PSEG Nuclear LLC
P.O. Box 236, Hancocks Bridge, New Jersey 08038-0236

PSEG
Nuclear LLC

DEC 0 5 2000

LR-N00-0464
LCR S00-06

United States Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555

Gentlemen:

SUPPLEMENT TO REQUEST FOR LICENSE AMENDMENT
INCREASED LICENSED POWER LEVEL
SALEM GENERATING STATION, UNIT NOS. 1 AND 2
FACILITY OPERATING LICENSE DPR-70 AND DPR-75
DOCKET NOS. 50-272 AND 50-311

By letter dated November 10, 2000, PSEG Nuclear LLC requested a change to Facility Operating License Nos. DPR-70 and DPR-75 and to the Technical Specifications (TS) in Appendix A thereto for Salem Generating Station Unit Nos. 1 and 2, respectively, to increase the licensed core power level for operation to 3459 megawatts, 1.4% greater than the current level. As part of the requested change, Technical Specification Figures 3.4-2 and 3.4-3, Reactor Coolant System Heatup and Cooldown Curves, and their associated Bases would be revised to support the increase in core power based on uprated fluence projections.

The attached reports were prepared to document the development of the revised pressure-temperature limit curves. They describe the criteria and methodology used to calculate the adjusted reference temperature and to calculate the pressure-temperature limits in the revised curves.

PSEG Nuclear has concluded that the information contained in Attachments 1 and 2 does not alter the conclusions reached in the 10CFR50.92 No Significant Hazards analysis previously submitted. Should you have any questions regarding this request, please contact Mr. Paul Duke at (856) 339-1466.

Sincerely,

David F. Garchow
Vice President - Operations

Affidavit
Attachments (2)

A001

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REF: LR-N00-0464
LCR S00-06

STATE OF NEW JERSEY)
) SS.
COUNTY OF SALEM)

David F. Garchow, being duly sworn according to law deposes and says:

I am Vice President - Operations of PSEG Nuclear LLC, and as such, I find the matters set forth in the above referenced letter, concerning Salem Generating Station, Units 1 and 2, are true to the best of my knowledge, information and belief.

[signature]

Subscribed and Sworn to before me
this 5 day of December, 2000

[signature]
Notary Public of New Jersey

My Commission expires on ______________

SHERI L. HUSTON
NOTARY PUBLIC OF NEW JERSEY
My Commission Expires 12/08/2003

WCAP-15565, Revision 0, "Salem Unit 1 Heatup and Cooldown Curves for Normal Operation"

Westinghouse Non-Proprietary Class 3

WCAP - 15565
Revision 0

Salem Unit 1 Heatup and Cooldown Curves for Normal Operation

Westinghouse Electric Company LLC

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-15565

Salem Unit 1 Heatup and Cooldown Curves for Normal Operation

ED Terek

C. M. Haas

November, 2000

Approved: ______________________
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PREFACE

This report has been technically reviewed and verified by:

Reviewer: Tom Laubham

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EXECUTIVE SUMMARY

This report documents the development pressure-temperature limit curves for the PSEG Nuclear LLC Salem Unit 1 electric generating plant for normal operation at 32 and 48 EFPY. These pressure-temperature limit curves include the 1.4% uprating fluence values and utilize the methodology from the 1995 ASME Boiler and Pressure Vessel Code, Section XI, Appendix G, through 1996 addendum. Regulatory Guide 1.99, Revision 2 is used for the calculation of Adjusted Reference Temperature (ART) values at the 1/4T and 3/4T location. The 1/4T and 3/4T values are summarized in Table 4-14. The pressure-temperature limit curves were generated with margins for instrumentation errors for heatup rates of 60 and 100°F/hr and cooldown rates of 0, 20, 40, 60 and 100°F/hr. These curves can be found in Figures 5-1 through 5-4. In addition, these heatup and cooldown pressure-temperature limit curves include ASME Code Case N-640[10], which allows the use of the K_{Ic} methodology, and the elimination of the reactor vessel flange temperature-pressure requirement (Ref, WCAP-15315[11]).

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"[1]. Regulatory Guide 1.99, Revision 2, is used for the calculation of Adjusted Reference Temperature (ART) values (IRT_{NDT} + ΔRT_{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 for normal operation. As a note, calculated capsule and vessel fluence projections[4,7] were used in determination of the most limiting ART values. The fluence evaluations used the ENDF/B-VI scattering cross-section data set. This is consistent with the methods presented in WCAP-14040-NP-A, "Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves"[8].

The heatup and cooldown curves documented in this report were generated using the most limiting ART values and the NRC approved methodology documented in WCAP-14040-NP-A, Revision 2[8], "Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves" with exception of the following: 1) The K_{Ic} critical stress intensities are used in place of the K_{Ia} critical stress intensities. This methodology is taken from approved ASME Code Case N-640[10]. 2) The reactor vessel flange temperature requirement has been eliminated. Justification has been provided in WCAP-15315[11]. 3) The 1995 Version of Appendix G to Section XI[3] through the 1996 addendum was utilized rather than the 1989 version.

2 PURPOSE

PSEG Nuclear LLC contracted Westinghouse to generate new heatup and cooldown curves for Salem Unit 1 at 32 and 48 EFPY based upon the 1.4% uprating projected fluence values using the latest Code Methodologies and the elimination of the flange requirement. The heatup and cooldown curves were generated with margins for instrumentation errors: 18°F for temperature uncertainty and 61 psig for pressure uncertainty and 2°F temperature uncertainty for boltup. The curves include a hydrostatic leak test limit curve from 2485 to 2000 psig.

The purpose of this report is to present the calculations and the development of the PSEG Nuclear LLC Salem Unit 1 heatup and cooldown curves for 32 and 48 EFPY. This report documents the calculated adjusted reference temperature (ART) values following the methods of Regulatory Guide 1.99, Revision 2[1], for all the beltline materials and the development of the heatup and cooldown pressure-temperature limit curves for normal operation.

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 PT Limit Curves for Section XI"[10] of the ASME Appendix G to Section XI[3]. 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 for $\sqrt{t} < 2$,
M_m = $0.926\sqrt{t}$ for $2 \leq \sqrt{t} \leq 3.464$,
M_m = 3.21 for $\sqrt{t} > 3.464$

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

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

Where: 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 $K_{It} = 0.953\text{x}10^{-3}$ x CR x $t^{2.5}$, where CR is the cooldown rate in °F/hr., or for a postulated outside surface defect, $K_{It} = 0.753\text{x}10^{-3}$ x HU x $t^{2.5}$, 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:

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

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 1 through 6 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, "Methodology used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves"[8] 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 (3106 psi). However, per WCAP-15315, "Reactor Vessel Closure Head/Vessel Flange Requirements Evaluation For Operating PWR and BWR Plants"[11], this requirement is no longer necessary when using the methodology of Code Case N-640[10]. Hence, the Salem Unit 1 heatup and cooldown limit curves were generated without flange requirements included.

3.4 Minimum Boltup Temperature

The minimum boltup temperature is equal to the material RT_{NDT} of the stressed region. The RT_{NDT} is calculated in accordance with the methods described in Branch Technical Position MTEB 5-2. The Westinghouse position is that the boltup temperature be no lower than 60°F. Thus, the minimum boltup temperature should be 60°F or the material RT_{NDT}, whichever is higher.

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:

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

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[6]. 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 is 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[5]) 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[4,7] The evaluation used the ENDF/B-VI scattering cross-section data set. This is consistent with the methods presented in WCAP-14040-NP-A, "Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves"[8]. Tables 4-1 and 4-2, herein, contain the calculated vessel surface fluence 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 Salem Unit 1 reactor vessel.

TABLE 4-1
Summary of the Peak Pressure Vessel Neutron Fluence Values
at 32 EFPY used for the Calculation of ART Values (n/cm^2, E > 1.0 MeV)

Material	Surface*	¼ T	¾ T
Intermediate Shell B2402-1	1.64 x 10^{19}	0.977 x 10^{19}	0.347 x 10^{19}
Intermediate Shell B2402-2	1.64 x 10^{19}	0.977 x 10^{19}	0.347 x 10^{19}
Intermediate Shell B2402-3	1.64 x 10^{19}	0.977 x 10^{19}	0.347 x 10^{19}
Lower Shell B2403-1	1.64 x 10^{19}	0.977 x 10^{19}	0.347 x 10^{19}
Lower Shell B2403-2	1.64 x 10^{19}	0.977 x 10^{19}	0.347 x 10^{19}
Lower Shell B2403-3	1.64 x 10^{19}	0.977 x 10^{19}	0.347 x 10^{19}
Intermediate to Lower Shell Circumferential Weld Seam 9-042 (Heat # 13253)	1.64 x 10^{19}	0.977 x 10^{19}	0.347 x 10^{19}
Longitudinal Weld Seams 2-042 A&B (Heat # 39B196/34B009 +NI200)	1.18 x 10^{19}	0.703 x 10^{19}	0.250 x 10^{19}
Longitudinal Weld Seam 2-042 C (Heat # 39B196/34B009 +NI200)	0.685 x 10^{19}	0.408 x 10^{19}	0.145 x 10^{19}
Longitudinal Weld Seams 3-042 A&B (Heat # 34B009+NI200, 13253)	1.08 x 10^{19}	0.664 x 10^{19}	0.229 x 10^{19}
Longitudinal Weld Seam 3-042 C (Heat # 34B009+NI200, 13253)	1.64 x 10^{19}	0.977 x 10^{19}	0.347 x 10^{19}

* Surface fluence values are calculated.

TABLE 4-2

Summary of the Peak Pressure Vessel Neutron Fluence Values at 48 EFPY used for the Calculation of ART Values (n/cm^2, E > 1.0 MeV)

Material	Surface*	¼ T	¾ T
Intermediate Shell B2402-1	2.42×10^{19}	1.44×10^{19}	0.512×10^{19}
Intermediate Shell B2402-2	2.42×10^{19}	1.44×10^{19}	0.512×10^{19}
Intermediate Shell B2402-3	2.42×10^{19}	1.44×10^{19}	0.512×10^{19}
Lower Shell B2403-1	2.42×10^{19}	1.44×10^{19}	0.512×10^{19}
Lower Shell B2403-2	2.42×10^{19}	1.44×10^{19}	0.512×10^{19}
Lower Shell B2403-3	2.42×10^{19}	1.44×10^{19}	0.512×10^{19}
Intermediate to Lower Shell Circumferential Weld Seam 9-042 (Heat # 13253)	2.42×10^{19}	1.44×10^{19}	0.512×10^{19}
Longitudinal Weld Seams 2-042 A&B (Heat # 39B196/34B009 +NI200)	1.75×10^{19}	1.04×10^{19}	0.371×10^{19}
Longitudinal Weld Seam 2-042 C (Heat # 39B196/34B009 +NI200)	1.03×10^{19}	0.614×10^{19}	0.218×10^{19}
Longitudinal Weld Seams 3-042 A&B (Heat # 34B009+NI200, 13253)	1.61×10^{19}	0.960×10^{19}	0.341×10^{19}
Longitudinal Weld Seam 3-042 C (Heat # 34B009+NI200, 13253)	2.42×10^{19}	1.44×10^{19}	0.512×10^{19}

* Surface fluence values are calculated.

TABLE 4-3
Calculated Integrated Neutron Exposure of the Salem Unit 1
Surveillance Capsules Tested to Date

Capsule	Fluence
T	2.73×10^{18} n/cm^2, (E > 1.0 MeV)
Y	9.13×10^{18} n/cm^2, (E > 1.0 MeV)
Z	1.33×10^{19} n/cm^2, (E > 1.0 MeV)
S	2.12×10^{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, σ_i, is 0°F when the initial RT_{NDT} is a measured value, and 17°F when a generic value is used. The standard deviation for the ΔRT_{NDT} margin term, σ_Δ, is 17°F for plates when surveillance capsule data is not used and 8.5°F for plates when surveillance capsule data is used. For welds, σ_Δ is 28°F when surveillance capsule data is not used and 14°F when surveillance capsule data is used. In addition, σ_Δ need not exceed one-half the mean value of ΔRT_{NDT}.

Contained in Table 4-4 is a summary of the Measured 30 ft-lb transition temperature shifts of the beltline materials[4]. These measured shift values were obtained using CVGRAPH, Version 4.1, which is a hyperbolic tangent curve-fitting program.

TABLE 4-4
Measured 30 ft-lb Transition Temperature Shifts of the Beltline Materials Contained in the Surveillance Program

Material	Capsule	Measured 30 ft-lb Transition Temperature Shift[a]
Intermediate Shell Plate B2402-1 (Longitudinal Orientation)	T	105.89°F
	Z	175.36°F
	S	172.61°F
Intermediate Shell Plate B2402-2 (Longitudinal Orientation)	T	87.17°F
	Z	153.82°F
Intermediate Shell Plate B2402-3 (Longitudinal Orientation)	T	66.07°F
	Y	114.75°F
	Z	105.77°F
Surveillance Program Weld Metal	Y	186.95°F
	S	230.65°F

Notes:
(a) Calculated using measured Charpy data plotted using CVGRAPH, Version 4.1.

Table 4-5 contains a summary of the weight percent of copper, the weight percent of nickel and the initial RT_{NDT} of the beltline materials. The weight percent values of Cu and Ni given in Table 4-5 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 4-7. Table 4-6 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 4-7.

TABLE 4-5

Reactor Vessel Beltline Material Unirradiated Toughness Properties

Material Description	**Cu (%)**	**Ni(%)**	**Initial RT_{NDT}**
Closure Head Flange B2811	- -	- -	28°F
Vessel Flange B2410	- -	- -	60°F
Intermediate Shell B2402-1[(a)]	0.24	0.53	45°F
Intermediate Shell B2402-2[(a)]	0.24	0.53	-5°F
Intermediate Shell B2402-3[(a)]	0.22	0.51	-3°F
Lower Shell B2403-1[(a)]	0.19	0.48	4°F
Lower Shell B2403-2[(a)]	0.19	0.49	18°F
Lower Shell B2403-3[(a)]	0.19	0.48	6°F
Intermediate to Lower Shell Circumferential Weld Seam 9-042 (Heat # 13253)	0.22	0.73	-56°F [(c)]
Longitudinal Weld Seams 2-042 A, B & C (Heat # 39B196/34B009 +NI200)	0.18	1.04	-56°F [(c)]
Longitudinal Weld Seams 3-042 A , B & C (Heat # 34B009+NI200, 13253)	0.19	1.04	-56°F [(c)]

Notes:

(a) Taken from WCAP-14702[5]

(b) The surveillance program weld metal was fabricated with 3/16" diameter high manganese moly wire, heat #39B196, Linde 1092 flux, lot #3617. This weld metal is only representative of the beltline welds, not identical. Hence, the weld metal surveillance data was not used in any ART calculations.

(c) Generic mean values per 10 CFR 50.61.

TABLE 4-6
Calculation of Chemistry Factors using Salem Unit 1 Surveillance Capsule Data

Material	Capsule	Capsule f[a]	FF[b]	ΔRT_{NDT}[c]	FF*ΔRT_{NDT}	FF^2
Intermediate Shell B2402-1[d] (Longitudinal)	T	0.273	0.646	105.89°F	68.40°F	0.417
	Y	0.913	0.974	--	--	--
	Z	1.33	1.079	175.36°F	189.21°F	1.166
	S	2.12	1.204	172.61°F	207.82°F	1.440
				Sum =	465.43°F	3.023
	$CF_{B2402\text{-}1} = \Sigma(FF \times \Delta RT_{NDT}) \div \Sigma(FF^2) = (465.43°F \div 3.023) = 153.6°F$					
Intermediate Shell B2402-2[d] (Longitudinal)	T	0.273	0.646	87.17°F	56.31°F	0.417
	Y	0.913	0.974	--	--	--
	Z	1.33	1.079	153.82°F	165.97°F	1.166
	S	2.12	1.204	--	--	--
				Sum =	222.28°F	1.583
	$CF_{B2402\text{-}2} = \Sigma(FF \times \Delta RT_{NDT}) \div \Sigma(FF^2) = (222.28°F \div 1.583) = 140.4°F$					
Intermediate Shell B2402-3[d] (Longitudinal)	T	0.273	0.646	66.07°F	42.68°F	0.417
	Y	0.913	0.974	114.75°F	111.77°F	0.949
	Z	1.33	1.079	105.77°F	114.13°F	1.166
	S	2.12	1.204	--	--	--
				Sum =	268.58°F	2.532
	$CF_{B2402\text{-}3} = \Sigma(FF \times \Delta RT_{NDT}) \div \Sigma(FF^2) = (268.58°F \div 2.532) = 106.1°F$					
Surveillance Program Weld Metal[d]	T	0.273	0.646	--	--	--
	Y	0.913	0.974	186.95°F	182.09°F	0.949
	Z	1.33	1.079	--	--	--
	S	2.12	1.204	230.65°F	277.70°F	1.440
				Sum =	459.79°F	2.389
	$CF_{Sur.\ Weld} = \Sigma(FF \times \Delta RT_{NDT}) \div \Sigma(FF^2) = (459.79°F \div 2.389) = 192.5°F$					

Notes:
(a) f = calculated fluence values.[4,7] (x 10^{19} n/cm^2, E > 1.0 MeV).
(b) FF = fluence factor = $f^{(0.28 - 0.1 \cdot \log f)}$.
(c) ΔRT_{NDT} values are the measured 30 ft-lb shift values.[4]
(d) Per Reference 12, all surveillance data is credible. However, the surveillance weld metal is only representative of the beltline welds, not identical. Hence, the weld metal surveillance data was not used in any ART calculations. It is only presented here for completeness.

TABLE 4-7
Summary of the Salem Unit 1 Reactor Vessel Beltline Material Chemistry Factors
Based on Regulatory Guide 1.99, Revision 2, Position 1.1 and Position 2.1

Material	Chemistry Factor	
	Position 1.1	Position 2.1
Intermediate Shell B2402-1*	161.9°F	153.6°F
Intermediate Shell B2402-2*	161.9°F	140.4°F
Intermediate Shell B2402-3*	148.9°F	106.1°F
Lower Shell B2403-1	128.8°F	--
Lower Shell B2403-2	129.9°F	--
Lower Shell B2403-3	128.8°F	--
Intermediate to Lower Shell Circumferential Weld Seam 9-042 (Heat # 13253)	188.5°F	--
Intermediate Shell Longitudinal Weld Seam 2-042 A,B &C (Heat # 39B196/34B009 +NI200)	217.2°F	--
Lower Shell Longitudinal Weld Seam 3-042 A,B & C (Heat # 34B009+NI200, 13253)	223.6°F	--

*Surveillance Material

Contained in Tables 4-8 and 4-9 are summaries of the fluence factors (FF) used in the calculation of adjusted reference temperatures for the Salem Unit 1 reactor vessel beltline materials for 32 and 48EFPY.

TABLE 4-8

Summary of the Calculated Fluence Factors used for the Generation of the 32 EFPY Heatup and Cooldown Curves

Material	¼ T f (n/cm^2, E > 1.0 MeV)	¼ T FF[a]	¾ T f (n/cm^2, E >1.0 MeV)	¾ T FF[b]
Intermediate Shell B2402-1	9.77 x 10^{18}	0.993	3.47 x 10^{18}	0.708
Intermediate Shell B2402-2	9.77 x 10^{18}	0.993	3.47 x 10^{18}	0.708
Intermediate Shell B2402-3	9.77 x 10^{18}	0.993	3.47 x 10^{18}	0.708
Lower Shell B2403-1	9.77 x 10^{18}	0.993	3.47 x 10^{18}	0.708
Lower Shell B2403-2	9.77 x 10^{18}	0.993	3.47 x 10^{18}	0.708
Lower Shell B2403-3	9.77 x 10^{18}	0.993	3.47 x 10^{18}	0.708
Intermediate to Lower Shell Circumferential Weld Seam 9-042 (Heat # 13253)	9.77 x 10^{18}	0.993	3.47 x 10^{18}	0.708
Intermediate Shell Longitudinal Weld Seams 2-042 A & B (Heat # 39B196/34B009 +NI200)	7.03 x 10^{18}	0.901	2.50 x 10^{18}	0.620
Intermediate Shell Longitudinal Weld Seam 2-042 C (Heat # 39B196/34B009 +NI200)	4.08 x 10^{18}	0.750	1.45 x 10^{18}	0.495
Lower Shell Longitudinal Weld Seams 3-042 A&B (Heat # 34B009+NI200, 13253)	6.44 x 10^{18}	0.880	2.29 x 10^{18}	0.602
Lower Shell Longitudinal Weld Seam 3-042 C (Heat # 34B009+NI200, 13253)	9.77 x 10^{18}	0.993	3.47 x 10^{18}	0.708

Notes:

(a) Fluence Factor at the 1/4T vessel thickness location.

(b) Fluence Factor at the 3/4T vessel thickness location.

TABLE 4-9
Summary of the Calculated Fluence Factors used for the Generation of the 48 EFPY Heatup and Cooldown Curves

Material	¼ T f (n/cm², E > 1.0 MeV)	¼ T FF[(a)]	¾ T f (n/cm², E > 1.0 MeV)	¾ T FF[(b)]
Intermediate Shell B2402-1	1.44×10^{19}	1.101	5.12×10^{18}	0.813
Intermediate Shell B2402-2	1.44×10^{19}	1.101	5.12×10^{18}	0.813
Intermediate Shell B2402-3	1.44×10^{19}	1.101	5.12×10^{18}	0.813
Lower Shell B2403-1	1.44×10^{19}	1.101	5.12×10^{18}	0.813
Lower Shell B2403-2	1.44×10^{19}	1.101	5.12×10^{18}	0.813
Lower Shell B2403-3	1.44×10^{19}	1.101	5.12×10^{18}	0.813
Intermediate to Lower Shell Circumferential Weld Seam 9-042 (Heat #13253)	1.44×10^{19}	1.101	5.12×10^{18}	0.813
Intermediate Shell Longitudinal Weld Seams 2-042 A&B (Heat # 39B196/34B009 +NI200)	1.04×10^{19}	1.010	3.71×10^{18}	0.726
Intermediate Shell Longitudinal Weld Seam 2-042 C (Heat # 39B196/34B009 +NI200)	6.14×10^{18}	0.860	2.18×10^{18}	0.590
Lower Shell Longitudinal Weld Seams 3-042 A&B (Heat # 34B009+NI200, 13253)	9.60×10^{18}	1.00	3.41×10^{18}	0.700
Lower Shell Longitudinal Weld Seam 3-042 C (Heat # 34B009+NI200, 13253)	1.44×10^{19}	1.101	5.12×10^{18}	0.813

Notes:
(a) Fluence Factor at the 1/4T vessel thickness location.
(b) Fluence Factor at the 3/4T vessel thickness location.

Contained in Tables 4-10 through 4-13 are the calculations of the ART values used for the generation of the 32 EFPY and 48 EFPY heatup and cooldown curves.

TABLE 4-10

Calculation of the ART Values for the 1/4T Location @ 32 EFPY

Material	CF (°F)	FF	IRT_{NDT}[(a)] (°F)	ΔRT_{NDT}[(b)] (°F)	Margin (°F)	ART[(c)] (°F)
Intermediate Shell B2402-1	161.9	0.993	45	160.8	34	240
→ Using Surveillance Data	153.6	0.993	45	152.5	17	215
Intermediate Shell B2402-2	161.9	0.993	-5	160.8	34	190
→ Using Surveillance Data	140.4	0.993	-5	139.4	17	151
Intermediate Shell B2402-3	148.9	0.993	-3	147.9	34	179
→ Using Surveillance Data	106.1	0.993	-3	105.4	17	119
Lower Shell B2403-1	128.8	0.993	4	127.9	34	166
Lower Shell B2403-2	129.9	0.993	18	129.0	34	181
Lower Shell B2403-3	128.8	0.993	6	127.9	34	168
Intermediate to Lower Shell Circumferential Weld Seam 9-042 (Heats:13253)	188.5	0.993	-56	187.2	65.5	197
Intermediate Shell Longitudinal Weld Seams 2-042 A&B (Heat # 39B196/34B009 +NI200)	217.2	0.901	-56	195.7	65.5	205
Intermediate Shell Longitudinal Weld Seam 2-042 C (Heat # 39B196/34B009 +NI200)	217.2	0.750	-56	162.8	65.5	172
Lower Shell Longitudinal Weld Seams 3-042-A&B (Heat # 34B009+NI200, 13253)	223.6	0.880	-56	196.8	65.5	206
Lower Shell Longitudinal Weld Seam 3-042 C (Heat # 34B009+NI200, 13253)	223.6	0.993	-56	222.0	65.5	**232**

NOTES:

(a) Initial RT_{NDT} values are measured values for the plate material and generic mean values for the weld metal.

(b) $\Delta RT_{NDT} = CF * FF$

(c) ART = I + ΔRT_{NDT} + M (This value was rounded per ASTM E29, using the "Rounding Method".)

TABLE 4-11
Calculation of the ART Values for the 3/4T Location @ 32 EFPY

Material	CF (°F)	FF	IRT_{NDT}[a] (°F)	ΔRT_{NDT}[b] (°F)	Margin (°F)	ART[c] (°F)
Intermediate Shell B2402-1	161.9	0.708	45	114.6	34	194
→ Using Surveillance Data	153.6	0.708	45	108.7	17	**171**
Intermediate Shell B2402-2	161.9	0.708	-5	114.6	34	144
→ Using Surveillance Data	140.4	0.708	-5	99.4	17	113
Intermediate Shell B2402-3	148.9	0.708	-3	105.4	34	136
→ Using Surveillance Data	106.1	0.708	-3	75.1	17	89
Lower Shell B2403-1	128.8	0.708	4	91.2	34	129
Lower Shell B2403-2	129.9	0.708	18	92.0	34	144
Lower Shell B2403-3	128.8	0.708	6	91.2	34	131
Intermediate to Lower Shell Circumferential Weld Seam 9-042 (Heat # 13253)	188.5	0.708	-56	133.5	65.5	143
Intermediate Shell Longitudinal Weld Seams 2-042 A&B (Heat # 39B196/34B009 +NI200)	217.2	0.620	-56	134.7	65.5	144
Intermediate Shell Longitudinal Weld Seam 2-042 C (Heat # 39B196/34B009 +NI200)	217.2	0.500	-56	108.6	65.5	118
Lower Shell Longitudinal Weld Seams 3-042 A&B (Heat # 34B009+NI200, 13253)	223.6	0.600	-56	134.2	65.5	144
Lower Shell Longitudinal Weld Seam 3-042 C (Heat # 34B009+NI200, 13253)	223.6	0.708	-56	158.3	65.5	168

NOTES:

(a) Initial RT_{NDT} values are measured values for the plate material and generic mean values for the weld metal.
(d) ΔRT_{NDT} = CF * FF
(c) ART = I + ΔRT_{NDT} + M (This value was rounded per ASTM E29, using the "Rounding Method".)

TABLE 4-12

Calculation of the ART Values for the 1/4T Location @ 48 EFPY

Material	CF (°F)	FF	IRT_{NDT}[a] (°F)	ΔRT_{NDT}[b] (°F)	Margin (°F)	ART[c] (°F)
Intermediate Shell B2402-1	161.9	1.101	45	178.3	34	257
→ Using Surveillance Data	153.6	1.101	45	169.1	17	231
Intermediate Shell B2402-2	161.9	1.101	-5	178.3	34	207
→ Using Surveillance Data	140.4	1.101	-5	154.6	17	167
Intermediate Shell B2402-3	148.9	1.101	-3	163.9	34	195
→ Using Surveillance Data	106.1	1.101	-3	116.8	17	131
Lower Shell B2403-1	128.8	1.101	4	141.8	34	180
Lower Shell B2403-2	129.9	1.101	18	143.0	34	195
Lower Shell B2403-3	128.8	1.101	6	141.8	34	182
Intermediate to Lower Shell Circumferential Weld Seam 9-042 (Heats # 13253)	188.5	1.101	-56	207.5	65.5	217
Intermediate Shell Longitudinal Weld Seams 2-042 A&B (Heat # 39B196/34B009 +NI200)	217.2	1.010	-56	219.4	65.5	229
Intermediate Shell Longitudinal Weld Seam 2-042 C (Heat # 39B196/34B009 +NI200)	217.2	0.860	-56	186.8	65.5	196
Lower Shell Longitudinal Weld Seam 3-042 A&B (Heat # 34B009+NI200, 13253)	223.6	1.000	-56	223.6	65.5	233
Lower Shell Longitudinal Weld Seam 3-042 C (Heat # 34B009+NI200, 13253)	223.6	1.101	-56	246.2	65.5	**256**

Notes:

(a) Initial RT_{NDT} values are measured values for the plate material and generic mean values for the weld metal.

(b) $\Delta RT_{NDT} = CF * FF$

(c) ART = Initial RT_{NDT} + ΔRT_{NDT} + Margin (°F) ; (Rounded per ASTM E29, using the "Rounding Method")

TABLE 4-13

Calculation of the ART Values for the 3/4T Location @ 48 EFPY

Material	CF (°F)	FF	IRT_{NDT}[(a)] (°F)	ΔRT_{NDT}[(b)] (°F)	Margin (°F)	ART[(c)] (°F)
Intermediate Shell B2402-1	161.9	0.813	45	131.6	34	211
→ Using Surveillance Data	153.6	0.813	45	124.9	17	187
Intermediate Shell B2402-2	161.9	0.813	-5	131.6	34	161
→ Using Surveillance Data	140.4	0.813	-5	114.1	17	126
Intermediate Shell B2402-3	148.9	0.813	-3	121.1	34	152
→ Using Surveillance Data	106.1	0.813	-3	86.3	17	100
Lower Shell B2403-1	128.8	0.813	4	104.7	34	143
Lower Shell B2403-2	129.9	0.813	18	105.6	34	158
Lower Shell B2403-3	128.8	0.813	6	104.7	34	145
Intermediate to Lower Shell Circumferential Weld Seam 9-042 (Heat # 13253)	188.5	0.813	-56	153.3	65.5	163
Intermediate Shell Longitudinal Weld Seams 2-042 A&B (Heat # 39B196/34B009 +NI200)	217.2	0.726	-56	157.7	65.5	167
Intermediate Shell Longitudinal Weld Seam 2-042 C (Heat # 39B196/34B009 +NI200)	217.2	0.590	-56	128.1	65.5	138
Lower Shell Longitudinal Weld Seams 3-042 A&B (Heat # 34B009+NI200, 13253)	223.6	0.700	-56	156.5	65.5	166
Lower Shell Longitudinal Weld Seam 3-042 C (Heat # 34B009+NI200, 13253)	223.6	0.813	-56	181.8	65.5	191

Notes:

(a) Initial RT_{NDT} values are measured values for the plate material and generic mean values for the weld metal.

(b) $\Delta RT_{NDT} = CF * FF$

(c) ART = Initial RT_{NDT} + ΔRT_{NDT} + Margin (°F) ; (Rounded per ASTM E29, using the "Rounding Method")

The longitudinal weld seam 3-042 C is the limiting beltline material for the ¼T case at 32 EFPY and the ¼T and ¾T cases at 48 EFPY. However, the intermediate shell plate B2402-1 using credible surveillance capsule data in limiting for the ¾T 32 EFPY case. Contained in Table 4-14 is a summary of the limiting ARTs to be used in the generation of the Salem Unit 1 reactor vessel heatup and cooldown curves.

TABLE 4-14
Summary of the Limiting ART Values Used in the
Generation of the Salem Unit 1 Heatup/Cooldown Curves

EFPY	1/4T Limiting ART	3/4T Limiting ART
32	232	171
48	256	191

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 discussed in Section 3 and 4 of this report. This approved methodology is also presented in WCAP-14040-NP-A[8], dated January 1996.

Figures 5-1 and 5-3 present the heatup curves with no margins for possible instrumentation errors for heatup rates of 60 and 100°F/hr. These curves are applicable for 32 EFPY and 48 EFPY respectively, for the Salem Unit 1 reactor vessel. Additionally, Figures 5-2 and 5-4 present the cooldown curves with margins for possible instrumentation errors, 18°F for temperature instrumentation and 61 psig for pressure instrumentation for cooldown rates of 0, 20, 40, 60, and 100°F/hr. These curves are also applicable for 32 EFPY and 48 EFPY, respectively, for the Salem Unit 1 reactor vessel. Figures 5-1 through 5-4 include the boltup temperature of 60°F with a margin of 2°F measurement uncertainty. Allowable combinations of temperature and pressure for specific temperature change rates are below and to the right of the limit lines shown in Figures 5-1 through 5-4. This is in addition to other criteria which must be met before the reactor is made critical, as discussed 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 5-1 and 5-3 (for the specific heatup rate being utilized). 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 Appendix G to Section XI of the ASME Code[3] as follows:

$$1.5K_{Im} < K_{Ic} \qquad (10)$$

where,

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

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

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 2. 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 of this report. 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 5-1 through 5-4 define all of the above limits for ensuring prevention of nonductile failure for the Salem Unit 1 reactor vessel. The data points for these heatup and cooldown pressure-temperature limit curves are presented in Tables 5-1 through 5-4, respectively.

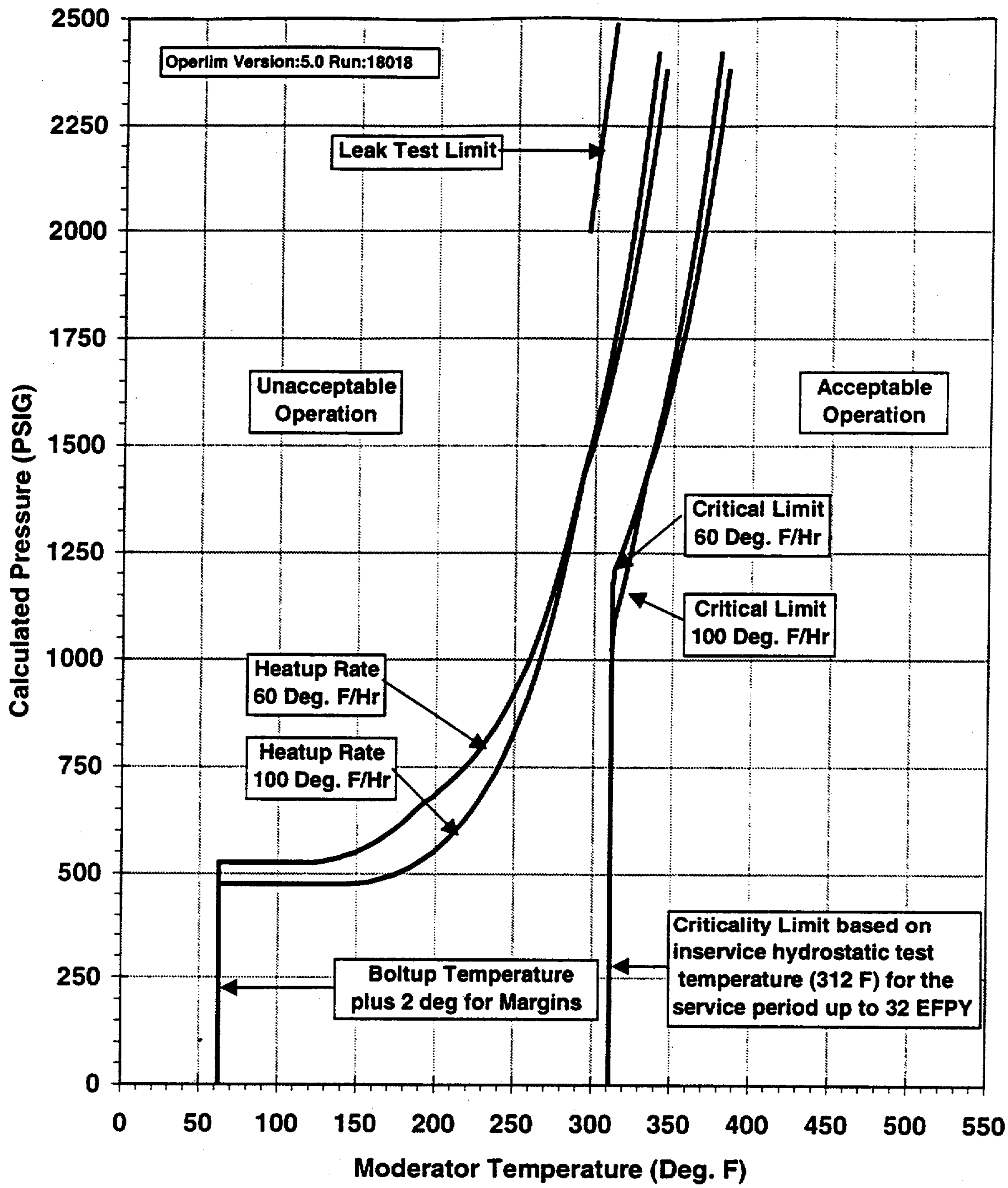

Figure 5-1: Salem Unit 1 Reactor Coolant System Heatup Limitations (Heatup Rates of 60 and 100°F/hr) Applicable to 32 EFPY (With Margins for Instrumentation Errors)

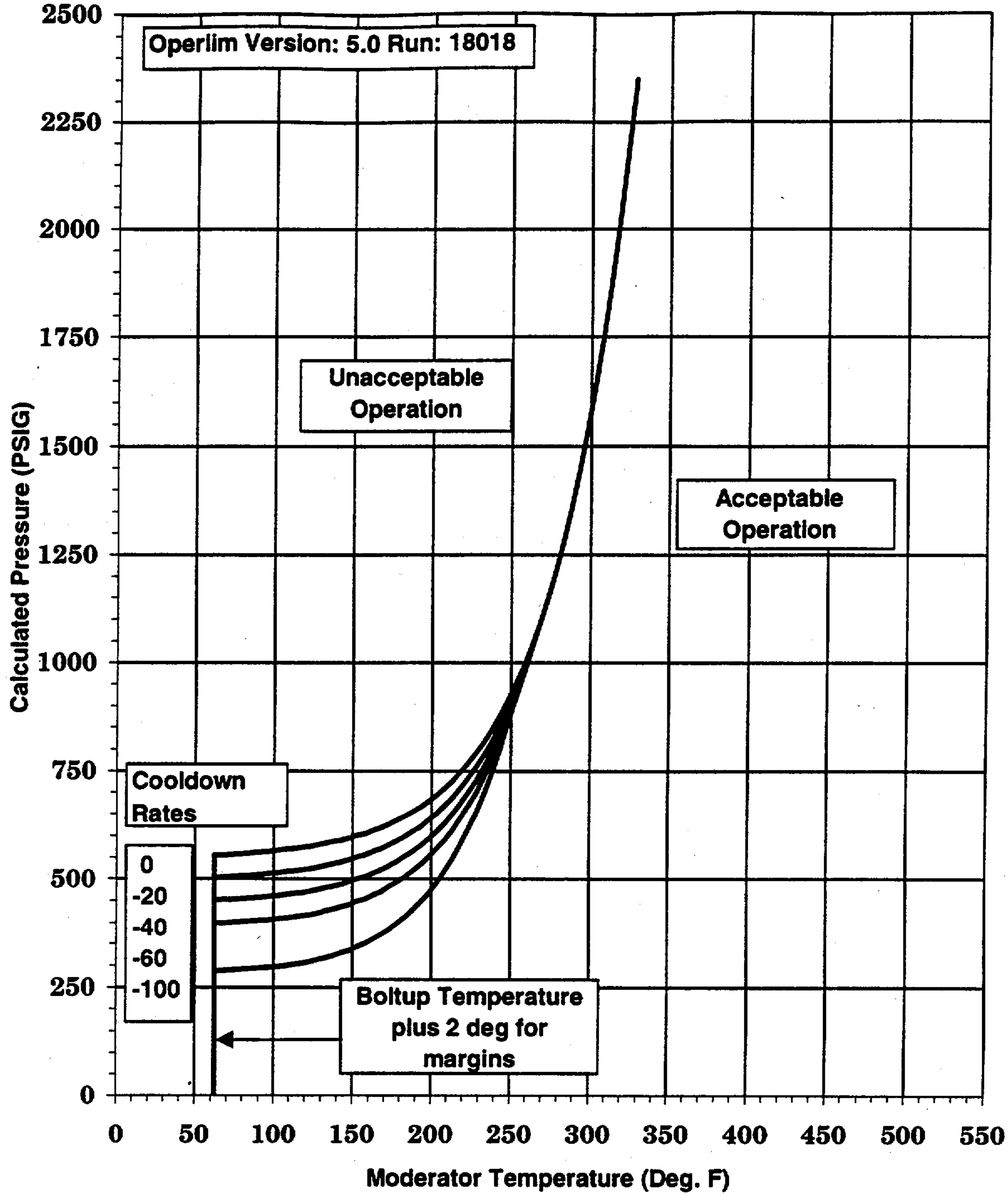

Figure 5- 2: Salem Unit 1 Reactor System Cooldown Limitations (Cooldown Rates of 0, 20, 40, 60 and 100°F/hr) Applicable to 32 EFPY (with Margins for Instrumentation Errors)

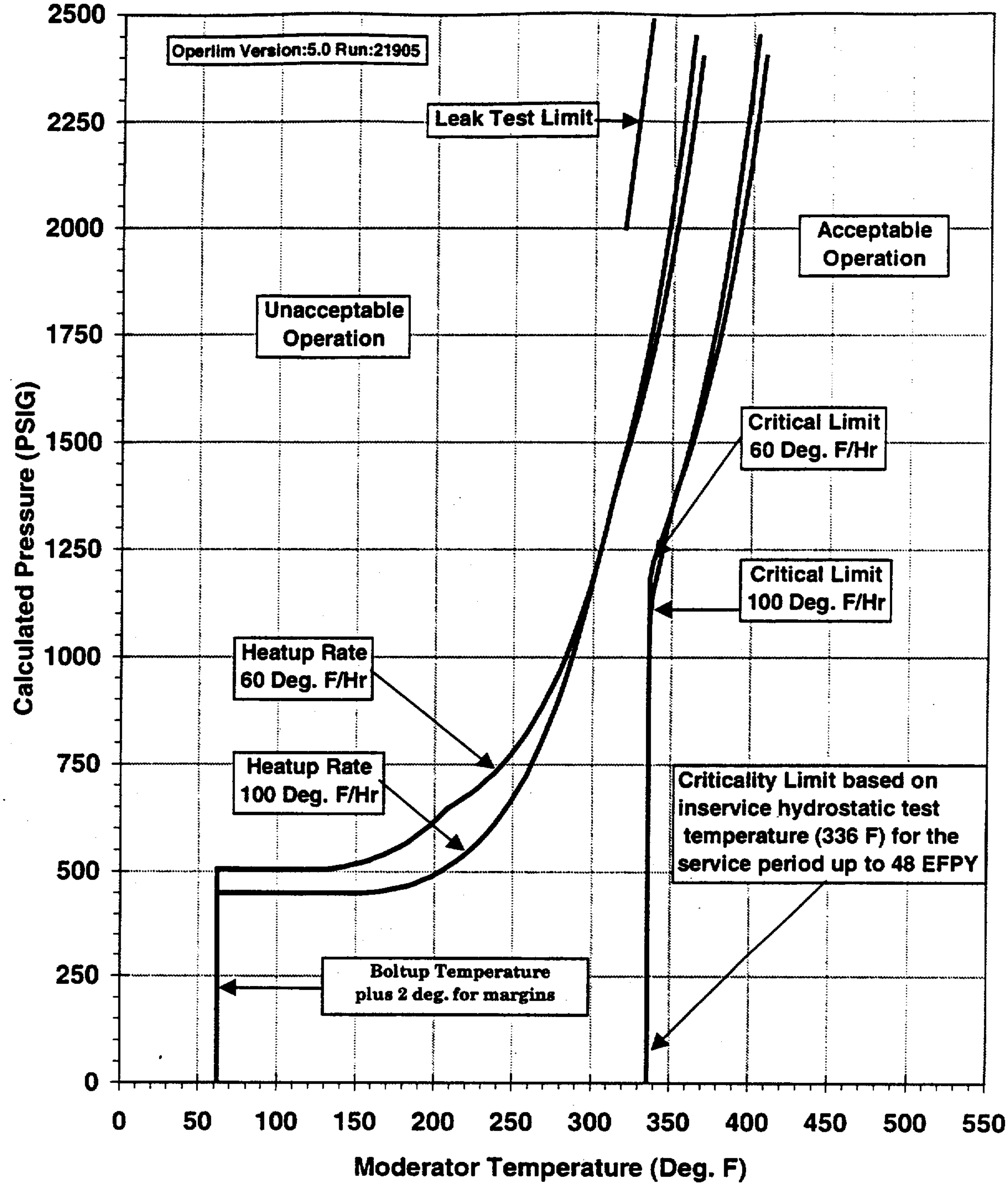

Figure 5- 3: Salem Unit 1 Reactor Coolant System Heatup Limitations (Heatup Rates of 60 and 100°F/hr) Applicable to 48 EFPY (With Margins for Instrumentation Errors)

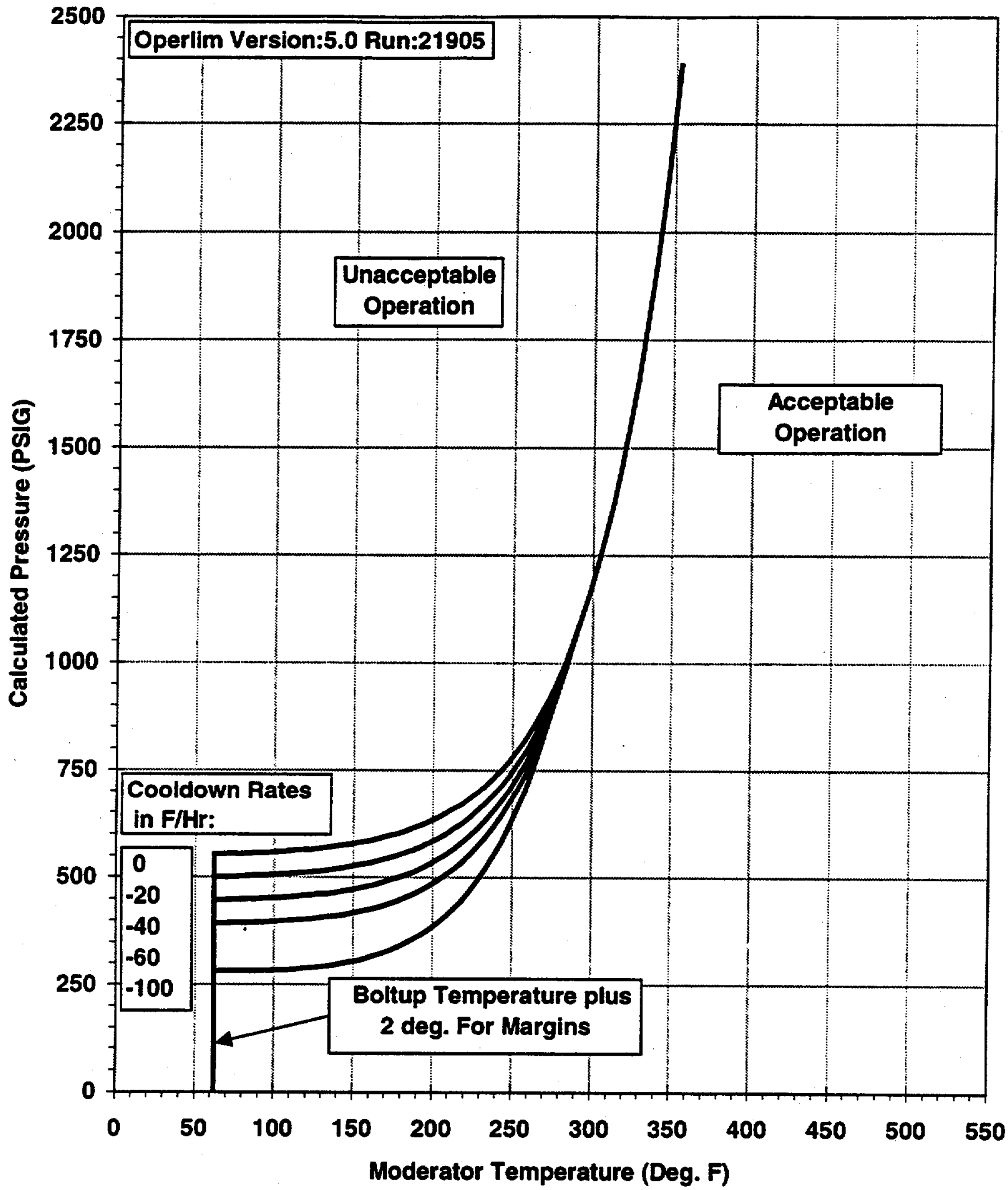

Figure 5- 4: Salem Unit 1 Reactor Coolant System Cooldown Limitations (Cooldown Rates of 0, 20, 40, 60, 100°F/hr) Applicable to 48 EFPY (With Margins for Instrumentation Errors)

TABLE 5-1
Salem Unit 1 Heatup Data at 32 EFPY with Margins for Instrumentation Errors

60 °F/hr. Heatup		60 °F/hr. Crit. Limit		100 °F/hr. Heatup		60 °F/hr. Crit. Limit		Inservice Leak Test	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
62	0	312	0	62	0	312	0	295	2000
62	526	312	526	62	476	312	476	312	2485
78	526	312	526	78	476	312	476		
83	526	312	527	83	476	312	476		
88	526	312	528	88	476	312	478		
93	526	312	529	93	476	312	478		
98	526	312	532	98	476	312	481		
103	526	312	534	103	476	312	481		
108	526	312	536	108	476	312	485		
113	526	312	540	113	476	312	486		
118	526	312	541	118	476	312	490		
123	526	312	548	123	476	312	491		
128	528	312	549	128	476	312	496		
133	532	312	556	133	476	312	499		
138	536	312	561	138	476	312	504		
143	541	312	565	143	476	312	507		
148	548	312	576	148	476	312	513		
153	556	312	576	153	478	312	518		
158	565	312	588	158	481	312	523		
163	576	312	601	163	485	312	531		
168	588	312	616	168	490	312	535		
173	601	312	633	173	496	312	545		
178	616	312	651	178	504	312	549		
183	633	312	672	183	513	312	562		
188	651	312	695	188	523	312	564		
193	667	312	721	193	535	312	580		
198	680	312	749	198	549	312	582		
203	694	312	780	203	564	312	601		
208	710	312	815	208	582	312	623		

TABLE 5-1 (continued)
Salem Unit 1 Heatup Data at 32 EFPY with Margins for Instrumentation Errors

60 °F/hr. Heatup		60 °F/hr. Crit. Limit		100 °F/hr. Heatup		60 °F/hr. Crit. Limit		Inservice Leak Test	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
213	727	312	853	213	601	312	647		
218	746	312	895	218	623	312	674		
223	767	312	942	223	647	312	704		
228	790	312	976	228	674	312	737		
233	816	312	1000	233	704	312	774		
238	844	312	1027	238	737	312	815		
243	876	312	1057	243	774	312	860		
248	910	312	1090	248	815	312	910		
253	949	312	1126	253	860	312	965		
258	991	312	1166	258	910	312	1025		
263	1038	313	1210	263	965	313	1092		
268	1089	318	1258	268	1025	318	1166		
273	1147	323	1312	273	1092	323	1248		
278	1210	328	1371	278	1166	328	1338		
283	1280	333	1436	283	1248	333	1430		
288	1357	338	1507	288	1338	338	1489		
293	1436	343	1586	293	1430	343	1554		
298	1507	348	1673	298	1489	348	1626		
303	1586	353	1769	303	1554	353	1704		
308	1673	358	1875	308	1626	358	1791		
313	1769	363	1992	313	1704	363	1887		
318	1875	368	2121	318	1791	368	1993		
323	1992	373	2264	323	1887	373	2109		
328	2121	378	2421	328	1993	378	2237		
333	2264			333	2109	383	2378		
338	2421			338	2237				
				343	2378				

TABLE 5-2
Salem Unit 1 Cooldown Data at 32 EFPY with Margins for Instrumentation Errors

Steady State		-20 °F/hr. Cooldown		-40 °F/hr. Cooldown		-60 °F/hr. Cooldown		-100 °F/hr. Cooldown	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
62	0	62	0	62	0	62	0	62	0
62	555	62	504	62	452	62	399	62	287
68	556	68	505	68	453	68	400	68	288
73	557	73	506	73	454	73	401	73	289
78	558	78	507	78	455	78	402	78	290
83	559	83	508	83	456	83	403	83	291
88	561	88	510	88	457	88	404	88	292
93	562	93	511	93	459	93	405	93	294
98	564	98	513	98	460	98	407	98	295
103	566	103	515	103	462	103	409	103	297
108	568	108	517	108	464	108	411	108	299
113	570	113	519	113	467	113	413	113	302
118	573	118	522	118	469	118	416	118	305
123	576	123	525	123	472	123	419	123	309
128	579	128	528	128	476	128	423	128	313
133	583	133	532	133	480	133	427	133	317
138	586	138	536	138	484	138	431	138	323
143	591	143	540	143	489	143	436	143	328
148	595	148	545	148	494	148	442	148	335
153	600	153	551	153	500	153	448	153	343
158	606	158	557	158	506	158	455	158	351
163	613	163	563	163	514	163	463	163	361
168	620	168	571	168	522	168	472	168	371
173	627	173	579	173	531	173	482	173	383
178	636	178	588	178	541	178	493	178	397
183	645	183	599	183	552	183	505	183	412
188	656	188	610	188	564	188	519	188	429
193	667	193	623	193	578	193	534	193	447
198	680	198	637	198	593	198	551	198	468
203	694	203	652	203	610	203	569	203	491
208	710	208	669	208	629	208	590	208	517
213	727	213	688	213	650	213	613	213	545
218	746	218	709	218	673	218	639	218	577
223	767	223	732	223	699	223	667	223	613
228	790	228	758	228	727	228	699	228	652
233	816	233	786	233	758	233	734	233	696
238	844	238	817	238	793	238	772	238	744

TABLE 5-2 (continued)

Salem Unit 1 Cooldown Data at 32 EFPY with Margins for Instrumentation Errors

Steady State		-20 °F/hr. Cooldown		-40 °F/hr. Cooldown		-60 °F/hr. Cooldown		-100 °F/hr. Cooldown	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
243	876	243	852	243	832	243	815	243	798
248	910	248	890	248	874	248	863	248	858
253	949	253	933	253	922	253	915	253	924
258	991	258	980	258	974	258	974	258	991
263	1038	263	1032	263	1032	263	1038	263	1038
268	1089	268	1089	268	1089	268	1089	268	1089
273	1147	273	1147	273	1147	273	1147	273	1147
278	1210	278	1210	278	1210	278	1210	278	1210
283	1280	283	1280	283	1280	283	1280	283	1280
288	1357	288	1357	288	1357	288	1357	288	1357
293	1442	293	1442	293	1442	293	1442	293	1442
298	1536	298	1536	298	1536	298	1536	298	1536
303	1640	303	1640	303	1640	303	1640	303	1640
308	1755	308	1755	308	1755	308	1755	308	1755
313	1883	313	1883	313	1883	313	1883	313	1883
318	2023	318	2023	318	2023	318	2023	318	2023
323	2179	323	2179	323	2179	323	2179	323	2179
328	2350	328	2350	328	2350	328	2350	328	2350

TABLE 5-3
Salem Unit 1 Heatup Data at 48 EFPY with Margins for Instrumentation Errors

60 °F/hr. Heatup		60 °F/hr. Crit. Limit		100 °F/hr. Heatup		60 °F/hr. Crit. Limit		Inservice Leak Test	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
62	0	336	0	62	0	336	0	319	2000
62	506	336	506	62	450	336	450	336	2485
78	506	336	506	78	450	336	451		
83	506	336	507	83	450	336	451		
88	506	336	507	88	450	336	452		
93	506	336	509	93	450	336	452		
98	506	336	509	98	450	336	455		
103	506	336	512	103	450	336	455		
108	506	336	513	108	450	336	458		
113	506	336	516	113	450	336	458		
118	506	336	518	118	450	336	462		
123	506	336	520	123	450	336	462		
128	506	336	525	128	450	336	467		
133	507	336	526	133	450	336	468		
138	509	336	533	138	450	336	473		
143	512	336	535	143	450	336	475		
148	516	336	540	148	450	336	480		
153	520	336	548	153	450	336	483		
158	526	336	549	158	451	336	489		
163	533	336	559	163	452	336	493		
168	540	336	564	168	455	336	499		
173	549	336	569	173	458	336	504		
178	559	336	582	178	462	336	510		
183	569	336	595	183	467	336	517		
188	582	336	611	188	473	336	522		
193	595	336	627	193	480	336	532		
198	611	336	646	198	489	336	536		
203	627	336	667	203	499	336	549		
208	646	336	690	208	510	336	552		

TABLE 5-3 (continued)
Salem Unit 1 Heatup Data at 48 EFPY with Margins for Instrumentation Errors

60 °F/hr. Heatup		60 °F/hr. Crit. Limit		100 °F/hr. Heatup		60 °F/hr. Crit. Limit		Inservice Leak Test	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
213	658	336	715	213	522	336	567		
218	670	336	743	218	536	336	569		
223	683	336	775	223	552	336	589		
228	697	336	809	228	569	336	611		
233	713	336	847	233	589	336	635		
238	731	336	889	238	611	336	662		
243	750	336	935	243	635	336	692		
248	771	336	960	248	662	336	725		
253	795	336	983	253	692	336	761		
258	821	336	1008	258	725	336	801		
263	850	336	1035	263	761	336	846		
268	882	336	1066	268	801	336	895		
273	918	336	1099	273	846	336	950		
278	957	336	1136	278	895	336	1010		
283	1000	336	1176	283	950	336	1076		
288	1048	338	1221	288	1010	338	1149		
293	1100	343	1270	293	1076	343	1230		
298	1159	348	1324	298	1149	348	1319		
303	1223	353	1384	303	1223	353	1388		
308	1294	358	1450	308	1294	358	1443		
313	1373	363	1522	313	1373	363	1502		
318	1450	368	1602	318	1443	368	1568		
323	1522	373	1691	323	1502	373	1641		
328	1602	378	1788	328	1568	378	1720		
333	1691	383	1896	333	1641	383	1808		
338	1788	388	2015	338	1720	388	1905		
343	1896	393	2146	343	1808	393	2012		
348	2015	398	2290	348	1905	398	2129		
353	2146	403	2450	353	2012	403	2259		
358	2290			358	2129	408	2402		
363	2450			363	2259				
				368	2402				

TABLE 5-4
Salem Unit 1 Cooldown Data at 48 EFPY with Margins for Instrumentation Errors

Steady State		-20 °F/hr. Cooldown		-40 °F/hr. Cooldown		-60 °F/hr. Cooldown		-100 °F/hr. Cooldown	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
62	0	62	0	62	0	62	0	62	0
62	553	62	500	62	488	62	394	62	283
68	553	68	501	68	488	68	394	68	283
73	554	73	501	73	449	73	395	73	283
78	554	78	502	78	449	78	395	78	283
83	554	83	503	83	450	83	396	83	283
88	555	88	504	88	451	88	396	88	283
93	556	93	504	93	451	93	397	93	283
98	557	98	505	98	452	98	397	98	284
103	558	103	506	103	453	103	398	103	285
108	560	108	508	108	454	108	399	108	285
113	561	113	509	113	455	113	401	113	287
118	563	118	510	118	457	118	402	118	288
123	564	123	512	123	459	123	404	123	290
128	566	128	514	128	460	128	406	128	292
133	569	133	516	133	463	133	408	133	294
138	571	138	519	138	465	138	410	138	297
143	574	143	521	143	468	143	413	143	300
148	576	148	524	148	471	148	416	148	304
153	580	153	528	153	474	153	420	153	308
158	583	158	531	158	478	158	424	158	313
163	587	163	535	163	483	163	429	163	318
168	592	168	540	168	487	168	434	168	324
173	596	173	545	173	493	173	440	173	331
178	602	178	551	178	499	178	446	178	339
183	607	183	557	183	506	183	454	183	348
188	614	188	564	188	513	188	462	188	358
193	621	193	571	193	521	193	471	193	369
198	629	198	580	198	531	198	481	198	381
203	638	203	589	203	541	203	492	203	395
208	647	208	600	208	552	208	505	208	410
213	658	213	612	213	565	213	519	213	428
218	670	218	624	218	579	218	534	218	447
223	683	223	639	223	595	223	552	223	468
228	697	228	654	228	612	228	571	228	492
233	713	233	672	233	631	233	592	233	519
238	731	238	691	238	653	238	616	238	548

TABLE 5-4 (continued)

Salem Unit 1 Cooldown Data at 48 EFPY with Margins for Instrumentation Errors

Steady State		-20 °F/hr. Cooldown		-40 °F/hr. Cooldown		-60 °F/hr. Cooldown		-100 °F/hr. Cooldown	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
243	750	243	712	243	676	243	642	243	581
248	771	248	736	248	703	248	671	248	617
253	795	253	762	253	732	253	703	253	658
258	821	258	791	258	764	258	739	258	703
263	850	263	823	263	799	263	779	263	753
268	882	268	859	268	839	268	823	268	808
273	918	273	898	273	883	273	872	273	870
278	957	278	941	278	931	278	926	278	938
283	1000	283	989	283	984	283	986	283	1000
288	1048	288	1043	288	1044	288	1048	288	1048
293	1100	293	1100	293	1100	293	1100	293	1100
298	1159	298	1159	298	1159	298	1159	298	1159
303	1223	303	1223	303	1223	303	1223	303	1223
308	1294	308	1294	308	1294	308	1294	308	1294
313	1373	313	1373	313	1373	313	1373	313	1373
318	1460	318	1460	318	1460	318	1460	318	1460
323	1556	323	1556	323	1556	323	1556	323	1556
328	1662	328	1662	328	1662	328	1662	328	1662
333	1780	333	1780	333	1780	333	1780	333	1780
338	1910	338	1910	338	1910	338	1910	338	1910
343	2053	343	2053	343	2053	343	2053	343	2053
348	2212	348	2212	348	2212	348	2212	348	2212
353	2387	353	2387	353	2387	353	2387	353	2387

6 REFERENCES

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

2 10 CFR Part 50, Appendix G, "Fracture Toughness Requirements", Federal Register, Volume 60, No. 243, dated December 19, 1995.

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

4 WCAP-14635, "Analysis of Capsule S from the Public Service Electric and Gas Company Salem Unit 1 Reactor Vessel Radiation Program", P. A. Grendys, et. al., June 1996.

6 1989 Section III, Division 1 of the ASME Boiler and Pressure Vessel Code, Paragraph NB-2331, "Material for Vessels".

7. LTR-REA-00-621, "Reactor Vessel Fluences for the Salem 1.4% Uprate Project", S.L. Anderson, June 27, 2000.

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 CE NPSD-1039, Rev. 2, "Best Estimate Copper and Nickel Values in CE Fabricated Reactor Vessel Welds, Appendix A, CE Reactor Vessel Weld Properties Database, Volume 1," CEOG Task 902, June 1997.

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

11 WCAP-15315, "Reactor Vessel Closure Head/Vessel Flange Requirements Evaluation For Operating PWR and BWR Plants", W. Bamford, et.al., October 1999.

APPENDIX A

PROJECTED UPPER SHELF ENERGY VALUES

FOR SALEM UNIT 1

APPENDIX A - PREDICTED EOL USE VALUES

Per Regulatory Guide 1.99, Revision 2, the Charpy upper-shelf energy is assumed to decrease as a function of fluence and copper content as indicated in Figure 2 of the guide when surveillance data is not used. Linear interpolation is permitted. In addition, if surveillance data is used, the decrease in upper-shelf energy may be obtained by plotting the reduced plant surveillance data on Figure 2 of the guide and fitting the data with a line drawn parallel to the existing lines as the upper bound of all the data. This line should be used in preference to the existing graph.

The EOL (32 EFPY) and license renewal (48 EFPY) USE values can be predicted using the ¼T fluence projections at 32 and 48 EFPY, the copper content of the beltline materials and/or the results of the capsules tested to date using Figure 2 in Regulatory Guide 1.99, Revision 2. The peak vessel clad/base metal interface fluence value was used to determine the EOL (32 EFPY) and license renewal (48 EFPY) USE values of all the beltline materials.

The Salem Unit 1 reactor vessel beltline region minimum thickness is 8.625 inches.

The calculation of the ¼T vessel fluence values at 32 EFPY for the beltline materials is contained in Table A-1.

The calculation of the EOL USE values at 32 EFPY for the beltline materials is contained in Table A-2.

The calculation of the ¼T vessel fluence value at 48 EFPY for the beltline materials is contained in Table A-3.

The calculation of the EOL USE values at 48 EFPY for the beltline materials is contained in Table A-4.

TABLE A-1

EOL (32 EFPY) ¼T Fluence Values for all the Salem Unit 1 Beltline Materials.

Material	f @ 32 EFPY[a]	¼T f @ 32 EFPY[b]
Intermediate Shell B2402-1	1.64	0.98
Intermediate Shell B2402-2	1.64	0.98
Intermediate Shell B2402-3	1.64	0.98
Lower Shell B2403-1	1.64	0.98
Lower Shell B2403-2	1.64	0.98
Lower Shell B2403-3	1.64	0.98
Intermediate to Lower Shell Circumferential Weld Seam 9-042 (Heat # 13253)	1.64	0.98
Longitudinal Weld Seams 2-042 A, B & C (Heat # 39B196/34B009 +NI200)	1.64	0.98
Longitudinal Weld Seams 3-042 A, B & C (Heat # 34B009+NI200, 13253)	1.64	0.98

Notes:

(a) f @ 32 EFPY is the 32 EFPY fluence at the clad/base metal interface ($x\ 10^{19}$ n.cm^2, E > 1.0 MeV).

(b) ¼T f @ 32 EFPY = f @ 32 EFPY * $e^{(-0.24 \cdot X)}$, ($x\ 10^{19}$ n.cm^2, E > 1.0 MeV) where X is the depth into the vessel wall (X = 0.25 * 8.625 inches = 2.15625 inches)

TABLE A-2

Salem 1 Predicted End-of-License (32 EFPY) USE Calculations for all the Beltline Region Materials

Material	**Weight % of Cu**	**¼T EOL Fluence (10^{19} n/cm^2, E>1.0MeV)**	**Unirradiated USE (ft-lb)**	**Projected USE Decrease (%)**	**Projected EOL USE (ft-lb)**
Intermediate Shell B2402-1	0.24	0.98	91	19	74
Intermediate Shell B2402-2	0.24	0.98	98	15	83
Intermediate Shell B2402-3	0.22	0.98	104	16	87
Lower Shell B2403-1	0.19	0.98	93	29	66
Lower Shell B2403-2	0.19	0.98	83	29	59
Lower Shell B2403-3	0.19	0.98	85	29	60
Intermediate to Lower Shell Circumferential Weld Seam 9-042 (Heat # 13253)	0.22	0.98	112	36	72
Longitudinal Weld Seams 2-042 A, B & C (Heat # 39B196/34B009 + NI200)	0.18	0.98	96.2	32	65
Longitudinal Weld Seams 3-042 A, B & C (Heat # 34B009+NI200, 13253)	0.19	0.98	112	32	76

TABLE A-3

EOL (48 EFPY) ¼T Fluence Values for all the Salem Unit 1 Beltline

Material	f @ 48 EFPY[a]	¼T f @ 48 EFPY[b]
Intermediate Shell B2402-1	2.42	1.44
Intermediate Shell B2402-2	2.42	1.44
Intermediate Shell B2402-3	2.42	1.44
Lower Shell B2403-1	2.42	1.44
Lower Shell B2403-2	2.42	1.44
Lower Shell B2403-3	2.42	1.44
Intermediate to Lower Shell Circumferential Weld Seam 9-042 (Heat # 13253)	2.42	1.44
Intermediate Shell Longitudinal Weld Seams 2-042 A, B & C (Heat # 39B196/34B009 +NI200)	2.42	1.44
Lower Shell Longitudinal Weld Seams 3-042 A, B & C (Heat # 34B009+NI200, 13253)	2.42	1.44

Notes:

(b) f @ 48 EFPY is the 48 EFPY fluence at the clad/base metal interface ($x\ 10^{19}$ n.cm^2, E > 1.0 MeV).

(b) ¼T f @ 48 EFPY = f @ 48 EFPY * $e^{(-0.24*X)}$, ($x\ 10^{19}$ n.cm^2, E > 1.0 MeV) where X is the depth into the vessel wall (X = 0.25 * 8.625 inches = 2.15625 inches)

TABLE A-4

Salem 1 Predicted Life Extension (48 EFPY) USE Calculations for all the Beltline Region Materials

Material	Weight % Cu	¼T Life Extension Fluence ($x 10^{19}$ n/cm^2)	Unirradiated USE (ft-lb)	Projected USE Decrease (%)	Projected Life Extension USE (ft-lb)
Intermediate Shell B2402-1	0.24	1.44	91	21	72
Intermediate Shell B2402-2	0.24	1.44	98	16	82
Intermediate Shell B2402-3	0.22	1.44	104	17	86
Lower Shell B2403-1	0.19	1.44	93	32	63
Lower Shell B2403-2	0.19	1.44	83	32	56
Lower Shell B2403-3	0.19	1.44	85	32	58
Intermediate to Lower Shell Circumferential Weld Seam 9-042 (Heats:13253)	0.22	1.44	112	40	67
Longitudinal Weld Seam 2-042 (Heat: 39B196/34B009 +NI200)	0.18	1.44	96.2	35	63
Longitudinal Weld Seam 3-042 (Heat: 34B009+NI200, 13253)	0.19	1.44	112	35	73

WCAP-15566, Revision 0, "Salem Unit 2 Heatup and Cooldown Curves for Normal Operation"

Westinghouse Non-Proprietary Class 3

WCAP - 15566
Revision 0

Salem Unit 2 Heatup and Cooldown Curves for Normal Operation

Westinghouse Electric Company LLC

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-15566

Salem Unit 2 Heatup and Cooldown Curves for Normal Operation

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PREFACE

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EXECUTIVE SUMMARY

This report documents the development of pressure-temperature limit curves for the PSEG Nuclear LLC Salem Unit 2 electric generating plant for normal operation at 32 and 48 EFPY. These pressure-temperature curves include the a 1.4% uprating fluence values and utilize the methodology from the 1995 ASME Boiler and Pressure Vessel Code, Section XI, Appendix G, through the 1996 addendum. Regulatory Guide 1.99, Revision 2 was used for the calculation of Adjusted Reference Temperature (ART) values at the 1/4T and 3/4T location. The 1/4T and 3/4T values are summarized in Table 4-14. The pressure-temperature limit curves were generated with margins for instrumentation errors for heatup rates of 60 and 100°F/hr and cooldown rates of 0, 20, 40, 60 and 100°F/hr. These curves can be found in Figures 5-1 through 5-4. In addition, these heatup and cooldown pressure-temperature limit curves include ASME Code Case N-640[10], which allows the use of the K_{Ic} methodology, and the elimination of the reactor vessel flange temperature-pressure requirement (Ref, WCAP-15315[11]).

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"[1]. Regulatory Guide 1.99, Revision 2, is used for the calculation of Adjusted Reference Temperature (ART) values (IRT_{NDT} + ΔRT_{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 the heatup and cooldown pressure-temperature limit curves for normal operation. The fluence evaluation in WCAP-13366 used the ENDF/B-IV scattering cross-section data set. This is not consistent with the methods presented in WCAP-14040-NP-A, "Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves"[8]. However, for the uprating evaluation, these calculations were adjusted to account for the use of ENDF/B-VI cross sections as required by WCAP-14040-NP-A. A capsule will be removed from the Salem Unit 2 reactor vessel and tested in the fall of 2000. This evaluation will include an updated fluence evaluation using the ENDF/B-VI scattering cross-section data set and re-evaluation of the pressure-temperature curves in accordance with WCAP-14040-NP-A.

The heatup and cooldown curves documented in this report were generated using the most limiting ART values and the NRC approved methodology documented in WCAP-14040-NP-A, Revision 2[8], "Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves" with exception of the following: 1) The K_{Ic} critical stress intensities are used in place of the K_{Ia} critical stress intensities. This methodology is taken from approved ASME Code Case N-640[10]. 2) The reactor vessel flange temperature requirement has been eliminated. Justification has been provided in WCAP-15315[11]. 3) The 1995 Version of Appendix G to Section XI[3], through the 1996 addendum, will be used rather than the 1989 version.

2 PURPOSE

PSEG Nuclear LLC contracted Westinghouse to generate new heatup and cooldown curves for Salem Unit 2 at 32 and 48 EFPY based upon the 1.4% uprating projected fluence values using the latest Code Methodologies and the elimination of the flange requirement. The heatup and cooldown curves were generated with margins for instrumentation errors of 18°F and 61 psig and 2°F for boltup. The curves also include a hydrostatic leak test limit curve from 2485 to 2000 psig.

The purpose of this report is to present the calculations and the development of the PSEG Nuclear LLC Salem Unit 2 heatup and cooldown curves for 32 and 48 EFPY. This report documents the calculated adjusted reference temperature (ART) values following the methods of Regulatory Guide 1.99, Revision 2[1], for all the beltline materials and the development of the heatup and cooldown pressure-temperature limit curves for normal operation.

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 PT Limit Curves for Section XI"[10] of the ASME Appendix G to Section XI. 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 for $\sqrt{t} < 2$,
M_m = $0.926\sqrt{t}$ for $2 \leq \sqrt{t} \leq 3.464$,
M_m = 3.21 for $\sqrt{t} > 3.464$

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

M_m = 1.77 for $\sqrt{t} < 2$,
M_m = $0.893\sqrt{t}$ for $2 \leq \sqrt{t} \leq 3.464$,
M_m = 3.09 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 $K_{It} = 0.953 \times 10^{-3}$ x CR x $t^{2.5}$, where CR is the cooldown rate in °F/hr., or for a postulated outside surface defect, $K_{It} = 0.753 \times 10^{-3}$ x HU x $t^{2.5}$, 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:

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

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 1 through 6 were implemented in the OPERLIM computer code, which is the W 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, "Methodology used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves"[8] 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 (3106 psi). However, per WCAP-15315, "Reactor Vessel Closure Head/Vessel Flange Requirements Evaluation For Operating PWR and BWR Plants"[11], this requirement is no longer necessary when using the methodology of Code Case N-640[10]. Hence, the Salem Unit 2 heatup and cooldown limit curves will be generated without flange requirements included.

3.4 Minimum Boltup Temperature

The minimum boltup temperature is equal to the material RT_{NDT} of the stressed region. The RT_{NDT} is calculated in accordance with the methods described in Branch Technical Position MTEB 5-2. The Westinghouse position is that the boltup temperature be no lower than 60°F. Thus, the minimum boltup temperature should be 60°F or the material RT_{NDT}, whichever is higher.

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:

$$ART = Initial\, RT_{NDT} + \Delta RT_{NDT} + Margin \qquad (7)$$

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[6]. 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 is calculated as follows:

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

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.

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

where x inches (vessel beltline thickness is 8.625 inches[4]) 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.

Evaluation of the last surveillance capsule removed from the Salem Unit 2 reactor is documented in WCAP-13366, "Analysis of Capsule X from the Public Service Electric and Gas Company Salem Unit 2 Reactor Vessel Radiation Surveillance Program". The fluence analysis provided in that report was based on the application of ENDF/B-IV neutron transport cross-section. Therefore, in the determination of the fluence projections for the Salem Unit 2 uprate program, adjustments were made to the calculated values to account for the incorporation of ENDF/B-VI cross-sections into the analysis. This adjustment was performed in order to meet the requirement of WCAP-14040-NP-A. This adjustment resulted in an increase in the calculated flux at the pressure vessel of from 10% to 12% depending on azimuthal angle. The upgrade from ENDF/B-IV to ENDF/B-VI transport cross-sections does not have a significant effect on the measurement based best estimate values reported in WCAP-13366.

In evaluating the incremental fluence due to an uprate from 3411 MWt to 3459 MWt, the assumption was made that the uprate occurred coincident with the last surveillance capsule withdrawal (i.e. 6.2 EFPY). This assumption introduces a slight conservatism in the final projections, but does not introduce a significant overestimate of the vessel fluence. Tables 4-1 and 4-2, herein, contain the uprated vessel surface fluence values along with the Regulatory Guide 1.99, Revision 2, 1/4T and 3/4T uprated fluences used to calculate the ART values for all beltline materials in the Salem Unit 2 reactor vessel. Additionally, the surveillance capsule fluence values are presented in Table 4-3.

TABLE 4-1
Summary of the Peak Pressure Vessel Neutron Fluence Values
at 32 EFPY used for the Calculation of ART Values (n/cm^2, E > 1.0 MeV)

Material	Surface*	¼ T	¾ T
Intermediate Shell B4712-1	1.78×10^{19}	1.06×10^{19}	3.77×10^{18}
Intermediate Shell B4712-2	1.78×10^{19}	1.06×10^{19}	3.77×10^{18}
Intermediate Shell B4712-3	1.78×10^{19}	1.06×10^{19}	3.77×10^{18}
Lower Shell B4713-1	1.78×10^{19}	1.06×10^{19}	3.77×10^{18}
Lower Shell B4713-2	1.78×10^{19}	1.06×10^{19}	3.77×10^{18}
Lower Shell B4713-3	1.78×10^{19}	1.06×10^{19}	3.77×10^{18}
Intermediate to Lower Shell Circumferential Weld Seam 9-442 (Heat # 90099)	1.78×10^{19}	1.06×10^{19}	3.77×10^{18}
Intermediate Shell Longitudinal Weld Seam 2-442 A (Heat # 13253/20291)	6.94×10^{18}	4.14×10^{18}	1.47×10^{18}
Intermediate Shell Longitudinal Weld Seams 2-442 B&C (Heat # 13253/20291)	1.20×10^{19}	7.15×10^{18}	2.54×10^{18}
Lower Shell Longitudinal Weld Seams 3-442 A& C (Heat # 21935/12008)	1.20×10^{19}	7.15×10^{18}	2.54×10^{18}
Lower Shell Longitudinal Weld Seam 3-442 B (Heat # 21935/12008)	6.94×10^{18}	4.14×10^{18}	1.47×10^{18}

* Surface fluence values are best-estimate values.

TABLE 4-2
Summary of the Peak Pressure Vessel Neutron Fluence Values
at 48 EFPY used for the Calculation of ART Values (n/cm^2, E > 1.0 MeV)

Material	Surface*	¼ T	¾ T
Intermediate Shell B4712-1	2.66×10^{19}	1.58×10^{19}	5.63×10^{18}
Intermediate Shell B4712-2	2.66×10^{19}	1.58×10^{19}	5.63×10^{18}
Intermediate Shell B4712-3	2.66×10^{19}	1.58×10^{19}	5.63×10^{18}
Lower Shell B4713-1	2.66×10^{19}	1.58×10^{19}	5.63×10^{18}
Lower Shell B4713-2	2.66×10^{19}	1.58×10^{19}	5.63×10^{18}
Lower Shell B4713-3	2.66×10^{19}	1.58×10^{19}	5.63×10^{18}
Intermediate to Lower Shell Circumferential Weld Seam 9-442 (Heat # 90099)	2.66×10^{19}	1.58×10^{19}	5.63×10^{18}
Intermediate Shell Longitudinal Weld Seam 2-442 A (Heat # 13253/20291)	1.04×10^{19}	6.20×10^{18}	2.20×10^{18}
Intermediate Shell Longitudinal Weld Seam 2-442 B&C (Heat # 13253/20291)	1.80×10^{19}	1.07×10^{19}	3.81×10^{18}
Lower Shell Longitudinal Weld Seam 3-442 A & C (Heat # 21935/12008)	1.80×10^{19}	1.07×10^{19}	3.81×10^{18}
Lower Shell Longitudinal Weld Seam 3-442 B (Heat # 21935/12008)	1.04×10^{19}	6.20×10^{18}	2.20×10^{18}

* Surface fluence values are best-estimate values.

TABLE 4-3
Best-Estimate Integrated Neutron Exposure of the Salem Unit 2 Surveillance Capsules Tested to Date

Capsule	Fluence
T	2.76×10^{18} n/cm^2, (E > 1.0 MeV)
U	5.07×10^{18} n/cm^2, (E > 1.0 MeV)
X	1.16×10^{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, σ_i, is 0°F when the initial RT_{NDT} is a measured value, and 17°F when a generic value is used. The standard deviation for the ΔRT_{NDT} margin term, σ_Δ, is 17°F for plates when surveillance capsule data is not used and 8.5°F for plates when surveillance capsule data is used. For welds, σ_Δ is 28°F when surveillance capsule data is not used and 14°F when surveillance capsule data is used. In addition, σ_Δ need not exceed one-half the mean value of ΔRT_{NDT}.

Contained in Table 4-4 is a summary of the Measured 30 ft-lb transition temperature shifts of the beltline materials. These measured shift values were obtained from Reference 4 and are based on a hand drawn curve utilizing engineering judgement.

TABLE 4-4
Measured 30 ft-lb Transition Temperature Shifts of the Beltline Materials Contained in the Surveillance Program

Material	Capsule	Measured 30 ft-lb Transition Temperature Shift
Intermediate Shell Plate	T	50°F
B4712-2	U	70°F
(Longitudinal Orientation)	X	80°F
Intermediate Shell Plate	T	70°F
B4712-2	U	95°F
(Transverse Orientation)	X	125°F
Surveillance Program	T	155°F
Weld Metal	U	190°F
	X	195°F

Table 4-5 contains a summary of the weight percent of copper, the weight percent of nickel and the initial RT_{NDT} of the beltline materials. The weight percent values of Cu and Ni given in Table 4-5 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 4-7. Table 4-6 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 4-7.

TABLE 4-5

Reactor Vessel Beltline Material Unirradiated Toughness Properties[4 & 5]

Material Description	Cu (%)	Ni(%)	Initial RT_{NDT}[a]
Closure Head Flange B4702-1	- -	- -	28°F
Vessel Flange B5001	- -	- -	12°F
Intermediate Shell B4712-1[d]	0.13	0.56	0°F
Intermediate Shell B4712-2[d]	0.12	0.62	12°F
Intermediate Shell B4712-3[d]	0.11	0.57	10°F
Lower Shell B4713-1[d]	0.12	0.60	8°F
Lower Shell B4713-2[d]	0.12	0.57	8°F
Lower Shell B4713-3[d]	0.12	0.58	10°F
Intermediate to Lower Shell Circumferential Weld Seam 9-442 (Heats # 90099) [c]	0.197	0.060	-56°F
Intermediate Shell Longitudinal Weld Seams 2-442 A,B & C (Heat # 13253/20291) [c]	0.219	0.735	-56°F
Lower Shell Longitudinal Weld Seams 3-442 A, B & C (Heat # 21935/12008) [c]	0.213	0.867	-56°F

Notes:

(a) The Initial RT_{NDT} values for the plates materials are measured values while the Initial RT_{NDT} values

for the weld materials are generic.[5]

(b) The surveillance program weld material was fabricated with 3/16" diameter type B-4 wire, heat #13253, Linde 1092 flux, lot #'s 3833/3774. This weld metal is only representative of the beltline welds, not identical. Hence, the weld metal surveillance data was not used in any ART

TABLE 4-6

Calculation of Chemistry Factors using Salem Unit 2 Surveillance Capsule Data

Material	Capsule	Capsule f(a)	FF(b)	ΔRT_{NDT} (c)	FF* ΔRT_{NDT}	FF^2
Intermediate Shell B4712-2 (Longitudinal)	T	0.276	0.649	50.00°F	32.45°F	0.42
	U	0.570	0.843	70.00°F	59.01°F	0.71
	X	1.160	1.041	80.00°F	83.28°F	1.08
Intermediate Shell B4712-2 (Transverse)	T	0.276	0.649	70.00°F	45.42°F	0.42
	U	0.570	0.843	95.00°F	80.06°F	0.71
	X	1.160	1.041	125.00°F	130.18°F	1.08
				Sum =	430.40°F	4.43
	$CF_{B4712-2} = \Sigma (FF * RT_{NDT}) \div \Sigma (FF^2) = 430.40°F \div 4.43 = 97.2°F$					
Surveillance Program Weld Material	T	0.276	0.649	155.00°F	100.60°F	0.42
	U	0.570	0.843	190.00°F	160.17°F	0.71
	X	1.160	1.041	195.00°F	203.00°F	1.08
				Sum =	463.77°F	2.22
	$CF_{SW} = \Sigma (FF * RT_{NDT}) \div \Sigma (FF^2) = 463.77°F \div 2.22 = 208.9°F$					

Notes:

(a) f = Best-estimate fluence[4 & 7] (Calculated values are not available)

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

(c) ΔRT_{NDT} values are the measured 30 ft-lb shift values [4].

TABLE 4-7
Summary of the Salem Unit 2 Reactor Vessel Beltline Material Chemistry Factors
Based on Regulatory Guide 1.99, Revision 2, Position 1.1 and Position 2.1

Material	Chemistry Factor	
	Position 1.1	Position 2.1
Intermediate Shell B4712-1	89.8°F	--
Intermediate Shell B4712-2	83.3°F	97.2°F
Intermediate Shell B4712-3	73.7°F	--
Lower Shell B4713-1	83.0°F	--
Lower Shell B4713-2	82.4°F	--
Lower Shell B4713-3	82.6°F	--
Intermediate to Lower Shell Circumferential Weld Seam 9-442 (Heat # 90099)	91.4°F	--
Intermediate Shell Longitudinal Weld Seam 2-442 A, B & C (Heat # 13253/20291)	189.0°F	--
Lower Shell Longitudinal Weld Seam 3-442 A, B & C (Heat # 21935/12008)	208.6°F	--

Contained in Tables 4-8 and 4-9 are summaries of the fluence factors (FF) used in the calculation of adjusted reference temperatures for the Salem Unit 2 reactor vessel beltline materials for 32 and 48EFPY.

TABLE 4-8
Summary of the Calculated Fluence Factors used for the Generation of the 32 EFPY Heatup and Cooldown Curves

Material	¼ T f (n/cm^2, E > 1.0 MeV)	¼ T FF[a]	¾ T f (n/cm^2, E >1.0 MeV)	¾ T FF[b]
Intermediate Shell B4712-1	1.06×10^{19}	1.016	3.77×10^{18}	0.729
Intermediate Shell B4712-2	1.06×10^{19}	1.016	3.77×10^{18}	0.729
Intermediate Shell B4712-3	1.06×10^{19}	1.016	3.77×10^{18}	0.729
Lower Shell B4713-1	1.06×10^{19}	1.016	3.77×10^{18}	0.729
Lower Shell B4713-2	1.06×10^{19}	1.016	3.77×10^{18}	0.729
Lower Shell B4713-3	1.06×10^{19}	1.016	3.77×10^{18}	0.729
Intermediate to Lower Shell Circumferential Weld Seam 9-442 (Heat # 90099)	1.06×10^{19}	1.016	3.77×10^{18}	0.729
Intermediate Shell Longitudinal Weld Seam 2-442 A (Heat # 13253/20291)	4.14×10^{18}	0.760	1.47×10^{18}	0.50
Intermediate Shell Longitudinal Weld Seams 2-442 B & C (Heat # 13253/20291)	7.15×10^{18}	0.906	2.54×10^{18}	0.628
Lower Shell Longitudinal Weld Seams 3-442 A & C (Heat # 21935/12008)	7.15×10^{18}	0.906	2.54×10^{18}	0.628
Lower Shell Longitudinal Weld Seam 3-442 B (Heat # 21935/12008)	4.14×10^{18}	0.760	1.47×10^{18}	0.50

Notes:

(a) Fluence Factor at the 1/4T vessel thickness location.

(b) Fluence Factor at the 3/4T vessel thickness location.

TABLE 4-9
Summary of the Calculated Fluence Factors used for the Generation of the 48 EFPY Heatup and Cooldown Curves

Material	¼ T f (n/cm^2, E > 1.0 MeV)	¼ T FF[(a)]	¾ T f (n/cm^2, E > 1.0 MeV)	¾ T FF[(b)]
Intermediate Shell B4712-1	1.58×10^{19}	1.126	5.63×10^{18}	0.839
Intermediate Shell B4712-2	1.58×10^{19}	1.126	5.63×10^{18}	0.839
Intermediate Shell B4712-3	1.58×10^{19}	1.126	5.63×10^{18}	0.839
Lower Shell B4713-1	1.58×10^{19}	1.126	5.63×10^{18}	0.839
Lower Shell B4713-2	1.58×10^{19}	1.126	5.63×10^{18}	0.839
Lower Shell B4713-3	1.58×10^{19}	1.126	5.63×10^{18}	0.839
Intermediate to Lower Shell Circumferential Weld Seam 9-442 (Heat # 90099)	1.58×10^{19}	1.126	5.63×10^{18}	0.839
Intermediate Shell Longitudinal Weld Seam 2-442 A (Heat # 13253/20291)	6.20×10^{18}	0.870	2.20×10^{18}	0.590
Intermediate Shell Longitudinal Weld Seams 2-442 B & C (Heat # 13253/20291)	1.07×10^{19}	1.019	3.81×10^{18}	0.733
Lower Shell Longitudinal Weld Seams 101-142 A & C (Heat # 21935/12008)	1.07×10^{19}	1.019	3.81×10^{18}	0.733
Lower Shell Longitudinal Weld Seam 3-442 B (Heat # 21935/12008)	6.20×10^{18}	0.870	2.20×10^{18}	0.590

Notes:
(a) Fluence Factor at the 1/4T vessel thickness location.
(b) Fluence Factor at the 3/4T vessel thickness location.

Contained in Tables 4-10 through 4-13 are the calculations of the ART values used for the generation of the 32 EFPY and 48 EFPY heatup and cooldown curves.

TABLE 4-10

Calculation of the ART Values for the 1/4T Location @ 32 EFPY

Material	CF (°F)	FF	IRT_{NDT}[a] (°F)	ΔRT_{NDT}[b] (°F)	Margin	ART[c] (°F)
Intermediate Shell B4712-1	89.8	1.016	0	91.2	34	125
Intermediate Shell B4712-2	83.3	1.016	12	84.6	34	131
→ Using Surveillance Data[d]	97.2	1.016	12	98.8	34	145
Intermediate Shell B4712-3	73.7	1.016	10	74.9	34	119
Lower Shell B4713-1	83.0	1.016	8	84.3	34	126
Lower Shell B4713-2	82.4	1.016	8	83.7	34	126
Lower Shell B4713-3	82.6	1.016	10	83.9	34	128
Intermediate to Lower Shell Circumferential Weld Seam 9-442 (Heat # 90099)	91.4	1.016	-56	92.9	65.5	102
Intermediate Shell Longitudinal Weld Seam 2-442 A (Heat # 13253/20291)	189	0.76	-56	143.6	65.5	153
Intermediate Shell Longitudinal Weld Seams 2-442 B&C (Heat # 13253/20291)	189	0.906	-56	171.2	65.5	181
Lower Shell Longitudinal Weld Seams 3-442 A&C (Heat # 21935/12008)	208.6	0.906	-56	189.0	65.5	**199**
Lower Shell Longitudinal Weld Seam 3-442 B (Heat # 21935/12008)	208.6	0.76	-56	158.5	65.5	168

NOTES:

(a) Initial RT_{NDT} values are measured values for the plate materials while the Initial RT_{NDT} values for the weld materials are generic.

(b) $\Delta RT_{NDT} = CF * FF$

(c) $ART = I + \Delta RT_{NDT} + M$ (This value was rounded per ASTM E29, using the "Rounding Method".)

(d) The Salem Unit 2 surveillance plate data is not credible (See Reference 9). However, the chemistry factor derived from the plate surveillance data is more conservative than the non-surveillance data chemistry factor. Hence, the plate surveillance data are reported here with a full $1\sigma_\Delta$.

TABLE 4-11

Calculation of the ART Values for the 3/4T Location @ 32 EFPY

Material	CF (°F)	FF	IRT_{NDT}[(a)] (°F)	ΔRT_{NDT}[(b)] (°F)	Margin (°F)	ART[(c)] (°F)
Intermediate Shell B4712-1	89.8	0.729	0	65.5	34	100
Intermediate Shell B4712-2	83.3	0.729	12	60.7	34	107
→ Using Surveillance Data[(d)]	97.2	0.729	12	70.9	34	117
Intermediate Shell B4712-3	73.7	0.729	10	53.7	34	98
Lower Shell B4713-1	83.0	0.729	8	60.5	34	103
Lower Shell B4713-2	82.4	0.729	8	60.1	34	102
Lower Shell B4713-3	82.6	0.729	10	60.2	34	104
Intermediate to Lower Shell Circumferential Weld Seam 9-442 (Heat # 90099)	91.4	0.729	-56	66.6	65.5	76
Intermediate Shell Longitudinal Weld Seam 2-442 A (Heat # 13253/20291)	189	0.500	-56	94.5	65.5	104
Intermediate Shell Longitudinal Weld Seams 2-442 B&C (Heat # 13253/20291)	189	0.628	-56	118.7	65.5	128
Lower Shell Longitudinal Weld Seams 3-442 A&C (Heat # 21935/12008)	208.6	0.628	-56	131	65.5	**140**
Lower Shell Longitudinal Weld Seam 3-442 B (Heat # 21935/12008)	208.6	0.500	-56	104.3	65.5	114

NOTES:

(a) Initial RT_{NDT} values are measured values for the plate materials while the Initial RT_{NDT} values for the weld materials are generic.

(b) $\Delta RT_{NDT} = CF * FF$

(c) $ART = I + \Delta RT_{NDT} + M$ (This value was rounded per ASTM E29, using the "Rounding Method".)

(d) The Salem Unit 2 surveillance plate data is not credible (See Reference 9). However, the chemistry factor derived from the plate surveillance data is more conservative than the non-surveillance data chemistry factor. Hence, the plate surveillance data are reported here with a full $1\sigma_{\Delta}$.

TABLE 4-12

Calculation of the ART Values for the 1/4T Location @ 48 EFPY

Material	CF (°F)	FF	IRT_{NDT} [a] (°F)	ΔRT_{NDT} [b] (°F)	Margin (°F)	ART[c] (°F)
Intermediate Shell B4712-1	89.8	1.126	0	101.1	34	135
Intermediate Shell B4712-2	83.2	1.126	12	93.7	34	140
→ Using Surveillance Data[d]	97.2	1.126	12	109.4	34	155
Intermediate Shell B4712-3	73.7	1.126	10	83	34	127
Lower Shell B4713-1	83.0	1.126	8	93.5	34	136
Lower Shell B4713-2	82.4	1.126	8	92.8	34	135
Lower Shell B4713-3	82.6	1.126	10	93.0	34	137
Intermediate to Lower Shell Circumferential Weld Seam 9-442 (Heat # 90099)	91.4	1.126	-56	102.9	65.5	112
Intermediate Shell Longitudinal Weld Seam 2-442 A (Heat # 13253/20291)	189	0.870	-56	164.4	65.5	174
Intermediate Shell Longitudinal Weld Seams 2-442 A,B & C (Heat # 13253/20291)	189	1.019	-56	192.6	65.5	202
Lower Shell Longitudinal Weld Seams 3-442 A&C (Heat # 21935/12008)	208.6	1.019	-56	212.6	65.5	**222**
Lower Shell Longitudinal Weld Seam 3-442 B (Heat # 21935/12008)	208.6	0.870	-56	181.5	65.5	191

NOTES:

(a) Initial RT_{NDT} values are measured values for the plate materials while the Initial RT_{NDT} values for the weld materials are generic.

(b) $\Delta RT_{NDT} = CF * FF$

(c) $ART = I + \Delta RT_{NDT} + M$ (This value was rounded per ASTM E29, using the "Rounding Method".)

(d) The Salem Unit 2 surveillance plate data is not credible (See Reference 9). However, the chemistry factor derived from the plate surveillance data is more conservative than the non-surveillance data chemistry factor. Hence, the plate surveillance data are reported here with a full $1\sigma_\Delta$.

TABLE 4-13

Calculation of the ART Values for the 3/4T Location @ 48 EFPY

Material	CF (°F)	FF	IRT_{NDT}[(a)] (°F)	ΔRT_{NDT}[(b)] (°F)	Margin (°F)	ART[(c)] (°F)
Intermediate Shell B4712-1	89.8	0.839	0	75.3	34	109
Intermediate Shell B4712-2	83.2	0.839	12	69.8	34	116
→ Using Surveillance Data[(d)]	97.2	0.839	12	81.6	34	128
Intermediate Shell B4712-3	73.7	0.839	10	61.8	34	106
Lower Shell B4713-1	83.0	0.839	8	69.6	34	112
Lower Shell B4713-2	82.4	0.839	8	69.1	34	111
Lower Shell B4713-3	82.6	0.839	10	69.3	34	113
Intermediate to Lower Shell Circumferential Weld Seam 9-442 (Heats # 90099)	91.4	0.839	-56	76.7	65.5	86
Intermediate Shell Longitudinal Weld Seam 2-442 A (Heat # 13253/20291)	189	0.590	-56	111.5	65.5	121
Intermediate Shell Longitudinal Weld Seams 2-442 B & C (Heat # 13253/20291)	189	0.733	-56	138.5	65.5	148
Lower Shell Longitudinal Weld Seams 3-442 A&C (Heat # 21935/12008)	208.6	0.733	-56	152.9	65.5	**162**
Lower Shell Longitudinal Weld Seam 3-442 B (Heat # 21935/12008)	208.6	0.590	-56	123.1	65.5	133

NOTES:

(a) Initial RT_{NDT} values are measured values for the plate materials while the Initial RT_{NDT} values for the weld materials are generic.

(b) $\Delta RT_{NDT} = CF * FF$

(c) $ART = I + \Delta RT_{NDT} + M$ (This value was rounded per ASTM E29, using the "Rounding Method".)

(d) The Salem Unit 2 surveillance plate data is not credible (See Reference 9). However, the chemistry factor derived from the plate surveillance data is more conservative than the non-surveillance data chemistry factor. Hence, the plate surveillance data are reported here with a full $1\sigma_{\Delta}$.

The longitudinal weld seams 3-442 A&C are the limiting beltline material for all heatup and cooldown curves to be generated. Contained in Table 4-14 is a summary of the limiting ARTs to be used in the generation of Salem Unit 2 reactor vessel heatup and cooldown curves.

TABLE 4-14
Summary of the Limiting ART Values Used in the
Generation of the Salem Unit 2 Heatup/Cooldown Curves

EFPY	1/4T Limiting ART	3/4T Limiting ART
32	199°F	140°F
48	222°F	162°F

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 reactor vessel beltline region using the methods discussed in Sections 3 and 4 of this report. This approved methodology is also presented in WCAP-14040-NP-A[8], dated January 1996.

Figures 5-1 and 5-3 present the heatup curves with margins of 18°F and 61 psig for possible instrumentation errors for heatup rates of 60 and 100°F/hr. These heatup curves are applicable for 32 EFPY and 48 EFPY respectively, for the Salem Unit 2 reactor vessel. Additionally, Figures 5-2 and 5-4 present the cooldown curves with margins of 18°F and 61 psig for possible instrumentation errors for cooldown rates of 0, 20, 40, 60, and 100°F/hr. These cooldown curves are also applicable for 32 EFPY and 48 EFPY, respectively, for the Salem Unit 2 reactor vessel. Figures 5-1 through 5-4 include the boltup temperature of 60°F with a margin of 2°F measurement uncertainty. Allowable combinations of temperature and pressure for specific temperature change rates are below and to the right of the limit lines shown in Figures 5-1 through 5-4. This is in addition to other criteria which must be met before the reactor is made critical, as discussed 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 5-1 and 5-3 (for the specific heatup rate being utilized). 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 Appendix G to Section XI of the ASME Code[3] as follows:

$$1.5K_{Im} < K_{Ic} \qquad (10)$$

where,

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

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

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 2. 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 of this report. 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 5-1 through 5-4 define all of the above limits for ensuring prevention of nonductile failure for the Salem Unit 2 reactor vessel. The data points for the heatup and cooldown pressure-temperature limit curves shown in Figures 5-1 through 5-4 are presented in Tables 5-1 through 5-4, respectively.

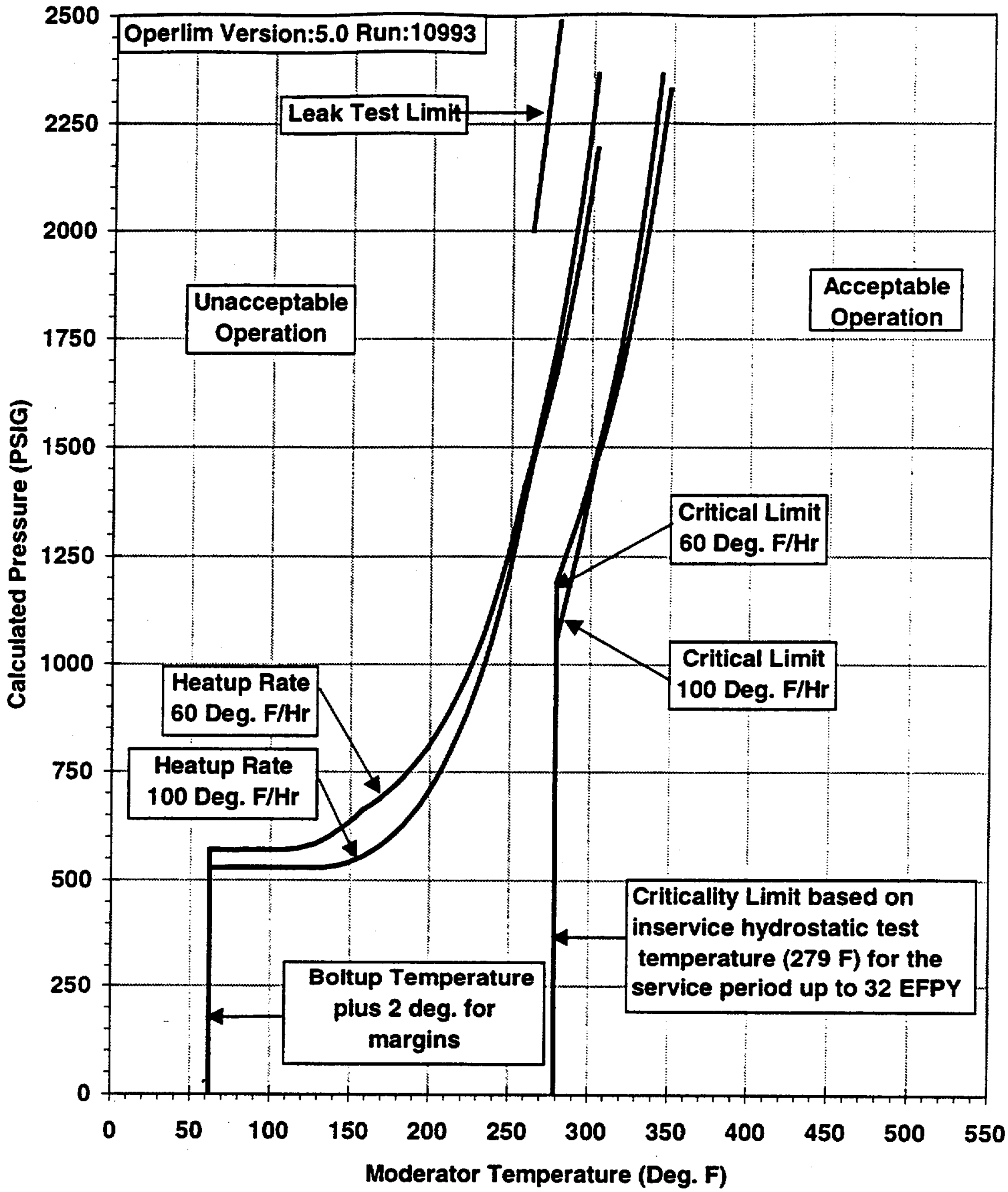

Figure 5- 1: Salem Unit 2 Reactor Coolant System Heatup Limitations (Heatup Rates of 60 and 100°F/hr) Applicable to 32 EFPY (With Margins for Instrumentation Errors)

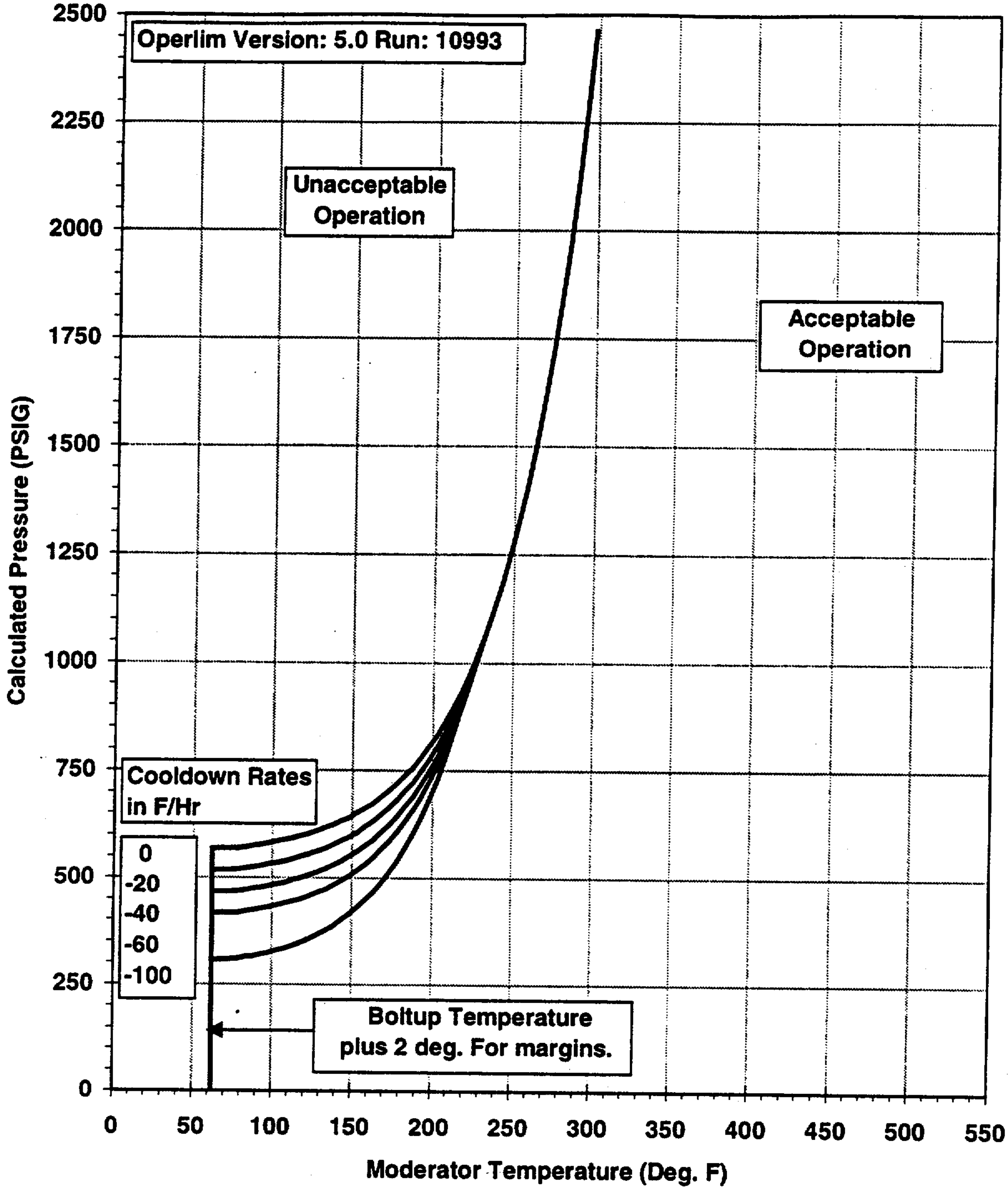

Figure 5- 2: Salem Unit 2 Reactor Coolant System Cooldown Limitations (Cooldown Rates of 0, 20, 40, 60 and 100°F/hr) Applicable to 32 EFPY (With Margins for Instrumentation Errors)

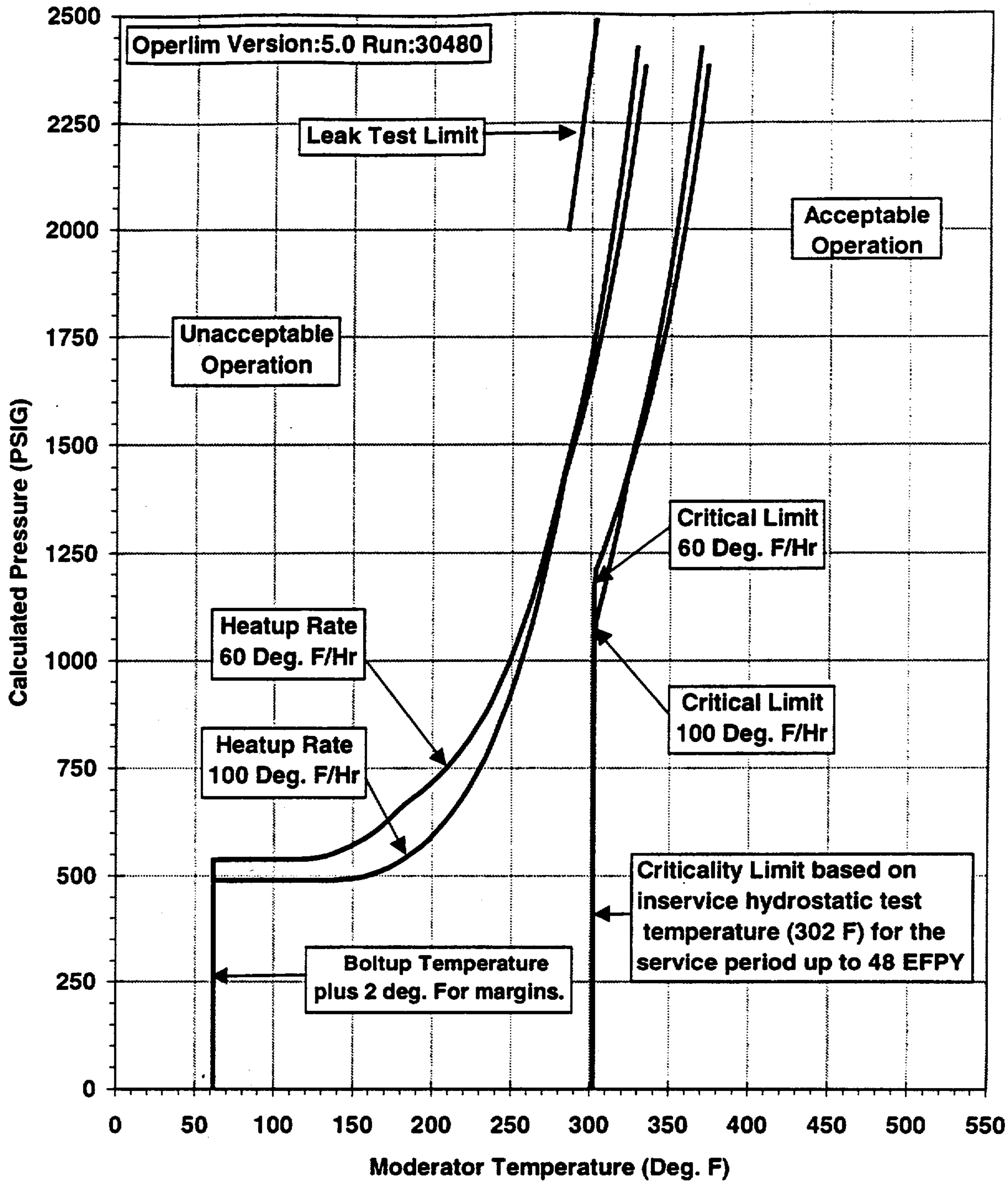

Figure 5- 3: Salem Unit 2 Heatup Limitations (Heatup Rates of 60 and 100°F/hr) Applicable to 48 EFPY (With Margins of for Instrumentation Errors)

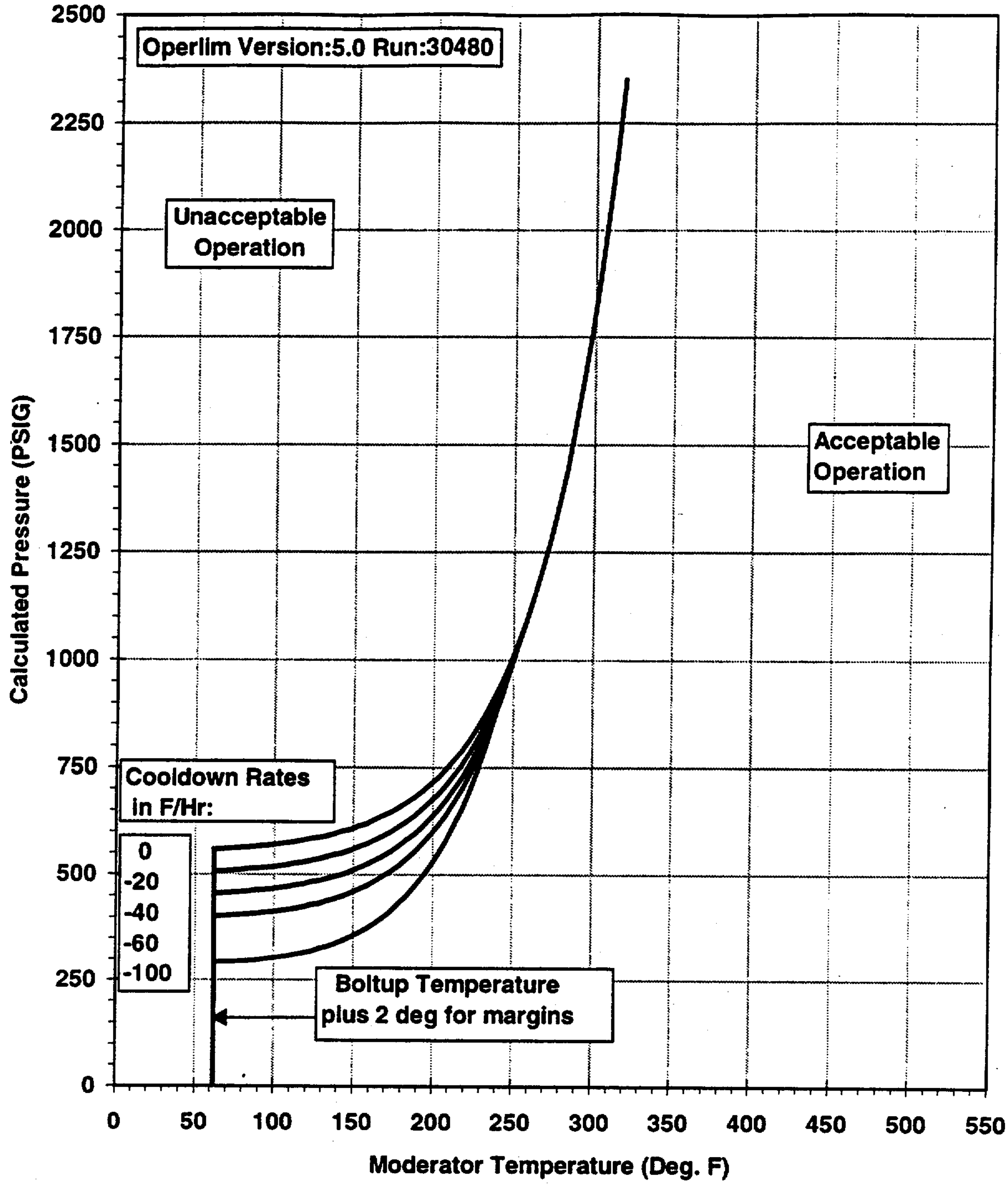

Figure 5-4: Salem Unit 2 Reactor Coolant System Cooldown Limitations (Cooldown Rates of 0, 20, 40, 60 and 100°F/hr) Applicable to 48 EFPY (With Margins for Instrumentation Errors)

TABLE 5-1

Salem Unit 2 Heatup Data at 32 EFPY with Margins for Instrumentation Errors

60 °F/hr. Heatup		60 °F/hr. Crit. Limit		100 °F/hr. Heatup		60 °F/hr. Crit. Limit		Inservice Leak Test	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
62	0	279	0	62	0	279	0	262	2000
62	570	279	571	62	528	279	528	279	2485
78	570	279	571	78	528	279	529		
83	571	279	572	83	528	279	530		
88	571	279	574	88	528	279	531		
93	571	279	576	93	528	279	533		
98	571	279	579	98	528	279	534		
103	571	279	584	103	528	279	538		
108	571	279	585	108	528	279	539		
113	572	279	593	113	528	279	545		
118	574	279	594	118	528	279	546		
123	579	279	604	123	528	279	554		
128	585	279	609	128	528	279	555		
133	593	279	615	133	529	279	565		
138	604	279	629	138	531	279	565		
143	615	279	645	143	534	279	578		
148	629	279	663	148	539	279	578		
153	645	279	683	153	546	279	592		
158	662	279	706	158	555	279	594		
163	675	279	731	163	565	279	608		
168	688	279	759	168	578	279	612		
173	703	279	790	173	592	279	627		
178	720	279	825	178	608	279	648		
183	738	279	864	183	627	279	672		
188	758	279	906	188	648	279	699		
193	781	279	953	193	672	279	728		
198	805	279	987	198	699	279	762		
203	833	279	1013	203	728	279	799		
208	863	279	1042	208	762	279	840		
213	896	279	1074	213	799	279	885		
218	933	279	1109	218	840	279	935		
223	973	279	1147	223	885	279	991		
228	1018	279	1190	228	935	279	1053		
233	1068	283	1237	233	991	283	1121		
238	1123	288	1288	238	1053	288	1196		
243	1184	293	1345	243	1121	293	1279		
248	1251	298	1408	248	1196	298	1371		

TABLE 5-1 (continued)

Salem Unit 2 Heatup Data at 32 EFPY with Margins for Instrumentation Errors

60 °F/hr. Heatup		60 °F/hr. Crit. Limit		100 °F/hr. Heatup		60 °F/hr. Crit. Limit		Inservice Leak Test	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
253	1325	303	1478	253	1279	303	1463		
258	1407	308	1554	258	1371	308	1526		
263	1478	313	1638	263	1463	313	1596		
268	1554	318	1731	268	1526	318	1673		
273	1638	323	1834	273	1596	323	1757		
278	1731	328	1947	278	1673	328	1851		
283	1834	333	2072	283	1757	333	1953		
288	1947	338	2210	288	1851	338	2066		
293	2072	343	2362	293	1953	343	2191		
298	2210			298	2066	348	2328		
303	2362			303	2191	353	2480		
				308	2328				
				313	2480				

TABLE 5-2
Salem Unit 2 Cooldown Data at 32 EFPY with Margins for Instrumentation Errors

Steady State		-20 °F/hr. Cooldown		-40 °F/hr. Cooldown		-60 °F/hr. Cooldown		-100 °F/hr. Cooldown	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
62	0	62	0	62	0	62	0	62	0
62	567	62	517	62	466	62	414	62	305
68	568	68	518	68	467	68	415	68	306
73	569	73	519	73	468	73	416	73	307
78	570	78	520	78	469	78	417	78	309
83	572	83	522	83	471	83	419	83	312
88	575	88	525	88	474	88	422	88	315
93	578	93	528	93	477	93	426	93	319
98	581	98	532	98	481	98	429	98	323
103	585	103	535	103	485	103	434	103	328
108	589	108	540	108	490	108	438	108	334
113	593	113	544	113	495	113	444	113	340
118	598	118	550	118	500	118	450	118	347
123	604	123	556	123	506	123	457	123	355
128	610	128	562	128	513	128	464	128	364
133	617	133	569	133	521	133	473	133	374
138	624	138	577	138	530	138	482	138	385
143	632	143	586	143	539	143	492	143	398
148	641	148	596	148	550	148	504	148	412
153	651	153	607	153	562	153	517	153	428
158	662	158	619	158	575	158	531	158	446
163	675	163	632	163	590	163	547	163	465
168	688	168	647	168	606	168	565	168	487
173	703	173	663	173	624	173	585	173	511
178	720	178	681	178	644	178	607	178	539
183	738	183	701	183	666	183	631	183	569
188	758	188	724	188	690	188	658	188	602
193	781	193	748	193	717	193	688	193	640
198	805	198	775	198	747	198	722	198	681
203	833	203	805	203	780	203	759	203	727
208	863	208	839	208	817	208	800	208	778
213	896	213	875	213	858	213	845	213	834
218	933	218	916	218	903	218	895	218	897
223	973	223	961	223	953	223	951	223	967
228	1018	228	1011	228	1008	228	1012	228	1018
233	1068	233	1066	233	1068	233	1068	233	1068

TABLE 5-2 (continued)

Salem Unit 2 Cooldown Data at 32 EFPY with Margins for Instrumentation Errors

Steady State		-20 °F/hr. Cooldown		-40 °F/hr. Cooldown		-60 °F/hr. Cooldown		-100 °F/hr. Cooldown	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
238	1123	238	1123	238	1123	238	1123	238	1123
243	1184	243	1184	243	1184	243	1184	243	1184
248	1251	248	1251	248	1251	248	1251	248	1251
253	1325	253	1325	253	1325	253	1325	253	1325
258	1407	258	1407	258	1407	258	1407	258	1407
263	1497	263	1497	263	1497	263	1497	263	1497
268	1597	268	1597	268	1597	268	1597	268	1597
273	1708	273	1708	273	1708	273	1708	273	1708
278	1830	278	1830	278	1830	278	1830	278	1830
283	1965	283	1965	283	1965	283	1965	283	1965
288	2115	288	2115	288	2115	288	2115	288	2115
293	2280	293	2280	293	2280	293	2280	293	2280
298	2462	298	2462	298	2462	298	2462	298	2462

TABLE 5-3
Salem Unit 2 Heatup Data at 48 EFPY with Margins for Instrumentation Errors

60 °F/hr. Heatup		60 °F/hr. Crit. Limit		100 °F/hr. Heatup		60 °F/hr. Crit. Limit		Inservice Leak Test	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
62	0	302	0	62	0	302	0	285	2000
62	537	302	537	62	489	302	489	302	2485
78	537	302	537	78	489	302	490		
83	537	302	539	83	489	302	490		
88	537	302	539	88	489	302	491		
93	537	302	542	93	489	302	493		
98	537	302	543	98	489	302	494		
103	537	302	546	103	489	302	496		
108	537	302	549	108	489	302	499		
113	537	302	552	113	489	302	501		
118	537	302	557	118	489	302	504		
123	539	302	559	123	489	302	508		
128	542	302	568	128	489	302	511		
133	546	302	569	133	489	302	516		
138	552	302	577	138	489	302	519		
143	559	302	584	143	490	302	527		
148	568	302	589	148	491	302	529		
153	577	302	602	153	494	302	539		
158	589	302	616	158	499	302	540		
163	602	302	632	163	504	302	553		
168	616	302	650	168	511	302	553		
173	632	302	671	173	519	302	568		
178	650	302	693	178	529	302	570		
183	667	302	718	183	540	302	585		
188	680	302	746	188	553	302	588		
193	694	302	776	193	568	302	604		
198	710	302	810	198	585	302	625		
203	727	302	848	203	604	302	649		
208	746	302	890	208	625	302	675		
213	767	302	935	213	649	302	704		
218	790	302	975	218	675	302	737		
223	816	302	999	223	704	302	773		
228	844	302	1026	228	737	302	813		
233	876	302	1056	233	773	302	857		
238	910	302	1089	238	813	302	906		
243	949	302	1125	243	857	302	960		
248	991	302	1165	248	906	302	1020		

TABLE 5-3 (continued)
Salem Unit 2 Heatup Data at 48 EFPY with Margins for Instrumentation Errors

60 °F/hr. Heatup		60 °F/hr. Crit. Limit		100 °F/hr. Heatup		60 °F/hr. Crit. Limit		Inservice Leak Test	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
253	1038	303	1209	253	960	303	1086		
258	1089	308	1258	258	1020	308	1159		
263	1147	313	1311	263	1086	313	1240		
268	1210	318	1370	268	1159	318	1329		
273	1280	323	1436	273	1240	323	1427		
278	1357	328	1507	278	1329	328	1488		
283	1436	333	1586	283	1427	333	1554		
288	1507	338	1674	288	1488	338	1626		
293	1586	343	1770	293	1554	343	1705		
298	1674	348	1876	298	1626	348	1792		
303	1770	353	1993	303	1705	353	1888		
308	1876	358	2123	308	1792	358	1994		
313	1993	363	2265	313	1888	363	2111		
318	2123	368	2423	318	1994	368	2239		
323	2265			323	2111	373	2381		
328	2423			328	2239				
				333	2381				

TABLE 5-4
Salem Unit 2 Cooldown Data at 48 EFPY with Margins for Instrumentation Errors

Steady State		-20 °F/hr. Cooldown		-40 °F/hr. Cooldown		-60 °F/hr. Cooldown		-100 °F/hr. Cooldown	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
62	0	62	0	62	0	62	0	62	0
62	558	62	507	62	455	62	402	62	291
68	559	68	508	68	456	68	103	68	293
73	560	73	509	73	457	73	404	73	294
78	561	78	510	78	458	78	405	78	295
83	562	83	512	83	460	83	406	83	296
88	564	88	513	88	461	88	408	88	298
93	566	93	515	93	463	93	410	93	300
98	568	98	517	98	465	98	412	98	302
103	570	103	520	103	468	103	414	103	304
108	573	108	522	108	470	108	417	108	307
113	576	113	525	113	473	113	420	113	311
118	579	118	528	118	477	118	424	118	315
123	583	123	532	123	480	123	428	123	320
128	586	128	536	128	485	128	432	128	325
133	591	133	540	133	489	133	437	133	331
138	595	138	545	138	495	138	443	138	337
143	600	143	551	143	501	143	449	143	345
148	606	148	557	148	507	148	456	148	353
153	613	153	564	153	514	153	464	153	363
158	620	158	571	158	523	158	473	158	374
163	627	163	580	163	532	163	483	163	386
168	636	168	589	168	542	168	494	168	399
173	645	173	599	173	553	173	506	173	414
178	656	178	610	178	565	178	520	178	430
183	667	183	623	183	579	183	535	183	449
188	680	188	637	188	594	188	552	188	470
193	694	193	652	193	611	193	570	193	493
198	710	198	669	198	630	198	591	198	518
203	727	203	688	203	651	203	614	203	547
208	746	208	709	208	674	208	640	208	579
213	767	213	732	213	699	213	668	213	614
218	790	218	758	218	728	218	699	218	653
223	816	223	786	223	759	223	734	223	697
228	844	228	818	228	794	228	773	228	745
233	876	233	852	233	832	233	816	233	798

TABLE 5-4 (continued)
Salem Unit 2 Cooldown Data at 48 EFPY with Margins for Instrumentation Errors

Steady State		-20 °F/hr. Cooldown		-40 °F/hr. Cooldown		-60 °F/hr. Cooldown		-100 °F/hr. Cooldown	
Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)	Temp. (°F)	Press. (psig)
238	910	238	891	238	875	238	863	238	858
243	949	243	933	243	922	243	916	243	924
248	991	248	980	248	974	248	974	248	991
253	1038	253	1032	253	1032	253	1038	253	1038
258	1089	258	1089	258	1089	258	1089	258	1089
263	1147	263	1147	263	1147	263	1147	263	1147
268	1210	268	1210	268	1210	268	1210	268	1210
273	1280	273	1280	273	1280	273	1280	273	1280
278	1357	278	1357	278	1357	278	1357	278	1357
283	1442	283	1442	283	1442	283	1442	283	1442
288	1536	288	1536	288	1536	288	1536	288	1536
293	1640	293	1640	293	1640	293	1640	293	1640
298	1755	298	1755	298	1755	298	1755	298	1755
303	1883	303	1883	303	1883	303	1883	303	1883
308	2023	308	2023	308	2023	308	2023	308	2023
313	2179	313	2179	313	2179	313	2179	313	2179
318	2350	318	2350	318	2350	318	2350	318	2350

6 REFERENCES

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

2 10 CFR Part 50, Appendix G, "Fracture Toughness Requirements", Federal Register, Volume 60, No. 243, dated December 19, 1995.

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

4 WCAP-13366, "Analysis of Capsule X from the Public Service Electric and Gas Company Salem Unit 2 Reactor Vessel Radiation Surveillance Program", J. M. Chicots, et al., June 1992.

5 NFS-00-178, Reactor Vessel Toughness Property/Chemistry Confirmation from PSE&G

6 1989 Section III, Division 1 of the ASME Boiler and Pressure Vessel Code, Paragraph NB-2331, "Material for Vessels".

7. LTR-REA-00-621, "Reactor Vessel Fluences for the Salem 1.4% Uprate Project", S.L. Anderson, June 27, 2000.

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 WCAP-15568, "Evaluation of Pressured Thermal Shock for Salem Unit-2 1.4% Uprating", E. Terek, et al., November 2000.

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

11 WCAP-15315, "Reactor Vessel Closure Head/Vessel Flange Requirements Evaluation For Operating PWR and BWR Plants", W. Bamford, et al., October 1999.

APPENDIX A

PROJECTED UPPER SHELF ENERGY VALUES

FOR SALEM UNIT 2

APPENDIX A - PREDICTED EOL USE VALUES

Per Regulatory Guide 1.99, Revision 2, the Charpy upper-shelf energy is assumed to decrease as a function of fluence and copper content as indicated in Figure 2 of the guide when surveillance data is not used. Linear interpolation is permitted. In addition, if surveillance data is to be used, the decrease in upper-shelf energy may be obtained by plotting the reduced plant surveillance data on Figure 2 of the guide and fitting the data with a line drawn parallel to the existing lines as the upper bound of all the data. This line should be used in preference to the existing graph.

The EOL (32 EFPY) and license renewal (48 EFPY) USE values can be predicted using the ¼T fluence projections at 32 and 48 EFPY, the copper content of the beltline materials and/or the results of the capsules tested to date using Figure 2 in Regulatory Guide 1.99, Revision 2. The peak vessel clad/base metal interface fluence value was used to determine the EOL (32 EFPY) and license renewal (48 EFPY) USE values of all the beltline materials.

The Salem Unit 2 reactor vessel beltline region minimum thickness is 8.625 inches.

The calculation of the ¼T peak vessel fluence value at 32 EFPY for the beltline materials is contained in Table A-1.

The calculation of the EOL USE values at 32 EFPY for the beltline materials is contained in Table A-2.

The calculation of the ¼T peak vessel fluence value at 48 EFPY for the beltline materials is contained in Table A-3.

The calculation of the EOL USE values at 48 EFPY for the beltline materials is contained in Table A-4.

TABLE A-1

EOL (32 EFPY) ¼T Fluence Values for all the Salem Unit 2 Beltline Materials

Material	f @ 32 EFPY[a]	¼T F @ 32 EFPY[b]
Intermediate Shell B4712-1	1.78	1.06
Intermediate Shell B4712-2	1.78	1.06
Intermediate Shell B4712-3	1.78	1.06
Lower Shell B4713-1	1.78	1.06
Lower Shell B4713-2	1.78	1.06
Lower Shell B4713-3	1.78	1.06
Intermediate to Lower Shell Circumferential Weld Seam 9-442 (Heat # 90099)	1.78	1.06
Intermediate Shell Longitudinal Weld Seams 2-442 A, B & C (Heat # 13253/20291)	1.78	1.06
Lower Shell Longitudinal Weld Seams 3-442 A, B & C (Heat # 21935/12008)	1.78	1.06

Notes:

(a) f @ 32 EFPY is the 32 EFPY fluence at the clad/base metal interface ($x\ 10^{19}$ n.cm^2, E > 1.0 MeV).

(b) ¼T f @ 32 EFPY = f @ 32 EFPY * $e^{(-0.24 * X)}$ ($x\ 10^{19}$ n.cm^2, E > 1.0 MeV), where X is the depth into the vessel wall (X = 0.25 * 8.625 inches = 2.15625 inches).

TABLE A-2

Salem 2 Predicted End-of-License (32 EFPY) USE Calculations for all the Beltline Region Materials

Material	**Weight % of Cu**	**1/4T EOL Fluence (10^{19} n/cm^2, E>1.0 MeV)**	**Unirradiate USE (ft-lb)**	**Projected USE Decrease (%)**	**Projected EOL USE (ft-lb)**
Intermediate Shell B4712-1	0.13	1.06	106	22	83
Intermediate Shell B4712-2	0.12	1.06	97	14.5	83
Intermediate Shell B4712-3	0.11	1.06	107	20	86
Lower Shell B4713-1	0.12	1.06	98	21	77
Lower Shell B4713-2	0.12	1.06	103	21	81
Lower Shell B4713-3	0.12	1.06	121	21	96
Intermediate to Lower Shell Circumferential Weld Seam 9-442 (Heat # 90099)	0.197	1.06	99.7	35	65
Intermediate Shell Longitudinal Weld Seams 2-442 A, B & C (Heat # 13253/20291)	0.219	1.06	96.2	37	61
Lower Shell Longitudinal Weld Seams 3-442 A, B & C (Heat # 21935/12008)	0.213	1.06	114	37	72

TABLE A-3

EOL (48 EFPY) ¼T Fluence Values for all the Salem Unit 2 Beltline Materials

Material	f @ 32 EFPY[a]	¼T F @ 32 EFPY[b]
Intermediate Shell B4712-1	2.66	1.58
Intermediate Shell B4712-2	2.66	1.58
Intermediate Shell B4712-3	2.66	1.58
Lower Shell B4713-1	2.66	1.58
Lower Shell B4713-2	2.66	1.58
Lower Shell B4713-3	2.66	1.58
Intermediate to Lower Shell Circumferential Weld Seam 9-442 (Heat # 90099)	2.66	1.58
Intermediate Shell Longitudinal Weld Seams 2-442 A, B & C (Heat # 13253/20291)	2.66	1.58
Lower Shell Longitudinal Weld Seams 3-442 A, B & C (Heat # 21935/12008)	2.66	1.58

Notes:

(b) f @ 48 EFPY is the 48 EFPY fluence at the clad/base metal interface ($x\ 10^{19}$ $n.cm^2$, E > 1.0 MeV).

(b) ¼T f @ 48 EFPY = f @ 48 EFPY * $e^{(-0.24*X)}$ ($x\ 10^{19}$ $n.cm^2$, E > 1.0 MeV), where X is the depth into the vessel wall (X = 0.25 * 8.625 inches = 2.15625 inches).

TABLE A-4

Salem 2 Predicted Life Extension (48 EFPY) USE Calculations for all the Beltline Region Materials

Material	Weight % Cu	¼T Life Extension Fluence (10^{19} n/cm^2, E>1.0 MeV)	Unirradiated USE (ft-lb)	Projected USE Decrease (%)	Projected Life Extension USE (ft-lb)
Intermediate Shell B4712-1	0.13	1.58	106	24	81
Intermediate Shell B4712-2	0.12	1.58	97	16	81
Intermediate Shell B4712-3	0.11	1.58	107	22	83
Lower Shell B4713-1	0.12	1.58	98	23	75
Lower Shell B4713-2	0.12	1.58	103	23	79
Lower Shell B4713-3	0.12	1.58	121	23	93
Intermediate to Lower Shell Circumferential Weld Seam 9-442 (Heat # 90099)	0.197	1.58	99.7	38	62
Intermediate Shell Longitudinal Weld Seams 2-442 A, B & C (Heat # 13253/20291)	0.219	1.58	96.2	40	58
Lower Shell Longitudinal Weld Seams 3-442 A, B & C (Heat # 21935/12008)	0.213	1.58	114	40	58