ATTACHMENT 8

Westinghouse Report WCAP-15285,
Catawba Unit 2 Heatup and Cooldown Limit Curves for Normal Operation Using Code Case N-640

Westinghouse Non-Proprietary Class 3

WCAP-15285

Catawba Unit 2 Heatup and Cooldown Curves for Normal Operation Using Code Case N-640

Westinghouse Electric Company LLC

WCAP-15285

Catawba Unit 2
Heatup and Cooldown Limit Curves for Normal Operation Using Code Case N-640

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October 1999

Work Performed Under Shop Order DJSP-139

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EXECUTIVE SUMMARY

This report provides the methodology and results of the generation of heatup and cooldown pressure temperature limit curves for normal operation of the Catawba Unit 2 reactor vessel. These curves were generated based on the latest available reactor vessel information (Capsule V analysis, WCAP-15243[1]).

The Catawba Unit 2 heatup and cooldown pressure-temperature limit curves have been updated based on the use of the ASME Code Case N-640[3], "Alternative Reference Fracture Toughness For Development of P-T Limit Curves for Section XI, Division 1", which allows the use of the K_{Ic} methodology and a relaxation of the reactor vessel flange temperature requirement.

1 INTRODUCTION

Heatup and cooldown limit curves are calculated using the adjusted RT_{NDT} (reference nil-ductility temperature) corresponding to the limiting beltline region material of the reactor vessel. The adjusted RT_{NDT} of the limiting material in the core region of the reactor vessel is determined by using the unirradiated reactor vessel material fracture toughness properties, estimating the radiation-induced ΔRT_{NDT}, and adding a margin. The unirradiated RT_{NDT} is designated as the higher of either the drop weight nil-ductility transition temperature (NDTT) or the temperature at which the material exhibits at least 50 ft-lb of impact energy and 35-mil lateral expansion (normal to the major working direction) minus 60°F.

RT_{NDT} increases as the material is exposed to fast-neutron radiation. Therefore, to find the most limiting RT_{NDT} at any time period in the reactor's life, ΔRT_{NDT} due to the radiation exposure associated with that time period must be added to the unirradiated RT_{NDT} (IRT_{NDT}). The extent of the shift in RT_{NDT} is enhanced by certain chemical elements (such as copper and nickel) present in reactor vessel steels. The Nuclear Regulatory Commission (NRC) has published a method for predicting radiation embrittlement in Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials."[4] Regulatory Guide 1.99, Revision 2, is used for the calculation of Adjusted Reference Temperature (ART) values ($IRT_{NDT} + \Delta RT_{NDT}$ + margins for uncertainties) at the 1/4T and 3/4T locations, where T is the thickness of the vessel at the beltline region measured from the clad/base metal interface. The most limiting ART values are used in the generation of heatup and cooldown pressure-temperature limit curves.

2 PURPOSE

The Duke Energy Company contracted Westinghouse to analyze capsule V from the Catawba Unit 2 reactor vessel. As part of this analysis Westinghouse generated new heatup and cooldown curves for 22, 34 and 51 EFPY using K_{Ic} in place of K_{IR} for the calculation of the stress intensity factors. The heatup and cooldown curves were generated without margins for instrumentation errors and included a hydrostatic leak test limit curve from 2485 to 2000 psig and pressure-temperature limits for the vessel flange regions per the requirements of 10 CFR Part 50, Appendix G[5].

The purpose of this report is to present the calculations and the development of the Duke Energy Company Catawba Unit 2 heatup and cooldown curves for 22, 34 and 51 EFPY utilizing the K_{Ic} methodology[3]. In addition, this report provides justification for relaxing the reactor vessel flange requirements of Appendix G to 10CFR Part 50 based on the use of K_{Ic} methodology rather than the K_{Ir} methodology. The use of K_{Ic} and relaxation of the reactor vessel flange requirements will add substantial pressure margin to the heatup and cooldown curves. This increase in allowable pressure is presented in Section 5 of this report.

3 CRITERIA FOR ALLOWABLE PRESSURE-TEMPERATURE RELATIONSHIPS

3.1 Overall Approach

The ASME approach for calculating the allowable limit curves for various heatup and cooldown rates specifies that the total stress intensity factor, K_I, for the combined thermal and pressure stresses at any time during heatup or cooldown cannot be greater than the reference stress intensity factor, K_{Ic}, for the metal temperature at that time. K_{Ic} is obtained from the reference fracture toughness curve, defined in Code Case N-640, "Alternative Reference Fracture Toughness for Development of P-T Limit Curves for Section XI, Division 1", of the ASME Appendix G to Section XI[3 & 6]. The K_{Ic} curve is given by the following equation:

$$K_{Ic} = 33.2 + 20.734 * e^{[0.02(T - RT_{NDT})]} \quad (1)$$

where,

K_{Ic} = reference stress intensity factor as a function of the metal temperature T and the metal reference nil-ductility temperature RT_{NDT}

This K_{Ic} curve is based on the lower bound of static critical K_I values measured as a function of temperature on specimens of SA-533 Grade B Class1, SA-508-1, SA-508-2, SA-508-3 steel.

3.2 Methodology for Pressure-Temperature Limit Curve Development

The governing equation for the heatup-cooldown analysis is defined in Appendix G of the ASME Code as follows:

$$C^* K_{Im} + K_{It} < K_{Ic} \quad (2)$$

where,

K_{Im} = stress intensity factor caused by membrane (pressure) stress

K_{It} = stress intensity factor caused by the thermal gradients

K_{Ic} = function of temperature relative to the RT_{NDT} of the material

C = 2.0 for Level A and Level B service limits

C = 1.5 for hydrostatic and leak test conditions during which the reactor core is not critical

For membrane tension, the corresponding K_I for the postulated defect is:

$$K_{Im} = M_m \times (pR_i / t) \quad (3)$$

where, M_m for an inside surface flaw is given by:

$$M_m = 1.85 \text{ for } \sqrt{t} < 2,$$
$$M_m = 0.926\sqrt{t} \text{ for } 2 \le \sqrt{t} \le 3.464,$$
$$M_m = 3.21 \text{ for } \sqrt{t} > 3.464$$

Similarly, M_m for an outside surface flaw is given by:

$$M_m = 1.77 \text{ for } \sqrt{t} < 2,$$
$$M_m = 0.893\sqrt{t} \text{ for } 2 \le \sqrt{t} \le 3.464,$$
$$M_m = 3.09 \text{ for } \sqrt{t} > 3.464$$

and p = internal pressure, Ri = vessel inner radius, and t = vessel wall thickness.

For bending stress, the corresponding K_I for the postulated defect is:

$K_{Ib} = M_b$ * Maximum Stress, where M_b is two-thirds of M_m

The maximum K_I produced by radial thermal gradient for the postulated inside surface defect of G-2120 is $K_{It} = 0.953 \times 10^{-3} \times CR \times t^{2.5}$, where CR is the cooldown rate in °F/hr., or for a postulated outside surface defect, $K_{It} = 0.753 \times 10^{-3} \times HU \times t^{2.5}$, where HU is the heatup rate in °F/hr.

The through-wall temperature difference associated with the maximum thermal K_I can be determined from Fig. G-2214-1. The temperature at any radial distance from the vessel surface can be determined from Fig. G-2214-2 for the maximum thermal K_I.

(a) The maximum thermal K_I relationship and the temperature relationship in Fig. G-2214-1 are applicable only for the conditions given in G-2214.3(a)(1) and (2).

(b) Alternatively, the K_I for radial thermal gradient can be calculated for any thermal stress distribution and at any specified time during cooldown for a ¼-thickness inside surface defect using the relationship:

$$K_{It} = (1.0359C_0 + 0.6322C_1 + 0.4753C_2 + 0.3855C_3) * \sqrt{\pi a} \quad (4)$$

or similarly, K_{IT} during heatup for a ¼-thickness outside surface defect using the relationship:

$$K_{It} = (1.043C_0 + 0.630C_1 + 0.481C_2 + 0.401C_3) * \sqrt{\pi a} \quad (5)$$

where the coefficients C_0, C_1, C_2 and C_3 are determined from the thermal stress distribution at any specified time during the heatup or cooldown using the form:

$$\sigma(x) = C_0 + C_1(x/a) + C_2(x/a)^2 + C_3(x/a)^3 \qquad (6)$$

and x is a variable that represents the radial distance from the appropriate (i.e., inside or outside) surface to any point on the crack front and a is the maximum crack depth.

Note, that equations 3, 4 and 5 were implemented in the OPERLIM computer code, which is the program used to generate the pressure-temperature (P-T) limit curves. No other changes were made to the OPERLIM computer code with regard to P-T calculation methodology. Therefore, the P-T curve methodology is unchanged from that described in WCAP-14040[8], "Methodology used to Develop Cold Overpressure Mitigating system Setpoints and RCS Heatup and Cooldown Limit Curves", Section 2.6 (equations 2.6.2-4 and 2.6.3-1) with the exceptions just described above.

At any time during the heatup or cooldown transient, K_{Ic} is determined by the metal temperature at the tip of a postulated flaw at the 1/4T and 3/4T location, the appropriate value for RT_{NDT}, and the reference fracture toughness curve. The thermal stresses resulting from the temperature gradients through the vessel wall are calculated and then the corresponding (thermal) stress intensity factors, K_{It}, for the reference flaw are computed. From Equation 2, the pressure stress intensity factors are obtained and, from these, the allowable pressures are calculated.

For the calculation of the allowable pressure versus coolant temperature during cooldown, the reference flaw of Appendix G to the ASME Code is assumed to exist at the inside of the vessel wall. During cooldown, the controlling location of the flaw is always at the inside of the wall because the thermal gradients produce tensile stresses at the inside, which increase with increasing cooldown rates. Allowable pressure-temperature relations are generated for both steady-state and finite cooldown rate situations. From these relations, composite limit curves are constructed for each cooldown rate of interest.

The use of the composite curve in the cooldown analysis is necessary because control of the cooldown procedure is based on the measurement of reactor coolant temperature, whereas the limiting pressure is actually dependent on the material temperature at the tip of the assumed flaw. During cooldown, the 1/4T vessel location is at a higher temperature than the fluid adjacent to the vessel inner diameter. This condition, of course, is not true for the steady-state situation. It follows that, at any given reactor coolant temperature, the ΔT (temperature) developed during cooldown results in a higher value of K_{Ic} at the 1/4T location for finite cooldown rates than for steady-state operation. Furthermore, if conditions exist so that the increase in K_{Ic} exceeds K_{It}, the calculated allowable pressure during cooldown will be greater than the steady-state value.

The above procedures are needed because there is no direct control on temperature at the 1/4T location and, therefore, allowable pressures may unknowingly be violated if the rate of cooling is decreased at various intervals along a cooldown ramp. The use of the composite curve eliminates this problem and ensures conservative operation of the system for the entire cooldown period.

Three separate calculations are required to determine the limit curves for finite heatup rates As is done in the cooldown analysis, allowable pressure-temperature relationships are developed for steady-state conditions as well as finite heatup rate conditions assuming the presence of a 1/4T defect at the inside of the wall. The heatup results in compressive stresses at the inside surface that alleviate the tensile stresses produced by internal pressure. The metal temperature at the crack tip lags the coolant temperature; therefore, the K_{Ic} for the 1/4T crack during heatup is lower than the K_{Ic} for the 1/4T crack during steady-state conditions at the same coolant temperature. During heatup, especially at the end of the transient, conditions may exist so that the effects of compressive thermal stresses and lower K_{Ic} values do not offset each other, and the pressure-temperature curve based on steady-state conditions no longer represents a lower bound of all similar curves for finite heatup rates when the 1/4T flaw is considered. Therefore, both cases have to be analyzed in order to ensure that at any coolant temperature the lower value of the allowable pressure calculated for steady-state and finite heatup rates is obtained.

The second portion of the heatup analysis concerns the calculation of the pressure-temperature limitations for the case in which a 1/4T flaw located at the 1/4T location from the outside surface is assumed. Unlike the situation at the vessel inside surface, the thermal gradients established at the outside surface during heatup produce stresses which are tensile in nature and therefore tend to reinforce any pressure stresses present. These thermal stresses are dependent on both the rate of heatup and the time (or coolant temperature) along the heatup ramp. Since the thermal stresses at the outside are tensile and increase with increasing heatup rates, each heatup rate must be analyzed on an individual basis.

Following the generation of pressure-temperature curves for both the steady-state and finite heatup rate situations, the final limit curves are produced by constructing a composite curve based on a point-by-point comparison of the steady-state and finite heatup rate data. At any given temperature, the allowable pressure is taken to be the lesser of the three values taken from the curves under consideration. The use of the composite curve is necessary to set conservative heatup limitations because it is possible for conditions to exist wherein, over the course of the heatup ramp, the controlling condition switches from the inside to the outside, and the pressure limit must at all times be based on analysis of the most critical criterion.

3.3 Closure Head/Vessel Flange Requirements

10 CFR Part 50, Appendix G addresses the metal temperature of the closure head flange and vessel flange regions. This rule states that the metal temperature of the closure flange regions must exceed the material unirradiated RT_{NDT} by at least 120°F for normal operation when the pressure exceeds 20 percent of the preservice hydrostatic test pressure (3107 psi), which is 621 psig for Catawba Unit 2 reactor vessel.

This requirement was originally based on concerns about the fracture margin in the closure flange region. During the boltup process, stresses in this region typically reach over 70 percent of the steady-state stress without being at steady-state temperature. The margin of 120°F and the pressure limitation of 20 percent of hydrotest pressure were developed using K_{ia} fracture toughness, in the mid 1970's.

Improved knowledge of fracture toughness and other issues which affect the integrity of the reactor vessel have led to the recent change to allow the use of K_{Ic} in development of pressure-temperature curves, as contained in Code Case N-640, "Alternative Reference Fracture Toughness for Development

of P-T Limit Curves for Section XI, Division 1". The following discussion uses a similar approach (i.e. using K_{Ic}) here to develop equivalent reactor vessel flange temperature requirements.

The geometry of the closure head flange region for a typical Westinghouse four loop plant reactor vessel is shown in Figure 1. The stresses in this region are highest near the outside of the head. Therefore, an outside reference flaw of 25 percent of the wall thickness parallel to the dome to flange weld (i.e. in the direction of the welding) was postulated in this region. To be consistent with ASME Section XI, Appendix G, a safety factor of two was applied and a fracture calculation performed.

Figure 2 shows the crack driving force or stress intensity factor for the postulated flaw in this region, along with a second curve which incorporates the safety factor of two. Note that the stress intensity factor with a safety factor of one for this region does not exceed 55 ksi$\sqrt{\text{in.}}$, even for postulated flaws up to 50 percent of the wall thickness. For reference flaw, with the safety factor of two, the applied stress intensity factor is 85.15 ksi$\sqrt{\text{in.}}$ at 25 percent of the wall thickness.

The determination of the boltup, or reactor vessel flange requirement, is shown in Figure 3, where the fracture toughness is plotted as a function of the temperature. In this figure, the intersection between the stress intensity factor curve and the K_{ia} toughness curve occurs at a value slightly higher than $T - RT_{NDT}$ = 100°F, which is in the range of the existing 120°F requirement. The reference calculation used for the original requirement (which is no longer available) must have had a slightly higher value of K, about 98 ksi$\sqrt{\text{in.}}$ Note that the use of K_{Ic} curve to determine this requirement results in a revised requirement of $T - RT_{NDT}$ = 45°F, as seen in Figure 3.

Therefore, the appropriate flange requirement for use with the K_{Ic} curve is as follows:

The pressure in the vessel should not exceed 20 percent of the pre-service hydro-test pressure until the temperature exceeds $T - RT_{NDT}$ = 45°F. This requirement has been implemented with the curves presented in this report.

The limiting unirradiated RT_{NDT} of 10°F occurs in the closure head and vessel flanges of the Catawba Unit 2 reactor vessel, so the minimum allowable temperature of this region is 55°F at pressures greater than 621 psig with no margins for instrument uncertainties.

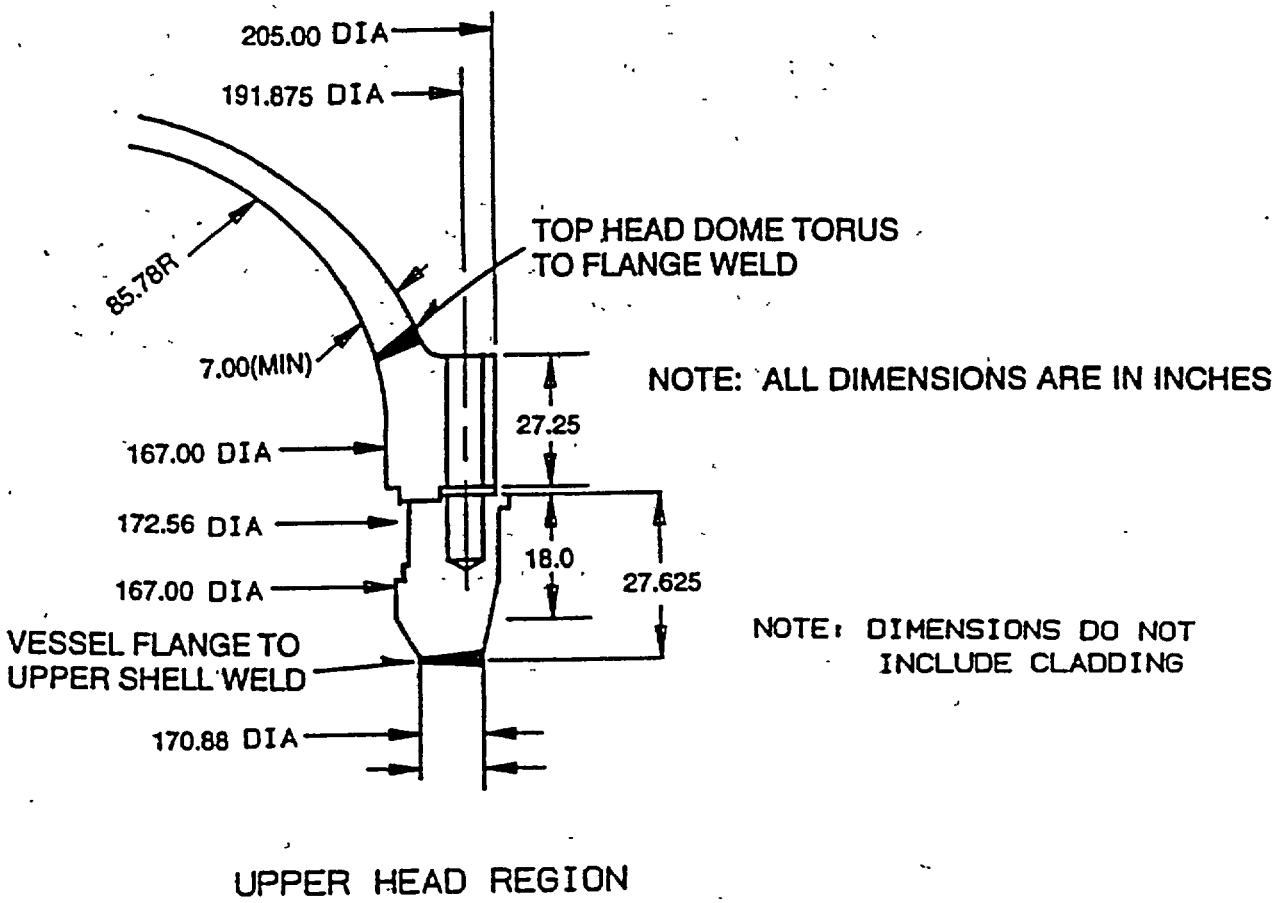

Figure 1 Geometry of the Upper Head/Flange Region of a Typical Westinghouse Four Loop Plant Reactor Vessel

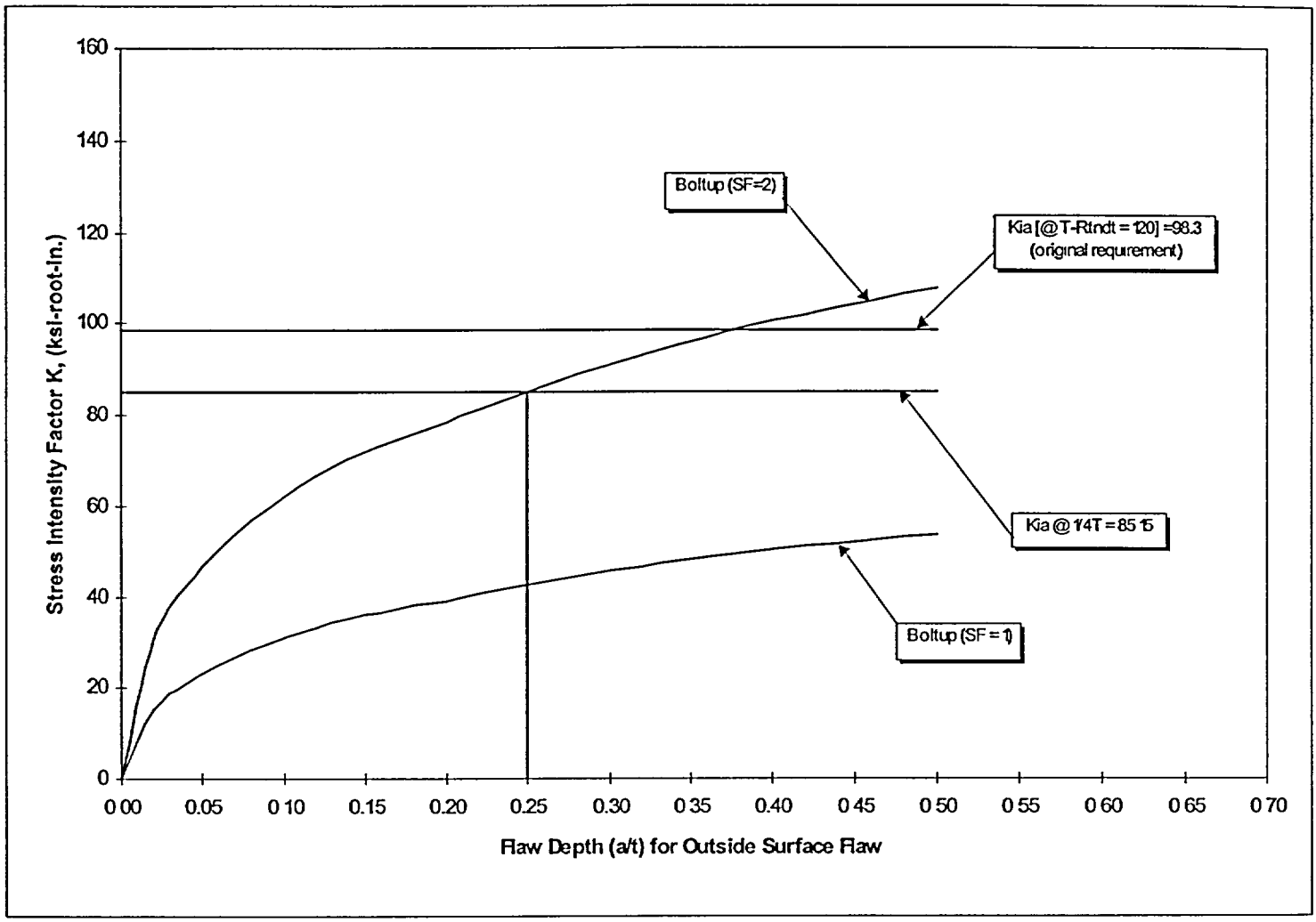

Figure 2 Crack Driving Force as a Function of Flaw Size: Outside Surface Flaw in the Closure Head to Flange Region Weld

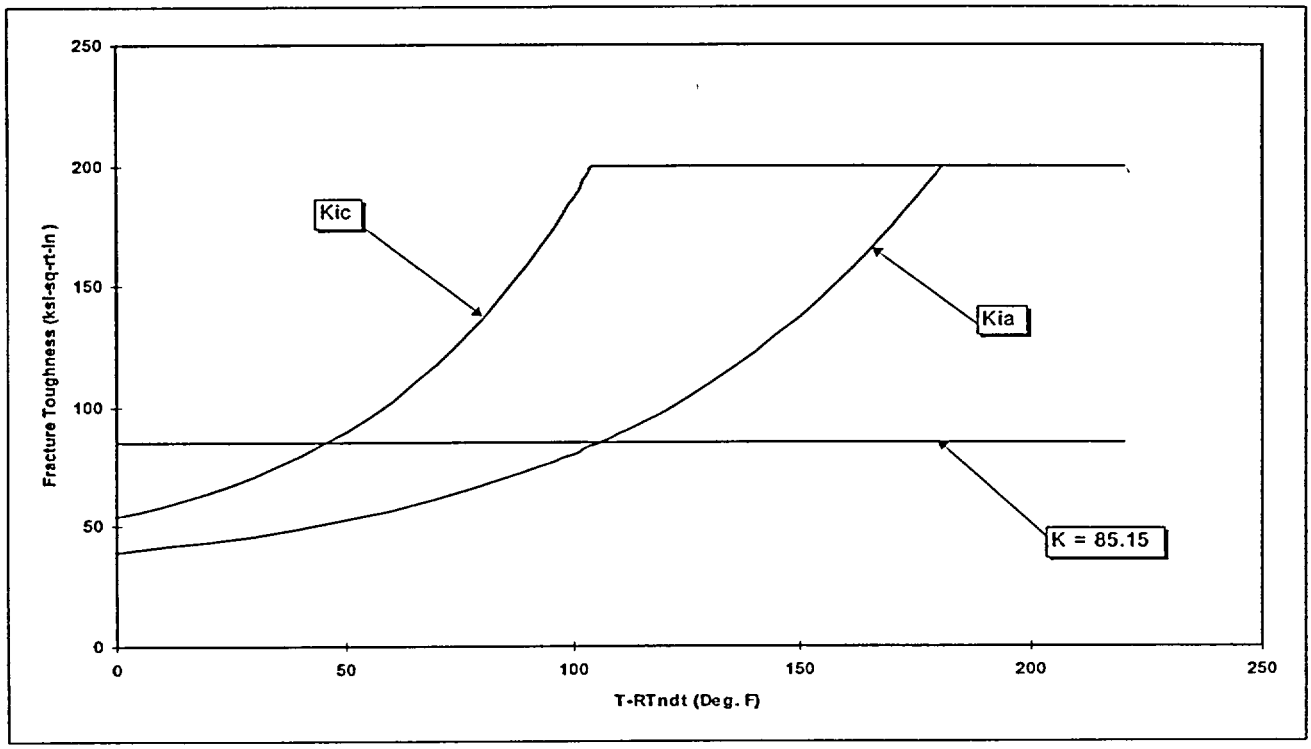

Figure 3 Determination of Boltup Requirement, Using K_{Ic}

4 CALCULATION OF ADJUSTED REFERENCE TEMPERATURE

From Regulatory Guide 1.99, Revision 2, the adjusted reference temperature (ART) for each material in the beltline region is given by the following expression:

$$ART = \text{Initial } RT_{NDT} + \Delta RT_{NDT} + \text{Margin} \quad (7)$$

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[7]. If measured values of initial RT_{NDT} for the material in question are not available, generic mean values for that class of material may be used if there are sufficient test results to establish a mean and standard deviation for the class.

ΔRT_{NDT} is the mean value of the adjustment in reference temperature caused by irradiation and should be calculated as follows:

$$\Delta RT_{NDT} = CF * f^{(0.28 - 0.10 \log f)} \quad (8)$$

To calculate ΔRT_{NDT} at any depth (e.g., at 1/4T or 3/4T), the following formula must first be used to attenuate the fluence at the specific depth.

$$f_{(depth\ x)} = f_{surface} * e^{(-0.24x)} \quad (9)$$

where x inches (vessel beltline thickness is 8.625 inches) is the depth into the vessel wall measured from the vessel clad/base metal interface. The resultant fluence is then placed in Equation 8 to calculate the ΔRT_{NDT} at the specific depth.

The Westinghouse Radiation Engineering and Analysis Group evaluated the vessel fluence projections as a part of WCAP-15243 and are also presented in a condensed version in Table 1 of this report. The evaluation used the ENDF/B-VI scattering cross-section data set. This is consistent with methods presented in WCAP-14040-NP-A, "Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves"[8]. Table 1 contains the calculated vessel surface fluences values along with the Regulatory Guide 1.99, Revision 2, 1/4T and 3/4T calculated fluences used to calculate the ART values for all beltline materials in the Catawba Unit 2 reactor vessel. Additionally, the surveillance capsule fluence values are presented in Table 2.

TABLE 1
Summary of the Peak Pressure Vessel Neutron Fluence Values
used for the Calculation of ART Values

EFPY	Surface	¼ T	¾ T
22	1.31×10^{19}	7.81×10^{18}	2.77×10^{18}
34	2.01×10^{19}	1.20×10^{19}	4.26×10^{18}
51	2.99×10^{19}	1.78×10^{19}	6.33×10^{18}

Notes:

(a) 1/4T and 3/4T = $F_{(Surface)} * e^{(-0.24*x)}$, where x is the depth into the vessel wall (i.e. 8.625*0.25 or 0.75)

TABLE 2
Measured Integrated Neutron Exposure of the Catawba Unit 2 Surveillance Capsules Tested To Date

Plant	Capsule	Fluence
Catawba Unit 2	Z	3.23×10^{18} n/cm^2, (E > 1.0 MeV)
Catawba Unit 2	X	1.23×10^{19} n/cm^2, (E > 1.0 MeV)
Catawba Unit 2	V	2.38×10^{19} n/cm^2, (E > 1.0 MeV)
Catawba Unit 2	Y	2.49×10^{19} n/cm^2, (E > 1.0 MeV)

Margin is calculated as, $M = 2\sqrt{\sigma_I^2 + \sigma_\Delta^2}$. The standard deviation for the initial RT_{NDT} margin term, is σ_I 0°F when the initial RT_{NDT} is a measured value, and 17°F when a generic value is available. The standard deviation for the ΔRT_{NDT} margin term, σ_Δ, is 17°F for plates or forgings, and 8.5°F for plates or forgings when surveillance data is used. For welds, σ_Δ is equal to 28°F when surveillance capsule data is not used, and is 14°F (half the value) when credible surveillance capsule data is used. σ_Δ need not exceed 0.5 times the mean value of ΔRT_{NDT}.

Contained in Table 3 is a summary of the Measured 30 ft-lb transition temperature shifts of the beltline materials[1]. These measured shift values were obtained using CVGRAPH, Version 4.1[9], which is a hyperbolic tangent curve-fitting program.

TABLE 3

Measured 30 ft-lb Transition Temperature Shifts of all Available Surveillance Data

Material	Capsule	Measured 30 ft-lb Transition Temperature Shift[(b)]
Intermediate Shell Plate	Z	24.68
B8605-1	X	48.07
(Longitudinal)	V	44.76
Inter. Shell Plate	Z	29.55
B8605-1	X	52.17
(Transverse)	V	61.29
Surveillance Program	Z	-30.25[(a)]
Weld Metal	X	34.94
	V	58.80

Notes:

(a) This value will be assumed to be 0°F in this evaluation for conservatism (i.e. higher CF value).

(b) Values documented in WCAP-15243[1].

Table 4 contains a summary of the weight percent of copper, the weight percent of nickel and the initial RT_{NDT} of the beltline materials and vessel flanges. The weight percent values of Cu and Ni given in Table 4 were used to generate the calculated chemistry factor (CF) values based on Tables 1 and 2 of Regulatory Guide 1.99, Revision 2, and presented in Table 6. Table 5 provides the calculation of the CF values based on surveillance capsule data, Regulatory Guide 1.99, Revision 2, Position 2.1, which are also summarized in Table 6.

TABLE 4
Reactor Vessel Beltline Material Unirradiated Toughness Properties

Material Description	Cu (%)	Ni(%)	Initial RT_{NDT}[a]
Closure Head Flange B8601-1	---	0.70	10
Vessel Flange B8602-1	---	0.71	10
Intermediate Shell Plate B8605-1	0.08	0.62	15
Intermediate Shell Plate B8605-2	0.08	0.61	33
Intermediate Shell Plate B8616-1	0.05	0.60	12
Lower Shell Plate B8806-1	0.06	0.56	6
Lower Shell Plate B8806-2	0.06	0.59	-10
Lower Shell Plate B8806-3	0.06	0.59	8
Intermediate Shell Plate Longitudinal Weld Seams 101-124A, B, C (Heat # 83648)	0.04	0.14	-80
Lower Shell Plate Longitudinal Weld Seams 101-142A, B, C (Heat # 83648)	0.04	0.14	-80
Intermediate to Lower Shell Plate Circumferential Weld Seam 101-171 (Heat # 83648)	0.04	0.14	-80
Surveillance Weld Catawba Unit 2 (Heat # 83648)[b]	0.04[c]	0.16[c]	---

Notes:

(a) Based on measured data.

(b) The surveillance weld was made with the same weld wire and flux as the intermediate and lower shell longitudinal welds and the intermediate to lower shell girth weld (Weld wire heat number 83648 and Linde 0091 flux, lot number 3536).

(c) Copper is the average of the two surveillance data points, 0.036 and 0.051. Nickel is the average of the two surveillance data points, 0.14 and 0.18

TABLE 5

Calculation of Chemistry Factors using Catawba Unit 2 Surveillance Capsule Data

Material	Capsule	Capsule f[a]	FF[b]	ΔRT_{NDT}[c]	$FF*\Delta RT_{NDT}$	FF^2
Inter. Shell Plate	Z	0.323	0.689	24.68	17.00	0.475
B8605-1	X	1.23	1.058	48.07	50.86	1.119
(Longitudinal)	V	2 38	1.234	44.76	55.23	1.523
Inter. Shell Plate	Z	0.323	0.689	29.55	20.36	0.475
B8605-1	X	1.29	1.058	52.17	55.20	1.119
(Transverse)	V	2.38	1.234	61.29	75.63	1.523
				SUM:	274.28	6.234
	$CF = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (274.28) \div (6.234) = 44.0°F$					
Catawba Unit 2 Surv.	Z	0.323	0.689	0.00[d, e]	0.00	0.475
Weld Material	X	1.29	1.058	33.19 (34.94)[d]	35.12	1.119
	V	2 38	1.234	55.86 (58.8)[d]	68.93	1.523
				SUM:	104.05	3.117
	$CF = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (104.05) \div (3.117) = 33.4°F$					

Notes:

(a) f = Calculated fluence from capsule V dosimetry analysis results[9], (x 10^{19} n/cm^2, E > 1.0 MeV).

(b) FF = fluence factor = $f^{(0.28 - 0.1*\log f)}$.

(c) ΔRT_{NDT} values are the measured 30 ft-lb shift values for Catawba 2 taken from App. B or C of Reference 9.

(d) The surveillance weld metal ΔRT_{NDT} values have been adjusted by a ratio factor of 0.95 (See calc. on previous page).

(e) Actual value of ΔRT_{NDT} is -30 25. This physically should not occur, therefore for conservatism (i.e. higher chemistry factor) a value of zero will be used.

TABLE 6

Summary of the Catawba Unit 2 Reactor Vessel Beltline Material Chemistry Factors

Material	Reg. Guide 1.99, Rev. 2 Position 1.1 CF's	Reg. Guide 1.99, Rev. 2 Position 2.1 CF's
Intermediate Shell Plate B8605-1	51.0°F	44.0°F
Intermediate Shell Plate B8605-2	51.0°F	*
Intermediate Shell Plate B8616-1	31.0°F	*
Lower Shell Plate B8806-1	37.0°F	*
Lower Shell Plate B8806-2	37.0°F	*
Lower Shell Plate B8806-3	37.0°F	*
Intermediate Shell Plate Longitudinal Weld Seams 101-124A, B, C (Heat # 83648)	37.3°F	33.4°F
Lower Shell Plate Longitudinal Weld Seams 101-142A, B, C (Heat # 83648)	37.3°F	33.4°F
Intermediate to Lower Shell Plate Circumferential Weld Seam 101-171 (Heat # 83648)	37.3°F	33.4°F
Surveillance Weld Catawba Unit 2 (Heat # 83648)	39.2°F	---

* No surveillance material, thus Position 2.1 does not apply.

Contained in Table 7 is a summary of the fluence factors (FF) used in the calculation of adjusted reference temperatures for the Catawba Unit 2 reactor vessel beltline materials.

TABLE 7
Summary of the Calculated Fluence Factors Used for the Generation of the 22, 34 and 51 EFPY Heatup and Cooldown Curves

EFPY	1/4T FF	3/4T FF
22	0.931	0.650
34	1.051	0.763
51	1.158	0.872

Note: $FF = fluence^{(0.28 - 0.1 Log(fluence))}$, where the fluence is taken from Table 1.

Based on the surveillance program credibility evaluation presented in Appendix D to WCAP-15243, the Catawba Unit 2 surveillance program data is credible. In addition, the surveillance program weld metal is representative of all of the beltline region girth weld seam. Hence, the adjusted reference temperature (ART) must be calculated for 22, 34 and 51 EFPY for each beltline material at the 1/4T and 3/4T locations. In addition, ART values must be calculated per Regulatory Guide 1.99, Revision 2, Position 1.1 and 2.1

Contained in Tables 8 through 13 are the calculations of the 22, 34 and 51 EFPY ART values used for generation of the heatup and cooldown curves.

TABLE 8
Calculation of the ART Values for the 1/4T Location @ 22 EFPY

Material	Reg. Guide 1.99 Rev. 2 Method	CF (°F)	FF	IRT_{NDT}[(a)] (°F)	ΔRT_{NDT}[(b)] (°F)	M (°F)	ART[(c)] (°F)
Intermediate Shell Plate	Position 1.1	51.0	0.931	15	47.5	34	97
B8605-1	Position 2.1	44.0	0.931	15	41.0	17	73
Intermediate Shell Plate B8605-2	Position 1.1	51.0	0.931	33	47.5	34	115
Intermediate Shell Plate B8616-1	Position 1.1	31.0	0.931	12	28.9	28.9	70
Lower Shell Plate B8806-1	Position 1.1	37.0	0.931	6	34.4	34	74
Lower Shell Plate B8806-2	Position 1.1	37.0	0.931	-10	34.4	34	58
Lower Shell Plate B8806-3	Position 1.1	37.0	0.931	8	34.4	34	76
Inter. Shell Longitudinal	Position 1.1	37.3	0.931	-80	34.7	34.7	-11
Weld Seams 101-124A,B,C	Position 2.1	33.4	0.931	-80	31.1	28.0	-21
Lower Shell Longitudinal	Position 1.1	37.3	0.931	-80	34.7	34.7	-11
Weld Seams 101-124A,B,C	Position 2.1	33.4	0.931	-80	31.1	28.0	-21
Circumferential Weld Seam	Position 1.1	37.3	0.931	-80	34.7	34.7	-11
101-171	Position 2.1	33.4	0.931	-80	31.1	28.0	-21

NOTES:
(a) Initial RT_{NDT} values are measured values.
(b) $\Delta RT_{NDT} = CF * FF$
(c) $ART = I + \Delta RT_{NDT} + M$ (This value was rounded per ASTM E29, using the "Rounding Method".)

TABLE 9
Calculation of the ART Values for the 3/4T Location @ 22 EFPY

Material	Reg. Guide 1.99 Rev. 2 Method	CF (°F)	FF	IRT_{NDT}[(a)] (°F)	ΔRT_{NDT}[(b)] (°F)	M (°F)	ART[(c)] (°F)
Intermediate Shell Plate	Position 1.1	51.0	0.650	15	33.2	33.2	81
B8605-1	Position 2.1	44.0	0.650	15	28.6	17.0	61
Intermediate Shell Plate B8605-2	Position 1.1	51.0	0.650	33	33.2	33.2	99
Intermediate Shell Plate B8616-1	Position 1.1	31.0	0.650	12	20.2	20.2	52
Lower Shell Plate B8806-1	Position 1.1	37.0	0.650	6	24.1	24.1	54
Lower Shell Plate B8806-2	Position 1.1	37.0	0.650	-10	24.1	24.1	38
Lower Shell Plate B8806-3	Position 1.1	37.0	0.650	8	24.1	24.1	56
Inter. Shell Longitudinal	Position 1.1	37.3	0.650	-80	24.2	24.2	-32
Weld Seams 101-124A,B,C	Position 2.1	33.4	0.650	-80	21.7	21.7	-37
Lower Shell Longitudinal	Position 1.1	37.3	0.650	-80	24.2	24.2	-32
Weld Seams 101-124A,B,C	Position 2.1	33.4	0.650	-80	21.7	21.7	-37
Circumferential Weld Seam	Position 1.1	37.3	0.650	-80	24.2	24.2	-32
101-171	Position 2.1	33.4	0.650	-80	21.7	21.7	-37

NOTES:
(a) Initial RT_{NDT} values are measured values.
(b) $\Delta RT_{NDT} = CF * FF$
(c) $ART = I + \Delta RT_{NDT} + M$ (This value was rounded per ASTM E29, using the "Rounding Method".)

TABLE 10
Calculation of the ART Values for the 1/4T Location @ 34 EFPY

Material	Reg. Guide 1.99 Rev. 2 Method	CF (°F)	FF	IRT_{NDT}[a] (°F)	ΔRT_{NDT}[b] (°F)	M (°F)	ART[c] (°F)
Intermediate Shell Plate	Position 1.1	51.0	1.051	15	53.6	34	103
B8605-1	Position 2.1	44.0	1.051	15	46.2	17	78
Intermediate Shell Plate B8605-2	Position 1.1	51.0	1.051	33	53.6	34	121
Intermediate Shell Plate B8616-1	Position 1.1	31.0	1.051	12	32.6	32.6	77
Lower Shell Plate B8806-1	Position 1.1	37.0	1.051	6	38.9	34	69
Lower Shell Plate B8806-2	Position 1.1	37.0	1.051	-10	38.9	34	63
Lower Shell Plate B8806-3	Position 1.1	37.0	1.051	8	38.9	34	81
Inter. Shell Longitudinal	Position 1.1	37.3	1.051	-80	39.2	39.2	-2
Weld Seams 101-124A,B,C	Position 2.1	33.4	1.051	-80	35.1	28.0	-17
Lower Shell Longitudinal	Position 1.1	37.3	1.051	-80	39.2	39.2	-2
Weld Seams 101-124A,B,C	Position 2.1	33.4	1.051	-80	35.1	28.0	-17
Circumferential Weld Seam	Position 1.1	37.3	1.051	-80	39.2	39.2	-2
101-171	Position 2.1	33.4	1.051	-80	35.1	28.0	-17

NOTES:
(a) Initial RT_{NDT} values are measured values
(b) $\Delta RT_{NDT} = CF * FF$
(c) $ART = I + \Delta RT_{NDT} + M$ (This value was rounded per ASTM E29, using the "Rounding Method".)

TABLE 11
Calculation of the ART Values for the 3/4T Location @ 34 EFPY

Material	Reg. Guide 1.99 Rev. 2 Method	CF (°F)	FF	IRT_{NDT}[a] (°F)	ΔRT_{NDT}[b] (°F)	M (°F)	ART[c] (°F)
Intermediate Shell Plate	Position 1.1	51.0	0.763	15	38.9	34	88
B8605-1	Position 2.1	44.0	0.763	15	33.6	17	66
Intermediate Shell Plate B8605-2	Position 1.1	51.0	0.763	33	38.9	34	106
Intermediate Shell Plate B8616-1	Position 1.1	31.0	0.763	12	23.7	23.7	59
Lower Shell Plate B8806-1	Position 1.1	37.0	0.763	6	28.2	28.2	62
Lower Shell Plate B8806-2	Position 1.1	37.0	0.763	-10	28.2	28.2	46
Lower Shell Plate B8806-3	Position 1.1	37.0	0.763	8	28.2	28.2	64
Inter. Shell Longitudinal	Position 1.1	37.3	0.763	-80	28.5	28.5	-23
Weld Seams 101-124A,B,C	Position 2.1	33.4	0.763	-80	25.5	25.5	-29
Lower Shell Longitudinal	Position 1.1	37.3	0.763	-80	28.5	28.5	-23
Weld Seams 101-124A,B,C	Position 2.1	33.4	0.763	-80	25.5	25.5	-29
Circumferential Weld Seam	Position 1.1	37.3	0.763	-80	28.5	28.5	-23
101-171	Position 2.1	33.4	0.763	-80	25.5	25.5	-29

NOTES:
(a) Initial RT_{NDT} values are measured values.
(b) $\Delta RT_{NDT} = CF * FF$
(c) $ART = I + \Delta RT_{NDT} + M$ (This value was rounded per ASTM E29, using the "Rounding Method".)

TABLE 12
Calculation of the ART Values for the 1/4T Location @ 51 EFPY

Material	Reg. Guide 1.99 Rev. 2 Method	CF (°F)	FF	IRT_{NDT}[a] (°F)	ΔRT_{NDT}[b] (°F)	M (°F)	ART[c] (°F)
Intermediate Shell Plate	Position 1.1	51.0	1.158	15	59.1	34	108
B8605-1	Position 2.1	44.0	1.158	15	51.0	17	83
Intermediate Shell Plate B8605-2	Position 1.1	51.0	1.158	33	59.1	34	126
Intermediate Shell Plate B8616-1	Position 1.1	31.0	1.158	12	35.9	34	82
Lower Shell Plate B8806-1	Position 1.1	37.0	1.158	6	42.8	34	83
Lower Shell Plate B8806-2	Position 1.1	37.0	1.158	-10	42.8	34	67
Lower Shell Plate B8806-3	Position 1.1	37.0	1.158	8	42.8	34	85
Inter. Shell Longitudinal	Position 1.1	37.3	1.158	-80	43.2	43.2	6
Weld Seams 101-124A,B,C	Position 2.1	33.4	1.158	-80	38.7	28.0	-13
Lower Shell Longitudinal	Position 1.1	37.3	1.158	-80	43.2	43.2	6
Weld Seams 101-124A,B,C	Position 2.1	33.4	1.158	-80	38.7	28.0	-13
Circumferential Weld Seam	Position 1.1	37.3	1.158	-80	43.2	43.2	6
101-171	Position 2.1	33.4	1.158	-80	38.7	28.0	-13

NOTES:
(a) Initial RT_{NDT} values are measured values.
(b) $\Delta RT_{NDT} = CF * FF$
(c) $ART = I + \Delta RT_{NDT} + M$ (This value was rounded per ASTM E29, using the "Rounding Method".)

TABLE 13
Calculation of the ART Values for the 3/4T Location @ 51 EFPY

Material	Reg. Guide 1.99 Rev. 2 Method	CF (°F)	FF	IRT_{NDT}[a] (°F)	ΔRT_{NDT}[b] (°F)	M (°F)	ART[c] (°F)
Intermediate Shell Plate	Position 1.1	51.0	0.872	15	44.5	34	94
B8605-1	Position 2.1	44.0	0.872	15	38.4	17	70
Intermediate Shell Plate B8605-2	Position 1.1	51.0	0.872	33	44.5	34	112
Intermediate Shell Plate B8616-1	Position 1.1	31.0	0.872	12	27.0	27.0	66
Lower Shell Plate B8806-1	Position 1.1	37.0	0.872	6	32.3	32.3	71
Lower Shell Plate B8806-2	Position 1.1	37.0	0.872	-10	32.3	32.3	55
Lower Shell Plate B8806-3	Position 1.1	37.0	0.872	8	32.3	32.3	73
Inter. Shell Longitudinal	Position 1.1	37.3	0.872	-80	32.5	32.5	-15
Weld Seams 101-124A,B,C	Position 2.1	33.4	0.872	-80	29.1	28.0	-22
Lower Shell Longitudinal	Position 1.1	37.3	0.872	-80	32.5	32.5	-15
Weld Seams 101-124A,B,C	Position 2.1	33.4	0.872	-80	29.1	28.0	-22
Circumferential Weld Seam	Position 1.1	37.3	0.872	-80	32.5	32.5	-15
101-171	Position 2.1	33.4	0.872	-80	29.1	28.0	-22

NOTES:
(a) Initial RT_{NDT} values are measured values
(b) $\Delta RT_{NDT} = CF * FF$
(c) $ART = I + \Delta RT_{NDT} + M$ (This value was rounded per ASTM E29, using the "Rounding Method".)

The intermediate shell plate B8605-2 is the limiting beltline material for all heatup and cooldown curves to be generated. Since the limiting material is not a circumferential weld, then the curves need not consider the circ. flaw methodology. Contained in Table 10 is a summary of the limiting ARTs to be used in the generation of the Catawba Unit 2 reactor vessel heatup and cooldown curves.

TABLE 14
Summary of the Limiting ART Values Used in the
Generation of the Catawba Unit 2 Heatup/Cooldown Curves

EFPY	1/4T Limiting ART	3/4T Limiting ART
22	115	99
34	121	106
51	126	112

5 HEATUP AND COOLDOWN PRESSURE-TEMPERATURE LIMIT CURVES

Pressure-temperature limit curves for normal heatup and cooldown of the primary reactor coolant system have been calculated for the pressure and temperature in the reactor vessel beltline region using the methods[2] discussed in Sections 3.0 and 4.0 of this report. The pressure difference between the wide-range pressure transmitter and the limiting beltline region has not been accounted for in the pressure-temperature limit curves generated for normal operation.

Figures 4 through 6, 8 through 10 and 12 through 14 present the heatup curve without margins for possible instrumentation errors using heatup rates of 60, 80 and 100°F/hr applicable for the first 22, 34 and 51 EFPY, respectively. Figures 7, 11 and 15 present the cooldown curves without margins for possible instrumentation errors using cooldown rates of 0, 20, 40, 60 and 100°F/hr applicable for 22, 34 and 51 EFPY, respectively. Allowable combinations of temperature and pressure for specific temperature change rates are below and to the right of the limit lines shown in Figures 4 through 15. This is in addition to other criteria which must be met before the reactor is made critical, as discussed below in the following paragraphs.

The reactor must not be made critical until pressure-temperature combinations are to the right of the criticality limit line shown in Figures 4 through 6, 8 through 10 and 12 through 14. The straight-line portion of the criticality limit is at the minimum permissible temperature for the 2485 psig inservice hydrostatic test as required by Appendix G to 10 CFR Part 50. The governing equation for the hydrostatic test is defined in Code Case N-640[3] as follows:

$$1.5\, K_{Im} < K_{Ic}$$

where,

K_{Im} is the stress intensity factor covered by membrane (pressure) stress,

$K_{Ic} = 33.2 + 20.734\, e^{[0.02\,(T - RT_{NDT})]}$,

T is the minimum permissible metal temperature, and

RT_{NDT} is the metal reference nil-ductility temperature.

The criticality limit curve specifies pressure-temperature limits for core operation to provide additional margin during actual power production as specified in Reference 5. The pressure-temperature limits for core operation (except for low power physics tests) are that the reactor vessel must be at a temperature equal to or higher than the minimum temperature required for the inservice hydrostatic test, and at least 40°F higher than the minimum permissible temperature in the corresponding pressure-temperature curve for heatup and cooldown calculated as described in Section 3.0 of this report. For the heatup and cooldown curves without margins for instrumentation errors, the minimum temperature for the in service hydrostatic leak tests for the Catawba Unit 2 reactor vessel at 22, 34 and 51 EFPY is 175°F, 181°F and 186°F, respectively. The vertical line drawn from these points on the pressure-temperature curve, intersecting a curve 40°F higher than the pressure-temperature limit curve, constitutes the limit for core operation for the reactor vessel.

Figures 4 through 15 define all of the above limits for ensuring prevention of nonductile failure for the Catawba Unit 2 reactor vessel.

The data points used for the heatup and cooldown pressure-temperature limit curves shown in Figures 4 through 15 are presented in Tables 15 through 20. When K_{Ic} and a relaxed reactor vessel flange temperature requirement is used in the calculation of heatup and cooldown limit curves, there is a significant increase in allowable pressure. This increase in allowable pressure associated with the K_{Ic} methodology and relaxed reactor vessel flange requirement has created a "knee" in the heatup curves which show the transition of the heatup curve from steady-state limiting to heatup rate "X°F/hr.". This can also be seen in Tables 15 through 20.

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL PLATE B8605-2
LIMITING ART VALUES AT 22 EFPY: 1/4T, 115°F
3/4T, 99°F

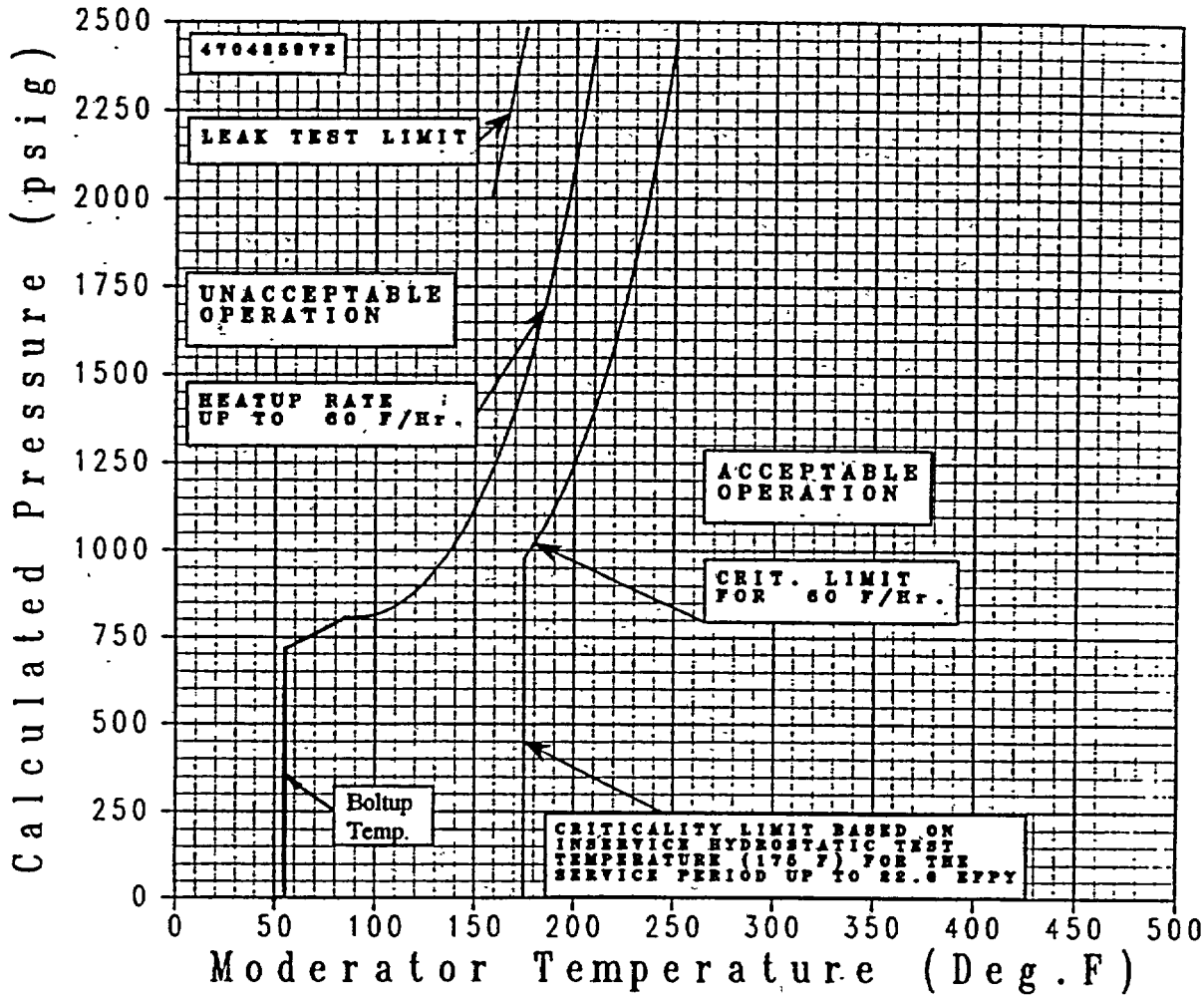

Figure 4 **Catawba Unit 2 Reactor Coolant System Heatup Limitations (Heatup Rate of 60°F/hr) Applicable for the First 22 EFPY (Without Margins for Instrumentation Errors)**

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL PLATE B8605-2
LIMITING ART VALUES AT 22 EFPY: 1/4T, 115°F
3/4T, 99°F

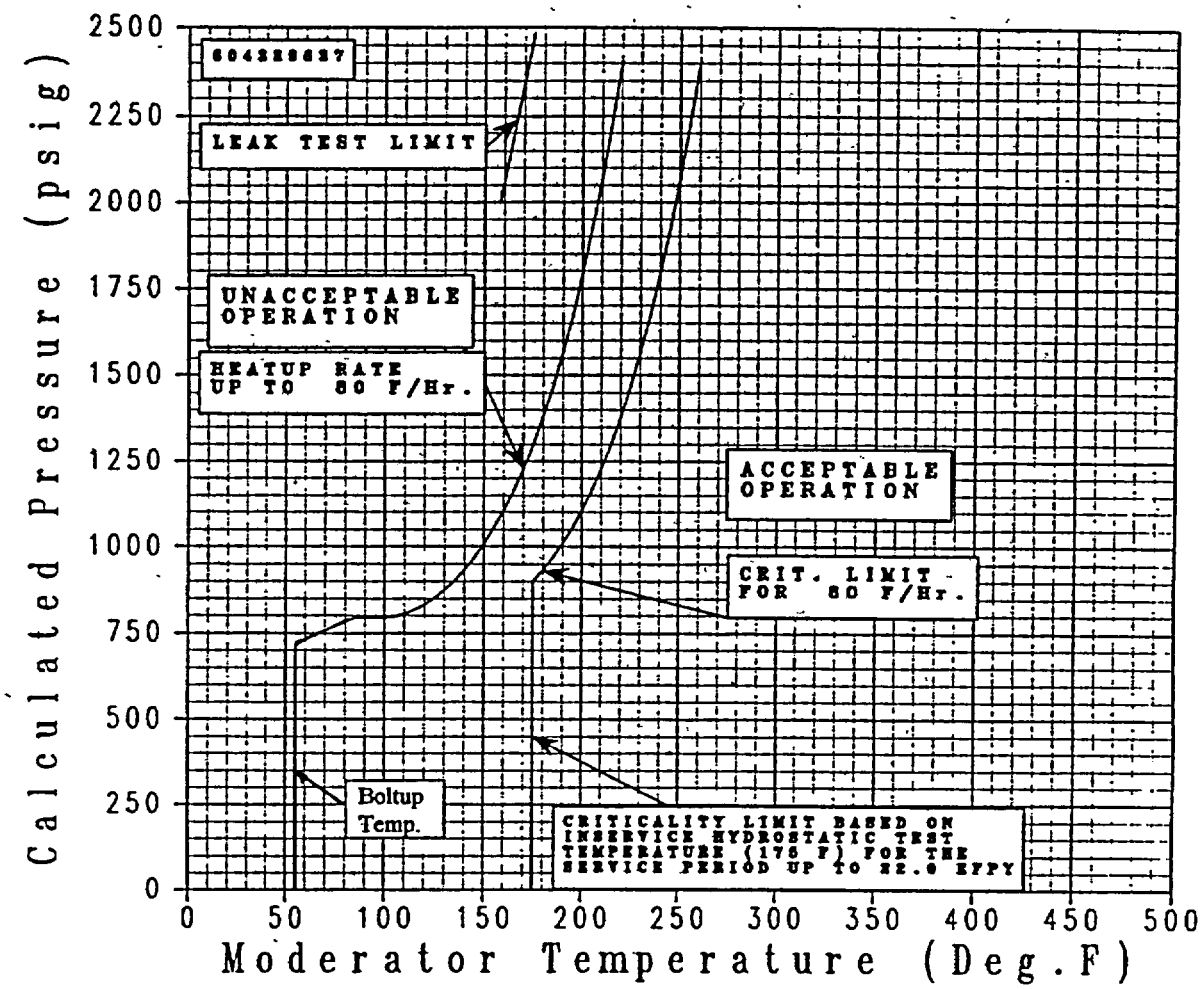

Figure 5 **Catawba Unit 2 Reactor Coolant System Heatup Limitations (Heatup Rate of 80°F/hr) Applicable for the First 22 EFPY (Without Margins for Instrumentation Errors)**

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL PLATE B8605-2
LIMITING ART VALUES AT 22 EFPY: 1/4T, 115°F
3/4T, 99°F

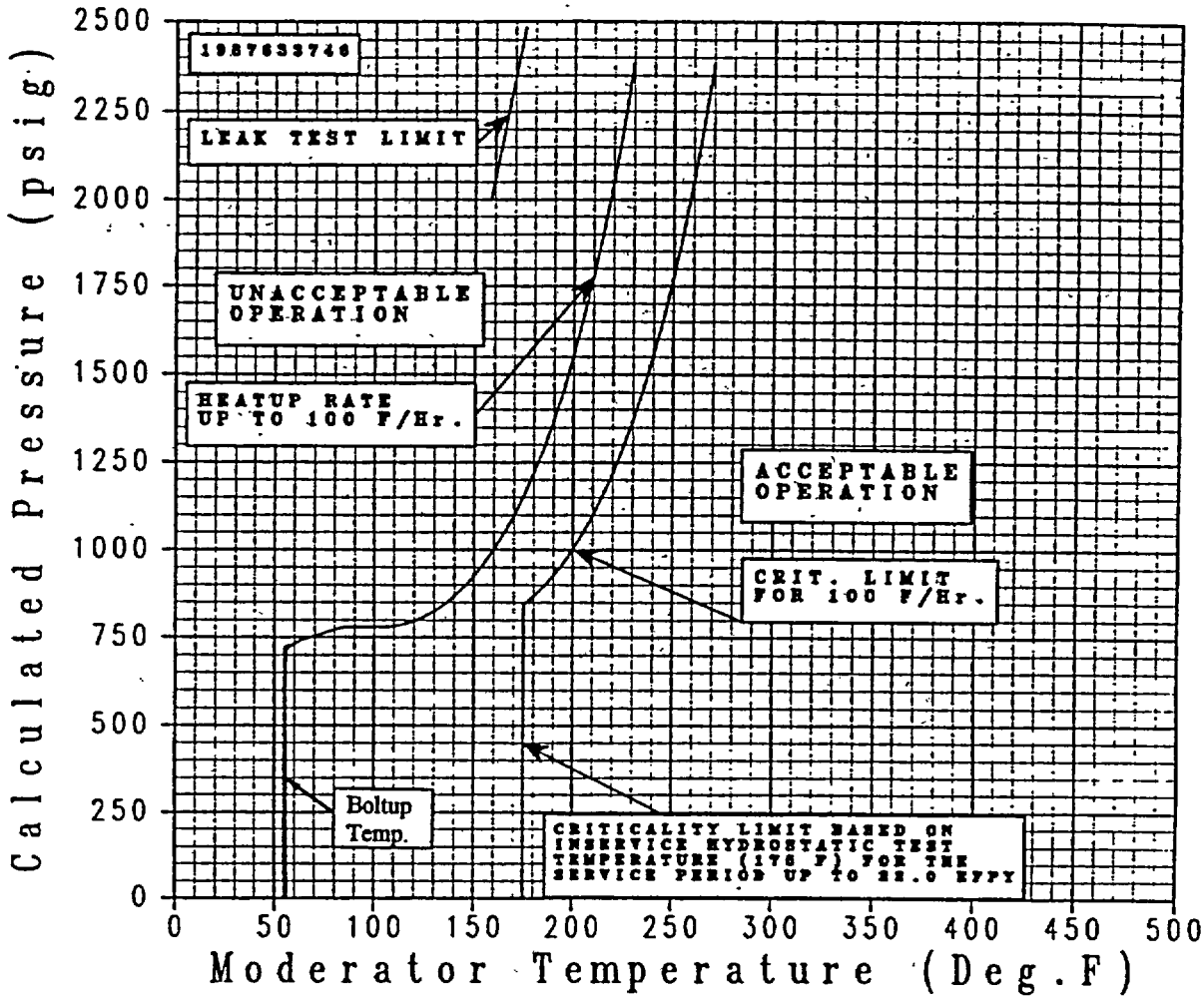

Figure 6 **Catawba Unit 2 Reactor Coolant System Heatup Limitations (Heatup Rate of 100°F/hr) Applicable for the First 22 EFPY (Without Margins for Instrumentation Errors)**

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL PLATE B8605-2
LIMITING ART VALUES AT 22 EFPY: 1/4T, 115°F
3/4T, 99°F

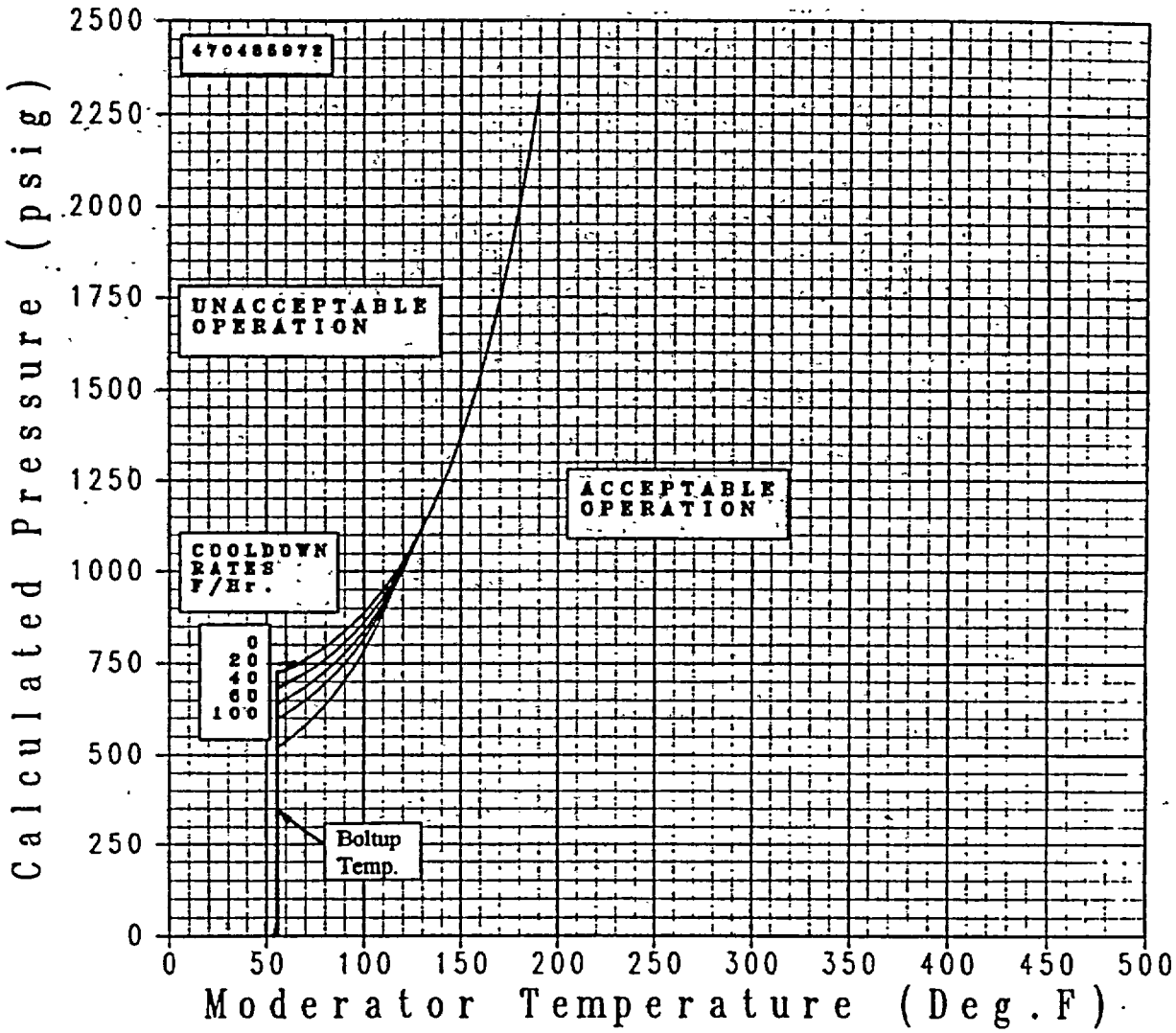

Figure 7 **Catawba Unit 2 Reactor Coolant System Cooldown Limitations (Cooldown Rates up to 100°F/hr) Applicable for the First 22 EFPY (Without Margins for Instrumentation Errors)**

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL PLATE B8605-2
LIMITING ART VALUES AT 34 EFPY: 1/4T, 121°F
3/4T, 106°F

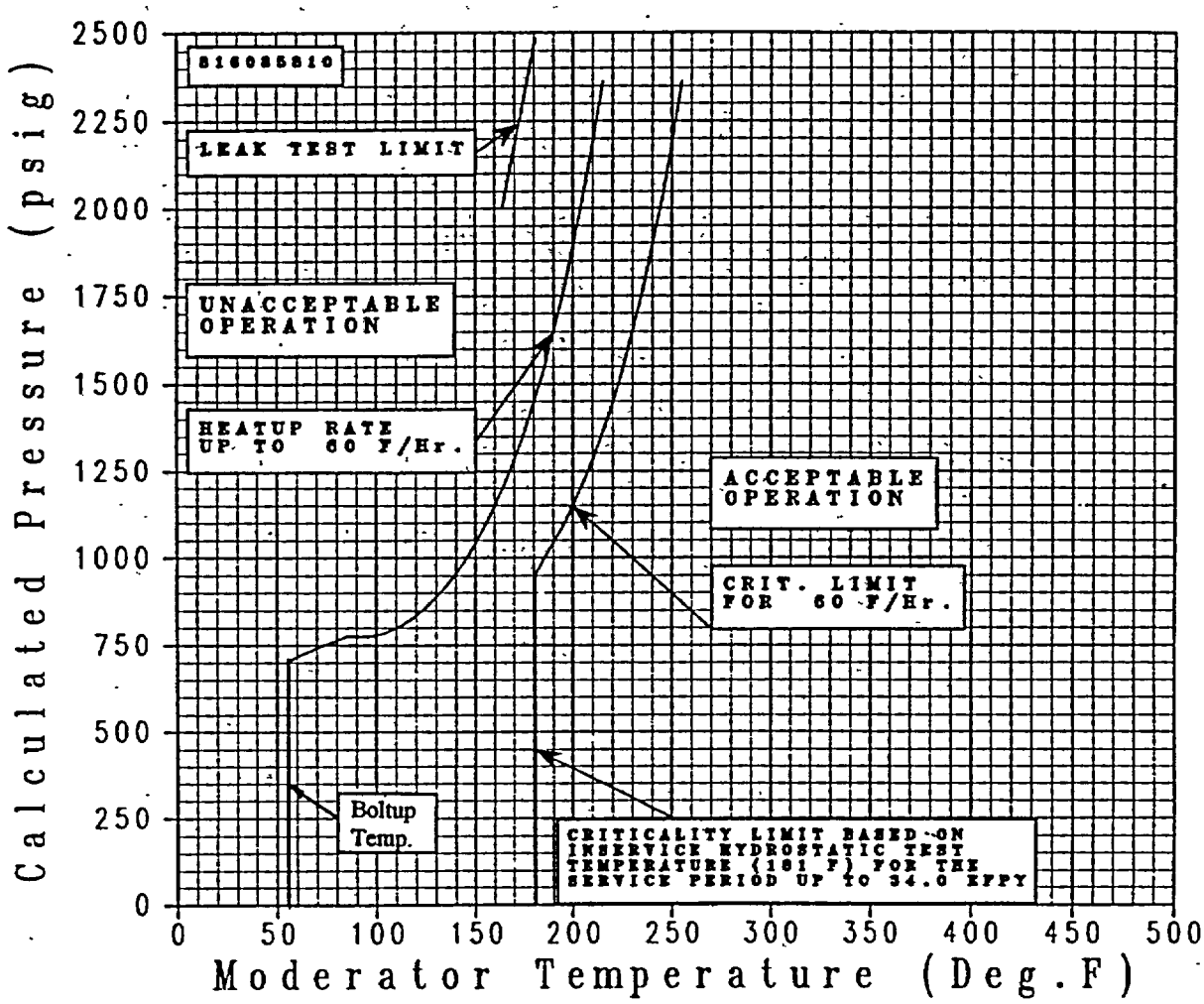

Figure 8 **Catawba Unit 2 Reactor Coolant System Heatup Limitations (Heatup Rate of 60°F/hr) Applicable for the First 34 EFPY (Without Margins for Instrumentation Errors)**

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL PLATE B8605-2
LIMITING ART VALUES AT 34 EFPY: 1/4T, 121°F
3/4T, 106°F

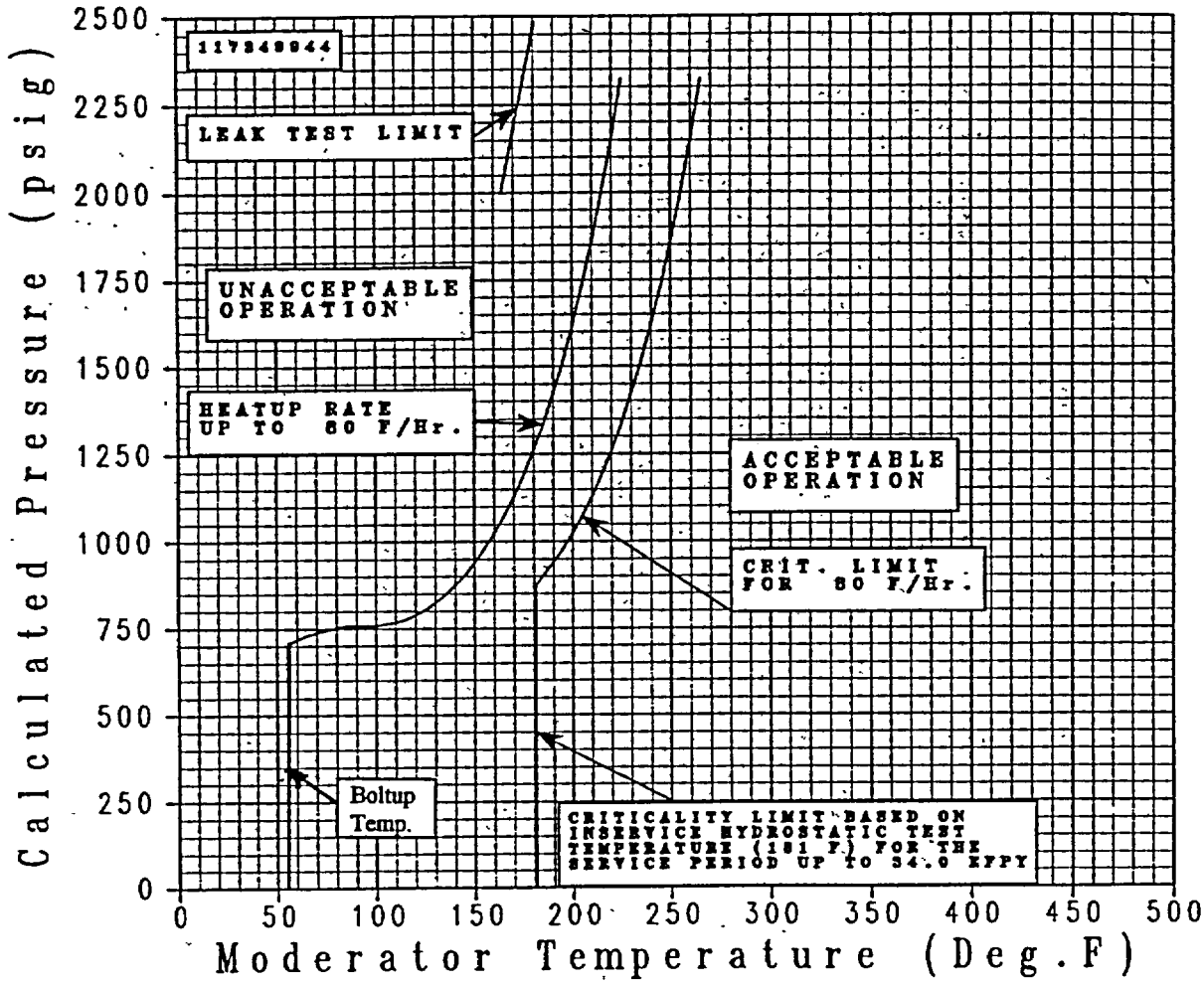

Figure 9 **Catawba Unit 2 Reactor Coolant System Heatup Limitations (Heatup Rate of 80°F/hr) Applicable for the First 34 EFPY (Without Margins for Instrumentation Errors)**

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL PLATE B8605-2
LIMITING ART VALUES AT 34 EFPY: 1/4T, 121°F
3/4T, 106°F

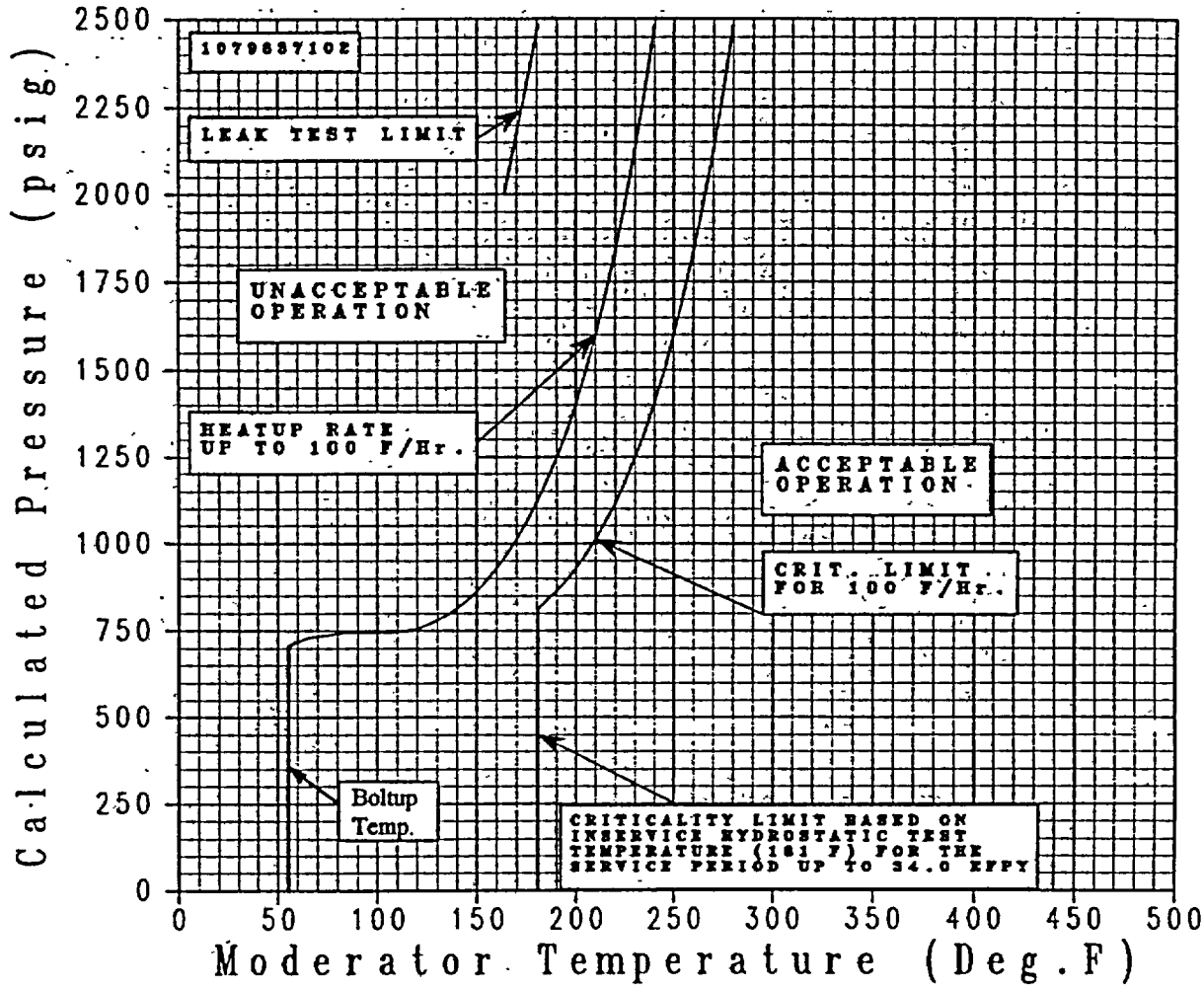

Figure 10 **Catawba Unit 2 Reactor Coolant System Heatup Limitations (Heatup Rate of 100°F/hr) Applicable for the First 34 EFPY (Without Margins for Instrumentation Errors)**

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL PLATE B8605-2
LIMITING ART VALUES AT 34 EFPY: 1/4T, 121°F
3/4T, 106°F

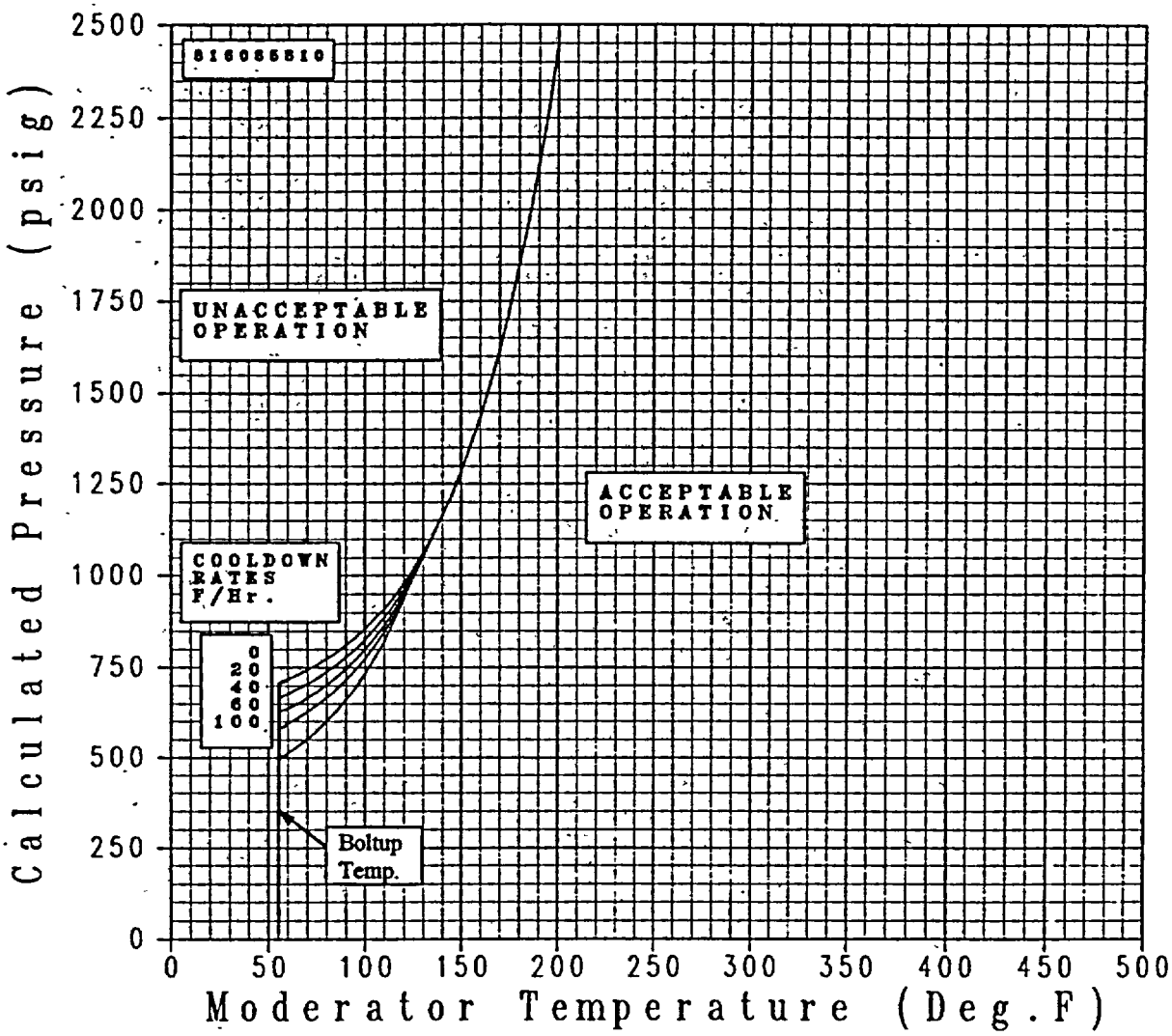

Figure 11 **Catawba Unit 2 Reactor Coolant System Cooldown Limitations (Cooldown Rates up to 100°F/hr) Applicable for the First 34 EFPY (Without Margins for Instrumentation Errors)**

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL PLATE B8605-2
LIMITING ART VALUES AT 51 EFPY: 1/4T, 126°F
3/4T, 112°F

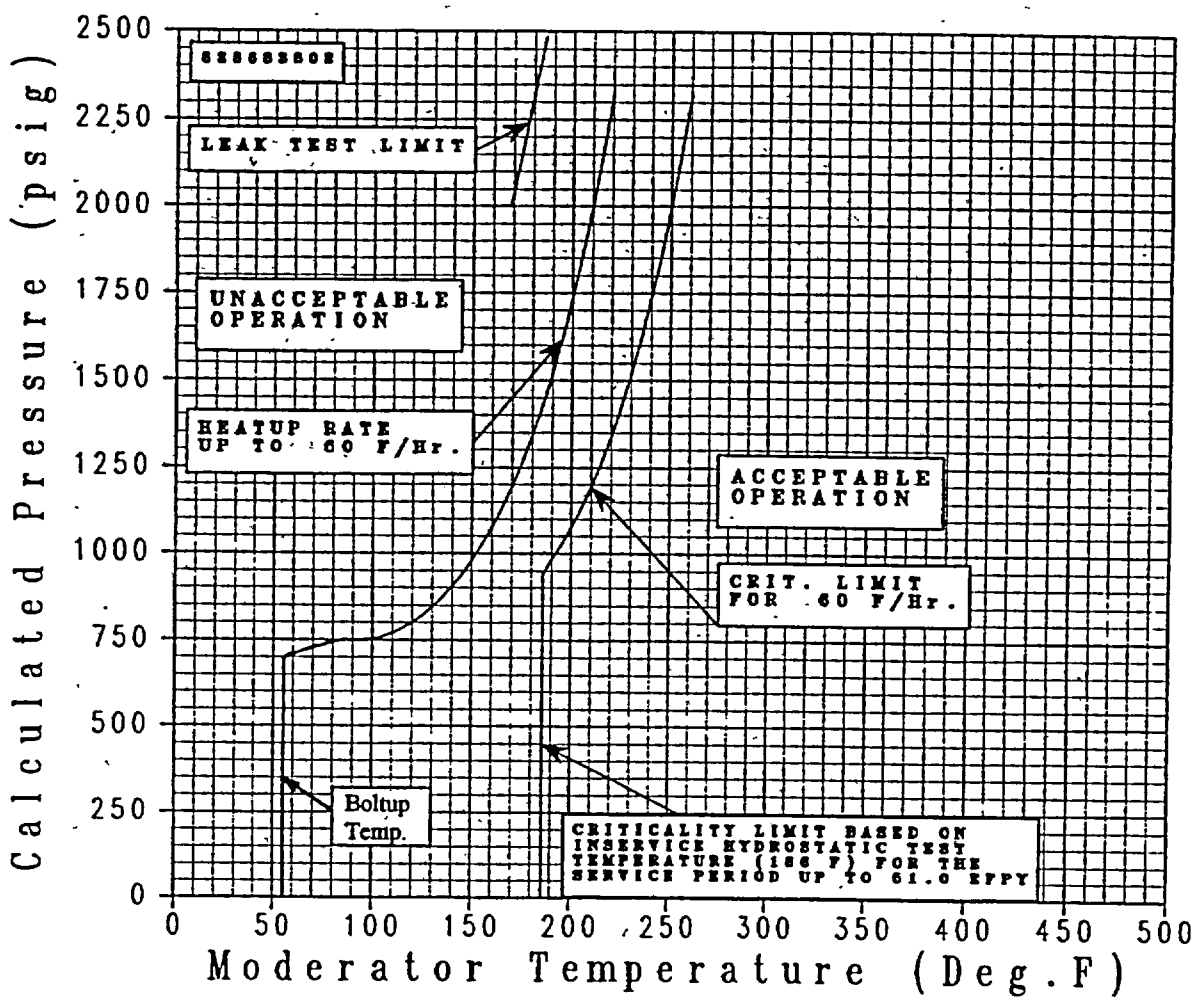

Figure 12 **Catawba Unit 2 Reactor Coolant System Heatup Limitations (Heatup Rate of 60°F/hr) Applicable for the First 51 EFPY (Without Margins for Instrumentation Errors)**

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL PLATE B8605-2
LIMITING ART VALUES AT 51 EFPY: 1/4T, 126°F
3/4T, 112°F

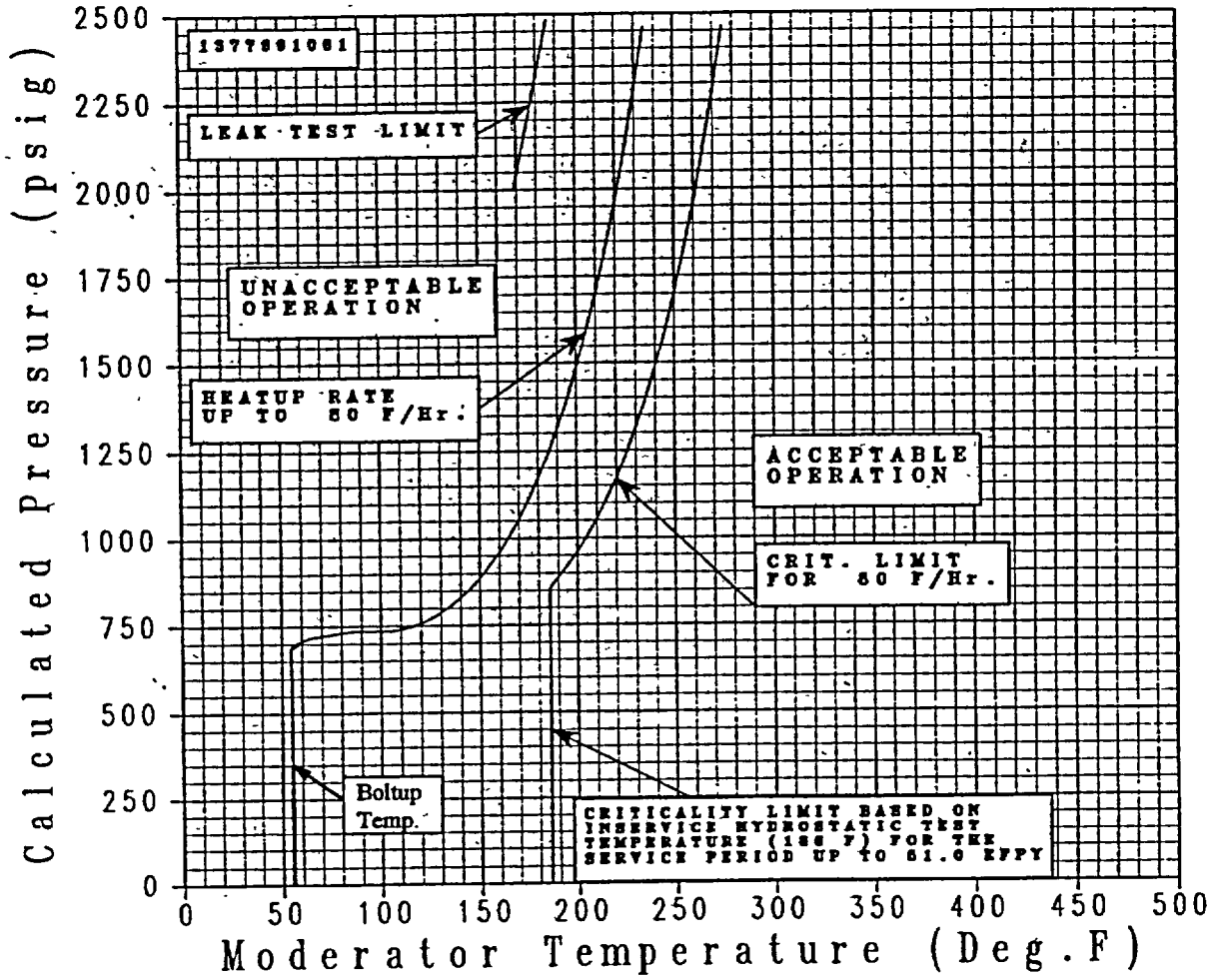

Figure 13 **Catawba Unit 2 Reactor Coolant System Heatup Limitations (Heatup Rate of 80°F/hr) Applicable for the First 51 EFPY (Without Margins for Instrumentation Errors)**

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL PLATE B8605-2
LIMITING ART VALUES AT 51 EFPY: 1/4T, 126°F
3/4T, 112°F

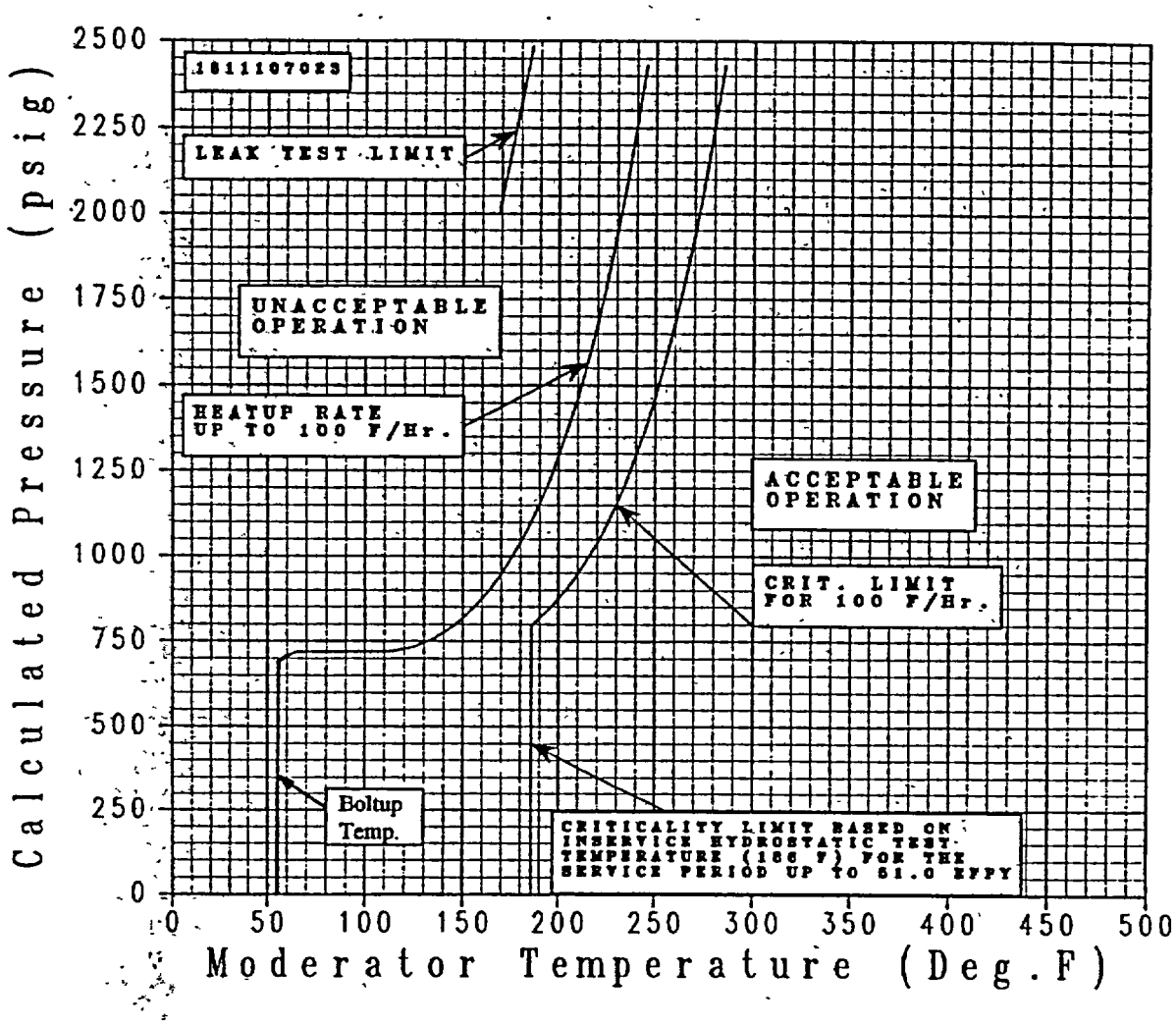

Figure 14 **Catawba Unit 2 Reactor Coolant System Heatup Limitations (Heatup Rate of 100°F/hr) Applicable for the First 51 EFPY (Without Margins for Instrumentation Errors)**

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL PLATE B8605-2
LIMITING ART VALUES AT 51 EFPY: 1/4T, 126°F
3/4T, 112°F

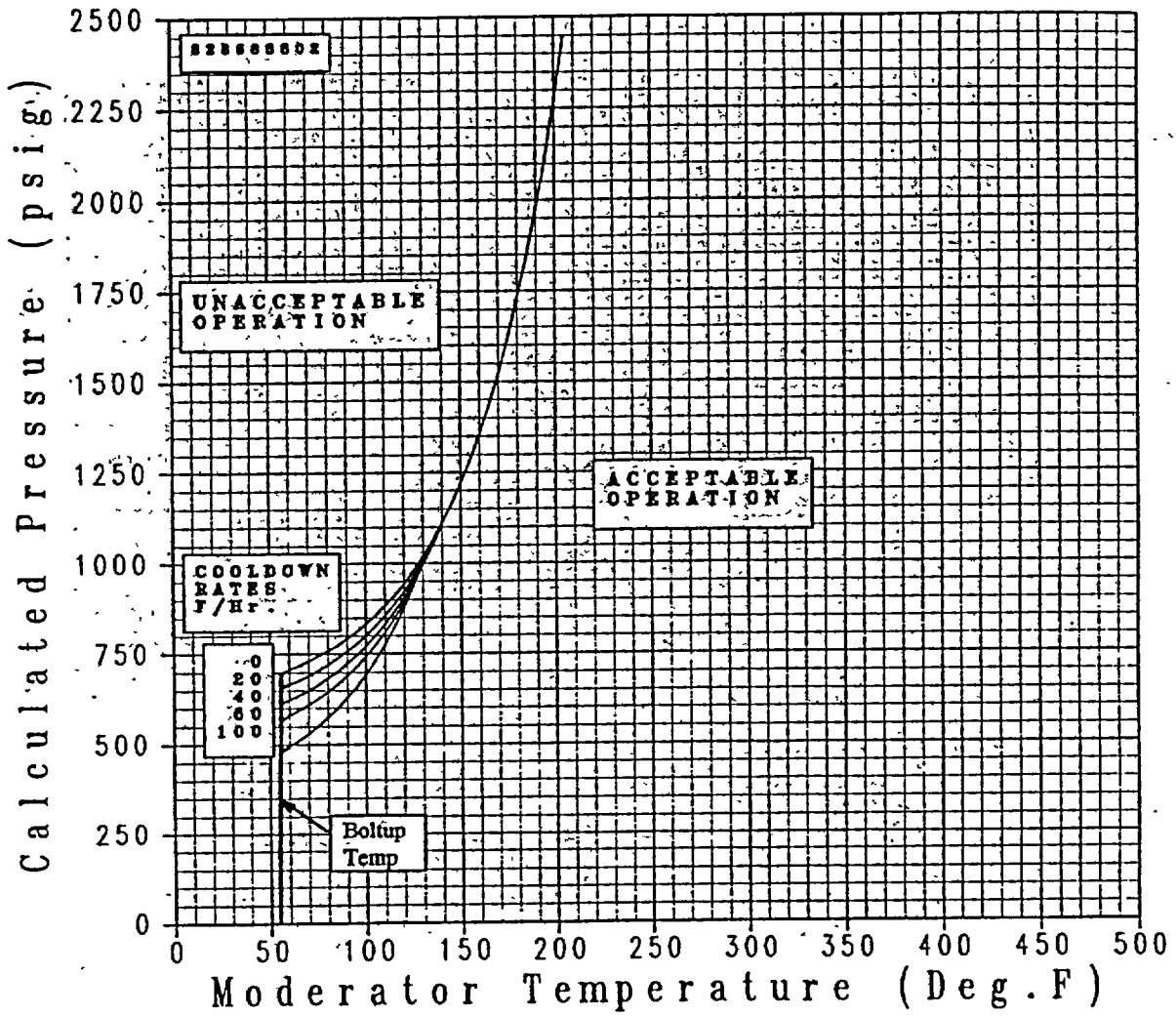

Figure 15 **Catawba Unit 2 Reactor Coolant System Cooldown Limitations (Cooldown Rates up to 100°F/hr) Applicable for the First 51 EFPY (Without Margins for Instrumentation Errors)**

TABLE 15
22 EFPY Heatup Curve Data Points Using 1996 App. G
(without Uncertainties for Instrumentation Errors)

60 Heatup		60 Critical Limit		80 Heatup		80 Critical Limit		100 Heatup		100 Critical Limit	
T	P	T	P	T	P	T	P	T	P	T	P
55	0	175	0	55	0	175	0	55	0	175	0
55	722	175	747	55	722	175	747	55	722	175	747
60	734	175	812	60	734	175	809	60	734	175	808
65	747	175	808	65	747	175	800	65	747	175	796
70	762	175	809	70	762	175	795	70	762	175	787
75	778	175	815	75	778	175	795	75	778	175	782
80	796	175	826	80	795	175	798	80	781	175	781
85	808	175	841	85	795	175	806	85	781	175	783
90	808	175	861	90	795	175	817	90	781	175	789
95	809	175	884	95	795	175	833	95	781	175	798
100	815	175	912	100	795	175	852	100	781	175	810
105	826	175	944	105	798	175	875	105	781	175	826
110	841	175	981	110	806	175	902	110	783	175	845
115	861	180	1023	115	817	180	933	115	789	180	868
120	884	185	1070	120	833	185	969	120	798	185	895
125	912	190	1122	125	852	190	1010	125	810	190	927
130	944	195	1181	130	875	195	1056	130	826	195	962
135	981	200	1247	135	902	200	1107	135	845	200	1003
140	1023	205	1319	140	933	205	1165	140	868	205	1048
145	1070	210	1400	145	969	210	1229	145	895	210	1099
150	1122	215	1490	150	1010	215	1300	150	927	215	1156
155	1181	220	1589	155	1056	220	1380	155	962	220	1220
160	1247	225	1698	160	1107	225	1468	160	1003	225	1291
165	1319	230	1819	165	1165	230	1565	165	1048	230	1369
170	1400	235	1953	170	1229	235	1673	170	1099	235	1456
175	1490	240	2101	175	1300	240	1792	175	1156	240	1553
180	1589	245	2264	180	1380	245	1924	180	1220	245	1660
185	1698	250	2444	185	1468	250	2070	185	1291	250	1778
190	1819			190	1565	255	2230	190	1369	255	1909
195	1953			195	1673	260	2408	195	1456	260	2053
200	2101			200	1792			200	1553	265	2212
205	2264			205	1924			205	1660	270	2388
210	2444			210	2070			210	1778		
				215	2230			215	1909		
				220	2408			220	2053		
								225	2212		
								230	2388		

Leak Test Limit				
	Temp.	158	175	
	Press.	2000	2485	

TABLE 16
22 EFPY Cooldown Curve Data Points Using 1996 App. G
(without Uncertainties for Instrumentation Errors)

Cooldown Curves									
Steady State		20F		40F		60F		100F	
T	P	T	P	T	P	T	P	T	P
55	0	55	0	55	0	55	0	55	0
55	722	55	681	55	640	55	600	55	519
60	734	60	694	60	654	60	615	60	538
65	747	65	708	65	670	65	632	65	558
70	762	70	724	70	687	70	651	70	581
75	778	75	742	75	707	75	672	75	607
80	796	80	762	80	728	80	696	80	636
85	816	85	783	85	752	85	722	85	668
90	838	90	807	90	778	90	751	90	703
95	862	95	834	95	807	95	783	95	743
100	889	100	863	100	839	100	818	100	786
105	918	105	895	105	875	105	858	105	835
110	951	110	931	110	915	110	901	110	889
115	987	115	971	115	958	115	950	115	948
120	1027	120	1015	120	1007	120	1003	120	1015
125	1071	125	1063	125	1060	125	1063		
130	1120	130	1117						
135	1173								
140	1233								
145	1299								
150	1371								
155	1452								
160	1541								
165	1639								
170	1747								
175	1867								
180	2000								
185	2146								
190	2308								

TABLE 17
34 EFPY Heatup Curve Data Points Using 1996 App. G
(without Uncertainties for Instrumentation Errors)

60 Heatup		60 Critical Limit		80 Heatup		80 Critical Limit		100 Heatup		100 Critical Limit	
T	P	T	P	T	P	T	P	T	P	T	P
55	0	181	0	55	0	181	0	55	0	181	0
55	709	181	731	55	709	181	731	55	709	181	731
60	719	181	782	60	719	181	779	60	719	181	779
65	731	181	777	65	731	181	769	65	731	181	766
70	744	181	776	70	744	181	763	70	744	181	756
75	759	181	780	75	759	181	761	75	747	181	750
80	775	181	789	80	761	181	763	80	747	181	747
85	776	181	801	85	761	181	769	85	747	181	748
90	776	181	817	90	761	181	778	90	747	181	751
95	776	181	837	95	761	181	790	95	747	181	758
100	780	181	861	100	761	181	806	100	747	181	768
105	789	181	888	105	763	181	825	105	747	181	780
110	801	181	920	110	769	181	848	110	748	181	796
115	817	181	956	115	778	181	875	115	751	181	816
120	837	185	997	120	790	185	905	120	758	185	838
125	861	190	1042	125	806	190	940	125	768	190	865
130	888	195	1093	130	825	195	980	130	780	195	895
135	920	200	1150	135	848	200	1024	135	796	200	930
140	956	205	1213	140	875	205	1074	140	816	205	969
145	997	210	1283	145	905	210	1129	145	838	210	1013
150	1042	215	1361	150	940	215	1191	150	865	215	1062
155	1093	220	1447	155	980	220	1260	155	895	220	1117
160	1150	225	1542	160	1024	225	1336	160	930	225	1178
165	1213	230	1647	165	1074	230	1421	165	969	230	1246
170	1283	235	1763	170	1129	235	1514	170	1013	235	1322
175	1361	240	1891	175	1191	240	1618	175	1062	240	1405
180	1447	245	2033	180	1260	245	1732	180	1117	245	1498
185	1542	250	2190	185	1336	250	1859	185	1178	250	1601
190	1647	255	2363	190	1421	255	1999	190	1246	255	1714
195	1763			195	1514	260	2153	195	1322	260	1839
200	1891			200	1618	265	2323	200	1405	265	1977
205	2033			205	1732			205	1498	270	2130
210	2190			210	1859			210	1601	275	2298
215	2363			215	1999			215	1714	280	2484
				220	2153			220	1839		
				225	2323			225	1977		
								230	2130		
								235	2298		
								240	2484		
Leak Test Limit			Temp.	164	181						
			Press.	2000	2485						

TABLE 18
34 EFPY Cooldown Curve Data Points Using 1996 App. G
(without Uncertainties for Instrumentation Errors)

Cooldown Curves									
Steady State		20F		40F		60F		100F	
T	P	T	P	T	P	T	P	T	P
55	0	55	0	55	0	55	0	55	0
55	709	55	667	55	624	55	596	55	514
60	719	60	678	60	637	60	596	60	514
65	731	65	691	65	651	65	611	65	533
70	744	70	705	70	666	70	628	70	553
75	759	75	721	75	683	75	647	75	576
80	775	80	738	80	702	80	667	80	601
85	792	85	757	85	723	85	690	85	629
90	812	90	778	90	747	90	716	90	660
95	833	95	802	95	772	95	744	95	695
100	857	100	828	100	801	100	776	100	734
105	883	105	857	105	832	105	811	105	777
110	912	110	888	110	867	110	849	110	824
115	944	115	924	115	906	115	892	115	877
120	979	120	963	120	949	120	940	120	936
125	1018	125	1006	125	997	125	992	125	1001
130	1062	130	1053	130	1049	130	1050		
135	1109	135	1106	135	1107				
140	1162								
145	1221								
150	1285								
155	1356								
160	1435								
165	1522								
170	1618								
175	1725								
180	1842								
185	1972								
190	2116								
195	2274								
200	2449								

TABLE 19
51 EFPY Heatup Curve Data Points Using 1996 App. G
(without Uncertainties for Instrumentation Errors)

60 Heatup		60 Critical Limit		80 Heatup		80 Critical Limit		100 Heatup		100 Critical Limit	
T	P	T	P	T	P	T	P	T	P	T	P
55	0	186	0	55	0	186	0	55	0	186	0
55	699	186	719	55	699	186	719	55	699	186	719
60	709	186	760	60	709	186	757	60	709	186	757
65	719	186	753	65	719	186	746	65	719	186	743
70	731	186	752	70	731	186	739	70	721	186	733
75	744	186	754	75	736	186	736	75	721	186	726
80	752	186	761	80	736	186	737	80	721	186	722
85	752	186	771	85	736	186	741	85	721	186	721
90	752	186	784	90	736	186	748	90	721	186	723
95	752	186	802	95	736	186	758	95	721	186	728
100	754	186	822	100	736	186	771	100	721	186	736
105	761	186	846	105	737	186	788	105	721	186	746
110	771	186	874	110	741	186	807	110	721	186	760
115	784	186	906	115	748	186	831	115	723	186	776
120	802	186	941	120	758	186	857	120	728	186	796
125	822	190	982	125	771	190	888	125	736	190	819
130	846	195	1027	130	788	195	923	130	746	195	845
135	874	200	1077	135	807	200	962	135	760	200	875
140	906	205	1133	140	831	205	1006	140	776	205	909
145	941	210	1195	145	857	210	1055	145	796	210	948
150	982	215	1263	150	888	215	1109	150	819	215	991
155	1027	220	1340	155	923	220	1170	155	845	220	1040
160	1077	225	1424	160	962	225	1237	160	875	225	1094
165	1133	230	1517	165	1006	230	1312	165	909	230	1154
170	1195	235	1620	170	1055	235	1395	170	948	235	1221
175	1263	240	1734	175	1109	240	1487	175	991	240	1295
180	1340	245	1860	180	1170	245	1588	180	1040	245	1376
185	1424	250	1998	185	1237	250	1700	185	1094	250	1467
190	1517	255	2152	190	1312	255	1824	190	1154	255	1567
195	1620	260	2321	195	1395	260	1961	195	1221	260	1678
200	1734			200	1487	265	2112	200	1295	265	1801
205	1860			205	1588	270	2278	205	1376	270	1936
210	1998			210	1700	275	2462	210	1467	275	2085
215	2152			215	1824			215	1567	280	2250
220	2321			220	1961			220	1678	285	2431
				225	2112			225	1801		
				230	2278			230	1936		
				235	2462			235	2085		
								240	2250		
								245	2431		
Leak Test Limit			Temp.	169	186						
T	P		Press.	2000	2485						

TABLE 20

51 EFPY Cooldown Curve Data Points Using 1996 App. G

(without Uncertainties for Instrumentation Errors)

Cooldown Curves									
Steady State		20F		40F		60F		100F	
T	P	T	P	T	P	T	P	T	P
55	0	55	0	55	0	55	0	55	0
55	699	55	656	55	613	55	569	55	482
60	709	60	667	60	624	60	582	60	497
65	719	65	678	65	637	65	595	65	513
70	731	70	691	70	651	70	610	70	532
75	744	75	705	75	666	75	627	75	552
80	759	80	721	80	683	80	646	80	575
85	775	85	738	85	702	85	667	85	600
90	792	90	757	90	723	90	690	90	628
95	812	95	778	95	746	95	715	95	660
100	833	100	802	100	772	100	744	100	694
105	857	105	828	105	801	105	775	105	733
110	883	110	857	110	832	110	810	110	776
115	912	115	888	115	867	115	849	115	824
120	944	120	924	120	906	120	892	120	877
125	979	125	962	125	949	125	939	125	935
130	1018	130	1006	130	996	130	992	130	1001
135	1062	135	1053	135	1049	135	1050		
140	1109	140	1106	140	1107				
145	1162								
150	1221								
155	1285								
160	1356								
165	1435								
170	1522								
175	1618								
180	1725								
185	1842								
190	1972								
195	2116								
200	2274								
205	2449								

6 REFERENCES

1. WCAP-15243, "Analysis of Capsule V and the Capsule Y Dosimeters from the Duke Energy Catawba Unit 2 Reactor Vessel Radiation Surveillance Program," T.J. Laubham, et al., Dated September 1999.

2. WCAP-7924-A, "Basis for Heatup and Cooldown Limit Curves," W. S. Hazelton, et al., April 1975.

3. ASME Code Case N-640, "Alternative Reference Fracture Toughness for Development of P-T Limit Curves for Section XI, Division 1", February 26, 1999.

4. Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials," U.S. Nuclear Regulatory Commission, May 1988.

5. Code of Federal Regulations, 10 CFR Part 50, Appendix G, "Fracture Toughness Requirements," U.S. Nuclear Regulatory Commission, Washington, D.C., Federal Register, Volume 60, No. 243, dated December 19, 1995.

6. Section XI of the ASME Boiler and Pressure Vessel Code, Appendix G, "Fracture Toughness Criteria for Protection Against Failure.", Dated 1989 & December 1995.

7. 1989 Section III, Division 1 of the ASME Boiler and Pressure Vessel Code, Paragraph NB-2331, "Material for Vessels."

8. WCAP-14040-NP-A, Revision 2, "Methodology used to Develop Cold Overpressure Mitigating system Setpoints and RCS Heatup and Cooldown Limit Curves", J.D. Andrachek, et. al., January 1996.

9. CVGRAPH, Hyperbolic Tangent Curve-Fitting Program, Version 4.0, developed by ATI Consulting, March 1995.