PMSTPCOL PEmails

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Cc: STPCOL; George Wunder; Neil Ray; 'Head, Scott'
Subject: Topical report on P-T Curves
Attachments: P-T Curves for DTE Energy Fermi (NP).pdf

Steve,

Per your request, attached is the non-proprietary version of DTE Fermi's P-T Curves topical report that was discussed during the drop-in with Scott last week.

Tekia

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ENCLOSURE 7
TO NRC-05-0011

REQUEST TO REVISE TS 3.4.10
REACTOR COOLANT SYSTEM
PRESSURE & TEMPERATURE LIMITS

GE REPORT NEDC-33133, REVISION 0
"PRESSURE-TEMPERATURE CURVES
FOR DTE ENERGY FERMI UNIT 2"
FEBRUARY 2005

NON-PROPRIETARY VERSION

GE Nuclear Energy

NEDO-33133
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February 2005

Pressure-Temperature Curves For DTE Energy Fermi Unit 2

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Revision 0
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February 2005

Non-Proprietary Version

Pressure-Temperature Curves For DTE Energy Fermi Unit 2

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REPORT REVISION STATUS

Revision	Purpose
0	Initial Issue

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IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT PLEASE READ CAREFULLY

The only undertakings of the General Electric Company (GE) respecting information in this document are contained in the contract between ***Detroit Edison*** and GE, ***Fermi 2 Energy Center Extended Power Uprate Project, WIN #8 P/T Curves***, effective ***5/18/04***, as amended to the date of transmittal of this document, and nothing contained in this document shall be construed as changing the contract. The use of this information by anyone other than ***Detroit Edison***, or for any purpose other than that for which it is furnished by GE, is not authorized; and with respect to any unauthorized use, GE makes no representation or warranty, express or implied, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document, or that its use may not infringe privately owned rights.

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. Fermi 2 is currently licensed to P-T curves for 32 EFPY [1]; the P-T curves in this report represent 24 and 32 effective full power years (EFPY), where 32 EFPY represents the end of the 40 year license, and 24 EFPY is provided as an intermediate point between the current EFPY and 32 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. This fluence was based upon a projection for the planned implementation of power uprate that provides additional conservatism. The latest information from the BWRVIP Integrated Surveillance Program that is applicable to Fermi Unit 2 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 (see Appendix C for additional guidance).

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 24 and 32 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 24 and 32 EFPY), and bottom head for the Pressure Test and Core Not Critical conditions.

TABLE OF CONTENTS

TABLE OF APPENDICES

TABLE OF FIGURES

TABLE OF FIGURES, Continued

TABLE OF TABLES

1.0 INTRODUCTION

The pressure-temperature (P-T) curves included in this report have been developed to present steam dome pressure versus minimum vessel metal temperature incorporating appropriate non-beltline limits and irradiation embrittlement effects in the beltline. Complete P-T curves were developed for 24 and 32 effective full power years (EFPY), where 32 EFPY represents the end of the 40-year license, and 24 EFPY is provided as an intermediate point between the current EFPY and 32 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. This fluence was based upon a projection for the planned implementation of power uprate that provides additional conservatism. The latest information from the BWRVIP Integrated Surveillance Program that is applicable to Fermi Unit 2 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 24 and 32 EFPY are included in Section 4.2. The peak ID fluence values of 7.13e17 n/cm^2 (24 EFPY) and 9.68e17 n/cm^2 (32 EFPY) used in this report are discussed in Section 4.2.1.2. Beltline chemistry values are discussed in Section 4.2.1.1.

Appendix A includes comprehensive documentation of the RPV discontinuities considered in this evaluation. This appendix also documents the non-beltline discontinuity curves that 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 demonstrates that all reactor vessel nozzles requiring fracture toughness evaluation are either included in the development of the P-T curves or are outside the beltline region. Appendix F provides the calculation for equivalent margin analysis (EMA) for upper shelf energy (USE). 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). Upjohn welds occur in various welds in the Fermi Unit 2 vessel; these welds are known to contain flaws. The limiting flaw, which exists in the beltline region, has been evaluated and is discussed in Appendix I of this report.

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 Fermi Unit 2 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 Fermi 2 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 demonstrates that all reactor vessel nozzles requiring fracture toughness evaluation are either included in the development of the P-T curves or are outside the beltline region. Appendix F provides the calculation for equivalent margin analysis (EMA) for upper shelf energy (USE). 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). Upjohn welds occur in various welds in the Fermi Unit 2 vessel; these welds are known to contain flaws. The limiting flaw, which exists in the beltline region, has been evaluated and is discussed in Appendix I of this report.

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 Fermi 2 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 initial RT_{NDT} values for all low alloy steel vessel components are needed to develop the vessel P-T limits. The applicable ASME Code for the Fermi 2 RPV is 1968 Edition with Summer 1969 Addenda. The requirements for establishing the vessel component toughness prior to 1972 were per the ASME Code Section III, Subsection NB-2300 and are summarized as follows:

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

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

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

10CFR50 Appendix G [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. Additional details are contained in the Fermi 2 UFSAR, Sections 3.1.2.4.2 and 5.2.4. 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 Fermi 2 vessel per the current requirements, calculations were performed in accordance with the GE method for determining RT_{NDT}. Example RT_{NDT} calculations for vessel plate, forging, and for bolting material LST are summarized in the remainder of this section. The initial RT_{NDT} for all materials remain unchanged from values previously reported for Fermi 2 with one exception. Lower-intermediate shell plate heat C4564-1 was previously reported to have an initial RT_{NDT} of –12°F. As demonstrated in Table 4-1 and in the calculation shown below, using the methods mentioned above and documented in [10] and [11], the initial RT_{NDT} for heat C4564-1 is determined to be –10°F.

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

For example, for the Fermi 2 beltline plate heat C4564-1 in the lower-intermediate shell course; the lowest Charpy energy and test temperature from the CMTRs is 45 ft-lb at 10°F. 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). Dropweight testing to establish NDT for plate material is listed in the CMTR; the NDT for the case above is –20°F. Thus, the initial RT_{NDT} for plate heat C4564-1 is –10°F.

For the Fermi 2 beltline weld heat 12008 Linde 1092 with flux lot 3833 (contained in the lower shell course), the CVN results are used to calculate the initial RT_{NDT}. The 50 ft-lb test temperature is applicable to the weld material, but the 30°F adjustment to convert longitudinal data to transverse data is not applicable to weld material. Heat 12008 Linde 1092 has a lowest Charpy energy of 47 ft-lb at 10°F as recorded in weld qualification records. Therefore,

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

The initial RT_{NDT} is the greater of nil-ductility transition temperature (NDT) or (T_{50T} - 60°F). For Fermi 2, the dropweight testing to establish NDT was not available and –50°F was assumed. 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 vessel forging material, such as nozzles and closure flanges, the method for establishing RT_{NDT} is the same as for vessel plate material. For the limiting heat in the feedwater nozzle at Fermi 2 (Heat AV3504 9B-9202), the NDT is -10°F and the lowest CVN data is 34 ft-lb at 10°F. The corresponding value of (T_{50T} – 60°F) is:

$$(T_{50T} - 60°F) = \{[10 + (50 - 34)\ ft\text{-}lb \cdot 2°F/ft\text{-}lb] + 30°F\} - 60°F = 12°F.$$

Therefore, the initial RT_{NDT} is the greater of nil-ductility transition temperature (NDT) or (T_{50T}– 60°F), which is 12°F.

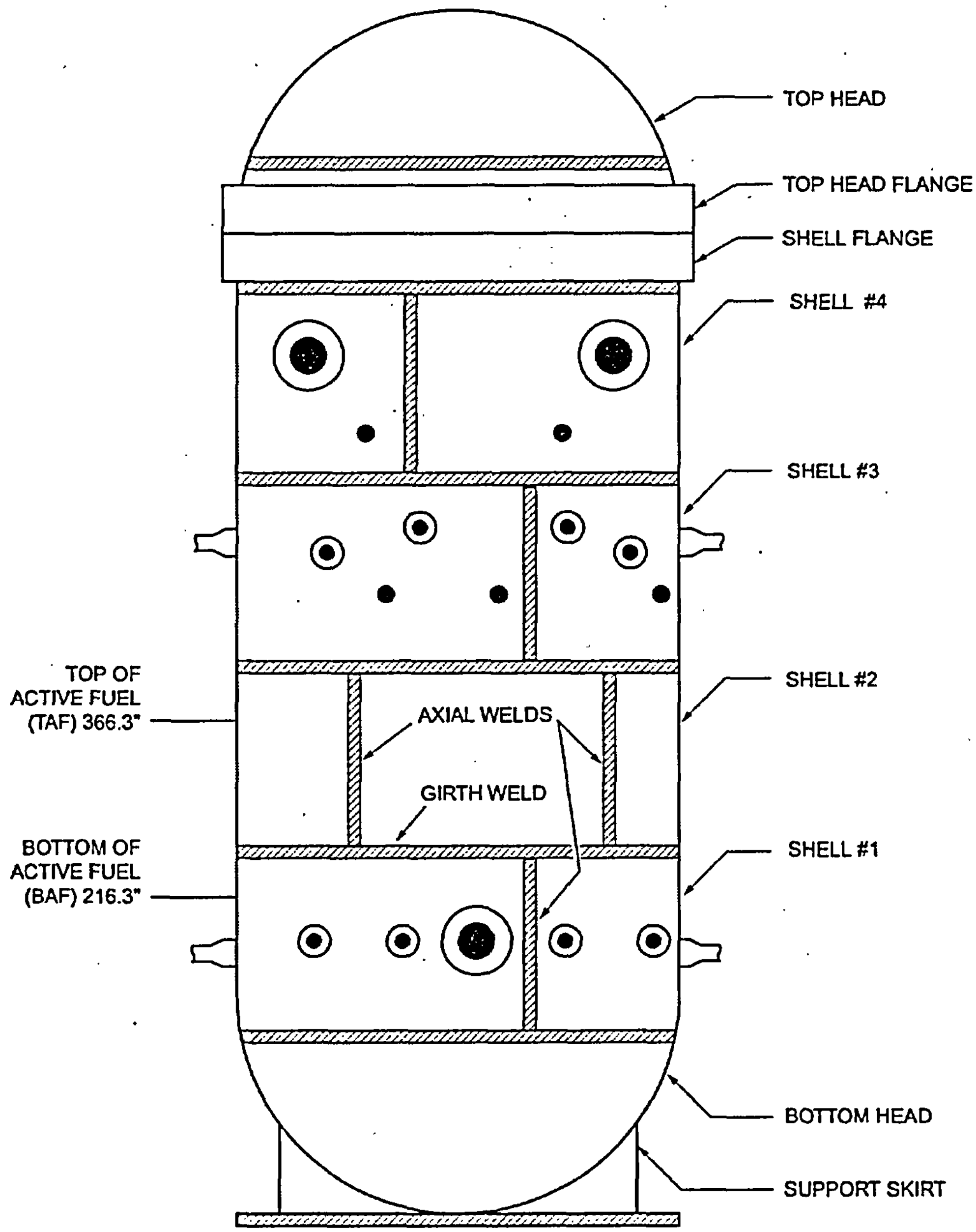
In the bottom head region of the vessel, the vessel plate method is applied for estimating RT_{NDT}. For the bottom head dollar plate heat of Fermi 2 (Heat C4504-2), the NDT is 10°F and the lowest CVN data was 40 ft-lb at 40°F. The corresponding value of (T_{50T} – 60°F) was:

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

Therefore, the initial RT_{NDT} was 30°F.

For bolting material, the current ASME Code requirements define the lowest service temperature (LST) as the temperature at which transverse CVN energy of 45 ft-lb and 25 mils lateral expansion (MLE) were achieved. If the required Charpy results are not met, or are not reported, but the CVN energy reported is above 30 ft-lb, the requirements of the ASME Code Section III, Subsection NB-2300 at construction are applied, namely that the 30 ft-lb test temperature plus 60°F is the LST for the bolting materials. All of the available reported Charpy data for the Fermi 2 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 Fermi 2 reactor vessel (refer to Figure 4-1 for the Fermi 2 Schematic) materials are listed in Tables 4-1, 4-2, 4-3 and 4-4. 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 Fermi 2 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 Fermi 2 RPV Showing Arrangement of Vessel Plates and Welds

Table 4-1: RT_{NDT} Values for Fermi 2 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								
G3701	AWH 113 2V-708	10	89	89	90	-20	10	10
Top Head Flange								
G3702	ACR 108	10	196	191	101	-20	10	10
Top Head Dollar								
C3732	C5445-1	10	79	86	79	-20	-10	-10
Top Head Lower Torus Plates								
G3731-1	C5445-2	10	95	91	97	-20	-10	-10
G3731-2	C5445-2	10	97	96	101	-20	-10	-10
Top Head Upper Torus Plates								
G3730	C5445-1	10	107	85	102	-20	-10	-10
Shell Courses								
Upper Shell Plates								
G3703-1	C4568-1	40	68	65	56	10	-10	10
G3703-2	C4564-2	40	64	49	54	12	-10	12
G3703-3	C4560-2	10	53	63	52	-20	-10	-10
G3703-4	C4554-2	40	74	75	87	10	-10	10
Upper Intermediate Plates								
G3704-1	C4574-1	10	70	68	66	-20	-10	-10
G3704-2	C4578-2	10	59	45	52	-10	-10	-10
G3704-3	C4578-1	10	44	56	68	-8	-10	-8
Lower-Intermediate Plates								
G3703-5	C4564-1	10	60	45	59	-10	-20	-10
G3705-1	B8614-1	10	62	64	56	-20	-20	-20
G3705-2	C4574-2	10	48	49	60	-16	-30	-16
G3705-3	C4568-2	10	46	67	63	-12	-30	-12
Lower Shell Plates								
G3706-1	C4540-2	10	64	76	74	-20	-10	-10
G3706-2	C4560-1	10	85	79	99	-20	-10	-10
G3706-3	C4554-1	10	59	65	68	-20	-10	-10
Bottom Head								
Bottom Head Dollar								
G3708	C3424-1	10	41	48	57	-2	-10	-2
Bottom Head Upper Torus Plates								
G3711-1	C4526-1	-40	57	60	55	-70	-10	-10
G3712-1	C4504-3	-40	70	64	56	-70	-10	-10
Bottom Head Lower Torus Plates								
C3709-1	C5050-2	10	58	70	83	-20	-10	-10
C3710-1	C4504-1	10	74	70	74	-20	-10	-10
C3710-2	C4504-2	40	40	48	42	30	10	30

NOTE: These are minimum Charpy values.

Table 4-2: RT_{NDT} Values for Fermi 2 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								
G3717-1	AJF 181	10	77	96	59	-20	-20	-20
G3717-2	AJF 193	10	91.5	89	85	-20	-30	-20
Recirculation Inlet Nozzle								
G3718-1	AV3505 9A-9239	10	54	45	38	4	0	4
G3718-2	AV3505 9A-9240	10	34	32	36	16	-10	16
G3718-3	AV3502 9A-9365	10	35	32	36	16	20	20
G3718-5	AV3503 9A-9368	10	42	36	60	8	-30	8
G3718-6	AV3503 9A-9369	10	49	40	49	0	-30	0
G3718-7	AV3504 9A-9371	10	58	28	37	24	-40	24
G3718-8	AV3857 9D-9407	10	48	32	46	16	20	20
G3718-9	AV3857 9D-9406	10	47	64	58	-14	10	10
G3718-10	AV3857 9D-9408	10	82	46	55	-12	10	10
G5218-4	AV3934 9E-9011	10	47	60	88	-14	40	40
Steam Outlet Nozzle								
G3714-1	AV3496 9A-9234	10	66	36	85	8	10	10
G3714-2	AV3507 9A-9235	10	74	75	36	8	0	8
G3714-3	AV3510 9A-9236	10	36	34	32	16	10	16
G3714-4	AV3511 9A-9237	10	52	32	42	16	10	16
Feedwater Nozzle								
G3715-1	AV3508 9A-9228	10	82	91	58	-20	0	0
G3715-2	AV3508 9A-9229	10	68	58	50	-20	0	0
G3715-3	AV3508 9A-9230	10	62	67	76	-20	-30	-20
G3715-4	AV3509 9A-9232	10	60	42	64	-4	-10	-4
G3715-5	AV3509 9A-9231	10	38	54	50	4	0	4
G3715-6	AV3504 9B-9202	10	39	46	34	12	-10	12
Core Spray Nozzle								
G3720-1	AV2997 9A-9363	10	67	52	96	-20	-10	-10
G3720-2	AV2997 9A-9364	10	70	99	84	-20	-10	-10
Instrumentation Nozzle								
G3811-1	Q2Q14W 969C-1	10	54	59	73	-20	10	10
G3811-2	Q2Q14W 969C-2	10	54	59	73	-20	10	10
Top Head Vent Nozzle								
G3810	Q2Q6W 986C	10	92	95	88	-20	10	10
Jet Pump Nozzle								
G3719-1	EV-9806 8L-9211A	10	99	124	105	-20	-20	-20
G3719-2	EV-9806 8L-9211B	10	99	124	105	-20	-20	-20
CRD HYD Return Nozzle								
G3716	AV3138 8L-9104	10	42	40	48	0	10	10
Core ΔP Nozzle	Alloy 600							
G3738	NX9492							(2)
Replacement Instrument Nozzles								
G3806	2127273	10	36	43	30	20	40	40
G3806R	6397860	10	250	230	247	-20	40	40
High Pressure Leak Detector Nozzle								
G4546								10 (1)
Drain Nozzle								
G3739	Q1Q1VW 738T	10	39	25	32	30	40	40
CRD Stub Tubes								
G3736-1 through -5	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 4-3: RT_{NDT} Values for Fermi 2 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								
2-307 A, B, C	13253 Linde 1092 Lot 3833	10	79	79	82	-50	-	-50
	12008 Linde 1092 Lot 3833	10	62	47	62	-44	-	-44
Lower-Intermediate Shell								
15-308 A, B, C, D	33A277 Linde 124 Lot 3878	10	83	94	87	-50	-	-50
Beltline - Girth								
Lower-Intermediate Shell to Lower Shell								
1-313	10137 Linde 0091 Lot 3999	10	101	108	107	-50	-	-50
Non-Beltline - Axial								
Upper-Intermediate Shell								
2-308 A through C	20291 & 12008 Linde 1092 Lot 3833	10	62	47	62	-44	-	-44
	HADH	10	112	110	114	-50	-	-50
	EOAG	10	173	133	135	-50	-	-50
Upper Shell 1-308 A through D	34B009 Linde 124 Lot 3687	10	55	65	57	-50	-	-50
	34B009 Linde 124 Lot 3688	10	69	70	63	-50	-	-50
Bottom Head Upper Torus Meridional Welds 1-306 A through K	HADH	10	112	110	114	-50	-	-50
Bottom Head Lower Torus Meridional Welds 2-306 A through G	LACH-2	10	125	119	119	-50	-	-50
	HADH	10	112	110	114	-50	-	-50
Top Head Upper Torus Meridional Welds 2-319 A through E	EOEJ	10	136	170	150	-50	-	-50
Top Head Lower Torus Meridional Welds 1-319 A through H	DOAJ	10	166	146	158	-50	-	-50
	AOFJ	10	112	105	115	-50	-	-50
	EOEJ	10	136	170	150	-50	-	-50
Non-Beltline - Girth								
Top Head Assembly								
3-319, 4-319, 5-319	33A277 Linde 0091 Lot 3977	10	111	106	113	-50	-	-50
	90099 Linde 0091 Lot 3977	10	56	30	52	-10	-	-10
Shell Flange to Upper Shell 13-308	21935 Linde 1092 Lot 3889	10	51	70	74	-50	-	-50
Upper Shell to Upper-Intermediate Shell 4-308-A	305424 Linde 1092 Lot 3889	10	82	87	92	-50	-	-50
Upper-Intermediate Shell to Lower-Intermediate Shell								
4-308-B	1P3571 Linde 1092 Lot 3958 Tandem	10	79	68	64	-50	-	-50
	1P3571 Linde 1092 Lot 3958 Single	10	40	46	46	-30	-	-30
Lower Shell to Bottom Head 9-307	90099 Linde 0091 Lot 3977	10	56	30	52	-10	-	-10
	90136 Linde 0091 Lot 3998	10	110	109	107	-50	-	-50
Bottom Head Assembly 3-306, 5-306, 6-306	1P2809 Linde 1092 Lot 3854	10	102	102	103	-50	-	-50
Support Skirt to Bottom Head 4-309	21935 Linde 1092 Lot 3869	10	62	59	60	-50	-	-50

Note: These are minimum Charpy values.

Table 4-3: RT_{NDT} Values for Fermi 2 Weld Materials, Continued

Component	Heat or Heat / Flux / Lot	Test Temp (°F)	Charpy Energy (ft-lb)			$(T_{50T}-60)$ (°F)	Drop Weight NDT (°F)	RT_{NDT} (°F)
Nozzle Welds								
Recirculation Outlet	LOBI	10	123	104	115	-50	-	-50
5-314 A & B	CBAI							10
	GBAI	10	120	105	128	-50	-	-50
Recirculation Inlet								
13-314 A through K	LOEH	10	113	123	140	-50	-	-50
13-314D (Replacement)	BBAI	10	97	100	77	-50	-	-50
	LACH	10	125	119	119	-50	-	-50
	HOGI	10	91	93	94	-50	-	-50
	IAGI	10	142	157	170	-50	-	-50
Steam Outlet	FAGI	10	135	121	136	-50	-	-50
8-316 A through D	LACH	10	125	119	119	-50	-	-50
Feedwater Nozzle	FACI							10
4-316 A through F	HOGI	10	91	93	94	-50	-	-50
	LOEH	10	113	123	140	-50	-	-50
	COFI	10	96	97	89	-50	-	-50
Core Spray Nozzles	IAGI	10	142	157	170	-50	-	-50
14-316 A & B	BBAI	10	97	100	77	-50	-	-50
Top Head Instrument Nozzle								
14-318 A & B	ABEA							10
	BOIA	10	99	110	113	-50	-	-50
Top Head Vent Nozzle	ABEA							10
2-318	BOIA	10	99	110	113	-50	-	-50
Jet Pump Nozzle	LACH	10	125	119	119	-50	-	-50
19-314 A & B	LOEH	10	113	123	140	-50	-	-50
CRD HYD Return Nozzle								
15-315	IAGI	10	142	157	170	-50	-	-50
Core ΔP Nozzle								
9-315	Inconel 182							
Instrument Nozzles								
4-315 A through F	Inconel 182							
Drain Nozzle								
17-315	CAFJ	10	85	101	108	-50	-	-50
Stub Tubes								
1-310	Inconel 182							
Appurtenance Welds								
Stabilizer Brackets	ICJJ	10	121	120	128	-50	-	-50
10-324 A through H	DBIJ	10	129	117	122	-50	-	-50
	HOCJ	10	165	174	140	-50	-	-50
	GBCJ	10	126	143	121	-50	-	-50
Steam Dryer Hold Down Brackets to Top Head								
10-319	KAHJ	10	108	116	107	-50	-	-50
Basin Seal Skirt								
6-324 A through D	IBEJ	10	160	151	145	-50	-	-50
	LOAJ	10	152	125	104	-50	-	-50
7-324 A through D; 8-324	HOKJ	10	110	177	154	-50	-	-50
	KACJ	10	102	81	108	-50	-	-50
Thermocouple Pads								
1-325	GBJJ	10	203	160	239	-50	-	-50
2-325	COEJ	10	129	95	81	-50	-	-50
3-325; 4-325; 6-325	FCJJ	10	180	224	171	-50	-	-50
	BBJJ	10	107	102	53	-50	-	-50
	COCA	10	120	139	137	-50	-	-50
	HOKJ	10	110	177	154	-50	-	-50
	FOIA	10	182	224	218	-50	-	-50
7-325; 8-325	BOLH	10	159	138	123	-50	-	-50
Top Head Lifting Lugs	GBCJ	10	126	143	121	-50	-	-50
8-319 A through D	DBIJ	10	129	117	122	-50	-	-50

NOTE: *These are minimum Charpy values.*

Table 4-4: RT_{NDT} Values for Fermi 2 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 S8530	AHC 178	10	81	100	102	-20	30	30
Shroud Support G3726	Alloy 600 580608-1X							(1)
Stabilizer Brackets C-6-1 C-6-2	 A4516-1 C5313-2	 40 10	 58 57	 49 45	 53 52	 12 -10	 10 -30	 12 -10
Guide Rod Brackets G3772	Stainless Steel							(1)
Steam Dryer Support Lugs G3775	Stainless Steel							(1)
Steam Dryer Hold Down Brackets G4871 D5591	 C2588-2D C6195-4	 10 10	 122 83	 129 69	 107 61	 -20 -20	 - -	 -20 -20
Core Spray Brackets G3774	Stainless Steel							(1)
Basin Seal Skirt G3818 G3819	 C2588-2B 22A459							 10 (2) 10 (2)
Surveillance Specimen Brackets G3776 G3777	 Stainless Steel Stainless Steel							 (1) (1)
Feedwater Sparger Brackets G3773	Stainless Steel							(1)
Top Head Lifting Lugs G3732								40 (2)

Component	Heat	Test Temp (°F)	Charpy Energy (ft-lb)			Min Lat Exp (mils)	LST (°F)
Closure Studs							
G3778-1	14677	10	50	50	52	-	70
G3778-2	67156	10	55	54	55	-	70
G3778-3	(3)	10	-	-	-	-	70
Closure Nuts							
G3779-1	48192	10	58	59	54	-	70
G3779-2	(3)	10	-	-	-	-	70
Closure Washers							
Closure Washers G5252	(3)	10	-	-	-	-	70
Bushings							
G4853	(3)	10	-	-	-	-	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 informatior
(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

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. An evaluation of ART for all beltline plates and welds was performed and is summarized in Tables 4-5 and 4-6 for 24 and 32 EFPY, respectively.

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

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

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

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.

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 has constant values of 17°F for plate and 28°F for weld as defined in RG1.99. However, σ_Δ need not be greater than $0.5 \cdot \Delta RT_{NDT}$. Since the GE/BWROG method of estimating RT_{NDT} operates on the lowest Charpy energy value (as described in Section 4.1.2) and provides a conservative adjustment to the 50 ft-lb level, the value of σ_I is taken to be 0°F for the vessel plate and weld materials.

4.2.1.1 Chemistry

The vessel beltline chemistries 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 1991 P-T curve report [1]. Chemistries for the surveillance materials evaluated in Tables 4-5 and 4-6 were obtained from the Integrated Surveillance Program [13]."

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 weld heat 13253, 12008, both the chemistry for the Fermi 2 vessel weld and the chemistry from the Integrated Surveillance Program (ISP) are presented. Heat CE-2(WM), which has been determined to be Heat 13253, 12008, is the surveillance weld material as defined by the Integrated Surveillance Program (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 24 and 32 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: $326.96 \cdot (224 / 206.6) = 354.5$.

4.2.1.2 Fluence

The fluence used in this evaluation reflects implementation of power uprate for Cycle 11. Delay of implementation of the power uprate will increase the conservatism for the beltline P-T curves. The peak fluence for the RPV inner surface, used for determination of the P-T curves, is 9.68e17 n/cm^2 for 32 EFPY. For 24 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]. The fluence used in developing the P-T curves is conservatively based upon operation at 3430 MWt for 12.04 EFPY and 3952 MWt for 19.96 EFPY.

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 this 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 32 and 24 EFPY fluences, respectively. The slight difference is due to the amount of time that Fermi Unit 2 will operate at the EPU power level.

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. Tables 4-5 and 4-6 list values of beltline ART for 24 and 32 EFPY, respectively.

Surveillance capsule material data is available from the Integrated Surveillance Program (ISP) to represent the Fermi Unit 2 vessel. These materials are included in the ART calculations provided in Tables 4-5 and 4-6, and in the determination of the limiting material that is represented in the beltline P-T curves.

Table 4-5: Fermi 2 Beltline ART Values (24 EFPY)

Lower-Intermediate Shell Plates and Axial Welds

Thickness in inches= 6.125

24 EFPY Peak I.D. fluence =	7.13E+17	n/cm^2
24 EFPY Peak 1/4 T fluence =	4.94E+17	n/cm^2
24 EFPY Peak 1/4 T fluence =	4.94E+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

24 EFPY Peak I.D. fluence =	4.66E+17	n/cm^2
24 EFPY Peak 1/4 T fluence =	3.04E+17	n/cm^2
24 EFPY Peak 1/4 T fluence =	3.04E+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	24 EFPY Δ RTndt °F	σ_I	σ_Δ	Margin °F	24 EFPY Shift °F	24 EFPY ART °F
PLATES:													
Lower Shell													
G3706-1	C4540-2	0.08	0.62	51		-10	3.04E+17	11	0	6	11	23	13
G3706-2	C4560-1	0.11	0.57	74		-10	3.04E+17	16	0	8	16	33	23
G3706-3	C4554-1	0.12	0.56	82		-10	3.04E+17	18	0	9	18	36	26
Lower-Intermediate Shell													
G3703-5	C4564-1	0.09	0.55	58		-10	4.94E+17	17	0	8	17	34	24
G3705-1	B8614-1	0.12	0.61	83		-20	4.94E+17	24	0	12	24	48	28
G3705-2	C4574-2	0.10	0.55	65		-16	4.94E+17	19	0	9	19	38	22
G3705-3	C4568-2	0.12	0.61	83		-12	4.94E+17	24	0	12	24	48	36
WELDS:													
Lower Shell Axial													
2-307 A, B, C	Tandem 13253, 12008 1092 Lot 3833	0.26	0.87	224		-44	3.04E+17	50	0	25	50	99	55
Lower-Intermediate Shell Axial													
15-308 A, B, C, D	33A277, 124 Lot 3878	0.32	0.50	188.5		-50	4.94E+17	55	0	27	55	110	60
Lower to Lower-Intermediate Girth													
1-313	10137, 0091 Lot 3999	0.23	1.00	236		-50	3.04E+17	52	0	26	52	104	54
INTEGRATED SURVEILLANCE PROGRAM (2):													
Plate (3)	C4114-2	0.12	0.69	84		-12	4.94E+17	24	0	12	24	49	37
Weld (4)	CE-2 (WM)(13253,12008)	0.21	0.86	207	354	-44	3.04E+17	78	0	28	28	106	62

(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 Fermi 2 plate, which is Heat C4568-2. ISP indicates that C4554-1 is also a limiting plate, however due to the reduced fluence at the lower shell, this material is no longer limiting.
(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 4-6: Fermi 2 Beltline ART Values (32 EFPY)

Lower-Intermediate Shell Plates and Axial Welds

Thickness in inches= 6 125

32 EFPY Peak I.D. fluence = 9.68E+17 n/cm^2
32 EFPY Peak 1/4 T fluence = 6.70E+17 n/cm^2
32PY Peak 1/4 T 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

32 EFPY Peak I.D. fluence = 6.23E+17 n/cm^2
32 EFPY Peak 1/4 T fluence = 4 06E+17 n/cm^2
32PY Peak 1/4 T fluence = 4 06E+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	32 EFPY Δ RTndt °F	σ_I	σ_Δ	Margin °F	32 EFPY Shift °F	32 EFPY ART °F
PLATES:													
Lower Shell													
G3706-1	C4540-2	0.08	0.62	51		-10	4.06E+17	13	0	7	13	27	17
G3706-2	C4560-1	0.11	0.57	74		-10	4.06E+17	19	0	10	19	38	28
G3706-3	C4554-1	0.12	0.56	82		-10	4.06E+17	21	0	11	21	43	33
Lower-Intermediate Shell													
G3703-5	C4564-1	0.09	0.55	58		-10	6.70E+17	20	0	10	20	40	30
G3705-1	B8614-1	0.12	0.61	83		-20	6.70E+17	28	0	14	28	57	37
G3705-2	C4574-2	0.10	0.55	65		-16	6.70E+17	22	0	11	22	44	28
G3705-3	C4568-2	0.12	0.61	83		-12	6.70E+17	28	0	14	28	57	45
WELDS:													
Lower Shell Axial													
2-307 A, B, C	Tandem 13253, 12008 1092 Lot 3833	0.26	0.87	224		-44	4.06E+17	59	0	28	56	115	71
Lower-Intermediate Shell Axial													
15-308 A, B, C, D	33A277, 124 Lot 3878	0.32	0.50	188.5		-50	6.70E+17	64	0	28	56	120	70
Lower to Lower-Intermediate Girth													
1-313	10137, 0091 Lot 3999	0.23	1.00	236		-50	4.06E+17	62	0	28	56	118	68
INTEGRATED SURVEILLANCE PROGRAM (2):													
Plate (3)	C4114-2	0.12	0 69	84		-12	6.70E+17	29	0	14	29	57	45
Weld (4)	CE-2 (WM)(13253,12008)	0.21	0.86	207	354	-44	4 06E+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 Fermi 2 plate, which is Heat C4568-2. ISP indicates that C4554-1 is also a limiting plate, however due to the reduced fluence at the lower shell, this material is no longer limiting
(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

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 and low-level physics tests, referred to as Curve B; and (c) core critical operation, referred to as Curve C.

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

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

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

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

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 4-7.

Table 4-7: 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), the closure flanges, some shell plates, the top and bottom head plates and the control rod drive (CRD) penetrations.

Detailed stress analyses of the non-beltline components were performed for the BWR/6 specifically for the purpose of fracture toughness analysis. The BWR/6 stress analysis bounds for BWR/2 through BWR/5 designs, and 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 nozzles (FW) and the CRD penetrations (bottom head). All other components in the non-beltline regions are categorized under one of these two components as described in Tables 4-8 and 4-9.

Table 4-8: Applicable BWR/4 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 Nozzles
Recirculation Outlet Nozzle

Table 4-9: Applicable BWR/4 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.

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 Fermi Unit 2 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.

The generic value was adapted to the conditions at Fermi Unit 2 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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An evaluation was performed for the bottom head wall thickness transition discontinuities located between the bottom head lower torus and upper torus and also between the bottom head torus and Shell #1. Appendix G of this report contains a detailed description of this 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. Upjohn welds occur in various welds in the Fermi Unit 2 vessel; these welds are known to contain flaws. The limiting flaw, which exists in the beltline region, has been evaluated as discussed in Appendix I of this report.

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:

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

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

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

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]:

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

The total K_I is therefore:

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

This equation includes a safety factor of 1.5 on primary stress. The method to solve for $(T - RT_{NDT})$ for a specific K_I is based on the K_{Ic} 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 4-10.

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The highest RT_{NDT} for the bottom head plates and welds is 30°F, as shown in Tables 4-1 and 4-3. [[

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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 Fermi Unit 2-specific bottom head dimensions are R = 127.38 inches and t =7.38 inches minimum [19], resulting in:

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

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

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

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

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

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

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

The generic curve was generated by scaling 192 ksi-in$^{1/2}$ by the nominal pressures and calculating the associated (T - RT_{NDT}) as shown in Table 4-11.

Table 4-11: 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 30°F, as shown in Tables 4-1 and 4-3. [[

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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 4-9 and Appendix A). With respect to thermal stresses, the transients evaluated for the CRD are similar to or more severe than those of the other components being bounded. Therefore, for heatup/cooldown conditions, the CRD penetration provides bounding limits.

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

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

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

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

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

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

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

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

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

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

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

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

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The highest RT_{NDT} for the feedwater nozzle materials is 12°F as shown in Table 4-2. However, the RT_{NDT} was increased to 25°F to consider the stresses in the bottom head/CRD and recirculation inlet nozzle together with the initial RT_{NDT} as described below. The generic pressure test P-T curve is applied to the Fermi Unit 2 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 Fermi Unit 2 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: σ = 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 σ $(\pi a)^{1/2} \cdot F(a/r_n)$:

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 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}:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$F(a / r_n) = 1.4$

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

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

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

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

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

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

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

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

$(T - RT_{NDT}) = 115°F$

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

$$(T_{saturation} - 40) / (551.4 - 40).$$

From K_I the associated $(T - RT_{NDT})$ can be calculated as shown in Table 4-13.

Table 4-13: Core Not Critical Feedwater Nozzle K_I and (T - RT_{NDT}) as a Function of Pressure

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

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

The highest non-beltline RT_{NDT} for the feedwater nozzle at Fermi Unit 2 is 12°F as shown in Table 4-2. However, the RT_{NDT} was increased to 25°F to consider the stresses in the bottom head/CRD and recirculation inlet nozzle as previously discussed. The generic curve is applied to the Fermi Unit 2 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.

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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. Due to the existence of a flaw in one of the Shell #2 axial welds, an evaluation was performed to determine requirements necessary to protect this flaw, as discussed in Appendix I and Section 4.3.2.2.2 below. Thermal stresses are calculated including clad thickness as defined by the ASME Code. As demonstrated in Tables 4-5 and 4-6, the ART is conservatively calculated using minimum wall thickness excluding clad thickness.

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 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:

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

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:

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

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

GE's current practice for the pressure test curve is to add a stress intensity factor, K_{It}, for a coolant heatup/cooldown rate, specified as 20°F/hr for Fermi Unit 2, to provide operating flexibility. For the core not critical and core critical condition curves, a stress intensity factor is added for a coolant heatup/cooldown rate of 100°F/hr. The K_{It} calculation for a coolant heatup/cooldown rate of 100°F/hr is described in Section 4.3.2.2.3 below.

4.3.2.2.2 Calculations for the Beltline Region - Pressure Test

This sample calculation is for a pressure test pressure of 1055 psig at 32 EFPY. The following inputs were used in the beltline limit calculation:

Adjusted RT_{NDT} = Initial RT_{NDT} + Shift	A = -44 + 121 + 5 = 82°F (Based on ART values in Table 4-6 and adjusted to protect the existing flaw discussed below)
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:

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

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:

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

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

T = 39.8 + 77 = 116.8°F for P = 1055 psig at 32 EFPY

As previously mentioned, a flaw exists in Weld 15-308B that is located at the upper boundary of the extended beltline region, at 374.6 inches above vessel '0'. An evaluation was performed, as detailed in Appendix I, to determine the impact of this flaw on the P-T curves, as its dimensions exceed the postulated 1/4T flaw upon which this evaluation is based. This evaluation was conservatively performed using the parameters for the minimum hydrotest pressure of 1030 psig. It was found that for 32 EFPY, the beltline hydrotest pressure test curve (Curve A) must be shifted 5°F in addition to the 77°F shift defined in Table 4-6. Similarly, for 24 EFPY, the curve must be shifted such that the Curve A temperature at 1030 psig is 113°F. Because Curve A is bounded by 10CFR50 Appendix G requirements at 1030 psig, a shift of 13°F is required in order to accomplish this and protect the beltline flaw.

Therefore, T is further adjusted by 5°F to protect the flaw:

T = 116.8°F + 5°F = 121.8°F for P = 1055 psig at 32 EFPY.

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

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

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

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

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

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

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

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

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

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

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

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

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.

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

This Fermi Unit 2 sample calculation is for a pressure of 1055 psig for 32 EFPY. The core not critical heatup/cooldown curve at 1055 psig 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 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 = 0.5365 ft (6.125" + 0.3125" = 6.4375")
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:

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

The analyzed case for thermal stress is a 1/4T flaw depth with wall thickness of C. The corresponding value of M_t (=0.2942) 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 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 $(T - RT_{NDT})$:

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

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

T = 68.2 + 77 = 145.2 °F for P = 1055 psig at 32 EFPY

As previously mentioned, a flaw exists in Weld 15-308B that is located at the upper boundary of the extended beltline region, at 374.6 inches above vessel '0'. An evaluation, as detailed in Appendix I, was performed to determine the impact of this flaw on the P-T curves, as its dimensions exceed the postulated 1/4T flaw upon which this evaluation is based. It was determined that the core not critical beltline curve calculated above bounds the requirements for protecting this flaw.

It is noted that the 32 EFPY core not critical beltline curve is bounded by upper vessel requirements at 1055 psig as can be seen in Figure 5-10 and Appendix B.

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 (the largest T-RT_{NDT} for the flange at 1563 psig is 73°F). For pressures below 312 psig, the flange curve is bounded by RT_{NDT} + 60 (the largest T - RT_{NDT} for the flange at 312 psig is 54°F); therefore, instead of determining a T (temperature) versus pressure curve for the flange (i.e., T - RT_{NDT}) the value RT_{NDT} + 60 is used for the closure flange limits.

In some cases, the results of analysis for other regions exceed these requirements and closure flange limits do not affect the shape of the P-T curves. However, some closure flange requirements do impact the curves, as is true with Fermi Unit 2 at low pressures.

The approach used for Fermi Unit 2 for the bolt-up temperature was based on the conservative value of (RT_{NDT} + 60), or the LST of the bolting materials, whichever is greater. The 60°F adder is included by GE for two reasons: 1) the pre-1971 requirements of the ASME Code Section III, Subsection NA, Appendix G included the 60°F adder, and 2) inclusion of the additional 60°F requirement above the RT_{NDT} provides the additional assurance that a 1/4T flaw size is acceptable. As shown in Tables 4-1, 4-2, and 4-3, 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. This conservatism is appropriate because bolt-up is one of the more limiting operating conditions (high stress and low temperature) for brittle fracture.

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

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

The shutdown margin, provided in the Fermi Unit 2 Technical Specification, is calculated for a water temperature of 68°F. Shutdown margin is the quantity of reactivity needed for a reactor core to reach criticality with the strongest-worth control rod fully withdrawn and all other control rods fully inserted. Although it may be possible to safely allow the water temperature to fall below this 68°F limit, further extensive calculations would be required to justify a lower temperature. The 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. When the head is not tensioned and fuel is not in the vessel, the requirements of 10CFR50 Appendix G [8] do not apply, and there are no limits on the vessel temperatures.

4.3.2.4 CORE CRITICAL OPERATION REQUIREMENTS OF 10CFR50, APPENDIX G

Curve C, the core critical operation curve, is generated from the requirements of 10CFR50 Appendix G [8], Table 1. Table 1 of [8] requires that core critical P-T limits be

40°F above any Curve A or B limits when pressure exceeds 20% of the pre-service system hydrotest pressure. Curve B is more limiting than Curve A, so limiting Curve C values are at least Curve B plus 40°F for pressures above 312 psig.

Table 1 of 10CFR50 Appendix G [8] indicates that for a BWR with water level within normal range for power operation, the allowed temperature for initial criticality at the closure flange region is (RT_{NDT} + 60°F) at pressures below 312 psig. This requirement makes the minimum criticality temperature 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 operating limits for pressure and temperature are required for three categories of operation: (a) hydrostatic pressure tests and leak tests, referred to as Curve A, (b) non-nuclear heatup/cooldown and low-level physics tests, referred to as Curve B, and (c) core critical operation, referred to as Curve C.

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

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

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

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

The following P-T curves were generated for Fermi Unit 2:

- Composite P-T curves were generated for each of the Pressure Test and Core Not Critical conditions at 24 and 32 effective full power years (EFPY). The composite curves were generated by enveloping the most restrictive P-T limits from the separate beltline, upper vessel and closure assembly P-T limits. A separate Bottom Head Limits (CRD Nozzle) curve is also individually included with the composite curve for the Pressure Test and Core Not Critical condition.
- Separate P-T curves were developed for the upper vessel, beltline (at 24 and 32 EFPY), and bottom head for the Pressure Test and Core Not Critical conditions.
- A composite P-T curve was also generated for the Core Critical condition at 24 and 32 EFPY. The composite curves were generated by enveloping the most restrictive P-T limits from the separate beltline, upper vessel, bottom head, and closure assembly P-T limits.

Using the 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 24 EFPY. The 32 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 - 24 EFPY	Figure 5-3	Table B-1
A	Beltline Limits – 32 EFPY	Figure 5-4	Table B-3
A	Bottom Head and Composite Curve A – 24 EFPY*	Figure 5-5	Table B-2
A	Bottom Head and Composite Curve A – 32 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 - 24 EFPY	Figure 5-9	Table B-1
B	Beltline Limits – 32 EFPY	Figure 5-10	Table B-3
B	Bottom Head and Composite Curve B – 24 EFPY*	Figure 5-11	Table B-2
B	Bottom Head and Composite Curve B – 32 EFPY*	Figure 5-12	Table B-4
C	Composite Curve C – 24 EFPY**	Figure 5-13	Table B-2
C	Composite Curve C – 32 EFPY**	Figure 5-14	Table B-4
ABC	Limiting Curves – 24 EFPY***	Figure 5-15	Table B-2
ABC	Limiting Curves – 32 EFPY***	Figure 5-16	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.

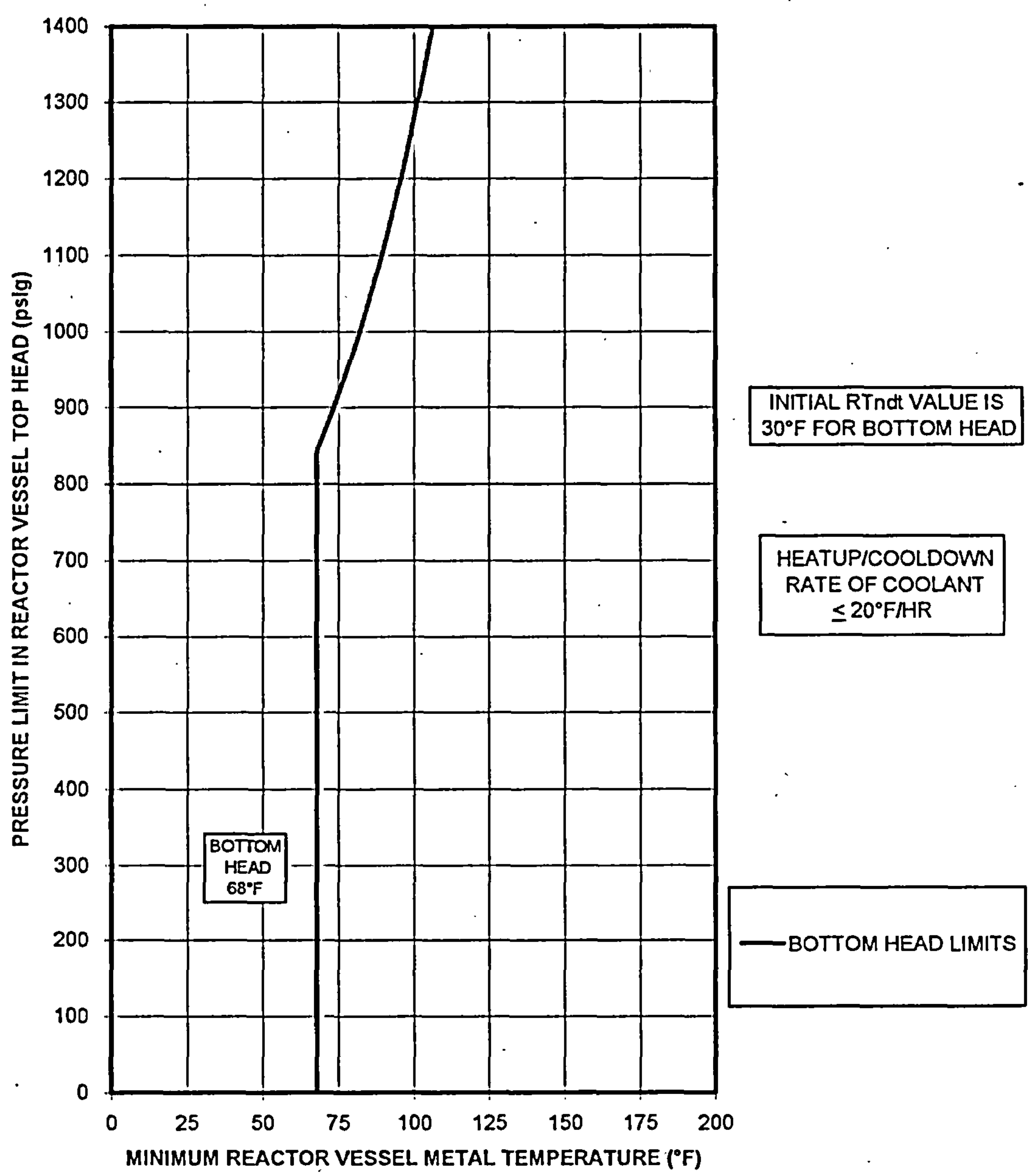

Figure 5-1: Bottom Head P-T Curve for Pressure Test [Curve A]
[20°F/hr or less coolant heatup/cooldown]

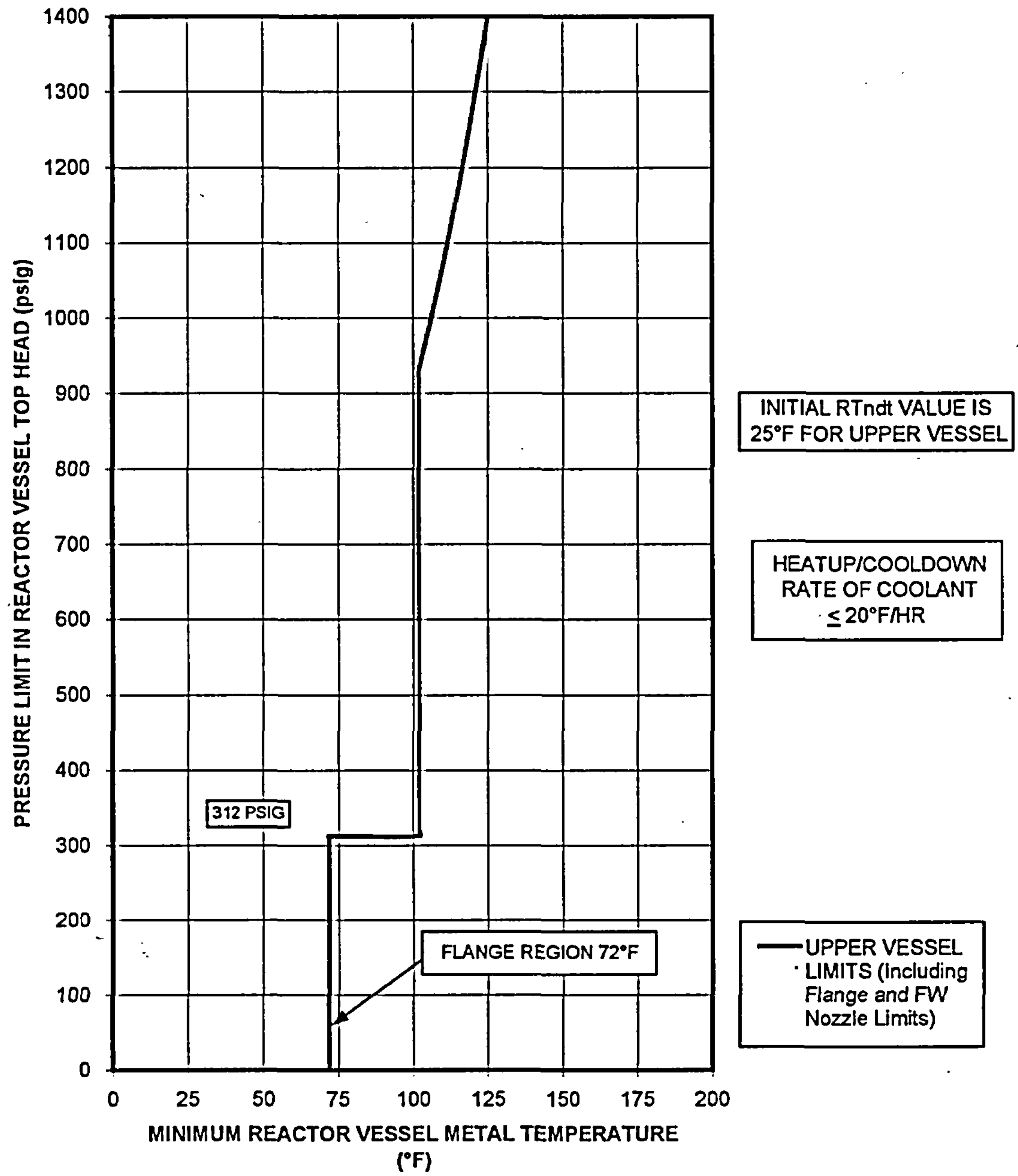

Figure 5-2: Upper Vessel P-T Curve for Pressure Test [Curve A]
[20°F/hr or less coolant heatup/cooldown]

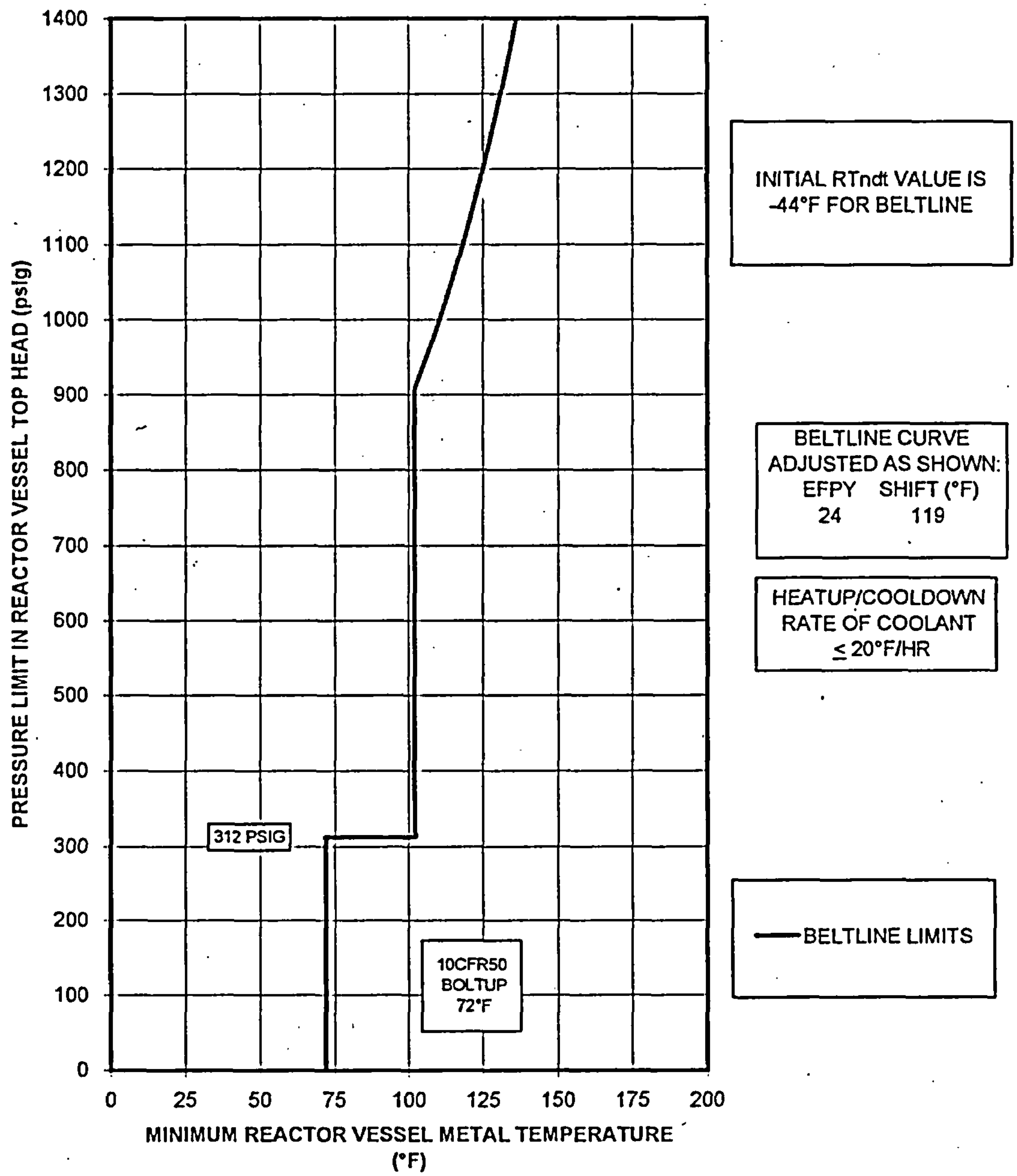

Figure 5-3: Beltline P-T Curve for Pressure Test [Curve A] up to 24 EFPY
[20°F/hr or less coolant heatup/cooldown]

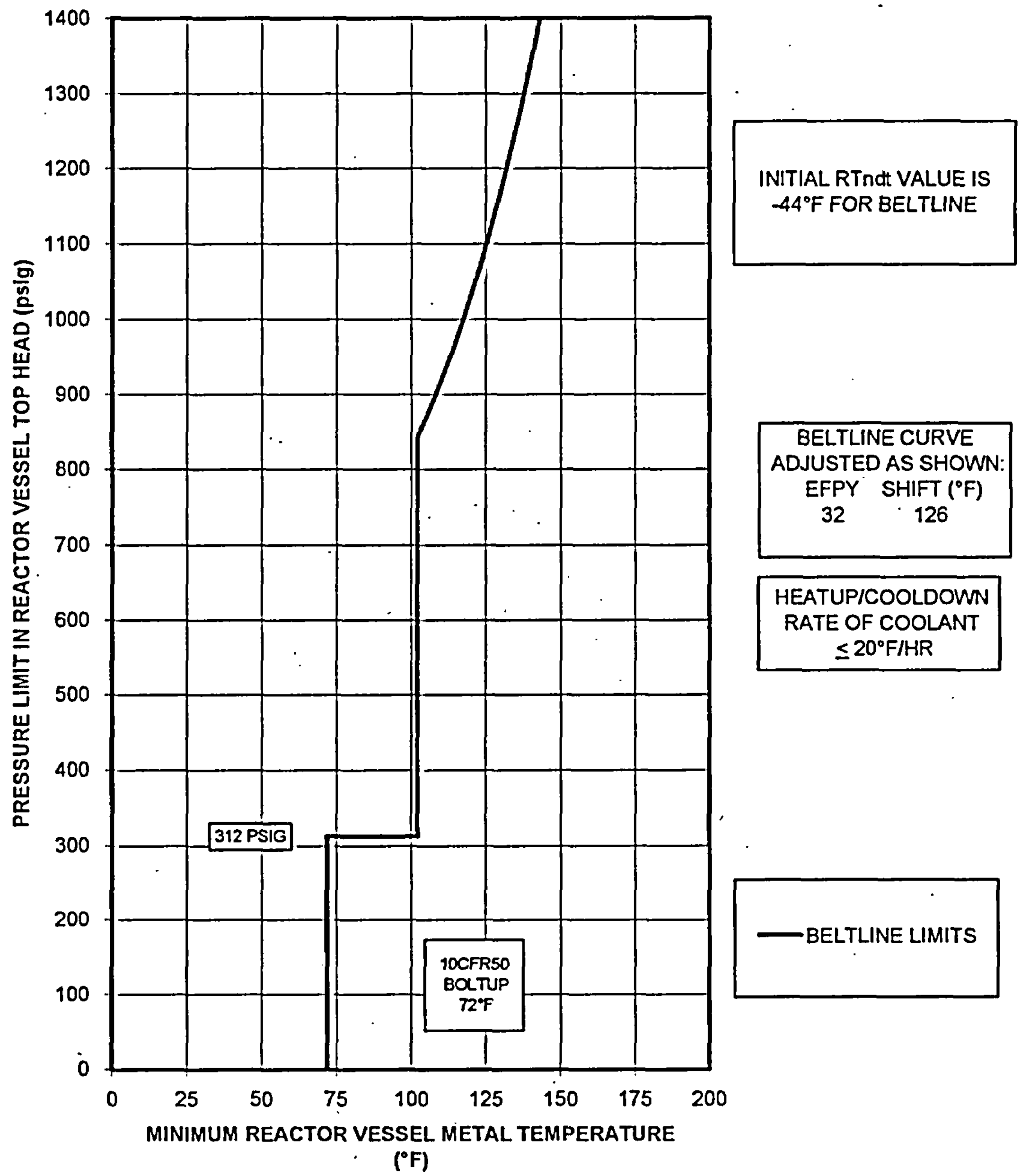

Figure 5-4: Beltline P-T Curve for Pressure Test [Curve A] up to 32 EFPY
[20°F/hr or less coolant heatup/cooldown]

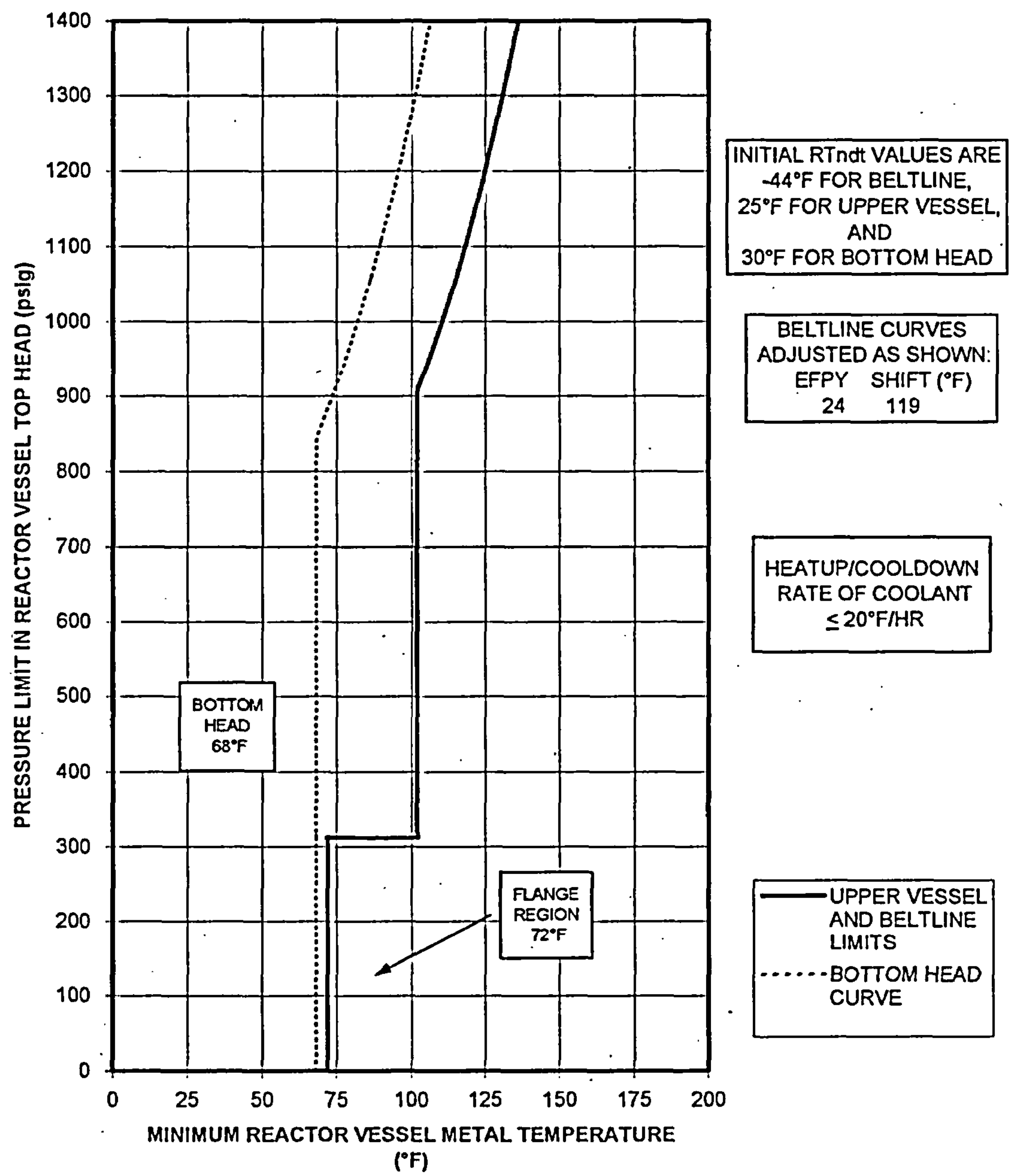

Figure 5-5: Composite Pressure Test P-T Curves [Curve A] up to 24 EFPY
[20°F/hr or less coolant heatup/cooldown]

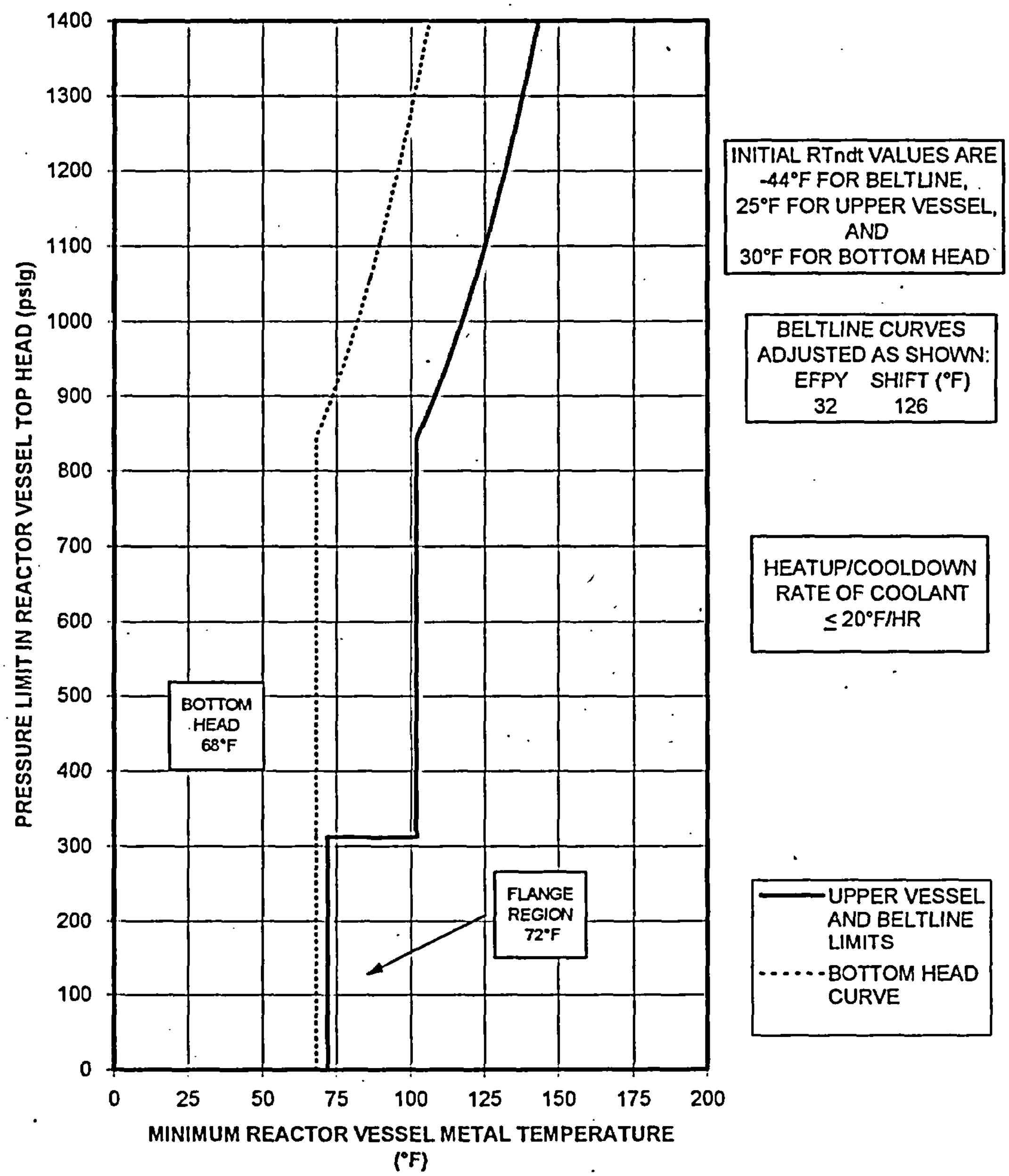

Figure 5-6: Composite Pressure Test P-T Curves [Curve A] up to 32 EFPY
[20°F/hr or less coolant heatup/cooldown]

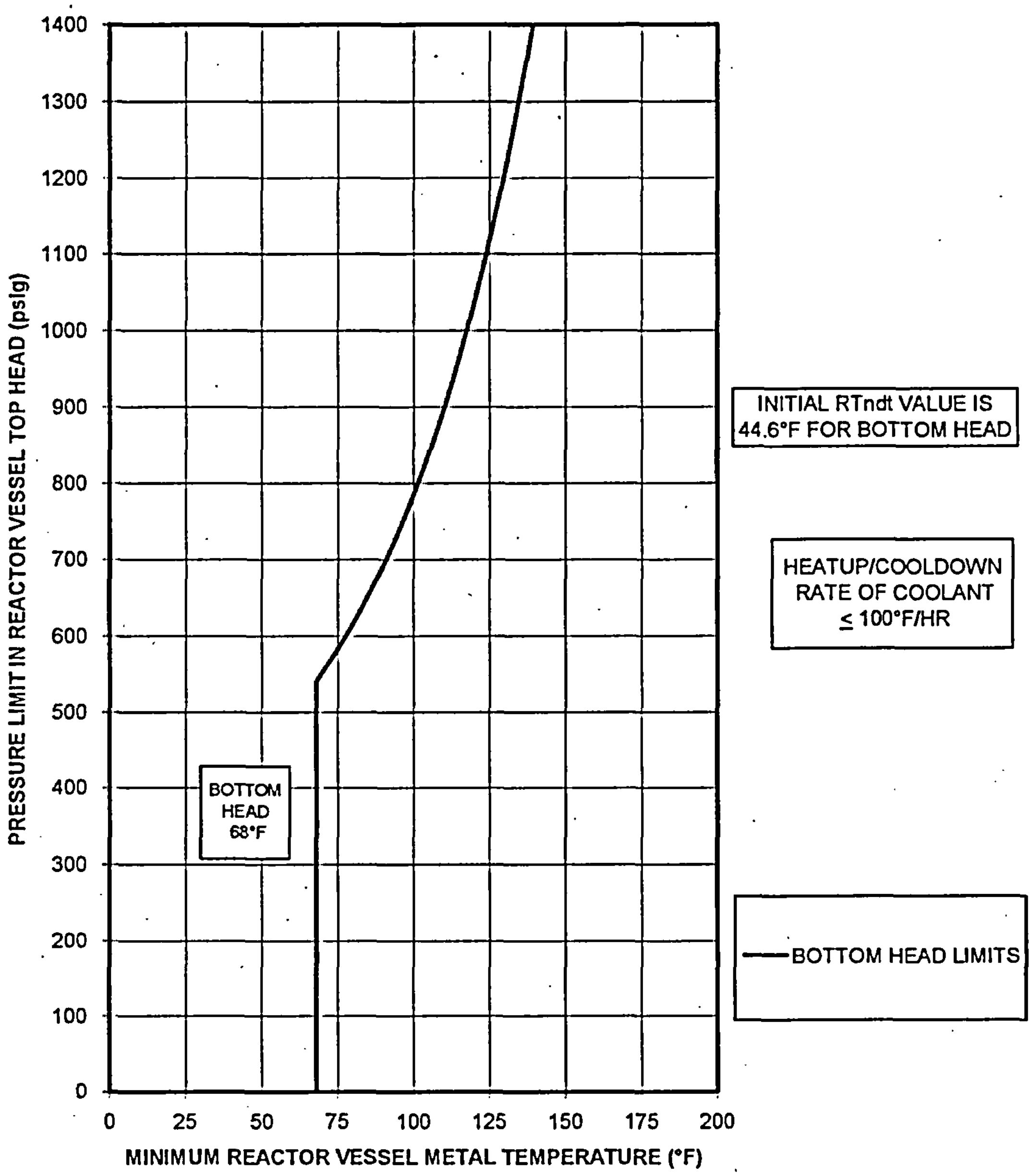

Figure 5-7: Bottom Head P-T Curve for Core Not Critical [Curve B]
[100°F/hr or less coolant heatup/cooldown]

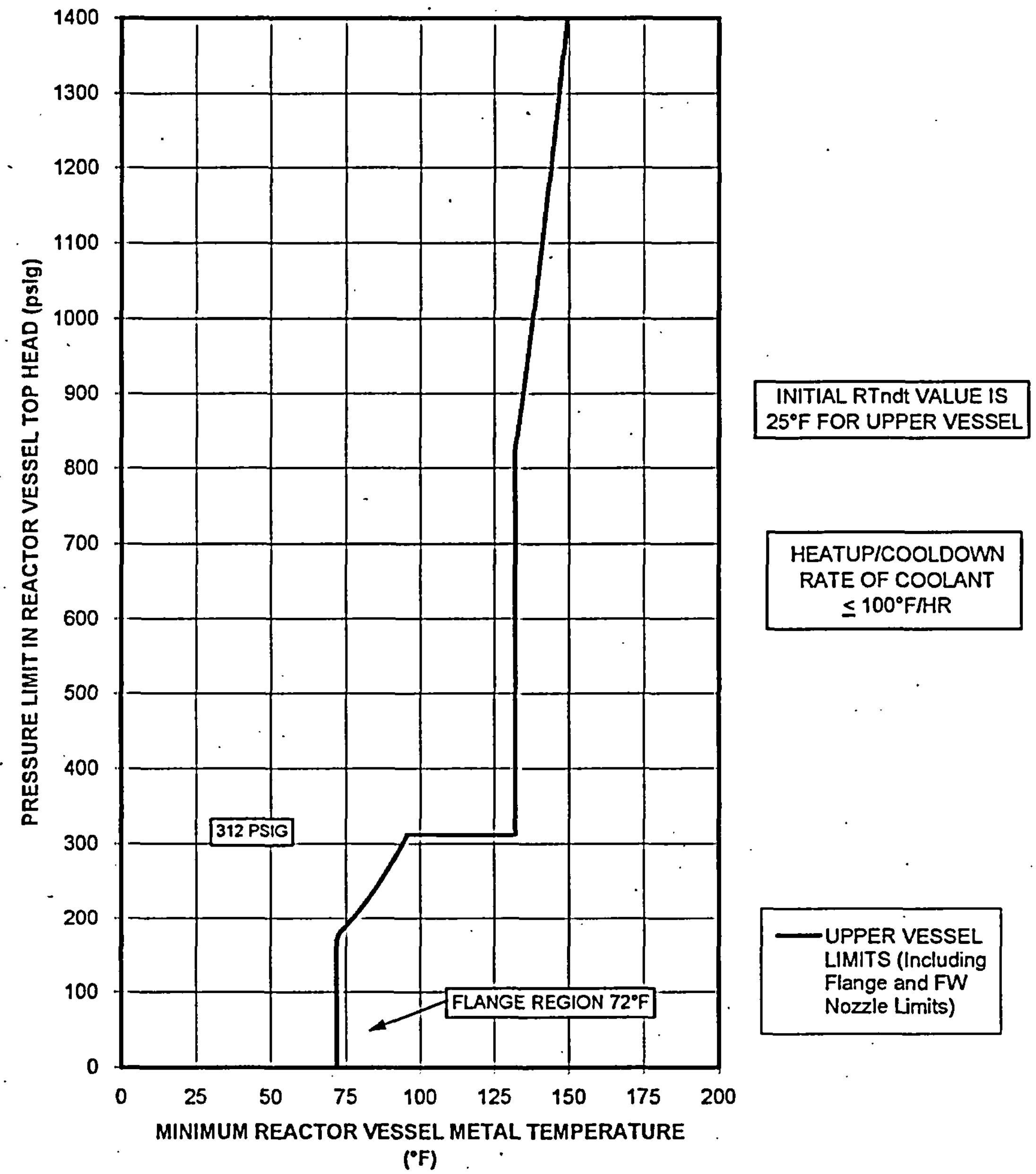

Figure 5-8: Upper Vessel P-T Curve for Core Not Critical [Curve B]
[100°F/hr or less coolant heatup/cooldown]

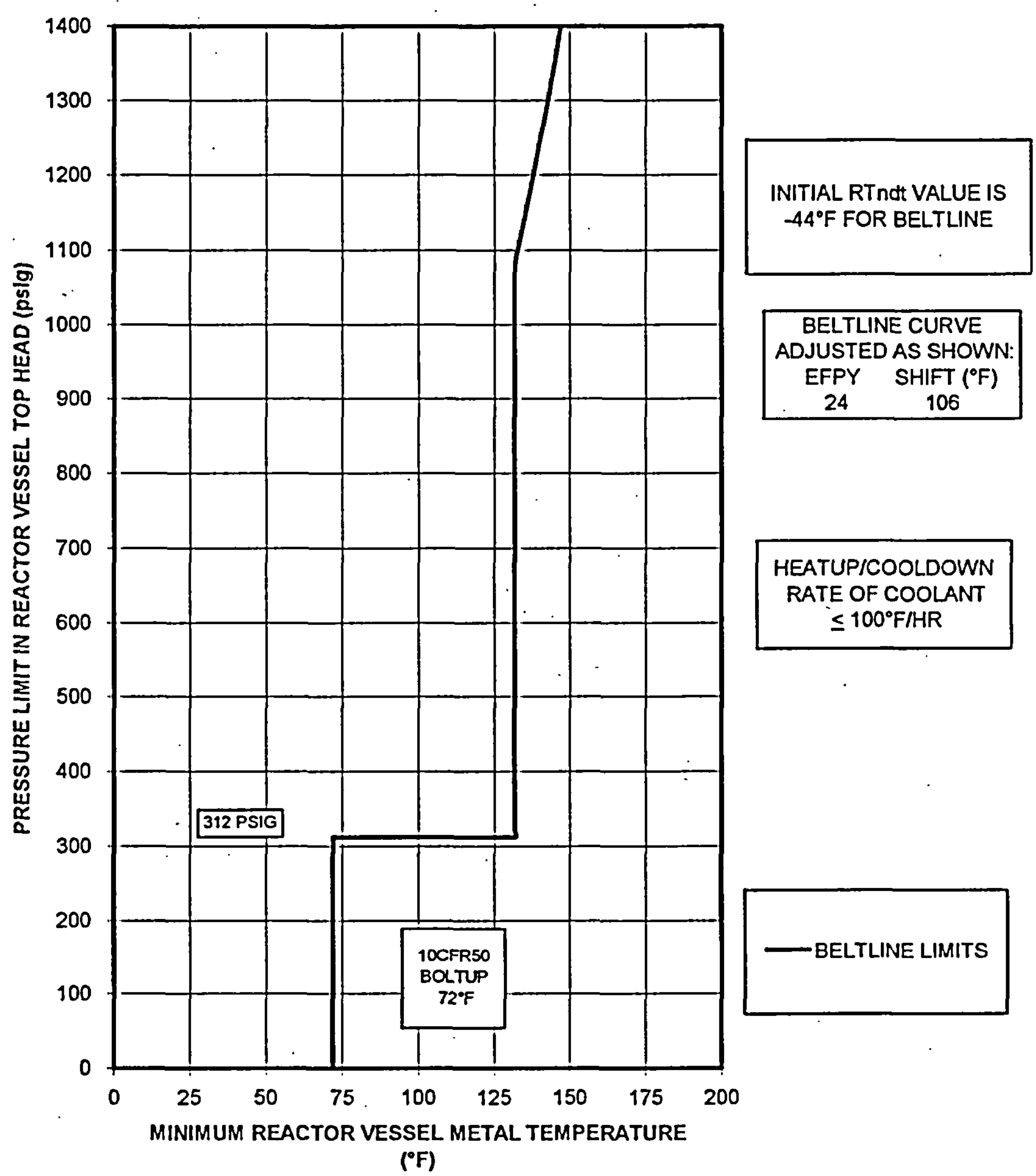

Figure 5-9: Beltline P-T Curve for Core Not Critical [Curve B] up to 24 EFPY
[100°F/hr or less coolant heatup/cooldown]

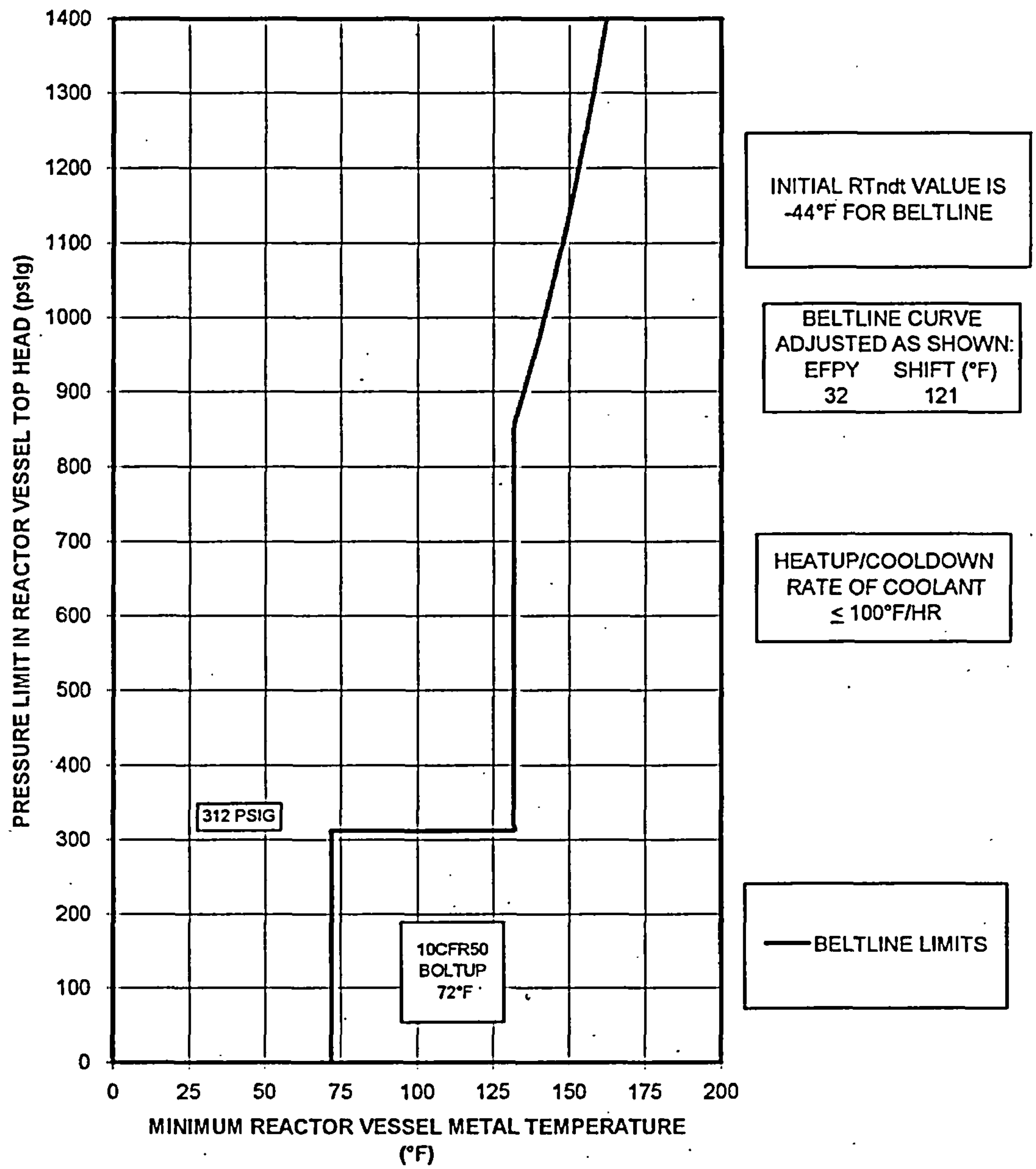

Figure 5-10: Beltline P-T Curve for Core Not Critical [Curve B] up to 32 EFPY
[100°F/hr or less coolant heatup/cooldown]

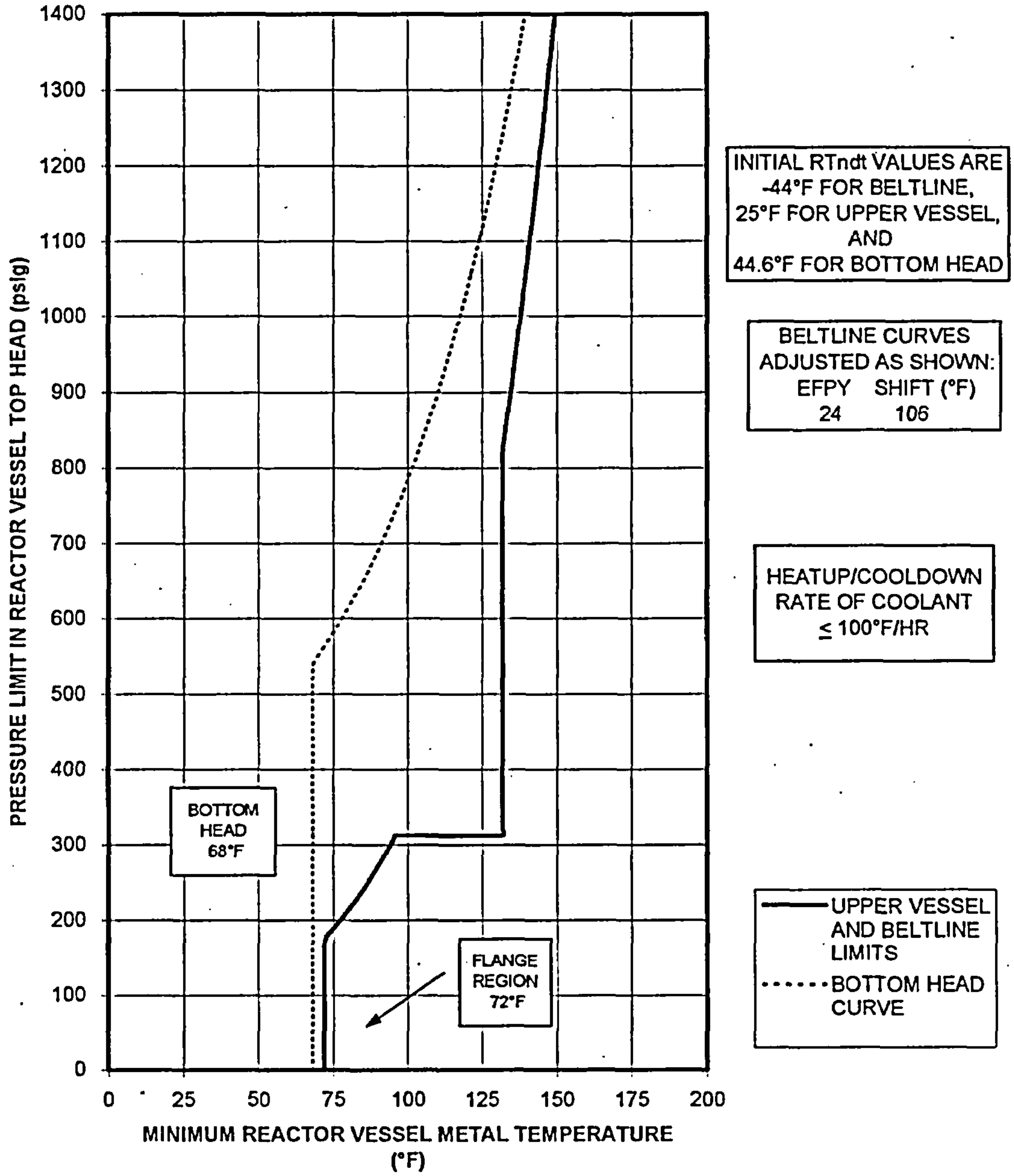

Figure 5-11: Composite Core Not Critical P-T Curves [Curve B] up to 24 EFPY
[100°F/hr or less coolant heatup/cooldown]

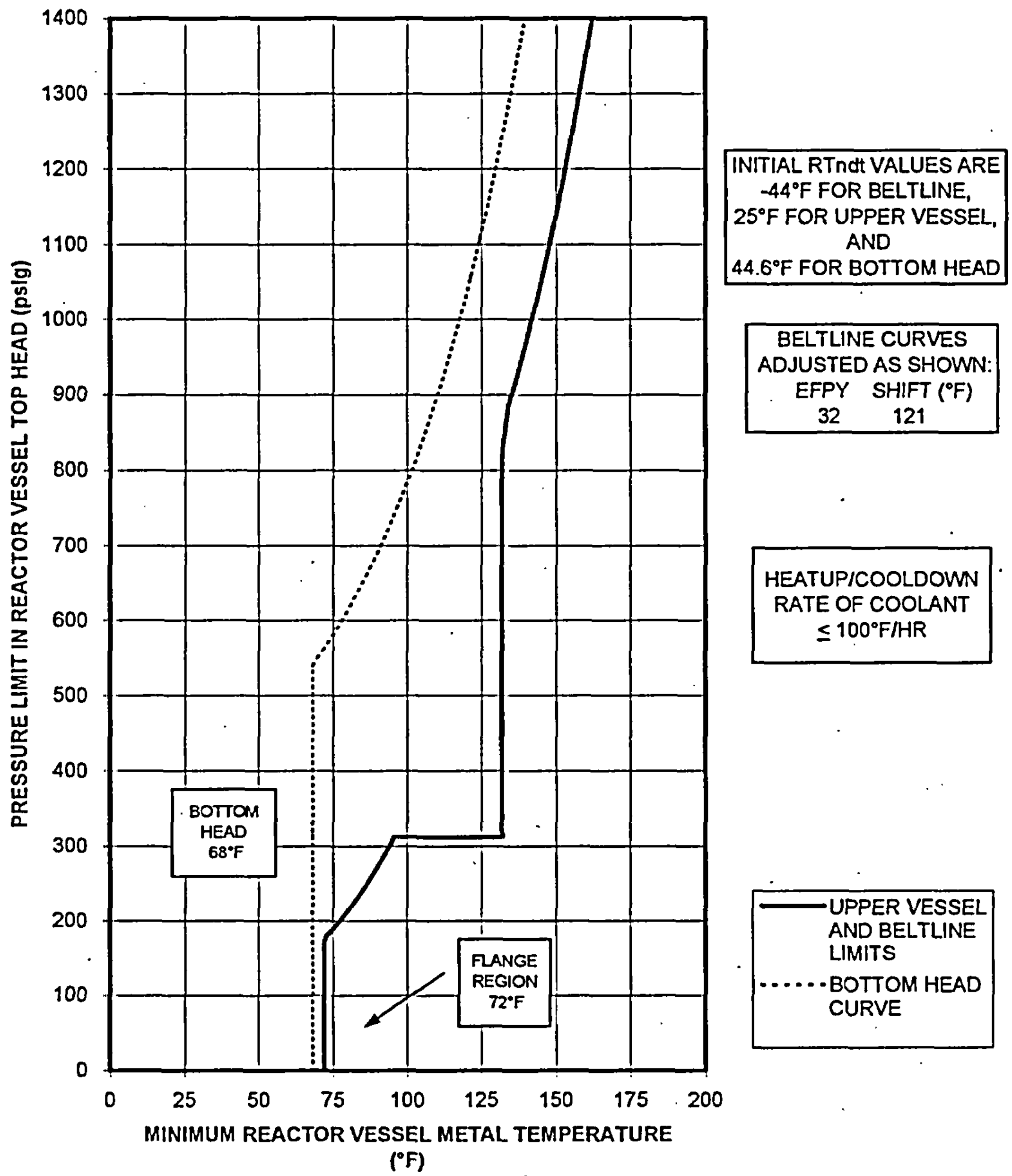

Figure 5-12: Composite Core Not Critical P-T Curves [Curve B] up to 32 EFPY [100°F/hr or less coolant heatup/cooldown]

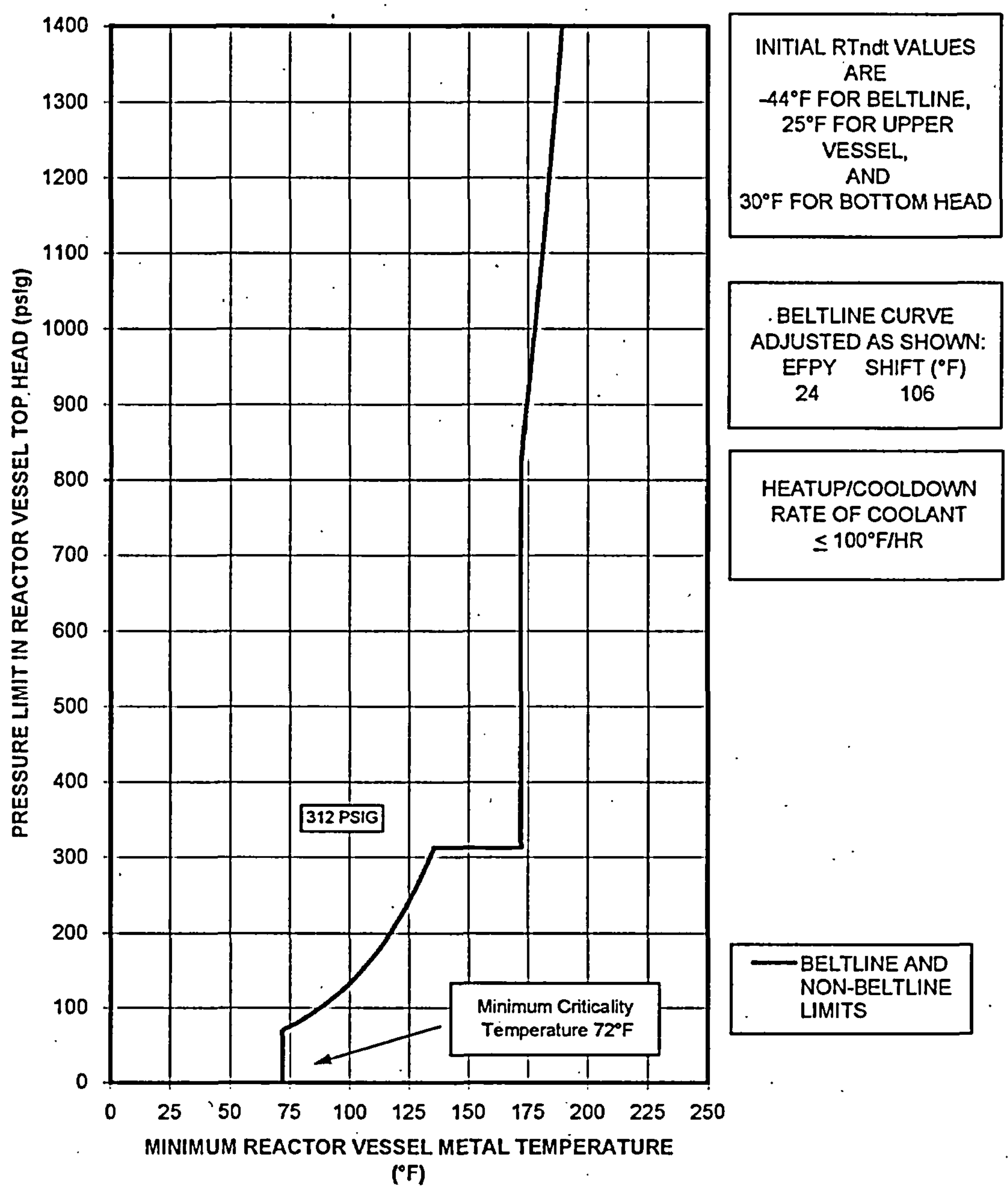

Figure 5-13: Composite Core Critical P-T Curves [Curve C] up to 24 EFPY [100°F/hr or less coolant heatup/cooldown]

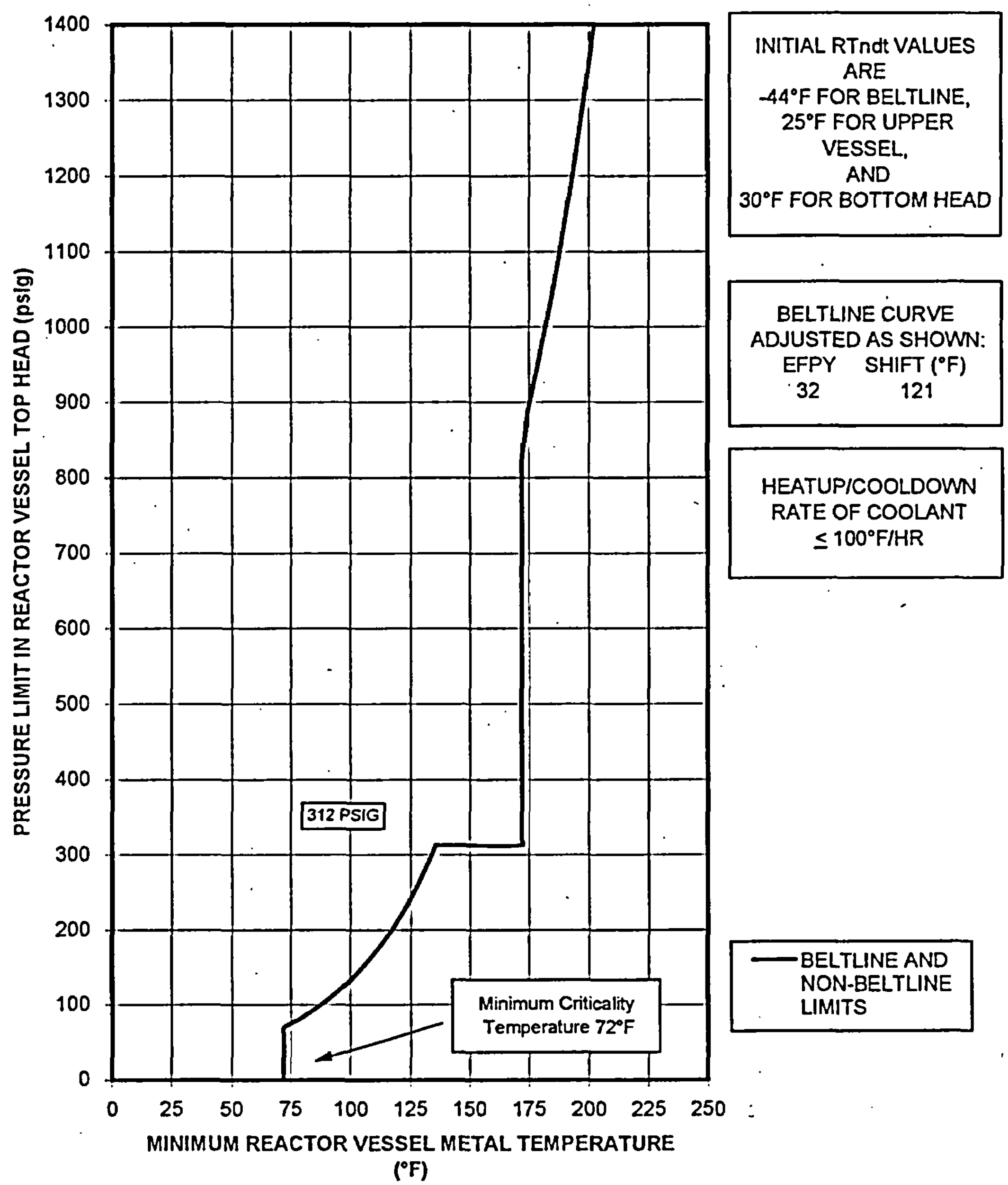

Figure 5-14: Composite Core Critical P-T Curves [Curve C] up to 32 EFPY [100°F/hr or less coolant heatup/cooldown]

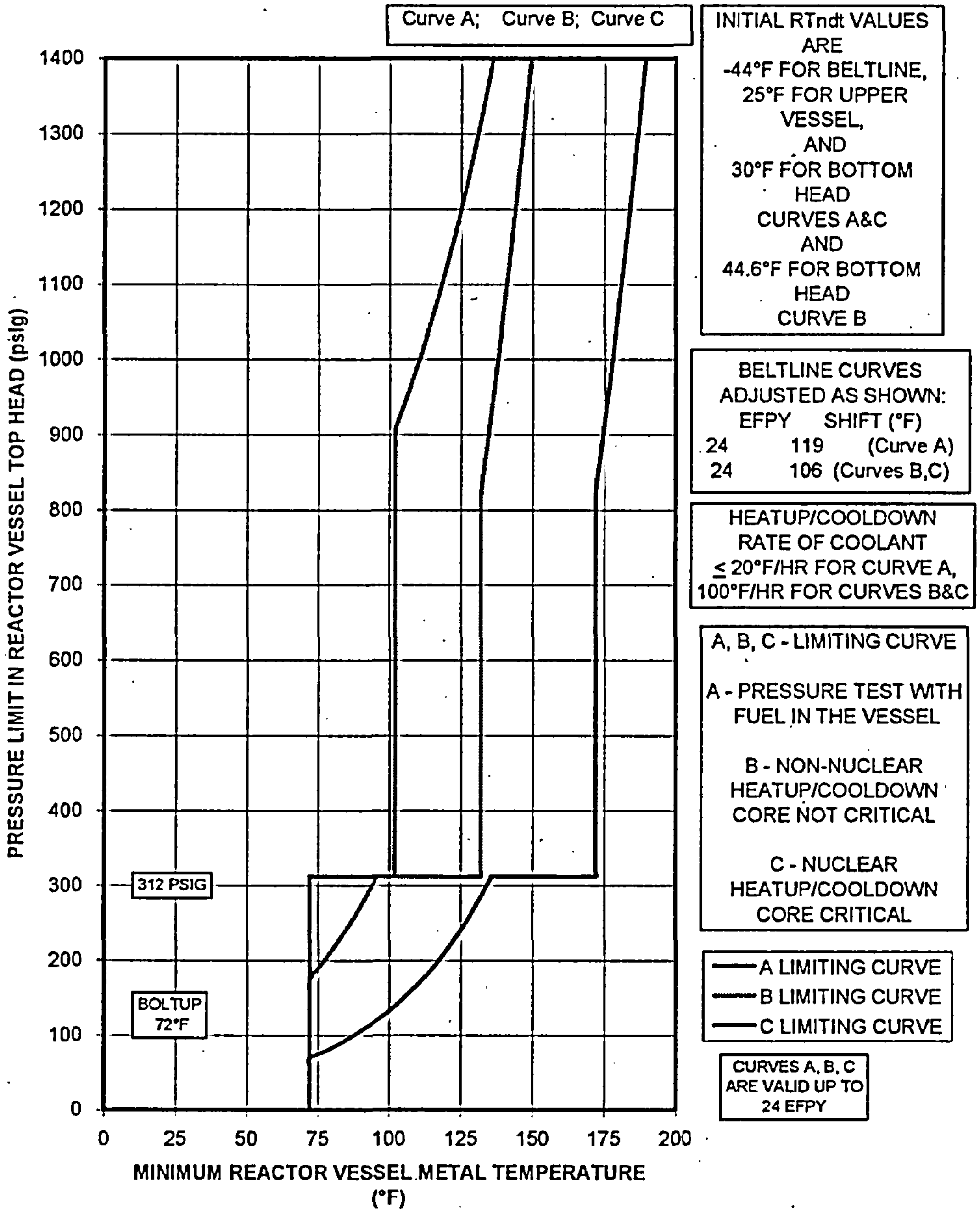

Figure 5-15: Limiting P-T Curves [Curves A, B, and C] up to 24 EFPY [20°F/hr or less coolant heatup/cooldown for Curve A and 100°F/hr or less coolant heatup/cooldown for Curves B and C]

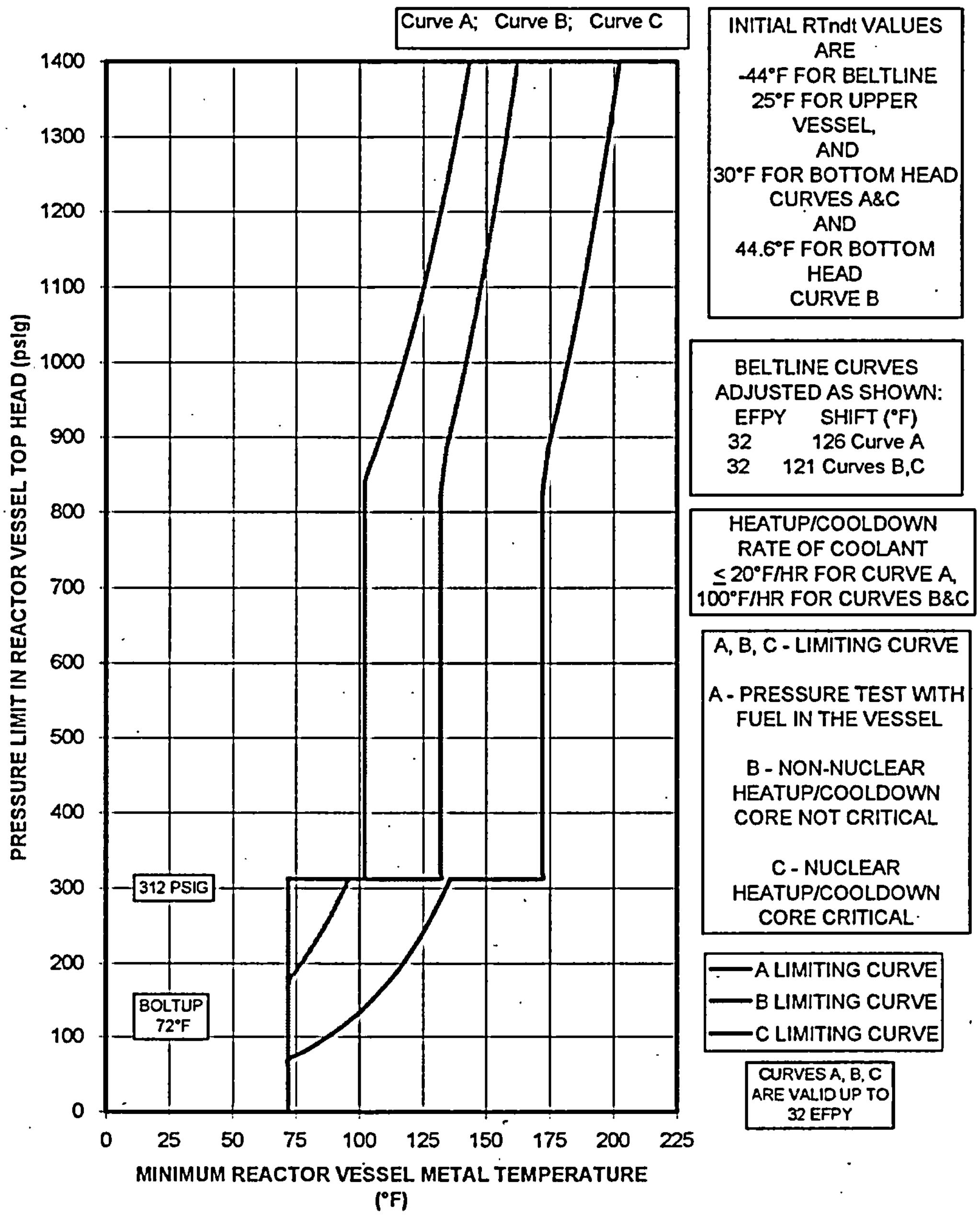

Figure 5-16: Limiting P-T Curves [Curves A, B, and C] up to 32 EFPY [20°F/hr or less coolant heatup/cooldown for Curve A and 100°F/hr or less coolant heatup/cooldown for Curves B and C]

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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.

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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.

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16. [[

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

18. [[

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19. Bottom Head and Feedwater Nozzle Dimensions:
    a. Drawing Number E232-900, Revision 5, "Bottom Head Machining and Welding", Combustion Engineering, Chattanooga, Tennessee (VPF # 1976-014).
    b. Drawing Number E232-910, Revision 8, "Nozzle Details", Combustion Engineering, Chattanooga, Tennessee (VPF # 1976-064).

20. [[

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

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
MK 321-05 High Pressure Seal Leak Detector Nozzle (attached to Shell Flange)	SA 106 Gr B	1, 27	Nozzles less than 2.5" require no fracture toughness evaluation.
MK 315-04 Core ΔP and Liquid Control Nozzle (See Table A-1 for Penetration in the Bottom Head Dollar Plate)	Inconel	1, 8, 20	Nozzles made from Inconel require no fracture toughness evaluation.
MK 315-01 Instrumentation Nozzles	SA 508 CL 1	1, 20, 28	Nozzles less than 2.5" in thickness require no fracture toughness evaluation.
MK 315-14 Drain Nozzle	SA 508 CL 1	1, 8, 20	Nozzles less than 2.5" in thickness require no fracture toughness evaluation.
MK 327-01 Shroud Support	SB-166 Inconel	1, 23, 29	Components made from Inconel require no fracture toughness evaluation.
MK 324-03 Basin Seal Skirt	SA 515 GR 70	1, 26	Not a pressure boundary component; therefore requires no fracture toughness evaluation.
MK 325-02 and 325-03 Thermocouple Pad	A 36 Carbon Steel	1,30, 31	Not a pressure boundary component; therefore requires no fracture toughness evaluation.
MK 310-02 through 310-29 CRD Stub Tubes (in Bottom Head Dollar Plate and Lower Torus)	SB-167 Alloy 600	1, 22, 23, 24	Components made from Alloy 600 and less than 2.5" require no fracture toughness evaluation.
MK 323-10 and 323-11 Surveillance Brackets	SA351 Gr CF8M	1, 32, 33	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
MK 323-06 Core Spray Brackets	SA351 Gr CF8M	1, 32, 33	Appurtenances made from Stainless Steel require no fracture toughness evaluation.
MK 323-07 Feedwater Sparger Brackets	SA351 Gr CF8M	1, 32, 33	Appurtenances made from Stainless Steel require no fracture toughness evaluation.
MK 323-05 Steam Dryer Support Lug	SA351 Gr CF8M	1, 32, 33	Appurtenances made from Stainless Steel require no fracture toughness evaluation.
MK 323-02 Guide Rod Bracket	SA351 Gr CF8M	1, 32	Appurtenances made from Stainless Steel require no fracture toughness evaluation
MK 319-06 Top Head Lifting Lugs	SA 533 Gr B CL 1	1, 5, 6, 17	Loading only occurs during outages. Not a pressure boundary component; therefore requires no fracture toughness evaluation.
MK 319-15 Steam Dryer Hold Down Bracket	SA 533 Gr B CL 1	1, 5	Not a pressure boundary component; therefore requires no fracture toughness evaluation.
Upjohn Welds	N/A	N/A	Upjohn welds do not require fracture toughness evaluation. It is, however, noted that any Upjohn welds within the beltline region are covered by the beltline curves.

APPENDIX A REFERENCES:

1. Vessel Drawings

- Drawing Number B-230-481, Revision 5, "Drawing Plan List", Combustion Engineering, Inc., Windsor, Conn. (VPF # 1976-087).
- Drawing Number E232-895, Revision 4, "General Arrangement Elevation for 251" ID BWR", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF # 1976-077).
- Drawing Number E232-907, Revision 4, "Vessel Assembly ", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF # 1976-069).
- Drawing Number E232-901, Revision 11, "Lower Vessel Shell Assembly – Machining & Welding", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF # 1976-11).
- Drawing Number E232-902, Revision 16, "Upper Vessel Shell Assembly – Machining & Welding", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF # 1976-012).
- Drawing Number E232-926, Revision 6, "As-Built Dimensions for 251" ID BWR", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF # 1976-109).
- Drawing Number E233-308, Revision 3, "As-Built Dimensions for 251" ID BWR", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF # 1976-212).
- Drawing Number E232-925, Revision 2, "Material Identification", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF # 1976-080).
- QA Records and RPV CMTRs for Fermi 2, GE PO Number 205-H0399, Contract Number 2667, Manufactured by Combustion Engineering, Inc., Chattanooga, Tenn.

2. Letter Number PFIP-04-0207/0801.26, J. Vargas (Detroit Edison) to G. Carlisle (GE), "Retransmittal of Design Input Request Response for WIN 8 Pressure Temperature Curves", October 21, 2004.

3. Wu, T., "DTE Energy Fermi-2 Energy Center Neutron Flux Evaluation", GE-NE-0000-0031-6254-R1, Revision 1, GE Nuclear Energy, San Jose, CA, February 2005 (GE Proprietary).

4. Drawing Number SC-2667-1, Revision 0, "Closure Head Flange Ordering Sketch", Combustion Engineering, Inc., Windsor, Conn. (VPF # 1976-002).

5. Drawing Number E232-913, Revision 4, "Closure Head Machining & Welding", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF # 1976-078).

6. Drawing Number E232-914, Revision 5, "Closure Head Final Machining", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-079).

7. Drawing Number SC-2667-2, Revision 0, "Vessel Flange Ordering Sketch", Combustion Engineering, Inc., Windsor, Conn. (VPF # 1976-003).

8. Drawing Number E232-900, Revision 5, "Bottom Head Machining and Welding", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-014).

9. Drawing Number C-200-061-2-F, Revision B, "Recirculation Outlet Nozzle", Ladish Company, Cudahy, Wisconsin (VPF #1976-067).

10. Drawing Number C-200-061-2, Revision 3, "Recirculation Outlet Nozzle", Combustion Engineering, Inc., Windsor, Conn. (VPF #1976-022).

11. Drawing Number E232-908, Revision 3, "Nozzle Details", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-050).

12. Drawing Number B-245-201, Revision 1, "Recirculation Inlet Nozzle", Combustion Engineering, Inc., Windsor, Conn. (VPF #1976-021).

13. Drawing Number E232-910, Revision 8, "Nozzle Details", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-064).

14. Drawing Number B-245-205, Revision 0, "Core Spray Nozzle", Combustion Engineering, Inc., Windsor, Conn. (VPF #1976-052).

15. Drawing Number E232-912, Revision 3, "Closure Head Nozzle Details", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-117).

16. Drawing Number E232-834, Revision 1, "As Built Location of Weld Seams – Closure Head", Combustion Engineering, Inc., Windsor, Conn. (VPF #1976-259).

17. Drawing Number E232-896, Revision 2, "General Arrangement Plans", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-075).

18. Drawing Number SB-2667-36, Revision 0, "Vent Nozzle Forging", Combustion Engineering, Inc., Windsor, Conn. (VPF #1976-128).

19. Drawing Number B-245-200, Revision 0, "Jet Pump Instrumentation Nozzle", Combustion Engineering, Inc., Windsor, Conn. (VPF #1976-020).

20. Drawing Number E232-909, Revision 7, "Nozzle Details", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-051).

21. Drawing Number B-245-204, Revision 1, "C.R.D. Hyd. System Return Nozzle", Combustion Engineering, Inc., Windsor, Conn. (VPF #1976-049).

22. Drawing Number E232-904, Revision 4, "Bottom Head Penetrations", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-066).

23. Drawing Number E232-905, Revision 7, "Vessel Machining", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-081).

24. Drawing Number E232-927, Revision 2, "As Built Dimensions Bottom Head Penetrations", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-108).

25. Drawing Number E232-903, Revision 7, "Vessel Support Skirt Assy and Details", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-065).

26. Drawing Number E232-918, Revision 4, "Vessel External Attachments", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-111).

27. Drawing Number E232-915, Revision 2, "Miscellaneous Details", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-082).

28. Drawing Number SB-2667-37, Revision 0, "Instrumentation Nozzle Forging", Combustion Engineering, Inc., Windsor, Conn. (VPF #1976-129).

29. Drawing Number E232-921, Revision 5, "Shroud Support Details and Assembly", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-083).

30. Drawing Number E232-919, Revision 7, "Vessel External Attachments", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-107).

31. Drawing Number E233-309, Revision 3, "Thermocouple Arrangement – Upper Vessel", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-219).

32. Drawing Number E232-917, Revision 8, "Vessel Internal Attachments", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-103).

33. Drawing Number E233-305, Revision 1, "Internal Bracket Removal and Replacement", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF #1976-215).

Note: As-built drawings for the top head flange and vessel flange are not available. Design sketches in References 4 and 7 have been used in lieu of the as-built drawings.

APPENDIX B

PRESSURE TEMPERATURE CURVE DATA TABULATION

TABLE B-1. Fermi Unit 2 P-T Curve Values for 24 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)	24 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	24 EFPY BELTLINE CURVE B (°F)
0	68.0	72.0	72.0	68.0	72.0	72.0
10	68.0	72.0	72.0	68.0	72.0	72.0
20	68.0	72.0	72.0	68.0	72.0	72.0
30	68.0	72.0	72.0	68.0	72.0	72.0
40	68.0	72.0	72.0	68.0	72.0	72.0
50	68.0	72.0	72.0	68.0	72.0	72.0
60	68.0	72.0	72.0	68.0	72.0	72.0
70	68.0	72.0	72.0	68.0	72.0	72.0
80	68.0	72.0	72.0	68.0	72.0	72.0
90	68.0	72.0	72.0	68.0	72.0	72.0
100	68.0	72.0	72.0	68.0	72.0	72.0
110	68.0	72.0	72.0	68.0	72.0	72.0
120	68.0	72.0	72.0	68.0	72.0	72.0
130	68.0	72.0	72.0	68.0	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
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

TABLE B-1. Fermi Unit 2 P-T Curve Values for 24 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)	24 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	24 EFPY BELTLINE CURVE B (°F)
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
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

TABLE B-1. Fermi Unit 2 P-T Curve Values for 24 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)	24 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	24 EFPY BELTLINE CURVE B (°F)
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
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

TABLE B-1. Fermi Unit 2 P-T Curve Values for 24 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)	24 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	24 EFPY BELTLINE CURVE B (°F)
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
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

TABLE B-1. Fermi Unit 2 P-T Curve Values for 24 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)	24 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	24 EFPY BELTLINE CURVE B (°F)
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
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

TABLE B-1. Fermi Unit 2 P-T Curve Values for 24 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)	24 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	24 EFPY BELTLINE CURVE B (°F)
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
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. Fermi Unit 2 Composite P-T Curve Values for 24 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 & 5-15

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 24 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 24 EFPY CURVE B (°F)	LIMITING 24 EFPY CURVE C (°F)
0	68.0	72.0	68.0	72.0	72.0
10	68.0	72.0	68.0	72.0	72.0
20	68.0	72.0	68.0	72.0	72.0
30	68.0	72.0	68.0	72.0	72.0
40	68.0	72.0	68.0	72.0	72.0
50	68.0	72.0	68.0	72.0	72.0
60	68.0	72.0	68.0	72.0	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
210	68.0	72.0	68.0	79.3	119.3
220	68.0	72.0	68.0	81.3	121.3

TABLE B-2. Fermi Unit 2 Composite P-T Curve Values for 24 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 & 5-15

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 24 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 24 EFPY CURVE B (°F)	LIMITING 24 EFPY CURVE C (°F)
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
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

TABLE B-2. Fermi Unit 2 Composite P-T Curve Values for 24 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 & 5-15

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 24 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 24 EFPY CURVE B (°F)	LIMITING 24 EFPY CURVE C (°F)
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
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

TABLE B-2. Fermi Unit 2 Composite P-T Curve Values for 24 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 & 5-15

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 24 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 24 EFPY CURVE B (°F)	LIMITING 24 EFPY CURVE C (°F)
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
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

TABLE B-2. Fermi Unit 2 Composite P-T Curve Values for 24 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 & 5-15

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 24 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 24 EFPY CURVE B (°F)	LIMITING 24 EFPY CURVE C (°F)
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
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

TABLE B-2. Fermi Unit 2 Composite P-T Curve Values for 24 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 & 5-15

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 24 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 24 EFPY CURVE B (°F)	LIMITING 24 EFPY CURVE C (°F)
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
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. Fermi Unit 2 P-T Curve Values for 32 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)	32 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	32 EFPY BELTLINE CURVE B (°F)
0	68.0	72.0	72.0	68.0	72.0	72.0
10	68.0	72.0	72.0	68.0	72.0	72.0
20	68.0	72.0	72.0	68.0	72.0	72.0
30	68.0	72.0	72.0	68.0	72.0	72.0
40	68.0	72.0	72.0	68.0	72.0	72.0
50	68.0	72.0	72.0	68.0	72.0	72.0
60	68.0	72.0	72.0	68.0	72.0	72.0
70	68.0	72.0	72.0	68.0	72.0	72.0
80	68.0	72.0	72.0	68.0	72.0	72.0
90	68.0	72.0	72.0	68.0	72.0	72.0
100	68.0	72.0	72.0	68.0	72.0	72.0
110	68.0	72.0	72.0	68.0	72.0	72.0
120	68.0	72.0	72.0	68.0	72.0	72.0
130	68.0	72.0	72.0	68.0	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
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

TABLE B-3. Fermi Unit 2 P-T Curve Values for 32 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)	32 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	32 EFPY BELTLINE CURVE B (°F)
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
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

TABLE B-3. Fermi Unit 2 P-T Curve Values for 32 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)	32 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	32 EFPY BELTLINE CURVE B (°F)
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
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

TABLE B-3. Fermi Unit 2 P-T Curve Values for 32 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)	32 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	32 EFPY BELTLINE CURVE B (°F)
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
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

TABLE B-3. Fermi Unit 2 P-T Curve Values for 32 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)	32 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	32 EFPY BELTLINE CURVE B (°F)
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
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

TABLE B-3. Fermi Unit 2 P-T Curve Values for 32 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)	32 EFPY BELTLINE CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER VESSEL CURVE B (°F)	32 EFPY BELTLINE CURVE B (°F)
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
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. Fermi Unit 2 Composite P-T Curve Values for 32 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 & 5-16

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE B (°F)	LIMITING 32 EFPY CURVE C (°F)
0	68.0	72.0	68.0	72.0	72.0
10	68.0	72.0	68.0	72.0	72.0
20	68.0	72.0	68.0	72.0	72.0
30	68.0	72.0	68.0	72.0	72.0
40	68.0	72.0	68.0	72.0	72.0
50	68.0	72.0	68.0	72.0	72.0
60	68.0	72.0	68.0	72.0	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
210	68.0	72.0	68.0	79.3	119.3
220	68.0	72.0	68.0	81.3	121.3

TABLE B-4. Fermi Unit 2 Composite P-T Curve Values for 32 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 & 5-16

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE B (°F)	LIMITING 32 EFPY CURVE C (°F)
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
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

TABLE B-4. Fermi Unit 2 Composite P-T Curve Values for 32 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 & 5-16

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE B (°F)	LIMITING 32 EFPY CURVE C (°F)
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
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

TABLE B-4. Fermi Unit 2 Composite P-T Curve Values for 32 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 & 5-16

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE B (°F)	LIMITING 32 EFPY CURVE C (°F)
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
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

TABLE B-4. Fermi Unit 2 Composite P-T Curve Values for 32 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 & 5-16

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE B (°F)	LIMITING 32 EFPY CURVE C (°F)
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
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

TABLE B-4. Fermi Unit 2 Composite P-T Curve Values for 32 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 & 5-16

PRESSURE (PSIG)	BOTTOM HEAD CURVE A (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE A (°F)	BOTTOM HEAD CURVE B (°F)	UPPER RPV & BELTLINE AT 32 EFPY CURVE B (°F)	LIMITING 32 EFPY CURVE C (°F)
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
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

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 nozzles are located where the peak neutron fluence is expected to exceed or equal 1.0e17 n/cm^2, then it can be concluded that all reactor vessel nozzles are outside the beltline region of the reactor vessel, and do not need to be considered in the P-T curve evaluation.

The following dimensions are obtained from the referenced drawings and are specified as the distance above vessel "0":

Shell # 2 - Top of Active Fuel (TAF)*	366.3" [1,2]
Shell # 1 - Bottom of Active Fuel (BAF)	216.3" [1,2]
Shell # 2 – Top of Extended Beltline Region	374.7" [2]
Shell # 1 – Bottom of Extended Beltline Region	210.5" [2]
Centerline of Recirculation Outlet Nozzle in Shell # 1	161.5" [3,4]
Top of Recirculation Outlet Nozzle N1 in Shell # 1	193.7" [3,4]
Centerline of Recirculation Inlet Nozzle N2 in Shell # 1	181.0" [3,4]
Top of Recirculation Inlet Nozzle N2 in Shell # 1	197.5" [3,4]
Centerline of 2" Instrumentation Nozzle in Shell # 2	366.0" [4,5]

From [4], 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). As shown in [4], the 2" Instrumentation Nozzle (MK 315-01) is contained within the core beltline region;

however, this nozzle has a thickness less than 2.5" and, as noted in Table A-2, requires no fracture toughness. 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 Tables 4-5 and 4-6, are outside the beltline region of the reactor vessel.

Based on the axial fluence profile, the RPV fluence at 32 EFPY drops to less than 1.0e17 n/cm^2 at ~6" below the BAF and at ~9" above TAF [2]. 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 32 EFPY.

Based on the above, it is concluded that none of the Fermi Unit 2 reactor vessel plates, nozzles, or welds, other than those included in Tables 4-5 and 4-6, are in the beltline region.

APPENDIX E REFERENCES:

1. Letter Number PFIP-04-0207/0801.26, J. Vargas (Detroit Edison) to G. Carlisle (GE), "Retransmittal of Design Input Request Response for WIN 8 Pressure Temperature Curves", October 21, 2004.
2. Wu, T., "DTE Energy Fermi-2 Energy Center Neutron Flux Evaluation", GE-NE-0000-0031-6254-R1, Revision 1, GE Nuclear Energy, San Jose, CA, February 2005 (GE Proprietary).
3. Drawing Number E232-908, Revision 3, "Nozzle Details", Combustion Engineering, Inc., Chattanooga, Tennessee (VPF #1976-050).
4. Drawing Number E232-895, Revision 4, "General Arrangement Elevation", Combustion Engineering, Inc., Chattanooga, Tennessee (VPF #1976-077).
5. Drawing Number E232-909, Revision 7, "Nozzle Details", Combustion Engineering, Inc., Chattanooga, Tennessee (VPF #1976-051).

APPENDIX F

UPPER SHELF ENERGY (USE)

Paragraph IV.B of 10CFR50 Appendix G [1] sets limits on the upper shelf energy of the beltline materials. The USE must remain above 50 ft-lb at all times during plant operation, assumed here to be 32 EFPY. Calculations of 32 EFPY USE, using Regulatory Guide 1.99, Revision 2 (RG1.99) [2] methods are summarized in Table F-1. A RG1.99 analysis is also provided for the weld materials where Position 2.2 is applied.

Surveillance capsules from the Fermi Unit 2 vessel have not been removed and tested. Fermi Unit 2 has committed to participate in the BWRVIP Integrated Surveillance Program (ISP), and surveillance capsule data that is representative of the weld material in this vessel is available from the ISP [3]. Test results for the weld materials from [3] were applied to the USE evaluation as seen in Table F-1.

When Fermi Unit 2 initially reported unirradiated USE values for weld heat 13253, 12008 1092 Lot 3833, insufficient test results were available and a conservative value of 62 ft-lbs was used. The 62 ft-lb value represents the lowest Charpy test result greater than 50 ft-lbs from the material certification report. The ISP has determined that the heat of material tested and designated as CE-2(WM) is the same heat of material. Sufficient unirradiated test data exists for this heat of material; the initial USE has been determined to be 119.3 ft-lbs, and this value is used in the USE evaluation for Fermi Unit 2.

The ISP test results for the weld material heat 13253, 12008 1092 Lot 3833 demonstrate that the measured % decrease in USE exceeds the RG1.99 predicted % decrease. In order to assure that the weld materials meet all RG1.99 requirements for end of license USE, Position 2.2 was applied to all beltline weld materials. Table F-2 provides the detailed information regarding the ISP test results.

Based on the results presented in Table F-1, the USE values for the Fermi Unit 2 reactor vessel beltline materials remain within the limits of RG1.99 and 10CFR50 Appendix G for 32 EFPY of operation.

Table F-1

Upper Shelf Energy Evaluation for Fermi Unit 2 at 32 EFPY

Material	Heat or Heat/Lot	Initial Longitudinal USE (ft-lb)	Initial Transverse USE(1) (ft-lb)	%Cu	32 EFPY 1/4T Fluence (n/cm^2)	% Decrease USE(2)	32 EFPY Transverse USE(3) (ft-lb)
Plates:							
Lower Shell							
G3706-1	C4540-2	145	94.3	0.08	4.06E+17	8	87
G3706-2	C4560-1	156	101.4	0.11	4.06E+17	10	91
G3706-3	C4554-1	132	85.8	0.12	4.06E+17	10.5	77
Lower-Intermediate Shell							
G3703-5	C4564-1	115	74.8	0.09	6.70E+17	9.5	68
G3705-1	B8614-1	130	84.5	0.12	6.70E+17	11.5	75
G3705-2	C4574-2	120	78.0	0.10	6.70E+17	10.5	70
G3705-3	C4568-2	119	77.4	0.12	6.70E+17	11.5	68
Welds:							
Vertical							
Lower Shell							
2-307 A,B,C	Tandem 13253, 12008 1092 Lot 3833	N/A	119	0.26	4.06E+17	19.5	96
2-307 A,B,C(4)	Tandem 13253, 12008 1092 Lot 3833	N/A	119	0.26	4.06E+17	32	81
Lower-Intermediate Shell							
15-308 A,B,C,D	33A277, 124 Lot 3878	N/A	94	0.32	6.70E+17	25	71
15-308 A,B,C,D(4)	33A277, 124 Lot 3878	N/A	94	0.32	6.70E+17	36	60
Girth							
1-313	10137, 0091 Lot 3999	N/A	108	0.23	4.06E+17	18	89
1-313(4)	10137, 0091 Lot 3999	N/A	108	0.23	4.06E+17	32	73

Notes:
1. Transverse USE for plate materials obtained using 65% of the longitudinal USE.
2. USE Decrease obtained from RG1.99 Figure 2.
3. 32 EFPY Transverse USE = Initial Transverse USE * [1 - (% Decrease USE /100)].
4. RG1.99 Position 2.2 applied to the weld materials.

Table F-2

Detailed ISP Test Results for Weld Heat 13253,12008 1092 Lot 3833 [3]

ISP Surveillance Weld USE [Heat CE-2(WM)(13253,12008)]:

%Cu	=	0.21	
Unirradiated USE	=	119.3 ft-lb	
SSP Capsule E Measured USE	=	67.7 ft-lb	
SSP Capsule E Fluence	=	1.76E+18 n/cm^2	
SSP Capsule G Measured USE	=	70.1 ft-lb	
SSP Capsule G Fluence	=	1.87E+18 n/cm^2	
SSP Capsule E Measured % Decrease	=	43.3	(Charpy Curves)
SSP Capsule E RG 1.99 Predicted % Decrease	=	23.6	(RG 1.99, Rev. 2, Figure 2)
SSP Capsule G Measured % Decrease	=	41.2	(Charpy Curves)
SSP Capsule G RG 1.99 Predicted % Decrease	=	23.9	(RG 1.99, Rev. 2, Figure 2)

APPENDIX F REFERENCES:

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

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

3. Letter Number PFIP-04-0207/0801.26, J. Vargas (Detroit Edison) to G. Carlisle (GE), "Retransmittal of Design Input Request Response for WIN 8 Pressure Temperature Curves", October 21, 2004.

APPENDIX G

THICKNESS TRANSITION DISCONTINUITY EVALUATION

G.1 OBJECTIVE

The purpose of the following evaluation is to determine the hydrotest, heat-up/cool-down, and transient temperatures (T) for the shell thickness transition discontinuities in the beltline, the bottom head upper to lower torus, and the bottom head to lower shell, 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 Fermi Unit 2 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 region and the bottom head. 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]. Similarly, the bottom head upper torus to lower shell is modeled as a transition from 3.4375 inches minimum thickness to 7.125 inches minimum thickness, respectively [1, 2].

Four (4) load cases defined on the Fermi Unit 2 vessel thermal cycle diagram [3] were evaluated for the beltline and bottom head shell discontinuity:

1) hydrostatic test pressure at 1055 psig,
2) cool-down 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 heat-up 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-ft2 °F [4] and that the ambient temperature is 100°F.

These are the bounding beltline transients of those described in Region B of the Fermi Unit 2 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 this report, 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 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 4-6 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.

The Control Rod Drive Penetrations in the bottom head were 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 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, bottom head to lower shell, 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, bottom head to lower 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 stress 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, $K_{Im} = M_m{}^*\sigma_m$ and $K_{Ib} = M_b{}^*\sigma_b$. The values of M_m and M_b were determined from the ASME Code Appendix G [6]. The stress intensity is based on a 1/4 T radial flaw with a six-to-one aspect ratio (length of 1.5T). The flaw is oriented normal to the maximum stress direction, in this case a vertically oriented flaw since the hoop stress was limiting.

The calculated value of $K_{Im} + K_{Ib}$ is multiplied by a safety factor (SF) (1.5 for pressure test and 2.0 for the transient cases), per ASME Appendix G [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$^{0.5}$):

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

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

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

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

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, heat-up, cool-down, 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 to Lower Shell

Thin Section Thickness: t_{min} = 3.438 inches

$\sqrt{(t)}$ = 1.85 $inch^{0.5}$

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 $inch^{0.5}$

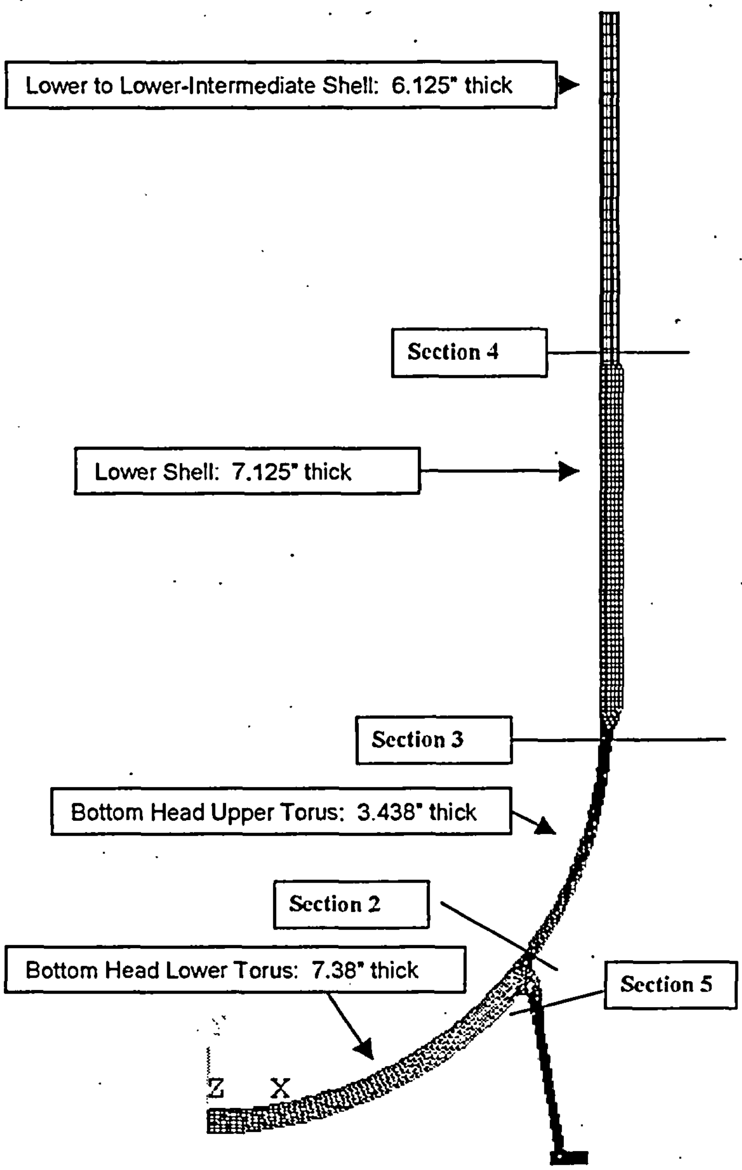

Figure G-1: Location and Wall Thickness of Evaluation Discontinuities in the Beltline and Bottom Head Regions

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	3	Inside	22350	-2892	1.85	41348	1.23	-3567	56.67	6.20
1000	3	Outside	22350	2892	1.85	41348	1.23	3567	67.37	24.98
1055	3	Inside	23579	-3051	1.85	43622	1.23	-3763	59.79	12.43
1055	3	Outside	23579	3051	1.85	43622	1.23	3763	71.08	30.13
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 to lower shell and bottom head torus (Figure 5-1) and beltline shell (Figure 5-4) discontinuities.

Beltline

The maximum Fermi Unit 2 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 4-6) at 32 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 4-6) at 32 EFPY, resulting in T = 76.44°F.

At 1055 psig, representing the 32 EFPY Fermi Unit 2 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 32 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 24 EFPY is the beltline weld at 62°F (see Table 4-5), resulting in T = 93.44°F. At 1055 psig, the "T" for the 24 EFPY beltline region Curve A is 102°F. Because the 24 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 to Lower Shell

The maximum T - RT_{NDT} calculated with the Finite Element Analysis results for the bottom head to lower shell region is 30.13°F, as shown for Section 3 (see Figure G-1 for location of this section) in Table G-2. The maximum RT_{NDT} for the bottom head to lower shell is -10°F for the plates (see Table 4-1) and welds (see Table 4-3). Thus a value of T = 20.13°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 = 20.13°F, obtained using the linearized stresses from the FEA analysis.

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 4-1) and –50°F for the welds (see Table 4-3). 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	3	Inside	23027	-3051	-461	-3568	1.85	1.23	38837	-5253	72422	31.87
Heatup	3	Outside	23027	3051	-461	3568	1.85	1.23	46363	3548	96274	**55.63**
Cooldown	3	Inside	23027	-3051	-8	9153	1.85	1.23	38837	11274	88949	49.45
Cooldown	3	Outside	23027	3051	-8	-9072	1.85	1.23	46363	-11203	81523	42.31
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
[[ ]]	3	Inside	23027	-3051	19	-36410	1.85	1.23	38837	-44870	32804	**80.67**
[[ ]]	3	Outside	23027	3051	19	36090	1.85	1.23	46363	44546	137273	58.15
[[ ]]	3	Inside	23027	-3051	-8	17740	1.85	1.23	38837	21865	99540	30.07
[[ ]]	3	Outside	23027	3051	-8	-17580	1.85	1.23	46363	-21696	71030	-
[[ ]]	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 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 to lower shell and 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 Fermi Unit 2 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 4-6) at 32 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 4-6) at 32 EFPY, resulting in T = 109.54°F.

At 1030 psig, the 32 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 24 EFPY is the beltline weld at 62°F (see Table 4-5), resulting in T = 126.54°F. At 1030 psig, the "T" for the 24 EFPY beltline region Curve B is 132°F. Because the 24 EFPY beltline region Curve B is greater than the "T" obtained by FEA, the thickness discontinuity remains bounded by the beltline curve.

Bottom Head to Lower Shell

The maximum Fermi Unit 2 plant-specific T - RT_{NDT} for the thickness discontinuity in the bottom head to lower shell region at 1030 psig is 80.67°F as shown for Section 3 (see

Figure G-1 for location of this section) in Tables G-4 and G-5. The maximum RT_{NDT} for this region is -10°F for the plates (see Table 4-1) and welds (see Table 4-3). This yields a maximum value of T = 70.67°F.

From Tables B-1 and B-3, the bottom head T (appropriate for this location) used in the analysis for Curve B is 119.6°F at 1030 psig. This value bounds the maximum value of T = 70.67°F, obtained using the linearized stresses from the FEA analysis.

Bottom Head Lower Torus to Upper Torus

The maximum Fermi Unit 2 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 4-1) and –50°F for the welds (see Table 4-3). 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, bottom head to lower shell, 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. Vessel Drawings
   a) Drawing Number E232-895, Rev. 4, "General Arrangement Elevation for 251" ID BWR", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF # 1976-077).
   b) Drawing Number E232-901, Rev. 11, "Lower Vessel Shell Assembly – Machining & Welding", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF # 1976-011).
   c) Drawing Number E232-902, Rev. 16, "Upper Vessel Shell Assembly – Machining & Welding", Combustion Engineering, Inc., Chattanooga, Tenn. (VPF # 1976-012).
2. Drawing Number E232-900, Rev. 5, "Bottom Head Machining and Welding", Combustion Engineering, Chattanooga, Tenn., (VPF # 1976-014).
3. GE Drawing Number 761E246, "Reactor Vessel Thermal Cycles – Reactor Vessel", GE-APED, San Jose, CA, Revision 1 (GE Proprietary Information).
4. "Reactor Vessel Purchase Specification Data Sheet", GE-APED, San Jose, CA, November 1971 (21A9242AC, Revision 3).
5. QA Records and RPV CMTRs for Fermi 2, GE PO Number 205-H0399, Contract Number 2667, Manufactured by Combustion Engineering, Inc., Chattanooga, Tenn.
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.

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 a 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 ¼ wall thickness semi-elliptical flaw with an aspect ratio of 6:1 (length to depth) be considered in the evaluation. When the bottom head specific geometry is considered in more detail the following items become evident:

[[

]]

Noting these items, the applicability of the methods suggested in Appendix G [[

]]. The ASME Code does not preclude using other methods; therefore, a

more detailed [[ ]] 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 ¼ thickness postulated flaw. [[

]]

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

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

]]

<u>Structural Boundary Conditions</u>

The modeled geometry is one-fourth of the Bottom Head hemisphere, so symmetry boundary conditions are used. [[
]] The mesh is shown in Figure 1.

[[

]]

Material Properties

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

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

[[

]]

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

Loads

Two loads cases were independently analyzed.

1. Pressure Loading –
An internal pressure of 1250 psi is applied to the interior of the vessel [[

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

]]

Figure 2. Pressure Loads

2. [[ ]] Thermal Transient
[[

]]

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

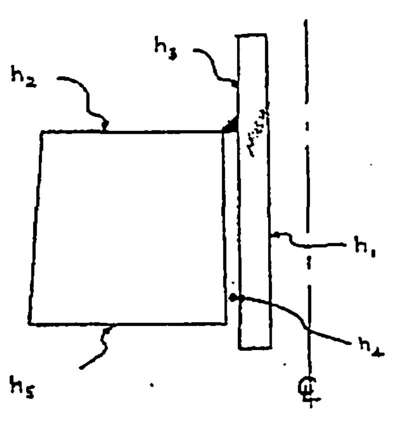

Figure 3. Regions To Which Thermal Loads Are Applied

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

b. Regions 2 and 3:

Time (min)	h_2	h_3	T
0	496	413	[[ ]]
[[ ]]	341	354	[[ ]]
[[ ]]	496	413	[[ ]]
[[ ]]	496	413	[[ ]]
[[ ]] Temperature Plot vs. Time (min.)			

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

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

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

Crack Configurations

The following four cracks were analyzed:

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

[[ ]]

The cracks considered for this analysis [[ ]]

[[

]]

[[

]]

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

[[

]]

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

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

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

[[

]]

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 $T\text{-}RT_{NDT}$. The Core Not Critical Bottom Head P-T curve $T\text{-}RT_{NDT}$ 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, 1998 Edition with Addenda to 2000.

2. ANSYS User's Manual, Version 6.1.

APPENDIX I

FRACTURE MECHANICS EVALUATION FOR

FLAW INDICATION 124

CONTAINED IN RPV LOWER-INTERMEDIATE SHELL

VERTICAL WELD 15-308B

Summary

The purpose of this appendix is to provide a summary of the results of the fracture mechanics evaluation performed to qualify flaw indication number 124 on the RPV lower-intermediate shell in vertical weld 15-308B. Analyses are performed to demonstrate the impact on the beltline curves for both 24 and 32 EFPY.

The indication dimensions used in this evaluation were obtained from [1]. Based on the results of this evaluation, it is concluded that continued operation in the as-is condition is justified for the 40-year (32 EFPY) design life of the RPV, including Extended Power Uprate (EPU). As this indication occurs within the beltline region of the RPV, fluence as defined in [2] is considered in order to account for irradiation effects.

Background

Combustion Engineering Company (CE) used the Upjohn welding technique to fabricate the longitudinal and meridional seams in a number of RPVs, including the Fermi 2 RPV. The Upjohn welding process allows fabrication of heavy plate sections without the use of positioning devices. With this welding technique, the major dimension of fabrication flaws extends through the weld thickness rather than parallel to the thickness as with other fabrication welding techniques. Other relevant details are:

- The initial inservice examination of the weld was performed in 1998. Fabrication RT was performed in 1970.
- The flaw being analyzed results from ASME Code required combination of two co-planar flaws, #123 and #124. In the 2003 ISI data, the flaw location is at 374.6 inches elevation above vessel '0', the flaw length (combined) is 2.0 inches, and the flaw depth (through-wall) is 4.24 inches.
- The initial (1998) inservice examination data was re-analyzed using the rules in effect in 2003. The area encompassed the location of the 2003 flaw. A flaw is present that corresponds with the 2003 flaw #124. The flaw elevation is 374.04 inches, the flaw length is 1.0 inch, and the flaw depth is 4.24 inches. The slight difference in elevation between the two examinations is attributable to a shift

in the weld '0' location. This is a low amplitude (<50% DAC) indication that did not require recording under the rules in effect in 1998. The indication would have been recorded and analyzed in 1998, had the current rules been in effect at that time.

- The flaw appears as an acceptable indication in the manufacturer's RT films. This confirms that it is a fabrication, rather than service-induced, flaw. Evaluation of preservice examination data is expected to provide further confirmation of this conclusion.

Indication Characterization

Figure 1 shows the GERIS data sheet that gives the through-wall dimension of the subject indication, along with its width and surface proximity information. The indication length (through-wall) is 4.24 inches and the width is 2.0 inches. The indication is 0.7 inches from the ID surface. The wall thickness at this location is 6.75 inches. Both the surface distance and the thickness include a clad thickness of 0.3125 inches. For the purposes of the fracture mechanics evaluation the indication was modeled as a planar indication with an elliptical shape and the plane of the indication perpendicular to the circumferential direction. Figure 2 shows the indication geometry used in the evaluation. The flaw characterization and surface proximity guidelines of Paragraph IWA-3300 of [3] were not used since the fracture mechanics evaluation results described later in this appendix modeled the exact flaw geometry and clearly showed that the indication is unlikely to become a surface flaw during future operation.

RPV Geometry, Material, and Loading Description

The vessel inside diameter is 251 inches at the clad surface and the base material thickness is 6.75 inches minus 0.3125 inches, or 6.44 inches. The leak test/operating pressure was taken as 1030 psig [1] and the leak test temperature as 120°F at this pressure as defined in Appendix B. The only other loading is the thermal gradient stress resulting from 100°F/hour heatup/cooldown during plant startup/shutdown. Upset and Emergency/Faulted condition events were considered as not limiting based upon [4].

The vessel material is SA-533, Gr B, Class 1. Since the indication is entirely located in the weld metal, the material fracture toughness properties of the weld were used in the fracture mechanics evaluation. The initial RT_{NDT} of the weld metal was determined to be –50°F as seen in Section 4 of this report. The indication is located at the upper limit of the beltline region, and there is consequently some effect from the attenuated fluence level at this location. There is a shift in the RT_{NDT} as a function of effective full power years (EFPY). The adjusted reference temperature (ART) at this location was determined to be –14°F based upon a fluence calculation for 32 EFPY that includes operation at EPU. Similarly, for 24 EFPY, the ART is –21°F.

Calculated Stresses

Stresses are the key inputs in the fracture mechanics evaluation. The circumferential stress due to internal pressure was calculated using the strength of materials formula ($\sigma = PD_i / 2t$). With the internal pressure, P, as 1030 psig, vessel inside diameter, D_i, as (251 + 2 * 0.3125) or 251.62 inches, and the thickness, t, as 6.44 inches, the circumferential stress, σ, was calculated as 20.1 ksi.

The thermal gradient stress for the 100°F/hour cooldown rate was calculated using a finite element model and a high heat transfer coefficient value, as 9.2 ksi at the vessel ID surface and –4.3 ksi at the OD surface. This stress was resolved into a membrane and a bending stress over the crack length for the purpose of fracture mechanics evaluation. It is conservative to consider only the cooldown rate since it produces a tensile stress at the ID surface.

A weld residual stress of 8 ksi with a cosine distribution through the thickness was assumed [5].

Fracture Mechanics Evaluation

The stress intensity factors at the end of the long and short axes for an elliptical flaw contained in a plate of infinite dimension are given in standard fracture mechanics handbooks such as [6] and [7]. The formulas in [7] cover both the membrane stress and bending stress loadings. However, due to the proximity of the indication to the ID surface, an increase in the calculated value of the stress intensity factor (K) is expected. This is called the "edge effect" due to surface proximity. A finite element analysis was conducted to determine the edge effect. Figure 3 shows a general view of the finite element model in which the indication is modeled. Figure 4 shows a close-up of the area where the indication is modeled. Crack tip elements were used at the periphery of the elliptical geometry representing the indication. Based on a comparison of the calculated value of K at the end away from the edge and that near the edge, the edge effect was determined to be 1.1. This means that the theoretical values of K based on the infinite plate geometry need to be multiplied by 1.1 to account for the surface proximity.

The K values were calculated for both the pressure stress and the thermal gradient stress. The K due to weld residual stress was determined to be 5 ksi-in$^{1/2}$ at the long end of the indication (location 'a' in Figure 2). K at the end of the short axis (location 'b' in Figure 2) was taken as zero since it is in the compressive region of the postulated residual stress.

The calculated values of K are shown in Table 1. A fatigue crack growth evaluation was also conducted using the largest value of calculated K (42.5 ksi-in$^{1/2}$) and assumed 390 cycles (equivalent to 15 cycles per EFPY for the remaining 21 EFPY in the 40-year license period). The calculated value of fatigue crack growth was 0.04 inches. This projected fatigue crack growth has insignificant effect on the calculated value of K. Therefore, the K values in Table 1 that were based on current indication dimensions were not recalculated.

Table 2 shows a comparison of calculated and allowable values of K for the leak test and the startup/shutdown conditions. It is seen that all of the calculated values of K (applied K) are less than the corresponding allowable values. The leak test condition is a more limiting case. Note that the allowable values of K are based upon location 'a' and are conservative for location 'b', which is farther from the ID surface and therefore sees a lower fluence.

Since the values of applied K at location 'a' are less than the allowable values, it is also concluded that the subject indication will not propagate and become a surface flaw during future operation.

Summary of Results

A fracture mechanics evaluation was conducted using techniques consistent with the philosophy of Section XI of the ASME Code. The indication was modeled with length equal to 4.24 inches (along the weld thickness direction) and width equal to 2 inches. The long end of the indication is located 0.7 inches from the ID surface, which includes a clad thickness of 0.3125 inches.

As demonstrated in Section 4.3.2.2.2 of this report, the hydrotest P-T curve is calculated, at 32 EFPY, to require a temperature of 116.8°F at 1055 psig; the corresponding temperature at 1030 psig is 114.9°F. For these conditions, the allowable value of K is 34.0 ksi-in$^{1/2}$ and does not bound the calculated value of K, which is 35.7 ksi-in$^{1/2}$. Therefore, the beltline hydrotest P-T curve must be shifted to the right in order to increase the allowable value of K, resulting in a calculated value of K that is bounded by the allowable value of K. For the 32 EFPY curve, an adjustment of 5°F was applied such that Curve A requires a temperature of 119.9°F at 1030 psig; similarly for 24 EFPY, an adjustment of 13°F was applied, resulting in a Curve A temperature of 112.9°F at 1030 psig.

Therefore, for the limiting leak test condition at both 24 and 32 EFPY, the highest calculated value of applied stress intensity factor, K, was 35.7 ksi-in$^{1/2}$ and the allowable value of K was calculated to be 35.9 ksi-in$^{1/2}$. Note that the allowable value of K was conservatively calculated for location 'a', and compared to the calculated value of K, which is maximum at location 'b'.

Because the calculated values of K are less than the allowable values of K, the indication is not expected to become a surface indication during future operation. Furthermore, the indication is acceptable in the as-is condition for operation over 32 EFPY/40 years including extended power uprate.

Appendix I References:

[1] Letter Number TMIS-04-0086/0801.26, MA Brooks (Detroit Edison) to K. Narayan (GE), "GE Design Input Request for Fermi RPV Flaw Handbook", June 14, 2004.

[2] T. Wu, "DTE Energy Fermi-2 Energy Center Neutron Flux Evaluation", GENE, San Jose, CA, (GE-NE-0000-0031-6254-R1, Revision 1, February 2005 (GE Proprietary Information).

[3] "Rules for Inservice Inspection of Nuclear Power Plants", Section XI of the ASME Boiler & Pressure Vessel Code, 1989 Edition.

[4] H.S. Mehta, et al, "10CFR50 Appendix G Equivalent Margin Analysis for Low Upper Shelf Energy in BWR/2 Through BWR/6 Vessels", GENE, San Jose, CA, (NEDO-32205A), February 1994 (GE Proprietary Information).

[5] "White Paper on Reactor Vessel Integrity Requirements for Level A and B Conditions", EPRI Report No. TR-100251, January 1993.

[6] H. Tada, et al, "The Stress Analysis of Cracks Handbook", Third Edition, 2000.

[7] DR Rooke and DJ Cartwright, "Compendium of Stress Intensity Factors", HMS Office (1976).

Table 1

Applied Stress Intensity Factor (K) Values

Plant Condition	K at Location 'a' ($ksi\text{-}in^{1/2}$)			K at Location 'b' ($ksi\text{-}in^{1/2}$)		
	Pressure + Thermal	Weld Residual	Total	Pressure + Thermal	Weld Residual	Total
Leak Test*	22.6	5.0	27.6	35.7	0.0	35.7
Startup/Shutdown	30.3	5.0	35.3	41.5	0.0	41.5

*No thermal gradient stress for leak test

Table 2

Comparison with Allowable Values

Plant Condition	Highest K, Applied ($ksi\text{-}in^{1/2}$)	ART at 32/24 EFPY (°F)	Temperature (°F)	Allowable K* ($ksi\text{-}in^{1/2}$)
Leak Test	35.7	-14 / -21	120	35.9
Startup/Shutdown	41.5	-14 / -21	Normal Operating Temperature	63.3

*Based on a safety factor of √10

Figure 1

GERIS 2000 Indication Evaluation Data Sheet for Weld 15-308B

GERIS 2000 Indication Evaluation Data Sheet

Project : Fermi Unit-2, 2003
Weld ID : 15-308B
Indication : 124

Summary No. : 09-05
Exam Data Sheet : 15-308B-04
Indication Data Sheet : 15-308B-013

Flaw Through Wall = 4.24
Flaw Length "l" = 2.0
Surface Separation "S" = 0.7

"T" nominal = 6.75
"T" measured = N/A
Clad "T" nominal = 0.3125

ASME Section XI, 1989 Edition, No Addenda
TABLE IWB-3510-1 for 6" to 12"

a/l	Surface %	Subsurface %	Surface %	Subsurface %
0.00	1.9	2.0	-	-
0.05	2.0	2.2	-	-
0.10	2.2	2.5	-	-
0.15	2.5	2.9	-	-
0.20	3.1	3.3	-	-
0.25	3.3	3.8	-	-
0.30	3.8	4.4	-	-
0.35	4.4	5.1	-	-
0.40	5.0	5.8	-	-
0.45	5.1	6.7	-	-
0.50	6.2	7.6	5.20	7.60 Y
			Allowed	Allowed
			5.20	1.08

a = 4.940
a/l value = 0.500
Y = 0.142

Flaw is Surface by Proximity

Allowed a/t = 5.20%
a/t = 73.19%

Flaw is unacceptable by Table IWB-3510-1.

Comments : Indication is real
Indications 123 and 124 are characterized as multiple planar flaws. The indication length and through wall dimensions are the combined dimensions

A review of the construction radiographs by Marc Brooks RT Level III confirmed the presence of an acceptable fabrication flaw correlating to this indication. This indication is [illegible] in accordance with [illegible]

Analyzed By: [illegible] Level: III Date: [illegible]

Reviewed By: [illegible] Level: III Date: 4-28-03

Fermi. Unit-2, 2003 Page 34 of 186

Figure 2

Idealized Flaw Geometry Used in the Analysis (Schematic)

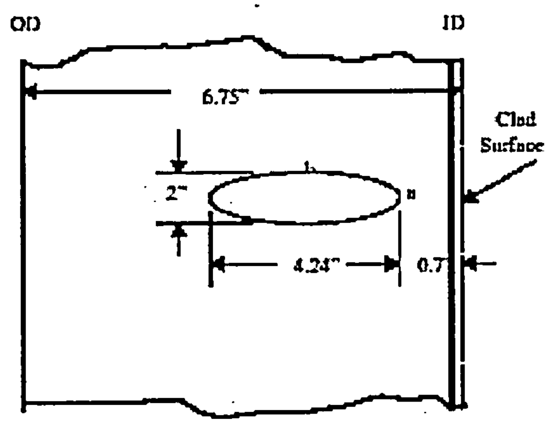

Figure 3

General View of Finite Element Model

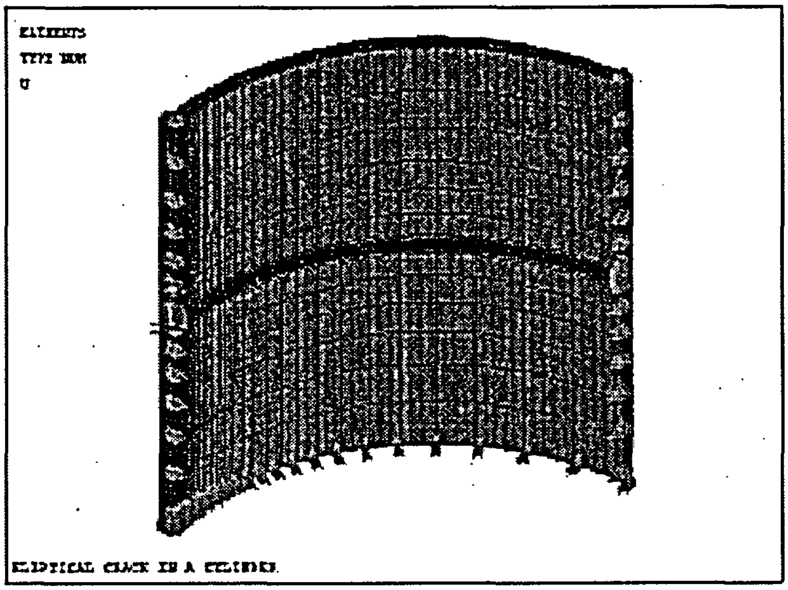

Figure 4

Close-up View of Finite Element Model