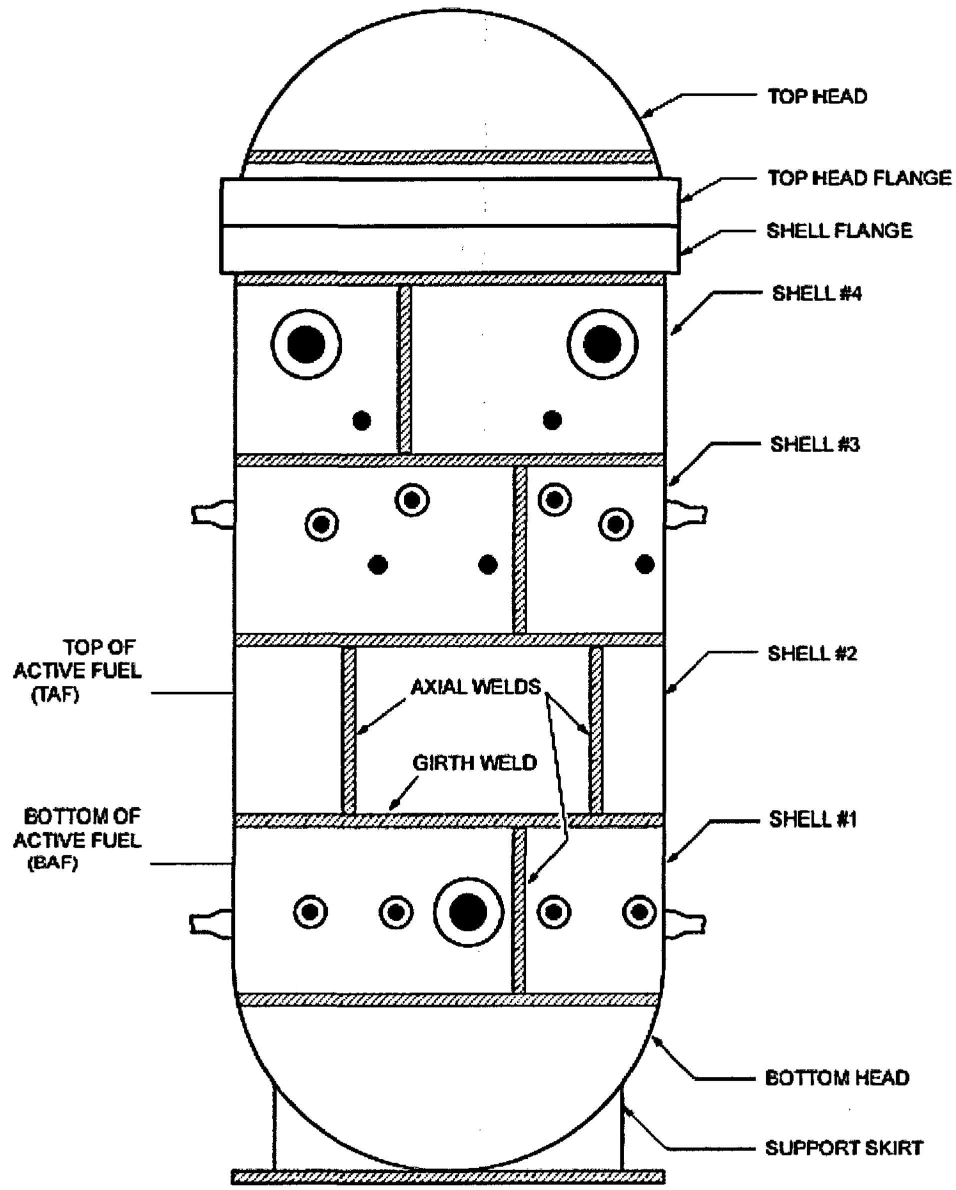
Figure of [PLANT NAME] Reactor Pressure Vessel



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[PLANT NAME] Initial RT_{NDT} Values for RPV Materials

Plate and Flange Materials

Component	Heat	Test Temp (°F)	Charpy Energy (ft-lb)			$(T_{50T}-60)$ (°F)	Drop Weight NDT (°F)	RT_{NDT} (°F)
Top Head & Flange								
Shell Flange		10	85	80	90	-20	10	10
Top Head Flange		10	100	111	101	-20	10	10
Top Head Dollar		10	70	86	70	-20	-10	-10
Top Head Lower Torus Plates		10	80	91	92	-20	-10	-10
		10	85	96	88	-20	-10	-10
Top Head Upper Torus Plates		10	102	85	100	-20	-10	-10
Shell Courses								
Upper Shell Plates		40	62	60	56	10	-10	10
		40	61	49	55	12	-10	12
		10	55	63	53	-20	-10	-10
		40	70	75	88	10	-10	10
Upper Intermediate Plates		10	70	62	66	-20	-10	-10
		10	57	45	52	-10	-10	-10
		10	44	55	58	-8	-10	-8
Lower-Intermediate Plates		10	61	45	58	-10	-20	-10
		10	65	64	54	-20	-20	-20
		10	48	49	63	-16	-30	-16
		10	46	65	60	-12	-30	-12
Lower Shell Plates		10	60	75	74	-20	-10	-10
		10	80	79	92	-20	-10	-10
		10	57	66	68	-20	-10	-10
Bottom Head								
Bottom Head Dollar		10	41	48	52	-2	-10	-2
Bottom Head Upper Torus Plates		-40	55	61	55	-70	-10	-10
		-40	66	64	54	-70	-10	-10
Bottom Head Lower Torus Plates		10	57	70	80	-20	-10	-10
		10	71	70	72	-20	-10	-10
		40	40	48	42	30	10	30

[PLANT NAME] Initial RT_{NDT} Values for RPV Materials, Continued
Nozzle Materials

Component	Heat or Heat / Flux / Lot	Test Temp (°F)	Charpy Energy (ft-lb)			$(T_{50T}-60)$ (°F)	Drop Weight NDT (°F)	RT_{NDT} (°F)
Recirculation Outlet Nozzle		10	70	92	59	-20	-20	-20
		10	90.0	89	80	-20	-30	-20
Recirculation Inlet Nozzle		10	51	45	38	4	0	4
		10	33	32	40	16	-10	16
		10	67	32	37	16	20	20
		10	43	36	55	8	-30	8
		10	48	40	45	0	-30	0
		10	55	28	39	24	-40	24
		10	50	32	48	16	20	20
		10	47	66	54	-14	10	10
		10	75	46	55	-12	10	10
		10	47	58	85	-14	40	40
Steam Outlet Nozzle		10	60	36	80	8	10	10
		10	70	70	36	8	0	8
		10	40	35	32	16	10	16
		10	55	32	44	16	10	16
Feedwater Nozzle		10	80	90	57	-20	0	0
		10	60	55	50	-20	0	0
		10	60	55	76	-20	-30	-20
		10	60	42	66	-4	-10	-4
		10	38	55	51	4	0	4
		10	41	44	34	12	-10	12
Core Spray Nozzle		10	66	52	85	-20	-10	-10
		10	65	80	82	-20	-10	-10
Instrumentation Nozzle		10	54	60	70	-20	10	10
		10	54	59	72	-20	10	10
Top Head Vent Nozzle		10	90	90	88	-20	10	10
Jet Pump Nozzle		10	80	101	105	-20	-20	-20
		10	82	105	105	-20	-20	-20
CRD HYD Return Nozzle		10	44	40	46	0	10	10
Core ΔP Nozzle	Alloy 600							(2)
Replacement Instrument Nozzles		10	38	42	30	20	40	40
		10	230	230	247	-20	40	40
High Pressure Leak Detector Nozzle								10 (1)
Drain Nozzle		10	40	25	33	30	40	40
CRD Stub Tubes	Alloy 600							(2)

(1) Information for this heat is not available; the purchase specification requirements are used for evaluation of this component.
(2) Alloy 600 components do not require fracture toughness evaluation; see Appendix A for additional information.

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[PLANT NAME] Initial RT_{NDT} Values for RPV Materials, Continued
Weld Materials

Component	Heat or Heat / Flux / Lot	Test Temp (°F)	Charpy Energy (ft-lb)			$(T_{50T}-60)$ (°F)	Drop Weight NDT (°F)	RT_{NDT} (°F)
Beltline - Axial								
Lower Shell		10	70	75	82	-50	-	-50
		10	60	47	61	-44	-	-44
Lower-Intermediate Shell		10	80	90	87	-50	-	-50
Beltline - Girth								
Lower-Intermediate Shell to Lower Shell		10	99	105	107	-50	-	-50
Non-Beltline - Axial								
Upper-Intermediate Shell		10	60	47	62	-44	-	-44
		10	109	110	111	-50	-	-50
		10	153	130	135	-50	-	-50
Upper Shell		10	54	60	57	-50	-	-50
		10	65	70	60	-50	-	-50
Bottom Head Upper Torus Meridional Welds		10	111	110	113	-50	-	-50
Bottom Head Lower Torus Meridional Welds		10	120	108	119	-50	-	-50
		10	111	110	112	-50	-	-50
Top Head Upper Torus Meridional Welds		10	130	165	150	-50	-	-50
Top Head Lower Torus Meridional Welds		10	167	142	154	-50	-	-50
		10	109	105	112	-50	-	-50
		10	130	168	151	-50	-	-50
Non-Beltline - Girth								
Top Head Assembly		10	111	105	111	-50	-	-50
		10	57	30	51	-10	-	-10
Shell Flange to Upper Shell		10	51	72	70	-50	-	-50
Upper Shell to Upper-Intermediate Shell		10	80	85	91	-50	-	-50
Upper-Intermediate Shell to Lower-Intermediate Shell		10	77	65	63	-50	-	-50
		10	40	47	48	-30	-	-30
Lower Shell to Bottom Head		10	57	30	51	-10	-	-10
		10	111	109	105	-50	-	-50
Bottom Head Assembly		10	101	105	103	-50	-	-50
Support Skirt to Bottom Head		10	63	57	59	-50	-	-50

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[PLANT NAME] Initial RT_{NDT} Values for RPV Materials, Continued Appurtenance and Bolting Materials

Component	Heat	Test Temp (°F)	Charpy Energy (ft-lb)			$(T_{50T}-60)$ (°F)	Drop Weight NDT (°F)	RT_{NDT} (°F)
Misc Appurtenances:								
Support Skirt Forging		10	75	85	102	-20	30	30
Shroud Support	Alloy 600							(1)
Stabilizer Brackets		40 10	57 55	49 45	52 50	12 -10	10 -30	12 -10
Guide Rod Brackets	Stainless Steel							(1)
Steam Dryer Support Lugs	Stainless Steel							(1)
Steam Dryer Hold Down Brackets		10 10	121 82	125 65	108 60	-20 -20	- -	-20 -20
Core Spray Brackets	Stainless Steel							(1)
Basin Seal Skirt								10 (2) 10 (2)
Surveillance Specimen Brackets	Stainless Steel Stainless Steel							(1) (1)
Feedwater Sparger Brackets	Stainless Steel							(1)
Top Head Lifting Lugs								40 (2)
Component	**Heat**	**Test Temp (°F)**	**Charpy Energy (ft-lb)**			**Min Lat Exp (mils)**	**LST (°F)**	
Closure Studs								
	(3)	10 10 10	50 52 -	50 54 -	50 52 -	- - -	70 70 70	
Closure Nuts								
	(3)	10 10	57 -	59 -	53 -	- -	70 70	

(1) Information for this heat is not available; the purchase specification requirements are used for evaluation of this component.
(2) Alloy 600 and Stainless Steel components do not require fracture toughness evaluation; see Appendix A for additional information
(3) *Information for this component is not available; ASME Code requirements are applied as defined in Section 4.1.2 of this report.*

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[PLANT NAME] Adjusted Reference Temperatures [25] EFPY

Lower-Intermediate Shell Plates and Axial Welds

Thickness in inches= 6.125

End of License EFPY Peak I.D. fluence = 7.50E+17 n/cm^2
Intermediate EFPY Peak I.D. fluence = 5.63E+17 n/cm^2
Intermediate EFPY Peak 1/4T fluence = 3.90E+17 n/cm^2

Lower Shell Plates and Axial Welds & Lower to Lower-Intermediate Girth Weld

Thickness in inches= 7.125

Axial Distribution Factor at Elevation of Girth Weld = 0.65

End of License EFPY Peak I.D. fluence = 4.88E+17 n/cm^2
Intermediate EFPY Peak I.D. fluence = 3.66E+17 n/cm^2
Intermediate EFPY Peak 1/4T fluence = 2.38E+17 n/cm^2

COMPONENT	HEAT OR HEAT/LOT	%Cu	%Ni	CF	Adjusted CF (1)	Initial RTndt °F	1/4 T Fluence n/cm^2	Intermediate EFPY Δ RTndt °F	σ_I	σ_Δ	Margin °F	Intermediate EFPY Shift °F	Intermediate EFPY ART °F
PLATES:													
Lower Shell		0.08	0.62	51		-10	2.38E+17	10	0	5	10	20	10
Lower-Intermediate Shell		0.12	0.61	83		-12	3.90E+17	21	0	11	21	42	30
WELDS:													
Lower Shell Axial		0.26	0.87	224		-44	2.38E+17	43	0	21	43	86	42
Lower-Intermediate Shell Axial		0.32	0.50	188.5		-50	3.90E+17	48	0	24	48	96	46
Lower to Lower-Intermediate Girth		0.23	1.00	236		-50	2.38E+17	45	0	23	45	90	40
INTEGRATED SURVEILLANCE PROGRAM (2):													
Plate (3)		0.12	0.69	84		-12	3.90E+17	21	0	11	21	43	31
Weld (4)		0.21	0.86	207	354	-44	2.38E+17	68	0	28	28	96	52

(1) Adjusted CF calculated per RG1.99 Position 2.1 as shown in Section 4.2.1.1 of this report.
(2) Procedures defined in BWRVIP-102 are applied to determine the ART considering the Integrated Surveillance Program.
(3) The ISP plate is not the identical heat and is presented using the ISP chemistry and CF and applied to the limiting plant-specific plate.
(4) The ISP weld is the identical heat and is presented using the ISP chemistry and adjusted CF with the vessel weld Initial RT_{NDT} and fluence. σ_Δ is presented as calculated, but is multiplied by 0.5 for the Margin calculation as defined in RG1.99, Position 2.1.

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[PLANT NAME] Adjusted Reference Temperatures
[32] EFPY

Lower-Intermediate Shell Plates and Axial Welds

Thickness in inches= 6.125

End of License EFPY Peak I.D. fluence = 9.68E+17 n/cm^2
Intermediate EFPY Peak I.D. fluence = 6.70E+17 n/cm^2
Intermediate EFPY Peak 1/4T fluence = 6.70E+17 n/cm^2

Lower Shell Plates and Axial Welds & Lower to Lower-Intermediate Girth Weld

Thickness in inches= 7.125

Axial Distribution Factor at Elevation of Girth Weld = 0.64

End of License EFPY Peak I.D. fluence = 6.23E+17 n/cm^2
Intermediate EFPY Peak I.D. fluence = 4.07E+17 n/cm^2
Intermediate EFPY Peak 1/4T fluence = 4.07E+17 n/cm^2

COMPONENT	HEAT OR HEAT/ LOT	%Cu	%Ni	CF	Adjusted CF (1)	Initial RTndt °F	1/4 T Fluence n/cm^2	End of License EFPY Δ RTndt °F	σ_I	σ_Δ	Margin °F	End of License EFPY Shift °F	End of License EFPY ART °F
PLATES:													
Lower Shell		0.08	0.62	51		-10	4.07E+17	13	0	7	13	27	17
Lower-Intermediate Shell		0.12	0.61	83		-12	6.70E+17	28	0	14	28	57	45
WELDS:													
Lower Shell Axial		0.26	0.87	224		-44	4.07E+17	59	0	28	56	115	71
Lower-Intermediate Shell Axial		0.32	0.50	188.5		-50	6.70E+17	64	0	28	56	120	70
Lower to Lower-Intermediate Girth		0.23	1.00	236		-50	4.07E+17	62	0	28	56	118	68
INTEGRATED SURVEILLANCE PROGRAM (2):													
Plate (3)		0.12	0.69	84		-12	6.70E+17	29	0	14	29	57	45
Weld (4)		0.21	0.86	207	354	-44	4.07E+17	93	0	28	28	121	77

(1) Adjusted CF calculated per RG1.99 Position 2.1 as shown in Section 4.2.1.1 of this report.
(2) Procedures defined in BWRVIP-102 are applied to determine the ART considering the Integrated Surveillance Program.
(3) The ISP plate is not the identical heat and is presented using the ISP chemistry and CF and applied to the limiting plant-specific plate.
(4) The ISP weld is the identical heat and is presented using the ISP chemistry and adjusted CF with the vessel weld Initial RT_{NDT} and fluence. σ_Δ is presented as calculated, but is multiplied by 0.5 for the Margin calculation as defined in RG1.99, Position 2.1.

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[PLANT NAME] RPV Beltline P-T Curve Input Values

Adjusted RT_{NDT} = Initial RT_{NDT} + Shift	A = [-44 + 121 = 77°F] (Based on ART values)
Vessel Height	H = [861.6] inches
Bottom of Active Fuel Height	B = [216.3] inches
Vessel Radius (to base metal)	R = [127] inches
Minimum Vessel Thickness (without clad)	t = [6.125] inches

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[PLANT NAME] Definition of RPV Beltline Region

Component	Elevation (inches from RPV "0")
[Shell # 2 - Top of Active Fuel (TAF)*	366.3"
Shell # 1 - Bottom of Active Fuel (BAF)	216.3"
Shell # 2 – Top of Extended Beltline Region	374.7"
Shell # 1 – Bottom of Extended Beltline Region	210.5"
Centerline of Recirculation Outlet Nozzle in Shell # 1	161.5"
Top of Recirculation Outlet Nozzle N1 in Shell # 1	193.7"
Centerline of Recirculation Inlet Nozzle N2 in Shell # 1	181.0"
Top of Recirculation Inlet Nozzle N2 in Shell # 1	197.5"
Centerline of 2" Instrumentation Nozzle in Shell # 2	366.0"]

Based on the above, it is concluded that none of the [PLANT] reactor vessel plates, nozzles, or welds, other than those included in the Adjusted Reference Temperature Table, are in the beltline region.

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Appendix C

[PLANT NAME] Reactor Pressure Vessel P-T Curve
Checklist

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Parameter	Completed	Comments/Resolutions/Clarifications
Initial RT_{NDT}		
Initial RT_{NDT} has been determined for [PLANT] for all vessel materials including plates, flanges, forgings, studs, nuts, bolts, welds. Include explanation (including methods/sources) of any exceptions, resolution of discrepant data (e.g., deviation from originally reported values).	☐	[1. Non-beltline weld material information is not available; therefore, GE Procedure Y1006A006 used. 2. Purchase Specification was used for main closure flange. 3. Value for heat X1234 was previously reported to be 12°F; new information has become available and the value has been revised to 14°F.
Appendix B contains tables of all Initial RT_{NDT} values for [PLANT]	☐	NA
Has any non-[PLANT] initial RT_{NDT} information (e.g., ISP, comparison to other plant) been used?	☐	Heat X2345 information obtained from ISP database. Heat X3456 information obtained from identical heat contained in Plant Y.
If deviation from the LTR process occurred, sufficient supporting information has been included (e.g., Charpy V-Notch data used to determine an Initial RT_{NDT}).	☐	No deviations other than those noted above.
All previously published Initial RT_{NDT} values from sources such as the GL88-01, RVID, FSAR, etc., have been reviewed.	☐	
Adjusted Reference Temperature (ART)		
Sigma I (standard deviation for Initial RT_{NDT}) is 0°F unless the RT_{NDT} was obtained from a source other than CMTRs. If σ_I is not equal to 0, reference/basis has been provided.	☐	
Sigma Δ (standard deviation for ΔRT_{NDT}) is determined per RG 1.99, Rev. 2	☐	

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Parameter	Completed	Comments/Resolutions/Clarifications
Chemistry has been determined for all vessel beltline materials including plates, forgings (if applicable), and welds for [PLANT] Include explanation (including methods/sources) of any exceptions, resolution of discrepant data (e.g., deviation from originally reported values).	☐	
Non-[PLANT] chemistry information (e.g., ISP, comparison to other plant) used has been adequately defined and described.	☐	Heat X2345 information obtained from ISP database. Heat X3456 information obtained from identical heat contained in Plant Y.
For any deviation from the LTR process, sufficient information has been included.	☐	No deviations other than those noted above.
All previously published chemistry values from sources such as the GL88-01, RVID, FSAR, etc., have been reviewed.	☐	
The fluence used for determination of ART and any extended beltline region was obtained using an NRC-approved methodology.	☐	
The fluence calculation provides an axial distribution to allow determination of the vessel elevations that experience fluence of 1.0e17 n/cm^2 both above and below active fuel.	☐	
The fluence calculation provides an axial distribution to allow determination of the fluence for intermediate locations such as the beltline girth weld (if applicable) or for any nozzles within the beltline region.	☐	

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Rev. [0]
[EFFECTIVE DATE]

Parameter	Completed	Comments/Resolutions/Clarifications
All materials within the elevation range where the vessel experiences a fluence ≥1.0e17 n/cm² have been included in the ART calculation. All initial RT_{NDT} and chemistry information is available or explained.	☐	
Discontinuities		
The discontinuity comparison has been performed as described in Section 4.3.2.1 of the LTR. Any deviations have been explained.	☐	
Discontinuities requiring additional components (such as nozzles) to be considered part of the beltline have been adequately described. It is clear which curve is used to bound this discontinuity.	☐	
Appendix G of the LTR describes the process for considering a thickness discontinuity, both beltline and non-beltline. If there is a discontinuity in the [PLANT] vessel that requires such an evaluation, the evaluation was performed. The affected curve was adjusted to bound the discontinuity, if required.	☐	
Appendix H of the LTR defines the basis for the CRD Penetration curve discontinuity and the appropriate transient application. The [PLANT] evaluation bounds the requirements of Appendix H.	☐	

ENCLOSURE 3

BWROG-06020

Affidavit

General Electric Company

AFFIDAVIT

I, Louis M. Quintana, state as follows:

(1) I am Manager, Licensing, General Electric Company ("GE"), and have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is contained in the GE proprietary report, NEDC-33178P, General Electric Methodology for Development of Reactor Pressure Vessel Pressure-Temperature Curves, Class III (GE Proprietary Information), dated July 2006. The GE proprietary information is identified by [[double underlines inside double square brackets{3}]]. In each case, the sidebars and the superscript notation {3} refer to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination.

(3) In making this application for withholding of proprietary information of which it is the owner, GE relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4), and 2.390(a)(4) for "trade secrets" (Exemption 4). The material for which exemption from disclosure is here sought also qualify under the narrower definition of "trade secret", within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975F2d871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704F2d1280 (DC Cir. 1983).

(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by General Electric's competitors without license from General Electric constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product;

c. Information which reveals aspects of past, present, or future General Electric customer-funded development plans and programs, resulting in potential products to General Electric;

d. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a. and (4)b. above.

(5) To address 10 CFR 2.390 (b) (4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GE, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GE, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Access to such documents within GE is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his delegate), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GE are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information identified in paragraph (2), above, is classified as proprietary because it contains detailed methods and processes, which GE has developed and applied to pressure-temperature curves for the BWR over a number of years. The development of the BWR pressure-temperature curves was achieved at a significant cost, on the order of ¾ million dollars, to GE.

The development of the evaluation process along with the interpretation and application of the analytical results is derived from the extensive experience database that constitutes a major GE asset.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GE's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GE's comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and

apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC approved methods.

The research, development, engineering, analytical and NRC review costs comprise a substantial investment of time and money by GE.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

GE's competitive advantage will be lost if its competitors are able to use the results of the GE experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GE would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GE of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing these very valuable analytical tools.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed on this 28th day of July 2006.

Louis M. Quintana

Louis M. Quintana
Manager, Licensing