Attachment 4 to AEP:NRC:2349-03

WCAP-15878, REVISION 0,
"D. C. COOK UNIT 1 HEATUP AND COOLDOWN LIMIT CURVES FOR NORMAL OPERATION FOR 40 YEARS AND FOR 60 YEARS,"
DATED DECEMBER 2002

Westinghouse Non-Proprietary Class 3

WCAP-15878
Revision 0

December 2002

D. C. Cook Unit 1
Heatup and Cooldown Limit Curves For Normal Operation For 40 Years And 60 Years

Westinghouse

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-15878, Revision 0

D.C. Cook Unit 1
Heatup and Cooldown Limit Curves
For Normal Operation For 40 Years and 60 Years

Justin H. Ledger

December 2002

Prepared by the Westinghouse Electric Company LLC
for the American Electric Power Company

Approved: _____
J. A. Gresham, Manager
Equipment & Materials Technology

WESTINGHOUSE ELECTRIC COMPANY LLC
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355

PREFACE

This report has been technically reviewed and verified by:

T. J. Laubham _____

This report covers the Heatup and Cooldown Curves based upon the uprate, 40 and 60 years of operation and methodology per WCAP-14040, Rev 2-A.

TABLE OF CONTENTS

TABLE OF CONTENTS - (Continued)

LIST OF TABLES

LIST OF TABLES - (Continued)

LIST OF FIGURES

1.0 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.

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[6], "Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves' with exception of the following: 1) The fluence values used in this report are calculated fluence values (i.e. comply with Reg. Guide 1.190), not the best estimate fluence values. 2) 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-641[9] (which covers Code Case N-640[8] and N-588[10]). 3) The 1996 Version of Appendix G to Section XI[3] will be used rather than the 1989 version.

2.0 PURPOSE

D.C. Cook Unit 1 has contracted Westinghouse to generate new heatup and cooldown curves for the current end of license and life extension based upon the power uprate. The D.C. Cook Unit 1 heatup and cooldown curves were generated without 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[2].

The purpose of this report is to present the calculations and the development of D.C. Cook Unit 1 heatup and cooldown curves for the current end of license and license renewal. 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.

3.0 CRITERIA FOR ALLOWABLE PRESSURE-TEMPERATURE RELATIONSHIPS

3.1 Overall Approach

Appendix G to 10 CFR Part 50, "Fracture Toughness Requirements"[2] 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, "Rule for Inservice Inspection of Nuclear Power Plant Components", Appendix G[3], contains the conservative methods of analysis.

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-641 of Appendix G of the ASME Code, Section XI. The K_{Ic} curve is given by the following equation:

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

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 K_I values measured as a function of temperature on specimens of SA-533 Grade B Class 1, SA-508-1, SA-508-2, and SA-508-3 steels.

3.2 Methodology for Pressure-Temperature Limit Curve Development

The governing equation for the heatup-cooldown analysis is defined in Code Case N-640 of 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 K_I corresponding to membrane tension for the postulated defect is:

$$K_{Im} = M_m * (pR_i \div t) \quad (3)$$

Where M_m for an inside surface is given by:

$M_m = 1.85$ for $\sqrt{t} < 2$,

$M_m = 0.926\sqrt{t}$ for $2 \leq \sqrt{t} \leq 3.464$, and

$M_m = 3.21$ 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 $2 \leq \sqrt{t} \leq 3.464$, and

$M_m = 3.09$ for $\sqrt{t} > 3.464$.

Where:

Ri = vessel inner radius,

t = vessel wall thickness, and

p = internal pressure,

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

$K_{Ib} = M_b$ * maximum bending stress, where M_b is two-thirds of M_m

For the Radial Thermal Gradient, the maximum K_I produced by radial thermal gradient for the postulated inside surface defect is:

$$K_{It} = 0.953 \times 10^{-3} \times CR \times t^{2.5} \quad (4)$$

where:

CR = the cooldown rate in °F/hr.

For the Radial Thermal Gradient, the maximum K_I produced by radial thermal gradient for the postulated outside surface defect is:

$$K_{It} = 0.753 \times 10^{-3} \times HU \times t^{2.5} \quad (5)$$

where:

HU = the heatup rate in °F/hr.

The through-wall temperature difference associated with the maximum thermal K_I can be determined from ASME Section XI, Appendix G, Figure G-2214-1. The temperature at any radial distance from the vessel surface can be determined from ASME Section XI, Appendix G, Figure 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) of Appendix G to ASME Section XI.

(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:

$$K_{It} = (1.0359C_0 + 0.6322C_1 + 0.4753C_2 + 0.3855C_3) * \sqrt{\pi a} \quad (6)$$

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

$$K_{It} = (1.043C_0 + 0.630C_1 + 0.481C_2 + 0.401C_3) * \sqrt{\pi a} \quad (7)$$

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:

$$\sigma(x) = C_0 + C_1(x/a) + C_2(x/a)^2 + C_3(x/a)^3 \quad (8)$$

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

Note, that equations 3 through 8 were added to the OPERLIM computer program, which is the Westinghouse computer program used to generate pressure-temperature limit curves. No other changes were made to the OPERLIM computer program with regard to the pressure-temperature curve calculation methodology. Hence, the pressure-temperature curve methodology described in WCAP-14040[6] Section 2.6 (equations 2.6.2-4 and 2.6.3-1) remains valid for the generation of the pressure-temperature curves documented in this report with the exceptions 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 ¼T and ¾T 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 ¼T 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 ¼T 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 ¼T 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 ¼T 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 ¼T crack during heatup is lower than the K_{IC} for the ¼T 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 ¼T 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 ¼T flaw located at the ¼T 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.

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[2] of the pre-service hydrostatic test pressure (3106 psig), which is 621 psig for the D.C. Cook Unit 1 reactor vessel.

The limiting unirradiated RT_{NDT} of 60°F occurs in the closure head flange of the D.C. Cook Unit 1 reactor vessel, so the minimum allowable temperature of this region is 180°F at pressure greater than 621 psig without uncertainties. This limit is reflected in the heatup and cooldown curves shown in Figures 9-1 through 9-4.

4.0 CHEMISTRY FACTOR DETERMINATION

4.1 Chemistry Factor Methodology:

The calculations of chemistry factor (CF) values for the D.C. Cook Unit 1 reactor vessel beltline materials are performed in accordance with Regulatory Guide 1.99, Revision 2 as follows:

The CF is based on the Cu and Ni weight % of the material or it is based on the results of surveillance capsule test data. When the weight percent of copper and nickel is used to determine the CF, the CF is obtained from either Table 1 or Table 2 of Regulatory Guide 1.99, Revision 2. The results of this method are given in Table 4-1.

When surveillance capsule data is used to determine the CF, the CF is determined as follows:

$$CF = \frac{\sum_{i=1}^{n} [A_i x f_i^{(0.28-0.1 \log f_i)}]}{\sum_{i=1}^{n} [f_i^{(0.28-0.1 \log f_i)}]^2} \qquad (9)$$

Where:	n	=	The Number of Surveillance Data Points
	A_i	=	The Measured Value of ΔRT_{NDT}
	f_i	=	Fluence for each Surveillance Data Point

When the surveillance weld copper and nickel content differs from that of the vessel weld, the measured values of ΔRT_{NDT} are adjusted by multiplying them by the ratio of the chemistry factor for the vessel weld to that for the surveillance weld based on the copper and nickel content of the materials. The Ratio Procedure is documented in Regulatory Guide 1.99 Revision 2 Position 2.1.

4.1.1 Application of the Ratio Procedure

The D. C. Cook Unit 1 Surveillance Weld was fabricated from weld heat 13253, while the lower shell axial welds included heats 13253/12008. Thus, the D. C. Cook Unit 1 surveillance weld data was not used for the determination of D. C. Cook Unit 1 pressure-temperature Curves.

However, surveillance weld data does exist for weld heat 1P3571 from Kewaunee and Maine Yankee. This is the same heat as the intermediate to lower shell circumferential weld for D. C. Cook Unit 1. Despite the fact the welds are of the same heat, the weight percent copper and nickel of the surveillance weld metal differs slightly versus the overall best estimate chemistry for the vessel weld metal (per D. C. Cook Design Information Transmittal, DIT-B-02230-00[7]). As reported in Table 4-1, the chemistry factor of the Kewaunee/Maine Yankee surveillance Weld is 211.9°F, while the vessel weld chemistry is 214.0°F. This produces a ratio of 1.01. Therefore a ratio of 1.01 was applied to the chemistry factor determined using Kewaunee and Maine Yankee surveillance data.

4.1.2 Temperature Effects on Surveillance Data:

Studies have shown that for temperatures near 550°F, a 1°F decrease in irradiation temperature will result in approximately 1°F increase in ΔRT_{NDT}. Thus, for plants that use surveillance data from other reactor vessels that operate at a different temperature or when the capsule is at a different temperature than the plant, then this difference must be considered.

The temperature adjustment is as follows:

Temp. Adjusted $\Delta RT_{NDT} = \Delta RT_{NDT}$ Measured + $(T_{capsule} - T_{plant})$

As noted above, the D. C. Cook Unit 1 surveillance weld data will not be used since the heat differs from the vessel weld. Thus, for surveillance weld heat 13253, no temperature adjustments are necessary. However, for vessel girth weld of heat 1P3571 surveillance data exists of the same heat from Kewaunee and Maine Yankee. Per DIT-B-02230-00[7] the operating temperature differences were considered in determining the chemistry factor using the Kewaunee and Maine Yankee surveillance weld data.

Following in Table 4-1 are best estimate chemistry values for all the beltline materials, including the surveillance capsule weld along with the chemistry factors (CF) as determined per Regulatory Guide 1.99, Revision 2, Position 1 or 2

TABLE 4-1			
Reactor Vessel Beltline Material Copper and Nickel Content and Calculated CF			
Material Description	wt. % Cu[(a)]	wt. % Ni[(a)]	CF
Intermediate Shell Plate B4406-1	0.12	0.52	81.4
Intermediate Shell Plate B4406-2	0.15	0.50	104.5[(d)]
Intermediate Shell Plate B4406-3	0.15	0.49	104[(d)]
Lower Shell Plate B4407-1	0.14	0.55	97.8
Lower Shell Plate B4407-2	0.12	0.59	82.8
Lower Shell Plate B4407-3	0.14	0.50	95.5
Intermediate Shell Axial Welds (Heat 13253/12008)	0.21	0.873	208.7
Lower Shell Axial Welds (Heat 13253/12008)	0.21	0.873	208.7
Intermediate to Lower Shell Circ. weld Seams (Heat 1P3571)	0.287	0.756	214[(c)]
Surveillance Weld Metal (Heat 13253)	0.27	0.74	206.4
Surveillance Weld Metal (Heat 1P3571)[(b)]	0.285	0.748	211.9

NOTES:

(a) These values were determined by ATI and Transmitted to Westinghouse via DIT-B-02230-00[7].

(b) From Kewaunee and Maine Yankee (Reference DIT-B-02230-00[7]).

(c) The Chemistry Factor using Regulatory Guide 1.99, Rev. 2 Position 2.1 was determined to be 218.6°F per DIT-B-02230-00[7].

(d) The Chemistry Factor using Regulatory Guide 1.99, Rev. 2 Position 2.1 was determined to be 102.3.

Table 4-2 provides the calculation of the CF values for the surveillance materials per Regulatory Guide 1.99, Revision 2, Position 2.1.

TABLE 4-2

Calculation of Chemistry Factors using D.C. Cook Unit 1 Surveillance Capsule Data

Material	Capsule	Fluence[a b]	FF	ΔRT_{NDT}[b]	$FF * \Delta RT_{NDT}$	FF^2
Inter. Shell Plate B4406-3 (Longitudinal)	T	0 267	0 641	60	38 460	0.411
	X	0 831	0.948	90	85.320	0 899
	Y	1.195	1.049	105	110.145	1.100
	U	1.837	1.167	115	134.205	1.362
Inter. Shell Plate B4406-3 (Transverse)	T	0.267	0.641	70	44 870	0 411
	X	0 831	0 948	110	104 280	0.899
	Y	1.195	1.049	115	120 635	1.100
	U	1 837	1.167	115	134.205	1.362
				SUM:	772.120	7.544
	$CF = \Sigma(FF * RT_{NDT}) + \Sigma(FF^2) = (772.120) + (7.544) = \mathbf{102.3°F}$					

(a) Calculated Fluence values are in units of n/cm^2, $E > 1.0$ MeV.

(b) Data obtained from WCAP-12483 Rev. 1[4], revised Capsule U Analysis.

4.2 Surveillance Program Credibility Evaluation:

Regulatory Guide 1.99, Revision 2, describes general procedures acceptable to the NRC staff for calculating the effects of neutron radiation embrittlement of the low-alloy steels currently used for light-water-cooled reactor vessels. Position C.2 of Regulatory Guide 1.99, Revision 2, describes the method for calculating the adjusted reference temperature and Charpy upper-shelf energy of reactor vessel beltline materials using surveillance capsule data. The methods of Position C.2 can only be applied when two or more credible surveillance data sets become available from the reactor in question.

To date there have been four surveillance capsules removed from D. C. Cook Unit 1. To use these surveillance data sets, they must be shown to be credible. In accordance with Regulatory Guide 1.99, Revision 2, there are five requirements that must be met for the surveillance data to be judged credible. The purpose of this evaluation is to apply these credibility requirements to the reactor vessel surveillance data obtained from D. C. Cook Unit 1 and determine if these surveillance data sets are credible.

EVALUATION

Criterion 1: Materials in the capsules should be those judged most likely to be controlling with regard to radiation embrittlement. The beltline region of the reactor vessel is defined in Appendix G to 10 CFR Part 50, "Fracture Toughness Requirements", December 19, 1995 to be:

"the reactor vessel (shell material including welds, heat affected zones, and plates or forgings) that directly surrounds the effective height of the active core and adjacent regions of the reactor vessel that are predicted to experience sufficient neutron radiation damage to be considered in the selection of the most limiting material with regard to radiation damage."

The D. C. Cook Unit 1 reactor vessel consists of the following beltline region materials:

- Intermediate shell plates: B4406-1, B4406-2, and B4406-3,
- Lower shell plates: B4407-1, B4407-2, and B4407-3,
- Intermediate shell axial welds: 2-442A, 2-442B, and 2-442C, heat 13253/12008 Linde 1092, Flux Lot 3791,
- Lower shell axial welds 3-442A, 3-442B, and 3-442C, heat 13253/12008, Linde 1092, Flux Lot 3791 and
- Intermediate to lower shell circumferential weld seam 9-442, heat 1P3571 Linde 1092, Flux Lot 3958.

Per WCAP-12483[4] the D. C. Cook Unit 1 surveillance program was based on ASTM E185-70, "Recommended Practice for Surveillance Tests on Structural Materials in Nuclear Reactors". Following is the evaluation of the selection of the D. C. Cook Unit 1 surveillance materials.

Weld metal:

The D. C. Cook Unit 1surveillance weld was fabricated with weld wire heat #13253. Since the Intermediate and Lower Shell longitudinal welds were fabricated with a tandem heat weld wire (13253/12008), the surveillance weld data from D. C. Cook Unit 1 is not applicable. No further credibility evaluations will be performed on heat 13253. It should be noted here, that surveillance data for weld heat 1P3571 is available from Kewuanee / Maine Yankee. Per DIT-B-02230-00[7] this data has been determined to be credible for use at D. C. Cook Unit 1.

Plates:

Intermediate Shell Plate B4406-2 and B4406-3 had the highest Cu content (0.15%) and the highest initial RT_{NDT} values; therefore they were selected as the surveillance program base metal.

Therefore, the materials selected for use in the D. C. Cook Unit 1 surveillance program were those judged to be most likely controlling with regard to radiation embrittlement according to the accepted methodology at the time the surveillance program was developed. Based on engineering judgement the D. C. Cook Unit 1 surveillance program meets the intent of this criteria.

Criterion 2: Scatter in the plots of Charpy energy versus temperature for the irradiated and unirradiated conditions should be small enough to permit the determination of the 30 ft-lb temperature and upper shelf energy unambiguously.

Plots of Charpy energy versus temperature for the unirradiated condition are presented in References 11, 12 and 13. Based on engineering judgement, the scatter in the data presented in those reports is small enough to determine the 30 ft-lb temperature and upper shelf energy of the D. C. Cook Unit 1 surveillance material unambiguously. Therefore, the D. C. Cook Unit 1 surveillance program meets this criteria.

Criterion 3: ***When there are two or more sets of surveillance data from one reactor, the scatter of ΔRT_{NDT} values about a best-fit line drawn as described in Regulatory Position 2.1 normally should be less than 28°F for welds and 17°F for base metal. Even if the fluence range is large (two or more orders of magnitude), the scatter should not exceed twice those values. Even if the data fail this criterion for use in shift calculations, they may be credible for determining decrease in upper shelf energy if the upper shelf can be clearly determined, following the definition given in ASTM E185-82.***

The functional form of the least squares method as described in Regulatory Position 2.1 will be utilized to determine a best-fit line for this data and to determine if the scatter of these ΔRT_{NDT} values about this line is less than 28°F for welds and less than 17°F for the plate.

Following is the calculation of the best fit line as described in Regulatory Position 2.1 of Regulatory Guide 1.99, Revision 2.

TABLE 4-3

DC Cook Unit 1 Surveillance Capsule Data

Material	Capsule	Capsule f[a,b]	FF[b]	ΔRT_{NDT}[a]	$FF*\Delta RT_{NDT}$	FF^2
Inter. Shell Plate B4406-3 (Longitudinal)	T	0.267	0.641	60	38.460	0.411
	X	0.831	0.948	90	85.320	0.899
	Y	1.195	1.049	105	110.145	1.100
	U	1.837	1.167	115	134.205	1.362
Inter. Shell Plate B4406-3 (Transverse)	T	0.267	0.641	70	44.870	0.411
	X	0.831	0.948	110	104.280	0.899
	Y	1.195	1.049	115	120.635	1.100
	U	1.837	1.167	115	134.205	1.362
				SUM:	772.120	7.544
	$CF_{B4406-3} = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (772.120) \div (7.544) = \mathbf{102.3}$					

Notes:

a) Calculated Fluence values are in units of 10^{19}n/cm^2, E > 1.0 MeV.

b) Data obtained from WCAP-12483 Rev. 1[4], revised Capsule U Analysis.

The scatter of ΔRT_{NDT} values about the functional form of a best-fit line drawn as described in Regulatory Position 2.1 is presented in Table 4-4.

TABLE 4-4						
Best Fit Evaluation for DC Cook Unit 1 Surveillance Materials						
Base Material	CF (°F)	FF	Measured ΔRT_{NDT} (30 ft-lb) (°F)	Best Fit[a] ΔRT_{NDT} (°F)	Scatter of ΔRT_{NDT} (°F)	< 17°F (Base Metals) < 28°F (Weld Metal)
Inter. Shell Plate B4406-3 (Longitudinal)	102.3	0.641	60	65.64	-5.64	Yes
	102.3	0.948	90	97.08	-7.08	Yes
	102.3	1.049	105	107.42	-2.42	Yes
	102.3	1.167	115	119.50	-4.50	Yes
Inter. Shell Plate B4406-3 (Transverse)	102.3	0.641	70	65.64	4.36	Yes
	102.3	0.948	110	97.08	12.92	Yes
	102.3	1.049	115	107.42	7.58	Yes
	102.3	1.167	115	119.50	-4.50	Yes

Notes:
(a) Best Fit Line Per Equation 2 of Reg. Guide 1.99 Rev. 2 Position 1.1.

Table 4-4 indicates that none of the eight measured plate ΔRT_{NDT} values are outside of the 1σ scatter band. Therefore, the plate data meet this criterion and the surveillance data is deemed credible.

Criterion 4: The irradiation temperature of the Charpy specimens in the capsule should match the vessel wall temperature at the cladding/base metal interface within +/- 25°F.

The D. C. Cook Unit 1 capsule specimens are located in the reactor between the thermal shield and the vessel wall and are positioned opposite the center of the core. The test capsules are in guide tubes attached to the thermal shields. The location of the specimens with respect to the reactor vessel beltline provides assurance that the reactor vessel wall and the specimens experience equivalent operating conditions such that the temperatures will not differ by more than 25°F. This engineering judgement is acceptable by the NRC.

Criterion 5: The surveillance data for the correlation monitor material in the capsule should fall within the scatter band of the database for that material.

The D. C. Cook Unit 1 surveillance program does contain correlation monitor material. NUREG/CR-6413, ORNL/TM-13133 contains a plot of residual vs. Fast fluence for the correlation monitor material (Figure 11 of NUREG/CR-6413). The data used for this plot is contained in Table 14 (in the NUREG Report). The data found in the report contains the four capsules that have been removed and tested (T, X, Y & U), however since the time of the report the fluences values have been updated. Thus, Table 4-5 contains an updated calculation of Residual vs. Fast fluence.

Table 4-5

Calculation of Residual vs. Fast Fluence

Capsule	Fluence ($x\ 10^{19}$ n/cm^2)	Fluence Factor (FF)	Measured Shift	RG 1.99 Shift (CF*FF)[a]	Residual (Meas.-RG Shift)
T	0.267	0.641	60	81.4	-21.4
X	0.831	0.948	100	120.4	-20.4
Y	1.195	1.049	110	133.2	-23.2
U	1.837	1.167	120	148.2	-28.2

Note

(a) Per NUREG/CR-6413, ORNL/TM-13133, the Cu and Ni values for the Correlation Monitor Material is 0.170 Cu and 0.640 Ni. This equates to a Chemistry Factor of 127°F from Reg. Guide 1.99 Rev. 2

Table 4-5 shows a 2σ uncertainty of less than 50°F, which is the allowable scatter in NUREG/CR-6413, ORNL/TM-13133. Hence, this criteria is met.

Based on the preceding responses to the criteria of Regulatory Guide 1.99, Revision 2, Section B and the application of engineering judgement, the D. C. Cook Unit 1 surveillance data is credible.

4.2.1 Application of the Credibility Criteria:

The Kewaunee/Maine Yankee Surveillance weld data (Heat 1P3571) for use at D. C. Cook Unit 1 is deemed credible per Regulatory Guide 1.99, Revision 2. Hence, ½ σ_Δ will be used in the ART evaluations for the surveillance program materials.

4.2.2 σ_Δ and How it was Determined:

Per Regulatory Guide 1.99, Revision, 2 Position 1.1, the values of σ_Δ are referred to as "28°F for welds and 17°F for base metal, except that σ_Δ need not exceed 0.50 times the mean value of ΔRT_{NDT}." The "mean value of ΔRT_{NDT}" is defined in Regulatory Guide 1.99, Revision 2, by Equation 2. The chemistry factor in Regulatory Guide 1.99, Revision 2, Equation 2 is calculated from Tables 1 and 2 or Position 2.1 of Regulatory Guide 1.99, Revision 2.

Per Regulatory Guide 1.99, Revision, 2 Position 2.1, when there is credible surveillance data, σ_Δ is taken to be the lesser of ½ ΔRT_{NDT} or 14°F (28°F/2) for welds, or 8.5°F (17°F/2) for base metal. ΔRT_{NDT} again is defined herein by Equation 13, while utilizing a "Best-Fit Chemistry Factor" calculated in accordance with Position 2.1 of Regulatory Guide 1.99, Revision 2 and is shown herein on Table 4-1.

5.0 UNIRRADIATED PROPERTIES

5.1 Initial RT_{NDT} of Beltline Materials

Charpy V-notch impact specimens from the base material plates of the reactor vessel were machined in the longitudinal orientation (longitudinal axis of the specimen parallel to the major working direction of the plate) and the transverse orientation (longitudinal axis of the specimen perpendicular to the major working direction of the plate). The core region weld Charpy impact specimen was perpendicular to the weld direction. The notch of the weld metal Charpy specimen was machined such that the direction of crack propagation in the specimen was in the welding direction.

Table 5-1 contains a description of the beltline materials and their initial RT_{NDT} values.

TABLE 5-1

Reactor Vessel Material Initial RT_{NDT}

Material Description	Heat #	Flux Type	Flux Lot	Initial RT_{NDT}[a]
D. C. Cook Unit 1				
Int. Shell Axial Welds 2-442A, B&C	13253/12008	Linde 1092	3791	-56°F
Intermediate Shell Plate B4406-1	C1260	--	--	5°F
Intermediate Shell Plate B4406-2	C3506	--	--	33°F
Intermediate Shell Plate B4406-3	C3506	--	--	40°F
Int./Lower Shell Circ. Weld 9-442	1P3571	Linde 1092	3958	-56°F
Lower Shell Axial Welds 3-442A, B&C	13253/12008	Linde 1092	3791	-56°F
Lower Shell Plate B4407-1	C3929	--	--	28°F
Lower Shell Plate B4407-2	C3932	--	--	-12°F
Lower Shell Plate B4407-3	C3929	--	--	38°F
Closure Head Flange	--	--	--	60°F
Vessel Flange	--	--	--	28°F

NOTES:

(a) The Initial RT_{NDT} values were obtained from WCAP-12483[4] are measured values for the plates and generic values for the welds.

5.2 Determination of σ_I :

Since the initial RT_{NDT} values are measured values, the D.C. Cook Unit 1 σ_I values are 0°F.

5.3 Bolt-up Temperature:

The minimum bolt-up temperature requirements for the D.C. Cook Unit 1 reactor pressure vessels are according to Paragraph G-2222 of the ASME Boiler and Pressure Vessel (B&PV) Code, Section XI, Appendix G, the reactor vessel may be bolted up and pressurized to 20 percent of the initial hydrostatic test pressure at the initial RT_{NDT} of the material stressed by the bolt-up. Therefore, since the most limiting initial RT_{NDT} value is 60°F (closure head flange), the reactor vessel can be bolted up at 60°F.

6.0 REACTOR VESSEL GEOMETRIC & SYSTEM PARAMETERS

6.1 Reactor Vessel Physical Dimensions and Operating Conditions:

The following are the D.C. Cook Unit 1 reactor vessel physical dimensions[14] and operating conditions:

Reactor vessel inner diameter (to clad)	= 173 inches
Clad thickness	= 7/32 inches
Reactor Vessel Beltline Thickness	= 8.5 inches
Pre-Service System Hydrostatic Pressure	= 3106 psig
Capacity Factor (Future Cycles)	= 90%

System and Component Operating Conditions/Dimensions:

Design Pressure	= 2485 psig
Operating Pressure	= 2235 psig

7.0 FLUENCE FACTOR DETERMINATION

7.1 Peak Clad Base Metal Interface Fluence for each Beltline Material:

Contained in Table 7-1 are the reactor vessel clad/base metal interface fluences. These values were obtained from WCAP-12483 Revision 1[4], "Analysis of Capsule U from the American Electric Power Company D.C. Cook Unit 1 Reactor Vessel Radiation Surveillance Program".

TABLE 7-1

Calculated Fluence (10^{19} n/cm^2, E > 1.0 MeV) at the Pressure Vessel Clad/Base Metal Interface for the D.C. Cook Unit 1 Reactor Vessel

EFPY	0°	15°	30°	45°
16.68 (EOC 17)	0.307	0.474	0.565	0.835
32	0.607	0.965	1.204	1.802
48	0.927	1.489	1.883	2.831

Per AEP the current end of license (EOL) EFPY is 32 EFPY and the EOL license renewal EFPY is 48 EFPY.

Thus, the EFPY values used to generate pressure/temperature curves and the calculated fluence values are:

Current EOL = 32 EFPY
Renewal EOL = 48 EFPY

7.2 1/4T & 3/4T Thickness Fluence for each Beltline Material:

The neutron fluence at the 1/4T & 3/4T depth in the vessel wall was calculated per Regulatory Guide 1.99, Revision 2, as follows:

$$f = f_{surf} * e^{\{-0.24(x)\}}, \ 10^{19} \text{ n/cm}^2 \ (E > 1.0 \text{ MeV}) \qquad (10)$$

where: f_{surf} = Vessel inner wall surface fluence, 10^{19} n/cm^2 (E > 1.0 MeV) (See Table 7-1)
x = is the depth into the vessel wall from the inner surface, inches (0.25 * 8.5 inches or 0.75 * 8.5 inches)

Contained in Tables 7-2 and 7-3 is a summary of the fluence values used to calculate the D.C. Cook Unit 1 ART values used to develop the pressure-temperature curves for normal operation.

TABLE 7-2

Summary of Fluence Values Used to Calculate the D.C. Cook Unit 1 32 EFPY ART Values

Material	Surface (n/cm^2 ,E > 1.0 MeV)	1/4T (n/cm^2 ,E > 1.0 MeV)	3/4T (n/cm^2 ,E > 1.0 MeV)
Intermediate Shell Plate B4406-1	1.802×10^{19}	1.082×10^{19}	3.902×10^{18}
Intermediate Shell Plate B4406-2	1.802×10^{19}	1.082×10^{19}	3.902×10^{18}
Intermediate Shell Plate B4406-3	1.802×10^{19}	1.082×10^{19}	3.902×10^{18}
Lower Shell Plate B4407-1	1.802×10^{19}	1.082×10^{19}	3.902×10^{18}
Lower Shell Plate B4407-2	1.802×10^{19}	1.082×10^{19}	3.902×10^{18}
Lower Shell Plate B4407-3	1.802×10^{19}	1.082×10^{19}	3.902×10^{18}
Intermediate and Lower Shell Weld Longitudinal Weld Seams (Heat 13253/12008) [(a)]	1.204×10^{19}	0.723×10^{19}	2.61×10^{18}
Intermediate to Lower Shell Circ. Weld Seams (Heat 1P3571)	1.802×10^{19}	1.082×10^{19}	3.902×10^{18}

NOTES:
(a) Intermediate and Lower Shell Weld Longitudinal Weld Seams are at the 30^0 location of the Core.

TABLE 7-3			
Summary of Fluence Values Used to Calculate the D.C. Cook Unit 1 48 EFPY ART Values			
Material	Surface (n/cm^2 ,E > 1.0 MeV)	1/4T (n/cm^2 ,E > 1.0 MeV)	3/4T (n/cm^2 ,E > 1.0 MeV)
Intermediate Shell Plate B4406-1	2.831×10^{19}	1.70×10^{19}	6.13×10^{18}
Intermediate Shell Plate B4406-2	2.831×10^{19}	1.70×10^{19}	6.13×10^{18}
Intermediate Shell Plate B4406-3	2.831×10^{19}	1.70×10^{19}	6.13×10^{18}
Lower Shell Plate B4407-1	2.831×10^{19}	1.70×10^{19}	6.13×10^{18}
Lower Shell Plate B4407-2	2.831×10^{19}	1.70×10^{19}	6.13×10^{18}
Lower Shell Plate B4407-3	2.831×10^{19}	1.70×10^{19}	6.13×10^{18}
Intermediate and Lower Shell Weld Longitudinal Weld Seams (Heat 13253/12008)[(a)]	1.883×10^{19}	1.131×10^{19}	4.077×10^{18}
Intermediate to Lower Shell Circ. weld Seams (Heat 1P3571)	2.831×10^{19}	1.70×10^{19}	6.13×10^{18}

NOTES:

(a) Intermediate and Lower Shell Weld Longitudinal Weld Seams are at the 30^0 location of the Core.

7.3 Fluence Factors:

The fluence factors were calculated per Regulatory Guide 1.99, Revision 2, using the following equation.

$$FF = \text{fluence factor} = f^{(0.28 - 0.1 \log(f))} \qquad (11)$$

where: f = Vessel inner wall surface fluence, 1/4 T fluence or 3/4T fluence, [10^{19} n/cm^2 (E > 1.0 MeV) ÷ 10^{19} n/cm^2 (E > 1.0 MeV)]

Contained in Tables 7-4 and 7-5 is a summary of the calculated fluence factors for 32 and 48 EFPY respectively.

TABLE 7-4				
Summary of Fluence Factors Used to Calculate the D.C. Cook Unit 1 32 EFPY ART Values				
Material	1/4T F (n/cm^2 ,E > 1.0 MeV)	1/4T FF	3/4T f (n/cm^2 ,E > 1.0 MeV)	3/4T FF
Intermediate Shell Plate B4406-1	1.082×10^{19}	1.022	3.902×10^{18}	0.739
Intermediate Shell Plate B4406-2	1.082×10^{19}	1.022	3.902×10^{18}	0.739
Intermediate Shell Plate B4406-3	1.082×10^{19}	1.022	3.902×10^{18}	0.739
Lower Shell Plate B4407-1	1.082×10^{19}	1.022	3.902×10^{18}	0.739
Lower Shell Plate B4407-2	1.082×10^{19}	1.022	3.902×10^{18}	0.739
Lower Shell Plate B4407-3	1.082×10^{19}	1.022	3.902×10^{18}	0.739
Intermediate and Lower Shell Weld Longitudinal Weld Seams (Heat 13253/12008)	7.23×10^{18}	0.909	2.61×10^{18}	0.635
Intermediate to Lower Shell Circ. weld Seams (Heat 1P3571)	1.082×10^{19}	1.022	3.902×10^{18}	0.739

TABLE 7-5				
Summary of Fluence Factors Used to Calculate the D.C. Cook Unit 1 48 EFPY ART Values				
Material	1/4T F (n/cm^2 ,E > 1.0 MeV)	1/4T FF	3/4T f (n/cm^2 ,E > 1.0 MeV)	3/4T FF
Intermediate Shell Plate B4406-1	1.70×10^{19}	1.146	6.13×10^{18}	0.863
Intermediate Shell Plate B4406-2	1.70×10^{19}	1.146	6.13×10^{18}	0.863
Intermediate Shell Plate B4406-3	1.70×10^{19}	1.146	6.13×10^{18}	0.863
Lower Shell Plate B4407-1	1.70×10^{19}	1.146	6.13×10^{18}	0.863
Lower Shell Plate B4407-2	1.70×10^{19}	1.146	6.13×10^{18}	0.863
Lower Shell Plate B4407-3	1.70×10^{19}	1.146	6.13×10^{18}	0.863
Intermediate and Lower Shell Weld Longitudinal Weld Seams (Heat 13253/12008)	1.131×10^{19}	1.034	4.077×10^{18}	0.751
Intermediate to Lower Shell Circ. weld Seams (Heat 1P3571)	1.70×10^{19}	1.146	6.13×10^{18}	0.863

8.0 CALCULATION OF ADJUSTED REFERENCE TEMPERATURE

8.1 Methodology:

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:

$$ART = Initial\ RT_{NDT} + \Delta RT_{NDT} + Margin \qquad (12)$$

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

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

$$\Delta RT_{NDT} = CF * f^{(0.28 - 0.10 \log f)} \qquad (13)$$

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. The resultant fluence is then placed in the equation above to calculate the ΔRT_{NDT} at the specific depth. The calculated CF and FF values are given in Tables 4-1, 4-2, 7-4 and 7-5 of this report.

$$f_{(depth\ x)} = f_{surface} * e^{(-0.24x)} \qquad (14)$$

When there are "two or more credible surveillance data sets"[1] available, Regulatory Guide 1.99 Revision 2, Position 2.1, states "To calculate the Margin in this case, use Equation 4; the values given there for σ_Δ may be cut in half". Equation 4 from Regulatory Guide 1.99 Revision 2, is as follows:

$$M = 2\sqrt{\sigma_I^2 + \sigma_\Delta^2} \qquad (15)$$

The values of σ_Δ are referred to as "28°F for welds and 17°F for base metals."

Standard Deviation for Initial RT_{NDT} Margin Term, σ_I: If the initial RT_{NDT} values are measured values, then σ_I is taken to be 0°F, otherwise use 17°F.

Standard Deviation for ΔRT_{NDT} Margin Term, σ_Δ: Per Regulatory Guide 1.99 Revision 2, Position 1.1, the values of σ_Δ are referred to as "28°F for welds and 17°F for base metal, except that σ_Δ need not exceed 0.50

times the mean value of ΔRT_{NDT}." The "mean value of ΔRT_{NDT}" is defined in Regulatory Guide 1.99 Revision 2, by Equation 2. The chemistry factor in Regulatory Guide 1.99, Revision 2, Equation 2 is calculated from Tables 1 and 2 of Regulatory Guide 1.99 Revision 2.

Per Regulatory Guide 1.99, Revision 2, Position 2.1, when there is credible surveillance data, σ_Δ is taken to be the lesser of $\frac{1}{2}\Delta RT_{NDT}$ or 14°F (28°F/2) for welds, or 8.5°F (17°F/2) for base metal. ΔRT_{NDT} again is defined herein by Equation 4, while utilizing a "Best-Fit Chemistry Factor" calculated in accordance with Position 2.1 of Regulatory Guide 1.99, Revision 2.

Since σ_I is taken to be zero when a heat-specific measured value of initial RT_{NDT} are available (as they are in this case for the plate material), the total margin term, based on Equation 4 of Regulatory Guide 1.99, Revision 2, is as follows:

Position 1.1: Lesser of ΔRT_{NDT} or 56°F for Welds
Lesser of ΔRT_{NDT} or 34°F for Base Metal

Position 2.1: Lesser of ΔRT_{NDT} or 28°F for Welds
Lesser of ΔRT_{NDT} or 17°F for Base Metal

8.2 Adjusted Reference Temperature (ART) Calculations:

The ART calculations along with the actual margin terms used for D.C. Cook Unit 1 are listed in Tables 8-1 through 8-4.

TABLE 8-1							
Calculation of the ART Values for D.C. Cook Unit 1 for the 1/4T Location and 32 EFPY							
Material	RG 1.99 R2 Method	CF	FF	ΔRT_{NDT}	Margin	IRT_{NDT}	ART
Intermediate Shell Plate B4406-1	Position 1.1	81.4°F	1.022	83.2°F	34°F	5°F	122
Intermediate Shell Plate B4406-2	Position 1.1	104.5°F	1.022	106.8°F	34°F	33°F	174
	Position 2.1	102.3°F	1.022	104.6°F	17°F	33°F	155
Intermediate Shell Plate B4406-3	Position 1.1	104°F	1.022	106.3°F	34°F	40°F	180
	Position 2.1	102.3°F	1.022	104.6°F	17°F	40°F	162
Lower Shell Plate B4407-1	Position 1.1	97.8°F	1.022	100.0°F	34°F	28°F	162
Lower shell Plate B4407-2	Position 1.1	82.8°F	1.022	84.6°F	34°F	-12°F	107
Lower Shell Plate B4407-3	Position 1.1	95.5°F	1.022	97.6°F	34°F	38°F	170
Intermediate and Lower Shell Axial Weld Seams	Position 1.1	208.7°F	0.909	189.7°F	65.5°F	-56°F	199[a]
Intermediate to Lower Shell Circ. Weld Seams	Position 1.1	214°F	1.022	218.7°F	65.5°F	-56°F	228
	Position 2.1	218.6°F	1.022	223.4°F	44°F	-56°F	211[a]

NOTES:

(a) The Intermediate to Lower Shell Circ. Weld Seam (Heat 1P3571) has the highest ART value. Since the material is a circumferential weld, less restrictive methodology can be used in generating PT curves. However, the highest Axial Flaw must be checked with the more restrictive methodology. It should be noted that since the axial flaw ART's are so close to the circ. flaw ART's the axial flaw ART values will produce a more restrictive curve overall.

TABLE 8-2							
Calculation of the ART Values for D.C. Cook Unit 1 for the 3/4T Location and 32 EFPY							
Material	RG 1.99 R2 Method	CF	FF	ΔRT_{NDT}	Margin	IRT_{NDT}	ART
Intermediate Shell Plate B4406-1	Position 1.1	81.4°F	.739	60.2°F	34°F	5°F	99°F
Intermediate Shell Plate B4406-2	Position 1.1	104.5°F	.739	77.2°F	34°F	33°F	144°F
	Position 2.1	102.3°F	.739	75.6°F	17°F	33°F	126°F
Intermediate Shell Plate B4406-3	Position 1.1	104°F	.739	76.9°F	34°F	40°F	151°F
	Position 2.1	102.3°F	.739	75.6°F	17°F	40°F	133°F
Lower Shell Plate B4407-1	Position 1.1	97.8°F	.739	72.3°F	34°F	28°F	134°F
Lower shell Plate B4407-2	Position 1.1	82.8°F	.739	61.2°F	34°F	-12°F	83°F
Lower Shell Plate B4407-3	Position 1.1	95.5°F	.739	70.6°F	34°F	38°F	143°F[a]
Intermediate and Lower Shell Axial Weld Seams	Position 1.1	208.7°F	.635	132.5°F	65.5°F	-56°F	142°F
Intermediate to Lower Shell Circ. Weld Seams	Position 1.1	214°F	.739	158.1 °F	65.5°F	-56°F	168°F
	Position 2.1	218.6°F	.739	161.5°F	44°F	-56°F	150°F[a]

NOTES:

(a) The Intermediate to Lower Shell Circ. Weld Seam (Heat 1P3571) has the highest ART value. Since the material is a circumferential weld, less restrictive methodology can be used in generating PT curves. However, the highest Axial Flaw must be checked with the more restrictive methodology. It should be noted that since the axial flaw ART's are so close to the circ. flaw ART's the axial flaw ART values will produce a more restrictive curve overall.

TABLE 8-3							
Calculation of the ART Values for D.C. Cook Unit 1 for the 1/4T Location and 48 EFPY							
Material	RG 1.99 R2 Method	CF	FF	ΔRT_{NDT}	Margin	IRT_{NDT}	ART
Intermediate Shell Plate B4406-1	Position 1.1	81.4°F	1.146	93.3°F	34°F	5°F	132°F
Intermediate Shell Plate B4406-2	Position 1.1	104.5°F	1.146	119.8°F	34°F	33°F	187°F
	Position 2.1	102.3°F	1.146	117.2°F	17°F	33°F	167°F
Intermediate Shell Plate B4406-3	Position 1.1	104°F	1.146	119.2°F	34°F	40°F	193°F
	Position 2.1	102.3°F	1.146	117.2°F	17°F	40°F	174°F
Lower Shell Plate B4407-1	Position 1.1	97.8°F	1.146	112.1°F	34°F	28°F	174°F
Lower shell Plate B4407-2	Position 1.1	82.8°F	1.146	94.9°F	34°F	-12°F	117°F
Lower Shell Plate B4407-3	Position 1.1	95.5°F	1.146	109.4°F	34°F	38°F	181°F
Intermediate and Lower Shell Axial Weld Seams	Position 1.1	208.7°F	1.034	215.8°F	65.5°F	-56°F	225°F[a]
Intermediate to Lower Shell Circ. Weld Seams	Position 1.1	214°F	1.146	245.2°F	65.5°F	-56°F	255°F
	Position 2.1	218.6°F	1.146	250.5°F	44°F	-56°F	239°F[a]

NOTES:

(a) The Intermediate to Lower Shell Circ. Weld Seam (Heat 1P3571) has the highest ART value. Since the material is a circumferential weld, less restrictive methodology can be used in generating PT curves. However, the highest Axial Flaw must be checked with the more restrictive methodology. It should be noted that since the axial flaw ART's are so close to the circ. flaw ART's the axial flaw ART values will produce a more restrictive curve overall.

TABLE 8-4							
Calculation of the ART Values for D.C. Cook Unit 1 for the 3/4T Location and 48 EFPY							
Material	RG 1.99 R2 Method	CF	FF	ΔRT_{NDT}	Margin	IRT_{NDT}	ART
Intermediate Shell Plate B4406-1	Position 1.1	81.4°F	.863	70.2°F	34°F	5°F	109°F
Intermediate Shell Plate B4406-2	Position 1.1	104.5°F	.863	90.2°F	34°F	33°F	157°F
	Position 2.1	102.3°F	.863	88.3°F	17°F	33°F	138°F
Intermediate Shell Plate B4406-3	Position 1.1	104°F	.863	89.8°F	34°F	40°F	164°F
	Position 2.1	102.3°F	.863	88.3°F	17°F	40°F	145°F
Lower Shell Plate B4407-1	Position 1.1	97.8°F	.863	84.4°F	34°F	28°F	146°F
Lower shell Plate B4407-2	Position 1.1	82.8°F	.863	71.5°F	34°F	-12°F	93°F
Lower Shell Plate B4407-3	Position 1.1	95.5°F	.863	82.4°F	34°F	38°F	154°F
Intermediate and Lower Shell Axial Weld Seams	Position 1.1	208.7°F	.751	156.7°F	65.5°F	-56°F	166°F[a]
Intermediate to Lower Shell Circ. Weld Seams	Position 1.1	214°F	.863	184.7°F	65.5°F	-56°F	194°F
	Position 2.1	218.6°F	.863	188.7°F	44°F	-56°F	177°F[a]

NOTES:

(a) The Intermediate to Lower Shell Circ. Weld Seam (Heat 1P3571) has the highest ART value. Since the material is a circumferential weld, less restrictive methodology can be used in generating PT curves. However, the highest Axial Flaw must be checked with the more restrictive methodology. It should be noted that since the axial flaw ART's are so close to the circ. flaw ART's the axial flaw ART values will produce a more restrictive curve overall.

Contained in Table 8-5 is a summary of the limiting ART values used in the generation of the D.C. Cook Unit 1 reactor vessel heatup and cooldown curves. It should be noted that the intermediate to lower shell girth weld (Heat #1P3571) has the highest overall ART values. However, since ASME Code Case N-641 (i.e. Code Case N-588) allows for less restrictive methodology when a circumferential weld has the highest ART, then the axial welds become limiting with the lower ART values and the traditional methodology from the 1996 version of the ASME Code, Appendix G.

TABLE 8-5		
Summary of the Limiting ART Values to be Used in the Generation of the Cook Unit 1 Reactor Vessel Heatup and Cooldown Curves		
EFPY	1/4 T Limiting ART	3/4 Limiting ART
Circumferential Flaw		
32	211°F	150°F
48	239°F	177°F
Axial Flaw		
32	199°F	143°F*
48	225°F	166°F

* Beltline Weld Seams (Axial. Weld) are the limiting materials for all cases except 32 EFPY 3/4T, which is Lower Shell Plate B4407-3 limited.

9.0 HEATUP AND COOLDOWN PRESSURE-TEMPERATURE LIMIT CURVES

9.1 Introduction and Methodology:

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 Sections 3 and 8 of this report.

Figure 9-1 presents the heatup curves without margins for possible instrumentation errors for a heatup rate of 60°F/hr. This curve is applicable to 32 EFPY (current end of license). Figure 9-2 presents the cooldown curves without margins for possible instrumentation errors for cooldown rates of 0, 20, 40, 60, and 100°F/hr. These curves are also applicable to 32 EFPY (current end of license). Figure 9-3 presents the heatup curves without margins for possible instrumentation errors for a heatup rates of 60°F/hr. This curve is applicable to 48 EFPY (end of license renewal). Figure 9-4 presents the cooldown curves without margins for possible instrumentation errors for cooldown rates of 0, 20, 40, 60, and 100°F/hr. These curves are also applicable to 48 EFPY (end of license renewal). Allowable combinations of temperature and pressure for specific temperature change rates are below and to the right of the limit lines shown in Figures 9-1 through 9-4. 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 9-1 and 9-3. The straight-line portion of the criticality limit is at the minimum permissible temperature for the 2485 psig inservice hydrostatic test as required by Appendix G to 10 CFR Part 50. The governing equation for the hydrostatic test is defined in Code Case N-640[8] and Appendix G to Section XI of the ASME Code[3] as follows:

$$1.5\,K_{Im} < K_{Ic} \qquad (15)$$

where,

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

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

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. For the heatup and cooldown curves without margins for instrumentation errors, the minimum temperature for the in service hydrostatic leak tests for D.C. Cook Unit 1 reactor vessel at 32 and 48 EFPY is 259°F and 285°F, respectively. The vertical line drawn from these points on the pressure-temperature curve, intersecting a curve 40°F higher than the pressure-temperature limit curve, constitutes the limit for core operation for the reactor vessel.

Figures 9-1 through 9-4 define all of the above limits for ensuring prevention of nonductile failure for the D.C. Cook Unit 1 reactor vessel. The data points for the heatup and cooldown pressure-temperature limit curves shown in Figures 9-1 through 9-4 are presented in Tables 9-1 through 9-4.

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: Intermediate Shell Axial Weld (Heat 13253/12008) & Lower Shell Plate B4407-3

LIMITING ART VALUES AT 32 EFPY: 1/4T, 199°F
3/4T, 143°F

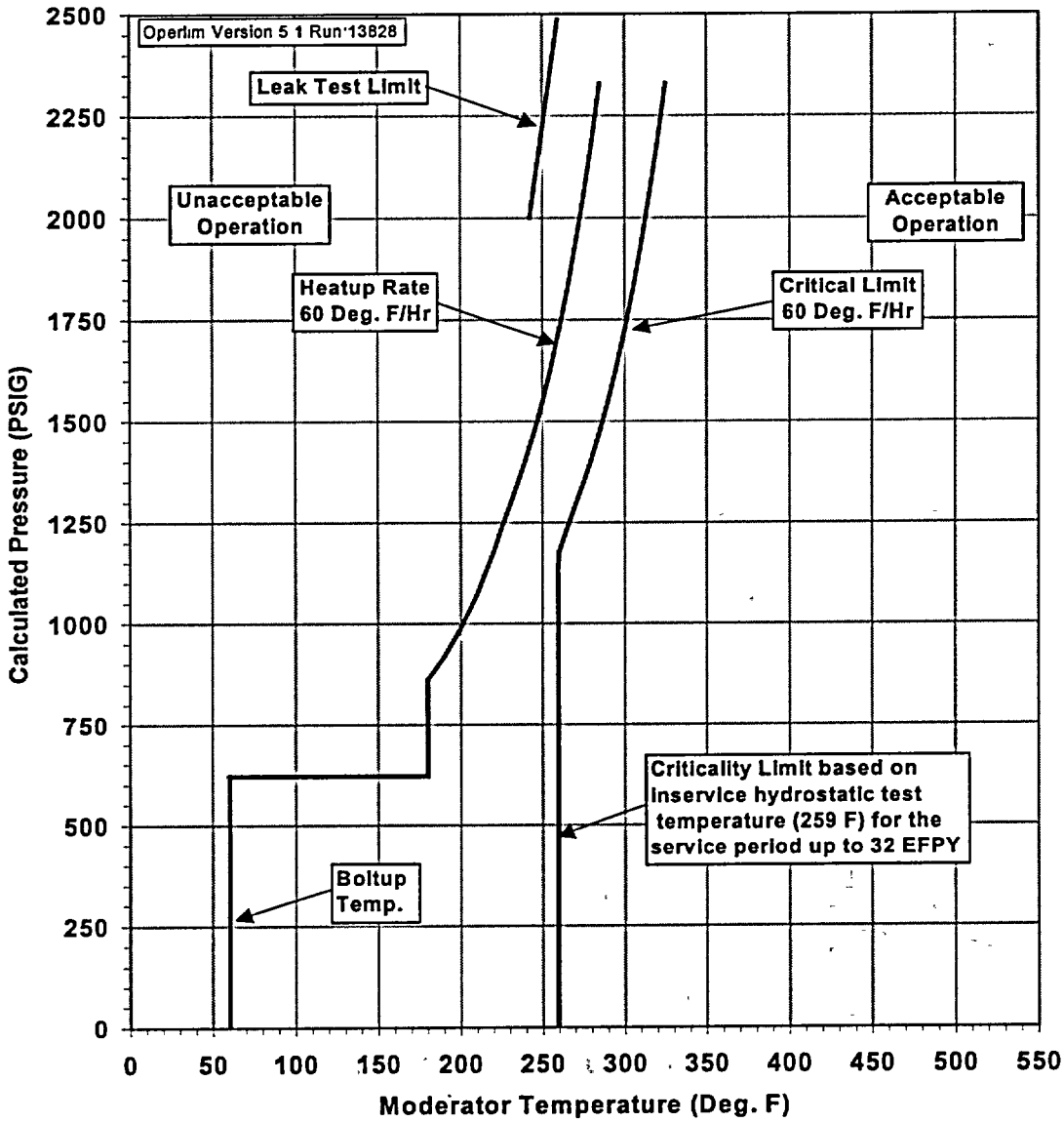

FIGURE 9-1 D.C. Cook Unit 1 Reactor Coolant System Heatup Limitations (Heatup Rate of 60°F/hr) Applicable for 32 EFPY (Without Margins for Instrumentation Errors) (Includes Vessel Flange Requirements of 180°F and 621 psi per 10CFR50)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: Intermediate Shell Axial Weld (Heat 13253/12008) & Lower Shell Plate B4407-3

LIMITING ART VALUES AT 32 EFPY: 1/4T, 199°F
3/4T, 143°F

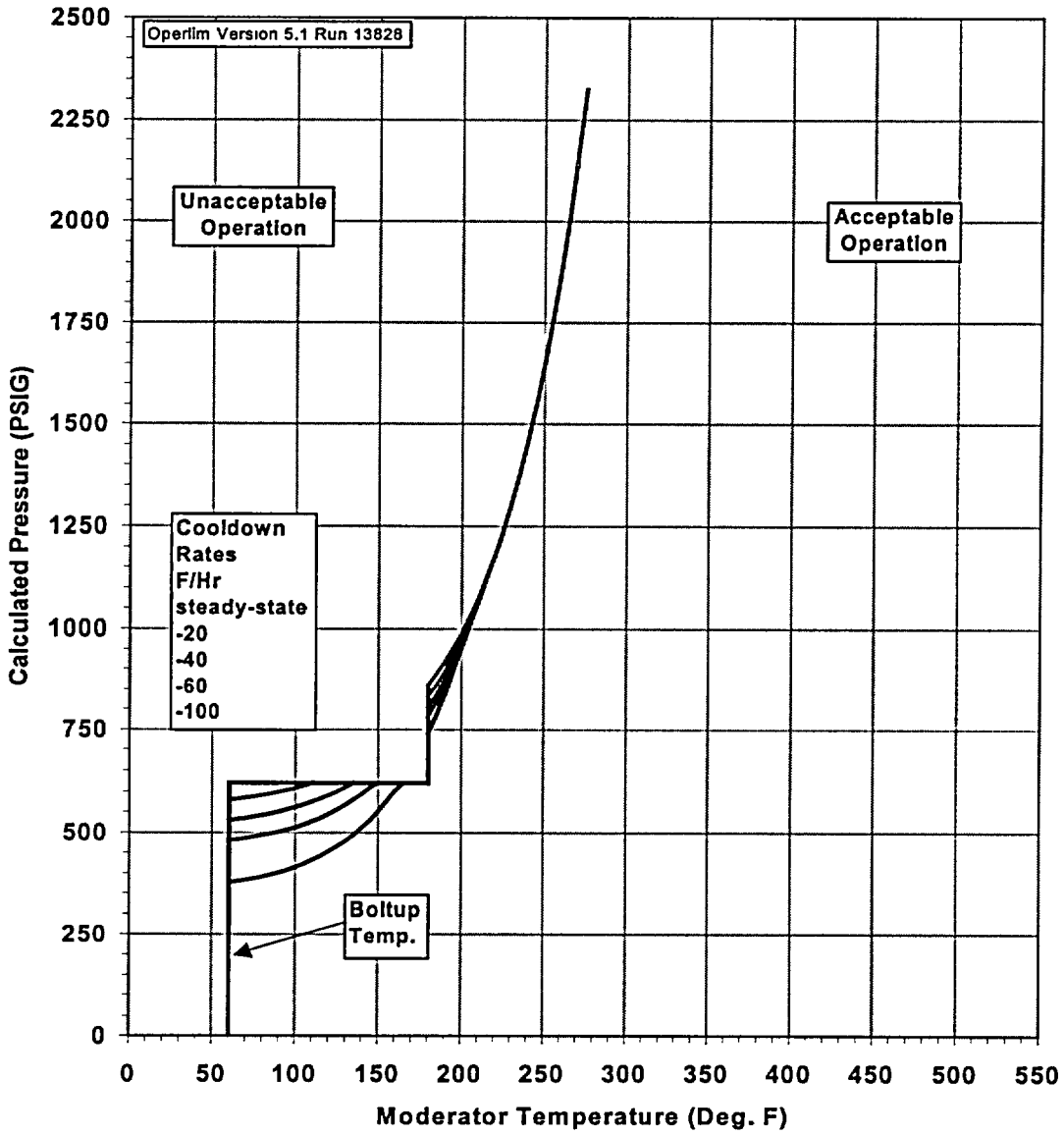

FIGURE 9-2 D.C. Cook Unit 1 Reactor Coolant System Cooldown Limitations (Cooldown Rates of 0, 20, 40, 60 and 100°F/hr) Applicable for 32 EFPY (Without Margins for Instrumentation Errors) (Includes Vessel Flange Requirements of 180°F and 621 psi per 10CFR50)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: Intermediate Shell Axial Weld (Heat 13253/12008)
LIMITING ART VALUES AT 48 EFPY: 1/4T, 225°F
3/4T, 166°F

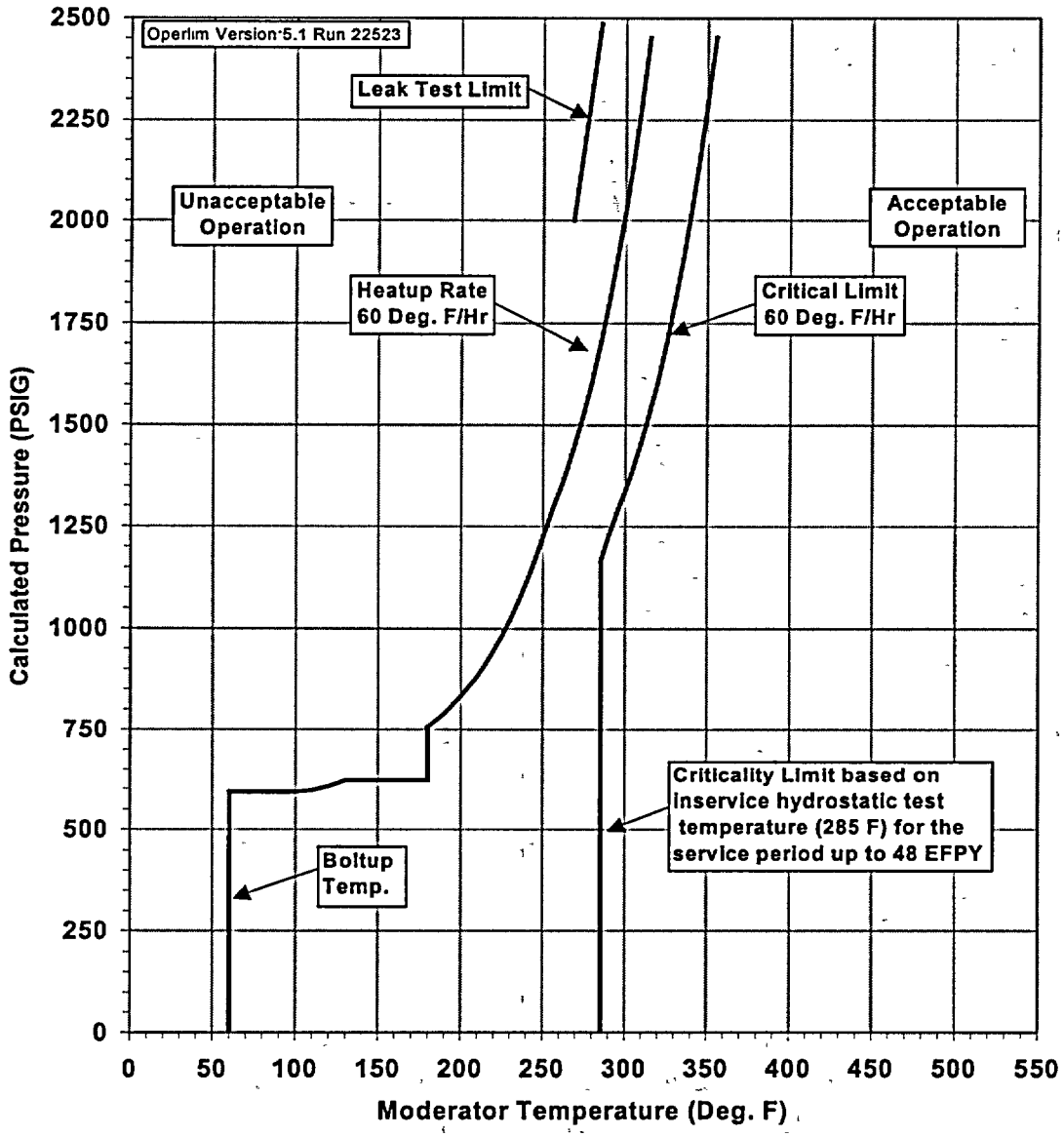

FIGURE 9-3 D.C. Cook Unit 1 Reactor Coolant System Heatup Limitations (Heatup Rate of 60°F/hr) Applicable for 48 EFPY (Without Margins for Instrumentation Errors) (Includes Vessel Flange Requirements of 180°F and 621 psi per 10CFR50)

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: Intermediate Shell Axial Weld (Heat 13253/12008)
LIMITING ART VALUES AT 48 EFPY: 1/4T, 225°F
3/4T, 166°F

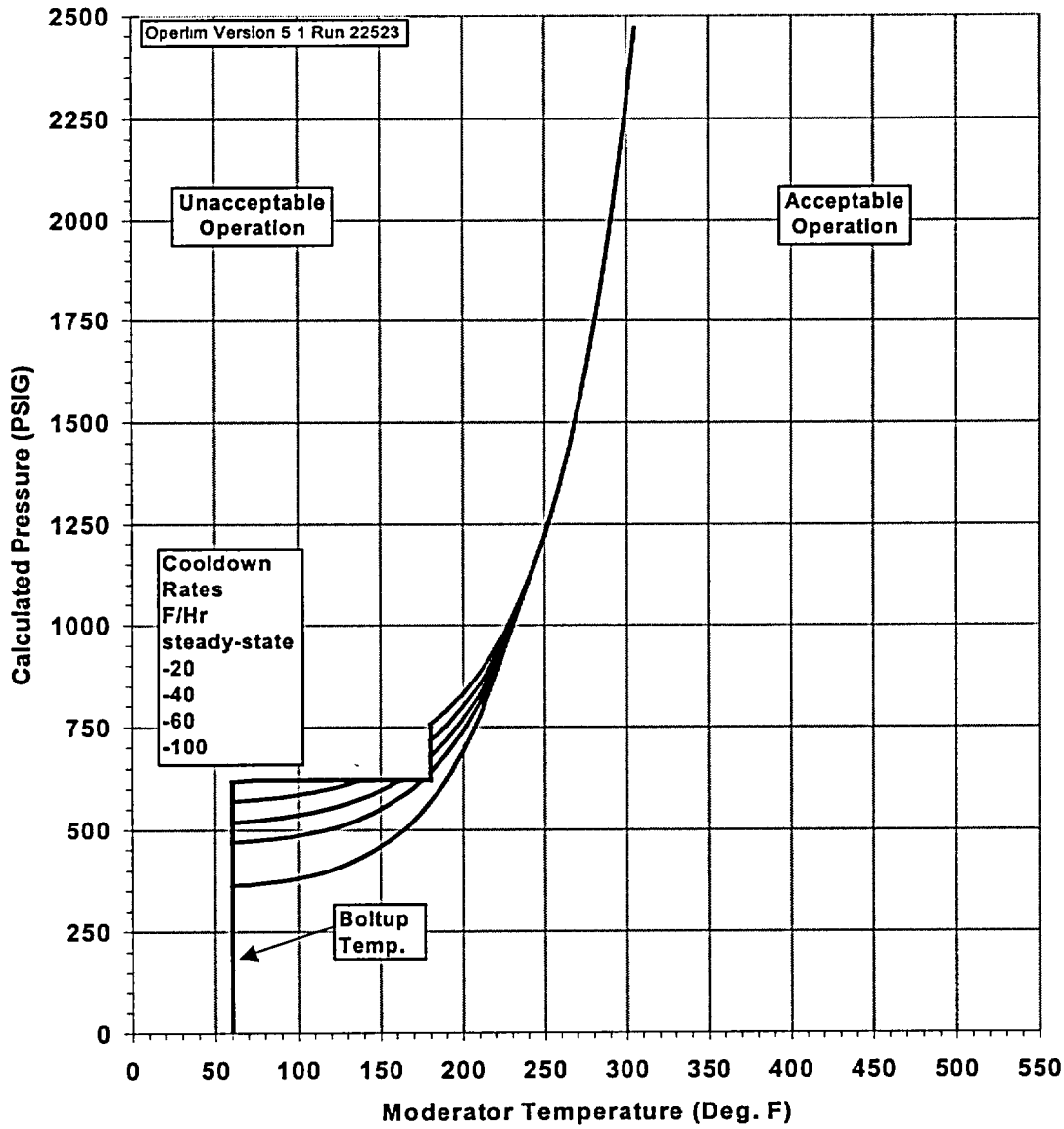

FIGURE 9-4 D.C. Cook Unit 1 Reactor Coolant System Cooldown Limitations (Cooldown Rates of 0, 20, 40, 60 and 100°F/hr) Applicable for 48 EFPY (Without Margins for Instrumentation Errors) (Includes Vessel Flange Requirements of 180°F and 621 psi per 10CFR50)

TABLE 9-1
D.C. Cook Unit 1 Reactor Vessel Heatup Curve Data Points for 32 EFPY
Without Margins for Instrumentation Errors
(Includes Vessel Flange Requirements of 180°F and 621 psi per 10CFR50)

60°F/hr. Heatup		60°F/hr. Criticality		Leak Test Limit	
T (°F)	P (psig)	T (°F)	P (psig)	T (°F)	P (psig)
60	0	259	0	242	2000
60	621	259	621	259	2485
65	621	259	621		
70	621	259	621		
75	621	259	621		
80	621	259	621		
85	621	259	621		
90	621	259	621		
95	621	259	621		
100	621	259	621		
105	621	259	621		
110	621	259	621		
115	621	259	621		
120	621	259	621		
125	621	259	621		
130	621	259	621		
135	621	259	621		
140	621	259	621		
145	621	259	621		
150	621	259	621		
155	621	259	621		
160	621	259	621		
165	621	259	621		
170	621	259	621		
175	621	259	621		
180	621	259	860		
180	621	259	887		
180	860	259	917		
185	887	259	950		
190	917	259	987		

195	950	259	1027		
200	987	259	1072		
205	1027	259	1121		
210	1072	260	1175		
215	1121	265	1236		
220	1175	270	1290		
225	1236	275	1345		
230	1290	280	1406		
235	1345	285	1473		
240	1406	290	1547		
245	1473	295	1628		
250	1547	300	1718		
255	1628	305	1817		
260	1718	310	1926		
265	1817	315	2047		
270	1926	320	2180		
275	2047	325	2327		
280	2180				
285	2327				

TABLE 9-2
D.C. Cook Unit 1 Reactor Vessel Cooldown Curve Data Points for 32 EFPY
Without Margins for Instrumentation Errors
(Includes Vessel Flange Requirements of 180°F and 621 psi per 10CFR50)

Steady State		20 °F/hr.		40°F/hr.		60°F/hr.		100°F/hr.	
T(°F)	P (psig)	T(°F)	P (psig)	T(°F)	P (psig)	T(°F)	P (psig)	T(°F)	P (psig)
60	0	60	0	60	0	60	0	60	0
60	621	60	578	60	530	60	480	60	377
65	621	65	581	65	532	65	482	65	380
70	621	70	584	70	535	70	485	70	383
75	621	75	587	75	538	75	489	75	387
80	621	80	590	80	542	80	492	80	391
85	621	85	594	85	546	85	497	85	396
90	621	90	598	90	550	90	501	90	401
95	621	95	603	95	555	95	507	95	408
100	621	100	608	100	561	100	513	100	415
105	621	105	614	105	567	105	519	105	422
110	621	110	620	110	574	110	527	110	431
115	621	115	621	115	581	115	535	115	441
120	621	120	621	120	590	120	544	120	452
125	621	125	621	125	600	125	555	125	465
130	621	130	621	130	610	130	566	130	478
135	621	135	621	135	621	135	579	135	494
140	621	140	621	140	621	140	593	140	511
145	621	145	621	145	621	145	609	145	530
150	621	150	621	150	621	150	621	150	552
155	621	155	621	155	621	155	621	155	576
160	621	160	621	160	621	160	621	160	602
165	621	165	621	165	621	165	621	165	621
170	621	170	621	170	621	170	621	170	621
175	621	175	621	175	621	175	621	175	621
180	621	180	621	180	621	180	621	180	621
180	860	180	831	180	805	180	780	180	741
185	887	185	861	185	838	185	817	185	786
190	917	190	894	190	874	190	857	190	836
195	950	195	931	195	914	195	902	195	891
200	987	200	971	200	959	200	951	200	951
205	1027	205	1015	205	1008	205	1006	205	1006
210	1072	210	1065	210	1063	210	1063	210	1063

215	1121	215	1119	215	1119	215	1119	215	1119
220	1175	220	1175	220	1175	220	1175	220	1175
225	1236	225	1236	225	1236	225	1236	225	1236
230	1302	230	1302	230	1302	230	1302	230	1302
235	1376	235	1376	235	1376	235	1376	235	1376
240	1457	240	1457	240	1457	240	1457	240	1457
245	1547	245	1547	245	1547	245	1547	245	1547
250	1646	250	1646	250	1646	250	1646	250	1646
255	1756	255	1756	255	1756	255	1756	255	1756
260	1877	260	1877	260	1877	260	1877	260	1877
265	2012	265	2012	265	2012	265	2012	265	2012
270	2160	270	2160	270	2160	270	2160	270	2160
275	2323	275	2323	275	2323	275	2323	275	2323

TABLE 9-3

D.C. Cook Unit 1 Reactor Vessel Heatup Curve Data Points for 48 EFPY
Without Margins for Instrumentation Errors
(Includes Vessel Flange Requirements of 180°F and 621 psi per 10CFR50)

60°F/hr. Heatup		60°F/hr. Criticality		Leak Test Limit	
T(°F)	P (psig)	T(°F)	P (psig)	T(°F)	P (psig)
60	0	285	0	268	2000
60	592	285	592	285	2485
65	592	285	592		
70	592	285	593		
75	592	285	593		
80	592	285	596		
85	592	285	597		
90	592	285	600		
95	592	285	603		
100	592	285	606		
105	593	285	611		
110	596	285	612		
115	600	285	620		
120	606	285	621		
125	612	285	621		
130	620	285	621		
135	621	285	621		
140	621	285	621		
145	621	285	621		
150	621	285	621		
155	621	285	621		
160	621	285	621		
165	621	285	621		
170	621	285	621		
175	621	285	621		
180	621	285	756		
180	756	285	772		
185	772	285	789		
190	789	285	809		
195	809	285	831		

200	831	285	855		
205	855	285	881		
210	881	285	911		
215	911	285	943		
220	943	285	979		
225	979	285	1019		
230	1019	285	1062		
235	1062	285	1111		
240	1111	285	1164		
245	1164	290	1223		
250	1223	295	1281		
255	1281	300	1335		
260	1335	305	1394		
265	1394	310	1459		
270	1459	315	1531		
275	1531	320	1610		
280	1610	325	1698		
285	1698	330	1795		
290	1795	335	1901		
295	1901	340	2019		
300	2019	345	2149		
305	2149	350	2292		
310	2292	355	2450		
315	2450				

TABLE 9-4
D.C. Cook Unit 1 Reactor Vessel Cooldown Curve Data Points for 48 EFPY
Without Margins for Instrumentation Errors
(Includes Vessel Flange Requirements of 180°F and 621 psi per 10CFR50)

Steady State		20 °F/hr.		40°F/hr.		60°F/hr.		100°F/hr.	
T(°F)	P (psig)	T(°F)	P (psig)	T(°F)	P (psig)	T(°F)	P (psig)	T(°F)	P (psig)
60	0	60	0	60	0	60	0	60	0
60	616	60	568	60	518	60	467	60	362
65	618	65	569	65	520	65	469	65	363
70	620	70	571	70	521	70	470	70	364
75	621	75	573	75	523	75	472	75	366
80	621	80	575	80	525	80	474	80	368
85	621	85	577	85	527	85	476	85	371
90	621	90	579	90	529	90	479	90	373
95	621	95	582	95	532	95	481	95	377
100	621	100	585	100	535	100	485	100	380
105	621	105	588	105	539	105	488	105	384
110	621	110	592	110	543	110	492	110	389
115	621	115	596	115	547	115	497	115	395
120	621	120	601	120	552	120	502	120	401
125	621	125	606	125	557	125	508	125	408
130	621	130	612	130	563	130	515	130	415
135	621	135	618	135	570	135	522	135	424
140	621	140	621	140	578	140	530	140	434
145	621	145	621	145	586	145	539	145	445
150	621	150	621	150	595	150	549	150	457
155	621	155	621	155	606	155	561	155	471
160	621	160	621	160	617	160	573	160	486
165	621	165	621	165	621	165	587	165	503
170	621	170	621	170	621	170	603	170	522
175	621	175	621	175	621	175	620	175	543
180	621	180	621	180	621	180	621	180	566
180	756	180	716	180	677	180	639	185	593
185	772	185	734	185	697	185	660	190	622
190	789	190	753	190	718	190	684	195	654
195	809	195	775	195	742	195	710	200	690
200	831	200	799	200	768	200	739	205	730
205	855	205	825	205	797	205	772	210	774

210	881	210	854	210	829	210	807	215	824
215	911	215	887	215	865	215	847	220	878
220	943	220	922	220	905	220	891	225	939
225	979	225	962	225	949	225	940	230	993
230	1019	230	1006	230	997	230	993	235	1051
235	1062	235	1054	235	1051	235	1051	240	1108
240	1111	240	1108	240	1108	240	1108	245	1164
245	1164	245	1164	245	1164	245	1164	250	1223
250	1223	250	1223	250	1223	250	1223	255	1288
255	1288	255	1288	255	1288	255	1288	260	1361
260	1361	260	1361	260	1361	260	1361	265	1440
265	1440	265	1440	265	1440	265	1440	270	1528
270	1528	270	1528	270	1528	270	1528	275	1626
275	1626	275	1626	275	1626	275	1626	280	1733
280	1733	280	1733	280	1733	280	1733	285	1852
285	1852	285	1852	285	1852	285	1852	290	1984
290	1984	290	1984	290	1984	290	1984	295	2129
295	2129	295	2129	295	2129	295	2129	300	2289
300	2289	300	2289	300	2289	300	2289	305	2467
305	2467	305	2467	305	2467	305	2467		

10.0 ENABLE TEMPERATURE CALCULATION:

10.1 ASME Code Case N-641 Methodology:

ASME Code Case N-641[9] presents alternative procedures for calculating pressure-temperature relationships and low temperature overpressure protection (LTOP) system effective temperatures and allowable pressures. "These procedures take into account alternative fracture toughness properties, circumferential and axial reference flaws, and plant-specific LTOP effective temperature calculations."

ASME Code Case N-641 provides the following temperature condition to protect against failure during reactor startup and shutdown. The code requires that the LTOP or COMS system be effective at coolant temperatures less than 200°F or at coolant temperatures less than a temperature corresponding to a reactor vessel metal temperature calculated below:

(1) $T_e = RT_{NDT} + 40 + \max(\Delta T_{metal})$, °F

(2) $T_e = RT_{NDT} + 50 \ln[((F * M_m (pR_i / t)) - 33.2) / 20.734]$, °F,

where,
- $M_m = 0.926(t)^{(1/2)}$, for an inside surface flaw (Ref. 3),
- $F = 1.1$, accumulation factor for safety relief valves (Ref. 9)
- $p = 2.485$, vessel design pressure, ksi (Section 6.1)
- $R_i = 173 / 2 = 86.5$, vessel inner radius, in. (Section 6.1)
- $t = 8.5$, vessel wall thickness, in. (Section 6.1)

RT_{NDT} is the highest adjusted reference temperature (ART) for the limiting beltline material at a distance one fourth of the vessel section thickness from the vessel inside surface (ie. clad/base metal interface), as determined by Regulatory Guide 1.99, Revision 2. The highest of the three temperatures determines the LTOP system effective temperature

10.2 32 EFPY Enable Temperature:

The highest calculated 1/4T ART of the critical material for the D.C. Cook Unit 1 reactor vessel beltline regions at 32 EFPY is 199°F.

From the OPERLIM computer code output for the D.C. Cook Unit 1 32 EFPY Pressure-Temperature limit curves without margins the maximum ΔT_{metal} is:

Cooldown Rate (Steady-State Cooldown):

$\max(\Delta T_{metal})$ at 1/4T = 0°F

Heatup Rate of 60°F/Hr:

$\max(\Delta T_{metal})$ at 1/4T = 17.902°F

Enable Temperature, T_e (1) $= RT_{NDT} + 40 + \max(\Delta T_{metal})$, °F
$= (199 + 40 + 17.902)$ °F
$= 256.902$°F

Enable Temperature, T_e (2) $= RT_{NDT} + 50 \ln[((F * M_m (pR_i / t)) - 33.2) / 20.734]$, °F
$= 199 + 50 \ln[((1.1 * .926(8.5)^{(1/2)} * 2.485 * 86.5 / 8.5)-33.2) / 20.734]$, °F
$= 199 + 50 \ln[41.90 / 20.734]$, °F
$= 199 + 50 \ln[2.021]$
$= 234.180$°F

The minimum required enable temperature for the D.C. Cook Unit 1 Reactor Vessels will be conservatively chosen to be 260°F for 32 EFPY.

10.3 48 EFPY Enable Temperature:

The highest calculated 1/4T ART of the critical material for the D.C. Cook Unit 1 reactor vessel beltline regions at 48 EFPY is 225°F.

From the OPERLIM computer code output for the D.C. Cook Unit 1 48 EFPY Pressure-Temperature limit curves without margins the maximum ΔT_{metal} is:

Cooldown Rate (Steady-State Cooldown):
max (ΔT_{metal}) at 1/4T = 0°F

Heatup Rate of 60°F/Hr:
max (ΔT_{metal}) at 1/4T = 17.902°F

Enable Temperature (ENBT) $= RT_{NDT} + 40 + \max(\Delta T_{metal})$, °F
$= (225 + 40 + 17.902)$ °F
$= 282.902$°F

Enable Temperature, T_e (2) $= RT_{NDT} + 50 \ln[((F * M_m (pR_i / t)) - 33.2) / 20.734]$, °F
$= 225 + 50 \ln[((1.1 * .926(8.5)^{(1/2)} * 2.485 * 86.5 / 8.5)-33.2) / 20.734]$, °F
$= 225 + 50 \ln[41.90 / 20.734]$, °F
$= 225 + 50 \ln[2.021]$
$= 260.180$°F

The minimum required enable temperature for the D.C. Cook Unit 1 Reactor Vessels will be conservatively chosen to be 285°F for 48 EFPY.

11.0 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 ASME Boiler and Pressure Vessel Code, Section XI, "Rule for Inservice Inspection of Nuclear Power Plant Components", Appendix G, "Fracture Toughness Criteria for Protection Against Failure", December 1995.

4 WCAP-12483, Revision 1, "Analysis of Capsule U from the Indiana Michigan Power Company D.C. Cook Unit 1 Reactor Vessel Radiation Surveillance Program", J. H. Ledger & E. T. Hayes, dated December 2002.

5 1989 Section III, Division 1 of the ASME Boiler and Pressure Vessel Code, Paragraph NB-2331, "Material for Vessels".

6 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.

7 AEP Design Information Transmittal (DIT), DIT-B-02230-00, "Material Chemistry of the Reactor Vessel Belt-line Materials for Cook Nuclear Plant Units 1 & 2", T.Satyan-Sharma, 10/23/01.

8 Cases of ASME Boiler and Pressure Vessel Code, Case N-640, "Alternative Reference Fracture Toughness for Development of P-T Limit Curves for Section XI, Division 1", Approved March 1999.

9 Cases of ASME Boiler and Pressure Vessel Code, Case N-641, "Alternative Pressure-Temperature Relationship and Low Temperature Overpressure Protection System Requirements," Approved 03/99.

10 Cases of ASME Boiler and Pressure Vessel Code, Case N-588, "Attenuation of Reference Flaw Orientation of Appendix G for Circumferential Welds in Reactor Vessels", Section XI, Division 1, Approved December 12, 1997.

11 "Reactor Vessel Material Surveillance Program for Donald C. Cook Unit No. 1 Analysis of Capsule T," Final Report SWRI Project 02-4770, December 1977.

12 "Reactor Vessel Material Surveillance Program for Donald C. Cook Unit No. 1 Analysis of Capsule X," Final Report SWRI Project 02-6159, June 1981.

13 "Reactor Vessel Material Surveillance Program for Donald C. Cook Unit No. 1 Analysis of Capsule Y," Final Report SWRI Project 06-7244-001, January 1984.

14 Combustion Engineering Drawing No. 233-440 "General Arrangement – Elevation"