# HEATUP AND COOLDOWN LIMIT CURVES
# FOR NORMAL OPERATION

## BRAIDWOOD UNIT 2
## (CAPSULE U)

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February 1991

Work Performed Under Shop Order BMVP-106

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## 1. INTRODUCTION

Heatup and cooldown limit curves are calculated using the most limiting value of $RT_{NDT}$ (reference nil-ductility temperature) for the reactor vessel. The most limiting $RT_{NDT}$ of the material in the core region of the reactor vessel is determined by using the preservice reactor vessel material fracture toughness properties and estimating the radiation-induced $\Delta RT_{NDT}$. $RT_{NDT}$ 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, $\Delta RT_{NDT}$ 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 Rev. 2 (Radiation Embrittlement of Reactor Vessel Materials)[1]. Regulatory Guide 1.99, Revision 2 is used for the calculation of $RT_{NDT}$ values at 1/4T and 3/4T locations (T is the thickness of the vessel at the beltline region).

## 2. 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 pre-irradiation fracture-toughness properties of the Braidwood Unit 2 reactor vessel are presented in Table 1.

## 3. 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 to the ASME Code[3]. The $K_{IR}$ curve is given by the following equation:

$$K_{IR} = 26.78 + 1.223 \exp [0.0145 (T - RT_{NDT} + 160)] \qquad (1)$$

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[3] as follows:

$$C\, K_{IM} + K_{IT} \leq K_{IR} \qquad (2)$$

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 the postulated flaw, 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 1/4 T vessel location is at a higher temperature than the fluid adjacent to the vessel ID. This condition, of course, is not true for the steady-state situation. It follows that, at any given reactor coolant temperature, the $\Delta T$ developed during cooldown results in a higher value of $K_{IR}$ at the 1/4 T 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 1/4 T 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 1/4 T defect at the inside of the wall 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 1/4 T crack during heatup is lower than the $K_{IR}$ for the 1/4 T 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 $K_{IR}$'s 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 1/4 T 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 1/4 T deep outside surface flaw 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.

Finally, the 1983 Amendment to 10CFR50[4] has a rule which 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 $RT_{NDT}$ by at least 120°F for normal operation when the pressure exceeds 20 percent of the preservice hydrostatic test pressure.

Table 1 indicates that the initial $RT_{NDT}$ of 20°F occurs in both the vessel flange and the closure head flange of Braidwood Unit 2, so the minimum allowable temperature of this region is 140°F. These limits are shown in Figures 1 and 2 whenever applicable.

## 4. HEATUP AND COOLDOWN LIMIT CURVES

Limit curves for normal heatup and cooldown of the primary Reactor Coolant System have been calculated using the methods discussed in Section 3. Figure 1 is the heatup curve up to 100°F/hr and applicable for the first 16 EFPY without margins for possible instrumentation errors. Figure 2 is the cooldown curve up to 100°F/hr and applicable for the first 16 EFPY without margins for possible instrumentation errors.

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 and 2. This is in addition to other criteria which must be met before the reactor is made critical.

The leak limit curve shown in Figure 1 represents minimum temperature requirements at the leak test pressure specified by applicable codes[2,3]. The ı..κ test limit curve was determi. by methods of References 2 and 4.

Figures 1 and 2 define limits for ensuring prevention of nonductile failure for the Braidwood Unit 2 reactor vessel.

5. ADJUSTED REFERENCE TEMPERATURE

From Regulatory Guide 1.99 Rev. 2[1] the adjusted reference temperature (ART) for each material in the beltline is given by the following expression:

$$ART = \text{Initial } RT_{NDT} + \Delta RT_{NDT} + \text{Margin} \tag{3}$$

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. 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.

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

$$\Delta RT_{NDT} = [CF]f^{(0.28-0.10 \log f)} \tag{4}$$

To calculate $\Delta RT_{NDT}$ 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.

$$f_{(\text{depth } X)} = f_{\text{surface}}(e^{-.24x}) \tag{5}$$

where x (in inches) is the depth into the vessel wall measured from the vessel clad/base metal interface. The resultant fluence is then put into equation (4) to calculate $\Delta RT_{NDT}$ at the specific depth.

CF (°F) is the ch stry factor, obtained from Ref nce 1. All materials in the beltline region of Braidwood Unit 2 were considered for the limiting material. $RT_{NDT}$ at 1/4T and 3/4T are summarized in Table 2. From Table 2, it can be seen that the limiting material is the circumferential weld for heatup and cooldown curves applicable up to 16 EFPY. A sample calculation for $RT_{NDT}$ is shown in Table 3.

TABLE 1

BRAIDWOOD UNIT 2 REACTOR VESSEL TOUGHNESS TABLE (Unirradiated)

| Component | Heat No. | Cu (%) | Ni (%) | I (a) (°F) |
|---|---|---|---|---|
| Closure head flange (b) | 2031-V-1 | - | - | 20 |
| Vessel flange (b) | 124P455 | - | - | 20 |
| Upper Shell | 49D963/ 49C904 1-1 | .03 | .71 | -30 |
| Lower Shell | 50D102/ 50C97 1-1 | .06 | .75 | -30 |
| Circumferential Weld (c) | WF562 | .04 | .67 | 40 |

a. The initial $RT_{NDT}$ (I) values for the forgings and weld are measured values.

b. To be used for considering flange requirements for heatup/cooldown curves[4]

c. These values from Weld Certification Test Report WF562 are higher than the values of 0.03% Cu and 0.67% Ni used in the PTS submittal[5].

TABLE 2

SUMMARY OF ADJUSTED REFERENCE TEMPERATURE (ART) AT 1/4T and 3/4T LOCATION

| | 16 EFPY | |
|---|---|---|
| | $RT_{NDT}$ AT | |
| Component | 1/4T (°F) | 3/4T (°F) |
| Upper Shell, 49D963/49C904 1-1 | 9 | -2 |
| Lower Shell, 50D102/50C97 1-1 | 40 | 21 |
| Circumferential Weld | 145* | 115* |

* These $RT_{NDT}$ numbers used to generate heatup and cooldown curves applicable up to 16 EFPY

TABLE 3

CALCULATION OF ADJUSTED REFERENCE TEMPERATURES FOR LIMITING BRAIDWOOD UNIT 2 REACTOR VESSEL MATERIAL - CIRCUMFERENTIAL WELD

| Parameter | Regulatory Guide 1.99 - Revision 2, 16 EFPY, 1/4 T | Regulatory Guide 1.99 - Revision 2, 16 EFPY, 3/4 T |
|---|---|---|
| Chemistry Factor, CF (°F) | 54.00 | 54.00 |
| Fluence, f ($10^{19}$ n/cm$^2$)(a) | 0.907 | 0.327 |
| Fluence Factor, ff | 0.973 | 0.693 |
| ******************** | | |
| $\Delta RT_{NDT}$ = CF x ff (°F) | 52.5 | 37.4 |
| Initial $RT_{NDT}$, I (°F) | 40.0 | 40.0 |
| Margin, M (°F) (b) | 52.5 | 37.4 |
| ******************** | | |
| Revision 2 to Regulatory Guide 1.99 | | |
| Adjusted Reference Temperature, ART = Initial $RT_{NDT}$ + $\Delta RT_{NDT}$ + Margin | 145 | 115 |

********************************************************************************

(a) Fluence, f, is based upon $f_{surf}$ ($10^{19}$ n/cm$^2$, E>1 Mev) = 1.51 at 16 EFPY[7]. The Braidwood Unit 2 reactor vessel wall thickness is 8.5 inches at the beltline region[6].

(b) Margin is calculated as, $M = 2\,[\sigma_I^2 + \sigma_\Delta^2]^{0.5}$. The standard deviation for the initial $RT_{NDT}$ margin term ($\sigma_I$) is assumed to be 0°F since the initial $RT_{NDT}$ is a measured value. The standard deviation for $\Delta RT_{NDT}$, ($\sigma_\Delta$) is 28°F for the weld, except that $\sigma_\Delta$ need not exceed 0.50 times the mean value of $\Delta RT_{NDT}$.

MATERIAL PROPERTY BASIS

CONTROLLING MATERIAL: CIRCUMFERENTIAL WELD

INITIAL $RT_{NDT}$: 40°F

ART AFTER 16 EFPY: 1/4T, 145°F

3/4T, 115°F

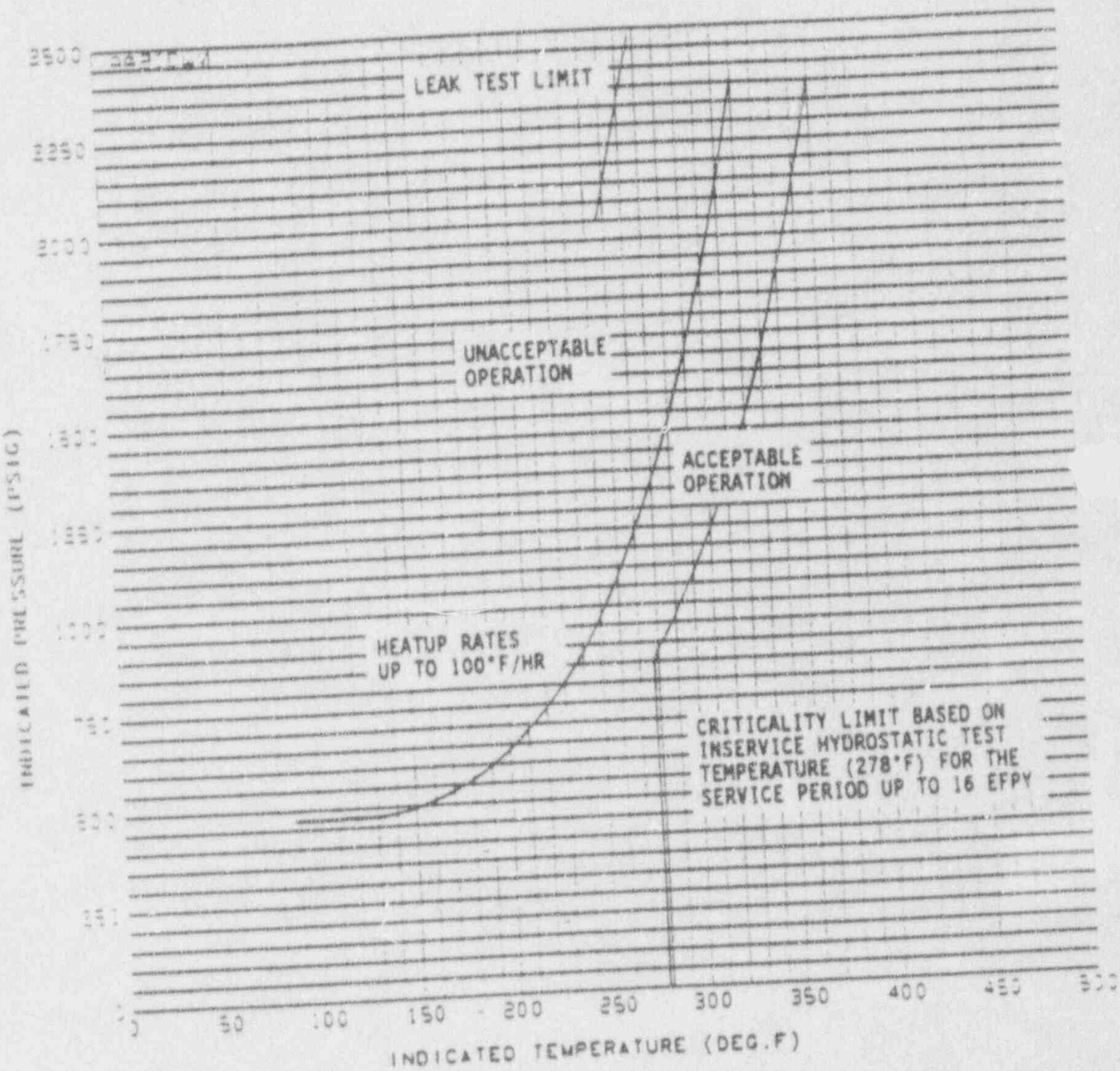


Figure 1. Braidwood Unit 2 Reactor Coolant System Heatup Limitations (Heat up rate up to 100°F/hr) Applicable for the First 16 EFPY (Without Margins For Instrumentation Errors)

MATERIAL PROPERTY BASIS

CONTROLLING MATERIAL: CIRCUMFERENTIAL WELD

INITIAL $RT_{NDT}$: 40°F

ART AFTER 16 EFPY: 1/4T, 145°F

3/4T, 115°F

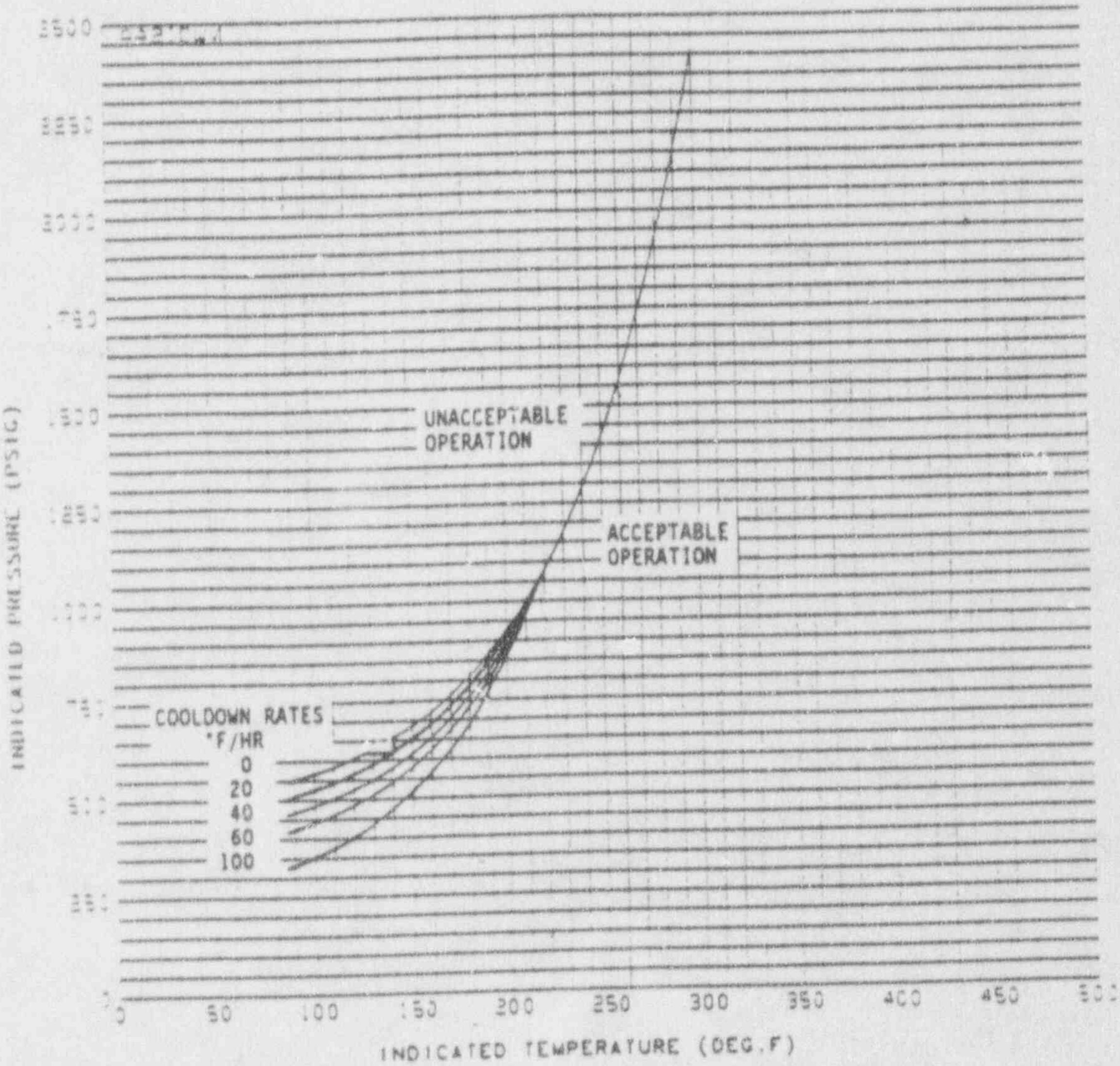


Figure 2. Braidwood Unit 2 Reactor Coolant System Cooldown (Cooldown rates up to 100°F/hr) Limitations Applicable for the First 16 EFPY (Without Margins For Instrumentation Errors)

## 6. REFERENCES

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

[2] "Fracture Toughness Requirements," Branch Technical Position MTEB 5-2, Chapter 5.3.2 in Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, LWR Edition, NUREG-0800, 1981.

[3] ASME Boiler and Pressure Vessel Code, Section III, Division 1 - Appendixes, "Rules for Construction of Nuclear Power Plant Components, Appendix G, Protection Against Nonductile Failure," pp. 558-563, 1986 Edition, American Society of Mechanical Engineers, New York, 1986.

[4] Code of Federal Regulations, 10CFR50, Appendix G, "Fracture Toughness Requirements," U.S. Nuclear Regulatory Commission, Washington, D.C., Federal Register, Vol. 48 No. 104, May 27, 1983.

[5] PTS Submittal for Braidwood Unit 1 Reactor Vessel (Section 5.3, Braidwood FSAR, Amendment 47, Commonwealth Edison Company, April 1986).

[6] MT-SMART-078(89), "Byron Unit 2 and Braidwood Unit 2 Reactor Vessel Heatup and Cooldown Limit Curves for Normal Operation", N. K. Ray, February 1989.

[7] WCAP-12845, "Analysis of Capsule U from the Commonwealth Edison Company Braidwood Unit 2 Reactor Vessel Radiation Surveillance Program", E. Terek, et. al., February 1991.

ATTACHMENT 1

DATA POINTS FOR HEATUP AND COOLDOWN CURVES

(Without Margins for Instrumentation Errors)

CDE 100 DEG F/HR HEATUP CURVE REG. GUIDE 1.99,REV 2 W/O MARGIN 01/11/91

THE FOLLOWING DATA WERE CALCULATEDFOR THE INSERVICE HYDROSTATIC LEAK TEST

MINIMUM INSERVICE LEAK TEST TEMPERATURE ( 16.000 EFPY)

| PRESSURE (PSI) | TEMPERATURE (DEG F) |
|---|---|
| 2000 | 256 |
| 2485 | 278 |

| PRESSURE (PSI) | PRESSURE STRESS (PSI) | 1.5 KIM (PSI SQ.RT IN.) |
|---|---|---|
| 2000 | 21142 | 89085 |
| 2485 | 26268 | 111649 |

CDE 100 DEG F/HR HEATUP CURVE REG. GUIDE 1.99,REV 2 W/O MARGIN 01/11/91

COMPOSITE CURVE PLOTTED FOR HEATUP PROFILE 2 HEATUP RATE(S) (DEG F/HR) = 100.0

IRRADIATION PERIOD = 16.000 EFP YEARS
FLAW DEPTH = (1-AOWIN)T

| | INDICATED TEMPERATURE (DEG.F) | INDICATED PRESSURE (PSI) | | INDICATED TEMPERATURE (DEG.F) | INDICATED PRESSURE (PSI) | | INDICATED TEMPERATURE (DEG.F) | INDICATED PRESSURE (PSI) |
|---|---|---|---|---|---|---|---|---|
| 1 | 85.000 | 528.23 | 18 | 170.000 | 534.55 | 35 | 255.000 | 1022.43 |
| 2 | 90.000 | 514.60 | 19 | 175.000 | 547.75 | 36 | 260.000 | 1075.42 |
| 3 | 95.000 | 503.40 | 20 | 180.000 | 562.50 | 37 | 265.000 | 1132.16 |
| 4 | 100.000 | 494.28 | 21 | 185.000 | 578.80 | 38 | 270.000 | 1193.34 |
| 5 | 105.000 | 487.22 | 22 | 190.000 | 596.55 | 39 | 275.000 | 1258.81 |
| 6 | 110.000 | 481.93 | 23 | 195.000 | 616.12 | 40 | 280.000 | 1328.94 |
| 7 | 115.000 | 478.45 | 24 | 200.000 | 637.43 | 41 | 285.000 | 1404.23 |
| 8 | 120.000 | 476.53 | 25 | 205.000 | 660.49 | 42 | 290.000 | 1484.74 |
| 9 | 125.000 | 476.19 | 26 | 210.000 | 685.63 | 43 | 295.000 | 1571.04 |
| 10 | 130.000 | 477.26 | 27 | 215.000 | 712.74 | 44 | 300.000 | 1663.31 |
| 11 | 135.000 | 479.77 | 28 | 220.000 | 742.01 | 45 | 305.000 | 1762.04 |
| 12 | 140.000 | 483.61 | 29 | 225.000 | 773.83 | 46 | 310.000 | 1867.61 |
| 13 | 145.000 | 488.81 | 30 | 230.000 | 807.97 | 47 | 315.000 | 1980.32 |
| 14 | 150.000 | 495.30 | 31 | 235.000 | 844.76 | 48 | 320.000 | 2100.72 |
| 15 | 155.000 | 503.04 | 32 | 240.000 | 884.37 | 49 | 325.000 | 2228.90 |
| 16 | 160.000 | 512.18 | 33 | 245.000 | 927.20 | 50 | 330.000 | 2365.61 |
| 17 | 165.000 | 522.69 | 34 | 250.000 | 973.12 | | | |

CDE COOLDOWN CURVES REG. GUIDE 1.99, REV 2 WITHOUT MARGIN 01/11/91

THE FOLLOWING DATA WERE PLOTTED FOR COOLDOWN PROFILE 1 ( STEADY-STATE COOLDOWN )

IRRADIATION PERIOD = 16.000 EFP YEARS
FLAW DEPTH = AOWIN I

| | INDICATED TEMPERATURE (DEG F) | INDICATED PRESSURE (PSI) | | INDICATED TEMPERATURE (DEG F) | INDICATED PRESSURE (PSI) | | INDICATED TEMPERATURE (DEG F) | INDICATED PRESSURE (PSI) |
|---|---|---|---|---|---|---|---|---|
| 1 | 85.000 | 546.34 | 16 | 160.000 | 720.73 | 31 | 235.000 | 1234.17 |
| 2 | 90.000 | 553.03 | 17 | 165.000 | 740.35 | 32 | 240.000 | 1291.99 |
| 3 | 95.000 | 560.22 | 18 | 170.000 | 761.65 | 33 | 245.000 | 1354.05 |
| 4 | 100.000 | 567.95 | 19 | 175.000 | 784.49 | 34 | 250.000 | 1420.56 |
| 5 | 105.000 | 576.26 | 20 | 180.000 | 808.95 | 35 | 255.000 | 1492.05 |
| 6 | 110.000 | 585.20 | 21 | 185.000 | 835.32 | 36 | 260.000 | 1568.66 |
| 7 | 115.000 | 594.68 | 22 | 190.000 | 863.62 | 37 | 265.000 | 1650.50 |
| 8 | 120.000 | 605.01 | 23 | 195.000 | 893.92 | 38 | 270.000 | 1738.64 |
| 9 | 125.000 | 616.11 | 24 | 200.000 | 926.70 | 39 | 275.000 | 1832.87 |
| 10 | 130.000 | ~~628.05~~ 621 * | 25 | 205.000 | 961.78 | 40 | 280.000 | 1933.53 |
| 11 | 135.000 | ~~640.86~~ 621 * | 26 | 210.000 | 999.45 | 41 | 285.000 | 2041.75 |
| 12 | 140.000 | ~~654.54~~ 621 * | 27 | 215.000 | 1039.89 | 42 | 290.000 | 2157.27 |
| 13 | 145.000 | 669.38 | 28 | 220.000 | 1083.35 | 43 | 295.000 | 2280.48 |
| 14 | 150.000 | 685.31 | 29 | 225.000 | 1130.06 | 44 | 300.000 | 2412.16 |
| 15 | 155.000 | 702.30 | 30 | 230.000 | 1180.24 | | | |

* Pressure limited to 621 psi due to flange requirement.

CDE COOLDOWN CURVES REG. GUIDE 1.99,REV 2 WITHOUT MARGIN 01/11/91

THE FOLLOWING DATA WERE PLOTTED FOR COOLDOWN PROFILE 2 ( 120 DEG F / HR COOLDOWN )

IRRADIATION PERIOD = 16.000 EFP YEARS
FLAW DEPTH = ADWIN T

| | INDICATED TEMPERATURE (DEG.F) | INDICATED PRESSURE (PSI) | | INDICATED TEMPERATURE (DEG.F) | INDICATED PRESSURE (PSI) | | INDICATED TEMPERATURE (DEG.F) | INDICATED PRESSURE (PSI) |
|---|---|---|---|---|---|---|---|---|
| 1 | 85.000 | 504.08 | 11 | 135.000 | 603.64 | 21 | 185.000 | 811.47 |
| 2 | 90.000 | 511.05 | 12 | 140.000 | 618.28 | 22 | 190.000 | 841.73 |
| 3 | 95.000 | 518.58 | 13 | 145.000 | 634.07 | 23 | 195.000 | 874.53 |
| 4 | 100.000 | 526.68 | 14 | 150.000 | 650.90 | 24 | 200.000 | 909.61 |
| 5 | 105.000 | 535.42 | 15 | 155.000 | 669.19 | 25 | 205.000 | 947.30 |
| 6 | 110.000 | 544.81 | 16 | 160.000 | 688.82 | 26 | 210.000 | 987.81 |
| 7 | 115.000 | 554.85 | 17 | 165.000 | 709.86 | 27 | 215.000 | 1031.39 |
| 8 | 120.000 | 565.74 | 18 | 170.000 | 732.59 | 28 | 220.000 | 1078.22 |
| 9 | 125.000 | 577.50 | 19 | 175.000 | 756.95 | 29 | 225.000 | 1128.60 |
| 10 | 130.000 | 590.14 | 20 | 180.000 | 783.25 | | | |

01/11/91

CDE COOLDOWN CURVES REG GUIDE 1.99,REV 2 WITHOUT MARGIN

THE FOLLOWING DATA WERE PLOTTED FOR COOLDOWN PROFILE 3 (40 DEG F / HR COOLDOWN )

IRRADIATION PERIOD = 16.000 EFP YEARS
FLAW DEPTH = AOWIN T

| | INDICATED TEMPERATURE (DEG F) | INDICATED PRESSURE (PSI) | | INDICATED TEMPERATURE (DEG F) | INDICATED PRESSURE (PSI) | | INDICATED TEMPERATURE (DEG F) | INDICATED PRESSURE (PSI) |
|---|---|---|---|---|---|---|---|---|
| 1 | 85.000 | 461.03 | 11 | 135.000 | 566.38 | 20 | 180.000 | 758.61 |
| 2 | 90.000 | 468.33 | 12 | 140.000 | 581.98 | 21 | 185.000 | 788.90 |
| 3 | 95.000 | 476.24 | 13 | 145.000 | 598.70 | 22 | 190.000 | 821.69 |
| 4 | 100.000 | 484.75 | 14 | 150.000 | 616.82 | 23 | 195.000 | 856.82 |
| 5 | 105.000 | 493.97 | 15 | 155.000 | 636.36 | 24 | 200.000 | 894.56 |
| 6 | 110.000 | 503.80 | 16 | 160.000 | 657.27 | 25 | 205.000 | 935.21 |
| 7 | 115.000 | 514.53 | 17 | 165.000 | 679.95 | 26 | 210.000 | 979.08 |
| 8 | 120.000 | 526.07 | 18 | 170.000 | 704.19 | 27 | 215.000 | 1026.15 |
| 9 | 125.000 | 538.55 | 19 | 175.000 | 730.49 | 28 | 220.000 | 1076.55 |
| 10 | 130.000 | 551.87 | | | | | | |

CDE COOLDOWN CURVES REG. GUIDE 1.99,REV 2 WITHOUT MARGIN 01/11/91

THE FOLLOWING DATA WERE PLOTTED FOR COOLDOWN PROFILE 4 (60 DEG F / HR COOLDOWN )

IRRADIATION PERIOD = 16.000 EFP YEARS
FLAW DEPTH = ADWIN T

| | INDICATED TEMPERATURE (DEG.F) | INDICATED PRESSURE (PSI) | | INDICATED TEMPERATURE (DEG.F) | INDICATED PRESSURE (PSI) | | INDICATED TEMPERATURE (DEG.F) | INDICATED PRESSURE (PSI) |
|---|---|---|---|---|---|---|---|---|
| 1 | 85.000 | 417.14 | 11 | 135.000 | 529.00 | 20 | 180.000 | 735.44 |
| 2 | 90.000 | 424.82 | 12 | 140.000 | 545.57 | 21 | 185.000 | 768.15 |
| 3 | 95.000 | 433.16 | 13 | 145.000 | 563.59 | 22 | 190.000 | 803.31 |
| 4 | 100.000 | 442.15 | 14 | 150.000 | 583.00 | 23 | 195.000 | 841.20 |
| 5 | 105.000 | 451.83 | 15 | 155.000 | 603.84 | 24 | 200.000 | 882.14 |
| 6 | 110.000 | 462.34 | 16 | 160.000 | 626.41 | 25 | 205.000 | 926.12 |
| 7 | 115.000 | 473.73 | 17 | 165.000 | 650.63 | 26 | 210.000 | 973.41 |
| 8 | 120.000 | 486.01 | 18 | 170.000 | 676.87 | 27 | 215.000 | 1024.31 |
| 9 | 125.000 | 489.28 | 19 | 175.000 | 705.01 | 28 | 220.000 | 1078.84 |
| 10 | 130.000 | 513.52 | | | | | | |

CDE COOLDOWN CURVES REG GUIDE 1.99,REV 2 WITHOUT MARGIN

THE FOLLOWING DATA WERE PLOTTED FOR COOLDOWN PROFILE 5 ( 100 DEG F/HR COOLDOWN )

IRRADIATION PERIOD = 16.000 EFP YEARS
FLAW DEPTH = AOWIN T

| | INDICATED TEMPERATURE (DEG.F) | INDICATED PRESSURE (PSI) |
|---|---|---|
| 1 | 85.000 | 326.72 |
| 2 | 90.000 | 335.32 |
| 3 | 95.000 | 344.70 |
| 4 | 100.000 | 354.85 |
| 5 | 105.000 | 365.89 |
| 6 | 110.000 | 377.78 |
| 7 | 115.000 | 390.76 |
| 8 | 120.000 | 404.78 |
| 9 | 125.000 | 419.94 |

| | INDICATED TEMPERATURE (DEG.F) | INDICATED PRESSURE (PSI) |
|---|---|---|
| 10 | 130.000 | 436.38 |
| 11 | 135.000 | 454.12 |
| 12 | 140.000 | 473.34 |
| 13 | 145.000 | 494.17 |
| 14 | 150.000 | 516.54 |
| 15 | 155.000 | 540.86 |
| 16 | 160.000 | 566.97 |
| 17 | 165.000 | 595.19 |
| 18 | 170.000 | 625.76 |

| | INDICATED TEMPERATURE (DEG.F) | INDICATED PRESSURE (PSI) |
|---|---|---|
| 19 | 175.000 | 658.64 |
| 20 | 180.000 | 694.07 |
| 21 | 185.000 | 732.48 |
| 22 | 190.000 | 773.75 |
| 23 | 195.000 | 818.25 |
| 24 | 200.000 | 866.17 |
| 25 | 205.000 | 917.80 |
| 26 | 210.000 | 973.42 |
| 27 | 215.000 | 1033.16 |

## 6.0 REFERENCES


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

2. NUREG-0800, "Pressure-Temperature Limits," Standard Review Plan, Section 5.3.2.

3. Letter from A. R. Checca (CECo) to T. E. Murley (USNRC), Subject: Braidwood Station, Units 1 and 2, Application for Amendment to Facility Operating License NPF-72 and NPF-77, NRC Docket No. 50-456 and 50-457, December 19, 1990.

4. WCAP-11651, "Analysis of Capsule U from the Commonwealth Edison Company Byron Unit 1 Reactor Vessel Radiation Surveillance Program," November 1987.

5. WCAP-12685, "Analysis of Capsule U from the Commonwealth Edison Company Braidwood Unit 1, Reactor Vessel Radiation Surveillance Program," August 1990.

6. WCAP-12845, "Analysis of Capsule U from the Commonwealth Edison Company Braidwood Unit 2, Reactor Vessel Radiation Surveillance Program," March 1991.