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WCAP - 14278
Revision 1

Kewaunee Heatup and Cooldown Limit Curves for Normal Operation

Westinghouse Energy Systems

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ATTACHMENT 6

Letter from Mark L. Marchi (WPSC)

To

Document Control Desk (NRC)

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Proposed Amendment 157

WCAP-14278 Revision 1
Kewaunee Heatup and Cooldown Limit Curves
For Normal Operation

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-14278

Kewaunee Heatup and Cooldown Limit Curves for Normal Operation

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PREFACE

This report has been technically reviewed and verified by:

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FORWARD

This report along with four other companion documents have been prepared by Westinghouse Electric Corporation and ATI Consulting to assess and document the integrity of the Kewaunee Nuclear Power Plant (KNPP) reactor vessel relative to the requirements of 10 CFR 50.60, 10 CFR 50.61, Appendices G and H to 10 CFR Part 50, (which encompass pressurized thermal shock (PTS) and upper shelf energy (USE) evaluations), and any potential impact on low temperature overpressure (LTOP) limits or pressure-temperature limits. These reports: (1) summarize the KNPP weld metal (1P3571) surveillance capsule test results performed to date (WCAP-15074); (2) document supplemental surveillance capsule fracture toughness testing results for the KNPP 1P3571 weld metal both in the unirradiated and irradiated condition (WCAP-14279, Rev. 1); (3) introduce and apply a new methodology, based on the Master Curve Approach, for assessing the integrity of the KNPP reactor vessel (WCAP-15075); (4) include various PTS evaluations for KNPP conducted in accordance with the methodology given in CFR 50.61 and the Master Curve Approach (WCAP-14280, Rev. 1); and (5) present heatup and cooldown curves corresponding to end of plant life fluence (WCAP-14278, Rev. 1). The heatup and cooldown limit curves presented in WCAP-14278, Rev. 1 are derived using ASME Code Case N-588. These five documents support a new proposed amendment to modify the KNPP Technical Specification limits for heatup, cooldown, and low temperature overpressure protection. The current Technical Specification heatup and cooldown limit curves will expire at 20 EFPY which is scheduled to occur in spring of 1999. The engineering evaluations incorporate all known data pertinent to the analysis of structural integrity of the KNPP reactor vessel and therefore meet and exceed the intent of NRC regulation and expectations.

Background for much of this work is linked to ongoing efforts by the NRC staff to generically resolve concerns raised during their review of reactor vessel integrity for the Yankee Rowe Nuclear Power Station. As part of this effort, the NRC staff issued Generic Letter 92-01, Revision 1 and Generic Letter 92-01, Revision 1, Supplement 1. These generic communiqué seek to obtain certain information that will permit the NRC staff to independently assess and ensure that licensees are in compliance with requirements regarding reactor pressure vessel integrity.

During review of the responses to Generic Letter 92-01, Revision 1 and Generic Letter 92-01, Revision 1, Supplement 1 the NRC discovered inconsistencies within the industry concerning the methodology used to assess reactor pressure vessel integrity including:

1. Large variability in the reported chemistries, i.e., copper and nickel contents, for welds fabricated from the same heat of weld wire.
2. Different initial properties (RT_{NDT}) for welds fabricated from the same heat and weld wire.
3. Different transition temperature shifts for welds fabricated from the same heat and weld wire.
4. Operation with irradiation temperature less than 525°F.
5. Different approaches for determining fluence of the limiting material.

In response to this discovery, to provide assurance that all plants will maintain adequate protection against PTS events, the practice of the NRC staff has been to require that evaluations be performed using conservative inputs. This increase in conservatism seems to apply equally to all areas of assessment of reactor vessel integrity. When best estimate values have been used by utilities for the chemical composition of the reactor vessel, it appears that the NRC staff may require the use of increased margin terms to account for potential variability in chemistries. Furthermore, through the process of issuing RAIs, the NRC staff has requested that evaluations be performed using generic values for initial properties and a corresponding higher margin value from either 28°F to 56°F (if the initial RT_{NDT} is measured) or 44°F to 66°F (if the generic RT_{NDT} is used). Other recent changes include the mandatory use of the ratio procedure, if applicable; a 1°F penalty for each degree Fahrenheit when the irradiation temperature is less than 525°F; and other penalties on the projected fluence of the limiting reactor vessel beltline material at end of license. Collectively, this practice of requiring multiple conservative inputs in a layered fashion for assessment of reactor vessel integrity has the effect that a reactor vessel would be predicted to reach the PTS screening criteria at an earlier date than that given by the PTS assessment methodology given in 10 CFR 50.61. A situation of applying too much conservatism can create the illusion that a reactor vessel is unsafe to operate when in fact it may possess sufficient fracture toughness. If too much conservatism is applied the overall affect can be a decrease in safety because of unnecessary changes made to plant operations and design for the sole reason of addressing a conservative but erroneous PTS evaluation.

At about the same time Generic Letter 92-01, Revision 1, Supplement 1 was being issued, the NRC staff became aware of ABB-CE proprietary data that could affect the PTS assessment of the KNPP reactor vessel. Subsequently, ABB-CE provided KNPP a summary of the data for its evaluation in a letter dated April 6, 1995. The NRC staff met with the KNPP staff on April 13, 1995 to discuss the effect that the ABB-CE data and its plant specific surveillance data would have on their PTS assessment. Prior to this meeting, the NRC staff verbally expressed concern to KNPP management that the KNPP reactor vessel may reach the PTS screening criteria before the end of their license. The KNPP staff presented its plant specific surveillance program results and some new information related to the reactor vessel chemistry variability. Based upon using best estimate input parameters, the KNPP staff showed that the KNPP reactor vessel will not reach the PTS screening criteria before the end of their license. Recognizing that the NRC staff was still concerned about the possibility of the KNPP reactor vessel reaching the PTS screening criteria prior to end of license, the KNPP staff remained steadfast in their use of best estimate input parameters for assessment of reactor vessel integrity. At the same time KNPP committed resources to develop industry programs that would facilitate implementation of the applicable requirements specified in the 1992 Edition of Appendix G to 10 CFR 50 should it become necessary: supplemental fracture toughness tests of the beltline material after exposure to neutron irradiation; perform analysis that demonstrates the existence of equivalent margins of safety for continued operation, and thermal annealing. At the conclusion of the April 13, 1995 meeting, the KNPP staff described their future plans to ensure compliance with the requirements for reactor vessel integrity. These plans included participation with industry groups to create programs and a data base detailing the chemical composition of reactor vessel beltline materials; demonstration of the feasibility for annealing of a PWR reactor vessel of US design; and direct measurement of fracture toughness from irradiated surveillance capsule specimens.

In a NRC internal memorandum (dated May 6, 1995 from Jack R. Strosnider, Chief - Materials and Chemical Engineering Branch, Division of Engineering to Ashok C. Thadani, Associate Director for Technical Assessment, Office of Nuclear Reactor Regulation) released following the April 13, 1995 meeting, the NRC staff wrote that they had not completed their review of the new information on the KNPP reactor vessel. The NRC staff noted that the new chemistry data could significantly change the KNPP PTS evaluation. However, based on conservative evaluations, the NRC staff concluded that the KNPP reactor vessel will not reach the PTS screening criteria in the near future. During this same time period, WPSC submitted a proposed amendment to the NRC to modify KNPP Technical Specification limits relating to heatup, cooldown, and low temperature overpressure protection (LTOP). The NRC issued two requests for additional information regarding this proposed amendment, dealing with surveillance capsule fluence and material properties, and then requested that WPSC withdraw it from the docket pending resolution of Generic Letter 92-01, Revision 1, Supplement 1 activities.

While the NRC was performing a detailed review of licensee responses to Generic Letter 92-01, Revision 1, each of the PWR NSSS Owners Groups developed and implemented programs dealing with measurement of fracture toughness for reactor vessel materials. WPSC has funded both the WOG and ABB-CE/RVWG to measure the fracture toughness of two 1P3571 archive weld metals (utilizing different coils of weld wires) using the Master Curve Approach. The WOG and ABB-CE RVWG have obtained unirradiated T_0 values for weld metal 1P3571 in accordance with ASTM 1921-97. The WOG has also obtained the fracture toughness for 1P3571 weld metal from unirradiated 1/2T-CT specimens. Furthermore, the WOG has generated irradiated T_0 values for two coils of 1P3571 weldments reconstituted from surveillance capsule specimens from the KNPP and Maine Yankee reactor vessels that were irradiated to 3.36×10^{19} n/cm^2 and 6.11×10^{19} n/cm^2, respectively. The ASME B&PVC is currently working under the direction of PVRC to develop recommendations and guidelines for the use of T_0 values in lieu of RT_{NDT} values for assessment of reactor vessel integrity. The results of the supplemental fracture toughness testing for both the unirradiated and irradiated 1P3571 weld metal, along with application of the results, has been presented to the PVRC and ASME.

WPSC concluded that it is prudent to report the results of the recently completed fracture toughness testing of the EOL and beyond EOL irradiated 1P3571 weld metal along with the values derived for the various PTS evaluations given by the methodology described in 10 CFR 50.61. The results of the irradiated fracture toughness testing will serve as a means of assuring adequate conservatism is incorporated into the integrity assessment of the KNPP reactor vessel. Furthermore, since the fracture toughness transition shift is larger and more accurate than the Charpy transition shift, it is felt that continued use of the Charpy results could be inappropriate. The KNPP has volunteered to be a lead plant on behalf of the WOG for application of the Master Curve Approach. NRC feedback obtained on this application of the Master Curve Method will be considered, as appropriate, by the WOG. The fracture toughness results along with the methodology presented in WCAP-15075 indicate that the KNPP 1P3571 weld metal will continue to conservatively provide adequate fracture toughness up to and beyond extended end-of-life fluence.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF FIGURES

LIST OF FIGURES (Cont.)

EXECUTIVE SUMMARY

The purpose of this report is to generate pressure-temperature (P-T) limit curves for the Kewaunee Nuclear Power Plant (KNPP) reactor vessel for normal operation at 33 and 51 EFPY using the methodology from the ASME Boiler and Pressure Vessel Code, Section XI, Appendix G and Code Case N-588. The P-T limit curves were generated for four (4) different cases for the beltline circumferential weld based on:

1. Charpy V-notch data from the Kewaunee surveillance program with no ratio adjustment. (Case 3-without (w/o) ratio)

2. Charpy V-notch data from the Kewaunee surveillance program adjusted using the ratio method in Regulatory Guide 1.99, Revision 2. (Case 3)

3. Measured fracture toughness data in the unirradiated condition to determine the initial reference temperature and Charpy V-notch data to estimate the shift in fracture toughness. (Case 5a)

4. Direct measurement of the irradiated fracture toughness and corresponding reference temperature. (Case 6)

Regulatory Guide 1.99, Rev. 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 Tables 4-1 through 4-8. The circumferential weld is the most limiting beltline material in terms of ART, but using Code Case N-588 for the pressure-temperature limit curves reveals that the intermediate shell forging material (which has a lower ART) is more restrictive (i.e., further to the right in P-T space) over most, if not the entire curve. The pressure-temperature limit curves were generated for heatup rates of 60 and 100°F/hr and cooldown rates of 0, 20, 40, 60 and 100°F/hr. The heatup and cooldown curves using the forging ART are found in Figures 5-1 through 5-6. For the cases where portions of the curves based on the forging ART and the circumferential weld ART are limiting, composite curves were generated. These curves can be found in Figures 5-7 through 5-16.

1 INTRODUCTION

Heatup and cooldown limit curves are generated using the adjusted RT_{NDT} (reference nil-ductility temperature) of the limiting beltline region materials of the reactor vessel. The adjusted RT_{NDT} values of the limiting materials in the core region of the reactor vessel are traditionally determined by using the unirradiated reactor vessel material Charpy V-notch impact toughness properties, estimating the radiation-induced ΔRT_{NDT}, (which is usually the 30 ft-lb temperature shift) and adding a margin. The unirradiated RT_{NDT}, as defined in the ASME Code, Section III, NB-2300,[1] is the higher of either the drop weight nil-ductility transition temperature (NDTT) or the temperature at which the material exhibits no less than 50 ft-lb of impact energy and 35-mil lateral expansion minus 60°F.

In this report, different methods for determining the adjusted RT_{NDT} of the limiting circumferential weld material are introduced, in addition to the Charpy V-notch impact toughness approach. The new methods are based on the Master Curve fracture toughness derivation of T_o, which can then be converted into the newly defined reference temperature, RT_{To}, using the draft ASME Code Case: $RT_{To} = T_o + 35°F$. This definition of RT_{To} is used in both the unirradiated and the irradiated conditions. See the companion reports to describe the approaches taken for the Master Curve fracture toughness methodology (WCAP-15075[2]) and the traditional Charpy approach (WCAP-15074[3]).

In the traditional approach, 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). The extent of the shift in RT_{NDT} is enhanced by certain chemical elements (such as copper and nickel) present in reactor vessel steels. The Nuclear Regulatory Commission (NRC) has published a method for predicting radiation embrittlement in Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials."[4] Regulatory Guide 1.99, Revision 2, is used for the calculation of Adjusted Reference Temperature (ART) values (IRT + 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. For each of the four (4) circumferential weld cases analyzed, the most limiting ART values are used in the generation of the heatup and cooldown pressure-temperature limit curves for normal operation. The curve(s) which are positioned at the highest temperatures define the limiting pressure-temperature curves; often this means that a composite curve from the forging material and the circumferential weld (using Code N-588[5]) is generated.

2 PURPOSE

The Wisconsin Public Service Corporation recently contracted Westinghouse to perform supplemental fracture toughness testing of the 1P3571 surveillance weld metal irradiated to Kewaunee end-of-life (EOL) and extended EOL fluences. The traditional Charpy surveillance Capsule S results were also evaluated. These test results are documented in WCAP14279, Rev. 1[6]. As a part of this evaluation Westinghouse generated new heatup and cooldown curves for EOL and extended EOL 33 and 51 EFPY. The heatup and cooldown curves were generated with appropriate margins for instrumentation errors. The curves include a hydrostatic leak test limit curve from 2485 to 2000 psig and pressure-temperature limits for the vessel flange regions per the requirements of 10 CFR Part 50, Appendix G [7] following the process in Chapter 5.3.2 of the Standard Review plan[8].

The purpose of this report is to present the calculations and the development of the Kewaunee Nuclear Power Plant heatup and cooldown curves for 33 and 51 EFPY. This report documents several methods for calculating adjusted reference temperature (ART) values following the general methods of Regulatory Guide 1.99, Revision 2, for the beltline weld material. The forging materials exactly follow the Regulatory Guide 1.99, Revision 2 method. The development of the heatup and cooldown pressure-temperature limit curves for normal operation are presented to cover the limiting P-T conditions for each of the methods used to determine the circumferential weld ART.

As addressed in the introduction, this report introduces additional fracture toughness methods of calculating the required ART values for the heatup and cooldown curves. These methods use 1) the Master Curve fracture toughness for defining the unirradiated condition initial reference temperature (IRT), and 2) the Master Curve fracture toughness for defining the irradiated condition ART directly. The traditional Charpy V-notch method was also used for two different cases. Thus, these are four different cases evaluated for the circumferential weld metal:

Case 3 — Credible Kewaunee Charpy V-notch surveillance data employing the ratio adjustment for heat uncertainty

Case 3-w/o ratio - Credible Kewaunee Charpy V-notch surveillance data as measured (no adjustment using the ratio method)

Case 5a — Master Curve fracture toughness approach for defining the IRT, and credible Kewaunee Charpy V-notch surveillance data for estimating ΔART

Case 6 — Master Curve fracture toughness approach for directly defining the irradiated condition reference temperature, RT_{To} (which is the ART)

The companion reports WCAP-15074 and WCAP-15075 describe the four different cases in complete detail. The case numbers follow the numbers used above except for Case 3 w/o ratio. Case 3 w/o ratio is included in the WCAP-15074 evaluation, but is not distinctly defined as such.

3 CRITERIA FOR ALLOWABLE PRESSURE-TEMPERATURE RELATIONSHIPS

Appendix G to 10 CFR Part 50, "Fracture Toughness Requirements" specifies fracture toughness requirements for ferritic materials of pressure-retaining components of the reactor coolant pressure boundary of light water nuclear power reactors to provide adequate margins of safety during any condition of normal operation, including anticipated operational occurrences and system hydrostatic tests, to which the pressure boundary may be subjected over its service lifetime. The ASME Boiler and Pressure Vessel Code forms the basis for these requirements. Section XI, Division 1, "Rules for Inservice Inspection of Nuclear power Plant Components," Appendix G,[9] contains conservative methods of analysis. The 1989 edition was used for the calculations here, with the only exception being that Code Case N588 was used for the circumferential welds.

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_{IR}, for the metal temperature at that time. K_{IR} is the same as the terminology "crack arrest reference stress intensity factor, K_{IR}, and is obtained from the reference fracture toughness curve, defined in Appendix G of the ASME Code, Section XI. The K_{Ia} curve is given by the following equation:

$$K_{Ia} = 26.78 + 1.233 * e^{[0.0145(T - RT_{NDT} + 160)]} \qquad (1)$$

where,

K_{Ia} = reference stress intensity factor as a function of the metal temperature T and RT_{NDT}

RT_{NDT} = the metal reference toughness temperature adjusted for irradiation damage; thus, for the calculations in this report; RT_{NDT} is the adjusted reference temperature (ART)

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

$$C * K_{Im} + K_{It} < K_{Ia} \qquad (2)$$

where,

K_{Im} = stress intensity factor caused by membrane (pressure) stress
K_{It} = stress intensity factor caused by the thermal gradients
K_{Ia} = 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

At any time during the heatup or cooldown transient, K_{Ia} 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_{Ia} at the 1/4T location for finite cooldown rates than for steady-state operation.

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_{Ia} for the 1/4T crack during heatup is lower than the K_{Ia} 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_{Ia} 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 are 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 (limiting) 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 possibly material to material), and the pressure limit must at all times be based on analysis of the most critical criterion.

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 psig[10]), which is 621 psig for the Kewaunee reactor vessel.

The limiting unirradiated RT_{NDT} of 60°F occurs in the closure head and vessel flange of the Kewaunee reactor vessel, so the minimum allowable temperature of this region is 180°F at pressures greater than 621 psig with no margin for uncertainties.

However, for these curves, margins of +13°F[11] and -58 psig[11] are included for instrumentation error. No delta pressure is included for these curves; however, this delta pressure will be addressed in the Kewaunee site administrative limits as discussed in Section 3.2. Therefore, the minimum allowable temperature-pressure for the flange is 193°F and 563 psig.

3.1 CIRCUMFERENTIAL WELDS (CODE CASE N-588):

In 1997 ASME Section XI, Appendix G, was revised to add methodology for the use of circumferential flaws when considering circumferential welds in developing pressure-temperature limit curves. This change was also implemented in a separate Code Case, N588.

The earlier ASME Section XI, Appendix G approach mandated the postulation of an axial flaw in circumferential welds for the purposes of calculating pressure-temperature limits. Postulating the Appendix G reference flaw in a circumferential weld is physically unrealistic because the length of the reference flaw is 1.5 times the vessel thickness and is much longer than the width of the vessel girth welds. In addition, historical experience, with repair weld indications found during pre-service inspection and data taken from destructive examination of actual vessel welds, confirms that any flaws are small, laminar in nature, and are not oriented transverse to the weld bead orientation. Because of this, any defects potentially introduced during the fabrication process (and not detected during subsequent non-destructive examinations) should only be oriented along the direction of the weld fabrication. Thus, for circumferential welds, any postulated defect should be in the circumferential orientation.

The revision now eliminates additional conservatism in the assumed flaw orientation for circumferential welds.

3.2 CRITERIA FOR KEWAUNEE PLANT SPECIFIC

Vessel dimension and flange requirements were the same as the input used for WCAP-14278, Revision 0[12]. New margins for instrumentation errors of +13°F and -58 psig have been provided by WPSC.[11] The curves presented in this report do not include the delta pressure (ΔP) margin of 634 psi for the difference between the point of pressure measurement and the limiting location in the beltline (which is coincidently the same for the limiting intermediate shell forging and the circumferential weld materials). The ΔP margins of 63.4 psi was based on an assumed tube plugging level of 0%[13]. This ΔP margin will be implemented in the Kewaunee site administrative curves.

4 CALCULATION OF ADJUSTED REFERENCE TEMPERATURE

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

$$ART = \text{Initial RT (IRT)} + \Delta RT + \text{Margin} \qquad (3)$$

The IRT is the initial RT_{NDT} for the unirradiated material as defined in paragraph NB-2331 of Section III of the ASME Boiler and Pressure Vessel Code[5] or the initial RT_{To} based upon measurement of Master Curve fracture toughness data. 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 is ΔRT_{NDT} caused by irradiation and can be calculated (from Charpy V-notch data) as follows:

$$\Delta RT_{NDT} = CF * f^{(0.28-0.10\log f)} = CF * ff \qquad (4)$$

Where f is fluence and ff is the fluence function.

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

$$f_{(depth x)} = f_{surface} * e^{(-0.24x)} \qquad (5)$$

where x is expressed in inches. The Kewaunee reactor vessel beltline thickness is 6.5 inches. x is the depth into the vessel wall measured from the vessel clad/base metal interface. The resultant fluence at point x is then used in Equation 4 to calculate the ΔRT_{NDT} at the specific depth.

This same approach is used for fracture toughness data and the estimation of ΔRT_{To} by using the measured irradiated RT_{To} values for Kewaunee end-of-life and Kewaunee extended life. See WCAP-15075 for details on how the CF is derived for the fracture toughness data. It is assumed that fracture toughness follows the same functional relationship with fluence as Charpy V-notch data (i.e., the same fluence relationship as indicated in Equation 4).

The Westinghouse Radiation Engineering and Analysis group evaluated the vessel fluence projections and the results are presented in Section 6 of WCAP-14279, Rev. 1. The evaluation used the latest ENDF/B-VI cross-section dosimetry. Tables 4-1 through 4-8, herein, contain the calculated vessel surface fluence values along with the Regulatory Guide 1.99, Revision 2, 1/4T and 3/4T calculated fluences from Equation 5) used to calculate the ART values for the beltline materials in the Kewaunee reactor vessel.

Cases Evaluated

Case 3 — Traditional Charpy V-notch approach (including ratio method) using the following:

a. Measured initial RT_{NDT} per ASME Code, Section III, NB-2300 of -50°F for the Kewaunee surveillance weld.

b. Shift based upon ratio-adjusted Kewaunee credible surveillance data; each individual shift measurement was adjusted by the ratio of the chemistry factors from the industry best estimate for the Kewaunee vessel (214.0°F) and the best estimate for the KW surveillance weld, (187.2°F); the fit to the ratio-adjusted shift data results in an adjusted CF = 219.9°F

c. Margin of 28°F for credible surveillance data and no uncertainty for the measured initial RT_{NDT}; $M = 2[(14)^2 + (0)^2]^{1/2} = 28$°F.

Case 3 w/o ratio — Traditional Charpy V-notch approach without ratio adjustment using the following:

a. Same as Case 3 for initial RT_{NDT}.

b. Shift based upon measured, credible Kewaunee surveillance data (no ratio adjustment); the fit to the data gives a CF = 192.3°F.

c. Same margin for credible data as for Case 3.

Case 5a — Master Curve fracture toughness initial reference temperature coupled with Charpy shift method using the following:

a. Measured initial RT_{To} using Master Curve toughness data and the draft Code Case for defining: $RT_{To} = T_o + 35$°F = -109°F. T_o is determined using ASTM E1921-97.

b. Shift based as in Case 3 with ΔT_o assumed to match the Charpy shift; an additional uncertainty is added below to account for this assumption.

c. Margin of 62°F that represents a 14°F uncertainty for credible shift data plus a 27°F uncertainty due to the correlation between Charpy shift and fracture toughness shift (ΔT_o); the 7°F uncertainty due to the initial RT_{To} is also included; $M = 2[(27)^2 + (14)^2 + (7)^2]^{1/2} = 62$°F.

Case 6 Direct Master Curve fracture toughness irradiated reference temperature using the following:

a. An initial reference temperature value is not used directly.

b. No measured shift since irradiated RT_{To} is determined at the fluence level of interest. An effective chemistry factor of 248°F is used to determine attenuated shift values through the thickness of the vessel (1/4T and 3/4T locations); refer to WCAP-15075 for details on the determination of the effective chemistry factor.

c. Margin of $2\sigma_{To}$ is used. σ_{To} is the uncertainty in the T_o value for the Kewaunee surveillance weld corresponding to 33 EFPY (8°F) and for the Maine Yankee surveillance weld of 51 EFPY; M = 2(8) = 16°F for 33 EFPY and M=2(12) = 24°F for 51 EFPY.

Contained in Tables 4-1 through 4-4 are the calculations of the ART values for the Kewaunee circumferential weld at 1/4T and 3/4T locations used for the generation of the 33 EFPY and 51 EFPY heatup and cooldown curves for the four (4) different cases described in Section 3.0.

Tables 4-5 through 4-8 show the calculated ART values for the Kewaunee limiting forging material (intermediate shell course). The 33 EFPY end-of-life fluence results are shown in Tables 4-5 and 4-6 for the 1/4T and 3/4T locations, and the extended end-of-life fluence (51 EFPY) results are contained in Tables 4-7 and 4-8. Note that the forging results are based on non-credible surveillance results and a measured value of IRT (RT_{NDT} = 60°F). The ΔRT_{NDT} is calculated using a conservative chemistry factor of 37°F from the table in Regulatory Guide 1.99, Rev. 2. The margin term is 2 (17°F) = 34°F. The other forging material (i.e., the lower shell course in the Kewaunee beltline has the same chemistry factor as the intermediate shell forging but the IRT is 40°F lower (IRT = RT_{NDT} = 20°F). Thus, this lower shell forging material is not limiting since it has superior properties as compared to the intermediate shell forging material.

Table 4-1 Calculation of the ART Values for the 1/4T Location of the Circ. Weld @ 33 EFPY

Method	CF deg. F	f (surface) n/cm²	f (1/4-T) n/cm²	ff	IRT deg. F	M deg. F	delta RT deg. F	ART deg. F
3	219.9*	3.34	2.26137	1.220861	-50	28	268.4673	246
3 w/o ratio	192.3	3.34	2.26137	1.220861	-50	28	234.7715	213
5a	219.9*	3.34	2.26137	1.220861	-109	65	268.4673	221
6	248**	3.34	2.26137	1.220861	-109	16	302.7735	210

Table 4-2 Calculation of the ART Values for the 3/4T Location of the Circ. Weld @ 33 EFPY

Method	CF	f (surface) n/cm²	f (3/4-T) n/cm²	ff	IRT deg. F	M deg. F	delta RT deg. F	ART deg. F
3	219.9*	3.34	1.036626	1.010066	-50	28	222.1135	200
3 w/o ratio	192.3	3.34	1.036626	1.010066	-50	28	194.2357	172
5a	219.9*	3.34	1.036626	1.010066	-109	62	222.1135	175
6	248**	3.34	1.036626	1.010066	-109	16	250.4964	157

*Adjusted chemistry factor determined after applying the ratio approach to the measured Kewaunee shift data.

**Note that the effective CF for case 6 is based on a function related to shift; therefore, the original IRT (based on T_o) has to be included, but it is subtracted out when the delta is added in since the delta includes the IRT based on T_o. The M value for case 6 is based on the Kewaunee irradiated data set -- see WCAP-15075.

Table 4-3 Calculation of the ART Values for the 1/4 T Location of the Circ. Weld @ 51 EFPY								
Method	CF deg. F	f (surface) n/cm^2	f (1/4-T) n/cm^2	ff	IRT deg. F	M deg. F	delta RT deg. F	ART deg. F
3	219.9*	5.06	3.425908	1.321718	-50	28	290.6457	269
3 w/o ratio	192.3	5.06	3.425908	1.321718	-50	28	254.1663	232
5a	219.9*	5.06	3.425908	1.321718	-109	62	290.6457	244
6	248**	5.06	3.425908	1.321718	-109	24	327.786	243

Table 4-4 Calculation of the ART Values for the 3/4 T Location of the Circ. Weld @ 51 EFPY								
Method	CF deg. F	f (surface) n/cm^2	f (3/4-T) n/cm^2	ff	IRT deg. F	M deg. F	delta RT deg. F	ART deg. F
3	219.9*	5.06	1.570457	1.124721	-50	28	247.3261	225
3 w/o ratio	192.3	5.06	1.570457	1.124721	-50	28	216.2838	194
5a	219.9*	5.06	1.570457	1.124721	-109	62	247.3261	200
6	248**	5.06	1.570457	1.124721	-109	24	278.9307	194

*Adjusted chemistry factor determined after applying the ratio approach to the measured Kewaunee shift data.

**Note that the effective CF for case 6 is based on a function related to shift; therefore, the original IRT (based on T_o) has to be included, but it is subtracted out when the delta is added in, since the delta includes the IRT based on T_o. The M value for case 6 is based on the Maine Yankee irradiated data set -- see WCAP-15075.

Table 4-5	Calculation of the ART Values for 1/4T Location of the Intermediate Shell Forging @ 33 EFPY							
Method	CF deg. F	f (surface) n/cm^2	f (1/4-T) n/cm^2	ff	IRT deg. F	M deg. F	delta RT deg. F	ART deg. F
All	37	3.34	2.26137	1.220861	60	34	45.17185	139

Table 4-6	Calculation of the ART Values for 3/4T Location of the Intermediate Shell Forging @ 33 EFPY							
Method	CF deg. F	f (surface) n/cm^2	f (3/4-T) n/cm^2	ff	IRT deg. F	M deg. F	delta RT deg. F	ART deg. F
All	37	3.34	1.036626	1.010066	60	34	37.37244	131

Table 4-7	Calculation of the ART Values for the 1/4T Location of the Intermediate Shell Forging @ 51 EFPY							
Method	CF deg. F	f (surface) n/cm^2	f (1/4-T) n/cm^2	ff	IRT deg. F	M deg. F	delta RT deg. F	ART deg. F
All	37	5.06	3.425908	1.321718	60	34	48.90355	143

Table 4-8	Calculation of the ART Values for the 3/4T Location of the Intermediate Shell Forging @ 51 EFPY							
Method	CF deg. F	f (surface) n/cm^2	f (3/4-T) n/cm^2	ff	IRT deg. F	M deg. F	delta RT deg. F	ART deg. F
All	37	5.06	1.570457	1.124721	60	34	41.61466	136

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.

Figures 5-1 through 5-6 present the heatup and cooldown (HU/CD) curves generated using only the adjusted reference temperature (ART) for the intermediate shell forging material. These curves are governing for the Kewaunee vessel (i.e., represent the most restrictive pressure-temperature condition for the vessel) for all cases except for the following which involve composite curves:

1. All Cooldown rates for Case 3 @ 33 EFPY
2. 60°F/hr heatup rate for Case 3 @ 33 EFPY
3. All cooldown rates for Case 3 @ 51 EFPY
4. 60°F and 100°F/hr heatup rates for Case 3 @ 51 EFPY
5. All cooldown rates for Case 3 w/o ratio @ 51 EFPY
6. All cooldown rates for Case 5a @ 51 EFPY
7. 60°F/hr heatup rate for Case 5a @ 51 EFPY
8. All cooldown rates for Case 6 @ 51 EFPY
9. 60°F/hr heatup rate for Case 6 @ 51 EFPY

The heatup and cooldown curves for these composite conditions require the ART for the circumferential weld as well as the ART for the intermediate shell forging material. Composite curves were generated for the cases listed above and are presented in Figures 5-7 through 5-16. Table 5-1 summarizes the applicable curves for heatup (HU) and cooldown (CD) for the four different cases @ 33 EFPY and 51 EFPY. Tables 5-2 through 5-14 list the pressure-temperature (P-T) values for the different cases as summarized in Table 5-1.

Heatup and cooldown limit curves for 33 EFPY are restricted by the forging material for all Cases except Case 3. Only the heatup at 100°F/hr for Case 3 is restricted by the forging material. The other curves are composite curves (Figures 5-7 and 5-8) where the forging dominates at the lower end (except for the flange region) and the circumferential weld dominates at the higher end.

For extended end-of-life at 51 EFPY, the majority of the pressure-temperature limits are composite curves. Only the heatup curves (60°F/hr and 100°F/hr) for Case 3 w/o ratio and the heatup curves at 100°F/hr for Cases 5a and 6 are restricted by the forging material.

Allowable combinations of temperature and pressure for specific temperature change rates are below and to the right of the limit lines shown in the given figures. These limits are 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 as shown for example in Figures 5-1 and 5-2 (for the specific heatup rate being utilized). The straight-line portion of the criticality limit is at the minimum permissible temperature for the 2485[8] 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 as follows:

$$1.5K_{Im} < K_{Ia} \quad (6)$$

where,

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

K_{Ia} is defined in Equation 1

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 specified as: 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 5-16 define all of the above limits for ensuring prevention of nonductile failure for the Kewaunee unit 1 reactor vessel.

This report introduces two new methods that are applicable for heatup and cooldown curves for the Kewaunee reactor pressure vessel circumferential weld: Code Case N-588 and ART calculated based on Master Curve fracture toughness data. To make a comparison between the traditional Charpy V-notch toughness approach (Cases 3 and 3 w/o ratio) and the Master Curve fracture toughness approach (Cases 5a and 6), four different cases are presented in this report. To evaluate the impact of the different toughness methods on heatup and cooldown curves for the circumferential weld alone, Figure 5-17 was generated as an example. Figure 5-17 shows 100°F/hr heatup curves (33 EFPY) for the four different cases with Code Case N-588 invoked; the forging material is ignored in this comparison. Case number 6 is the most realistic since it is based on measured fracture toughness data. Case 3 is the traditional

Charpy-based approach accepted by the NRC. Note the 44°F shift in the curves between Case 6 and 3 reflecting the extra conservatism in the traditional Charpy-based approach.

Appendix A has been added to this report to summarize the information requested by the NRC in the latest attempt to close out Generic Letter 92-01. The information contained in Tables A-1 through A-3 has been compiled from the various companion reports related to the Kewaunee vessel integrity assessment (WCAP-14279, Rev. 1, WCAP-14280, Rev. 1[13], WCAP-15074, and WCAP-15075).

Table 5-1 Summary of the Applicable HU/CD Curves for the Different Evaluation Cases

	33 EFPY										
	Cooldown					Heatup		Applicable Tables		Applicable Figures	
	0	20	40	60	100	60	100	Cooldown	Heatup 60/100	Cooldown	Heatup 60/100
Case 3	C	C	C	C	C	C	F*	5-6	5-7/5-3*	5-7	5-8/5-2
Case 3 w/o ratio	F	F	F	F	F	F	F	5-2	5-3	5-3	5-1/5-2
Case 5a	F	F	F	F	F	F	F	5-2	5-3	5-3	5-1/5-2
Case 6	F	F	F	F	F	F	F	5-2	5-3	5-3	5-1/5-2
	51 EFPY										
Case 3	C	C	C	C	C	C	C	5-8	5-9	5-9	5-10/5-11
Case 3 w/o ratio	C	C	C	C	C	F	F	5-10	5-5	5-12	5-4/5-5
Case 5a	C	C	C	C	C	C	F	5-11	5-12/5-5	5-13	5-14/5-5
Case 6	C	C	C	C	C	C	F	5-13	5-14/5-5	5-15	5-16/5-5

Heatup and cooldown rates are in °F/hour; 0 refers to steady state (SS)

C: Composite Curve; Forging and Circ. Weld Limited

F: Forging Limited

Note that Table 5-4 and Figure 5-6 are not applicable to any of the conditions listed above.

***For 100°F/hr criticality, see note associated with Table 5-3.**

Table 5-2 Data Points of the Cooldown Curves for the Forging @ 33 EFPY

Steady State		20F		40F		60F		100F	
T	P	T	P	T	P	T	P	T	P
73	539	73	516	73	492	73	468	73	419
78	545	78	522	78	498	78	474	78	426
83	551	83	528	83	504	83	481	83	433
88	558	88	535	88	512	88	488	88	440
93	563	93	542	93	519	93	496	93	448
98	563	98	550	98	527	98	504	98	457
103	563	103	559	103	536	103	513	103	467
108	563	108	563	108	545	108	523	108	477
113	563	113	563	113	556	113	533	113	489
118	563	118	563	118	563	118	545	118	501
123	563	123	563	123	563	123	557	123	514
128	563	128	563	128	563	128	563	128	528
133	563	133	563	133	563	133	563	133	543
138	563	138	563	138	563	138	563	138	560
143	563	143	563	143	563	143	563	143	563
148	563	148	563	148	563	148	563	148	563
153	563	153	563	153	563	153	563	153	563
158	563	158	563	158	563	158	563	158	563
163	563	163	563	163	563	163	563	163	563
168	563	168	563	168	563	168	563	168	563
173	563	173	563	173	563	173	563	173	563
178	563	178	563	178	563	178	563	178	563
183	563	183	563	183	563	183	563	183	563
188	563	188	563	188	563	188	563	188	563
193	563	193	563	193	563	193	563	193	563
193	898	193	887	193	877	193	868	193	851
198	930	198	921	198	912	198	905	198	891
203	965	203	958	203	951	203	944	203	934
208	1003	208	997	208	991	208	987	208	981
213	1043	213	1039	213	1035	213	1033	213	1031
218	1087	218	1084	218	1083	218	1082	218	1085
223	1133	223	1133	223	1133				
228	1183								
233	1237								
238	1294								
243	1356								
248	1423								
253	1494								
258	1570								
263	1652								
268	1739								
273	1833								
278	1934								
283	2041								
288	2156								
293	2278								
298	2409								

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-3 Data Points of the Heatup Curves for the Forging @ 33 EFPY									
60 Heatup		Critical. Limit		100 Heatup		Critical. Limit		Leak Test Limit	
T	P	T	P	T	P	T*	P	T*	P
73	529	275	0	73	508	275	0	253	2000
78	529	275	529	78	508	275	508	275	2485
98	529	275	529	98	508	275	508		
103	529	275	529	103	508	275	508		
108	530	275	530	108	508	275	508		
113	534	275	534	113	508	275	508		
118	539	275	539	118	508	275	508		
123	546	275	546	123	510	275	510		
128	555	275	555	128	513	275	513		
133	563	275	564	133	518	275	518		
138	563	275	575	138	524	275	524		
143	563	275	587	143	531	275	531		
148	563	275	600	148	540	275	540		
153	563	275	614	153	551	275	551		
158	563	275	629	158	562	275	562		
163	563	275	646	163	563	275	575		
168	563	275	664	168	563	275	589		
173	563	275	683	173	563	275	604		
178	563	275	704	178	563	275	620		
183	563	275	726	183	563	275	638		
188	563	275	750	188	563	275	658		
193	563	275	776	193	563	275	679		
193	776	275	804	193	679	275	702		
198	804	275	834	198	702	275	726		
203	834	275	866	203	726	275	753		
208	866	275	900	208	753	275	782		
213	900	275	937	213	782	275	812		
218	937	275	977	218	812	275	845		
223	977	275	1019	223	845	275	881		
228	1019	275	1065	228	881	275	919		
233	1065	278	1114	233	919	278	960		

Table 5-3 Data Points of the Heatup Curves for the Forging @ 33 EFPY (cont.)

60 Heatup		Critical. Limit		100 Heatup		Critical. Limit		Leak Test Limit	
238	1114	283	1167	238	960	283	1004		
243	1167	288	1224	243	1004	288	1051		
248	1224	293	1284	248	1051	293	1102		
253	1284	298	1349	253	1102	298	1156		
258	1349	303	1419	258	1156	303	1215		
263	1419	308	1494	263	1215	308	1277		
268	1494	313	1574	268	1277	313	1344		
273	1574	318	1660	273	1344	318	1416		
278	1660	323	1751	278	1416	323	1493		
283	1751	328	1850	283	1493	328	1575		
288	1850	333	1955	288	1575	333	1664		
293	1955	338	2067	293	1664	338	1758		
298	2067	343	2187	298	1758	343	1859		
303	2187	348	2315	303	1859	348	1967		
308	2315	353	2451	308	1967	353	2082		
313	2451			313	2082	358	2205		
				318	2205	363	2336		
				323	2336	368	2476		
				328	2476				

* **For the 100°F/hr. criticality curve data points for Case 3 @ 33 EFPY only, replace temperatures up to a pressure of 960 psig with 281°F. In addition, the final leak test temperature should also be 281°F @ 2485 psig (See Figure 5-2). If ΔP of 70 psig is included replace temperatures up to a pressure of 1004 psig with 286°F. In addition, the final leak test temperatures should be 257°F @ 2000 psig and 286°F @ 2485 psig[14].**

Table 5-4 Data Points of the Cooldown Curves for the Forging @ 51 EFPY

Steady State		20F		40F		60F		100F	
T	P	T	P	T	P	T	P	T	P
73	535	73	511	73	487	73	463	73	414
78	540	78	517	78	493	78	469	78	420
83	546	83	523	83	499	83	475	83	427
88	552	88	529	88	506	88	482	88	434
93	559	93	536	93	513	93	489	93	441
98	563	98	544	98	520	98	497	98	450
103	563	103	552	103	529	103	506	103	459
108	563	108	560	108	538	108	515	108	469
113	563	113	563	113	547	113	525	113	479
118	563	118	563	118	557	118	535	118	491
123	563	123	563	123	563	123	547	123	503
128	563	128	563	128	563	128	559	128	516
133	563	133	563	133	563	133	563	133	530
138	563	138	563	138	563	138	563	138	546
143	563	143	563	143	563	143	563	143	563
148	563	148	563	148	563	148	563	148	563
153	563	153	563	153	563	153	563	153	563
158	563	158	563	158	563	158	563	158	563
163	563	163	563	163	563	163	563	163	563
168	563	168	563	168	563	168	563	168	563
173	563	173	563	173	563	173	563	173	[illegible]
178	563	178	563	178	563	178	563	178	[illegible]
183	563	183	563	183	563	183	563	183	563
188	563	188	563	188	563	188	563	188	563
193	563	193	563	193	563	193	563	193	563
193	873	193	862	193	851	193	840	193	821
198	904	198	894	198	884	198	875	198	859
203	937	203	928	203	920	203	912	203	899
208	973	208	965	208	958	208	953	208	943
213	1011	213	1005	213	1000	213	996	213	991
218	1052	218	1048	218	1045	218	1042	218	1041
223	1096	223	1094	223	1092	223	1092		
228	1143	228	1143						
233	1194								
238	1248								
243	1307								
248	1369								
253	1436								
258	1509								
263	1586								
268	1669								
273	1757								
278	1852								
283	1955								
288	2063								
293	2179								
298	2304								
303	2437								

Table 5-5 Data Points of the Heatup Curves for the Forging @ 51 EFPY									
60 Heatup		Critical. Limit		100 Heatup		Critical. Limit		Leak Test Limit	
T	P	T	P	T	P	T	P	T	P
73	521	279	0	73	499	279	0	257	2000
78	521	279	521	78	499	279	499	279	2485
98	521	279	521	98	499	279	499		
103	521	279	521	103	499	279	499		
108	522	279	522	108	499	279	499		
113	525	279	525	113	499	279	499		
118	530	279	530	118	499	279	499		
123	536	279	536	123	501	279	501		
128	544	279	544	128	503	279	503		
133	553	279	553	133	508	279	508		
138	563	279	563	138	513	279	513		
143	563	279	574	143	520	279	520		
148	563	279	586	148	528	279	528		
153	563	279	599	153	538	279	538		
158	563	279	613	158	548	279	548		
163	563	279	629	163	560	279	560		
168	563	279	645	168	563	279	573		
173	563	279	663	173	563	279	587		
178	563	279	683	178	563	279	602		
183	563	279	703	183	563	279	619		
188	563	279	726	188	563	279	637		
193	563	279	750	193	563	279	657		
193	750	279	775	193	657	279	678		
198	775	279	803	198	678	279	701		
203	803	279	833	203	701	279	725		
208	833	279	865	208	725	279	752		
213	865	279	900	213	752	279	780		
218	900	279	936	218	780	279	811		
223	936	279	976	223	811	279	844		
228	976	279	1019	228	844	279	879		
233	1019	279	1064	233	879	279	917		
238	1064	283	1113	238	917	283	958		
243	1113	288	1166	243	958	288	1002		
248	1166	293	1223	248	1002	293	1050		
253	1223	298	1283	253	1050	298	1100		
258	1283	303	1348	258	1100	303	1154		
263	1348	308	1418	263	1154	308	1213		
268	1418	313	1493	268	1213	313	1275		
273	1493	318	1572	273	1275	318	1342		
278	1572	323	1658	278	1342	323	1414		
283	1658	328	1750	283	1414	328	1491		
288	1750	333	1848	288	1491	333	1573		
293	1848	338	1953	293	1573	338	1661		
298	1953	343	2065	298	1661	343	1756		
303	2065	348	2185	303	1756	348	1856		
308	2185	353	2313	308	1856	353	1964		
313	2313	358	2449	313	1964	358	2079		
318	2449			318	2079	363	2202		
				323	2202	368	2333		
				328	2333	373	2473		
				333	2473				

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-6 Composite Cooldown Curves for Case 3 @ 33 EFPY					
Steady State		20F	40F	60F	100F
T	P	P	P	P	P
73	539	516	492	468	419
78	545	522	498	474	426
83	551	528	504	481	433
88	558	535	512	488	440
93	563	542	519	496	448
98	563	550	527	504	457
103	563	559	536	513	467
108	563	563	545	523	477
113	563	563	556	533	489
118	563	563	563	545	501
123	563	563	563	557	514
128	563	563	563	563	528
133	563	563	563	563	543
138	563	563	563	563	560
143	563	563	563	563	563
148	563	563	563	563	563
153	563	563	563	563	563
158	563	563	563	563	563
163	563	563	563	563	563
168	563	563	563	563	563
173	563	563	563	563	563
178	563	563	563	563	563
183	563	563	563	563	563
188	563	563	563	563	563
193	563	563	563	563	563
193	898	887	877	868	851
198	930	921	912	905	891
203	965	958	951	944	934
208	1003	997	991	987	981
213	1043	1039	1035	1033	1031
218	1087	1084	1083	1082	1085
223	1133	1133	1133	1133	1133
228	1183	1183	1183	1183	1178
233	1237	1237	1237	1237	1210
238	1294	1294	1294	1294	1243
243	1356	1356	1356	1356	1280
248	1423	1423	1423	1418	1319
253	1494	1494	1494	1457	1361
258	1570	1570	1545	1499	1407
263	1652	1634	1589	1544	1456
268	1723	11679	1635	1593	1509
273	1769	1727	1686	1645	1566

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-6 Composite Cooldown Curves for Case 3 @ 33 EFPY (cont.					
Steady State		20F	40F	60F	100F
T	P	P	P	P	P
278	1819	1779	1740	1701	1627
283	1872	1835	1798	1762	1694
288	1930	1895	1860	1827	1765
293	1992	1959	1928	1898	1842
298	2058	2029	2000	1974	1925
303	2130	2103	2078	2055	2015
308	2207	2184	2162	2143	2111
313	2289	2270	2253	2238	2215
318	2378	2363	2350	2339	2327
323	2474	2463	2454	2449	2447

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-7 **Composite Heatup Curves for Case 3 @ 33 EFPY**

60 Heatup		Critical. Limit			Leak Test Limit	
T	P	T	P		T	P
73	529	281	0		253	2000
78	529	281	529		281	2485
98	529	281	529			
103	529	281	529			
108	530	281	530			
113	534	281	534			
118	539	281	539			
123	546	281	546			
128	555	281	555			
133	563	281	564			
138	563	281	575			
143	563	281	587			
148	563	281	600			
153	563	281	614			
158	563	281	629			
163	563	281	646			
168	563	281	664			
173	563	281	683			
178	563	281	704			
183	563	281	726			
188	563	281	750			
193	563	281	776			
193	776	281	804			
198	804	281	834			
203	834	281	866			
208	866	281	900			
213	900	281	937			
218	937	281	977			

Table 5-7 Composite Heatup Curves for Case 3 @ 33 EFPY (cont.)

60 Heatup		Critical. Limit			Leak Test Limit	
T	P	T	P		T	P
223	977	281	1019			
228	1019	281	1065			
233	1065	281	1114			
238	1114	283	1167			
243	1167	288	1224			
248	1224	293	1284			
253	1284	298	1349			
258	1349	303	1419			
263	1419	308	1494			
268	1494	313	1574			
273	1574	318	1660			
278	1660	323	1751			
283	1751	328	1850			
288	1850	333	1955			
293	1955	338	2058			
298	2058	343	2130			
303	2130	348	2207			
308	2207	353	2289			
313	2289	358	2378			
318	2378	363	2474			
323	2474					

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-8 Composite Cooldown Curves for Case 3 @ 51 EFPY					
Steady State		20F	40F	60F	100F
T	P	P	P	P	P
73	535	511	487	463	414
78	540	517	493	469	420
83	546	523	499	475	427
88	552	529	506	482	434
93	559	536	513	489	441
98	563	544	520	497	450
103	563	552	529	506	459
108	563	560	538	515	469
113	563	563	547	525	479
118	563	563	557	535	491
123	563	563	563	547	503
128	563	563	563	559	516
133	563	563	563	563	530
138	563	563	563	563	546
143	563	563	563	563	563
148	563	563	563	563	563
153	563	563	563	563	563
158	563	563	563	563	563
163	563	563	563	563	563
168	563	563	563	563	563
173	563	563	563	563	563
178	563	563	563	563	563
183	563	563	563	563	563
188	563	563	563	563	563
193	563	563	563	563	563
193	873	862	851	840	821
198	904	894	884	875	859
203	937	928	920	912	899

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-8 Composite Cooldown Curves for Case 3 @ 51 EFPY (cont.)

Steady State		20F	40F	60F	100F
T	P	P	P	P	P
208	973	965	958	953	943
213	1011	1005	1000	996	991
218	1052	1048	1045	1042	1018
223	1096	1094	1092	1092	1036
228	1143	1143	1143	1143	1057
233	1194	1194	1194	1194	1079
238	1248	1248	1248	1219	1102
243	1307	1307	1300	1243	1128
248	1369	1369	1325	1269	1155
253	1436	1407	1352	1296	1185
258	1489	1435	1380	1326	1217
263	1517	1464	1411	1358	1252
268	1548	1496	1445	1393	1290
273	1581	1531	1480	1430	1330
278	1617	1568	1519	1470	1374
283	1655	1608	1560	1514	1421
288	1697	1651	1605	1560	1472
293	1741	1697	1653	1610	1527
298	1789	1746	1705	1664	1586
303	1840	1800	1761	1723	1649
308	1895	1857	1821	1785	1718
313	1954	1919	1885	1853	1792
318	2018	1986	1955	1925	1872
323	2086	2057	2030	2004	1958
328	2160	2134	2110	2088	2050
333	2239	2217	2197	2178	2150
338	2324	2306	2290	2276	2257
343	2416	2401	2390	2381	2373

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-9 Composite Heatup Curves for Case 3 @ 51 EFPY						
60 Heatup		Critical. Limit			Leak Test Limit	
T	P	T	P		T	P
73	521	304	0		244	2000
78	521	304	521		304	2485
98	521	304	521			
103	521	304	521			
108	522	304	522			
113	525	304	525			
118	530	304	530			
123	536	304	536			
128	544	304	544			
133	553	304	553			
138	563	304	563			
143	563	304	574			
148	563	304	586			
153	563	304	599			
158	563	304	613			
163	563	304	629			
168	563	304	645			
173	563	304	663			
178	563	304	683			
183	563	304	703			
188	563	304	726			
193	563	304	750			
193	750	304	775			
198	775	304	803			
203	803	304	833			
208	833	304	865			
213	865	304	900			
218	900	304	936			
223	936	304	976			
228	976	304	1019			
233	1019	304	1064			
238	1064	304	1113			
243	1113	304	1166			
248	1166	304	1223			
253	1223	304	1283			
258	1283	304	1348			
263	1348	308	1418			
268	1418	313	1493			

Table 5-9 Composite Heatup Curves for Case 3 @ 51 EFPY (cont.)						
60 Heatup		Critical. Limit			Leak Test Limit	
T	P	T	P		T	P
273	1493	318	1572			
278	1572	323	1655			
283	1655	328	1697			
288	1697	333	1741			
293	1741	338	1789			
298	1789	343	1840			
303	1840	348	1895			
308	1895	353	1954			
313	1954	358	2018			
318	2018	363	2086			
323	2086	368	2160			
328	2160	373	2239			
333	2239	378	2324			
338	2324	383	2416			
343	2416					

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-9 Composite Heatup Curves for Case 3 @ 51 EFPY (cont.)						
100 Heatup		Critical. Limit			Leak Test Limit	
T	P	T	P		T	P
73	499	304	0			
78	499	304	499			
98	499	304	499			
103	499	304	499			
108	499	304	499			
113	499	304	499			
118	499	304	499			
123	501	304	501			
128	503	304	503			
133	508	304	508			
138	513	304	513			
143	520	304	520			
148	528	304	528			
153	538	304	538			
158	548	304	548			
163	560	304	560			
168	563	304	573			
173	563	304	587			
178	563	304	602			
183	563	304	619			
188	563	304	637			
193	563	304	657			
193	657	304	678			
198	678	304	701			
203	701	304	725			
208	725	304	752			
213	752	304	780			
218	780	304	811			

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-9 Composite Heatup Curves for Case 3 @ 51 EFPY (cont.)

100 Heatup		Critical. Limit	
T	P	T	P
223	811	304	844
228	844	304	879
233	879	304	917
238	917	304	958
243	958	304	1002
248	1002	304	1050
253	1050	304	1100
258	1100	304	1154
263	1154	308	1213
268	1213	313	1275
273	1275	318	1342
278	1342	323	1414
283	1414	328	1491
288	1491	333	1573
293	1573	338	1660
298	1660	343	1719
303	1719	348	1783
308	1783	353	1852
313	1852	358	1926
318	1926	363	2005
323	2005	368	2090
328	2090	373	2182
333	2182	378	2280
338	2280	383	2386
343	2386		

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-10 Cooldown Curves for Case 3 w/o Ratio @ 51 EFPY

Steady State		20F	40F	60F	100F
T	P	P	P	P	P
73	535	511	487	463	414
78	540	517	493	469	420
83	546	523	499	475	427
88	552	529	506	482	434
93	559	536	513	489	441
98	563	544	520	497	450
103	563	552	529	506	459
108	563	560	538	515	469
113	563	563	547	525	479
118	563	563	557	535	491
123	563	563	563	547	503
128	563	563	563	559	516
133	563	563	563	563	530
138	563	563	563	563	546
143	563	563	563	563	563
148	563	563	563	563	563
153	563	563	563	563	563
158	563	563	563	563	563
163	563	563	563	563	563
168	563	563	563	563	563
173	563	563	563	563	563
178	563	563	563	563	563
183	563	563	563	563	563
188	563	563	563	563	563
193	563	563	563	563	563
193	873	862	851	840	821
198	904	894	884	875	859

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-10 Cooldown Curves for Case 3 w/o Ratio @ 51 EFPY (cont.)					
Steady State		20F	40F	60F	100F
T	P	P	P	P	P
203	937	928	920	912	899
208	973	965	958	953	943
213	1011	1005	1000	996	991
218	1052	1048	1045	1042	1041
223	1096	1094	1092	1092	1096
228	1143	1143	1143	1143	1143
233	1194	1194	1194	1194	1194
238	1248	1248	1248	1248	1248
243	1307	1307	1307	1307	1307
248	1369	1369	1369	1369	1369
253	1436	1436	1436	1436	1436
258	1509	1509	1509	1509	1509
263	1586	1586	1586	1586	1586
268	1669	1669	1669	1669	1669
273	1757	1757	1757	1757	1753
278	1852	1852	1852	1852	1828
283	1955	1955	1955	1955	1910
288	2063	2063	2063	2039	1998
293	2179	2167	2146	2126	2093
298	2272	2253	2235	2219	2195
303	2360	2344	2330	2319	2305
308	2454	2442	2433	2427	2423

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-11 Composite Cooldown Curves for Case 5a @ 51 EFPY					
Steady State		20F	40F	60F	100F
T	P	P	P	P	P
73	535	511	487	463	414
78	540	517	493	469	420
83	546	523	499	475	427
88	552	529	506	482	434
93	559	536	513	489	441
98	563	544	520	497	450
103	563	552	529	506	459
108	563	560	538	515	469
113	563	563	547	525	479
118	563	563	557	535	491
123	563	563	563	547	503
128	563	563	563	559	516
133	563	563	563	563	530
138	563	563	563	563	546
143	563	563	563	563	563
148	563	563	563	563	563
153	563	563	563	563	563
158	563	563	563	563	563
163	563	563	563	563	563
168	563	563	563	563	563
173	563	563	563	563	563
178	563	563	563	563	563
183	563	563	563	563	563
188	563	563	563	563	563
193	563	563	563	563	563
193	873	862	851	840	821
198	904	894	884	875	859

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-11 Composite Cooldown Curves for Case 5a @ 51 EFPY (cont.)					
Steady State		20F	40F	60F	100F
T	P	P	P	P	P
203	937	928	920	912	899
208	973	965	958	953	943
213	1011	1005	1000	996	991
218	1052	1048	1045	1042	1041
223	1096	1094	1092	1092	1096
228	1143	1143	1143	1143	1143
233	1194	1194	1194	1194	1194
238	1248	1248	1248	1248	1248
243	1307	1307	1307	1307	1295
248	1369	1369	1369	1369	1336
253	1436	1436	1436	1436	1379
258	1509	1509	1509	1509	1426
263	1586	1586	1586	1563	1477
268	1669	1669	1655	1613	1531
273	1757	1747	1707	1667	1590
278	1840	1801	1763	1725	1654
283	1895	1858	1822	1788	1722
288	1954	1920	1887	1855	1796
293	2018	1986	1956	1928	1875
298	2086	2058	2031	2006	1961
303	2160	2135	2111	2090	2053
308	2239	2217	2198	2180	2152
313	2324	2306	2291	2277	2259
318	2416	2402	2391	2382	2374

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-12 Composite Heatup Curve (60°F/Hr) for Case 5a @ 51 EFPY					
60 Heatup		Critical Limit		Leak Test Limit	
T	P	T	P	T	P
73	521	279	0	257	2000
78	521	279	521	279	2485
98	521	279	521		
103	521	279	521		
108	522	279	522		
113	525	279	525		
118	530	279	530		
123	536	279	536		
128	544	279	544		
133	553	279	553		
138	563	279	563		
143	563	279	574		
148	563	279	586		
153	563	279	599		
158	563	279	613		
163	563	279	629		
168	563	279	645		
173	563	279	663		
178	563	279	683		
183	563	279	703		
188	563	279	726		
193	563	279	750		
193	750	279	775		
198	775	279	803		
203	803	279	833		
208	833	279	865		
213	865	279	900		
218	900	279	936		
223	936	279	976		
228	976	279	1019		
233	1019	279	1064		
238	1064	283	1113		
243	1113	288	1166		
248	1166	293	1223		
253	1223	298	1283		
258	1283	303	1348		
263	1348	308	1418		
268	1418	313	1493		

Table 5-12 Composite Heatup Curve (60°F/Hr) for Case 5a @ 51 EFPY (cont.)					
60 Heatup		Critical Limit		Leak Test Limit	
T	P	T	P	T	P
273	1493	318	1572		
278	1572	323	1658		
283	1658	328	1750		
288	1750	333	1848		
293	1848	338	1953		
298	1953	343	2065		
303	2065	348	2185		
308	2185	353	2313		
313	2313	358	2416		
318	2416				

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-13 Composite Cooldown Curves for Case 6 @ 51 EFPY					
Steady State		20F	40F	60F	100F
T	P	P	P	P	P
73	535	511	487	463	414
78	540	517	493	469	420
83	546	523	499	475	427
88	552	529	506	482	434
93	559	536	513	489	441
98	563	544	520	497	450
103	563	552	529	506	459
108	563	560	538	515	469
113	563	563	547	525	479
118	563	563	557	535	491
123	563	563	563	547	503
128	563	563	563	559	516
133	563	563	563	563	530
138	563	563	563	563	546
143	563	563	563	563	563
148	563	563	563	563	563
153	563	563	563	563	563
158	563	563	563	563	563
163	563	563	563	563	563
168	563	563	563	563	563
173	563	563	563	563	563
178	563	563	563	563	563
183	563	563	563	563	563
188	563	563	563	563	563
193	563	563	563	563	563
193	873	862	851	840	821
198	904	894	884	875	859

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-13 Composite Cooldown Curves for Case 6 @ 51 EFPY (cont.)

Steady State		20F	40F	60F	100F
T	P	P	P	P	P
203	937	928	920	912	899
208	973	965	958	953	943
213	1011	1005	1000	996	991
218	1052	1048	1045	1042	1041
223	1096	1094	1092	1092	1096
228	1143	1143	1143	1143	1143
233	1194	1194	1194	1194	1194
238	1248	1248	1248	1248	1248
243	1307	1307	1307	1307	1303
248	1369	1369	1369	1369	1344
253	1436	1436	1436	1436	1389
258	1509	1509	1509	1509	1436
263	1586	1586	1586	1573	1488
268	1669	1669	1665	1624	1543
273	1757	1757	1718	1679	1603
278	1850	1812	1774	1738	1667
283	1906	1870	1835	1801	1736
288	1966	1933	1900	1869	1811
293	2031	2000	1971	1943	1892
298	2101	2073	2047	2022	1979
303	2175	2151	2128	2107	2072
308	2256	2235	2216	2199	2173
313	2342	2325	2310	2298	2281
318	2435	2422	2412	2404	2398

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

Table 5-14 Composite Heatup Curve (60°F/Hr) for Case 6 @ 51 EFPY						
60 Heatup		Critical. Limit			Leak Test Limit	
T	P	T	P		T	P
73	521	279	0		257	2000
78	521	279	521		279	2485
98	521	279	521			
103	521	279	521			
108	522	279	522			
113	525	279	525			
118	530	279	530			
123	536	279	536			
128	544	279	544			
133	553	279	553			
138	563	279	563			
143	563	279	574			
148	563	279	586			
153	563	279	599			
158	563	279	613			
163	563	279	629			
168	563	279	645			
173	563	279	663			
178	563	279	683			
183	563	279	703			
188	563	279	726			
193	563	279	750			
193	750	279	775			
198	775	279	803			
203	803	279	833			
208	833	279	865			
213	865	279	900			
218	900	279	936			

Table 5-14 Composite Heatup Curve (60°F/Hr) for Case 6 @ 51 EFPY (cont.)						
60 Heatup		Critical. Limit			Leak Test Limit	
T	P	T	P		T	P
223	936	279	976			
228	976	279	1019			
233	1019	279	1064			
238	1064	283	1113			
243	1113	288	1166			
248	1166	293	1223			
253	1223	298	1283			
258	1283	303	1348			
263	1348	308	1418			
268	1418	313	1493			
273	1493	318	1572			
278	1572	323	1658			
283	1658	328	1750			
288	1750	333	1848			
293	1848	338	1953			
298	1953	343	2065			
303	2065	348	2185			
308	2185	353	2313			
313	2313	358	2435			
318	2435					

Note that rates are in °F/hour; T is in units of °F and P is in units of psig.

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 33 EFPY 1/4 T: 139°F

3/4 T: 131°F

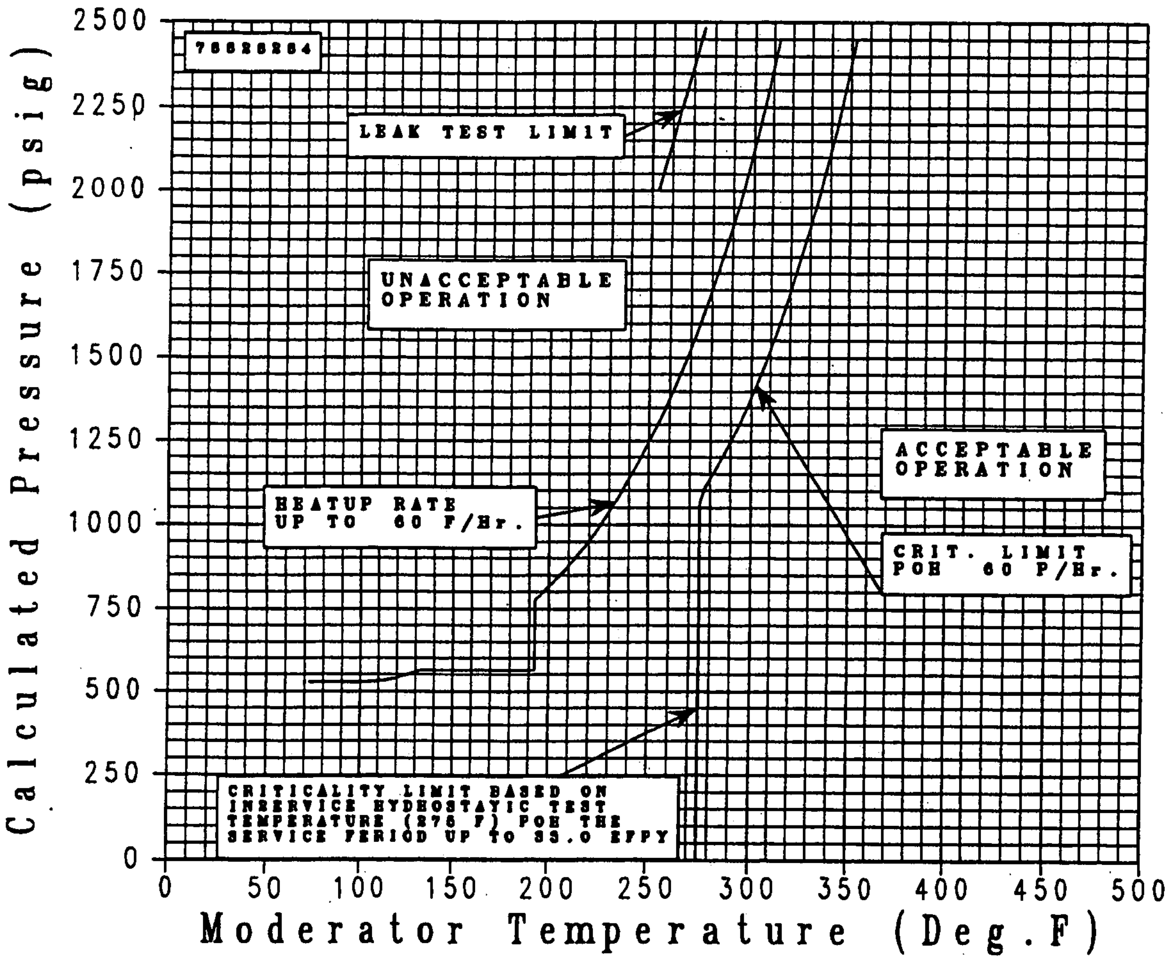

Figure 5-1 Kewaunee Unit 1 Reactor Coolant System Heatup Limitations (Heatup Rate of 60°F/hr) Applicable to 33 EFPY (With Margins for Instrumentation Errors of +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 33 EFPY 1/4 T: 139°F

3/4 T: 131°F

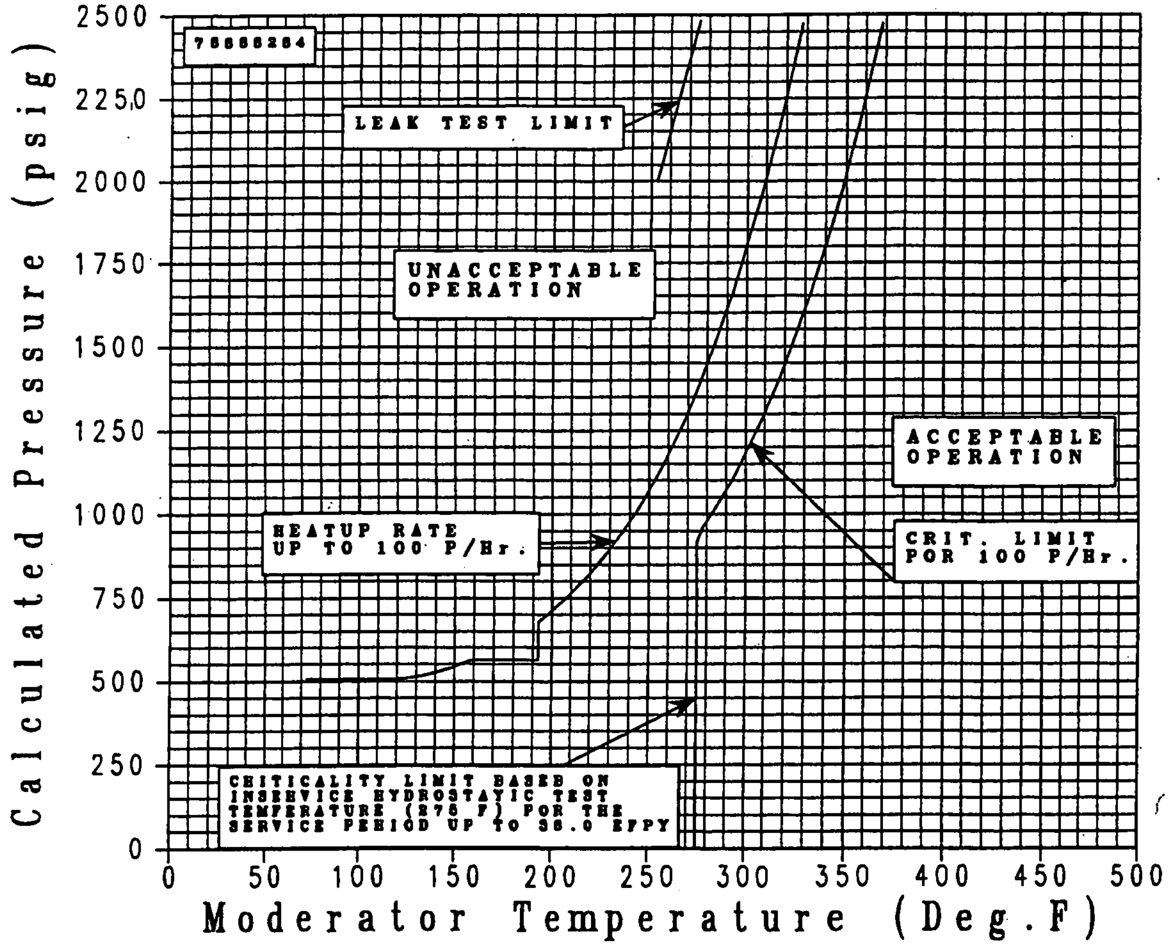

Figure 5-2 Kewaunee Unit 1 Reactor Coolant System Heatup Limitations (Heatup Rate of 100°F/hr) Applicable to 33 EFPY (With Margins for Instrumentation Errors of +13°F and -58 psig)

*NOTE: For Case 3 @ 33 EFPY only, the 100°F/hr criticality initial temperature is 281°F up to pressures equal to 960 psig. In addition, the leak test final temperature is 281°F @ 2485 psig.

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 33 EFPY 1/4 T: 139°F

3/4 T: 131°F

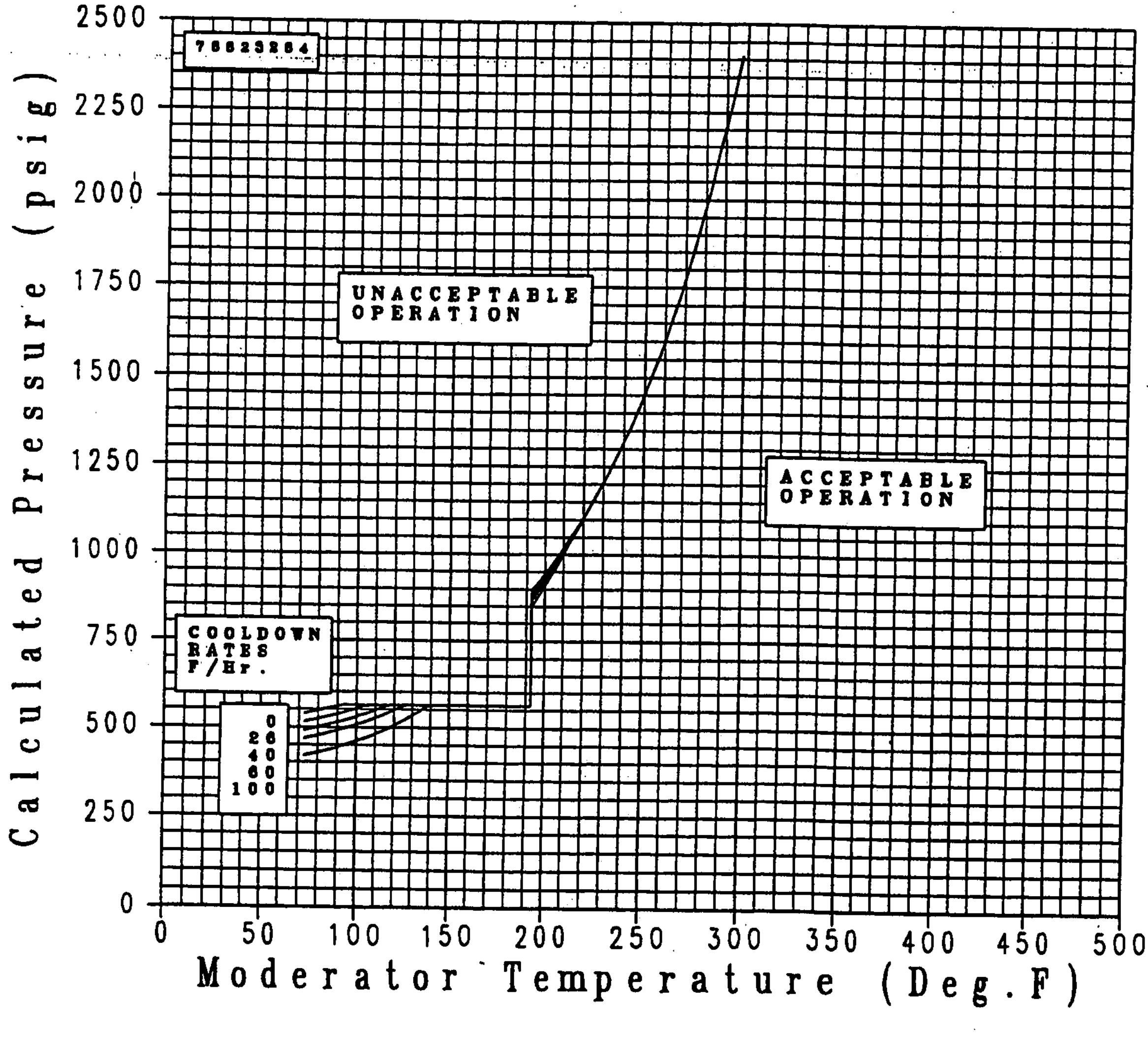

Figure 5-3 Kewaunee Unit 1 Reactor Coolant System Cooldown Limitations (Cooldown Rates up to 100°F/hr) Applicable to 33 EFPY (With Margins for Instrumentation Errors of +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 51 EFPY 1/4 T: 143°F

3/4 T: 136°F

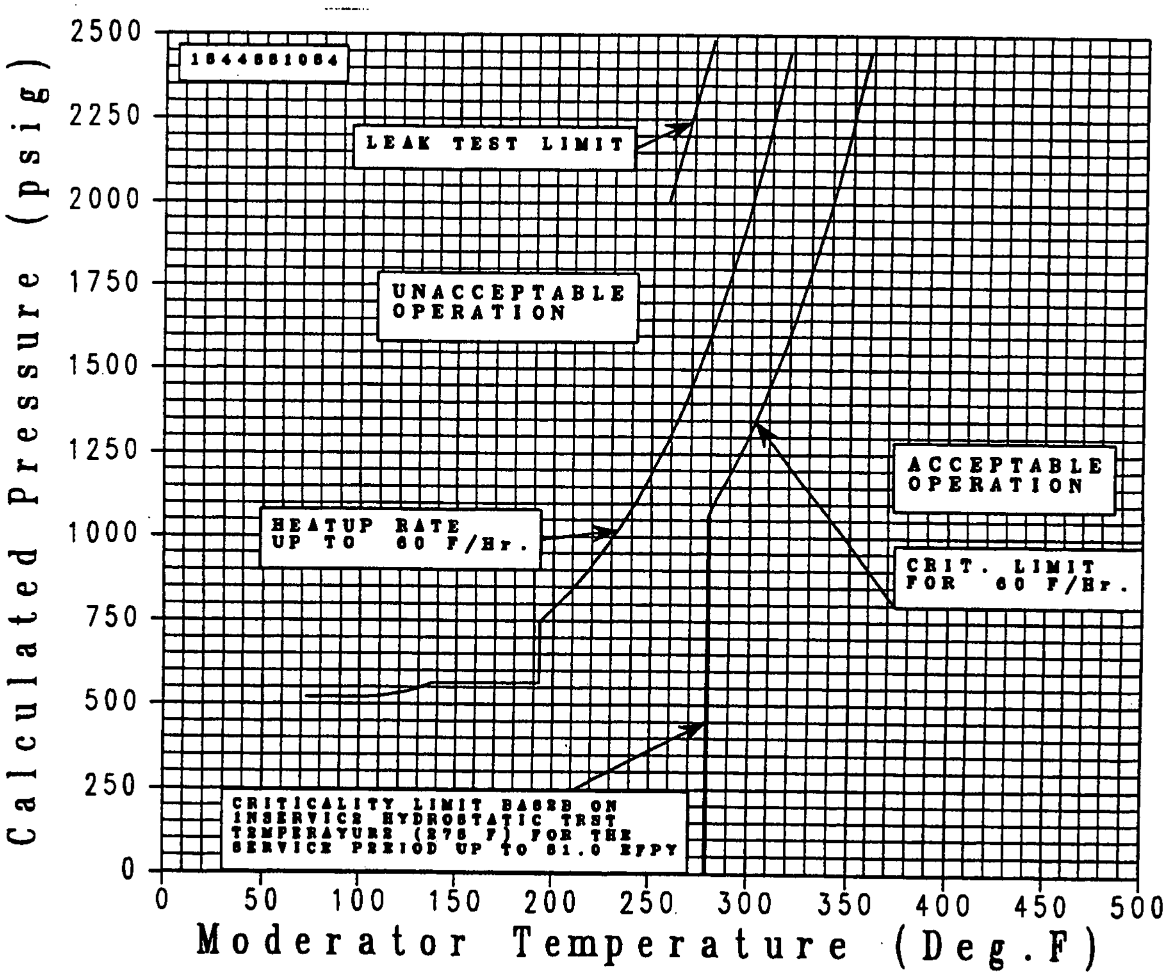

Figure 5-4 Kewaunee Unit 1 Reactor Coolant System Heatup Limitations (Heatup Rate of 60°F/hr) Applicable to 51 EFPY (With Margins for Instrumentation Errors of +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 51 EFPY 1/4 T: 143°F

3/4 T: 136°F

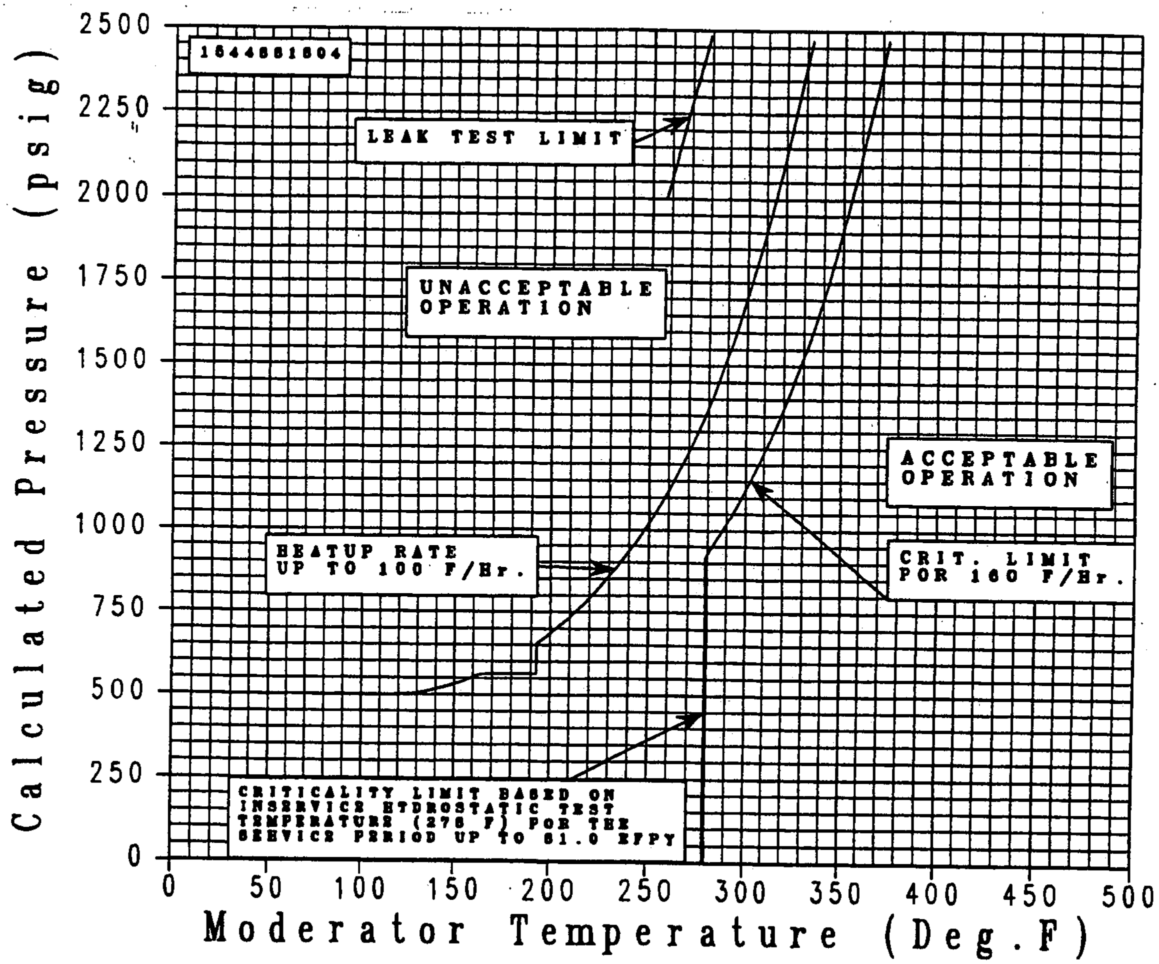

Figure 5-5 Kewaunee Unit 1 Reactor Coolant System Heatup Limitations (Heatup Rate of 100°F/hr) Applicable to 51 EFPY (With Margins for Instrumentation Errors of +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 51 EFPY 1/4 T: 143°F

3/4 T: 136°F

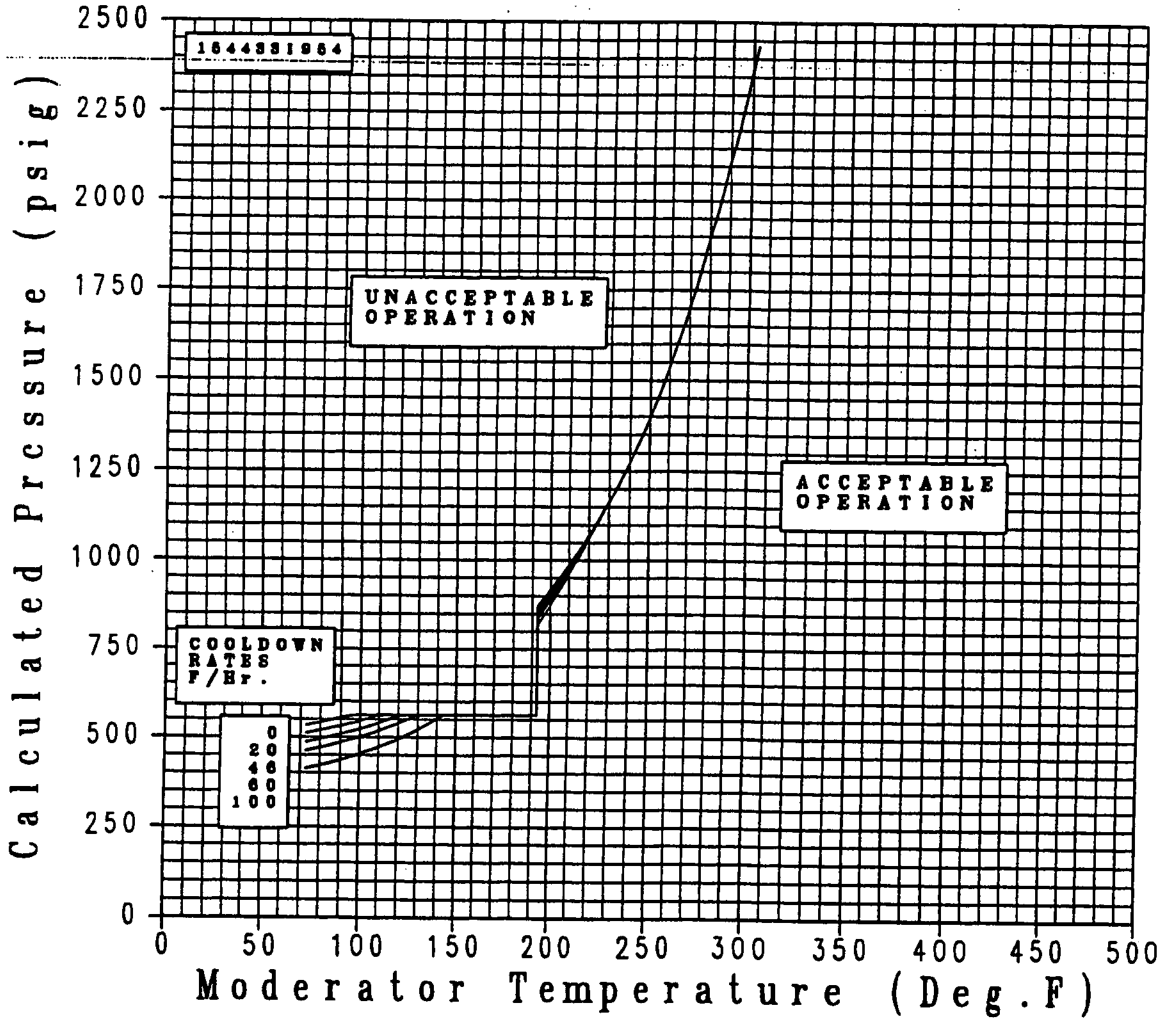

Figure 5-6 Kewaunee Unit 1 Reactor Coolant System Cooldown Limitations (Cooldown Rates up to 100°F/hr) Applicable to 51 EFPY (With Margins for Instrumentation Errors of +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: CIRCUMFERENTIAL WELD AND INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 33 EFPY

INTERMEDIATE SHELL FORGING	1/4 T: 139°F	3/4 T: 131°F
CIRCUMFERENTIAL WELD	1/4 T: 246°F	3/4 T: 200°F

P-T Cooldown Curve for Case 3 @ 33 EFPY

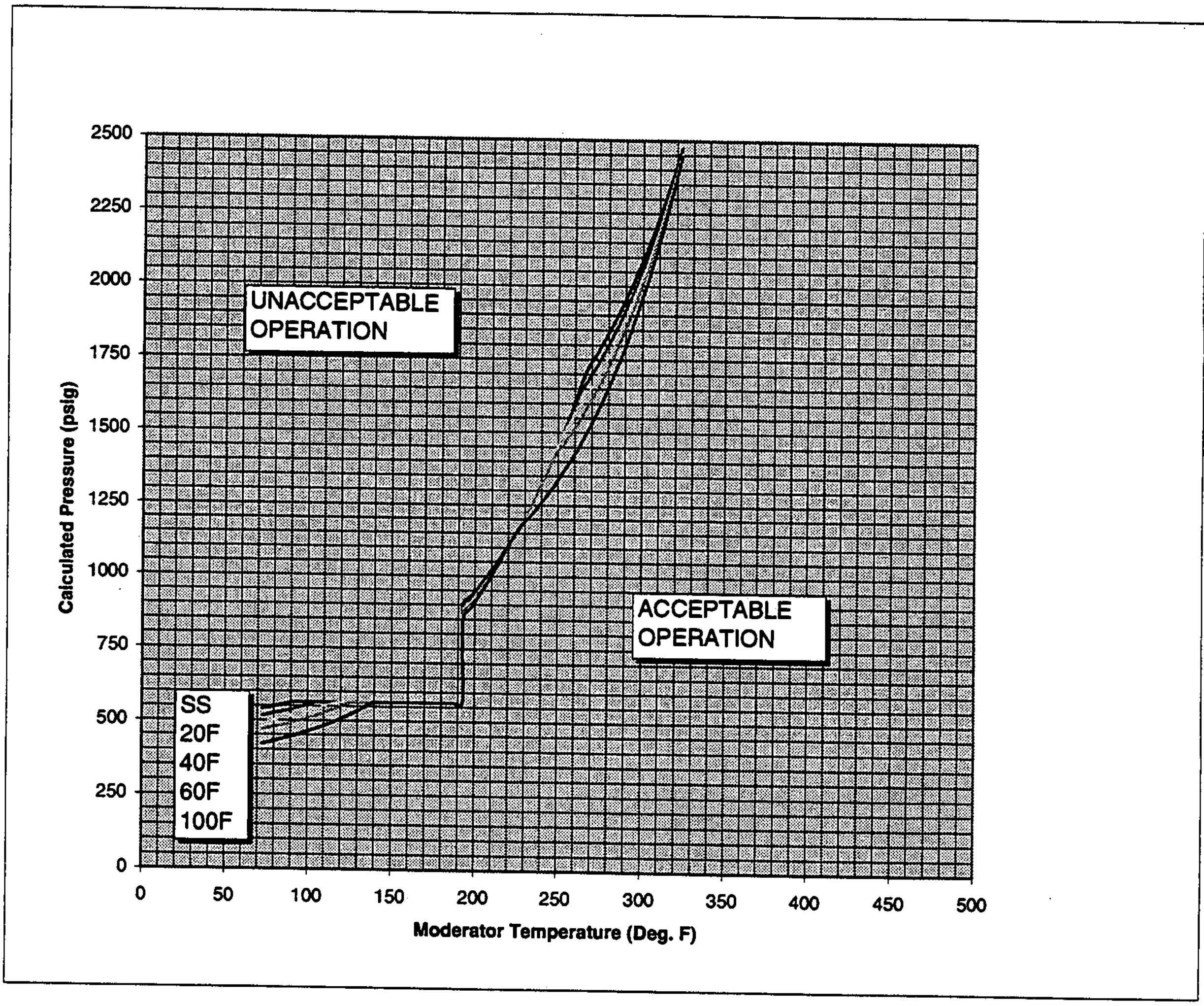

Figure 5-7 Kewaunee Unit 1 Reactor Coolant System Composite Cooldown Limitations (Cooldown Rates up to 100°F/hr) Applicable to 33 EFPY for Case 3 (With Margins for Instrumentation Errors of +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: CIRCUMFERENTIAL WELD AND INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 33 EFPY

INTERMEDIATE SHELL FORGING	1/4 T: 139°F	3/4 T: 131°F
CIRCUMFERENTIAL WELD	1/4 T: 246°F	3/4 T: 200°F

60 Deg./hr. Heatup Curve for Case 3 @ 33 EFPY

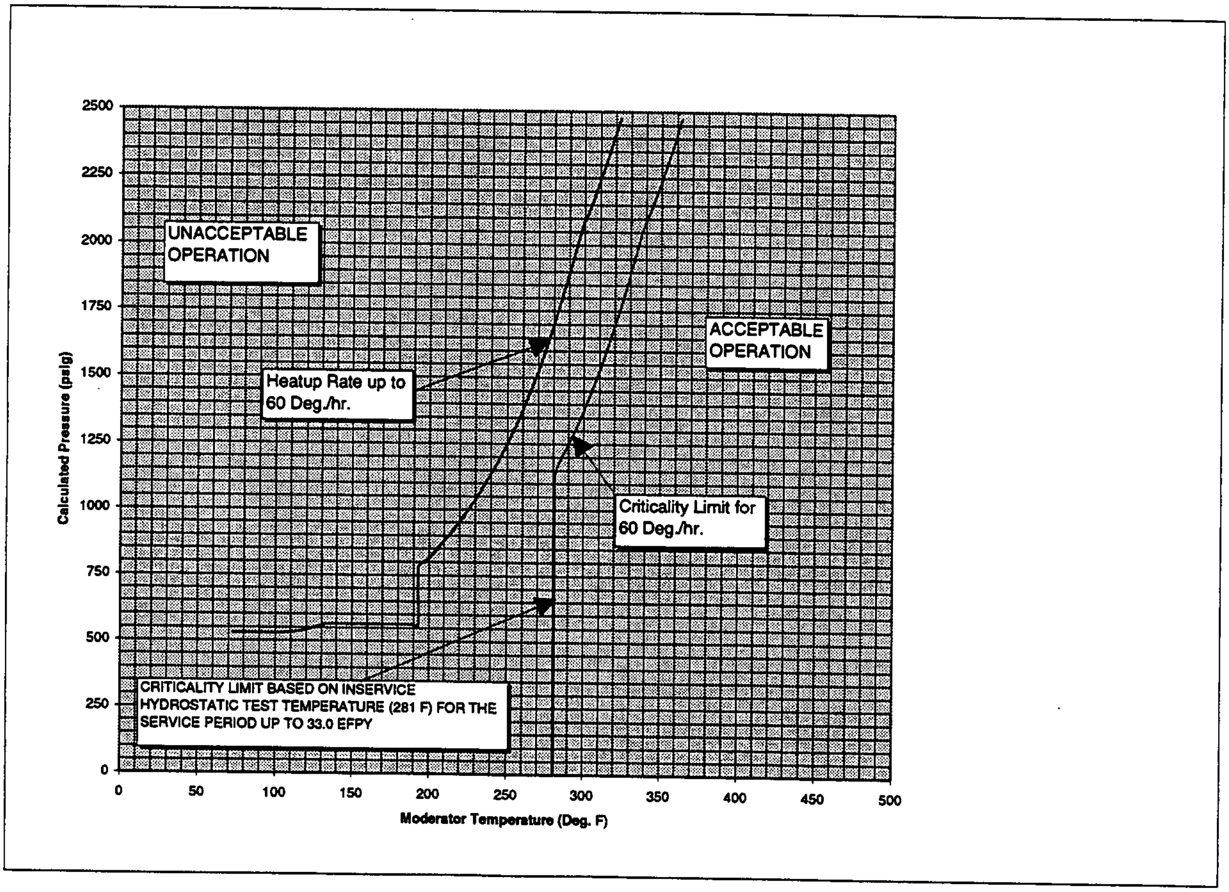

Figure 5-8 Kewaunee Unit 1 Reactor Coolant System Composite Heatup Limitations (Heatup Rate of 60°F/hr) Applicable to 33 EFPY for Case 3 (With Margins for Instrumentation Errors of +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: CIRCUMFERENTIAL WELD AND INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 51 EFPY

INTERMEDIATE SHELL FORGING	1/4 T: 143°F	3/4 T: 136°F
CIRCUMFERENTIAL WELD	1/4 T: 269°F	3/4 T: 225°F

P-T Cooldown for Case 3 @ 51 EFPY

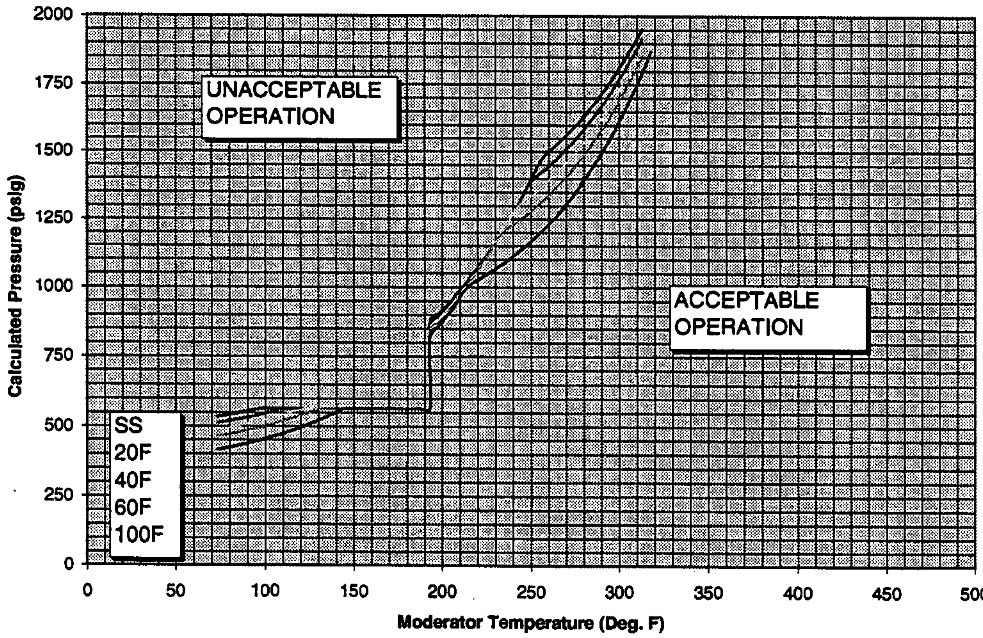

Figure 5-9 Kewaunee Unit 1 Reactor Coolant System Composite Cooldown Limitations (Cooldown Rates up to 100°F/hr) Applicable to 51 EFPY for Case 3 (With Margins for Instrumentation Errors of +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: CIRCUMFERENTIAL WELD AND INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 51 EFPY

INTERMEDIATE SHELL FORGING	1/4 T: 143°F	3/4 T: 136°F
CIRCUMFERENTIAL WELD	1/4 T: 269°F	3/4 T: 225°F

60 Deg./hr. Heatup Curve for Case 3 @ 51 EFPY

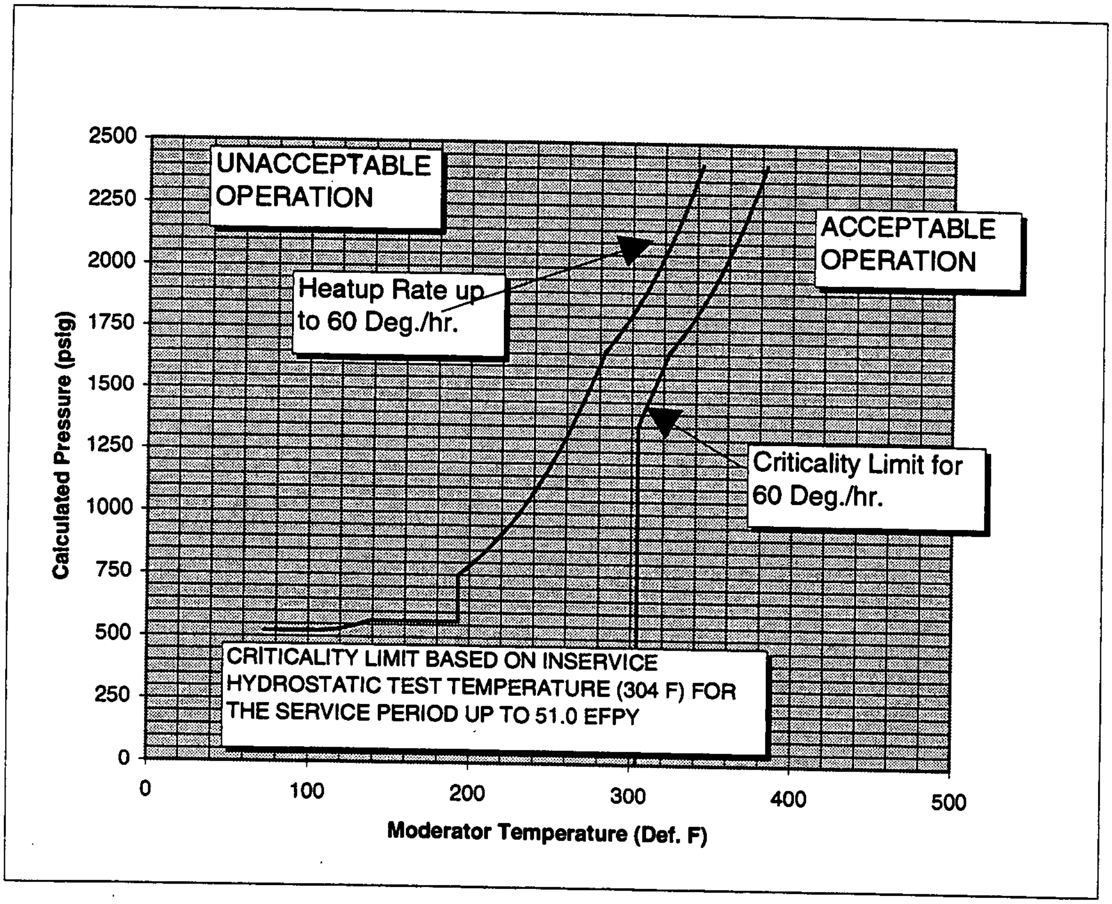

Figure 5-10 Kewaunee Unit 1 Reactor Coolant System Composite Heatup Limitations (Heatup Rate of 60 F/hr) Applicable to 51 EFPY for Case 3 (With Margins for Instrumentation Errors of +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: CIRCUMFERENTIAL WELD AND INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 51 EFPY

INTERMEDIATE SHELL FORGING	1/4 T: 143°F	3/4 T: 136°F
CIRCUMFERENTIAL WELD	1/4 T: 269°F	3/4 T: 225°F

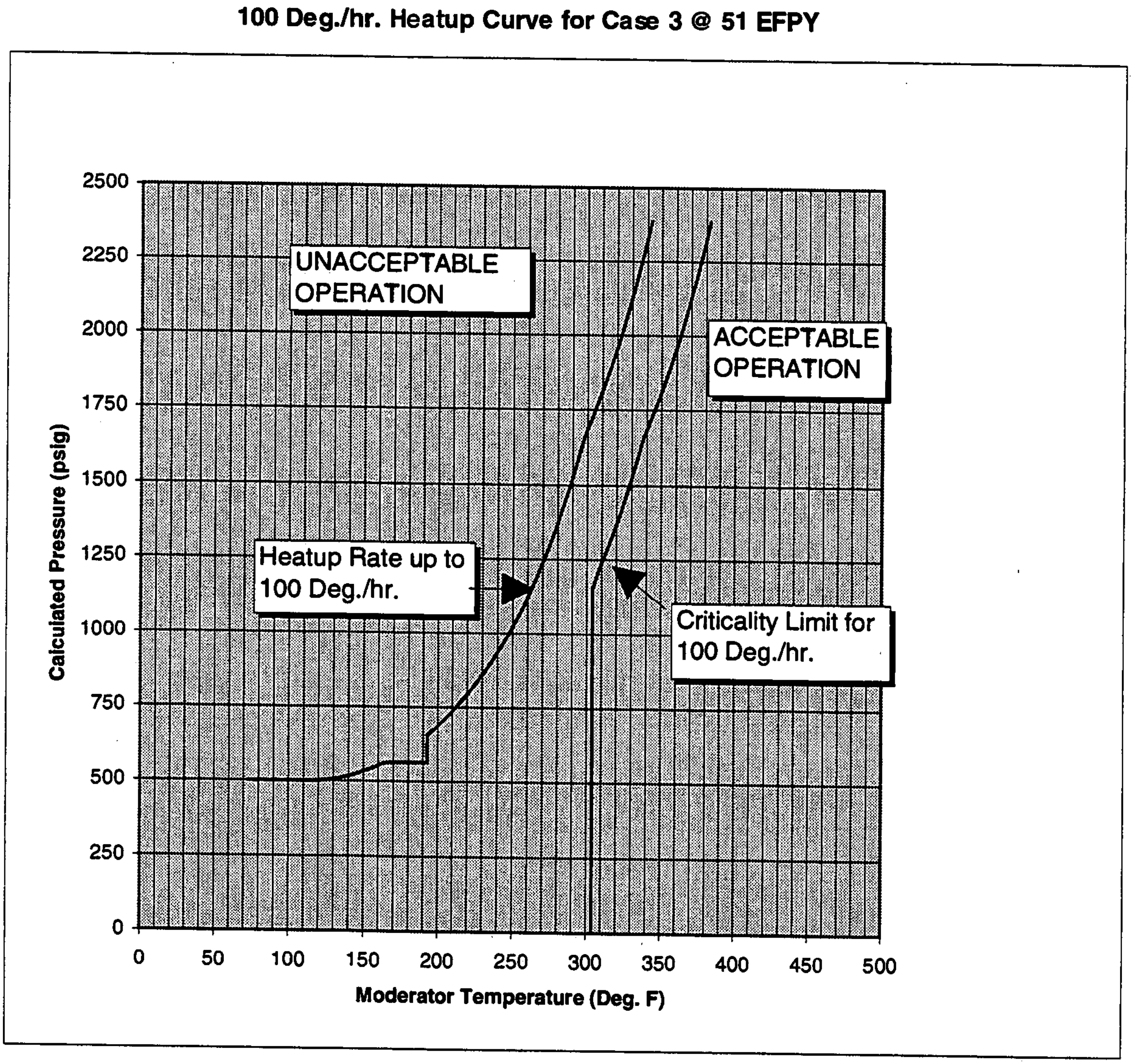

Figure 5-11 Kewaunee Unit 1 Reactor Coolant System Composite Heatup Limitations (Heatup Rate of 100°F/hr) Applicable to 51 EFPY for Case 3 (With Margins for Instrumentation Errors of +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: INTERMEDIATE SHELL FORGING FOR 0, 20, 40°F/hr COOLDOWN RATES, CIRCUMFERENTIAL WELD AND INTERMEDIATE SHELL FORGING FOR 60, 100°F/hr COOLDOWN RATES

LIMITING ART VALUES AT 51 EFPY

INTERMEDIATE SHELL FORGING	1/4 T: 143°F	3/4 T: 136°F
CIRCUMFERENTIAL WELD	1/4 T: 232°F	3/4 T: 194°F

P-T Cooldown Curve for Case 3 w/o Ratio @ 51 EFPY

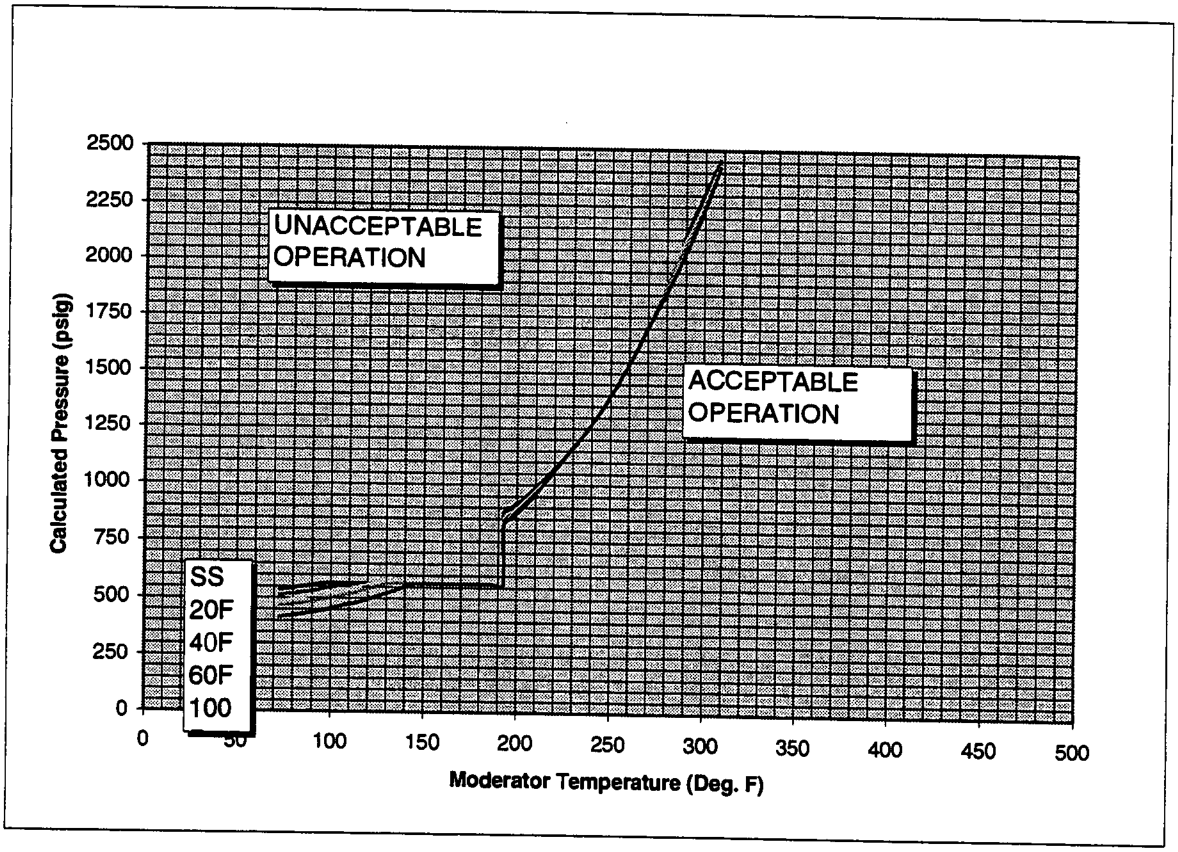

Figure 5-12 Kewaunee Unit 1 Reactor Coolant System Composite Cooldown Limitations (Cooldown Rates up to 100°F/hr) Applicable to 51 EFPY for Case 3-w/o ratio (With Margins for Instrumentation Errors +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: CIRCUMFERENTIAL WELD AND INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 51 EFPY

INTERMEDIATE SHELL FORGING	1/4 T: 143°F	3/4 T: 136°F
CIRCUMFERENTIAL WELD	1/4 T: 244°F	3/4 T: 200°F

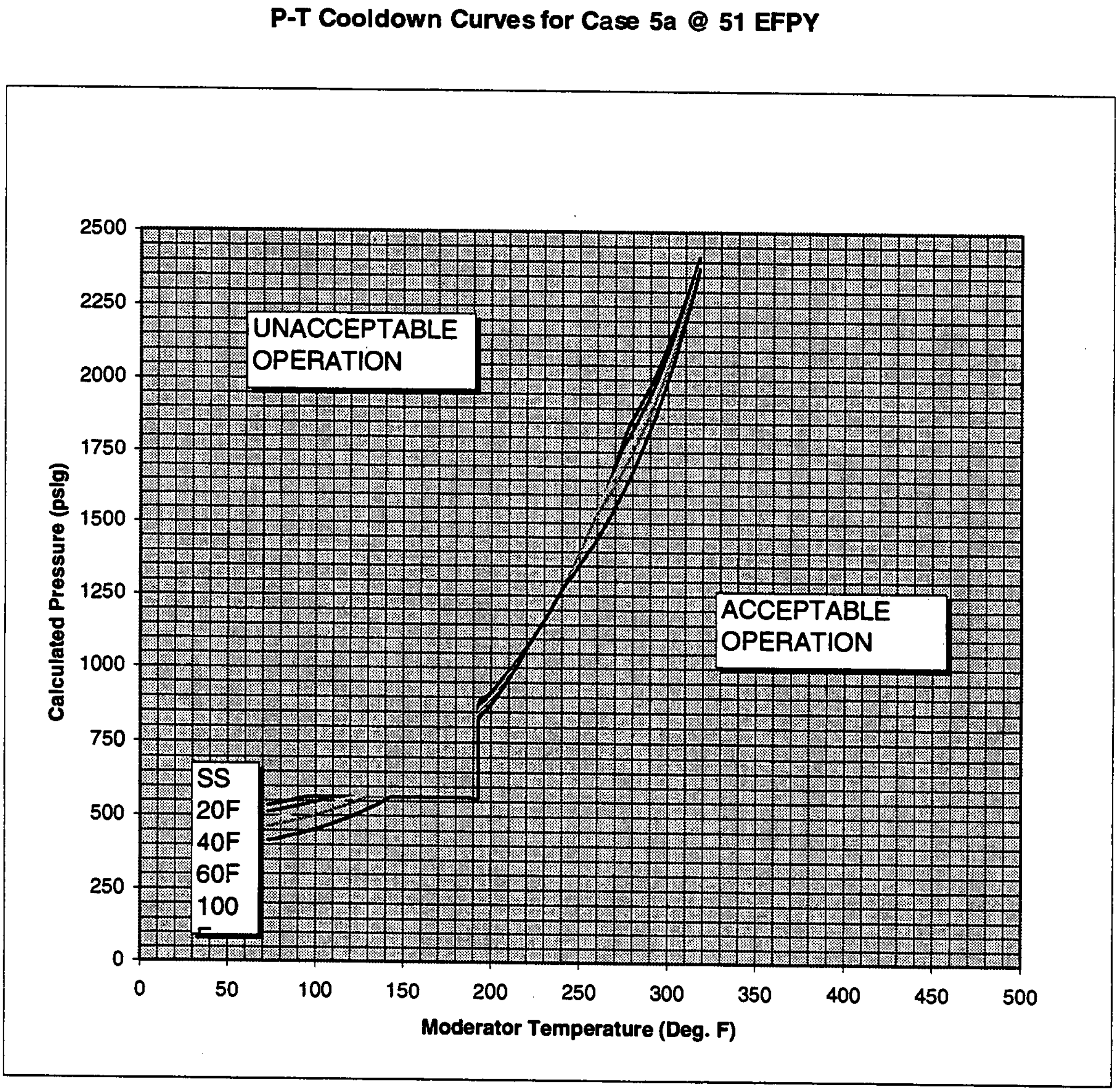

Figure 5-13 Kewaunee Unit 1 Reactor Coolant System Composite Cooldown Limitations (Cooldown Rates up to 100°F/hr) Applicable to 51 EFPY for Case 5a (With Margins for Instrumentation Errors of +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: CIRCUMFERENTIAL WELD AND INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 51 EFPY

INTERMEDIATE SHELL FORGING	1/4 T: 143°F	3/4 T: 136°F
CIRCUMFERENTIAL WELD	1/4 T: 244°F	3/4 T: 200°F

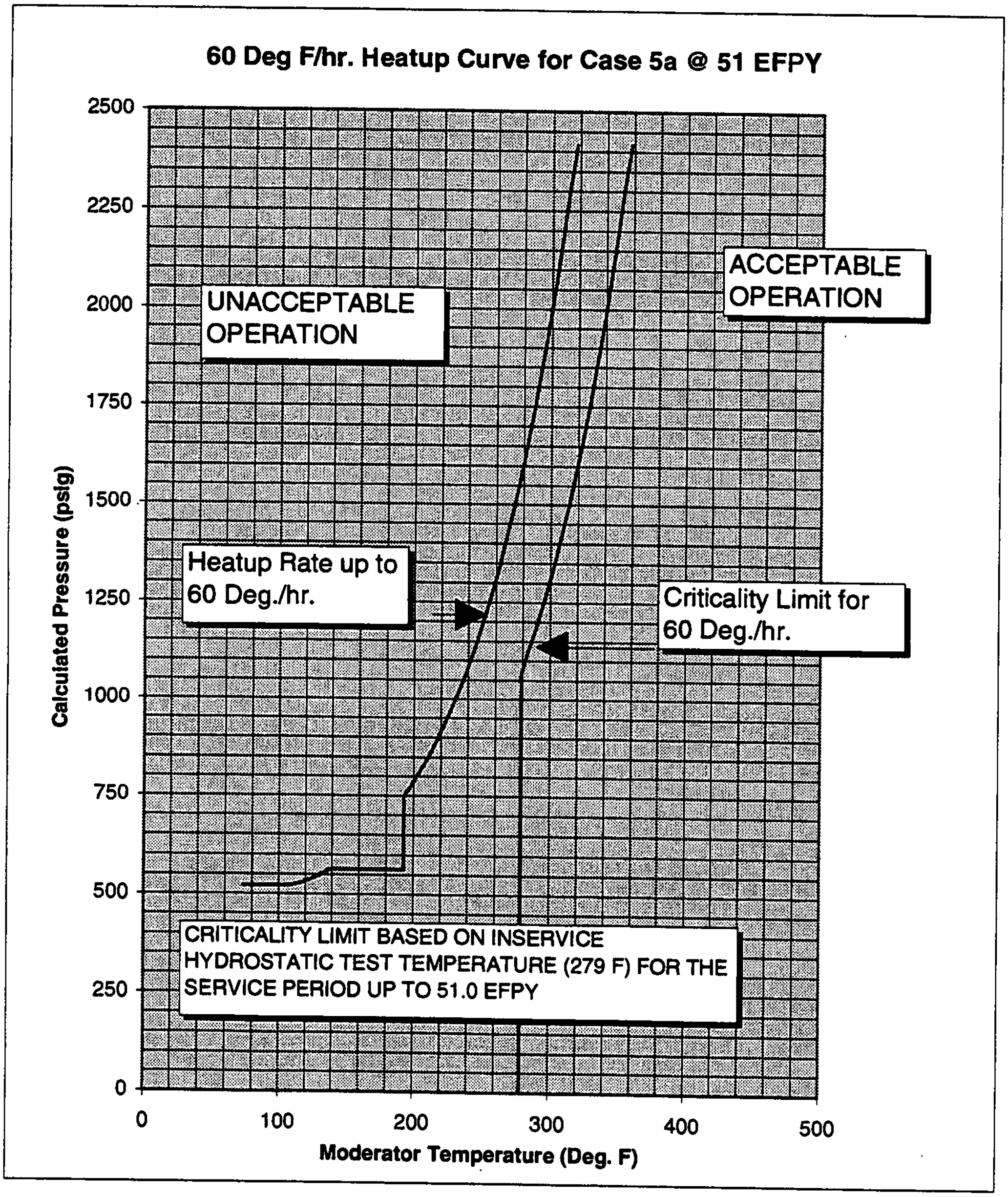

Figure 5-14 Kewaunee Unit 1 Reactor Coolant System Composite Heatup Limitations (Heatup Rate of 60°F/hr) Applicable to 51 EFPY for Case 5a (With Margins for Instrumentation Errors of +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: CIRCUMFERENTIAL WELD AND INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 51 EFPY

INTERMEDIATE SHELL FORGING	1/4 T: 143°F	3/4 T: 136°F
CIRCUMFERENTIAL WELD	1/4 T: 243°F	3/4 T: 194°F

P-T Cooldown Curves for Case 6 @ 51 EFPY

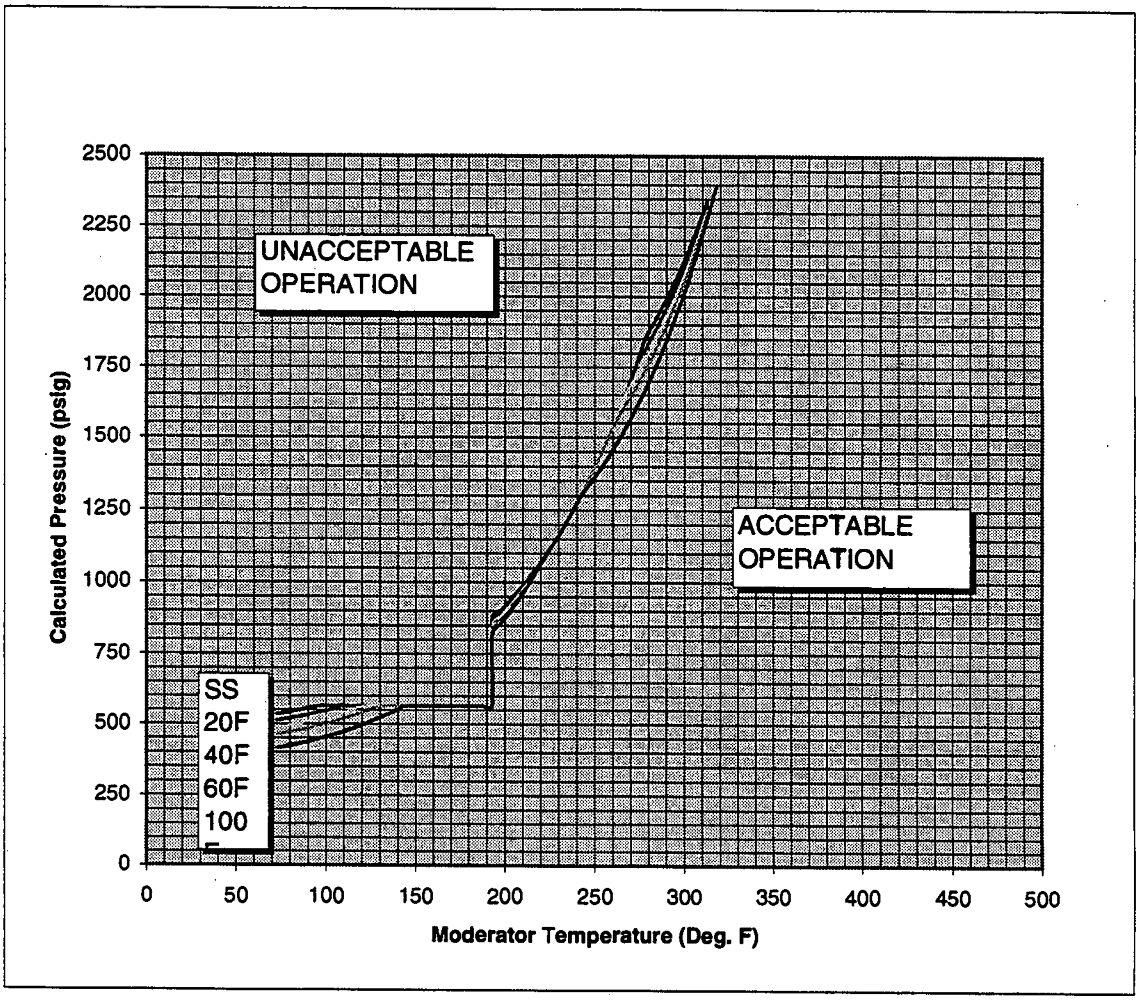

Figure 5-15 Kewaunee Unit 1 Reactor Coolant System Composite Cooldown Limitations (Cooldown Rates up to 100°F/hr) Applicable to 51 EFPY for Case 6 (With Margins for Instrumentation Errors of +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: CIRCUMFERENTIAL WELD AND INTERMEDIATE SHELL FORGING

LIMITING ART VALUES AT 51 EFPY

INTERMEDIATE SHELL FORGING	1/4 T: 143°F	3/4 T: 136°F
CIRCUMFERENTIAL WELD	1/4 T: 244°F	3/4 T: 200°F

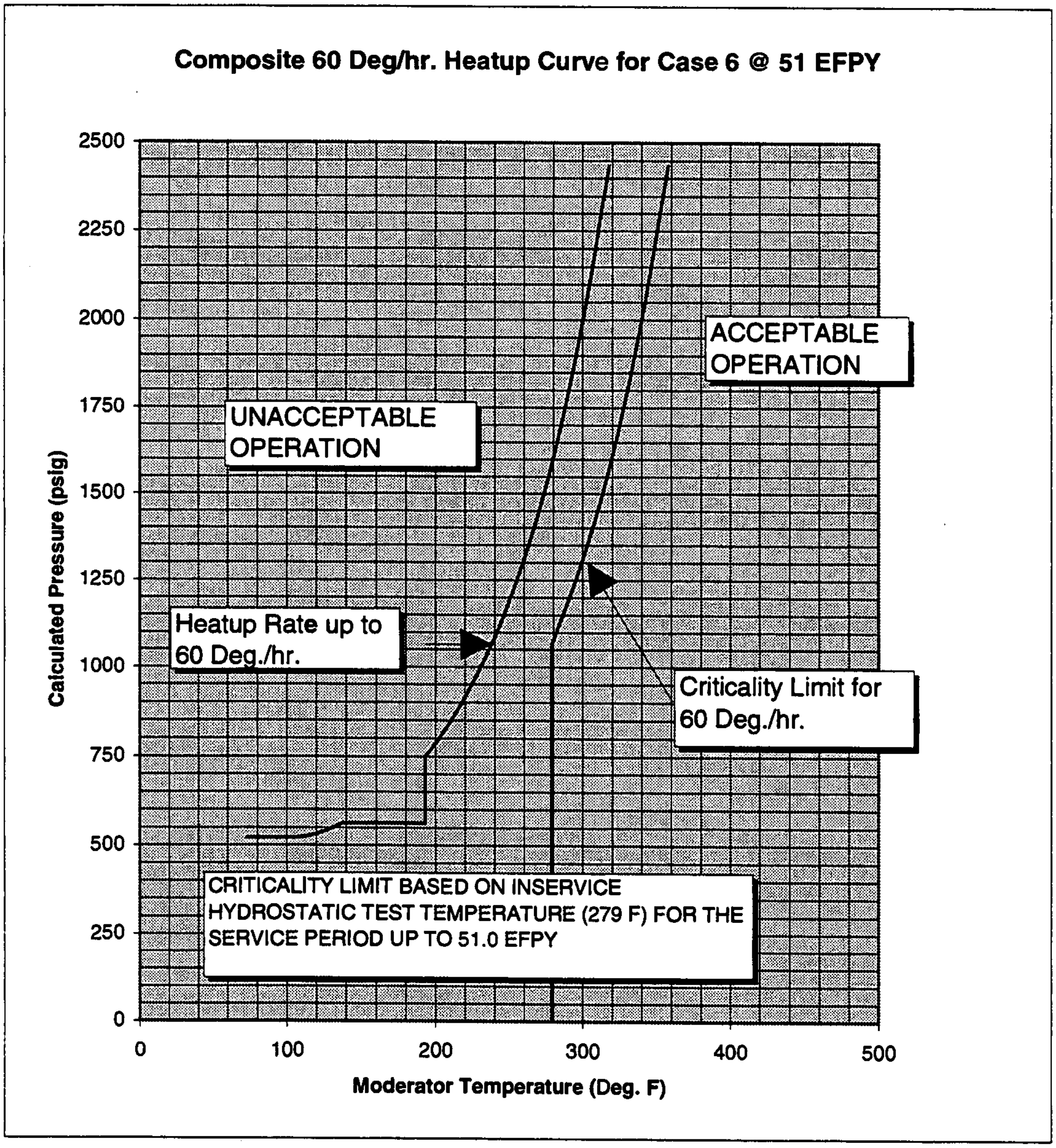

Figure 5-16 Kewaunee Unit 1 Reactor Coolant System Composite Heatup Limitations (Heatup Rate of 60°F/hr) Applicable to 51 EFPY for Case 6 (With Margins for Instrumentation Errors of +13°F and -58 psig)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: CIRCUMFERENTIAL WELD (Linde 1092)

Comparison of 100 Deg./hr Heatup Curves (Using Code Case N-588)

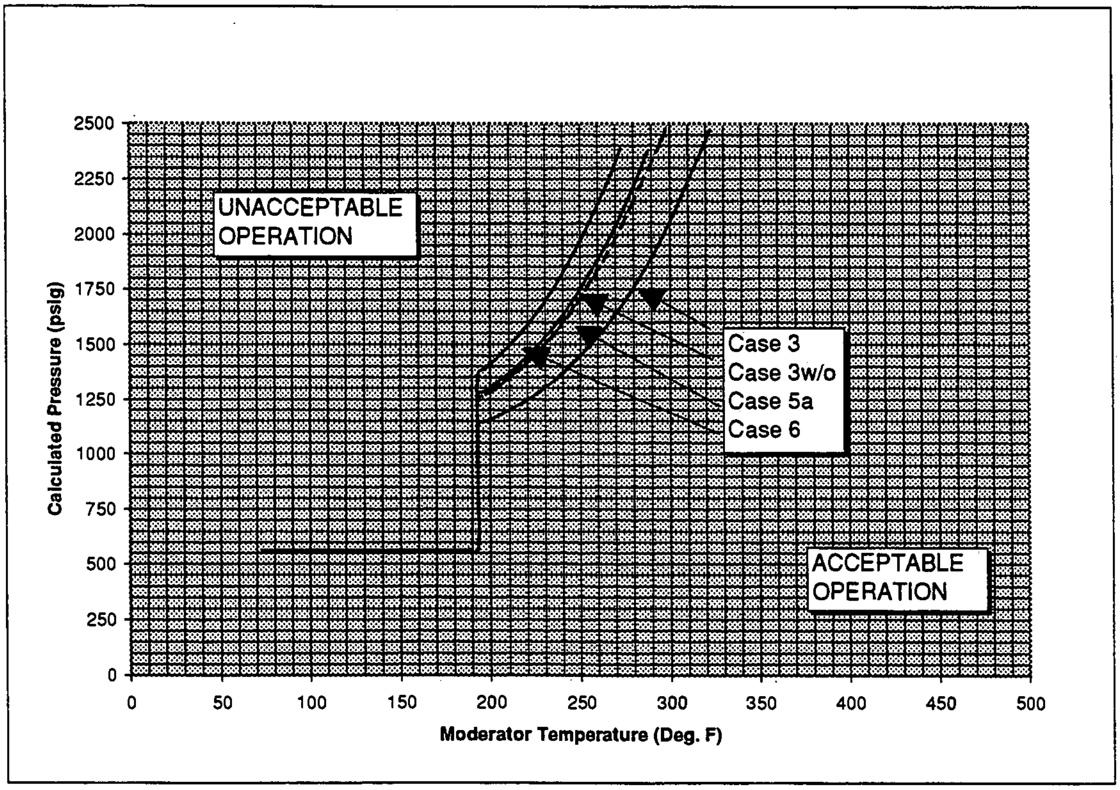

Figure 5-17 Comparison of Kewaunee Unit 1 Reactor Coolant System Heatup Limitations (Heatup Rate of 100°F/hr) Applicable to 33 EFPY for Four (4) Different Cases Using Code Case N-588

6 REFERENCES

1. ASME Boiler and Pressure Vessel Code, Paragraph NB-2300, "Fracture Toughness Requirements for Material."

2. WCAP 15075, "Master Curve Strategies for RPV Assessment," M. Kirk et. al., September 1998.

3. WCAP 15074, "Evaluation of 1P3571 Weld Metal from the Surveillance Programs for Kewaunee and Maine Yankee," W. Server et. al., September 1998.

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

5. Code Case N588, "Alternative to Reference Flaw Orientation of Appendix G for Circumferential Welds in Reactor Vessel," Section XI, Division I, December 12, 1997.

6. WCAP 14279, Rev. 1, "Evaluation of Capsules from the Kewaunee and Capsule A-35 from the Maine Yankee Nuclear Plant Reactor Vessel Radiation Surveillance Programs," C. Kim et. al., September 1988.

7. 10 CFR Part 50, Appendix G, "Fracture Toughness Requirements," Federal Register, Volume 60, No. 243, dated December 19, 1995.

8. "Pressure-Temperature Limits", Branch Technical Position MTEB 5-2, Chapter 5.3.2 in Standard Review Plan for the Safety Analysis Reports for Nuclear Power Plants, LWR Edition, NUREG-0800, 1981.

9. ASME Boiler and Pressure Vessel (B&PV) Code, Section XI, Appendix G, "Fracture Toughness Criteria for Protection Against Failure."

10. G-677164, Rev. 1, "Reactor Coolant System Series "51" Steam Generator Equipment Specification issued on 7-10-69.

11. Calc./Eval. No. C10979, WPSC Kewaunee NPP.

12. WCAP 14278, Rev. 0 "Kewaunee Reactor Vessel HU/CD Limit Curves for Normal Operation," P. Peter, April, 1995.

13. Calculation SAE/FSE-C-WPS-0283, "Kewaunee Pressure Drop between the Core and the Pressure Transmitter for COMS with 0% STGP Level," October 5, 1998.

14. Level Test and Initial Criticality Data Points for Kewaunee P-T Curves, WPS-98-045, issued October 13, 1998 by Westinghouse.

APPENDIX A

Information Requested on RPV Weld and/or Limiting Materials

Table A-1: Kewaunee Limiting Materials

Facility: Kewaunee Nuclear Power Plant

Vessel Manufacturer: Combustion Engineering / B&W Forgings

Information requested on RPV Weld and/or Limiting Materials

RPV Weld Wire Heat [1]	Best-Estimate Copper	Best-Estimate Nickel	EOL ID Fluence ($x 10^{19}$)	Assigned Material Chemistry Factor (CF)	Method of Determining CF [2]	Initial RT_{NDT} ($RT_{NDT(U)}$)	σ_I	σ_Δ	Margin	ART or RT_{PTS} at EOL
1P3571*	0.287	0.756	3.34	219.9	Surveillance Data	-50°F	0°F	14°F	28°F	267°F
Int. Shell Forging** 122K208VA1	0.06	0.71	3.34	37	Tables	60°F	0°F	17°F	34°F	143°F

(1) Or the material identification of the limiting material as requested in Section 1.0 (Request 1).
(2) Determined from tables or from surveillance data.
* Limiting material for PTS and for some portions of the P-T curves (see Case 3 in this report).
** Limiting material for majority of the P-T curves.

Discussion of the Analysis Method and Data Used for Each Weld Wire Heat

Weld Wire Heat	Discussion
1P3571	Credible Surveillance Data adjusted using the ratio approach in Regulatory Guide 1.99, Revision 2

Table A-2: Kewaunee Heat 1P3571 Surveillance Data

Capsule ID (including source)	Cu	Ni	Irradiation Temperature (°F)	Fluence ($x10^{19}$ n/cm^2)	Measured ΔRT_{NDT} (°F)	Data Used in Assessing Vessel (Y or N)
V (WCAP-8908)	0.219	0.724	532	0.597	175	Y
R (WCAP-9878)	0.219	0.724	532	1.81	235	Y
P (WCAP-8908)	0.219	0.724	532	2.74	230	Y
S (WCAP-14279, Revision 1)	0.219	0.724	532	3.36	250	Y

Table A-3: Kewaunee Weld Heat 1P3571 Surveillance Data Assessment

Capsule ID (including source)	Cu	Ni	Irradiation Temperature (°F)	Fluence Factor	Measured ΔRT_{NDT} (°F)	Adjusted ΔRT_{NDT} (°F)	Predicted ΔRT_{NDT} (°F)	(Adjusted-Predicted) ΔRT_{NDT} (°F)
V (WCAP-8908)	0.219	0.724	532	0.856	175	200	188	12
R (WCAP-9878)	0.219	0.724	532	1.163	235	269	256	13
P (WCAP-8908)	0.219	0.724	532	1.269	230	263	279	-16
S (WCAP-14279, Revision 1)	0.219	0.724	532	1.317	250	286	290	-4