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February 23, 2001
BVY 01-14

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555

Subject: **Vermont Yankee Nuclear Power Station**
License No. DPR-28 (Docket No. 50-271)
Technical Specification Proposed Change No. 244
Response to Request for Additional Information

On December 19, 2000, Vermont Yankee (VY) submitted to the Staff a combined Proposed Change to the Technical Specifications and Exemption Request[1]. On February 2, 2001, the Staff submitted a Request for Additional Information[2]. The following is a re-statement of the question followed by our response. We trust that the information provided will facilitate completion of the Staff's review of our licensing action request.

P-T Limit Generation Methods

Question 1:

In Table 2 of Structural Integrity Associates' (SIA) Assessment No. SIR-00-155, Rev. 0, you list the following Initial RT_{NDT} values for the Vermont Yankee Nuclear Power Station (VYNPS) beltline materials:

Plate No. 1-14: Initial RT_{NDT} value of 30 °F
Plate No. 1-15: Initial RT_{NDT} value of -10 °F
Plate No. 1-16: Initial RT_{NDT} value of 0 °F
Plate No. 1-17: Initial RT_{NDT} value of 0 °F
Beltline Weld: Initial RT_{NDT} value of 0 °F

In contrast, both the NRC's Reactor Vessel Integrity Database and the Vermont Yankee Nuclear Power Corporation (VYNPC) submittal of September 24, 1993, list the Initial RT_{NDT} values for these materials as:

Plate No. 1-14: Initial RT_{NDT} value of 40 °F
Plate No. 1-15: Initial RT_{NDT} value of 30 °F

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[1] Reference Vermont Yankee Nuclear Power Corporation letter to the USNRC, BVY 00-113, "Technical Specification Proposed Change No. 244, Revised P/T Curves and Exemption Request to use Code Cases N-588 and N-640," dated December 19, 2000.

[2] Reference USNRC letter to Vermont Yankee Nuclear Power Corporation, NVY 01-09, "Vermont Yankee Nuclear Power Station – Request for Additional Information - Proposed Technical Specification Change No. 244, TAC Nos. MB0763 and MB0764," dated February 2, 2001.

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Plate No. 1-16: Initial RT_{NDT} value of 30 °F
Plate No. 1-17: Initial RT_{NDT} value of 30 °F
Beltline Weld: Initial RT_{NDT} value of -70 °F

Provide your technical bases for changing the initial RT_{NDT} data for the VY reactor pressure vessel (RPV) beltline materials, and reference any "docketed" documents (if any exist) that may support your bases for doing so.

Response to Question 1:

The basis for the VY initial RT_{NDT} data for pressure boundary components is documented in Structural Integrity Calculation VY-04Q-301. The charpy and drop weight test data used in this assessment was the same data that was used in BVY 93-107[3]. Structural Integrity concluded that VY was overly conservative in our previous assessment of the initial RT_{NDT} for the beltline basemetal materials. The revised beltline initial RT_{NDT} values are summarized below:

Plate No. 1-14: Initial RT_{NDT} value of 30°F
Plate No. 1-15: Initial RT_{NDT} value of -10°F
Plate No. 1-16: Initial RT_{NDT} value of 0°F
Plate No. 1-17: Initial RT_{NDT} value of 0°F
Beltline Weld: Initial RT_{NDT} value of -70°F

The initial weld RT_{NDT}, -70°F, is the same as the value provided in BVY 93-107. These values should be used to update the NRC's Reactor Vessel Integrity Data Base. The appropriate sections from VY-04Q-301 that support the basis for the beltline Initial RT_{NDT} values are provided as Attachment 1 to this letter.

Question 2:

In SIA Assessment No. SIR-00-155, Rev. 0, a limiting 1/4T ART_{NDT} value of 89 °F was used for P-T Limit Calculation Tables 6 and 8, and a limiting 3/4T ART_{NDT} value of 73 °F was used for P-T Limit Calculation Tables 5 and 7. Discuss your bases for selecting 89 °F and 73 °F as the conservative 1/4T and 3/4T ART_{NDT} values used for the generation of the P-T limit data in the Tables.

Response to Question 2:

The conservative 89°F at the 1/4T point and 73°F at the 3/4T point ART_{NDT} values were the same values used by VY in our previous P-T curve submittal, BVY 89-113[4].

In our BVY 89-113 submittal, the 89°F and 73°F ART_{NDT} values were calculated as follows:

ART_{NDT} = Initial RT_{NDT} + ΔRT_{NDT} + Margin

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[3] Reference Vermont Yankee Nuclear Power Corporation letter to the USNRC, BVY 93-107, "Response to Request for Additional Information, Generic letter 92-01 - Reactor Vessel Structural Integrity," dated September 24, 1993.

[4] Reference Vermont Yankee Nuclear Power Corporation letter to the USNRC, BVY 89-113, "Proposed Change to Revise the Reactor Vessel Pressure-Temperature Curves in Vermont Yankee Technical Specifications (Generic Letter 88-11)," dated November 10, 1989.

where;

1) Initial $RT_{NDT} = 40°F$

2) $\Delta RT_{NDT} = (\text{VY Factor})(\text{CF}) \cdot (f \times 10^{-19})^{(0.28 - 0.10 \cdot \log(f \times 10\text{^}(-19)))}$

'f' factor was based on $f = f_{surf} \times (e^{-0.24\,X})$,
$X_{1/4T}$=.25 x 5.06", inches
$X_{3/4T}$=.75 x 5.06", inches
$f_{surf} = 2.31 \times 10^{17}$ n/cm^2

'f' at 1/4T = 1.71×10^{17} n/cm^2
'f' at 3/4T = 9.30×10^{16} n/cm^2

CF = 74

VY Factor = 4.29 (from VY current Technical Specification Figure 3.6.2.)

3) Margin = 0 when the 'VY Factor' method is used.

The VY curve (current Technical Specification Figure 3.6.2) was submitted to the NRC in FVY 85-46[5]. This curve was fit through the first VY surveillance capsule data point.

In the SER for Figure 3.6.2 (NVY 86-121)[6] the NRC stated, "The measured shift is within one standard deviation of that calculated... Regulatory Guide 1.99, Revision 2 proposes that surveillance test results can be used after two capsules have been tested with reliable results. However, we consider the described method of using one data point from one capsule to be very conservative in this case and therefore acceptable."

While much lower ART_{NDT} values could be supported based on the revised RT_{NDT} values and guideline of Regulatory Guide 1.99 Revision 2, VY elected to maintain the very conservative ART_{NDT}'s to provide additional margin for beltline region shift due to fluence and shift uncertainty.

Question 3:

Appendix 5 to Welding Resource Council (WRC) Bulletin 175 provides an alternative basis for estimating the stress intensity factors for nozzles to pressure vessels. Provide the following plant-specific dimensional data relative to the design configuration documents for the N2 Recirculation and Feedwater nozzles to VYNPC RPV, as relative to the evaluation dimension criteria used in Appendix 5 of WRC Bulletin 175:

A. Thickness of the each nozzle in inches
B. Assumed nozzle crack size "a" for each nozzle, in inches
C. Apparent radius of the each nozzle (r_n value) in inches
D. Actual inner radius of each nozzle (r_i value) in inches
E. Nozzle corner radius (r_c value) for each nozzle in inches
F. RPV thickness and inner radius values, in inches, at the points were the nozzles are joined to the vessel.

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[5] Reference Vermont Yankee Nuclear Power Corporation letter to the USNRC, FVY 85-46, "Reactor Vessel Pressure/Temperature Curves," dated May 10, 1985.

[6] Reference USNRC letter to Vermont Yankee Nuclear Power Corporation, NVY 86-121, "Untitled," dated June 24, 1986.

Response to Question 3:

NRC Requested Data for the Recirc Inlet (N2) Nozzle				
A. Thickness of Nozzle	t_n	(inches)	7.06	overlay thickness not included
B. Assumed Crack Size Through Blend	a_f	(inches)	2.54	Crack Size; t_{blend} /4 plus overlay thickness
C. Apparent Radius of Nozzle: $r_n = r_i + .29 \times r_c$	r_n	(inches)	7.73	WRC-175 App 5
D. Nozzle Inner Radius	r_i	(inches)	7.06	overlay thickness not included
E. Nozzle Corner Radius	r_c	(inches)	2.31	overlay thickness not included
F. Shell Thickness	t_s	(inches)	5.44	overlay thickness not included

NRC Requested Data for the Feedwater (N4) Nozzle				
A. Thickness of Nozzle	t_n	(inches)	6.13	Bore is not overlayed
B. Assumed Crack Size Through Blend	a_f	(inches)	1.25	Crack Size; tblend / 8 plus overlay thickness
C. Apparent Radius of Nozzle: $r_n = r_i + .29 \times r_c$	r_n	(inches)	6.05	WRC-175 App 5
D. Nozzle Inner Radius	r_i	(inches)	5.38	Bore is not overlayed
E. Nozzle Corner Radius	r_c	(inches)	2.31	overlay thickness not included
F. Shell Thickness	t_s	(inches)	5.44	overlay thickness not included

Question 4:

Confirm that the neutron fluence levels for the feedwater nozzles and N2 recirculation nozzles are lower than the threshold value for neutron irradiation embrittlement of $1x10^{17}$ *n/cm*^{2}. *If not, the effects of neutron irradiation embrittlement need to be accounted for in the* ART_{NDT} *assessments for the nozzle materials.*

Response to Question 4:

The N4 feedwater nozzles are well above the top of active fuel and the N2 recirculation nozzles are below the bottom of active fuel. The fluence in these locations is substantially below the beltline peak fluence levels and the fluence at these nozzles is projected to be less than $1x10^{17}$ n/cm^2. Confirmatory documentation from our vendor is being finalized.

Question 5:

Provide the thermal stress intensity value and ΔT *value data, as a function of temperature, that were used to generate the P-T data for the limiting flange and nozzle materials assessed in SIA Assessment No. SIR-00-155, Rev. 0.*

Response to Question 5:

For the cooldown transients, temperature lag (delta T) was conservatively assumed to be zero. For the bottom head and flange components, the proposed Technical Specification change requires that the minimum of the fluid temperature and the outside skin temperature be used to monitor P-T limits. Therefore the monitoring temperature will always be lower than the crack tip temperature and heatup lag does not need to be used in the associated calculation.

For the Bottom Head and N2 (Recirc Inlet) Nozzle curves, the constant maximum thermal stress intensity, K_{IT}, is used at all temperatures. The allowable stress intensity for pressure at a given temperature is calculated as follows:

$$K_{IP} = (K_{IC}-K_{IT})/SF$$

with the appropriate K_{IC} for a conservative crack tip temperature. The SF is the safety factor from ASME XI. A safety factor of 1.5 was used for the pressure test curves and 2.0 was used for the normal operating curves. The constant thermal stress values (K_{IT}) for the Bottom Head and the N2 (Recirculation Inlet) Nozzle are provided in Table 5-1. It is noted that the thermal stress intensity values presented Table 5-1 for the N2 Nozzles utilize very conservative bounding values to expedite our analysis and to demonstrate the N2 nozzles are not controlling components from the standpoint of P-T limits.

The Flange Curves were done in a similar manner with the exception that a constant stress intensity term associated with safety factor and bolt preload, SF x K_{IPL}, was also included.

$$K_{IP} = (K_{IC}- (K_{IT} + SF \times K_{IPL}))/SF$$

The constant combined stress intensity term (K_{IT} + SF x K_{IPL}) is also shown in Table 5-1.

The N4 Feedwater Nozzle curves conservatively assumed cold (50°F) feedwater injection at all temperatures. Therefore thermal stress intensity K_{IT} varied with temperature. This transient was assumed for both the pressure test and the normal operating conditions. The 1/8T temperatures and temperature dependent K_{IT} values are presented in Table 5-2 for the feedwater nozzle blend region and Table 5-3 for the feedwater nozzle bore region.

For the N4 Feedwater Nozzle the allowable stress intensity for pressure at a given temperature is again calculated as $K_{IP} = (K_{IC}-K_{IT})/SF$.

Table 5-1

Pressure Test Condition

RPV Component	Load Condition	Location	Temperature (deg F)	K_{1T} (ksi*sqrt*(inch))
Bottom Head CD	40 F/HR CD	1/4T	note 1	4.19
Bottom Head HU	40 F/HR HU	3/4 T	note 2	3.31
FW Blend HU-CD	Injection Transient	1/8 T	(Tfluid + 50F)/2	see Table 5-2
FW Bore HU-CD	Injection Transient	1/8 T	(Tfluid + 50F)/2	see Table 5-3
N2 Recirc Nozzle CD	40 F/HR CD	1/4T	note 1	10.03

RPV Component	Load Condition	Location	Temperature (deg F)	$K_{IT} + 1.5 \times K_{IPL}$ (note 3) (ksi*sqrt*(inch))	$K_{IT} + 2.0 \times K_{IPL}$ (note 3&4) (ksi*sqrt*(inch))
Upper Flange 1 CD	40 F/HR CD plus Bolt Preload	1/4T	note 1	50.25	66.74
Upper Flange 1 HU	40 F/HR HU plus Bolt Preload	3/4T	note 2	50.91	67.88
Upper Flange 2 CD	40 F/HR CD plus Bolt Preload	1/4T	note 1	51.56	68.53
Upper Flange 2 HU	40 F/HR HU plus Bolt Preload	3/4T	note 2	70.62	93.47

Normal Operation Condition

RPV Component	Load Condition	Location	Temperature (deg F)	K_{1T} (ksi*sqrt*(inch))
Bottom Head CD	100 F/HR CD	1/4T	note 1	10.49
Bottom Head HU	100 F/HR HU	3/4 T	note 2	8.28
FW Blend HU-CD	Injection Transient	1/8 T	(Tfluid + 50)/2	see Table 5-2
FW Bore HU-CD	Injection Transient	1/8 T	(Tfluid + 50)/2	see Table 5-3
N2 Recirc Nozzle CD	100 F/HR CD	1/4T	note 1	25.07

RPV Component	Load Condition	Location	Temperature (deg F)	$K_{IT} + 2 \times K_{IPL}$ (ksi*sqrt*(inch))
Upper Flange 1 CD	100 F/HR CD plus Bolt Preload	1/4T	note 1	67.91
Upper Flange 1 HU	100 F/HR HU plus Bolt Preload	3/4T	note 2	67.88
Upper Flange 2 CD	100 F/HR CD plus Bolt Preload	1/4T	note 1	69.51
Upper Flange 2 HU	100 F/HR HU plus Bolt Preload	3/4T	note 2	96.58

Note 1 For cooldown transients, temperature lag of metal verses fluid conservatively ignored.

Note 2 For these components both inside fluid temperature and outside skin temperature are monitored. The minimum temperature is used for monitoring PT limits. Therefore HU lag does not need to be used.

Note 3 In assessment of flange PT limits, a constant stress intensity term associated with safety factor (SF) and bolt preload must also be included, ($K_{IT} + SF \times K_{IPL}$). The appropriate SF for the pressure test case is 1.5.

Note 4 In the development of the VY Flange Curves a conservative SF of 2.0 vs 1.5 was used in development of the combined thermal plus preload stress intensity for the pressure test case.

Table 5-2

Temperature and K_{IT} Values

(FW Injection (Blend) - Corner Nozzle Crack)

Inputs:

Plant =	**Yankee**	
Component =	**FW Nozzle Blend**	
ART_{NDT} =	**40.0**	
Anlaysis Basis	**502**	°F Step
K_{1T} for 552F - 50F Step=	**106.56**	ksi*inch$^{1/2}$
K_{1P} for 1025 psig =	**33.80**	ksi*inch$^{1/2}$

Fluid Temperature T (°F)	**1/8t Temperatur (°F)**	**K_{IC} (ksi*inch$^{1/2}$)**	**Kit (ksi*inch$^{1/2}$)**
50	50.0	58.52	0.00
55	52.5	59.82	1.06
60	55.0	61.19	2.12
65	57.5	62.62	3.18
70	60.0	64.13	4.25
75	62.5	65.72	5.31
80	65.0	67.38	6.37
85	67.5	69.14	7.43
90	70.0	70.98	8.49
95	72.5	72.92	9.55
100	75.0	74.95	10.61
105	77.5	77.09	11.67
110	80.0	79.34	12.74
115	82.5	81.71	13.80
120	85.0	84.20	14.86
125	87.5	86.81	15.92
130	90.0	89.56	16.98
135	92.5	92.45	18.04
140	95.0	95.49	19.10
145	97.5	98.68	20.17
150	100.0	102.04	21.23
155	102.5	105.57	22.29
160	105.0	109.28	23.35

Table 5-3

Temperature and K_{IT} Values

(FW Injection (Bore)- Corner Nozzle Crack)

Inputs:

Plant =	**Yankee**	
Component =	**FW Nozzle Bore**	
ART_{NDT} =	**40.0**	°F ======>
Analysis Basis	**502**	°F Step
K_{1T} for 552F - 50F Step=	**133.39**	ksi*inch$^{1/2}$
K_{1P} for 1025 psig =	**28.36**	ksi*inch$^{1/2}$

Fluid Temperatur T (°F)	**1/8t emperatur (°F)**	**K_{IC} (ksi*inch$^{1/2}$)**	**Kit (ksi*inch$^{1/2}$)**
50	50.0	58.52	0.00
55	52.5	59.82	1.33
60	55.0	61.19	2.66
65	57.5	62.62	3.99
70	60.0	64.13	5.31
75	62.5	65.72	6.64
80	65.0	67.38	7.97
85	67.5	69.14	9.30
90	70.0	70.98	10.63
95	72.5	72.92	11.96
100	75.0	74.95	13.29
105	77.5	77.09	14.61
110	80.0	79.34	15.94
115	82.5	81.71	17.27
120	85.0	84.20	18.60
125	87.5	86.81	19.93
130	90.0	89.56	21.26
135	92.5	92.45	22.59
140	95.0	95.49	23.91
145	97.5	98.68	25.24
150	100.0	102.04	26.57
155	102.5	105.57	27.90
160	105.0	109.28	29.23

Neutron Fluence Data Questions

In your license amendment request, you are proposing to delete Figure 3.6.2, "Fast Neutron Fluence (E>1 MeV) as a Function of Thermal Energy and Full Power Years," from the VY Technical Specifications (TS). However, the end-of-life neutron fluence value was derived from these curves and was based on Battelle Report BCL-585-84-3, dated May 15, 1984. Address the following questions in regard to how VY TS Fig. 3.6.2 and the Batelle (sic) report relate to the operation of the VYNPS.

Question A:

At the time this figure was generated, how many full power years was the vessel exposed, and how were the values of the fast flux, which form the basis of Figure 3.6.2, estimated?

Response to Question A:

The vessel was estimated to have 2755 equivalent full power days or about 7.54 equivalent full power years when the Battelle report was generated in 1983.

Since Figure 3.6.2 is a fluence vs. time plot, it is assumed that the question relates to fluence instead of flux. In 1983, the fluence was calculated to be 5.19×10^{16} n/cm^2 at the surface, 3.78×10^{16} n/cm^2 at 1/4T and 1.48×10^{16} n/cm^2 at 3/4T. For subsequent full power years (i.e., 9, 12.8, 32), VY utilized the guidance contained within Regulatory Guide 1.99. This information is documented in VY Technical Specifications change, FVY 85-46.

Question B:

How many full power years of exposure does the vessel currently have?

Response to Question B:

At the end of January 2001, the vessel is estimated to have 8071 equivalent full power days or about 22.11 equivalent full power years.

Question C:

When was a low leakage fuel management program implemented, and how long has the low leakage fuel management program been in effect? Answer both questions in terms of effective full power years (EFPY).

Response to Question C:

Low leakage fuel management (i.e., placing low energy three or four times burned bundles on the core periphery) was implemented at VY at the end of Cycle 10 (EFPY on vessel approximately 8.15). The core has been designed as a low leakage core for approximately 14 EFPY.

Question D:

Since this figure was created, what efforts have been made to estimate (either computationally or experimentally) the fluence at the pressure vessel, and what are the results and how do they compare to the values given by in Figure 3.6.2? What is the impact of the low leakage fuel management program on Figure 3.6.2?

Response to Question D:

In 1989, VY performed a vessel fluence analysis for Reload 11/Cycle 12 to evaluate what, if any, the impact of high-energy bundles would have on vessel fluence. This analysis concluded that the edge powers have the maximum impact of vessel fluence and not the bundle. Since the neutron transport code used by Battelle was not available, the analysis was performed by determining the relative contribution per unit flux from each assembly using the distances to the vessel wall. Normalizing to the overall contribution of all assemblies, a weighting factor for each location was determined. The calculated weighting factors were applied to the powers used in the Battelle report and to the exposed averaged powers of several recent core reloads. The results showed that the impact on vessel fluence from previous reloads was less than that which was assumed in the Battelle Report.

A similar analysis has been performed for Reload 20/Cycle 21 and Reload 21/Cycle 22. In both cases, the results show that the impact on vessel fluence is less than that which was assumed in the Battelle Report.

Since implementation of the low leakage fuel management program, the impact of peak fast fluence on the reactor vessel has been between 1-3% less than that which was assumed in the Battelle Report.

Exemption Requests

The staff has not been able to determined (sic) that Code Case N-588 will provide VYNPC with any reduction in unnecessary burden benefit because the VY RPV is limited by the plate materials in upper intermediate shell, and not by one of the circumferential weld material in the vessel. Since application of Code Case N-588 does not appear to provide VY with any reduction in unnecessary burden benefit, the staff requests that VYNPC either withdraw the exemption request that would allow VYNPC to apply Code Case N-588 to the VY P-T limit calculations or that you provide additional information that demonstrates a reduction in unnecessary burden.

Response to Exemption Requests:

In a recent letter to the NRC[7], VY withdrew the Exemption Request that would allow application of Code Case N-588 to the P-T limit calculations. Attachment 2 provides a revised Structural Integrity Report SIR-00-155, Rev 1, supporting the revised P-T curves without reliance on Code Case N-588. This report supercedes the report previously submitted with BVY 00-113.

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[7] Reference Vermont Yankee Nuclear Power Corporation letter to the USNRC, BVY 01-13, "Supplement to Technical Specification Proposed Change No. 244, Withdrawal of Exemption Request to Use Code Case N-588," dated February 13, 2001.

If you have any questions on this transmittal, please contact Mr. Thomas B. Silko at (802) 258-4146.

Sincerely,

VERMONT YANKEE NUCLEAR POWER CORPORATION

Michael A. Balduzzi

Michael A. Balduzzi
Vice President, Operations

STATE OF VERMONT)
)ss
WINDHAM COUNTY)

Then personally appeared before me, Michael A. Balduzzi, who, being duly sworn, did state that he is Vice President, Operations of Vermont Yankee Nuclear Power Corporation, that he is duly authorized to execute and file the foregoing document in the name and on the behalf of Vermont Yankee Nuclear Power Corporation, and that the statements therein are true to the best of his knowledge and belief.

T.B. Silko

Thomas B. Silko, Notary Public
My Commission Expires February 10, 2003

Attachments

cc: USNRC Region 1 Administrator
USNRC Resident Inspector - VYNPS
USNRC Project Manager - VYNPS
Vermont Department of Public Service

Attachment 1

Vermont Yankee Nuclear Power Station

Technical Specification Proposed Change No. 244

Revised P/T Curves

Response to Request for Additional Information

Portions of Calculation VY-04Q-301

STRUCTURAL INTEGRITY Associates, Inc.	**CALCULATION PACKAGE**	**FILE No.: VY-04Q-301** **PROJECT No.:** VY-04Q

PROJECT NAME: P-T Curves for Vermont Yankee

CLIENT: Vermont Yankee Nuclear Power Corp.

CALCULATION TITLE: Material Data Review and Adjusted Reference Temperature Determination

Document Revision	**Affected Pages**	**Revision Description**	**Project Mgr. Approval Signature & Date**	**Preparer(s) & Checker(s) Signatures & Date**
0	1-38	Original Issue	A.F. Deardorff	T.D. Gilman A.F. Deardorff
1	1,29, 30	Provided additional details for weld RT_{NDT}	A.F. Deardorff	T. D. Gilman A. F. Deardorff

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Revision	0	1		
Preparer/Date	TDG 12/4/00	TDG 1/29/01		
Checker/Date	AFD 12/4/00	AFD 1/29/01		

1.0 INTRODUCTION / OBJECTIVE

Define the Adjusted Reference Temperatures (ARTs) for all RPV plate, weld, and forging materials so that the limiting material properties can be used in the P-T curve development.

This calculation package defines RPV material properties, including initial RT_{NDT}'s, material chemistry factors, and uncertainties, as they relate to evaluating fracture toughness.

The fracture toughness of all ferritic materials used for pressure-retaining components of the reactor coolant pressure boundary shall be evaluated in accordance with the requirements of Appendix G, 10 CFR Part 50. However, the fracture toughness test requirements for plants with construction permits prior to August 15, 1973 may not comply with the new Codes and Regulations in all respects. Since Vermont Yankee was fabricated before the adoption of latest fracture toughness requirements into the ASME Code, certain material property tests were not performed. In order to address the lack of data, the guidance of USNRC Branch Technical Position MTEB 5-2 has been followed [4]. This document provides criteria that may be used in assessing the fracture toughness of the materials for earlier plants by using the available test data to estimate the fracture toughness in the same terms as the new requirements.

2.0 TECHNICAL APPROACH OR METHODOLOGY

Some of the material data for Vermont Yankee is available from previous P-T curve work performed by VYNPC. However, additional input data are necessary to complete the scope of work. In addition, VYNPC has asked Structural Integrity (SI) to verify previous VYNPC Initial Reference Temperatures (RT_{NDT}'s) values.

The Initial RT_{NDT}'s and ARTs will be computed in accordance with NRC Regulatory Guide 1.99, Rev. 2 [3] and Branch Technical Position MTEB 5-2 [4],for all critical RPV locations.

3.0 ANALYSIS

All major pressure retaining components of the vessel were considered including:

- Shell Ring (Beltline)
- Bottom Head
- Top Head
- Nozzles (Inlet Recirc, FW/others)
- Top Head Flange
- Shell Flange
- Welds

Materials

The Vermont Yankee low alloy steel forgings for the flanges and nozzles were fabricated from ASME SA-508, Class II alloy steels in accordance with ASME Code Case 1332-3, Paragraph 5 [6].

The Vermont Yankee reactor pressure vessel and shell were fabricated from ASME SA-533 Grade B Class 1 [6].

CB&I "As-Fabricated" [1] and Certified Test Report (CTR) Charpy V-Notch and Drop Weight test reports (Ref [2]), and the Battelle report on testing of Unirradiated Pressure Vessel Surveillance Baseline Specimens (Ref[11]) were provided by VYNPC in Refs. [13].

The materials data relative to fracture toughness included both Certified Material Test Reports (CMTR's) and data from testing after fabrication, referred to as "as fabricated" data. The Charpy testing was for longitudinal specimens. The drop weight testing reported the results for two "no-break" tests. The data does not provide any indication if drop-weight testing was conducted to determine a "break" condition.

The Lukens CMTR data from Lukens predates the as-fabricated information. It is our understanding that the Lukens data is for the fabricated plate. The CB&I data represent simulated re-annealed properties following vessel fabrication.

The austenitize, quench and temper processes on the plate were performed by Lukens Steel. CB&I performed stress relief and simulated post weld heat treatments that are almost identical to those used by Lukens in their tests. It is believed that the Luken's data is a simulation of the planned production heat treatment to demonstrate capability. Then, the CB&I results were produced from test material removed from the plate after forming. The test material was then given a simulated post weld heat treatment. Therefore, both sets of data are considered to be applicable. Except for Plate 1-13 (C2669-

1) the 40°F impact data are higher than at 10°F. In the cases where the two groups of data were produced at the same temperature the results are the same within normally expected scatter.

For Plate 1-14 (Heat No. C3017-2), additional testing was performed by Battelle, at the time that the first surveillance capsule was evaluated. This data is also representative and can be used in the evaluation.

Thus, in this evaluation, all of the above-mentioned data will be used.

Charpy RT_{NDT} Determination

The Branch Technical Position MTEB 5-2 for Fracture Toughness Requirements [4] was used as the basis for computing Initial RT_{NDT}'s.

The current ASME Code requirements for fracture toughness testing require that a reference temperature be established, that is at or above the nil-ductility transition temperature (NDTT) the temperature at which specimens exhibit break behavior with a Drop Weight Test per ASTM E-208. Then, at a temperature that does not exceed 60°F above the reference temperature, the minimum Charpy energy using transverse specimens must not be less than 50 ft-lb, and the lateral expansion of the test samples must not be less than 35 mils.

At the time that VYNPC was constructed, these requirements were not in place. Instead, the GE fabrication specification [10] required that:

1) Closure flanges and adjacent shell and plate material meet ASME Code , Section III Paragraph N-330 at a temperature no higher than 10°F and have a NDT temperature (ASTM E208) no higher than 10°F. (section 10.3.1.1).
2) All other carbon and low alloy steel pressure containing material meet ASME Code , Section III Paragraph N-330 at a temperature no higher than40°F and have a NDT (ASTM E208) no higher than 40°F. (section 10.3.1.2).
3) The actual NDT temperature of all material opposite the center of the active fuel as indicated on drawing 919D294 shall be determined (section 10.3.1.2).

For the materials used at VYNPC, the Branch Technical Position states that if limited Charpy V-Notch tests were performed at a single temperature to confirm that at least 30 ft-lbs was obtained, that temperature may be used as an estimate of RT_{NDT}, provided that at least 45 ft-lbs was obtained if the specimens were longitudinally oriented. If the minimum value obtained was less than 45 ft-lbs, the RT_{NDT} may be estimated as 20°F above the test temperature [4].

Earlier plants, including Vermont Yankee, did not have materials testing conducted using transverse specimens. MTEB 5-2 states that a) the 50 ft-lb and 35 mils lateral expansion (mle) requirement could be met based on testing of longitudinal specimens using the following criteria:

1. If the Charpy energy and mle were reduced by 35 percent and still met the 50 ft-lb and 35 mle requirement, then the specimen would have met the 35 ft-lb and 35 mle requirement with a transverse speciment.
2. If the 50 ft-lb and 35 mle requirement were met, then the similar requirement would have been met at a test temperature increase by 20°F.

Determination of NDTT

The testing for the VY materials did not specifically identify the NDTT. Instead, the temperature at which two tests exhibited no-break behavior was reports. Per ASTM E-208, the NDTT can conservatively be estimated as the test temperature minus 10°F.

Determination of Initial RT_{NDT}

Values of Initial RT_{NDT} for selected locations on the reactor vessel are evaluated in the following pages. The minimum fracture toughness results contained in References [1,2]. Two groups of tests were conducted for almost all of the materials. The results of both sets of test data have been evaluated together to arrive at a value of RT_{NDT}. The initial RT_{NDT} values are summarized in Table 1.

Location: Shell #1, 1-17

CMTR Results:

Charpy Energy (ft-lb) at 10 °F: 63 Minimum
Mils Lateral Expansion: Not Reported

Drop Weight Results at 10 °F: No break

NDTT, °F: ≤ 0

RT_{NDT}, °F: ≤ 10 Note 1

As-Fabricated Results:

Charpy Energy (ft-lb) at 40°F: 65 Minimum
Mils Lateral Expansion: 49 Minimum

Drop Weight Results at 40°F: No Break

NDTT, °F: ≤ 30

RT_{NDT}, °F: ≤ 0 Note 4 (using NDTT for CMTR)

Evaluation Notes:

1. Criteria 1.1(4)(a): Limited Charpy V-Notch tests were performed. The CVN energies were at least 45 ft-lb, so the RT_{NDT} may be taken as the test temperature.
2. Criteria 1.1(4)(b): Limited Charpy V-Notch tests were performed. The CVN energies were at least 30 ft-lb but less than 45 ft-lb, so the RT_{NDT} may be taken as the test temperature + 20°F.
3. Criteria 1.1(3)(a): CVN energy and mils lateral expansion reduced by a factor of 0.65 meet 50 ft-lb and 35 mle. The 50 ft-lb and 35 mle requirement for transverse speciments would have been met at the test temperature. Thus, RTNDT > test temperature - 60°F but not less than NDTT
4. Criteria 1.1(3)(b): CVN energy and mils lateral expansion meet 50 ft-lb and 35 mle. The 50 ft-lb and 35 mle requirement for transverse speciments would have been met at the test temperature + 20°F. Thus, RTNDT > test temperature - 40°F but not less than NDTT.

Evaluation:

The purchase specification [10] required that the actual NDT be determined for all material opposite the center of the active fuel. Figure 1 shows that the lower shell course only slightly projects into the active core region. Thus, it is believed that CB&I did not report the minimum NDT temperatures in certified test documentation provided to VY [1,2]. Only the drop weight, no break results were reported. The Lukens CMTR data clearly demonstrates that this material had good Charpy properties

and the NDTT was less than 0°F. The CB&I as fabricated Charpy results at 40°F combined with the CMTR NDTT results would support $RT_{NDT} = 0°F$ under Criteria 4. The 40°F no-break drop weight results reported by CB&I for the as-fabricated tests are not considered representative of a minimum drop weight temperature. The high as-fabricated Charpy results at the same temperature, would indicate that the minimum drop weight temperature to be significantly lower.

Location: Shell #1, 1-16

CMTR Results:

Charpy Energy (ft-lb) at 10 °F: 57 Minimum
Mils Lateral Expansion: Not Reported

Drop Weight Results at 10 °F: No break

NDTT, °F: ≤ 0

RT_{NDT}, °F: ≤ 10 Note 1

As-Fabricated Results:

Charpy Energy (ft-lb) at 40°F: 83 Minimum
Mils Lateral Expansion: 64 Minimum

Drop Weight Results at 40°F: No Break

NDTT, °F: ≤ 30

RT_{NDT}, °F: ≤ 0 Note 3 (using NDTT for CMTR)

Evaluation Notes:

1. Criteria 1.1(4)(a): Limited Charpy V-Notch tests were performed. The CVN energies were at least 45 ft-lb, so the RT_{NDT} may be taken as the test temperature.
2. Criteria 1.1(4)(b): Limited Charpy V-Notch tests were performed. The CVN energies were at least 30 ft-lb but less than 45 ft-lb, so the RT_{NDT} may be taken as the test temperature + 20°F.
3. Criteria 1.1(3)(a): CVN energy and mils lateral expansion reduced by a factor of 0.65 meet 50 ft-lb and 35 mle. The 50 ft-lb and 35 mle requirement for transverse speciments would have been met at the test temperature. Thus, RTNDT > test temperature - 60°F but not less than NDTT
4. Criteria 1.1(3)(b): CVN energy and mils lateral expansion meet 50 ft-lb and 35 mle. The 50 ft-lb and 35 mle requirement for transverse speciments would have been met at the test temperature + 20°F. Thus, RTNDT > test temperature - 40°F but not less than NDTT.

Evaluation:

The purchase specification [10] required that the actual NDT be determined for all material opposite the center of the active fuel. Figure 1 shows that the lower shell course only slightly projects into the active core region. Thus, it is believed that CB&I did not report the minimum NDT temperatures in certified test documentation provided to VY [1,2]. Only the drop weight, no break results were reported. The Lukens CMTR data clearly demonstrates that this material had good Charpy properties

and the NDTT was less or equal than 0°F. The CB&I as fabricated Charpy results at 40°F combined with the CMTR NDTT results would support $RT_{NDT} = 0°F$ using Criteria 3. The 40°F no-break drop weight results reported by CB&I for the as-fabricated tests are not considered representative of a minimum drop weight temperature. The high as-fabricated Charpy results at the same temperature, would indicate that the minimum drop weight temperature to be significantly lower.

Location: Shell #2, 1-15

CMTR Results:

Charpy Energy (ft-lb) at 10°F: 69 minimum

Mils Lateral Expansion: Not reported

Drop Weight Results at 10°F: No break

NDTT, °F: ≤ 0

RT_{NDT}, °F: ≤ 10

As-Fabricated Results:

Charpy Energy (ft-lb) at 40°F: 90 minimum

Mils Lateral Expansion: 68 minimum

Drop Weight Results at 0°F: No break

NDTT, °F: ≤ -10

RT_{NDT}, °F: ≤ -10 Note 3

Evaluation Notes:

1. Criteria 1.1(4)(a): Limited Charpy V-Notch tests were performed. The CVN energies were at least 45 ft-lb, so the RT_{NDT} may be taken as the test temperature.
2. Criteria 1.1(4)(b): Limited Charpy V-Notch tests were performed. The CVN energies were at least 30 ft-lb but less than 45 ft-lb, so the RT_{NDT} may be taken as the test temperature + 20°F.
3. Criteria 1.1(3)(a): CVN energy and mils lateral expansion reduced by a factor of 0.65 meet 50 ft-lb and 35 mle. The 50 ft-lb and 35 mle requirement for transverse speciments would have been met at the test temperature. Thus, RTNDT > test temperature - 60°F but not less than NDTT
4. Criteria 1.1(3)(b): CVN energy and mils lateral expansion meet 50 ft-lb and 35 mle. The 50 ft-lb and 35 mle requirement for transverse speciments would have been met at the test temperature + 20°F. Thus, RTNDT > test temperature - 40°F but not less than NDTT.

Evaluation:

The purchase specification [10] required that the actual NDT be determined for all material opposite the center of the active fuel. Figure 1 shows that the lower shell course only slightly projects into the active core region. Thus, it is believed that CB&I did not report the minimum NDT temperatures in certified test documentation provided to VY [1,2]. Only the drop weight, no break results were reported. The Lukens CMTR data clearly demonstrates that this material had good Charpy properties

and the NDTT was less or equal than 0°F. The CB&I as fabricated Charpy results at 40°F combined with the CMTR NDTT results supported $RT_{NDT} = -10°F$ using Criteria 3. The 10°F no-break drop weight results reported by CB&I for the as-fabricated tests are not considered representative of a minimum drop weight temperature since the high as-fabricated Charpy results at the same temperature indicates that the minimum drop weight temperature would be significantly lower.

Location: Shell #2, 1-14

CMTR Results:

Charpy Energy (ft-lb) at 10°F: 42 minimum

Mils Lateral Expansion: Not Reported

Drop Weight Results at 40°F: No break

NDTT, °F: ≤ 30

RT_{NDT}, °F: ≤ 30 Note 2

As-Fabricated Results:

Charpy Energy (ft-lb) at 40°F: 65 minimum

Mils Lateral Expansion: 54

Drop Weight Results at 20°F: No break

NDTT, °F: ≤ 10

RT_{NDT}, °F: ≤ 10 Note 4

Battelle Columbus Charpy Data

The report by Battelle Columbus (BCL-585-84-1 Ref [11]) reports longitudinal Charpy data taken for Plate 1-14. The following data are relevant:

Test Temperature (°F)	Charpy Energy (ft-lb)	Mils Lateral Expansion
0	30.5	27.4
0	40	35.4
10	32.5	28.8
40	46.5	39.6
80	57.5	50.2
120	87.5	70.8

Conservatively using the 80°F data and the slope of the 80°F-120°F data, it is estimated that 50 ft-lb could have been obtained at ≤ 70°F and the mle would have been greater than 35 mils. (By observation, this method is more conservative than using the slope one would derive using a hyperbolic tangent fit.) Using Note 4, the RTNDT can be taken equal to 30°F.

Evaluation Notes:

1. Criteria 1.1(4)(a): Limited Charpy V-Notch tests were performed. The CVN energies were at least 45 ft-lb, so the RT_{NDT} may be taken as the test temperature.
2. Criteria 1.1(4)(b): Limited Charpy V-Notch tests were performed. The CVN energies were at least 30 ft-lb but less than 45 ft-lb, so the RT_{NDT} may be taken as the test temperature + 20°F.
3. Criteria 1.1(3)(a): CVN energy and mils lateral expansion reduced by a factor of 0.65 meet 50 ft-lb and 35 mle. The 50 ft-lb and 35 mle requirement for transverse speciments would have been met at the test temperature. Thus, RTNDT > test temperature - 60°F but not less than NDTT
4. Criteria 1.1(3)(b): CVN energy and mils lateral expansion meet 50 ft-lb and 35 mle. The 50 ft-lb and 35 mle requirement for transverse speciments would have been met at the test temperature + 20°F. Thus, RTNDT > test temperature - 40°F but not less than NDTT.

Evaluation:

Based on the test temperature of 40°F, and meeting Criteria 4, RT_{NDT} would be justified as 10°F using NDTT = 10°F. However, to account for the relatively low Charpy energies obtained by Battelle, the RT_{NDT} will be taken as 30°F. This is also consistent with more conservative of NDTT's, required to be determined by testing in the GE specification.

Location: Top Head Flange, 1-8 and Shell Flange 1-9

NOT A BELTLINE COMPONENT.

CMTR Results:

Charpy Energy (ft-lb) at 10°F: 69 minimum
Mils Lateral Expansion: 52 minimum

Drop Weight Results at 20°F: No break

NDTT, °F: ≤ 10

RT_{NDT}, °F: ≤ 10 Note 1

Evaluation Notes:

1. Criteria 1.1(4)(a): Limited Charpy V-Notch tests were performed. The CVN energies were at least 45 ft-lb, so the RT_{NDT} may be taken as the test temperature.
2. Criteria 1.1(4)(b): Limited Charpy V-Notch tests were performed. The CVN energies were at least 30 ft-lb but less than 45 ft-lb, so the RT_{NDT} may be taken as the test temperature + 20°F.
3. Criteria 1.1(3)(a): CVN energy and mils lateral expansion reduced by a factor of 0.65 meet 50 ft-lb and 35 mle. The 50 ft-lb and 35 mle requirement for transverse speciments would have been met at the test temperature. Thus, RTNDT > test temperature - 60°F but not less than NDTT
4. Criteria 1.1(3)(b): CVN energy and mils lateral expansion meet 50 ft-lb and 35 mle. The 50 ft-lb and 35 mle requirement for transverse speciments would have been met at the test temperature + 20°F. Thus, RTNDT > test temperature - 40°F but not less than NDTT.

Evaluation:

Based on the test temperature of 10°F, and meeting Criteria 1, RT_{NDT} = 10°F.

Location: Welds

CB&I Production Run Results: [7, Attachment A.4]

Charpy Energy (ft-lb) at 10°F: 67 minimum, 92 average
Mils Lateral Expansion: 58 minimum

Drop Weight Results at -60°F: Two no break

NDTT= -70°F

Battelle Weld Surveillance Data Test Results: [11, Table 3]

Test Temp (deg F)	Impact Energy (ft-lbs)	Lateral expansion (mils)
-110.0	3.5	2.6
-60.0	22.0	21.6
-50.0	29.5	28.0
-40.0	40.5	37.2
-30.0	57.0	50.8
-20.0	85.5	69.2
0.0	71.0	56.8
40.0	95.0	78.0
80.0	110.2	88.4
160.0	102.0	85.2
240.0	118.0	90.2
320.0	156.0	88.2

Charpy Energy (ft-lb) [11, Table 5]

50 ft-lb	Transition Temperature	-35°F
35-mil	Lateral Expansion Temperature:	-45°F

No Drop Weight Test

Evaluation Notes:

1. Criteria 1.1(4)(a): Limited Charpy V-Notch tests were performed. The CVN energies were at least 45 ft-lb, so the RT_{NDT} may be taken as the test temperature.
2. Criteria 1.1(4)(b): Limited Charpy V-Notch tests were performed. The CVN energies were at least 30 ft-lb but less than 45 ft-lb, so the RT_{NDT} may be taken as the test temperature + 20°F.
3. Criteria 1.1(3)(a): CVN energy and mils lateral expansion reduced by a factor of 0.65 meet 50 ft-lb and 35 mle. The 50 ft-lb and 35 mle requirement for transverse speciments would have been met at the test temperature. Thus, RTNDT > test temperature - 60°F but not less than NDTT
4. Criteria 1.1(3)(b): CVN energy and mils lateral expansion meet 50 ft-lb and 35 mle. The 50 ft-lb and 35 mle requirement for transverse speciments would have been met at the test temperature + 20°F. Thus, RTNDT > test temperature - 40°F but not less than NDTT.

Evaluation:

Based on the production run data NDTT of =-70°F and Battelle surveillance capsule weld Cv Data under Criteria 4, RT_{NDT} = -70°F. This is consistent with the assessment provided by VY in Reference 7. Per direction from VY and consistent with Reference 14, the initial RT_{NDT} of the weld is conservatively assumed to be 0°F.

4.0 REFERENCES

1. Pressure Vessel Record Exhibit E "As Fabricated" Test Reports, CB&I Contract 9-6201, SI File VY-04Q-203.
2. Pressure Vessel Record Exhibit D "Certified" Test Reports, CB&I Contract 9-6201, SI File VY-04Q-204.
3. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.99, Revision 2, May 1988, SI File: YAEC-21Q-210.
4. Branch Technical Position - MTEB 5-2, "Fracture Toughness Requirements", July 1981, Rev. 1, SI File: YAEC-21Q-209.
5. VYNPC Drawing No. 5920-103, Rev. 3, "General Plan Reactor," 10/12/68, SI File VY-04Q-202.
6. General Electric 21A1115 rev. 3, "Reactor Pressure Vessel Purchase Specification," Section 8.0 MATERIALS, July 14, 1969, SI File VY-04Q-203.
7. VY Document: BVY-93-107, "Response to Request for Additional Information, Generic Letter 92-01-'Reactor Vessel Structural Integrity'," September 24, 1993, SI File VY-04Q-209.
8. ASME Boiler and Pressure Vessel Code, Section III, 1986.
9. VY Document BVY 94-62, Attachment 2, "Corrected 'Summary File for Pressure-Temperature Limits' and Corrected 'Summary File for Upper Shelf Energy' for Vermont Yankee Reactor Pressure Vessel," June 10, 1994, SI File VY-04Q-210.
10. General Electric 21A1115 rev. 3, "Reactor Pressure Vessel Purchase Specification," Section 10.0 INSPECTION AND TEST, July 14, 1969, SI File VY-04Q-203.
11. Battelle Columbus Report BCL-585-84-1, "Testing of Unirradiated Pressure Vessel Surveillance Baseline Specimens for the Vermont Yankee Nuclear Generating Plant," 3/21/84, SI File VY-04Q-203.
12. VY Document NVY 90-077, NRC Docket No. 50-271, "Issuance of Amendment No. 120 to Facility Operating License No. DPR-28 – Vermont Yankee Nuclear Power Station (TAC No. 75499)," Apr. 17, 1990, SI File VY-04Q-210.
13. Engineering Record Correspondence, "Design and Fabrication Records For Structural Integrity's Update to Vermont Yankee RPV PT Calculation", Betti to Stevens, ERC-2000-17, Sept. 28, 2000, SI File VY-04Q-201.
14. Engineering Record Correspondence, Revision 3 to VYC-829, "Reactor Pressure Vessel Pressure Temperature Limits", ERC No. 2000-029, Vita to Betti, 11-28-2000, SI File VY-04Q-210.
15. Battelle Report BCL-585-84-3, "Examination, Testing and Evaluation of Irradiated Pressure Vessel Surveillance Specimens for the Vermont Yankee Nuclear Power Station", 5-15-84, SI File VY-04Q-203.

Attachment 2

Vermont Yankee Nuclear Power Station

Technical Specification Proposed Change No. 244

Revised P/T Curves

Response to Request for Additional Information

Structural Integrity Report SIR-00-155, Rev 1

ATTACHMENT 1
REVISED PRESSURE-TEMPERATURE CURVES FOR VERMONT YANKEE NUCLEAR POWER STATION

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REVISED P-T CURVES FOR VERMONT YANKEE NUCLEAR POWER STATION

1.0 Introduction

This attachment documents the revised set of pressure-temperature (P-T) curves developed for the Vermont Yankee Nuclear Power Station (VY). This work includes a full set of updated P-T curves (i.e., pressure and leak test, core not critical, and core critical conditions) applicable for a gross power generation of 4.46×10^8 MWHR(th). (which will bound VY power generation beyond March 12, 2012, the end of VY's current operating license (EOL).)

The curves were developed using the methodology specified in ASME Code Case N-640 [2], the 1995 ASME Code, Section XI, Appendix G (including the Summer 1996 Addenda) [3], and 10CFR50 Appendix G [4].

2.0 Material Properties

An assessment of the fracture toughness properties of all material used in the VY reactor vessel plate, weld and forgings was conducted by SI. Estimation of the initial value of the nil-ductility reference temperature (RT_{NDT}) was based on the methods described in Branch Technical Position MTEB 5-2 [5]. Charpy impact and drop weight test data from original construction Certified Materials Test Reports (CMTRs) and as-fabricated material testing [6,7], supplemented by more recent data from Battelle for one beltline plate [8], were used. The resulting initial RT_{NDT}'s are listed in Table 1.

For all material adjacent to the reactor vessel flange region, the GE vessel purchase contract required that a nil-ductility transition temperature (NDTT) of 10°F be met. Review of the CMTR data shows that the minimum Charpy energy (longitudinal specimens) was 69 ft-lb at 10°F, with 52 mils lateral expansion reported. Two "no-break" drop weight tests at 20°F were also reported. Based on MTEB 5-2, this justifies an $RT_{NDT} = 10$°F.

For the limiting material adjacent to the core region, the previous submittal by VY [10] stated that the initial RT_{NDT} of plate 1-14 was 40°F. Further evaluation justifies that the RT_{NDT} can be conservatively taken as 30°F.

- Evaluation of the CMTR data shows that the minimum Charpy energy (from longitudinal specimens) was 42 ft-lb at a test temperature of 10°F. Lateral expansion was not reported. Two no-break drop weight tests at 40°F were reported, justifying the NDTT of ≤ 30°F. Based on MTEB 5-2, this justifies an initial $RT_{NDT} = 30$°F.
- Evaluation of the "as-fabricated" test data shows that the minimum Charpy energy (from longitudinal specimens) was 65 ft-lb at 40°F. The minimum lateral expansion was 54 mils. Two no-break drop weight tests at 20°F were reported, justifying an NDTT of ≤ 10°F. Based on MTEB 5-2, this justifies an initial $RT_{NDT} \leq 10$°F.
- Additional testing by Battelle exhibited relatively low Charpy energy (longitudinal specimens) [8]. At 40°F, 80°F and 120°F, the Charpy energy was 46.5 ft-lb, 57.5 ft-lb and 87.5 ft-lb, respectively with lateral expansion greater than 35 mils in all cases. From this data, it is estimated that the 50 ft-lb Charpy energy could have been achieved at ≤ 70°F. Using the criteria from MTEB 5-2, this also justifies an RT_{NDT} of 30°F.

Similar evaluations were conducted by SI in establishing the initial RT_{NDT}'s for all other materials.

Table 2 shows an evaluation of the expected irradiation shift for the beltline plates. The peak fluence of 2.3×10^{17} m/cm^2 (E>1.0 MeV) used in this table was used in VY's previous 1989 PT submittal [10]. The fluence value was from the peak fluence of 2.2×10^{17} n/cm^2 (>1.0 MeV) calculated by Battelle [9] with an additional $0.1 \text{x} E^{17}$ n/cm^2 added for axial fluence variation effects.

For purposes of determining the P-T curves for the vessel core region materials, the evaluation has been based on the more conservatively shifted ART_{NDT}'s previously used by VY: 89°F at the 1/4T point and 73°F at the 3/4T point. Based on NRC's safety evaluation of the VY submittal, lower values of ART_{NDT} could have been used [11].

The conservatism of employing these ART_{NDT} values is expressed in terms of equivalent fluence in Table 3. Based on the initial RT_{NDT} values and chemistry factors from Table 2, and Regulatory Guide 1.99, Rev. 2 [12] criteria for calculating ART_{NDT}, the use of the conservative ART_{NDT} values equate to a minimum end-of-life surface fluence of 1.24×10^{18} n/cm^2 for the four core region plates. This is more than 5 times the peak end-of-life surface fluence calculated for Vermont Yankee by Battle [9]. This also confirms that plate 1-14, used for the VY surveillance specimens [9], is the critical plate from the standpoint of brittle failure up to fluence levels well beyond that expected at VY.

3.0 P-T Curve Methodology

The P-T curve methodology is based on the requirements of References [2] through [4]. There are five regions of the reactor pressure vessel (RPV) that were evaluated by SI: (1) the reactor vessel beltline region, (2) the bottom head region, (3) the feedwater nozzle, (4) the recirculation inlet nozzle, and (5) the upper vessel flange region. These regions will bound all other regions in the vessel with respect to considerations for brittle fracture. For the feedwater nozzle, the limiting conditions of sudden injection of 50°F cold water into the nozzle were considered. For the remainder of the locations, 100°F/hr heatup and cooldown were considered for Service Level A/B curves and 40°F/hr heatup and cooldown were conservatively assumed for pressure and leak test conditions. The bottom head region was independently evaluated for anticipated operational occurrences including rapid cooling following a plant scram and hot sweep transients typically associated with re-initiation of recirculation flow into a relatively colder lower head region following a reactor scram and recirculation pump trip.

3.1 General Approach for Analytical P-T Limit Curves

The general approach for development of the P-T curves was as follows:

a. A temperature at the crack tip, $T_{1/4t}$ (i.e., 1/4t into the inside or outside vessel wall surface) is either determined using ASME Section XI, Appendix G methods or is assumed. The method for each location addressed in discussed in subsequent sections.

b. Calculate the allowable stress intensity factor, K_{IC}, based on $T_{1/4t}$ using the relationship specified by Code Case N-640 [2], as follows:

$$K_{IC} = 20.734\, e^{[0.02(T_{1/4t} - ART_{NDT})]} + 33.2$$

where: $T_{1/4t}$ = metal temperature at assumed flaw tip (°F)

ART_{NDT} = adjusted reference temperature for location under consideration and desired EFPY (°F)

K_{IC} = allowable stress intensity factor (ksi√inch)

c. Calculate the thermal stress intensity factor, K_{IT}. This is calculated based on ASME Section XI, Appendix G [3] for the beltline and lower head regions, from alternate analysis for the feedwater nozzle or recirculation inlet nozzle/upper vessel regions, or using membrane and bending stresses from the reactor vessel stress report for the upper flange region.

d. Calculate the allowable pressure stress intensity factor, K_{IP}, using the following relationship:

$$K_{IP} = (K_{IC} - K_{IT})/SF$$

where: K_{IP} = allowable pressure stress intensity factor (ksi$\sqrt{\text{inch}}$)

SF = safety factor

= 1.5 for pressure test conditions

= 2.0 for normal operation heatup/cooldown conditions (Level A/B)

For the upper flange region, the expression also includes an additional term that subtracts the preload stress intensity factor (multiplied by SF) from the numerator of the equation.

e. Compute the allowable pressure, P, from the allowable pressure stress intensity factor, K_{IP}, using either ASME Appendix G [3] for the beltline or alternate analytical values for other locations.

f. Make adjustments for temperature and/or pressure uncertainties and hydrostatic head to $T_{1/4t}$ and P, respectively.

g. Repeat steps (a) through (f) for other temperatures to generate a series of P-T points.

3.2 Adjustments to the Curves

The following additional requirements were used to define the P-T curves. These limits are established in Reference [4]:

For Pressure Test Conditions (Curve A):

- If the pressure is greater than 20% of the pre-service hydrotest pressure, the temperature must be greater than RT_{NDT} of the limiting flange material + 90°F.

- If the pressure is less than or equal to 20% of the pre-service hydrotest pressure, the minimum temperature is conservatively taken as greater than or equal to the RT_{NDT} of the limiting flange material + 60°F. This limit has been a standard GE recommendation for the BWR industry for non-ductile failure protection.

For Core Not Critical Conditions (Curve B):

- If the pressure is greater than 20% of the pre-service hydrotest pressure, the temperature must be greater than RT_{NDT} of the limiting flange material + 120°F.
- If the pressure is less than or equal to 20% of the pre-service hydrotest pressure, the minimum temperature is conservatively taken as greater than or equal to the RT_{NDT} of the limiting flange material + 60°F. This limit has been a standard GE recommendation for the BWR industry for non-ductile failure protection.

For Core Critical Conditions (Curve C):

- The core critical P-T limits must be 40°F above any Pressure Test or Core Not Critical curve limits. Core Not Critical conditions are more limiting than Pressure Test conditions, so Core Critical conditions are equal to Core Not Critical conditions plus 40°F. In addition, when pressure is less than or equal to 20% of the pre-service hydro test pressure and water level is in the normal range for power operation, the minimum temperature must be greater than or equal to the RT_{NDT} of the limiting flange material + 60°F.

- At pressures above 20% of the pre-service hydro test pressure, the minimum Core Critical curve temperature must be at least that required for the in-service pressure test (taken as 1,100 psig), or 160°F above the highest RT_{NDT} of the vessel flange region. As a result of these requirements, the Core Critical curve must have a step at a pressure equal to 20% of the pre-service hydro pressure to the temperature required by the Pressure Test curve at 1,100 psig, or Curve B + 40°F, whichever is greater.

The resulting pressure and temperature points constitute the P-T curves. These curves relate the minimum required monitored temperature to the allowable reactor pressure. Applicable temperature and pressure adjustments (described below) are also included in Curves A, B, and C.

The lower head area of a BWR, due to convection cooling, stratification, and cool CRD flow is subject to lower temperatures than the balance of the pressure vessel. In addition, the RT_{NDT} of the lower head is much lower than the assumed ART_{NDT} being used for the beltline. The lower head is also not subject same high level of stress as the flange and feedwater nozzle regions. Therefore, separate curves were provided for the lower head. These curves are less restrictive than the enveloping curve used for the beltline and the balance of the vessel. This will provide Operator's with a more accurate data for assessment of PT limits for this cooler region.

3.3 Instrument Uncertainty and Hydrostatic Head

A conservative evaluation of instrument uncertainty by VY derived the following bounding error due to instruments:

Temperature:	±10F
Pressure:	± 30 psig

Thus, the derived P-T curves were shifted to the right by 10°F. When adjusted for the maximum effects of hydrostatic head (from the top head), the resulting pressure margins are shown in Table 4, where the conservatively adjusted margins are used in the P-T curves.

3.4 Beltline Evaluation

For the beltline evaluation, the equations in ASME Section XI, Appendix G [3] are used to predict the stress intensity factors and temperature shifts for inside and outside 1/4T flaws. For the cooldown, K_{IC} was conservatively based on reactor temperature; for heatup, the ASME Section XI, Appendix G methods for estimation of temperature at the 3/4T point in the wall were used. Tables 5-8 provide detailed results for the calculations.

3.5 Flange Region

For the flange evaluation, membrane and bending stresses were extracted from the original vessel stress report for pressure, preload and thermal expansion (heatup/cooldown) loadings. The critical location was determined to be weld region between the upper head and the head flange [13]. Stress intensity factors were calculated based on the equations similar to ASME Section XI, Appendix G for membrane and bending stress except that actual stresses were substituted for the pressure stresses in ASME Section XI. For this region, notes have been added to the P-T curves requiring that the minimum of the fluid or the measured vessel flange skin temperatures be used; thus this temperature may conservatively be used to compute K_{IC}. At temperatures in excess of the 10CFR50 Appendix B limits, the P-T limits based on the flange are much higher than those resulting from the beltline. Tables 9 and 10 provide detailed results for the critical cases (without the margins discussed in Section 3.2).

3.5 N4 Feedwater Nozzle

For the feedwater nozzle, the assessment did not consider heatup and cooldown, but considered the effects of injection of 50°F feedwater into the nozzle at various reactor temperatures, this being the minimum realistic temperature for establishing flow into the feedwater nozzles. The stress intensities for pressure and for the feedwater injection were taken from previous analysis in support of VY's NUREG-0619 feedwater nozzle inspection interval evaluation. For this evaluation, a 1/8T flaw at the feedwater nozzle blend radius region (1.0 inches base metal, 1.1875 inches including the cladding) was evaluated. This is considerably larger than the 0.823 maximum allowable flaw size (including cladding) that determines the blend radius inspection interval at VY and has been accepted by the NRC [14]. K_{IC} for the thermal shock transient was conservatively based on the mean of the injected feedwater and the reactor temperature, whereas the initial temperature is steady state at reactor temperature. The deepest point of the postulated blend radius would actually be slightly more affected by reactor temperature due to the larger exposed area for heat transfer. The results are shown in Table 11.

3.6 N2 Recirculation Nozzle

This nozzle was evaluated because of the relatively high RT_{NDT} of one of the nozzles. An evaluation, based on the similar FW nozzle analysis discussed above, was conducted to determine a conservative stress intensity factor for a 1/4T nozzle corner crack. Cooldown was the only condition evaluated since the postulated flaw is at the inside surface in the nozzle blend radius. No credit was taken for the difference between the fluid temperature and the crack-tip temperature in computing K_{IC}. The results are shown in Table 10 and show that significant margin exists.

3.7 Bottom Head

The bottom head evaluation was conducted with methods similar to that for the beltline region. Since the bottom head has the control rod drive penetrations, the stresses and stress intensity factors were modified. An evaluation of the effects of the effects of the penetrations showed that the membrane stresses in the bottom head could be bounded by using a factor of 2.75 times the nominal stress computed for the spherical bottom head. Then, the stress intensity factors were multiplied by a factor of 1.28 based on assuming a flaw aspect ratio (a/L) of zero instead of a 1/6 aspect ratio flaw traditionally utilized for ASME Appendix G evaluations. This approach conservatively accounted for the fact that elliptical cracks could potentially interact with the CRD penetrations in the bottom head region. For the bottom head, the P-T curves were based on the minimum of the bottom head fluid or the measured outside surface temperatures, such that K_{IC} is based on a minimum temperature.

Alternate evaluations were conducted to show that anticipated operating occurrences would not control for the bottom head region. Of significance to a BWR is a reactor scram with recirculation trip. For this transient, the lower head region can cool relatively quickly from normal reactor temperature. Then, if recirculation pumps are restarted, the relatively colder water in the bottom head can be swept out by hot water from the bottom head region.

- For the cooldown transients, a transient was synthesized that bounded data taken from a reactor scram transient at VY and another BWR plant. It included cooldown for 527°F to 375°F in 10 minutes, then a 200°F/hr cooldown to 175°F, followed by a 100°F/hr cooldown. This transient showed that the limiting high pressure was 1050 psig (with margins) at the end of the initial rapid cooldown period, and that the low temperature portion of the cooldown was essentially the same as that based on the normal P-T cooldown evaluations. The resulting allowable pressure versus bottom head fluid temperature for an inside 1/4T flaw is shown in Figure 1. This evaluation is conservative since 1) there is normally a slight depressurization following a reactor scram, and 2) the initial assumed cooldown was significantly more severe than experienced at VY.
- For the recirculation pump restart transient, the maximum possible pressure and temperature conditions of the water sweeping the bottom head region are at saturated conditions, coming from the upper vessel region. Analysis was conducted to evaluate a transient temperature and stress intensity factor for an outside 1/4T flaw due to a step-change transient in the bottom head. Then, using these results, a limiting step change from any initial bottom head temperature to saturated steam conditions could be iteratively determined such that the K_{IC} would not be exceeded at the assumed flaw. The results are shown in Figure 2. Additional pressure margin would be available above 350°F, since the maximum possible value of the step-change temperature difference starts to decrease as a result of BWR operating pressure and temperatures conditions. Also shown on the curve is the expected pressure based on a maximum recommended top-to-bottom temperature difference of 145°F between the top and

bottom head region temperatures for recirculation pump start, as recommended in GE Service Information Letter (SIL) 251 [15]. This shows that there is significant margin between the fracture limiting pressure and the pressures expected when using the SIL as a guideline for when the recirculation pumps may be restarted.

4.0 P-T Curves

The resulting P-T curves, including the 10CRF 50 margins discussed in Section 3.2 are shown in Figures 3 through 5.

5.0 References

1. NOT USED
2. ASME Boiler and Pressure Vessel Code, Code Case N-640, "Alternative Reference Fracture Toughness for Development of P-T Limit Curves," Section XI, Division 1, Approved February 26, 1999.
3. ASME Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, Nonmandatory Appendix G, "Fracture Toughness Criteria for Protection Against Failure," 1995 Edition, Summer 1996 Addenda.
4. U. S. Code of Federal Regulations, Title 10, Part 50, Appendix G, "Fracture Toughness Requirements," December 1995.
5. Branch Technical Position - MTEB 5-2, "Fracture Toughness Requirements", July 1981, Rev. 1.
6. Pressure Vessel Record Exhibit E "As Fabricated Test Reports," CB&I Contract 9-6201.
7. Pressure Vessel Record Exhibit D "Certified Test Reports," CB&I Contract 9-6201.
8. Battelle Columbus Report BCL-585-84-1, "Testing of Unirradiated Pressure Vessel Surveillance Baseline Specimens for the Vermont Yankee Nuclear Generating Plant," 3/21/84.
9. Battelle Columbus Report BCL-585-84-3, "Examination, Testing and Evaluation of Irradiated Pressure Vessel Surveillance Specimens from the Vermont Yankee Nuclear Power Station," 8/15/84.

10. Letter from Vermont Yankee Nuclear Power Corporation BVY 89-113, to U.S. NRC, "Proposed Change to Revise the Reactor Vessel Pressure-Temperature Curves in the Vermont Yankee Technical Specifications (Generic Letter 88-11)," 11/10/89.

11. Letter from Nuclear Regulatory Commission, NVY 90-077 to Vermont Yankee Nuclear Power Corporation, "Issuance of Amendment No. 120 To Facility Operating License No. DPR-28 – Vermont Yankee Nuclear Power Station (Tac No. 75499).

12. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.99, Revision 2, May 1988.

13. Chicago Bridge & Iron Company Stress Report # 9-6201-I, Volume 3, Vermont Yankee Reactor Vessel, Revision 6, 1/06/71, S.I. File No. VY-04Q-205.

14. Letter from U.S. Nuclear Regulatory Commission NVY 95-02, "Evaluation of the Request for Relief From NUREG-0619 for Vermont Yankee Nuclear Power Station (TAC No. M88803)," 2/6/95.

15. GE Service Information Letter (SIL) No. 251, "Control of RPV Bottom Head Temperature," 10/31/77.

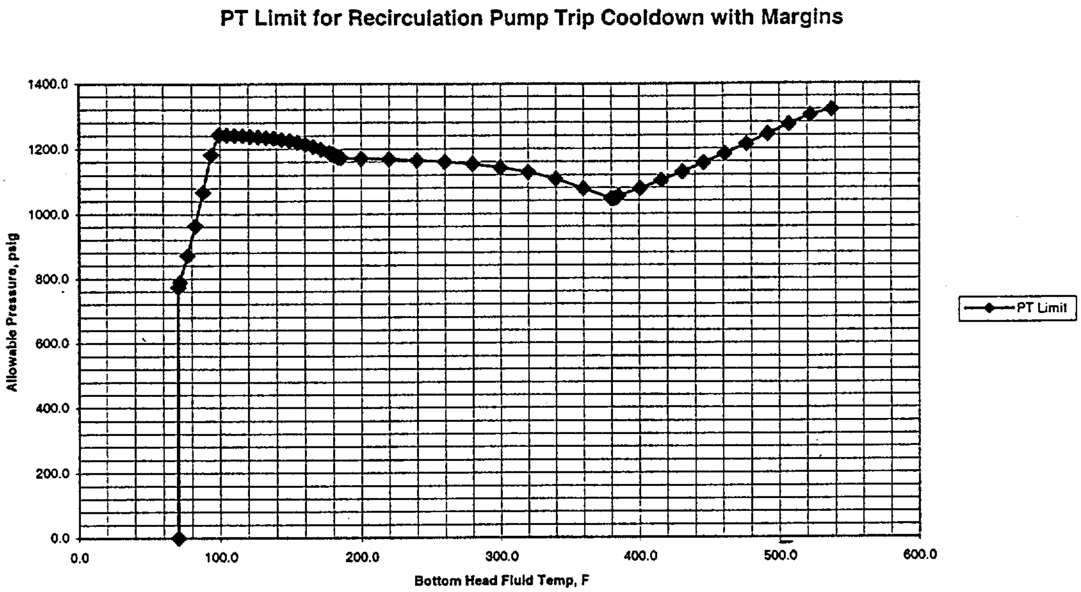


Figure 1: Bottom Head Recirculation Pump Trip Pressure/Temperature Limit Curve

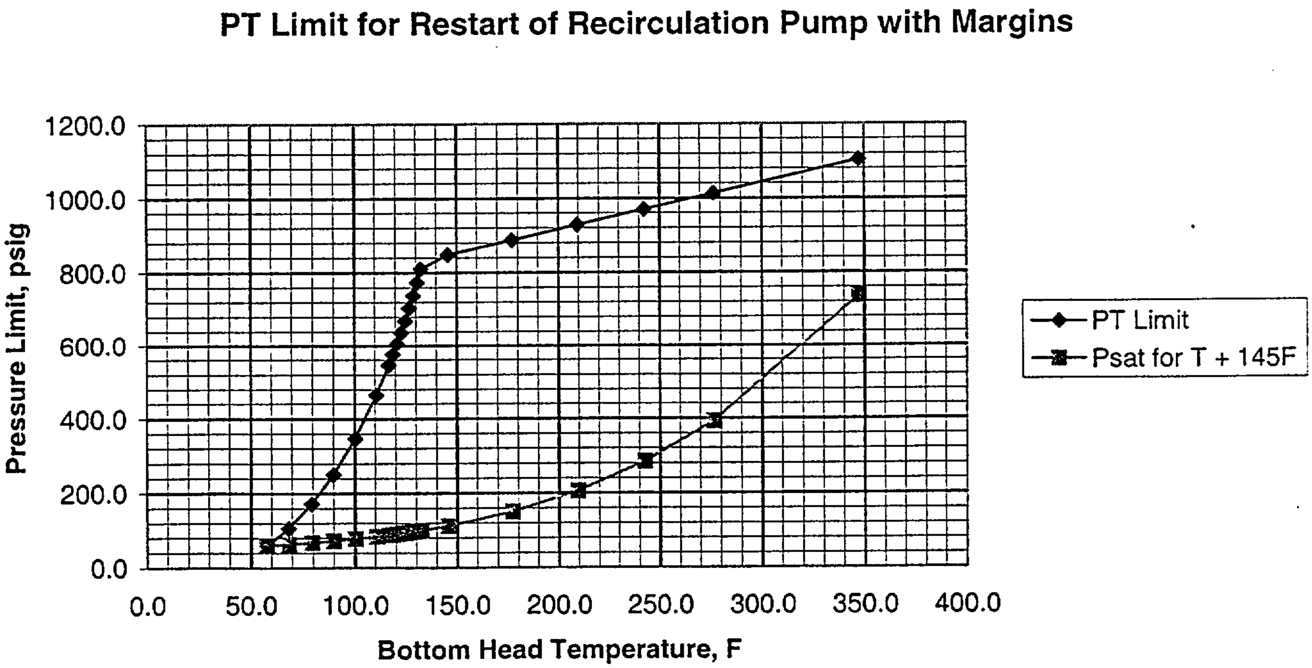
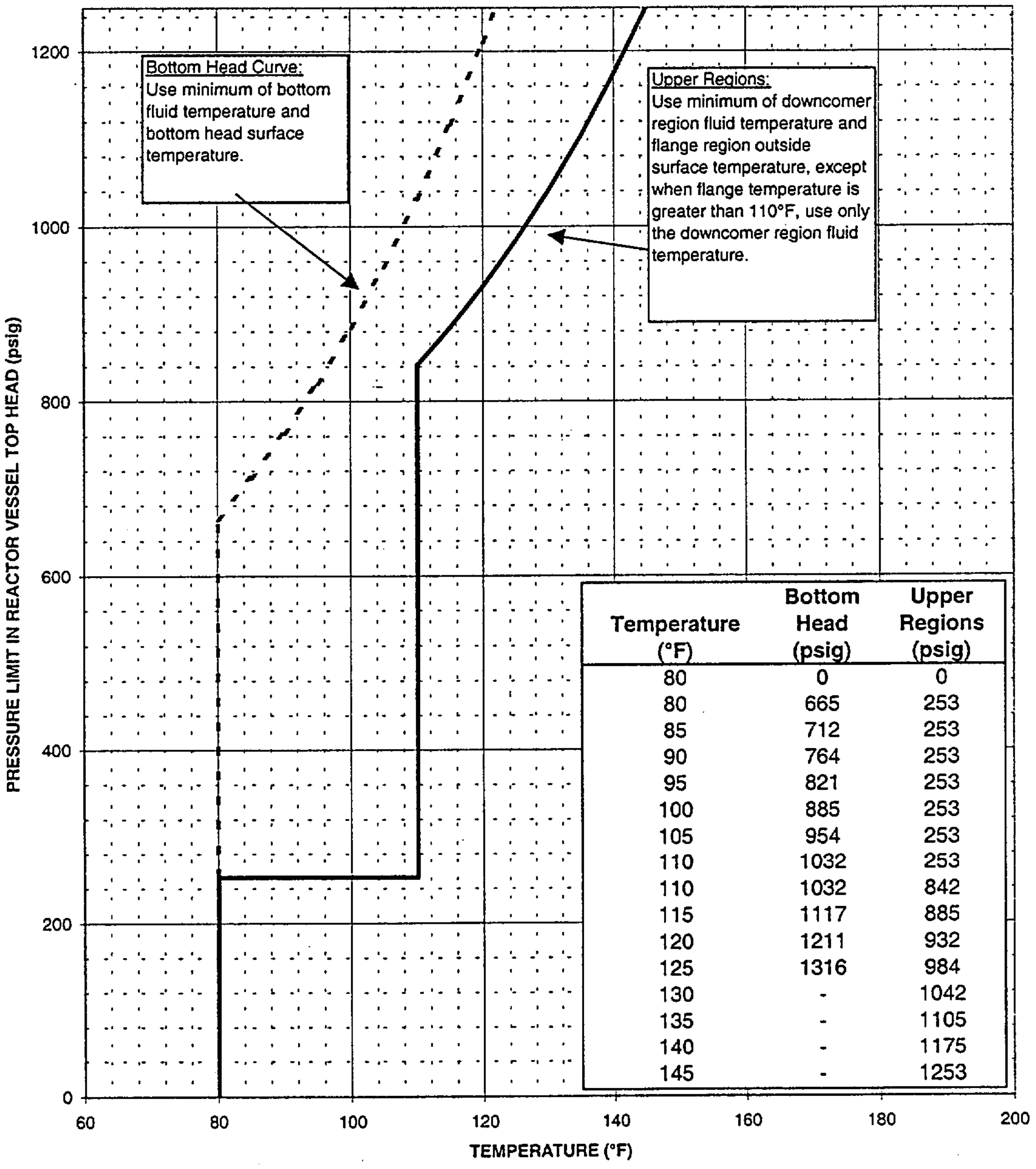


Figure 2: Pressure/Temperature Limit Curve for Recirculation Pump Start

Leak Test and Hydro P-T Curve
40°F/hr Heatup/Cooldown Limit
Valid Through 4.46E8 MWH(t)



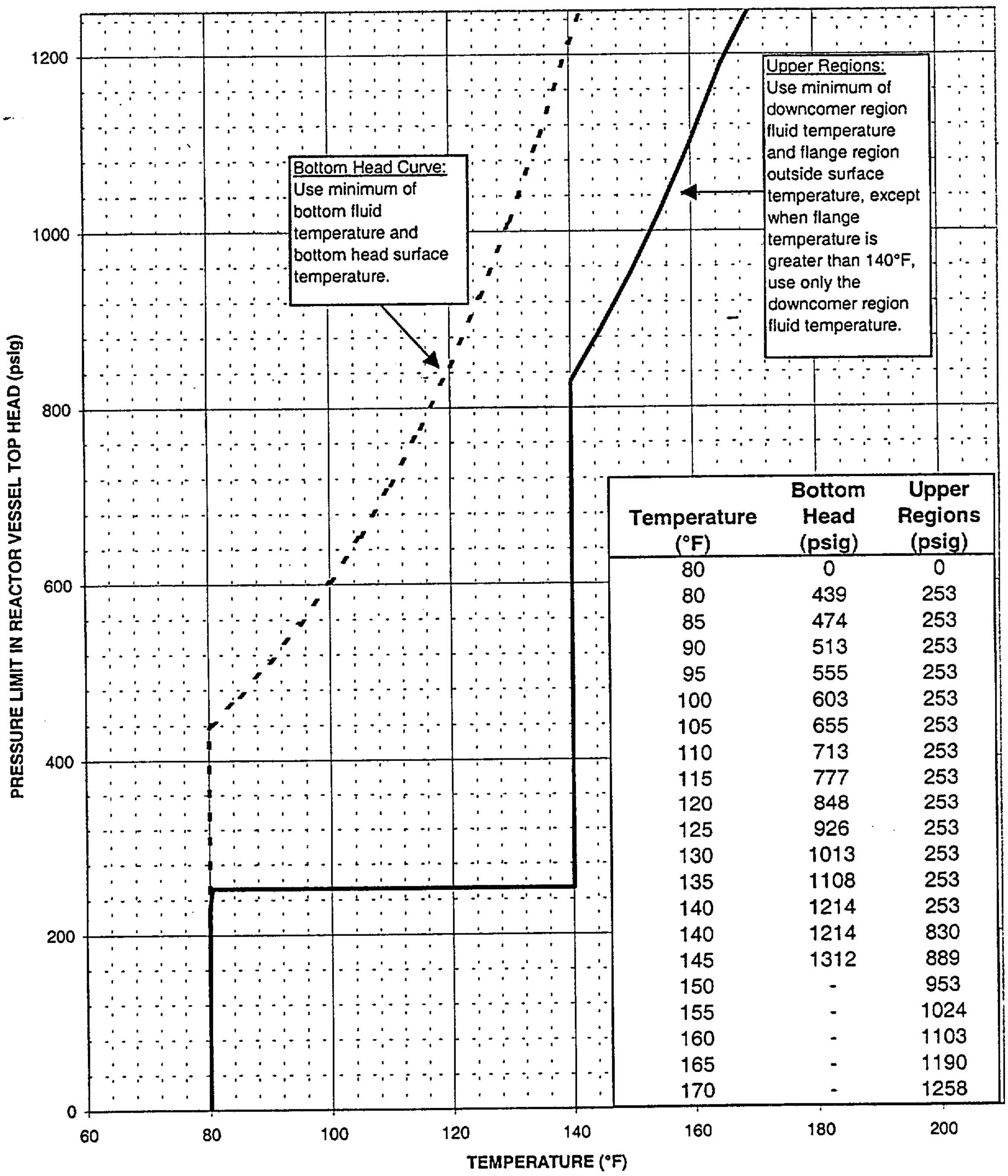
Bottom Head Curve:
Use minimum of bottom fluid temperature and bottom head surface temperature.

Upper Regions:
Use minimum of downcomer region fluid temperature and flange region outside surface temperature, except when flange temperature is greater than 110°F, use only the downcomer region fluid temperature.

Temperature (°F)	Bottom Head (psig)	Upper Regions (psig)
80	0	0
80	665	253
85	712	253
90	764	253
95	821	253
100	885	253
105	954	253
110	1032	253
110	1032	842
115	1117	885
120	1211	932
125	1316	984
130	-	1042
135	-	1105
140	-	1175
145	-	1253

Figure 3: Pressure Test P-T Curve (Curve A)

Core Not Critical P-T Curve
100°F/hr Heatup/Cooldown Limit
Valid Through 4.46E8 MWH(t)



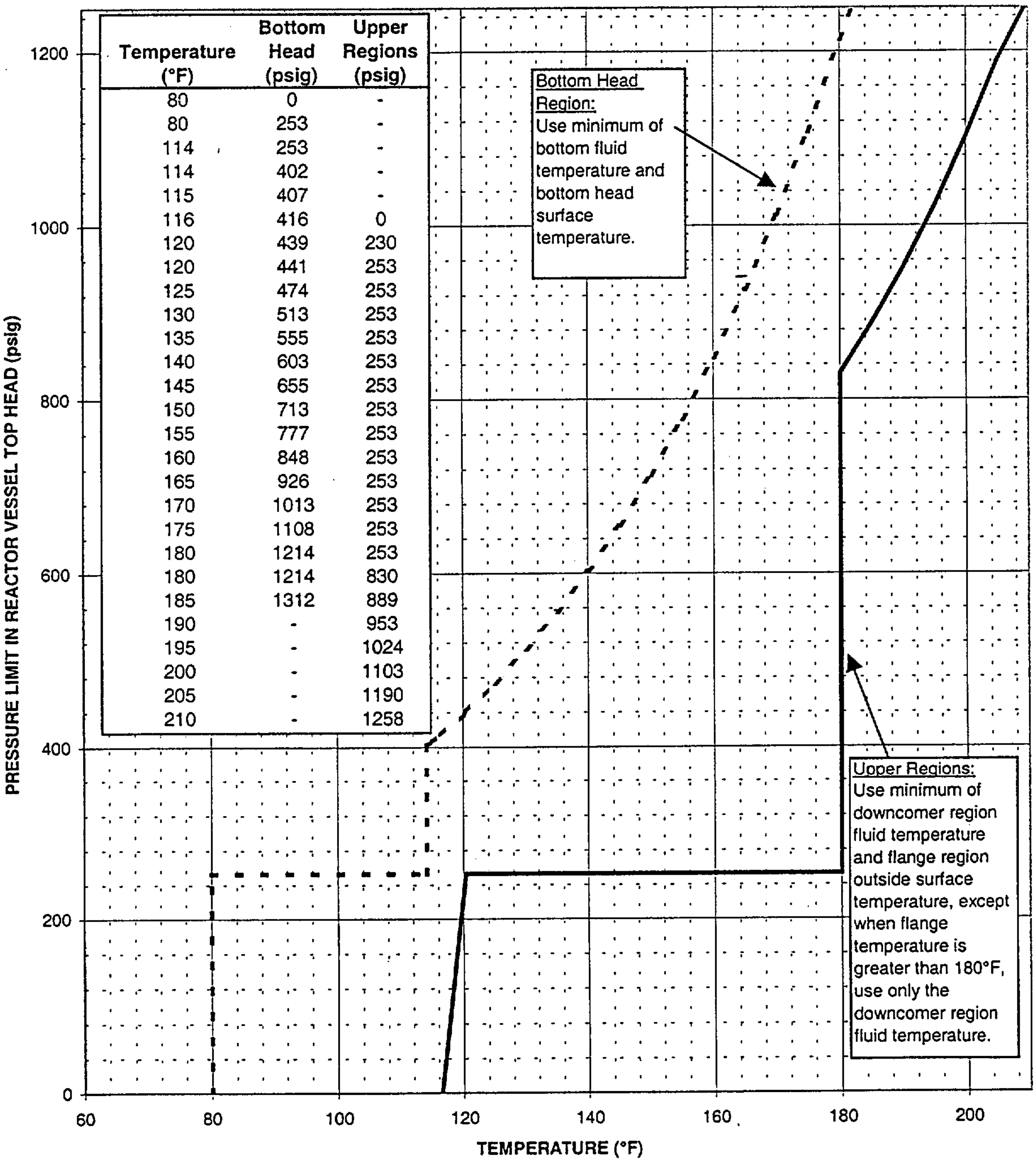
Bottom Head Curve:
Use minimum of bottom fluid temperature and bottom head surface temperature.

Upper Regions:
Use minimum of downcomer region fluid temperature and flange region outside surface temperature, except when flange temperature is greater than 140°F, use only the downcomer region fluid temperature.

Temperature (°F)	Bottom Head (psig)	Upper Regions (psig)
80	0	0
80	439	253
85	474	253
90	513	253
95	555	253
100	603	253
105	655	253
110	713	253
115	777	253
120	848	253
125	926	253
130	1013	253
135	1108	253
140	1214	253
140	1214	830
145	1312	889
150	-	953
155	-	1024
160	-	1103
165	-	1190
170	-	1258

Figure 4: Core Not Critical P-T Curve (Curve B)

Core Critical P-T Curve
100°F/hr Heatup/Cooldown Limit
If Pressure < 253 psig, Water Level must be within
Normal Range for Power Operation
Valid Through 4.46E8 MWH(t)



Temperature (°F)	Bottom Head (psig)	Upper Regions (psig)
80	0	-
80	253	-
114	253	-
114	402	-
115	407	-
116	416	0
120	439	230
120	441	253
125	474	253
130	513	253
135	555	253
140	603	253
145	655	253
150	713	253
155	777	253
160	848	253
165	926	253
170	1013	253
175	1108	253
180	1214	253
180	1214	830
185	1312	889
190	-	953
195	-	1024
200	-	1103
205	-	1190
210	-	1258

Bottom Head Region: Use minimum of bottom fluid temperature and bottom head surface temperature.

Upper Regions: Use minimum of downcomer region fluid temperature and flange region outside surface temperature, except when flange temperature is greater than 180°F, use only the downcomer region fluid temperature.

Figure 5: Core Critical P-T Curve (Curve C)

Table 1: Initial RT_{NDT} for Materials in Vermont Yankee Reactor Vessel

Region	Material Location	Initial RT_{NDT}, °F
Top Head	Top Head Dollar 1-1	0
Flange Region	Top Head Knuckle 1-5/7	0
	Top Head Knuckle 1-2/4	0
	Top Head Flange	10
	Vessel Shell Flange	10
	Upper (#4) Shell 1-10	0
	Upper(#4) Shell 1-11	0
Intermediate Shell Region	Upper Int. (#3) Shell 1-12	10
	Upper Int. (#3) Shell 1-13	60
Irradiated Shell Region Adjacent to Core	Lower Int. (#2) Shell 1-14	30[1]
	Lower Int. (#2) Shell 1-15	-10
	Lower (#1) Shell 1-16	0
	Lower (#1) Shell 1-17	0
Bottom Head Region	Skirt Knuckle 17-1	40
	Bottom Head Knuckle 1-18/21	30
	Bottom Head Knuckle 1-22/25	0
	Bottom Head Dollar 1-26	30[2]
	Bottom Head Dollar 1-27	0[2]
	Bottom Head Dollar 1-28	30[2]
Nozzles	Recirculation Nozzle N2B	60
	Nozzles (All Others, Incl. Feedwater)	40
All Areas	Welds	-70

1. Limiting beltline plate used in initial surveillance capsule evaluation [9]
2. Bottom head dollar plate includes all bottom head control rod drive penetrations

Table 2: Evaluation of Shift in RT_{NDT} for Core Region Plates

Beltline Plate	I-14	I-15	I-16	I-17	Weld
Initial RT_{NDT},°F	30	-10	0	0	0[1]
Cu w/%	0.11	0.14	0.13	0.12	0.04
Ni w/%	0.63	0.66	0.59	0.61	1.00
Chemistry Factor	74	102	91	83	54
ΔRT_{NDT},°F (1/4T)	11.5	15.8	14.1	12.9	8.4
ΔRT_{NDT}, °F (3/4T)	7.7	10.6	9.5	8.6	5.6
σ_{Δ}°F (1/4T	5.7	7.9	7.1	6.4	4.2
σ_{Δ}°F (3/4T)	3.8	5.3	4.7	4.3	2.8
σ_i°F	0.0	0.0	0.0	0.0	0.0
ART_{NDT},°F (1/4T)	53.0	21.6	28.2	25.8	16.8
ART_{NDT}, °F (3/4T)	45.4	11.2	18.9	17.2	11.2

Based on ID Fluence = 2.3×10^{17} n/cm^2
1/4T Fluence = 1.7×10^{17} n/cm^2
3/4T Fluence = 9.2×10^{16} n/cm^2

1) The initial weld RT_{NDT} is -70°F. The 0°F used here is a bounding value and demonstrates that weld material is not limiting.

Table 3: Calculation of Equivalent Peak Beltline Fluence Values

Parameters	Units	Regulatory Guide 1.99 fluence that matches ART_{NDT} used by VY		
Plate		1-14	1-15	1-16
Equivalent Factor on Fluence, k	-	5.37	14.5	11.5
Effective Operating Duration	EFPY	32 EFPY	32 EFPY	32 EFPY
Effective Inside Surface Fluence Value=k*2.3x10^{17}	n/cm^2	1.24E+18	3.34E+18	2.65E+18
Vessel Thickness	Inches	5.06	5.06	5.06
Fluence at 1/4 thickness	n/cm^2	9.12E+17	2.46E+18	1.95E+18
Fluence at 3/4 thickness	n/cm^2	4.97E+17	1.34E+18	1.06E+18
Initial RT_{NDT}	°F	30	-10	0
Chemistry Factor, CF	-	74	102	91
Delta RT_{NDT} @ 1/4 T	°F	29.5	63.3	51.3
Delta RT_{NDT} @ 3/4 T	°F	21.6	48.8	39.1
σ_i, Standard Deviation of Initial RT_{NDT}	°F	0.0	0.0	0.0
Margin@ 1/4T=2*SQRT($\sigma_\Delta^2+\sigma_i^2$)	°F	29.5	34.0	34.0
σ_Δ, Standard Deviation of ΔRT_{NDT} @ 1/4T	°F	14.7	17.0	17.0
Margin@ 3/4T=2*SQRT($\sigma_\Delta^2+\sigma_i^2$)	°F	21.6	34.0	34.0
σ_Δ, Standard Deviation of ΔRT_{NDT} @ 3/4T	°F	10.8	17.0	17.0
Adjusted RT_{NDT} @ 1/4T	°F	89.0	87.3	85.3
Adjusted RT_{NDT} @ 3/4T	°F	73	73	73

NOTE: σ_Δ lesser value of 17°F or ½ ΔRT_{NDT}

Table 4: Pressure Margins at Locations of Interest

Location	Instrument Uncertainty, psi	Static Head Pressure, psi	Total Margin Calculated, psi	Total Margin Used, psi
Closure Head Flange	30	3.72	33.72	35.0
N4 FW Nozzle	30	10.54	10.54	45.0
Bottom of Core Region	30	19.87	19.87	50.0
N2 Recirculation Nozzle	30	20.65	20.65	55.0
Bottom Head	30	27.36	27.36	60.0

Table 5: P-T Evaluation - Beltline Hydrostatic Test (Heatup)

Pressure-Temperature Curve Calculation

(Pressure Test w/ Heatup = Curve A)

Inputs:

Plant =	**Yankee**			
Component =	**Beltline**			
Vessel thickness, t =	**5.0600**	inches, so √t =	2.249	√inch
Vessel Radius, R =	**103.1875**	inches		
ART_{NDT} =	**73.0**	°F		
Heatup Rate, HU =	**40**	°F/hr		
K_{IT} =	**1.73**	ksi*inch$^{1/2}$ (for cooldown rate above)		
M_T =	**0.26**	(From App G, Fig. G-2214-1)		
$\Delta T_{1/4t}$ =	**6.1**	°F = (K_{IT}/M_T) * 0.92 using Figs. G-2214-1 & G-2214-2		
Safety Factor =	**1.50**	(for hydrotest)		
M_m =	**2.009**	(for inside surface axial flaw)		
Temperature Adjustment =	**10.0**	°F		
Pressure Adjustment =	**50.0**	psig (hydrostatic pressure + Uncertainty)		

Fluid Temperature T (°F)	**1/4t Temperature (°F)**	**K_{IC} (ksi*inch$^{1/2}$)**	**K_{IP} (ksi*inch$^{1/2}$)**	**Calculated Pressure P (psig)**	**Adjusted Temperature for P-T Curve (°F)**	**Adjusted Pressure for P-T Curve (psig)**
50.0	43.9	44.78	28.69	700	60.0	650
55.0	48.9	45.99	29.51	720	65.0	670
60.0	53.9	47.34	30.40	742	70.0	692
65.0	58.9	48.83	31.39	766	75.0	716
70.0	63.9	50.47	32.49	793	80.0	743
75.0	68.9	52.29	33.70	823	85.0	773
80.0	73.9	54.29	35.04	855	90.0	805
85.0	78.9	56.51	36.52	891	95.0	841
90.0	83.9	58.96	38.15	931	100.0	881
95.0	88.9	61.67	39.96	975	105.0	925
100.0	93.9	64.67	41.96	1024	110.0	974
105.0	98.9	67.98	44.16	1078	115.0	1,028
110.0	103.9	71.64	46.60	1138	120.0	1,088
115.0	108.9	75.68	49.30	1203	125.0	1,153
120.0	113.9	80.15	52.27	1276	130.0	1,226
125.0	118.9	85.08	55.57	1356	135.0	1,306

Table 6: P-T Evaluation - Beltline Hydrostatic Test (Cooldown)

Pressure-Temperature Curve Calculation

(Pressure Test w/ Cooldown = Curve A)

Inputs:

Plant = **Yankee**
Component = **Beltline**
Vessel thickness, t = **5.0600** inches, so √t = 2.249 √inch
Vessel Radius, R = **103.1875** inches
ART_{NDT} = **89.0** °F
Cooldown Rate, CR = **40** °F/hr
K_{IT} = **2.20** ksi*inch$^{1/2}$ (for cooldown rate above)
M_T = **0.26** (From App G, Fig. G-2214-1)
$\Delta T_{1/4t}$ = **3.7** °F = (K_{IT}/M_T) * 0.44 using Figs. G-2214-1 & G-2214-2
Safety Factor = **1.50** (for hydrotest)
M_m = **2.083** (for inside surface axial flaw)
Temperature Adjustment = **10.0** °F
Pressure Adjustment = **50.0** psig (hydrostatic pressure + Uncertainty)

Fluid Temperature T (°F)	**1/4t Temperature (°F)**	**K_{IC} (ksi*inch$^{1/2}$)**	**K_{IP} (ksi*inch$^{1/2}$)**	**Calculated Pressure P (psig)**	**Adjusted Temperature for P-T Curve (°F)**	**Adjusted Pressure for P-T Curve (psig)**
50.0	50.0	42.70	27.01	636	60.0	586
55.0	55.0	43.70	27.67	651	65.0	601
60.0	60.0	44.81	28.41	669	70.0	619
65.0	65.0	46.03	29.22	688	75.0	638
70.0	70.0	47.38	30.12	709	80.0	659
75.0	75.0	48.87	31.12	733	85.0	683
80.0	80.0	50.52	32.22	758	90.0	708
85.0	85.0	52.34	33.43	787	95.0	737
90.0	90.0	54.35	34.77	819	100.0	769
95.0	95.0	56.58	36.25	853	105.0	803
100.0	100.0	59.04	37.89	892	110.0	842
105.0	105.0	61.75	39.71	935	115.0	885
110.0	110.0	64.76	41.71	982	120.0	932
115.0	115.0	68.08	43.92	1034	125.0	984
120.0	120.0	71.74	46.37	1092	130.0	1,042
125.0	125.0	75.80	49.07	1155	135.0	1,105
130.0	130.0	80.28	52.05	1225	140.0	1,175
135.0	135.0	85.23	55.35	1303	145.0	1,253

Table 7: P-T Evaluation - Beltline Level A/B (Heatup)

Pressure-Temperature Curve Calculation

(Core Not Critical/ Heatup = Curve B)

Inputs:

Plant =	**Yankee**			
Component =	**Beltline**			
Vessel thickness, t =	**5.0600**	inches, so √t =	2.249	√inch
Vessel Radius, R =	**103.1875**	inches		
ART_{NDT} =	**73.0**	°F		
Heatup Rate, HU =	**100**	°F/hr		
K_{IT} =	**4.34**	ksi*inch1/2 (for heatup rate above)		
M_T =	**0.26**	(From App G, Fig. G-2214-1)		
$\Delta T_{1/4t}$ =	**15.3**	°F = (K_{IT}/M_T) * 0.92 using Figs. G-2214-1 & G-2214-2		
Safety Factor =	**2.00**	(for level A/B)		
M_m =	**2.009**	(for outside surface axial flaw)		
Temperature Adjustment =	**10.0**	°F		
Pressure Adjustment =	**50.0**	psig (hydrostatic pressure + uncertainty)		

Fluid Temperature T (°F)	**1/4t Temperature (°F)**	**K_{IC} (ksi*inch$^{1/2}$)**	**K_{IP} (ksi*inch$^{1/2}$)**	**Calculated Pressure P (psig)**	**Adjusted Temperature for P-T Curve (°F)**	**Adjusted Pressure for P-T Curve (psig)**
50.0	34.7	42.83	19.25	470	60.0	420
55.0	39.7	43.84	19.75	482	65.0	432
60.0	44.7	44.96	20.31	496	70.0	446
65.0	49.7	46.20	20.93	511	75.0	461
70.0	54.7	47.57	21.61	528	80.0	478
75.0	59.7	49.08	22.37	546	85.0	496
80.0	64.7	50.75	23.20	566	90.0	516
85.0	69.7	52.59	24.13	589	95.0	539
90.0	74.7	54.63	25.15	614	100.0	564
95.0	79.7	56.89	26.27	641	105.0	591
100.0	84.7	59.38	27.52	672	110.0	622
105.0	89.7	62.13	28.90	705	115.0	655
110.0	94.7	65.17	30.42	743	120.0	693
115.0	99.7	68.53	32.10	784	125.0	734
120.0	104.7	72.25	33.96	829	130.0	779
125.0	109.7	76.36	36.01	879	135.0	829
130.0	114.7	80.90	38.28	934	140.0	884
135.0	119.7	85.91	40.79	996	145.0	946
140.0	124.7	91.46	43.56	1063	150.0	1,013
145.0	129.7	97.58	46.62	1138	155.0	1,088
150.0	134.7	104.36	50.01	1221	160.0	1,171
155.0	139.7	111.84	53.75	1312	165.0	1,262

Table 8: P-T Evaluation - Beltline Level A/B (Cooldown)

Pressure-Temperature Curve Calculation

(Core Not Critical/ Cooldown = Curve B)

Inputs:

Plant = **Yankee**
Component = **Beltline**
Vessel thickness, t = **5.0600** inches, so √t = 2.249 √inch
Vessel Radius, R = **103.1875** inches
ART_{NDT} = **89.0** °F
Cooldown Rate, CR = **100** °F/hr
K_{IT} = **5.49** ksi*inch1/2 (for cooldown rate above)
M_T = **0.26** (From App G, Fig. G-2214-1)
$\Delta T_{1/4t}$ = **9.3** °F = $(K_{IT}/M_T) * 0.44$ using Figs. G-2214-1 & G-2214-2
Safety Factor = **2.00** (for level A/B)
M_m = **2.083** (for inside surface axial flaw)
Temperature Adjustment = **10.0** °F
Pressure Adjustment = **50.0** psig (hydrostatic pressure + uncertainty)

Fluid Temperature T (°F)	1/4t Temperature (°F)	K_{IC} (ksi*inch$^{1/2}$)	K_{IP} (ksi*inch$^{1/2}$)	Calculated Pressure P (psig)	Adjusted Temperature for P-T Curve (°F)	Adjusted Pressure for P-T Curve (psig)
50.0	50.0	42.70	18.61	438	60.0	388
55.0	55.0	43.70	19.11	450	65.0	400
60.0	60.0	44.81	19.66	463	70.0	413
65.0	65.0	46.03	20.27	477	75.0	427
70.0	70.0	47.38	20.95	493	80.0	443
75.0	75.0	48.87	21.69	511	85.0	461
80.0	80.0	50.52	22.51	530	90.0	480
85.0	85.0	52.34	23.43	551	95.0	501
90.0	90.0	54.35	24.43	575	100.0	525
95.0	95.0	56.58	25.54	601	105.0	551
100.0	100.0	59.04	26.77	630	110.0	580
105.0	105.0	61.75	28.13	662	115.0	612
110.0	110.0	64.76	29.63	698	120.0	648
115.0	115.0	68.08	31.29	737	125.0	687
120.0	120.0	71.74	33.13	780	130.0	730
125.0	125.0	75.80	35.15	828	135.0	778
130.0	130.0	80.28	37.39	880	140.0	830
135.0	135.0	85.23	39.87	939	145.0	889
140.0	140.0	90.70	42.61	1003	150.0	953
145.0	145.0	96.75	45.63	1074	155.0	1,024
150.0	150.0	103.43	48.97	1153	160.0	1,103
155.0	155.0	110.82	52.66	1240	165.0	1,190
160.0	160.0	118.98	56.75	1336	170.0	1,286

Table 9: P-T Evaluation - Flange Hydrostatic Test (Heatup)

Pressure-Temperature Curve Calculation

(Pressure Test - Upper Flange 2 - Heatup)

Inputs:

Plant = **Yankee**
Component = **Upper Flange 2** Upper Flange/Hub Intersection Axial Flaw
Vessel thickness, t = **N/A** inches
Vessel Radius, R = **NA** inches
ART_{NDT} = **10.0** °F ======> **All EFPYs**
$K_{IT} + 2 \times K_{IPL}$ **93.47** ksi*inch$^{1/2}$ (Note: Factor of 2 not 1.5 conservatively used as Safety Factor)
Safety Factor = **1.50** (for hydrotest)
K_{1P} for 1000 psig = **10.30** ksi*inch$^{1/2}$
Temperature Adjustment = **10.0** °F
Pressure Adjustment = **35.0** psig (hydrostatic pressure + Uncertainty)

K, ksi*inch$^{1/2}$
K_{IPL}=Preload = **45.7**
K_{IT}=Thermal = **2.072**

Fluid Temperature T (°F)	1/4t Temperature (°F)	K_{IC} (ksi*inch$^{1/2}$)	K_{IP} (ksi*inch$^{1/2}$)	Calculated Pressure P (psig)	Adjusted Temperature for P-T Curve (°F)	Adjusted Pressure for P-T Curve (psig)
64	64.0	94.25	0.52	51	74	16
65	65.0	95.49	1.34	131	75	96
66	66.0	96.75	2.18	212	76	177
67	67.0	98.03	3.04	295	77	260
68	68.0	99.34	3.91	380	78	345
69	69.0	100.68	4.80	466	79	431
70	70.0	102.04	5.71	555	80	520
71	71.0	103.43	6.64	645	81	610
72	72.0	104.85	7.58	736	82	701
73	73.0	106.30	8.55	830	83	795
74	74.0	107.77	9.53	926	84	891
75	75.0	109.28	10.54	1023	85	988
76	76.0	110.82	11.56	1123	86	1088
77	77.0	112.38	12.61	1224	87	1189
78	78.0	113.98	13.67	1328	88	1293

Table 10: P-T Evaluation - Flange Level A/B (Heatup)

Pressure-Temperature Curve Calculation

(Core Not Critical - Upper Flange 2- Heatup)

Inputs:

Plant =	**Yankee**			
Component =	**Upper Flange 2**	Upper Flange/Hub Intersection Axial Flaw		
Vessel thickness, t =	**N/A**	inches		
Vessel Radius, R =	**NA**	inches		
ART_{NDT} =	**10.0**	°F ======>	**All EFPYs**	
K_{IT} + 2 x K_{IPL}	**96.58**	ksi*inch$^{1/2}$ (Note: Factor of 2 is Safety Factor)		
Safety Factor =	**2.00**	(for level A/B)		K, ksi*inch$^{1/2}$
K_{1P} for 1000 psig =	**10.30**	ksi*inch$^{1/2}$	K_{IPL}=Preload =	**45.7**
Temperature Adjustment =	**10.0**	°F	K_{IT}=Thermal =	**5.18**
Pressure Adjustment =	**35.0**	psig (hydrostatic pressure + uncertainty)		

Fluid Temperature T (°F)	**1/4t Temperature (°F)**	**K_{IC} (ksi*inch$^{1/2}$)**	**K_{IP} (ksi*inch$^{1/2}$)**	**Calculated Pressure P (psig)**	**Adjusted Temperature for P-T Curve (°F)**	**Adjusted Pressure for P-T Curve (psig)**
67	67.0	98.03	0.73	70	77	35
68	68.0	99.34	1.38	134	78	99
69	69.0	100.68	2.05	199	79	164
70	70.0	102.04	2.73	265	80	230
71	71.0	103.43	3.42	333	81	298
72	72.0	104.85	4.13	401	82	366
73	73.0	106.30	4.86	472	83	437
74	74.0	107.77	5.60	543	84	508
75	75.0	109.28	6.35	616	85	581
76	76.0	110.82	7.12	691	86	656
77	77.0	112.38	7.90	767	87	732
78	78.0	113.98	8.70	845	88	810
79	79.0	115.62	9.52	924	89	889
80	80.0	117.28	10.35	1005	90	970
81	81.0	118.98	11.20	1087	91	1052
82	82.0	120.71	12.07	1171	92	1136
83	83.0	122.48	12.95	1257	93	1222
84	84.0	124.28	13.85	1345	94	1310

Table 11: P-T Evaluation – Feedwater Nozzle Level A/B

Pressure-Temperature Curve Calculation

(Core Not Critical - FW Injection - Corner Nozzle Crack)

Inputs:

Plant = **Yankee**
Component = **FW Nozzle Blend**
Vessel thickness, t = **N/A** inches
Vessel Radius, R = **N/A** inches
ART_{NDT} = **40.0** °F ======> **All EFPYs**
K_{1T} for 552F - 50F Step = **106.56** ksi*inch$^{1/2}$ Temp. Change 502 °F Step
Safety Factor = **2.00** (for level A/B)
K_{1P} for 1025 psig = **33.80** ksi*inch$^{1/2}$
Temperature Adjustment = **10.0** °F
Pressure Adjustment = **45.0** psig (hydrostatic pressure + uncertainty)

Fluid Temperature T (°F)	**1/8t Temperature (°F)**	**K_{IC} (ksi*inch$^{1/2}$)**	**K_{IT} (ksi*inch$^{1/2}$)**	**K_{IP} (ksi*inch$^{1/2}$)**	**Calculated Pressure P (psig)**	**Adjusted Temperature for P-T Curve (°F)**	**Adjusted Pressure for P-T Curve (psig)**
50	50.0	58.52	0.00	29.26	887	60	842
55	52.5	59.82	1.06	29.38	891	65	846
60	55.0	61.19	2.12	29.53	896	70	851
65	57.5	62.62	3.18	29.72	901	75	856
70	60.0	64.13	4.25	29.94	908	80	863
75	62.5	65.72	5.31	30.21	916	85	871
80	65.0	67.38	6.37	30.51	925	90	880
85	67.5	69.14	7.43	30.85	936	95	891
90	70.0	70.98	8.49	31.24	948	100	903
95	72.5	72.92	9.55	31.68	961	105	916
100	75.0	74.95	10.61	32.17	976	110	931
105	77.5	77.09	11.67	32.71	992	115	947
110	80.0	79.34	12.74	33.30	1010	120	965
115	82.5	81.71	13.80	33.96	1030	125	985
120	85.0	84.20	14.86	34.67	1051	130	1006
125	87.5	86.81	15.92	35.45	1075	135	1030
130	90.0	89.56	16.98	36.29	1100	140	1055
135	92.5	92.45	18.04	37.20	1128	145	1083
140	95.0	95.49	19.10	38.19	1158	150	1113
145	97.5	98.68	20.17	39.26	1191	155	1146
150	100.0	102.04	21.23	40.41	1225	160	1180
155	102.5	105.57	22.29	41.64	1263	165	1218
160	105.0	109.28	23.35	42.96	1303	170	1258

Table12: P-T Evaluation – Recirculation Nozzle Level A/B

Pressure-Temperature Curve Calculation

(Core Not Critical - N2 Recirc Nozz - Cooldown)

Inputs:

Plant = **Yankee**
Component = **N2 Recirc Noz**
Vessel thickness, t = **N/A**
Vessel Radius, R = **N/A**
ART_{NDT} = **60.0** °F ======> **All EFPYs**
K_{1T} **25.07** ksi*inch$^{1/2}$
Safety Factor = **2.00** (for level A/B)
K_{1P} for 1025 psig = **44.25** ksi*inch$^{1/2}$
Temperature Adjustment = **10.0** °F
Pressure Adjustment = **55.0** psig (hydrostatic pressure + uncertainty)

Fluid Temperature T (°F)	1/4t Temperature (°F)	K_{IC} (ksi*inch$^{1/2}$)	K_{IP} (ksi*inch$^{1/2}$)	Calculated Pressure- P (psig)	Adjusted Temperature for P-T Curve (°F)	Adjusted Pressure for P-T Curve (psig)
0	0.0	39.44	7.19	166	10	111
5	5.0	40.10	7.52	174	15	119
10	10.0	40.83	7.88	183	20	128
15	15.0	41.63	8.28	192	25	137
20	20.0	42.52	8.72	202	30	147
25	25.0	43.50	9.21	213	35	158
30	30.0	44.58	9.75	226	40	171
35	35.0	45.78	10.35	240	45	185
40	40.0	47.10	11.01	255	50	200
45	45.0	48.56	11.75	272	55	217
50	50.0	50.18	12.55	291	60	236
55	55.0	51.96	13.45	311	65	256
60	60.0	53.93	14.43	334	70	279
65	65.0	56.11	15.52	360	75	305
66	66.4	56.78	15.86	367	76	312
70	70.0	58.52	16.73	387	80	332
70	70.3	58.70	16.81	389	80	334
75	75.0	61.19	18.06	418	85	363
80	80.0	64.13	19.53	452	90	397
85	85.0	67.38	21.16	490	95	435
90	90.0	70.98	22.95	532	100	477
95	95.0	74.95	24.94	578	105	523
100	100.0	79.34	27.14	629	110	574
105	105.0	84.20	29.56	685	115	630
110	110.0	89.56	32.25	747	120	692
115	115.0	95.49	35.21	816	125	761
120	120.0	102.04	38.48	891	130	836
125	125.0	109.28	42.10	975	135	920
130	130.0	117.28	46.11	1068	140	1013

Table 13: P-T Evaluation – Bottom Head Hydrostatic Test (Cooldown)

Pressure-Temperature Curve Calculation

(Pressure Test w/ Cooldown = Curve A)

Inputs:

Plant = **Yankee**
Component = **Bot. Head**
Vessel thickness, t = **5.9375** inches, so $\sqrt{t}$ = 2.437 $\sqrt{\text{inch}}$
Vessel Radius, R = **103.1875** inches
ART_{NDT} = **30.0** °F
Cooldown Rate, CR = **40** °F/hr
K_{IT} = **4.19** ksi*inch$^{1/2}$ (for cooldown rate above)
M_T = **N/A** (From App G, Fig. G-2214-1)
$\Delta T_{1/4t}$ = **N/A** °F = (K_{IT}/M_T) * 0.44 using Figs. G-2214-1 & G-2214-2
Safety Factor = **1.50** (for hydrotest)
Factor = **1.2808** M_m concentration factor
M_m = **2.256** (for inside surface axial flaw)
Temperature Adjustment = **10.0** °F
Pressure Adjustment = **60.0** psig (hydrostatic pressure + Uncertainty)

Fluid Temperature T (°F)	**1/4t Temperature (°F)**	**K_{IC} (ksi*inch$^{1/2}$)**	**K_{IP} (ksi*inch$^{1/2}$)**	**Calculated Pressure P (psig)**	**Adjusted Temperature for P-T Curve (°F)**	**Adjusted Pressure for P-T Curve (psig)**
50.0	50.0	64.13	39.96	579	60.0	519
55.0	55.0	67.38	42.13	610	65.0	550
60.0	60.0	70.98	44.52	645	70.0	585
65.0	65.0	74.95	47.17	683	75.0	623
70.0	70.0	79.34	50.10	725	80.0	665
75.0	75.0	84.20	53.34	772	85.0	712
80.0	80.0	89.56	56.91	824	90.0	764
85.0	85.0	95.49	60.86	881	95.0	821
90.0	90.0	102.04	65.23	945	100.0	885
95.0	95.0	109.28	70.06	1014	105.0	954
100.0	100.0	117.28	75.39	1092	110.0	1,032
105.0	105.0	126.12	81.29	1177	115.0	1,117
110.0	110.0	135.90	87.80	1271	120.0	1,211
115.0	115.0	146.70	95.00	1376	125.0	1,316

Table 14: P-T Evaluation – Bottom Head Level A/B (Cooldown)

Pressure-Temperature Curve Calculation

(Core Not Critical/ Cooldown = Curve B)

Inputs:

Plant = **Yankee**
Component = **Bot. Head**
Vessel thickness, t = **5.9375** inches, so √t = 2.437 √inch
Vessel Radius, R = **103.1875** inches
ART_{NDT} = **30.0** °F
Cooldown Rate, CR = **100** °F/hr
K_{IT} = **10.49** ksi*inch1/2 (for cooldown rate above)
M_T = **N/A** (From App G, Fig. G-2214-1)
$\Delta T_{1/4t}$ = **N/A** °F = (K_{IT}/M_T) * 0.44 using Figs. G-2214-1 & G-2214-2
Safety Factor = **2.00** (for level A/B)
Factor = **1.2808** M_m concentration factor
M_m = **2.256** (for inside surface axial flaw)
Temperature Adjustment = **10.0** °F
Height of Water for a Full Vessel = **N/A** inches
Pressure Adjustment = **60.0** psig (hydrostatic pressure + uncertainty)

Fluid Temperature T (°F)	**1/4t Temperature (°F)**	**K_{IC} (ksi*inch$^{1/2}$)**	**K_{IP} (ksi*inch$^{1/2}$)**	**Calculated Pressure P (psig)**	**Adjusted Temperature for P-T Curve (°F)**	**Adjusted Pressure for P-T Curve (psig)**
50.0	50.0	64.13	26.82	388	60.0	328
55.0	55.0	67.38	28.45	412	65.0	352
60.0	60.0	70.98	30.25	438	70.0	378
65.0	65.0	74.95	32.23	467	75.0	407
70.0	70.0	79.34	34.43	499	80.0	439
75.0	75.0	84.20	36.86	534	85.0	474
80.0	80.0	89.56	39.54	573	90.0	513
85.0	85.0	95.49	42.50	615	95.0	555
90.0	90.0	102.04	45.78	663	100.0	603
95.0	95.0	109.28	49.40	715	105.0	655
100.0	100.0	117.28	53.40	773	110.0	713
105.0	105.0	126.12	57.82	837	115.0	777
110.0	110.0	135.90	62.71	908	120.0	848
115.0	115.0	146.70	68.11	986	125.0	926
120.0	120.0	158.63	74.07	1073	130.0	1,013
125.0	125.0	171.83	80.67	1168	135.0	1,108
130.0	130.0	186.40	87.96	1274	140.0	1,214
135.0	135.0	200.00	94.76	1372	145.0	1,312