ATTACHMENT C

to

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Kewaunee Reactor Vessel Heatup and Cooldown
Limit Curves for Normal Operation

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WESTINGHOUSE CLASS 3 (Non-Proprietary)

WCAP-14278

KEWAUNEE REACTOR VESSEL
HEATUP AND COOLDOWN LIMIT CURVES
FOR NORMAL OPERATION

P. A. Peter

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Work Performed Under Shop Order KFZP-139

Prepared by Westinghouse Electric Corporation
for the Wisconsin Public Service Corporation

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PREFACE

This report has been technically reviewed and verified by:

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EXECUTIVE SUMMARY

The report provides the methodology and results of the generation of heatup and cooldown pressure-temperature limit curves for normal operation for the Kewaunee Nuclear Generating Station. These curves were generated based on the latest available reactor vessel information, including data from the recent Capsule S analysis (WCAP-14279).

The previous set of heatup and cooldown curves were generated for Kewaunee in March 1992 and documented in WCAP-13229. The 1992 curves were based on:

- the average weight percent values of copper and nickel for the Kewaunee reactor vessel girth weld material available at the time of the evaluation,
- the utilization of the girth weld metal chemistry factor determined from Table 1 of Regulatory Guide 1.99, Revision 2, and
- projected fluence values based on the neutron dosimetry results from the first three surveillance capsules, utilizing the 47-group ENDF/B-IV data set integrated with the analytical predictions performed for the Kewaunee reactor vessel.

Since 1992, a fourth surveillance capsule (Capsule S) has been removed from the Kewaunee reactor vessel and the specimens tested. Additionally, LaSalle County Unit 1 has obtained additional weight percent copper and nickel data for a weld material identical to the Kewaunee reactor vessel girth weld material.

Consequently, the Kewaunee heatup and cooldown pressure-temperature limit curves have been updated to account for the latest available information. This reevaluation is based on:

- the latest weight percent copper and nickel data for the Kewaunee reactor vessel beltline materials (including the recent weld chemistry data obtained from LaSalle Unit 1),
- the current projected vessel fluence values based on the neutron dosimetry results from the four surveillance capsules removed to date, using the ENDF/B-VI data set and updated integrated analytical predictions performed for the Kewaunee reactor vessel,
- the measured initial RT_{NDT} for the limiting girth weld material determined from drop weight tests (performed in April 1994 and documented in WCAP-14042) and unirradiated Charpy test data (provided in the Kewaunee unirradiated surveillance program, WCAP-8107), and
- credible surveillance capsule data from four surveillance capsule specimens tested to date.

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SECTION 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 for 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 then 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 original unirradiated RT_{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 (irradiated RT_{NDT} with 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.

SECTION 2.0

FRACTURE TOUGHNESS PROPERTIES

The fracture-toughness properties of the ferritic material in the reactor coolant pressure boundary are determined in accordance with the NRC Regulatory Standard Review Plan[2]. The beltline material properties of the Kewaunee reactor vessel presented in Table 1 are from References 3 through 6.

Additionally, credible surveillance capsule data is available for four capsules (Capsules V, R, P, and S) already removed from the Kewaunee reactor vessel. This surveillance capsule data was used to calculate chemistry factor (CF) values (Table 2) in addition to those calculated per Tables 1 and 2 of Regulatory Guide 1.99, Revision 2.

The closure head flange and vessel flange material properties were obtained from Reference 5.

TABLE 1

Kewaunee Reactor Vessel Material Properties Used in Calculations

Material	Method	Cu%	Ni%	Chemistry Factor	Initial RT_{NDT}[(a)]
Closure Head Flange[5]	--	0.16	0.76	--	60
Vessel Flange[5]	--	0.14	0.68	--	60
Intermediate Shell Forging 122X208VA1[3,4]	Chemistry Data	0.06	0.71	37	60
	S/C Data			23.3	60
Lower Shell Forging 123X167VA1[3,4]	Chemistry Data	0.06	0.75	37	20
	S/C Data			20.8	20
Weld Metal[3,4]	Chemistry Data	0.30[(b)]	0.842[(b)]	231.7	-50[6]
	S/C Data			190.6	-50[6]

NOTE:
(a) Initial RT_{NDT} values of the base metal and weld metal materials are measured values.
(b) From Appendix of the PTS Report, WCAP-14280[11].

TABLE 2
Calculation of Chemistry Factors Using Kewaunee Credible Surveillance Capsule Data[6]

Material	Capsule	f[(a)]	FF[(b)]	ΔRT_{NDT}	FF*ΔRT_{NDT}	FF^2
Intermediate Shell Forging 122X208VA1	V	0.629	0.87	0	0	0.757
	R	1.94	1.18	15	17.7	1.392
	P	2.89	1.28	25	32.0	1.638
	S	3.45	1.32	60	79.2	1.742
				Sum:	128.9	5.529
	$CF = \sum(FF * RT_{NDT}) \div \sum(FF^2) = 23.3$					
Lower Shell Forging 123X167VA1	V	0.629	0.87	0	0	0.757
	R	1.94	1.18	20	23.6	1.392
	P	2.89	1.28	20	25.6	1.638
	S	3.45	1.32	50	66.0	1.742
				Sum:	115.2	5.529
	$CF = \sum(FF * RT_{NDT}) \div \sum(FF^2) = 20.8$					
Weld Metal	V	0.629	0.87	175	152.3	0.757
	R	1.94	1.18	235	277.3	1.392
	P	2.89	1.28	230	294.4	1.638
	S	3.45	1.32	250	330.0	1.742
				Sum:	1054.0	5.529
	$CF = \sum(FF * RT_{NDT}) \div \sum(FF^2) = 190.6$					

NOTES:
(a) f = fluence ÷ 10^{19} n/cm^2; All values taken from Capsule S analysis, WCAP-14279[6].
(b) FF = fluence factor = $f^{(0.28 - 0.1*\log f)}$

Therefore, the calculated Chemistry Factor for the Intermediate Shell Forging based on surveillance capsule data = 23.3°F. The calculated Chemistry Factor for the Lower Shell Forging based on surveillance capsule data = 20.8°F. The calculated Chemistry Factor for Weld Metal based on surveillance capsule data = 190.6°F

SECTION 3.0

CRITERIA FOR ALLOWABLE PRESSURE-TEMPERATURE RELATIONSHIPS

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 obtained from the reference fracture toughness curve, defined in Appendix G of the ASME Code, Section III[7]. The K_{IR} curve is given by the following equation:

$$K_{IR} = 26.78 + 1.223 * e^{[0.0145 (T - RTNDT + 160)]} \qquad (1)$$

where,

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

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

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

where,

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

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

K_{IR} = 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_{IR} 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_{IR} at the 1/4T location for finite cooldown rates than for steady-state operation. Furthermore, if conditions exist so that the increase in K_{IR} exceeds K_{It}, the calculated allowable pressure during cooldown will be greater than the steady-state value.

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

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

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

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

The 1983 Amendment to 10CFR50, Appendix G[8] addresses the metal temperature of the closure head flange and vessel flange regions. This rule states that the metal temperature of the closure flange regions must exceed the material unirradiated RT_{NDT} by at least 120°F for normal operation when the pressure exceeds 20 percent of the preservice hydrostatic test pressure (3107 psig per Table 4.1-2 of the USAR), which is 621 psig for Kewaunee.

Table 1 indicates that the limiting unirradiated RT_{NDT} of 60°F occurs in the closure head flange 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. This limit (where the horizontal line indicates that the pressure shall not exceed 621 psig for temperatures less than 180°F) is shown as a notch in the curves, presented wherever applicable in Figures 1 through 6.

SECTION 4.0

CALCULATION OF ADJUSTED REFERENCE TEMPERATURE

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

$$ART = \text{Initial } RT_{NDT} + \Delta RT_{NDT} + \text{Margin} \qquad (3)$$

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[9]. 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:

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

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

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

where x inches (vessel beltline thickness is 6.5 inches) is the depth into the vessel wall measured from the vessel clad/base metal interface. The resultant fluence is then placed in Equation 4 to calculate the ΔRT_{NDT} at the specific depth. The calculated surface fluence for the Kewaunee base metal and circumferential weld (at the 0° azimuthal angle of the reactor vessel) at 25 and 34 EFPY is 2.64×10^{19} n/cm^2 and 3.49×10^{19} n/cm^2, respectively.

The chemistry factor values (°F), obtained from Tables 1 and 2 of Regulatory Guide 1.99, Revision 2, were determined using the copper and nickel content values reported in Table 1. Chemistry factors were also calculated using credible surveillance capsule data as shown in Table 2.

Margin is calculated as, $M = 2\sqrt{\sigma_i^2 + \sigma_\Delta^2}$. The standard deviation for the initial RT_{NDT} margin term, σ_i, is 0°F when the initial RT_{NDT} is a measured value, and 17°F when a generic value is available. The standard deviation for the ΔRT_{NDT} margin term, σ_Δ, is 17°F for the forging, and 8.5°F for the forging (half the value) when surveillance data is used. For welds, σ_Δ is equal to 28°F when surveillance capsule is not used, and equal to 14°F when credible surveillance capsule data is used. σ_Δ need not exceed 0.5 times the mean value of ΔRT_{NDT}. See Table 3.

TABLE 3

Margins for Adjusted Reference Temperature (ART) Calculations
per Regulatory Guide 1.99, Revision 2

Material Properties	Surv. Capsule Data NOT Used	Surv. Capsule Data Used
Forgings		
Measured IRT_{NDT}	34	17
Generic IRT_{NDT}	48	38
Weld Metal		
Measured IRT_{NDT}	56	28
Generic IRT_{NDT}	66	44

All materials in the beltline region of Kewaunee reactor vessel were considered in determining the limiting material. Sample calculations, to determine the ART values for Weld Metal at 25 and 34 EFPY, are shown in Table 4. The resulting ART values for all beltline materials at the 1/4T and 3/4T locations are summarized in Table 5. From this table, it can be seen that the limiting material to be used in the generation of the heatup and cooldown curves is the Weld Metal using credible surveillance capsule data.

(Note: When two or more credible surveillance data sets become available, the data sets may be used to determine ART values as described in Regulatory Guide 1.99, Revision 2, Position 2.1. If the ART values based on surveillance capsule data are larger than those calculated per Regulatory Guide 1.99, Revision 2, Position 1.1, the surveillance data should be used. If the surveillance capsule data gives lower values, either may be used.)

TABLE 4

Calculation of ART Values for the Limiting Kewaunee Reactor Vessel Material -- Weld Metal Using Surveillance Capsule Data

Parameter	Values			
Operating Time	25 EFPY		34 EFPY	
Location	1/4T[b]	3/4T	1/4T	3/4T
Chemistry Factor, CF (°F)	190.6	190.6	190.6	190.6
Fluence, f (10^{19} n/cm^2)[a]	1.79	0.819	2.36	1.08
Fluence Factor, FF	1.16	0.944	1.23	1.02
ΔRT_{NDT} = CF x ff (°F)	221	180	235	194
Initial RT_{NDT}, I (°F)	-50	-50	-50	-50
Margin, M (°F)	28	28	28	28
Adjusted Reference Temperature (ART), (°F) per Reg. Guide 1.99, Revision 2	199	158	213	172

NOTES:
(a) Fluence, f, is based upon f_{surf} (10^{19} n/cm^2, E>1.0 MeV) = 2.64 at 25 EFPY and 3.49 at 34 EFPY.
(b) The Kewaunee reactor vessel wall thickness is 6.5 inches at the beltline region.

TABLE 5

Summary of ART Values at the 1/4T and 3/4T Locations

Material	Method	24 EFPY		34 EFPY	
		1/4T ART (°F)	3/4T ART (°F)	1/4T ART (°F)	3/4T ART (°F)
Intermediate Shell Forging 122X208VA1	Chemistry Data	137	129	140	132
	S/C Data	104	99	106	101
Lower Shell Forging 123X167VA1	Chemistry Data	97	89	100	92
	S/C Data	61	57	63	58
Weld Metal	Chemistry Data	275	225	292	242
	S/C Data	199	158	213	172

SECTION 5.0

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[10] discussed in Section 3.0 and 4.0 of this report. Since indication of reactor vessel beltline pressure is not available on the plant, the pressure difference between the wide-range pressure transmitter and the limiting beltline region of -64 psig (determined by the Wisconsin Public Service Corporation) has been accounted for in all of the pressure-temperature limit curves generated for normal operation.

Figures 1, 2, 4, and 5 present the heatup curves without margins for possible instrumentation errors using heatup rates of 60°F/hr and 100°F/hr applicable for the first 25 and 34 EFPY, respectively. Figures 3 and 6 present the cooldown curves without margins for possible instrumentation errors using cooldown rates up to 100°F/hr applicable for 25 and 34 EFPY, respectively. Allowable combinations of temperature and pressure for specific temperature change rates are below and to the right of the limit lines shown in Figures 1 through 6. This is in addition to other criteria which must be met before the reactor is made critical, as discussed below in the following paragraphs.

The reactor must not be made critical until pressure-temperature combinations are to the right of the criticality limit line shown in Figures 1, 2, 4, and 5. 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 10CFR Part 50[8]. The governing equation for the hydrostatic test is defined in Appendix G to Section III of the ASME Code as follows:

$1.5\ K_{Im} < K_{IR}$, where

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

$K_{IR} = 26.78 + 1.233\ e^{[0.0145\ (T\ -\ RTNDT\ +\ 160)]}$,

T is the minimum permissible metal temperature, and

RTNDT 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 8. The pressure-temperature limits for core operation (except for low power physics tests) are that the reactor vessel must be at a temperature equal to or higher than the minimum temperature required for the inservice hydrostatic test, and at least 40°F higher than the minimum permissible temperature in the corresponding pressure-temperature curve for heatup and cooldown calculated as described in Section 3.0 of this report. The minimum temperatures for the inservice hydrostatic leak tests for the Kewaunee reactor vessel at 25 EFPY is 320°F and 334°F at 34 EFPY. 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 1 through 6 define all of the above limits for ensuring prevention of nonductile failure for the Kewaunee reactor vessel.

The data points used for the heatup and cooldown pressure-temperature limit curves shown in Figures 1 through 6 are presented in Tables 6 and 7.

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: WELD METAL USING SURVEILLANCE CAPSULE DATA
LIMITING ART VALUES AT 25 EFPY: 1/4T, 199°F
3/4T, 158°F

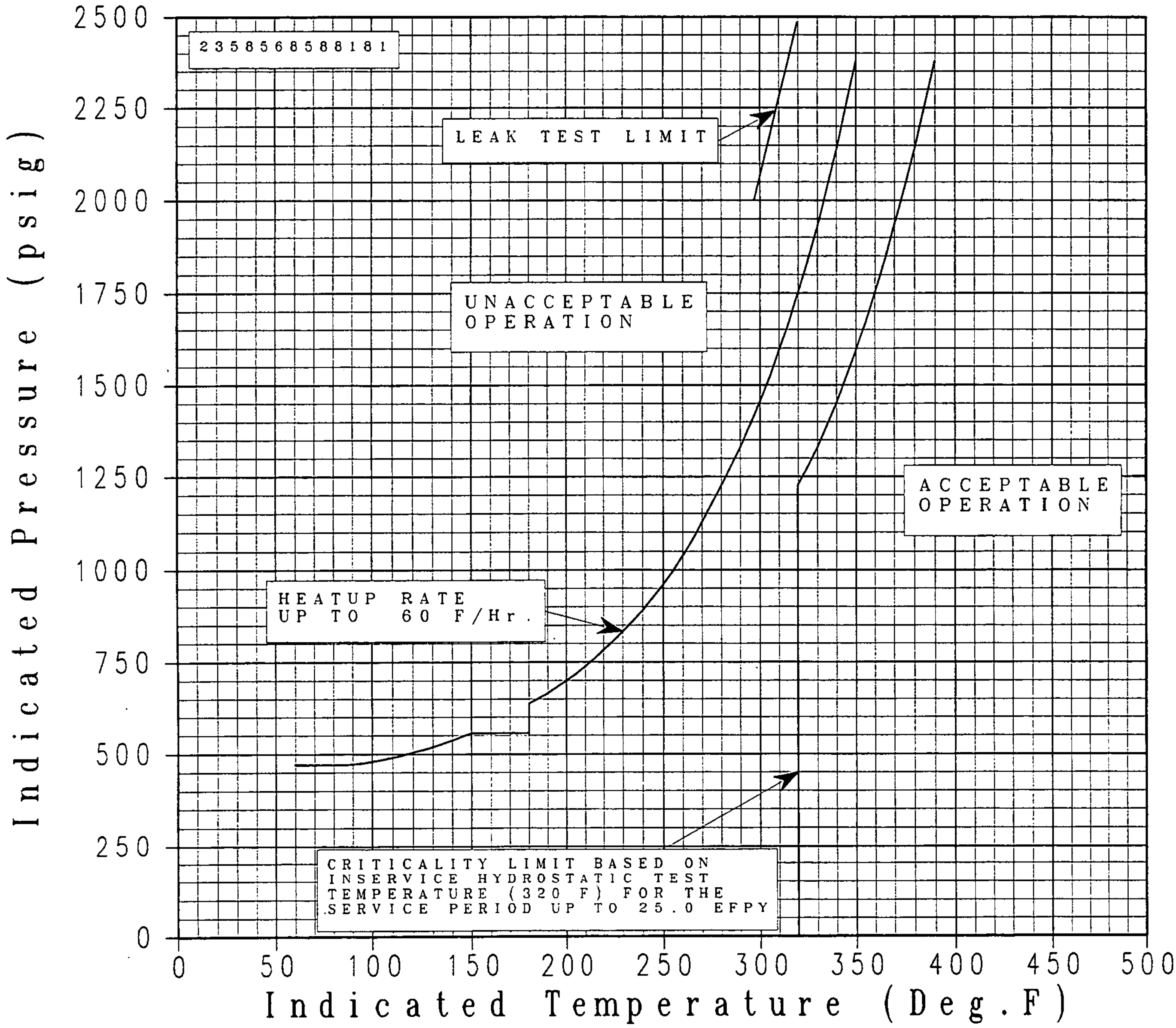

FIGURE 1 Kewaunee Reactor Coolant System Heatup Limitations (Heatup Rates up 60°F/hr) Applicable for the First 25 EFPY (Without Margins for Instrumentation Errors)
Includes 1) Vessel flange requirements of 180°F and 621 psig per 10CFR50, Appendix G, and 2) Pressure Margin of 64 psig for the difference between the gage and beltline region.

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: WELD METAL USING SURVEILLANCE CAPSULE DATA
LIMITING ART VALUES AT 25 EFPY: 1/4T, 199°F
3/4T, 158°F

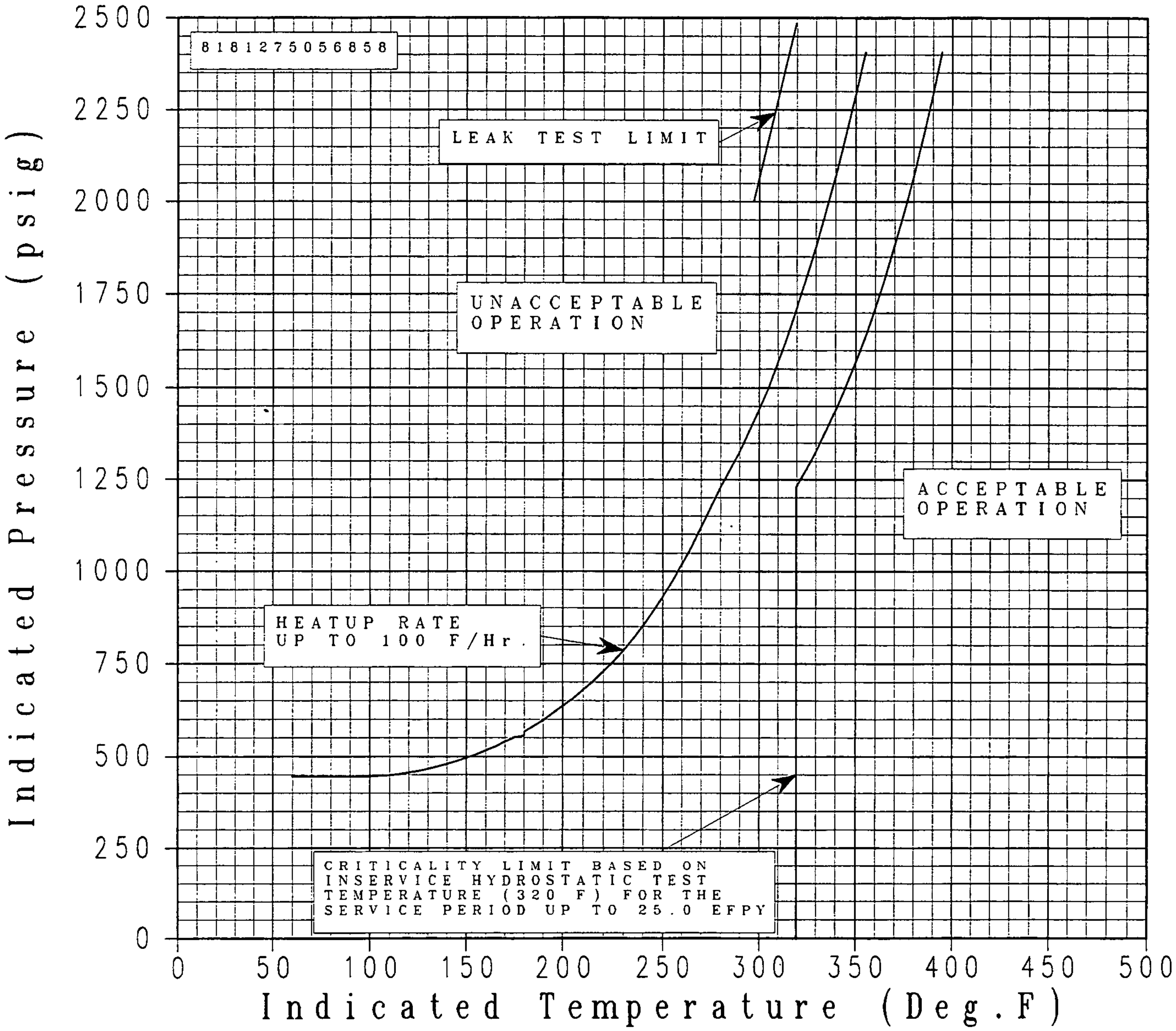

FIGURE 2 Kewaunee Reactor Coolant System Heatup Limitations (Heatup Rates up 100°F/hr) Applicable for the First 25 EFPY (Without Margins for Instrumentation Errors)
Includes 1) Vessel flange requirements of 180°F and 621 psig per 10CFR50, Appendix G, and
2) Pressure Margin of 64 psig for the difference between the gage and beltline region.

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: WELD METAL USING SURVEILLANCE CAPSULE DATA
LIMITING ART VALUES AT 25 EFPY: 1/4T, 199°F
3/4T, 158°F

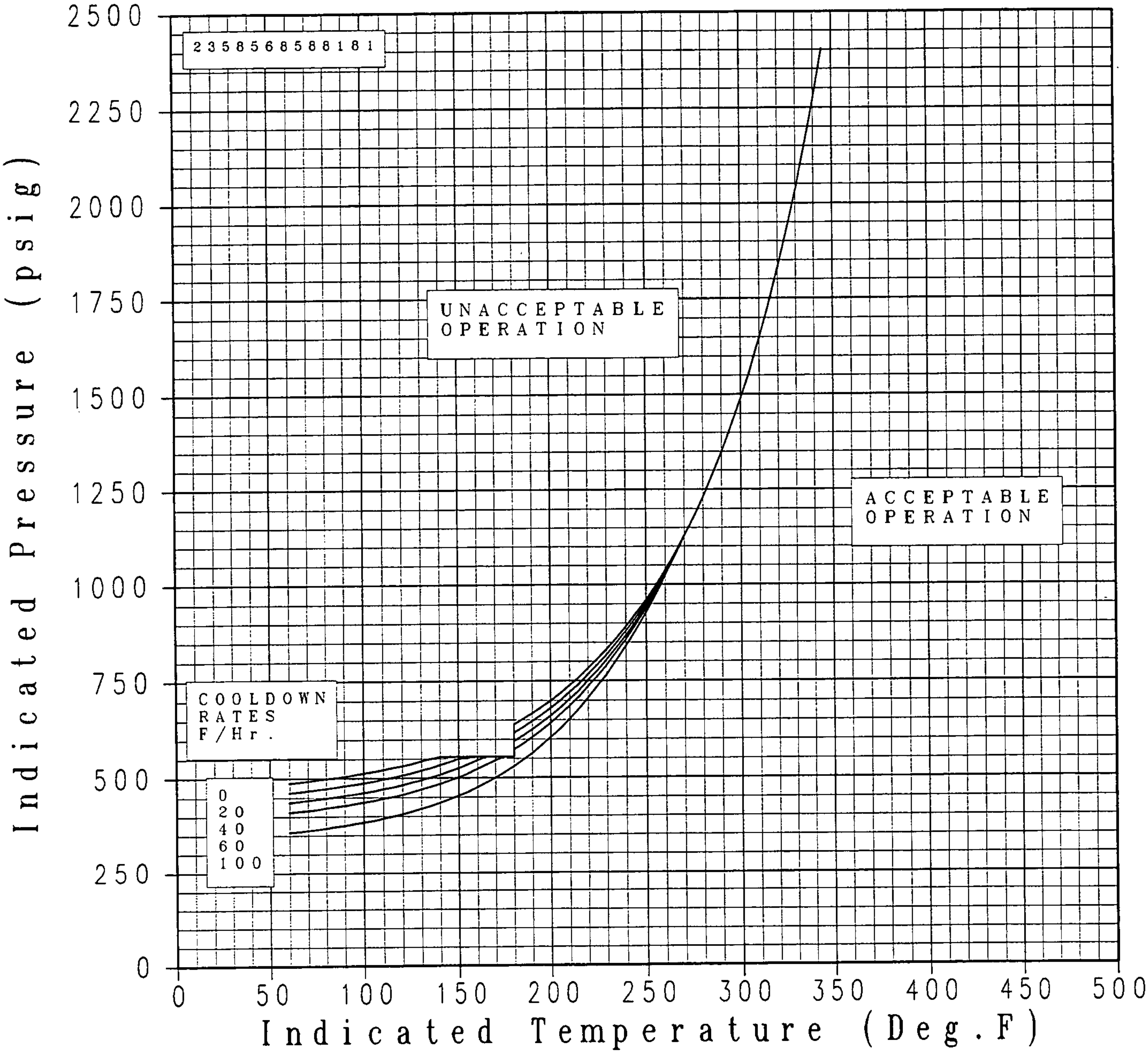

FIGURE 3 Kewaunee Reactor Coolant System Cooldown Limitations (Cooldown Rates up to 100°F/hr) Applicable for the First 25 EFPY (Without Margins for Instrumentation Errors)
Includes 1) Vessel flange requirements of 180°F and 621 psig per 10CFR50, Appendix G, 2) Pressure Margin of 64 psig for the difference between the gage and beltline region.

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: WELD METAL USING SURVEILLANCE CAPSULE DATA
LIMITING ART VALUES AT 34 EFPY: 1/4T, 213°F
3/4T, 172°F

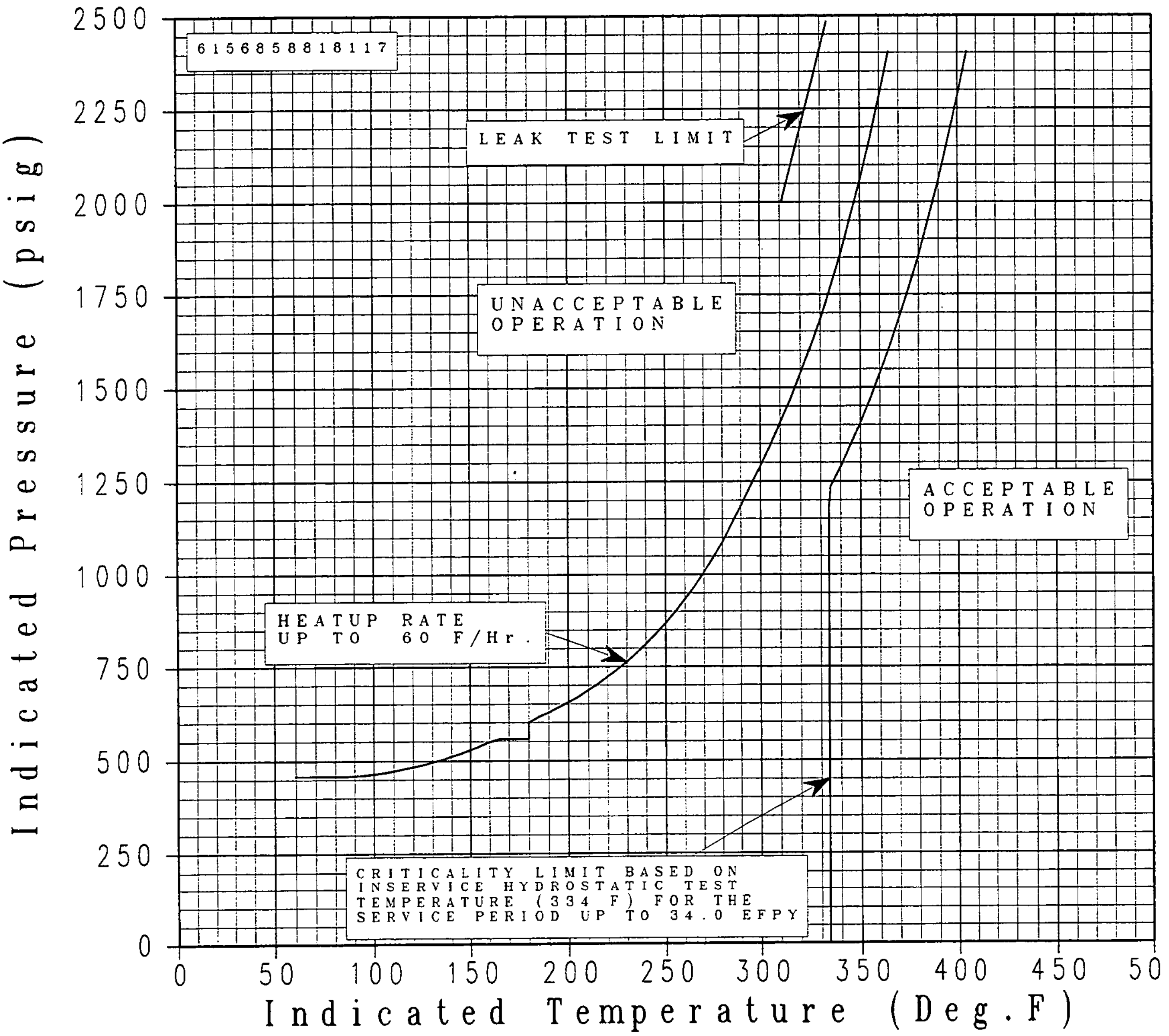

FIGURE 4 Kewaunee Reactor Coolant System Heatup Limitations (Heatup Rates up 60°F/hr) Applicable for the First 34 EFPY (Without Margins for Instrumentation Errors)
Includes 1) Vessel flange requirements of 180°F and 621 psig per 10CFR50, Appendix G, and
2) Pressure Margin of 64 psig for the difference between the gage and beltline region.

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: WELD METAL USING SURVEILLANCE CAPSULE DATA
LIMITING ART VALUES AT 34 EFPY: I/4T, 213°F
3/4T, 172°F

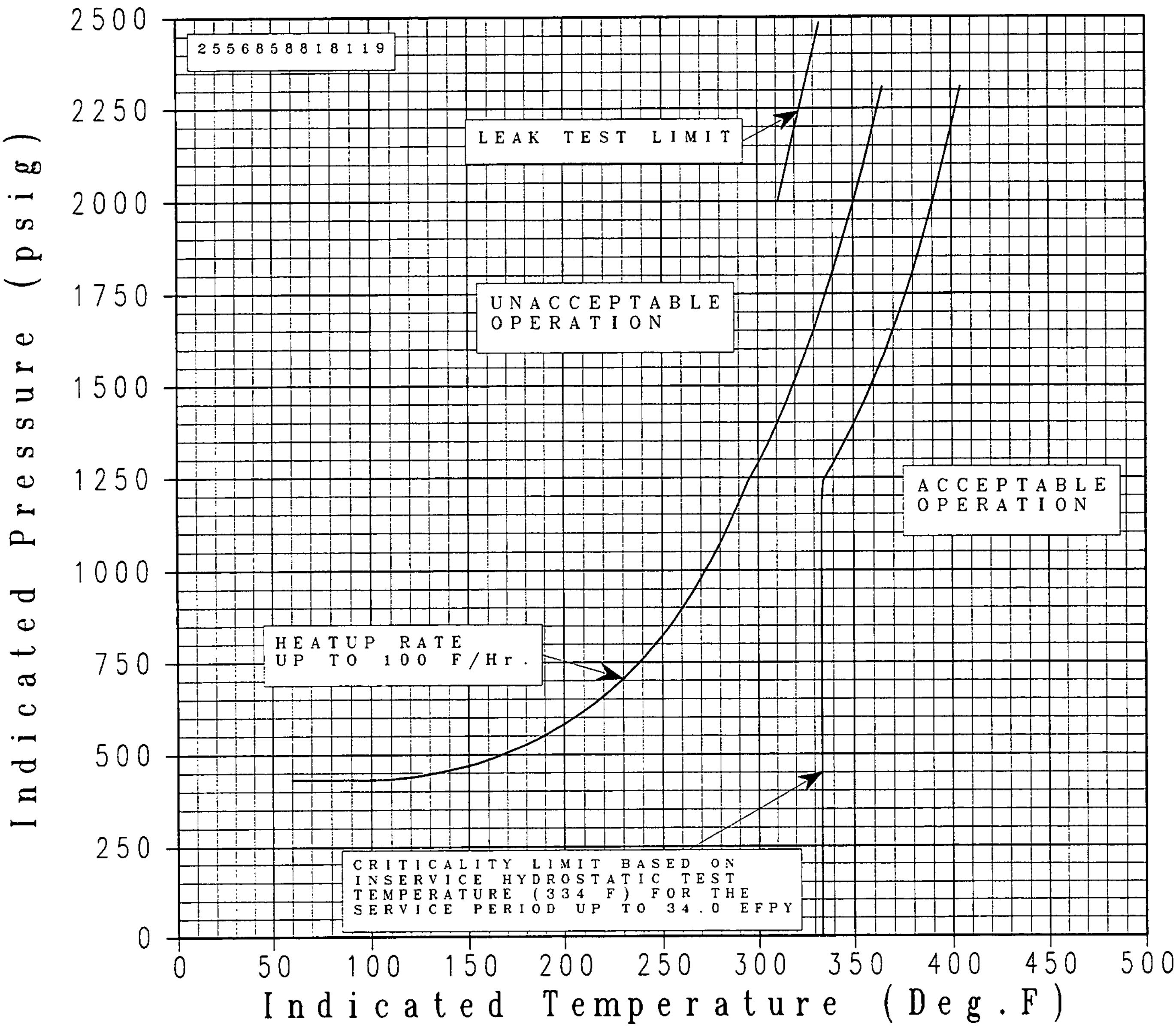

FIGURE 5 Kewaunee Reactor Coolant System Heatup Limitations (Heatup Rates up 100°F/hr) Applicable for the First 34 EFPY (Without Margins for Instrumentation Errors)
Includes 1) Vessel flange requirements of 180°F and 621 psig per 10CFR50, Appendix G, and
2) Pressure Margin of 64 psig for the difference between the gage and beltline region.

MATERIAL PROPERTY BASIS

LIMITING MATERIAL: WELD METAL USING SURVEILLANCE CAPSULE DATA
LIMITING ART VALUES AT 34 EFPY: 1/4T, 213°F
3/4T, 172°F

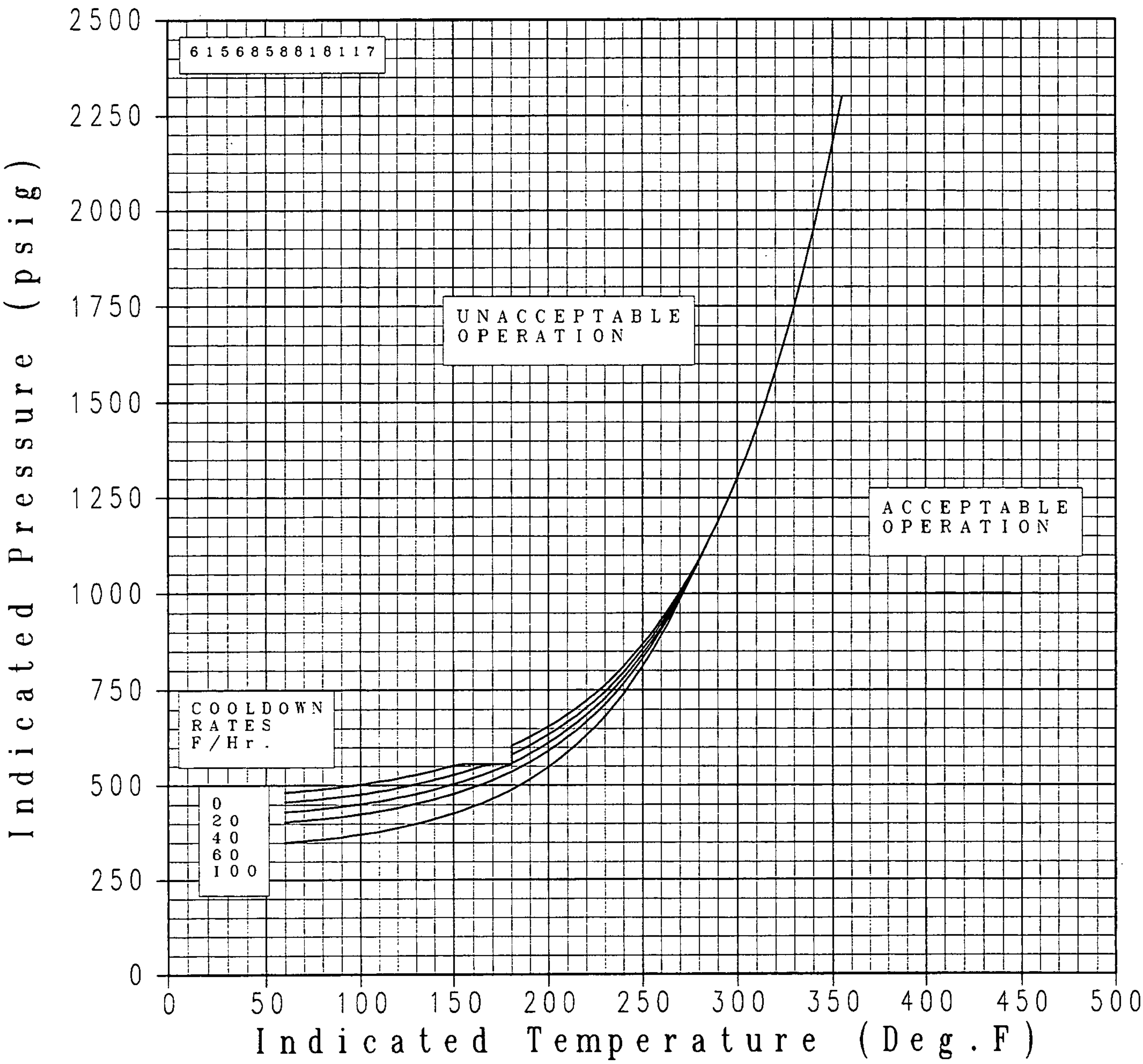

FIGURE 6 Kewaunee Reactor Coolant System Cooldown Limitations (Cooldown Rates up to 100°F/hr) Applicable for the First 34 EFPY (Without Margins for Instrumentation Errors)

Includes 1) Vessel flange requirements of 180°F and 621 psig per 10CFR50, Appendix G, 2) Pressure Margin of 64 psig for the difference between the gage and beltline region,.

TABLE 6

Kewaunee Heatup and Cooldown Curve Data Points Applicable to 25 EFPY

Cooldown Curves

Steady State		20 DEG CD		40 DEG CD		60 DEG CD		100 DEG CD	
T	P	T	P	T	P	T	P	T	P
60	488.64	60	463.39	60	437.75	60	411.83	60	358.72
65	491.06	65	465.83	65	440.17	65	414.22	65	361.10
70	493.66	70	468.42	70	442.74	70	416.80	70	363.69
75	496.46	75	471.23	75	445.56	75	419.62	75	366.54
80	499.47	80	474.14	80	448.58	80	422.66	80	369.62
85	502.71	85	477.40	85	451.87	85	425.98	85	373.02
90	506.19	90	480.90	90	455.39	90	429.55	90	376.61
95	509.93	95	484.68	95	459.23	95	433.35	95	380.63
100	513.95	100	488.75	100	463.35	100	437.53	100	384.97
105	518.27	105	493.15	105	467.83	105	442.09	105	389.72
110	522.80	110	497.87	110	472.63	110	446.99	110	394.84
115	527.79	115	502.97	115	477.74	115	452.32	115	400.43
120	533.17	120	508.45	120	483.33	120	458.04	120	406.45
125	538.94	125	514.36	125	489.39	125	464.26	125	413.02
130	545.16	130	520.71	130	495.90	130	470.94	130	420.09
135	551.83	135	527.44	135	502.95	135	478.08	135	427.78
140	557.00	140	534.81	140	510.51	140	485.87	140	435.98
145	557.00	145	542.75	145	518.70	145	494.31	145	444.98
150	557.00	150	551.29	150	527.36	150	503.38	150	454.67
155	557.00	155	557.00	155	536.86	155	513.19	155	465.18
160	557.00	160	557.00	160	547.07	160	523.62	160	476.40
165	557.00	165	557.00	165	557.00	165	535.03	165	488.66
170	557.00	170	557.00	170	557.00	170	547.29	170	501.86
175	557.00	175	557.00	175	557.00	175	557.00	175	516.15
180	557.00	180	557.00	180	557.00	180	557.00	180	531.41
180	639.36	180	617.91	180	596.30	180	574.65	185	548.05
185	653.14	185	632.05	185	611.11	185	590.03	190	565.94
190	667.76	190	647.40	190	626.88	190	606.57	195	585.16
195	683.68	195	663.89	195	644.05	195	624.26	200	606.00
200	700.78	200	681.50	200	662.47	200	643.45	205	628.32
205	718.98	205	700.60	205	682.21	205	664.11	210	652.53
210	738.76	210	720.97	210	703.57	210	686.23	215	678.48
215	759.93	215	743.08	215	726.41	215	710.18	220	706.56
220	782.64	220	766.63	220	751.13	220	735.84	225	736.72
225	807.11	225	792.18	225	777.61	225	763.42	230	769.13
230	833.36	230	819.46	230	806.17	230	793.30	235	804.26
235	861.45	235	848.96	235	836.89	235	825.29	240	841.92
240	891.92	240	880.58	240	869.77	240	859.64	245	882.49
245	924.45	245	914.45	245	905.17	245	896.88	250	926.09
250	959.35	250	951.08	250	943.47	250	936.71	255	973.07
255	997.06	255	990.28	255	984.48	255	979.60	260	1023.56
260	1037.42	260	1032.46	260	1028.50	260	1025.65	265	1077.88
265	1080.80	265	1077.78	265	1075.88	265	1075.19		
270	1127.36	270	1126.43	270	1126.73				
275	1177.35								
280	1230.99								
285	1288.48								
290	1350.45								
295	1416.71								
300	1487.85								
305	1563.85								
310	1645.85								
315	1733.40								
320	1827.20								
325	1927.67								
330	2034.74								
335	2149.83								
340	2272.33								
345	2403.24								

Heatup Curves

60 DEG		Crit. Limit		100 DEG		Crit. Limit	
T	P	T	P	T	P	T	P
60	471.05	320	0.00	60	445.68	320	0.00
65	471.05	320	484.16	65	445.68	320	483.65
70	471.05	320	476.81	70	445.68	320	471.11
75	471.05	320	472.52	75	445.68	320	461.45
80	471.05	320	471.05	80	445.68	320	454.61
85	471.40	320	471.40	85	445.68	320	449.84
90	473.38	320	473.38	90	445.68	320	447.04
95	476.28	320	476.28	95	445.68	320	445.68
100	480.33	320	480.33	100	445.75	320	445.75
105	485.11	320	485.11	105	446.88	320	446.88
110	490.70	320	490.70	110	449.11	320	449.11
115	496.91	320	496.91	115	452.21	320	452.21
120	503.84	320	503.84	120	456.23	320	456.23
125	511.37	320	511.37	125	461.02	320	461.02
130	519.63	320	519.63	130	466.65	320	466.65
135	528.42	320	528.42	135	473.01	320	473.01
140	538.11	320	538.11	140	480.06	320	480.06
145	548.51	320	548.51	145	487.97	320	487.97
150	557.00	320	559.79	150	496.71	320	496.71
155	557.00	320	571.74	155	506.25	320	506.25
160	557.00	320	584.81	160	516.66	320	516.66
165	557.00	320	598.84	165	527.83	320	527.83
170	557.00	320	613.95	170	540.09	320	540.09
175	557.00	320	626.55	175	553.33	320	553.33
180	557.00	320	639.36	180	557.00	320	567.64
180	639.36	320	653.14	180	567.64	320	582.95
185	653.14	320	667.76	185	582.95	320	599.62
190	667.76	320	683.68	190	599.62	320	617.52
195	683.68	320	700.78	195	617.52	320	636.72
200	700.78	320	718.98	200	636.72	320	657.50
205	718.98	320	738.76	205	657.50	320	679.71
210	738.76	320	759.93	210	679.71	320	703.76
215	759.93	320	782.64	215	703.76	320	729.46
220	782.64	320	807.11	220	729.46	320	757.21
225	807.11	320	833.36	225	757.21	320	786.96
230	833.36	320	861.45	230	786.96	320	818.84
235	861.45	320	891.92	235	818.84	320	853.28
240	891.92	320	924.45	240	853.28	320	890.14
245	924.45	320	959.35	245	890.14	320	929.76
250	959.35	320	997.06	250	929.76	320	972.23
255	997.06	320	1037.42	255	972.23	320	1017.84
260	1037.42	320	1080.80	260	1017.84	320	1066.80
265	1080.80	320	1127.36	265	1066.80	320	1119.34
270	1127.36	320	1177.35	270	1119.34	320	1175.61
275	1177.35	320	1227.93	275	1175.61	320	1230.99
280	1227.93	325	1278.55	280	1230.99	325	1278.34
285	1278.55	330	1332.62	285	1278.34	330	1328.21
290	1332.62	335	1391.01	290	1328.21	335	1381.60
295	1391.01	340	1453.40	295	1381.60	340	1439.08
300	1453.40	345	1520.03	300	1439.08	345	1500.44
305	1520.03	350	1591.85	305	1500.44	350	1566.00
310	1591.85	355	1668.55	310	1566.00	355	1636.67
315	1668.55	360	1750.75	315	1636.67	360	1711.96
320	1750.75	365	1838.70	320	1711.96	365	1792.84
325	1838.70	370	1932.63	325	1792.84	370	1879.10
330	1932.63	375	2033.02	330	1879.10	375	1971.42
335	2033.02	380	2140.85	335	1971.42	380	2070.11
340	2140.85	385	2255.64	340	2070.11	385	2175.28
345	2255.64	390	2378.22	345	2175.28	390	2288.02
350	2378.22			350	2288.02	395	2407.80
				355	2407.80		

Leak Test Data

T	P
297	2000
320	2485

TABLE 7

Kewaunee Heatup and Cooldown Curve Data Points Applicable to 34 EFPY

Cooldown Curves										Heatup Curves								Leak Test Data	
Steady State		20 DEG CD		40 DEG CD		60 DEG CD		100 DEG CD		60 DEG		Crit. Limit		100 DEG		Crit. Limit			
T	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P	T	P
60	482.72	60	457.24	60	431.35	60	405.18	60	351.50	60	458.94	334	0.00	60	432.14	334	0.00	311	2000
65	484.69	65	459.21	65	433.28	65	407.06	65	353.34	65	458.94	334	474.04	65	432.14	334	473.67	334	2485
70	486.82	70	461.31	70	435.34	70	409.10	70	355.33	70	458.94	334	466.31	70	432.14	334	460.79		
75	489.11	75	463.58	75	437.60	75	411.34	75	357.55	75	458.94	334	461.40	75	432.14	334	450.81		
80	491.56	80	466.02	80	440.02	80	413.75	80	359.95	80	458.94	334	459.31	80	432.14	334	443.55		
85	494.20	85	468.66	85	442.66	85	416.39	85	362.61	85	458.94	334	458.94	85	432.14	334	438.27		
90	497.05	90	471.49	90	445.50	90	419.24	90	365.49	90	460.10	334	460.10	90	432.14	334	434.86		
95	500.10	95	474.46	95	448.59	95	422.35	95	368.66	95	462.20	334	462.20	95	432.14	334	432.83		
100	503.38	100	477.76	100	451.91	100	425.70	100	372.09	100	465.26	334	465.26	100	432.14	334	432.14		
105	506.91	105	481.32	105	455.52	105	429.35	105	375.78	105	468.97	334	468.97	105	432.42	334	432.42		
110	510.71	110	485.16	110	459.39	110	433.20	110	379.84	110	473.39	334	473.39	110	433.72	334	433.72		
115	514.79	115	489.30	115	463.61	115	437.48	115	384.29	115	478.22	334	478.22	115	435.80	334	435.80		
120	519.16	120	493.75	120	468.13	120	442.08	120	389.09	120	483.79	334	483.79	120	438.72	334	438.72		
125	523.77	125	498.55	125	473.03	125	447.09	125	394.34	125	489.85	334	489.85	125	442.31	334	442.31		
130	528.84	130	503.72	130	478.19	130	452.48	130	399.99	130	496.52	334	496.52	130	446.63	334	446.63		
135	534.29	135	509.29	135	483.90	135	458.33	135	406.16	135	503.72	334	503.72	135	451.58	334	451.58		
140	540.15	140	515.29	140	490.03	140	464.62	140	412.81	140	511.57	334	511.57	140	457.23	334	457.23		
145	546.45	145	521.74	145	496.67	145	471.44	145	420.04	145	520.00	334	520.00	145	463.50	334	463.50		
150	553.23	150	528.57	150	503.80	150	478.67	150	427.83	150	529.03	334	529.03	150	470.47	334	470.47		
155	557.00	155	536.06	155	511.51	155	486.61	155	436.21	155	538.86	334	538.86	155	478.00	334	478.00		
160	557.00	160	544.11	160	519.79	160	495.16	160	445.33	160	549.48	334	549.48	160	486.37	334	486.37		
165	557.00	165	552.79	165	528.63	165	504.40	165	455.23	165	557.00	334	560.88	165	495.46	334	495.46		
170	557.00	170	557.00	170	538.25	170	514.35	170	465.89	170	557.00	334	573.05	170	505.35	334	505.35		
175	557.00	175	557.00	175	548.64	175	524.98	175	477.34	175	557.00	334	586.26	175	516.05	334	516.05		
180	557.00	180	557.00	180	557.00	180	536.54	180	489.77	180	557.00	334	600.51	180	527.52	334	527.52		
180	605.87	180	582.83	180	559.81	185	549.03	185	503.24	180	600.51	334	615.77	185	540.02	334	540.02		
185	617.08	185	594.46	185	571.72	190	562.47	190	517.74	185	615.77	334	629.04	190	553.53	334	553.53		
190	629.04	190	606.98	190	584.67	195	576.83	195	533.30	190	629.04	334	642.04	195	568.07	334	568.07		
195	642.04	195	620.27	195	598.65	200	592.43	200	550.19	195	642.04	334	656.00	200	583.63	334	583.63		
200	656.00	200	634.76	200	613.66	205	609.28	205	568.43	200	656.00	334	670.85	205	600.52	334	600.52		
205	670.85	205	650.35	205	629.71	210	627.22	210	587.95	205	670.85	334	687.00	210	618.55	334	618.55		
210	687.00	210	666.93	210	647.12	215	646.76	215	609.17	210	687.00	334	704.35	215	638.11	334	638.11		
215	704.35	215	684.96	215	665.84	220	667.57	220	631.85	215	704.35	334	722.82	220	659.15	334	659.15		
220	722.82	220	704.35	220	685.87	225	690.23	225	656.50	220	722.82	334	742.89	225	681.62	334	681.62		
225	742.89	225	725.02	225	707.57	230	714.37	230	682.86	225	742.89	334	764.22	230	705.93	334	705.93		
230	764.22	230	747.46	230	730.76	235	740.63	235	711.45	230	764.22	334	787.42	235	731.93	334	731.93		
235	787.42	235	771.38	235	755.87	240	768.62	240	742.11	235	787.42	334	812.08	240	759.98	334	759.98		
240	812.08	240	797.31	240	782.76	245	799.00	245	775.11	240	812.08	334	838.85	245	790.06	334	790.06		
245	838.85	245	825.01	245	811.63	250	831.49	250	810.61	245	838.85	334	867.38	250	822.29	334	822.29		
250	867.38	250	854.94	250	842.90	255	866.44	255	849.10	250	867.38	334	898.22	255	856.90	334	856.90		
255	898.22	255	887.01	255	876.40	260	904.16	260	890.31	255	898.22	334	931.27	260	894.32	334	894.32		
260	931.27	260	921.45	260	912.31	265	944.67	265	934.70	260	931.27	334	966.71	265	934.34	334	934.34		
265	966.71	265	958.42	265	951.17	270	988.20	270	982.43	265	966.71	334	1004.77	270	977.25	334	977.25		
270	1004.77	270	998.40	270	992.78	275	1035.03	275	1033.81	270	1004.77	334	1045.84	275	1023.33	334	1023.33		
275	1045.84	275	1041.13	275	1037.52	280	1085.31	280	1089.02	275	1045.84	334	1089.84	280	1072.80	334	1072.80		
280	1089.84	280	1087.12	280	1085.59					280	1089.84	334	1137.09	285	1125.82	334	1125.82		
285	1137.09	285	1136.49							285	1137.09	334	1187.56	290	1182.72	334	1182.72		
290	1187.56									290	1187.56	335	1237.83	295	1241.17	335	1241.17		
295	1242.08									295	1237.83	340	1289.12	300	1288.27	540	1288.27		
300	1300.60									300	1289.12	345	1344.24	305	1338.86	345	1338.86		
305	1363.33									305	1344.24	350	1403.12	310	1393.02	350	1393.02		
310	1430.45									310	1403.12	355	1466.36	315	1451.08	355	1451.08		
315	1502.70									315	1466.36	360	1533.99	320	1513.23	360	1513.23		
320	1579.99									320	1533.99	365	1606.61	325	1579.74	365	1579.74		
325	1662.73									325	1606.61	370	1684.24	330	1651.01	370	1651.01		
330	1751.39									330	1684.24	375	1767.44	335	1727.37	375	1727.37		
335	1846.49									335	1767.44	380	1856.45	340	1808.94	380	1808.94		
340	1948.50									340	1856.45	385	1951.64	345	1896.11	385	1896.11		
345	2057.40									345	1951.64	390	2053.58	350	1989.47	390	1989.47		
350	2173.36									350	2053.58	395	2162.31	355	2089.53	395	2089.53		
355	2297.93									355	2162.31	400	2278.47	360	2196.09	400	2196.09		
										360	2278.47	405	2402.63	365	2310.00	405	2310.00		
										365	2402.63								

SECTION 6.0
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