# ENCLOSURE 5

## GENERAL ELECTRIC-HITACHI NEDO-33820, REVISION 0
## NON-PROPRIETARY

## MONTICELLO NUCLEAR GENERATING PLANT
## UPPER SHELF ENERGY EVALUATION FOR PLATE C2220 MATERIAL
## FOR 54 EFPY

**34 pages follow**

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# Monticello Nuclear Generating Plant

# Upper Shelf Energy Evaluation for Plate C2220 Material for 54 EFPY

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## ACRONYMS & ABBREVIATIONS

| Short Version | Definition |
|---|---|
| 1/4T | ¼ Depth into the Vessel Wall from the Inside Diameter (Clad Is Not Considered) |
| ASME | American Society of Mechanical Engineers |
| ASME Code Edition | MNGP was fabricated in accordance with the 1965 Edition, including Summer 1966 Addenda. |
| BWR | Boiling Water Reactor |
| BWROG | BWR Owners' Group |
| BWRVIP | BWR Vessel & Internals Program |
| CMTR | Certified Material Test Report |
| CVN | Charpy V-Notch USE (ft-lbs) |
| EMA | Equivalent Margin Analysis |
| EOL | End of License |
| EPRI | Electric Power Research Institute |
| EPU | Extended Power Uprate |
| ft-lb | Foot-pound |
| GE | General Electric |
| GEH | GE Hitachi Nuclear Energy, LLC |
| ISP | Integrated Surveillance Program |
| $J_{0.1}$ | J-Integral from Applied Loads at a Ductile Crack Growth of 0.1 inch Depth into the Vessel Wall |
| $J_{applied}$ | J-Integral from Applied Loads (in-lb/$in^2$) |
| $J_{material}$ | Material's J-Integral Fracture Resistance J-R Curve (in-lb/$in^2$) |
| $J_R$ | J-Integral Fracture Resistance Curve |
| J-R | J-Integral Fracture Resistance |
| ksi | psi/1000 |
| MF | Margin Factor |
| MNGP | Monticello Nuclear Generating Plant |
| n/$cm^2$ | Neutrons/ centimeter squared (measure of fluence) |
| NRC | United States Nuclear Regulatory Commission (sometimes US NRC) |
| psi | Pounds per Square Inch |
| RAI | Request for Additional Information |
| Region B | Vessel Region from the Bottom of the Jet Pump to the Bottom of the Feedwater Nozzle |
| RG | Regulatory Guide |
| RPV | Reactor Pressure Vessel |
| $RT_{NDT}$ | Reference Temperature of Nil-Ductility Transition |
| S | Sulphur |
| SF | Safety Factor |
| USE | Upper Shelf Energy |
| wt% | Weight Percent (Elemental Content) |

## EXECUTIVE SUMMARY

10CFR50 Appendix G [1] states that the reactor pressure vessel (RPV) must maintain upper shelf energy (USE) of no less than 50 ft-lbs throughout its life, unless it is demonstrated in a manner approved by the Director, Office of Nuclear Reactor Regulation, that lower values of USE will provide margins of safety against fracture equivalent to those required by Appendix G of Section XI the ASME Code [2]. The BWR Owners' Group (BWROG) developed a licensing topical report, NEDO-32205-A, [3] on equivalent margin analysis for low USE BWR/2 through BWR/6 RPVs, which was reviewed and approved by the NRC for use by individual utilities. The NEDO-32205-A report was updated to represent 54 EFPY in BWRVIP-74-A [4], which was used in this analysis.

In their Extended Power Uprate (EPU) submittal, Monticello Nuclear Generating Plant (MNGP) provided an Equivalent Margin Analysis (EMA) for USE. The evaluation considered all surveillance data that was available at the time. During NRC review, a Request for Additional Information (RAI) (ML13150A255) specifically requested that this calculation be updated to include additional surveillance data that has been published in BWRVIP-135, Revision 2 [5].

The results presented for EPU demonstrated that the plate material, heat C2220, was bounded by the EMA, as the 22.5% decrease was bounded by the 23.5% decrease allowed for 54 EFPY. However, the data from the first surveillance capsule demonstrated that an adjustment would be required, once a second set of credible surveillance data became available. At that time, only one set of surveillance data was available; therefore Position 2.2 of Regulatory Guide (RG) 1.99 [6] was not required. Considering the second set of surveillance data that became available when BWRVIP-135, Revision 2 was issued, an adjustment must now be performed.

Considering the second data set of surveillance data for heat C2220, in accordance with MTEB 5-2, a Branch Technical Position for Fracture Toughness Requirements [7] that provides a summary and clarification of the requirements of 10CFR50 Appendix G and Appendix H, the unirradiated USE reported in BWRVIP-135, Revision 2 was reduced by a factor of 0.65. The MNGP plate minimum end of license (EOL) USE is determined to be 48 ft-lbs, less than the 50 ft-lb requirement. Therefore, to demonstrate the acceptability of the plate USE, a J-Integral Fracture Resistance (J-R) Integral evaluation was performed.

This USE evaluation follows the methodology outlined in ASME Code Case N-512-1 [8], Appendix K of ASME Section XI [9], and RG 1.161 [10]. The evaluation shows that the Level A/B Condition is governing.

Based on the results of this plant-specific evaluation, it is concluded that the plate materials in the MNGP RPV meet the margins of safety against fracture equivalent to those required by Appendix G of Section XI the ASME Code and RG 1.161. This conclusion is valid for operation including Extended Power Uprate conditions and a 60-year plant license (54 EFPY).

# 1.0 INTRODUCTION AND BACKGROUND

This report will demonstrate that the MNGP plate material exhibits sufficient tear resistance and ductile stability for Levels A, B, C, and D operating conditions. The Upper Shelf Energy (USE) margin evaluation methodology used in this report is consistent with that prescribed in Code Case N-512-1 [8], Section XI Code Non-Mandatory Appendix K [9], and RG 1.161 [10]. Although Code Case N-512 [11], [8], and [9] were in development at the same time that the topical report [3] was being developed, and [10] was published later, a review of the methodology used in [3] indicated that in almost all respects, it is consistent with [8, 9, and 10]. If there were any small differences, such as that in the selection of J-R curves, the topical report used a conservative approach. The methodology prescribed in [10] is exclusively followed in this report.

The BWROG topical report [3] clearly defines an NRC-approved J-R curve methodology, including the use of specific transients applicable to BWRs, and is therefore cited throughout this report.

## 1.1 Historical Background

The nuclear reactor pressure vessels (RPVs) are typically made of low-alloy ferritic steels (e.g., SA302B; or SA533, Grade B, Class 1). They are exposed to high energy neutrons in the beltline region; as a result, the constituent parts (i.e., the plates, forgings, and welds) can experience degradation of material properties: yield and ultimate tensile strengths increase, brittle-to-ductile transition temperature increases, and the upper shelf toughness decreases. The last two effects are the most important from the point of view of structural margins during operation of an RPV. The impact of low Charpy USE on the MNGP RPV integrity analyses is the subject of this report.

10CFR50 Appendix G [1] states that the RPV must maintain USE of no less than 50 ft-lbs throughout its life, unless it is demonstrated in a manner approved by the Director, Office of Nuclear Reactor Regulation, that lower values of USE will provide margins of safety against fracture equivalent to those required by Appendix G of Section XI the ASME Code [2]. In September 1992, the Nuclear Regulatory Commission (NRC), in discussing the preliminary review of the responses to Generic Letter 92-01, strongly recommended the equivalent margin analyses (EMA) be performed by the Owners' Group. In response to this, the BWROG developed a licensing topical report on equivalent margin analysis for low USE BWR/2 through BWR/6 vessels [3] that was reviewed and approved by the NRC [12]. This topical report was updated to represent 54 EFPY in BWRVIP-74-A [4]. The topical report, which could be referenced by utilities as part of their licensing basis, can be used to address compliance with the 50 ft-lb requirement. Appendix B of the topical report presents the steps required to show that the USE requirements presented in the report can be applied to individual BWR plants. The plants always have the option to perform a plant-specific USE margin evaluation.

The topical report followed the methods provided in the then-draft Appendix X of the ASME Code, which has since become Code Case N-512 [11] and subsequently revised as Code Case N-512-1 [8]. This Code Case was incorporated in the Section XI Code as Non-Mandatory Appendix K [9]. The NRC staff reviewed the analysis methods in Appendix K and found them to be technically acceptable but not complete with respect to information on the selection of transients, and the selection of material properties. As a result the NRC issued RG 1.161 [10] providing specific guidance on these issues.

### 1.2 MNGP Beltline Plate Heat C2220

Plate heat C2220 from the MNGP RPV is included in the Integrated Surveillance Program. Initial, or unirradiated, USE is defined in BWRVIP-135 [5] as [[ ]] ft-lbs. Because the data was not identified as being in the strong or weak direction, the USE was assumed to be in the strong direction, and was reduced using a factor of 0.65 in accordance with MTEB 5-2 [7]. Therefore, the minimum initial USE for the plate was [[ ]] ft-lbs. The end of license USE values did not meet the minimum required value of 50 ft-lbs defined in 10CFR50 Appendix G or the acceptance criterion provided in BWRVIP-74-A [4]. Therefore, a plant-specific evaluation was conducted to show compliance.

The plant-specific evaluation followed the methodology consistent with the requirements of Section XI Code Case N-512-1 [8], Appendix K [9], and RG 1.161 [10]. Also, the selection of transients was justified in relation to the MNGP vessel transients for Levels A through D operating conditions. The most limiting transients were considered for Levels A, B, C, and D, in accordance with the requirements of Section 4 of RG1.161, as discussed in more detail in the following sections.

## 2.0 SCOPE

The objective of the analysis documented in this report is to demonstrate that the MNGP RPV plate materials meet the margins of safety against fracture equivalent to those required by 10CFR50 Appendix G. This will be accomplished by demonstrating, by a plant-specific equivalent margin analysis, that a USE less than 50 ft-lbs maintains the required margin of safety against fracture, thereby meeting the requirements of 10CFR50 Appendix G.

## 3.0 SUMMARY OF ANALYSIS RESULTS

10CFR50 Appendix G states that the RPV must maintain USE throughout its life of no less than 50 ft-lbs, unless it is demonstrated in a manner approved by the Director, Office of Nuclear Reactor Regulation, that lower values of USE will provide margins of safety against fracture equivalent to those required by Appendix G of Section XI the ASME Code. The BWROG developed a licensing topical report on equivalent margin analysis for low USE BWR/2 through BWR/6 RPVs, which was reviewed and approved by the NRC for use by individual utilities.

This MNGP USE evaluation followed the methodology outlined in ASME Code Case N-512-1 [8], Appendix K of ASME Section XI [9], and RG 1.161 [10]. The evaluation showed that the Level A/B Condition was governing.

Based on the results of this plant-specific evaluation, it is concluded that the plate material in the MNGP RPV meets the margins of safety against fracture equivalent to those required by Appendix G of Section XI the ASME Code. This conclusion is valid for operation at EPU conditions for 60 years (54 EFPY).

# 4.0 MNGP RPV PLATE DATA

## 4.1 Plate Heat C2220 Unirradiated Upper Shelf Energy

The MNGP vessel was purchased to the 1965 Edition of the ASME Boiler & Pressure Vessel Code, Section III, with Addenda up to and including Summer 1966. At that time, requirements for determining USE had not yet been established. The MNGP plate heat C2220 is identified in BWRVIP-135, Revision 2 [5] as having an initial USE of [[ ]] ft-lb. This report does not include definition sufficient to determine whether these results are based on longitudinally-oriented or transversely-oriented specimens. Therefore, the conservative assumption is made that the specimens were longitudinally-oriented, and are converted to the equivalent of transversely-oriented results by factoring the USE by 0.65 [7].

The plate heat C2220 initial USE is conservatively determined to be:

| | |
|---|---|
| Initial USE: | [[ ]] ft-lb (assumed longitudinal) |
| Factor: | 0.65 (to convert to transverse USE) |
| Initial $USE_{converted}$: | =[[ ]] |

## 4.2 Plate Heat C2220 End of License Upper Shelf Energy

BWRVIP-135, Revision 2 defines the weight percent copper to be [[ ]]. However, MNGP plate heat C2220 has previously been evaluated for 0.17% copper. The end of license 54 EFPY predicted decrease defined by RG1.99 [6] at a 1/4T fluence of 4.75e17 n/cm$^2$ is 22.5%.

The first capsule specimen test results demonstrate that the USE after exposure to a fluence of 2.93e17 n/cm$^2$ is [[ ]] ft-lbs. This indicates a measured decrease of [[ ]]. The RG1.99 predicted decrease for this fluence and 0.17% copper is 11.5%. As the measured decrease exceeds the predicted, an adjustment is required as defined in Position 2.2 of RG1.99.

Similarly, the second capsule test results demonstrate that the USE after exposure to a fluence of [[ ]] n/cm$^2$ is [[ ]] ft-lb. This indicates a measured decrease of [[ ]]. The RG1.99 predicted decrease for this fluence and [[ ]] copper [5] is 14.5%. Again, the measured decrease exceeds the predicted, and an adjustment is again required.

The adjusted decrease in USE was determined in accordance with RG1.99, Position 2.2, and resulted in a decrease of 44%. Therefore, reducing [[ ]] ft-lbs by 44% results in an end of license USE of 48 ft-lbs. As this value does not meet the 50 ft-lb end of license criterion, a J-R fracture mechanics evaluation is performed. The data set and results are shown in Table 4-1.

**Table 4-1: Equivalent Margin Analysis for Plate Heat C2220**

[[

]]

### 4.3 Fluence

This calculation is based upon a license of 60 years, considering 54 EFPY. The peak surface fluence applied in the MNGP USE evaluation is 6.43e18 n/cm$^2$; this is representative of a calculation that was performed using the GEH fluence methodology [13]. The 1/4T fluence was calculated in accordance with RG 1.99, Revision 2, resulting in a fluence of 4.75e18 n/cm$^2$ [14].

### 4.4 Plant-Specific Transients

The limiting transients for each level of operating conditions were selected for this evaluation in accordance with Section 4 of RG1.161. The limiting Level A and B condition is the 100°F/hr heatup/cooldown; limiting for Level C is the "Improper Start of a Cold Recirculation Loop"; and limiting for Level D is the "Pipe Rupture and Blowdown". These are discussed in more detail in the following sections.

## 5.0 USE MARGIN EVALUATION METHODOLOGY

The USE margin evaluation methodology used in this report is consistent with that prescribed in [8, 9, and 10]. Although [8, 9 and 11] were in development at the same time that the topical report [3] was being developed, and [10] was published later, a review of the methodology used in [3] indicated that in almost all respects, it is consistent with [8, 9, and 10]. If there were any small differences, such as that in the selection of J-R curves, the topical report used a conservative approach. The methodology prescribed in [10] is exclusively followed in this report.

The acceptance criteria and the equations for the calculation of J applied values are described in this section. The selection of appropriate J-R curves is described in the next section.

### 5.1 Acceptance Criteria

The acceptance criteria for Level A & B Normal/Upset conditions are described as:

$$J_{applied} < J_{0.1} \quad (1)$$

$$\partial J_{applied}/\partial a < \partial J_{material}/\partial a, \text{ load held constant at } J_{applied} = J_{material} \quad (2)$$

Equation (2) assures stability under ductile crack growth as demonstrated in Figure 5-1 below:

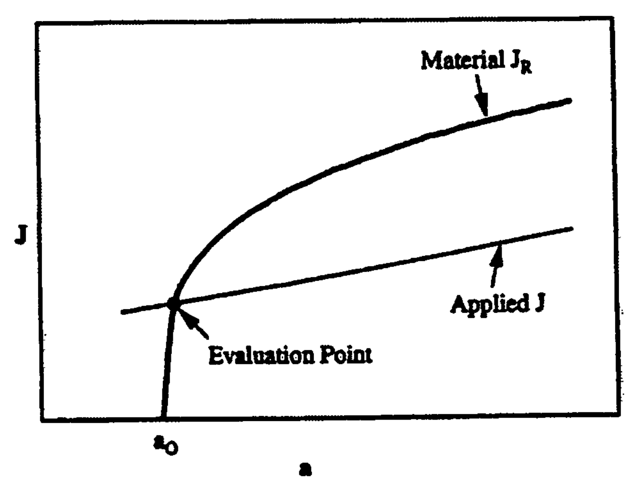


**Figure 5-1: Illustration of Ductile Crack Growth Stability Evaluation**

Both axial and circumferential flaws are postulated. For all operating conditions, the flaws are considered to be semi-elliptical surface flaws with an aspect ratio of 6:1 surface length to flaw depth. The assumed crack is ¼ of the thickness of the base metal wall.

The acceptance criteria for Level C conditions are provided in Section 3.1.2 of [3] and are essentially the same as Equations (1) and (2) above. For Level C, however, the postulated flaw depth is 1/10 of the thickness of the base metal wall plus the clad thickness, with total depth < 1.0 inch. A safety factor of 1.0 is considered for applied pressure loading.

For Level D conditions, only the ductile crack growth stability is evaluated. The flaw depth is the same as that for Level C, and the material J-Integral resistance curve is based on best estimate. Level D also uses a safety factor on applied loading equal to 1.0.

## 5.2 Calculation of Applied J-Integral

The calculation of the applied J-Integral consists of three steps:

- Step 1 is to calculate the $K_I$ values from pressure and heatup/cooldown loadings;
- Step 2 is to calculate the effective flaw depth, which includes a plastic zone size correction; and
- Step 3 is to calculate the J-Integral for small-scale yielding based on this effective flaw depth.

The calculated $K_I$ values are in the units of ksi√in.

### *5.2.1 Internal Pressure Loading*

For an axial flaw with depth 'a', the stress intensity factor from internal pressure, $p_a$, with a safety factor, (SF), on pressure using Equation (3) below, is obtained from [10]:

$$K_{Ip}^{Axial} = (SF)\, p_a\, [1 + (R_i/t)]\, (\pi a)^{0.5}\, F_1 \quad (3)$$

$$F_1 = 0.982 + 1.006\, (a/t)^2$$

For a circumferential flaw with depth 'a', the stress intensity factor from internal pressure, $p_a$, with a safety factor, SF, on pressure using Equation (4), is obtained from [10]:

$$K_{Ip}^{Circum.} = (SF)\, p_a\, [1 + \{R_i/(2t)\}]\, (\pi a)^{0.5}\, F_2 \quad (4)$$

$$F_2 = 0.885 + 0.233\, (a/t) + 0.345\, (a/t)^2$$

### *5.2.2 Heatup/Cooldown Loading*

For an axial or circumferential flaw with depth 'a', the "steady state" (time independent) stress intensity factor from radial thermal gradients is obtained by using Equation (5), obtained from [10]:

$$K_{It} = (CR/1000)\, t^{2.5}\, F_3 \quad (5)$$

$$F_3 = 0.69 + 3.127\, (a/t) - 7.435\, (a/t)^2 + 3.532\, (a/t)^3$$

The above equation for $K_{It}$ is valid for $0 \leq CR \leq 100$°F/hr.

For the transients in which the heatup/cooldown rates are greater than 100°F/hr, [3] used finite element analysis to determine the stress distribution through the RPV wall and the $K_I$ values were then calculated using the Raju-Newman method as described in [3].

### *5.2.3 Effective Flaw Depth*

The effective flaw depth for small-scale yielding, $a_e$, was based on Equation (6), obtained from [10]:

$$a_e = a + \{1/(6\pi)\}[(K_{Ip} + K_{It})/\sigma_y]^2 \tag{6}$$

The topical report [3] identifies the yield strength as 69 ksi; the average MNGP plate heat C2220 CMTR value of $\sigma_y$ for SA533 Grade B Class 1 is approximately [[ ]] ksi at room temperature. The ASME Code value from the MNGP Code of Construction is determined to be [[ ]] ksi at [[ ]]. The Code value at operating temperature was scaled by the Code value at room temperature (100°F) and the measured room temperature value from the CMTRs. Therefore, $\sigma_y$ of approximately [[ ]] ksi was used in this evaluation.

### *5.2.4 J-Integral Calculation*

The J-Integral from the $K_I$ values was calculated using Equation (7), obtained from [10]:

$$J_{applied} = 1000\,(K'_{Ip} + K'_{It})^2/E' \tag{7}$$

where the $K'_I$ values are stress intensity factors based on effective flaw depth and E' is $E/(1-\nu^2)$. The value of $\nu$ was taken as 0.3 and is consistent with [3]; the value of E was determined to be 27900 ksi at room temperature, obtained from the ASME Code. The units of J are in-lb/in$^2$.

## 6.0 SELECTION OF MATERIAL J-R CURVES

The generic J-Integral fracture resistance curve equation is given as Equation (8), obtained from [10]:

$$J_R = (MF)\ \{C1\ (\Delta a)^{C2} \exp\ [C3\ (\Delta a)^{C4}]\} \qquad (8)$$

Section 3.3 (Reactor Pressure Vessel Base (Plate) Materials) of [10] is used to calculate the values of various constants in the preceding equation. Section 3.3 of [10] provides different equations based upon the Sulphur (S) wt% content of the materials being evaluated. NEDO-24197 [15] documents the maximum S content as 0.014 wt% . Therefore, Section 3.3.1 (High-Toughness Model for S < 0.018 wt%) of [10] is used.

For analyses addressing Service Levels A, B, and C, the margin factor (MF) was set to 0.749 as defined in Section 3.3.1 of [10]. For analyses addressing Service Level D, the value of MF was set to 1.0. The mathematical expressions for other constants are given by Equations (9) through (12), obtained from [10]:

$$C1 = \exp\left[-2.44 + 1.13 \ln (CVN) - 0.00277T\right] \tag{9}$$

$$C2 = 0.077 + 0.116 \ln C1 \tag{10}$$

$$C3 = -0.0812 - 0.0092 \ln C1 \tag{11}$$

$$C4 = -0.409 \tag{12}$$

The term 'CVN' is the Charpy USE. As indicated above, the EOL Charpy USE for the MNGP plate is 48 ft-lbs. This value was used in calculating the value of constant C1. The normal operating temperature for region B (that contains the beltline region) of the vessel is specified as [[ ]] [16]; for EPU this temperature was revised to [[ ]] [17]. Therefore, this value was used in calculating the value of constant C1.

The calculated J-Integral resistance curves for the various operating conditions are shown in Figure 6-1 below.

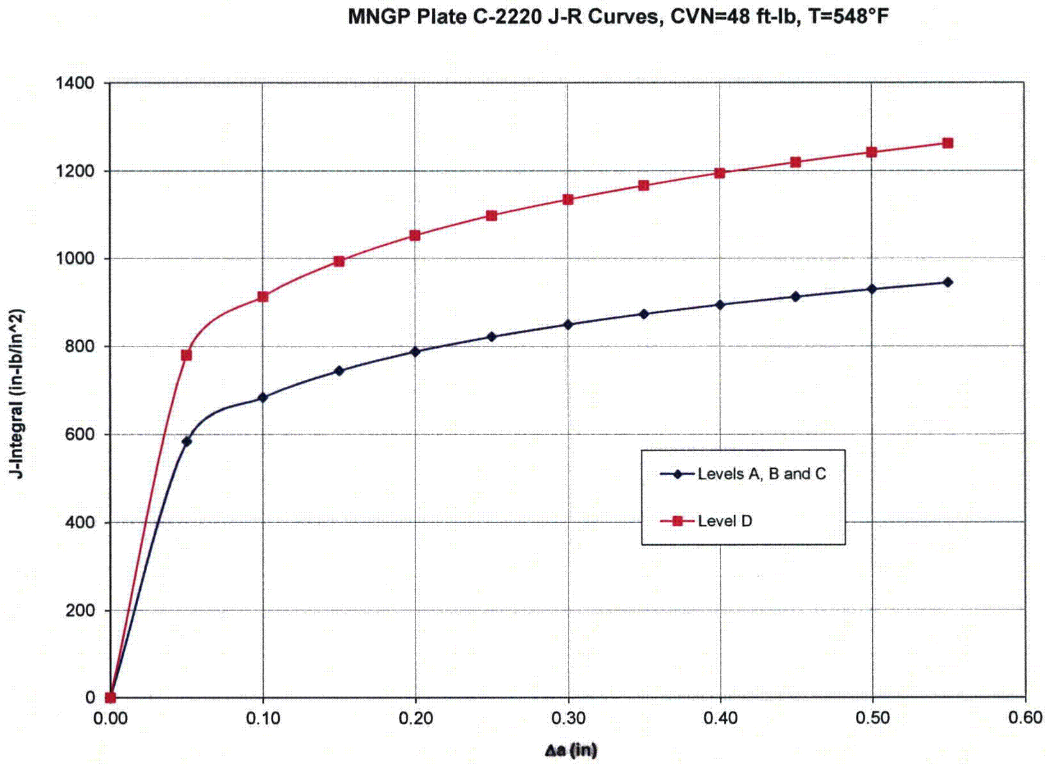


**Figure 6-1: MNGP J-Integral Resistance Curves**

# 7.0 EVALUATION OF LEVEL A & B CONDITIONS

Key steps in this evaluation are the calculation of the applied J-Integral and the flaw stability evaluation.

## 7.1 Level A and B Service Loadings

The two loadings to be considered are internal pressure and thermal heatup/cooldown rates. The Level A and B heatup/cooldown rates for the MNGP RPV are specified in the associated reactor thermal cycle diagram [16] amended by the EPU certified design specification [17]. The topical report [3] also analyzed an additional transient identified as "Loss of Feedwater Pumps" that is specified for BWR/6 standard plants in their RPV thermal cycle drawing. However, the analysis in the topical report showed that the 100°F/hr case was still bounding compared to this transient. The MNGP plant-specific thermal cycle diagram was reviewed; it was determined that the heatup/cooldown case is bounded by the evaluation presented in the topical report.

The RPV geometry considered in the topical report (R= 126.7 inches and t= 6.19 inches) bounds the MNGP RPV geometry (R=[[ ]] inches and t= 5.06 inches); therefore, use of the topical report in terms of the calculated thermal transient stress is conservative. Thus, the conclusion reached in [3] was also determined to be valid for the MNGP case and only the 100°F/hr case was considered in this evaluation.

The specified design pressure for the MNGP RPV is 1250 psi, defined in [17]. Consistent with the NRC-approved topical report, the accumulation pressure is 1.1 times the design pressure and is, thus, equal to 1375 psi. The internal pressure value used in the $J_{0.1}$ criterion is 1.15 times the accumulation pressure (i.e., 1375 * 1.15 or 1581 psi). Similarly, the internal pressure value used in the flaw stability criterion is 1.25 times the accumulation pressure or 1719 psi.

The MNGP RPV wall thickness in the beltline region is 5.06 inches. RG1.161 states that, for Levels A and B, the evaluation is to postulate a semi-elliptical surface flaw with an a/t = 0.25 and with an aspect ratio of 6:1 surface length to flaw depth. Clad thickness is not required for this calculation. Therefore, the postulated 1/4T flaw has a depth of (5.06 * 0.25) or 1.27 inches.

## 7.2 Level A and B Conditions Evaluation

Table 7-1 below shows the calculated values of the applied J-Integral for 1.15 accumulation pressure at several crack depths beginning with the 1/4T depth. The calculations for the axial flaw are shown first, followed by those for the circumferential flaw. For the $J_{0.1}$ criterion, the applied J-Integral values at a = 1.37 inches are relevant. A review of this table indicates that the applied J-Integral values for the axial flaw case bound those for the circumferential flaw case. Therefore, the $J_{0.1}$ criterion check was conducted only for the axial flaw case. Figure 7-1 shows a comparison between the calculated applied J-Integral value for the axial flaw and the MNGP plate J-R curve. It is seen that the $J_{0.1}$ criterion is satisfied for the limiting case of an axial flaw.

**Table 7-1: Calculated Values of Applied J-Integral for 1.15 x Accumulation Pressure**

| | |
|---|---|
| Pressure (psi)= | 1581 |
| Vessel Ri (in.)= | 103.1875 |
| Vessel Th (in.)= | 5.06 |
| Cooling Rate (F/Hr)= | 100 |
| a0 (in.)= | 1.265 |
| E (ksi)= | 27900 |
| YS (ksi)= | 55.4 |

AXIAL FLAW CALCULATION

| a (in) | Δa (in) | F1 | F3 | Kp (ksi-in$^{1/2}$) | Kt (ksi-in$^{1/2}$) | ae (in) | F1' | F3' | K,total (ksi-in$^{1/2}$) | J,app (in-lb/in$^2$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.27 | 0.00 | 1.045 | 1.062 | 70.45 | 6.12 | 1.366 | 1.055 | 1.062 | 80.07 | 209.10 |
| 1.32 | 0.05 | 1.050 | 1.062 | 72.18 | 6.12 | 1.421 | 1.061 | 1.060 | 81.95 | 219.04 |
| 1.37 | 0.10 | 1.055 | 1.062 | 73.91 | 6.12 | 1.476 | 1.068 | 1.057 | 83.83 | 229.22 |
| 1.42 | 0.15 | 1.061 | 1.060 | 75.64 | 6.11 | 1.531 | 1.074 | 1.053 | 85.72 | 239.67 |
| 1.47 | 0.20 | 1.066 | 1.058 | 77.37 | 6.09 | 1.585 | 1.081 | 1.048 | 87.62 | 250.39 |
| 1.52 | 0.25 | 1.072 | 1.055 | 79.11 | 6.07 | 1.640 | 1.088 | 1.043 | 89.52 | 261.40 |
| 1.57 | 0.30 | 1.078 | 1.050 | 80.86 | 6.05 | 1.696 | 1.095 | 1.036 | 91.44 | 272.71 |
| 1.62 | 0.35 | 1.084 | 1.045 | 82.62 | 6.02 | 1.751 | 1.102 | 1.028 | 93.37 | 284.35 |
| 1.67 | 0.40 | 1.091 | 1.040 | 84.39 | 5.99 | 1.806 | 1.110 | 1.019 | 95.32 | 296.32 |
| 1.72 | 0.45 | 1.098 | 1.033 | 86.17 | 5.95 | 1.862 | 1.118 | 1.010 | 97.28 | 308.65 |
| 1.77 | 0.50 | 1.104 | 1.026 | 87.96 | 5.91 | 1.917 | 1.126 | 1.000 | 99.26 | 321.35 |
| 1.82 | 0.55 | 1.111 | 1.018 | 89.76 | 5.86 | 1.973 | 1.135 | 0.988 | 101.26 | 334.45 |
| 1.87 | 0.60 | 1.119 | 1.009 | 91.58 | 5.81 | 2.029 | 1.144 | 0.976 | 103.29 | 347.97 |
| 1.92 | 0.65 | 1.126 | 1.000 | 93.42 | 5.76 | 2.085 | 1.153 | 0.963 | 105.34 | 361.91 |
| 1.97 | 0.70 | 1.134 | 0.990 | 95.27 | 5.70 | 2.141 | 1.162 | 0.949 | 107.41 | 376.32 |
| 2.02 | 0.75 | 1.142 | 0.979 | 97.14 | 5.64 | 2.198 | 1.172 | 0.935 | 109.52 | 391.20 |
| 2.07 | 0.80 | 1.150 | 0.968 | 99.03 | 5.57 | 2.254 | 1.182 | 0.920 | 111.65 | 406.59 |
| 2.12 | 0.85 | 1.158 | 0.956 | 100.94 | 5.51 | 2.311 | 1.192 | 0.904 | 113.82 | 422.51 |
| 2.17 | 0.90 | 1.166 | 0.943 | 102.86 | 5.43 | 2.368 | 1.202 | 0.887 | 116.01 | 438.98 |
| 2.22 | 0.95 | 1.175 | 0.930 | 104.81 | 5.36 | 2.425 | 1.213 | 0.870 | 118.24 | 456.04 |
| 2.27 | 1.00 | 1.184 | 0.917 | 106.78 | 5.28 | 2.482 | 1.224 | 0.852 | 120.51 | 473.70 |

CIRCUMFERENTIAL FLAW CALCULATION

| a (in) | Δa (in) | F2 | F3 | Kp (ksi-in$^{1/2}$) | Kt (ksi-in$^{1/2}$) | ae (in) | F1' | F3' | K,total (ksi-in$^{1/2}$) | J,app (in-lb/in$^2$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.27 | 0.00 | 0.965 | 1.062 | 34.05 | 6.12 | 1.293 | 0.967 | 1.063 | 40.62 | 53.81 |
| 1.32 | 0.05 | 0.969 | 1.062 | 34.86 | 6.12 | 1.344 | 0.971 | 1.062 | 41.45 | 56.03 |
| 1.37 | 0.10 | 0.973 | 1.062 | 35.67 | 6.12 | 1.395 | 0.975 | 1.061 | 42.26 | 58.25 |
| 1.42 | 0.15 | 0.977 | 1.060 | 36.47 | 6.11 | 1.446 | 0.980 | 1.059 | 43.07 | 60.50 |
| 1.47 | 0.20 | 0.981 | 1.058 | 37.27 | 6.09 | 1.497 | 0.984 | 1.056 | 43.87 | 62.77 |
| 1.52 | 0.25 | 0.986 | 1.055 | 38.07 | 6.07 | 1.549 | 0.989 | 1.052 | 44.66 | 65.05 |
| 1.57 | 0.30 | 0.990 | 1.050 | 38.86 | 6.05 | 1.600 | 0.993 | 1.047 | 45.44 | 67.36 |
| 1.62 | 0.35 | 0.995 | 1.045 | 39.65 | 6.02 | 1.651 | 0.998 | 1.041 | 46.22 | 69.69 |
| 1.67 | 0.40 | 0.999 | 1.040 | 40.45 | 5.99 | 1.702 | 1.002 | 1.035 | 47.00 | 72.04 |
| 1.72 | 0.45 | 1.004 | 1.033 | 41.24 | 5.95 | 1.753 | 1.007 | 1.028 | 47.76 | 74.41 |
| 1.77 | 0.50 | 1.008 | 1.026 | 42.03 | 5.91 | 1.805 | 1.012 | 1.020 | 48.53 | 76.81 |
| 1.82 | 0.55 | 1.013 | 1.018 | 42.82 | 5.86 | 1.856 | 1.017 | 1.011 | 49.29 | 79.23 |
| 1.87 | 0.60 | 1.018 | 1.009 | 43.61 | 5.81 | 1.907 | 1.022 | 1.001 | 50.04 | 81.68 |
| 1.92 | 0.65 | 1.023 | 1.000 | 44.40 | 5.76 | 1.958 | 1.027 | 0.991 | 50.80 | 84.16 |
| 1.97 | 0.70 | 1.028 | 0.990 | 45.19 | 5.70 | 2.010 | 1.032 | 0.980 | 51.55 | 86.67 |
| 2.02 | 0.75 | 1.032 | 0.979 | 45.98 | 5.64 | 2.061 | 1.037 | 0.969 | 52.30 | 89.20 |
| 2.07 | 0.80 | 1.038 | 0.968 | 46.78 | 5.57 | 2.112 | 1.042 | 0.957 | 53.04 | 91.77 |
| 2.12 | 0.85 | 1.043 | 0.956 | 47.58 | 5.51 | 2.164 | 1.048 | 0.944 | 53.79 | 94.37 |
| 2.17 | 0.90 | 1.048 | 0.943 | 48.37 | 5.43 | 2.215 | 1.053 | 0.930 | 54.53 | 97.00 |
| 2.22 | 0.95 | 1.053 | 0.930 | 49.17 | 5.36 | 2.266 | 1.059 | 0.916 | 55.28 | 99.67 |
| 2.27 | 1.00 | 1.058 | 0.917 | 49.98 | 5.28 | 2.318 | 1.064 | 0.902 | 56.02 | 102.37 |

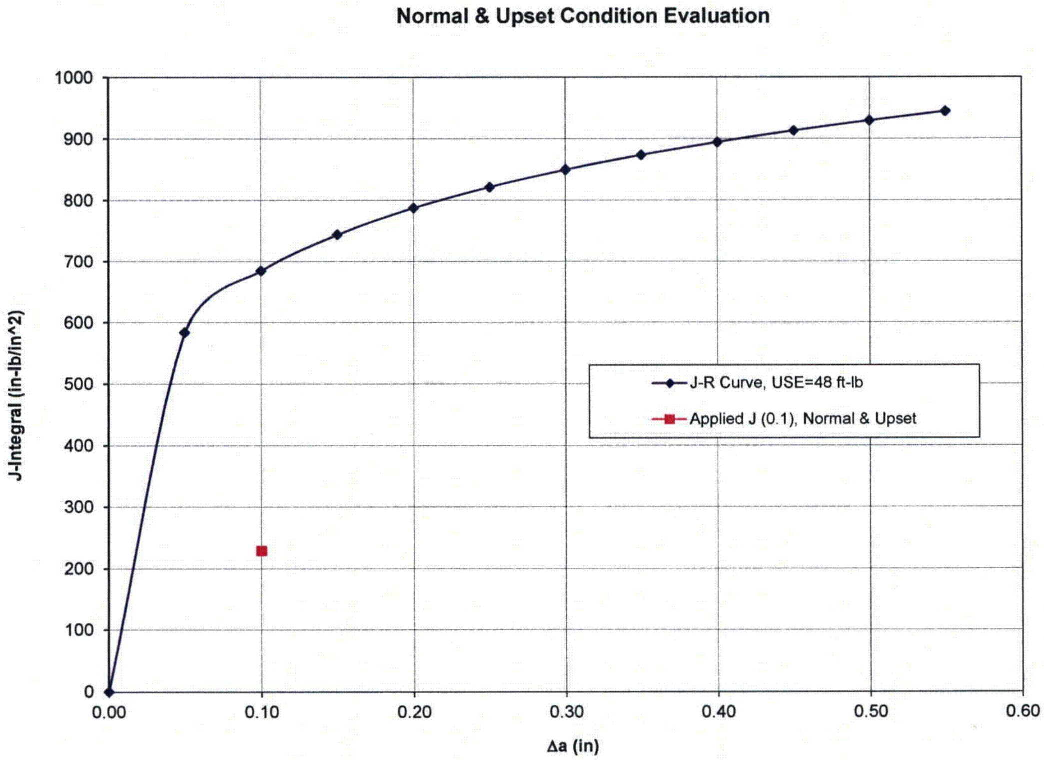


**Figure 7-1: $J_{0.1}$ Criterion Evaluation for Axial Flaw and MNGP Plate J-R Curve**

Table 7-2 shows the calculated values of applied J-Integral for 1.25 accumulation pressure at several crack depths beginning with 1/4T depth. The calculations are shown for both the axial and the circumferential flaws. However, a review of this table indicates that the axial flaw case is governing. Figure 7-2 shows the plot of the applied J-Integral curve and the MNGP plate material J-R curve. Flaw stability at a given applied load is assured when the slope of the applied J-Integral curve is less than the slope of the material J-R curve at the point on the J-R curve where the two curves intersect (see Figure 5-1). It is seen that the stability criterion is satisfied with the limiting EOL USE of 48 ft-lbs for the MNGP plate material. (Note: In the stability evaluation, the J applied at $\Delta a = 0.1$ inch is not a concern; only the slope of the J applied curve is of importance.)

Review of the $J_{0.1}$ criterion was performed to determine the minimum required USE; this was determined to be 12.5 ft-lbs. Material stability was evaluated demonstrating the minimum required USE to be 15 ft-lbs. It can therefore be seen that the minimum USE of 48 ft-lbs determined using RG1.99 is significantly greater than the critical USE of 15 ft-lbs, with a margin of 33 ft-lbs, determined using RG1.161.

## Table 7-2: Calculated Values of Applied J-Integral for 1.25 x Accumulation Pressure

| | |
|---|---|
| Pressure (psi)= | 1719 |
| Vessel Ri (in.)= | 103.1875 |
| Vessel Th (in.)= | 5.06 |
| Cooling Rate (F/Hr)= | 100 |
| a0 (in.)= | 1.265 |
| E (ksi)= | 27900 |
| YS (ksi)= | 55.4 |

AXIAL FLAW CALCULATION

| a (in) | Δa (in) | F1 | F3 | Kp (ksi-in$^{1/2}$) | Kt (ksi-in$^{1/2}$) | ae (in) | F1' | F3' | K,total (ksi-in$^{1/2}$) | J,app (in-lb/in$^2$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.27 | 0.00 | 1.045 | 1.062 | 76.60 | 6.12 | 1.383 | 1.057 | 1.061 | 87.16 | 247.77 |
| 1.32 | 0.05 | 1.050 | 1.062 | 78.48 | 6.12 | 1.439 | 1.063 | 1.059 | 89.23 | 259.71 |
| 1.37 | 0.10 | 1.055 | 1.062 | 80.36 | 6.12 | 1.494 | 1.070 | 1.056 | 91.31 | 271.97 |
| 1.42 | 0.15 | 1.061 | 1.060 | 82.24 | 6.11 | 1.550 | 1.076 | 1.052 | 93.40 | 284.55 |
| 1.47 | 0.20 | 1.066 | 1.058 | 84.13 | 6.09 | 1.606 | 1.083 | 1.046 | 95.50 | 297.48 |
| 1.52 | 0.25 | 1.072 | 1.055 | 86.02 | 6.07 | 1.662 | 1.090 | 1.040 | 97.61 | 310.78 |
| 1.57 | 0.30 | 1.078 | 1.050 | 87.92 | 6.05 | 1.718 | 1.098 | 1.033 | 99.74 | 324.46 |
| 1.62 | 0.35 | 1.084 | 1.045 | 89.83 | 6.02 | 1.774 | 1.106 | 1.025 | 101.88 | 338.55 |
| 1.67 | 0.40 | 1.091 | 1.040 | 91.75 | 5.99 | 1.830 | 1.114 | 1.015 | 104.04 | 353.08 |
| 1.72 | 0.45 | 1.098 | 1.033 | 93.69 | 5.95 | 1.887 | 1.122 | 1.005 | 106.23 | 368.05 |
| 1.77 | 0.50 | 1.104 | 1.026 | 95.64 | 5.91 | 1.943 | 1.130 | 0.994 | 108.43 | 383.51 |
| 1.82 | 0.55 | 1.111 | 1.018 | 97.60 | 5.86 | 2.000 | 1.139 | 0.983 | 110.67 | 399.46 |
| 1.87 | 0.60 | 1.119 | 1.009 | 99.58 | 5.81 | 2.057 | 1.148 | 0.970 | 112.93 | 415.95 |
| 1.92 | 0.65 | 1.126 | 1.000 | 101.57 | 5.76 | 2.114 | 1.158 | 0.956 | 115.22 | 432.99 |
| 1.97 | 0.70 | 1.134 | 0.990 | 103.59 | 5.70 | 2.171 | 1.167 | 0.942 | 117.54 | 450.61 |
| 2.02 | 0.75 | 1.142 | 0.979 | 105.62 | 5.64 | 2.229 | 1.177 | 0.927 | 119.89 | 468.85 |
| 2.07 | 0.80 | 1.150 | 0.968 | 107.67 | 5.57 | 2.287 | 1.187 | 0.911 | 122.29 | 487.74 |
| 2.12 | 0.85 | 1.158 | 0.956 | 109.75 | 5.51 | 2.345 | 1.198 | 0.894 | 124.71 | 507.31 |
| 2.17 | 0.90 | 1.166 | 0.943 | 111.84 | 5.43 | 2.403 | 1.209 | 0.877 | 127.18 | 527.59 |
| 2.22 | 0.95 | 1.175 | 0.930 | 113.96 | 5.36 | 2.461 | 1.220 | 0.858 | 129.69 | 548.62 |
| 2.27 | 1.00 | 1.184 | 0.917 | 116.10 | 5.28 | 2.520 | 1.231 | 0.840 | 132.25 | 570.44 |

CIRCUMFERENTIAL FLAW CALCULATION

| a (in) | Δa (in) | F2 | F3 | Kp (ksi-in$^{1/2}$) | Kt (ksi-in$^{1/2}$) | ae (in) | F1' | F3' | K,total (ksi-in$^{1/2}$) | J,app (in-lb/in$^2$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.27 | 0.00 | 0.965 | 1.062 | 37.02 | 6.12 | 1.297 | 0.967 | 1.063 | 43.71 | 62.30 |
| 1.32 | 0.05 | 0.969 | 1.062 | 37.90 | 6.12 | 1.348 | 0.972 | 1.062 | 44.61 | 64.90 |
| 1.37 | 0.10 | 0.973 | 1.062 | 38.78 | 6.12 | 1.400 | 0.976 | 1.061 | 45.50 | 67.52 |
| 1.42 | 0.15 | 0.977 | 1.060 | 39.65 | 6.11 | 1.451 | 0.980 | 1.059 | 46.38 | 70.16 |
| 1.47 | 0.20 | 0.981 | 1.058 | 40.52 | 6.09 | 1.503 | 0.985 | 1.055 | 47.25 | 72.82 |
| 1.52 | 0.25 | 0.986 | 1.055 | 41.39 | 6.07 | 1.554 | 0.989 | 1.051 | 48.12 | 75.51 |
| 1.57 | 0.30 | 0.990 | 1.050 | 42.25 | 6.05 | 1.605 | 0.994 | 1.046 | 48.98 | 78.23 |
| 1.62 | 0.35 | 0.995 | 1.045 | 43.11 | 6.02 | 1.657 | 0.998 | 1.041 | 49.83 | 80.98 |
| 1.67 | 0.40 | 0.999 | 1.040 | 43.98 | 5.99 | 1.708 | 1.003 | 1.034 | 50.67 | 83.76 |
| 1.72 | 0.45 | 1.004 | 1.033 | 44.84 | 5.95 | 1.760 | 1.008 | 1.027 | 51.52 | 86.56 |
| 1.77 | 0.50 | 1.008 | 1.026 | 45.70 | 5.91 | 1.811 | 1.013 | 1.019 | 52.35 | 89.40 |
| 1.82 | 0.55 | 1.013 | 1.018 | 46.55 | 5.86 | 1.862 | 1.018 | 1.010 | 53.19 | 92.27 |
| 1.87 | 0.60 | 1.018 | 1.009 | 47.41 | 5.81 | 1.914 | 1.022 | 1.000 | 54.02 | 95.17 |
| 1.92 | 0.65 | 1.023 | 1.000 | 48.27 | 5.76 | 1.965 | 1.028 | 0.990 | 54.84 | 98.11 |
| 1.97 | 0.70 | 1.028 | 0.990 | 49.14 | 5.70 | 2.017 | 1.033 | 0.979 | 55.67 | 101.08 |
| 2.02 | 0.75 | 1.032 | 0.979 | 50.00 | 5.64 | 2.069 | 1.038 | 0.967 | 56.49 | 104.09 |
| 2.07 | 0.80 | 1.038 | 0.968 | 50.86 | 5.57 | 2.120 | 1.043 | 0.955 | 57.31 | 107.15 |
| 2.12 | 0.85 | 1.043 | 0.956 | 51.73 | 5.51 | 2.172 | 1.049 | 0.942 | 58.14 | 110.24 |
| 2.17 | 0.90 | 1.048 | 0.943 | 52.60 | 5.43 | 2.223 | 1.054 | 0.928 | 58.96 | 113.37 |
| 2.22 | 0.95 | 1.053 | 0.930 | 53.47 | 5.36 | 2.275 | 1.059 | 0.914 | 59.78 | 116.55 |
| 2.27 | 1.00 | 1.058 | 0.917 | 54.34 | 5.28 | 2.326 | 1.065 | 0.899 | 60.60 | 119.77 |

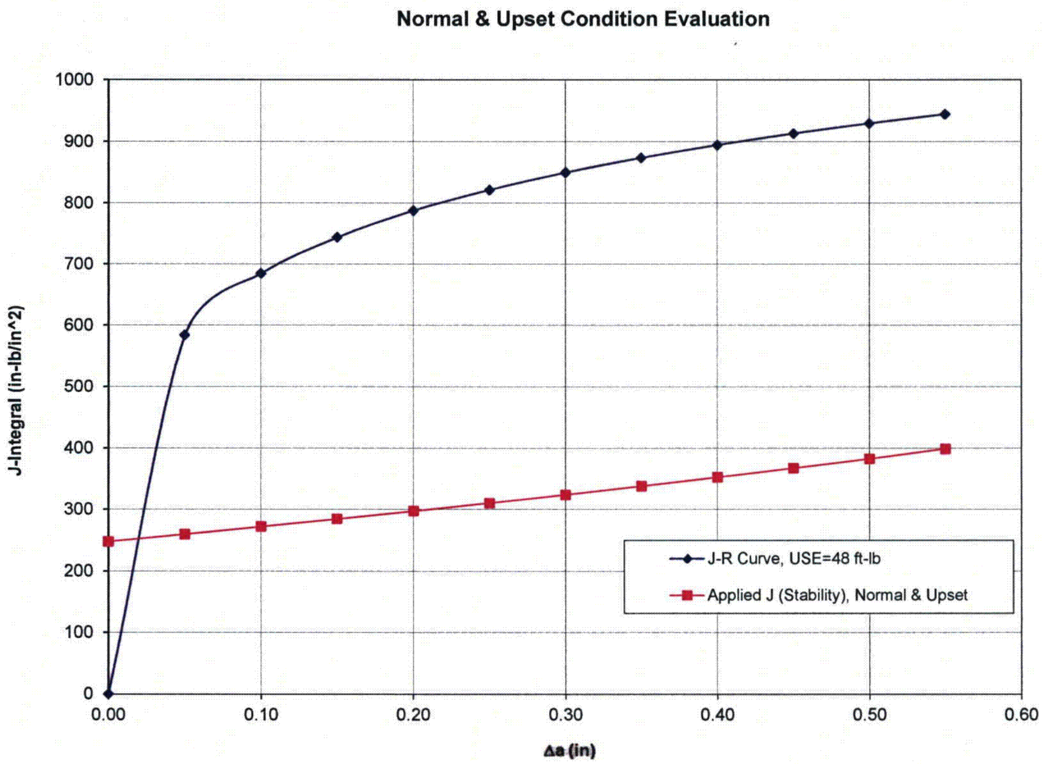


**Figure 7-2: Flaw Stability Criterion Evaluation for Axial Flaw with MNGP Plate J-R Curve**

## 8.0 EVALUATION OF LEVEL C & D CONDITIONS

The postulated flaw depth for the evaluation of Level C and D loadings is one-tenth the base metal wall thickness, plus the clad thickness, but with total depth not to exceed 1.0 inch. The plate thickness in the beltline region is 5.06 inches. The nominal thickness of the clad is [[ ]] inch. Therefore, the postulated crack depth is (5.06 * 0.1 + [[ ]]) or [[ ]] inch.

### 8.1 Level C Service Loading

The MNGP RPV thermal cycle drawing [16] amended by [17] specifies Level C events. The topical report [3] used an RPV thermal cycle drawing to select a limiting Level C transient (or event). It was determined that for the BWR/3-6 product lines, the "Improper Start of a Cold Recirculation Loop" transient is the most limiting Level C transient. Figure 8-1 shows this transient, which is identified without nomenclature in the MNGP vessel thermal cycle diagram [16] (Transient 24 in [3]), amended by [17]. (Note that the pressure shown in Figure 8-1 specifies 1050 psig. The MNGP EPU pressure is [[ ]] psig; as the difference is small and the evaluation used is bounding, it therefore remains applicable to the MNGP evaluation.) Since the geometry differences between the MNGP RPV and the RPV geometry analyzed in the topical report show the topical report to be bounding (as previously discussed), the $K_I$ values calculated in the topical report were also used in this evaluation. This meant using the same $K_t$ fit coefficients as shown in Table 6-1b of the topical report. The MNGP plant-specific thermal cycle diagram was reviewed; it was determined that the Level C event defined in [16] is bounded by the evaluation presented in the topical report.

Section 6.1.3 of [3] discusses the calculation method for the $K_I$ values due to cladding. The same technical approach and clad stress were used in this report.

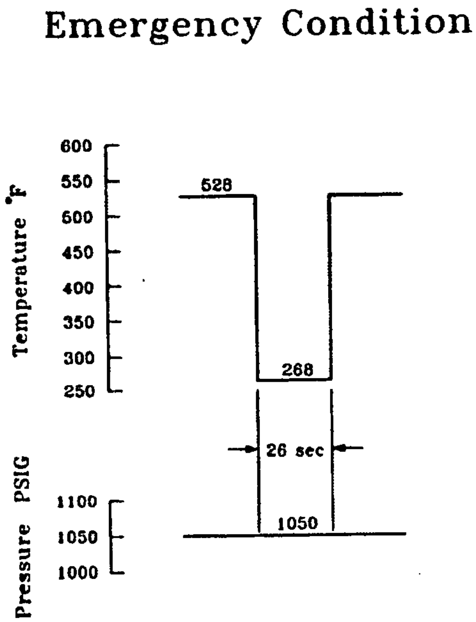


**Figure 8-1: Pressure & Temperature Conditions During Improper Start of Cold Recirculation Loop Transient for Limiting Level C Event**

### 8.2 Level C Service Evaluation

Table 8-1 shows the calculated values of the Level C condition applied J-Integral for axial and circumferential flaws. Since the internal pressure did not change during the thermal transient (see Figure 8-1), only one set of applied J-Integral calculations (shown in Table 8-1) was performed to evaluate the $J_{0.1}$ and the flaw stability criteria. As expected, the axial flaw case is governing. The material J-R curve for the Level C condition is the same as that for the Level A and B conditions. The $J_{0.1}$ criterion and the flaw stability evaluations are graphically shown in Figures 8-2 and 8-3, respectively. It is seen that both the criteria are satisfied.

# Table 8-1: Calculated Values of Applied J-Integral for Level C Transient

**Emergency Condition: Transient Event 24**

| | | | | | |
|---|---|---|---|---|---|
| Pressure (psi)= | 1050 | | | | |
| Vessel Ri (in.)= | 103.188 | Kt Coefficients | | Clad Stress | |
| Vessel Th (in.)= | 5.06 | a= | 8.831288 | | |
| Clad thickness (in.)= | 0.1875 | b= | 74.92595 | S (ksi)= | 6 |
| a0 (in.)= | 0.6935 | c= | -107.681 | | |
| E (ksi)= | 27900 | d= | 63.6289 | | |
| YS (ksi)= | 55.4 | e= | -14.3416 | | |

AXIAL FLAW CALCULATION

| a (in) | Δa (in) | F1 | Kt ($ksi\text{-}in^{1/2}$) | Kp ($ksi\text{-}in^{1/2}$) | Kclad ($ksi\text{-}in^{1/2}$) | ae (in) | F1' | K't ($ksi\text{-}in^{1/2}$) | K'p ($ksi\text{-}in^{1/2}$) | K'clad ($ksi\text{-}in^{1/2}$) | Ktotal ($ksi\text{-}in^{1/2}$) | Japp ($in\text{-}lb/in^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.69 | 0.00 | 1.001 | 26.91 | 33.19 | 2.13 | 0.760 | 1.005 | 26.72 | 34.88 | 2.02 | 63.63 | 132.05 |
| 0.74 | 0.05 | 1.004 | 26.78 | 34.46 | 2.05 | 0.813 | 1.008 | 26.50 | 36.18 | 1.95 | 64.62 | 136.22 |
| 0.79 | 0.10 | 1.007 | 26.59 | 35.70 | 1.97 | 0.865 | 1.011 | 26.23 | 37.45 | 1.88 | 65.55 | 140.16 |
| 0.84 | 0.15 | 1.010 | 26.34 | 36.93 | 1.91 | 0.917 | 1.015 | 25.91 | 38.70 | 1.82 | 66.43 | 143.94 |
| 0.89 | 0.20 | 1.013 | 26.06 | 38.14 | 1.85 | 0.969 | 1.019 | 25.58 | 39.93 | 1.76 | 67.27 | 147.59 |
| 0.94 | 0.25 | 1.017 | 25.74 | 39.33 | 1.79 | 1.021 | 1.023 | 25.22 | 41.15 | 1.71 | 68.08 | 151.18 |
| 0.99 | 0.30 | 1.021 | 25.41 | 40.51 | 1.74 | 1.073 | 1.027 | 24.85 | 42.36 | 1.67 | 68.87 | 154.71 |
| 1.04 | 0.35 | 1.025 | 25.06 | 41.68 | 1.69 | 1.124 | 1.032 | 24.47 | 43.56 | 1.63 | 69.65 | 158.22 |
| 1.09 | 0.40 | 1.029 | 24.70 | 42.84 | 1.65 | 1.176 | 1.036 | 24.08 | 44.75 | 1.59 | 70.41 | 161.71 |
| 1.14 | 0.45 | 1.033 | 24.32 | 44.00 | 1.61 | 1.228 | 1.041 | 23.67 | 45.94 | 1.55 | 71.16 | 165.18 |
| 1.19 | 0.50 | 1.038 | 23.94 | 45.15 | 1.57 | 1.280 | 1.046 | 23.26 | 47.13 | 1.52 | 71.90 | 168.61 |
| 1.24 | 0.55 | 1.043 | 23.55 | 46.30 | 1.54 | 1.332 | 1.052 | 22.81 | 48.32 | 1.48 | 72.61 | 171.97 |
| 1.29 | 0.60 | 1.048 | 23.14 | 47.44 | 1.51 | 1.383 | 1.057 | 22.34 | 49.50 | 1.45 | 73.30 | 175.22 |
| 1.34 | 0.65 | 1.053 | 22.71 | 48.59 | 1.48 | 1.435 | 1.063 | 21.82 | 50.69 | 1.42 | 73.94 | 178.31 |
| 1.39 | 0.70 | 1.058 | 22.24 | 49.74 | 1.45 | 1.487 | 1.069 | 21.24 | 51.89 | 1.40 | 74.53 | 181.16 |
| 1.44 | 0.75 | 1.064 | 21.73 | 50.89 | 1.42 | 1.538 | 1.075 | 20.59 | 53.08 | 1.37 | 75.04 | 183.69 |
| 1.49 | 0.80 | 1.070 | 21.16 | 52.04 | 1.39 | 1.590 | 1.081 | 19.85 | 54.28 | 1.35 | 75.47 | 185.80 |
| 1.54 | 0.85 | 1.076 | 20.52 | 53.20 | 1.37 | 1.641 | 1.088 | 18.99 | 55.48 | 1.33 | 75.80 | 187.39 |
| 1.59 | 0.90 | 1.082 | 19.79 | 54.37 | 1.35 | 1.692 | 1.094 | 18.00 | 56.68 | 1.31 | 75.99 | 188.34 |
| 1.64 | 0.95 | 1.088 | 18.95 | 55.54 | 1.33 | 1.743 | 1.101 | 16.86 | 57.89 | 1.29 | 76.03 | 188.54 |
| 1.69 | 1.00 | 1.095 | 17.97 | 56.72 | 1.30 | 1.793 | 1.108 | 15.53 | 59.09 | 1.27 | 75.89 | 187.86 |

CIRCUMFERENTIAL FLAW CALCULATION

| a (in) | Δa (in) | F2 | Kt ($ksi\text{-}in^{1/2}$) | Kp ($ksi\text{-}in^{1/2}$) | Kclad ($ksi\text{-}in^{1/2}$) | ae (in) | F2' | K't ($ksi\text{-}in^{1/2}$) | K'p ($ksi\text{-}in^{1/2}$) | K'clad ($ksi\text{-}in^{1/2}$) | Ktotal ($ksi\text{-}in^{1/2}$) | Japp ($in\text{-}lb/in^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.69 | 0.00 | 0.923 | 26.91 | 16.02 | 2.13 | 0.729 | 0.926 | 26.83 | 16.46 | 2.07 | 45.36 | 67.12 |
| 0.74 | 0.05 | 0.927 | 26.78 | 16.65 | 2.05 | 0.779 | 0.929 | 26.65 | 17.09 | 1.99 | 45.73 | 68.22 |
| 0.79 | 0.10 | 0.930 | 26.59 | 17.26 | 1.97 | 0.830 | 0.932 | 26.42 | 17.70 | 1.92 | 46.04 | 69.13 |
| 0.84 | 0.15 | 0.933 | 26.34 | 17.86 | 1.91 | 0.880 | 0.936 | 26.14 | 18.30 | 1.86 | 46.30 | 69.91 |
| 0.89 | 0.20 | 0.937 | 26.06 | 18.45 | 1.85 | 0.931 | 0.940 | 25.83 | 18.89 | 1.80 | 46.52 | 70.58 |
| 0.94 | 0.25 | 0.940 | 25.74 | 19.03 | 1.79 | 0.981 | 0.943 | 25.49 | 19.46 | 1.75 | 46.71 | 71.17 |
| 0.99 | 0.30 | 0.944 | 25.41 | 19.61 | 1.74 | 1.031 | 0.947 | 25.14 | 20.04 | 1.70 | 46.88 | 71.70 |
| 1.04 | 0.35 | 0.948 | 25.06 | 20.17 | 1.69 | 1.082 | 0.951 | 24.78 | 20.60 | 1.66 | 47.04 | 72.18 |
| 1.09 | 0.40 | 0.951 | 24.70 | 20.73 | 1.65 | 1.132 | 0.954 | 24.41 | 21.16 | 1.62 | 47.19 | 72.63 |
| 1.14 | 0.45 | 0.955 | 24.32 | 21.29 | 1.61 | 1.182 | 0.958 | 24.03 | 21.71 | 1.58 | 47.32 | 73.04 |
| 1.19 | 0.50 | 0.959 | 23.94 | 21.83 | 1.57 | 1.232 | 0.962 | 23.64 | 22.26 | 1.55 | 47.44 | 73.42 |
| 1.24 | 0.55 | 0.963 | 23.55 | 22.38 | 1.54 | 1.282 | 0.966 | 23.23 | 22.80 | 1.51 | 47.55 | 73.74 |
| 1.29 | 0.60 | 0.967 | 23.14 | 22.92 | 1.51 | 1.333 | 0.970 | 22.80 | 23.34 | 1.48 | 47.63 | 73.98 |
| 1.34 | 0.65 | 0.971 | 22.71 | 23.46 | 1.48 | 1.383 | 0.974 | 22.34 | 23.88 | 1.45 | 47.67 | 74.13 |
| 1.39 | 0.70 | 0.975 | 22.24 | 23.99 | 1.45 | 1.433 | 0.979 | 21.84 | 24.41 | 1.43 | 47.68 | 74.14 |
| 1.44 | 0.75 | 0.980 | 21.73 | 24.52 | 1.42 | 1.483 | 0.983 | 21.29 | 24.94 | 1.40 | 47.63 | 73.99 |
| 1.49 | 0.80 | 0.984 | 21.16 | 25.05 | 1.39 | 1.533 | 0.987 | 20.66 | 25.47 | 1.38 | 47.51 | 73.62 |
| 1.54 | 0.85 | 0.988 | 20.52 | 25.58 | 1.37 | 1.582 | 0.992 | 19.96 | 25.99 | 1.35 | 47.30 | 72.98 |
| 1.59 | 0.90 | 0.993 | 19.79 | 26.11 | 1.35 | 1.632 | 0.996 | 19.15 | 26.52 | 1.33 | 46.99 | 72.03 |
| 1.64 | 0.95 | 0.997 | 18.95 | 26.64 | 1.33 | 1.682 | 1.001 | 18.22 | 27.03 | 1.31 | 46.56 | 70.71 |
| 1.69 | 1.00 | 1.002 | 17.97 | 27.16 | 1.30 | 1.731 | 1.005 | 17.14 | 27.55 | 1.29 | 45.99 | 68.98 |

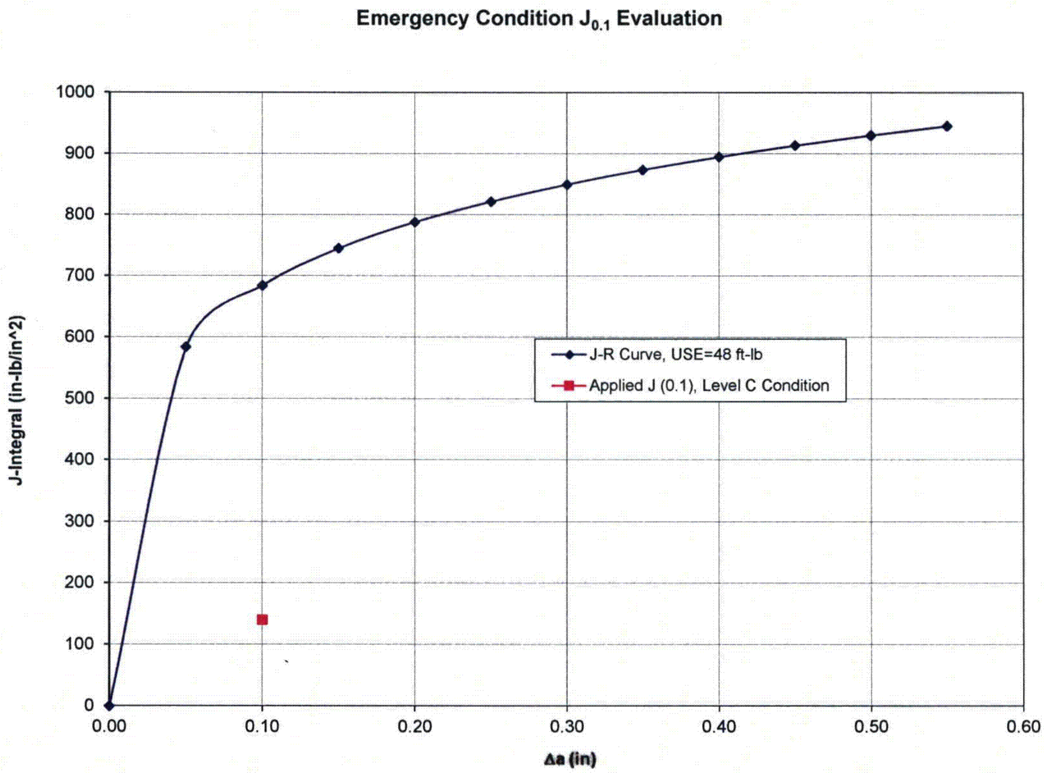


**Figure 8-2: $J_{0.1}$ Evaluation for Level C Condition**

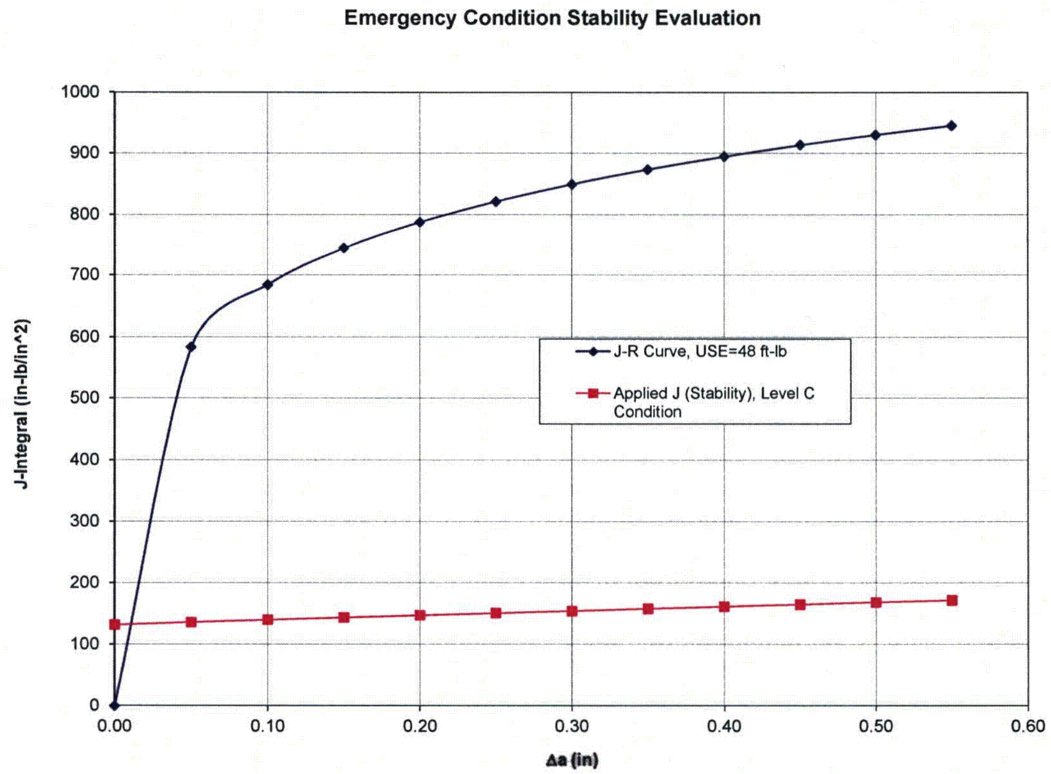


**Figure 8-3: Crack Growth Stability Criterion Evaluation for Level C Condition**

## 8.3 Level D Service Loading

The limiting Level D transient is the "Pipe Rupture and Blowdown" event, identified as Transient 27 in [3]. The pressure temperature profile is shown in Figure 8-4. Since the geometry differences between the MNGP RPV and the RPV geometry analyzed in the topical report [3] show the topical report to be bounding (as previously discussed), the $K_I$ values for Transient 27 calculated in the topical report were also used in this evaluation. Section 6.2.2 of [3] describes the fracture mechanics methodology used in the derivation of the $K_I$ values. The $K_t$ fit coefficients shown in Table 6-2 of the topical report were therefore also used in this evaluation. The MNGP plant-specific thermal cycle diagram was reviewed; it was determined that the Level D event defined in [16] is bounded by the evaluation presented in the topical report.

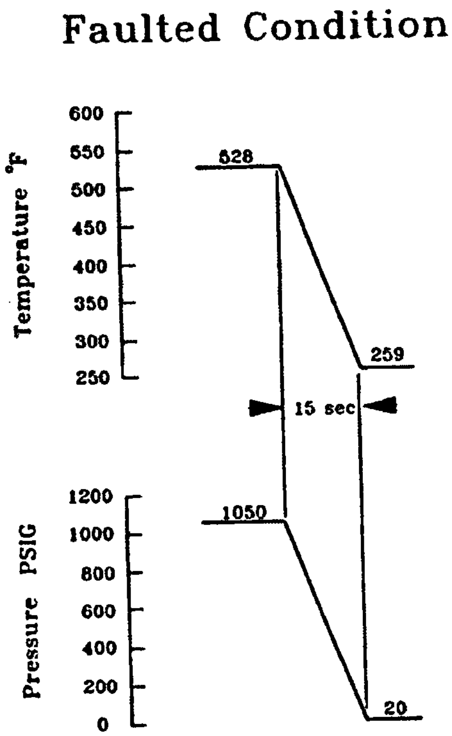


**Figure 8-4: Limiting Level D Transient**

### 8.4 Level D Service Evaluation

Table 8-2 shows the calculated values of the Level D condition applied J-Integral for axial and circumferential flaws. The internal pressure at the end of the transient was used in the applied J-Integral calculations. The axial flaw case is governing. The material J-R curve for Level D conditions is based on the MF of 1.0 as specified in [10]. Figure 8-5 graphically shows the flaw stability evaluation. It is seen that the ductile flaw crack growth stability criterion is satisfied.

## Table 8-2: Calculated Values of Applied J-Integral for Level D Transient

**Faulted Condition: Transient Event 27**

| | | Kt Coefficients | | Clad Stress | |
|---|---|---|---|---|---|
| Pressure (psi)= | 20 | | | | |
| Vessel Ri (in.)= | 103.19 | | | | |
| Vessel Th (in.)= | 5.06 | a= | 14.01 | | |
| Clad thickness (in.)= | 0.188 | b= | 130.91 | S (ksi)= | 16.5 |
| a0 (in.)= | 0.694 | c= | -155.73 | | |
| E (ksi)= | 27900 | d= | 89.845 | | |
| YS (ksi)= | 55.4 | e= | -20.64 | | |

AXIAL FLAW CALCULATION

| a | Δa | F1 | Kt | Kp | Kclad | ae | F1' | K't | K'p | K'clad | Ktotal | Japp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (in) | (in) | | (ksi-in$^{1/2}$) | (ksi-in$^{1/2}$) | (ksi-in$^{1/2}$) | (in) | | (ksi-in$^{1/2}$) | (ksi-in$^{1/2}$) | (ksi-in$^{1/2}$) | (ksi-in$^{1/2}$) | (in-lb/in$^2$) |
| 0.69 | 0.00 | 1.001 | 55.09 | 0.63 | 5.86 | 0.759 | 1.005 | 56.09 | 0.66 | 5.56 | 62.32 | 126.68 |
| 0.74 | 0.05 | 1.004 | 55.88 | 0.66 | 5.63 | 0.810 | 1.008 | 56.74 | 0.69 | 5.36 | 62.79 | 128.59 |
| 0.79 | 0.10 | 1.007 | 56.54 | 0.68 | 5.43 | 0.861 | 1.011 | 57.29 | 0.71 | 5.18 | 63.18 | 130.18 |
| 0.84 | 0.15 | 1.010 | 57.10 | 0.70 | 5.24 | 0.912 | 1.015 | 57.75 | 0.73 | 5.02 | 63.50 | 131.52 |
| 0.89 | 0.20 | 1.013 | 57.59 | 0.73 | 5.07 | 0.963 | 1.018 | 58.14 | 0.76 | 4.87 | 63.77 | 132.64 |
| 0.94 | 0.25 | 1.017 | 58.00 | 0.75 | 4.92 | 1.014 | 1.022 | 58.48 | 0.78 | 4.73 | 64.00 | 133.58 |
| 0.99 | 0.30 | 1.021 | 58.36 | 0.77 | 4.78 | 1.064 | 1.026 | 58.77 | 0.80 | 4.61 | 64.18 | 134.35 |
| 1.04 | 0.35 | 1.025 | 58.66 | 0.79 | 4.66 | 1.115 | 1.031 | 59.01 | 0.83 | 4.49 | 64.33 | 134.97 |
| 1.09 | 0.40 | 1.029 | 58.92 | 0.82 | 4.54 | 1.165 | 1.035 | 59.20 | 0.85 | 4.38 | 64.43 | 135.42 |
| 1.14 | 0.45 | 1.033 | 59.13 | 0.84 | 4.43 | 1.215 | 1.040 | 59.35 | 0.87 | 4.29 | 64.50 | 135.69 |
| 1.19 | 0.50 | 1.038 | 59.29 | 0.86 | 4.33 | 1.265 | 1.045 | 59.43 | 0.89 | 4.19 | 64.52 | 135.76 |
| 1.24 | 0.55 | 1.043 | 59.40 | 0.88 | 4.23 | 1.315 | 1.050 | 59.45 | 0.91 | 4.11 | 64.47 | 135.57 |
| 1.29 | 0.60 | 1.048 | 59.45 | 0.90 | 4.14 | 1.365 | 1.055 | 59.40 | 0.94 | 4.02 | 64.36 | 135.08 |
| 1.34 | 0.65 | 1.053 | 59.43 | 0.93 | 4.06 | 1.415 | 1.061 | 59.25 | 0.96 | 3.95 | 64.15 | 134.23 |
| 1.39 | 0.70 | 1.058 | 59.32 | 0.95 | 3.98 | 1.465 | 1.066 | 58.99 | 0.98 | 3.88 | 63.84 | 132.94 |
| 1.44 | 0.75 | 1.064 | 59.11 | 0.97 | 3.91 | 1.514 | 1.072 | 58.60 | 1.00 | 3.81 | 63.41 | 131.14 |
| 1.49 | 0.80 | 1.070 | 58.78 | 0.99 | 3.84 | 1.563 | 1.078 | 58.06 | 1.02 | 3.74 | 62.83 | 128.74 |
| 1.54 | 0.85 | 1.076 | 58.30 | 1.01 | 3.77 | 1.612 | 1.084 | 57.35 | 1.04 | 3.68 | 62.07 | 125.68 |
| 1.59 | 0.90 | 1.082 | 57.64 | 1.04 | 3.71 | 1.661 | 1.090 | 56.44 | 1.07 | 3.63 | 61.13 | 121.87 |
| 1.64 | 0.95 | 1.088 | 56.79 | 1.06 | 3.65 | 1.709 | 1.097 | 55.30 | 1.09 | 3.57 | 59.96 | 117.26 |

CIRCUMFERENTIAL FLAW CALCULATION

| a | Δa | F2 | Kt | Kp | Kclad | ae | F2' | K't | K'p | K'clad | Ktotal | Japp |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (in) | (in) | | (ksi-in$^{1/2}$) | (ksi-in$^{1/2}$) | (ksi-in$^{1/2}$) | (in) | | (ksi-in$^{1/2}$) | (ksi-in$^{1/2}$) | (ksi-in$^{1/2}$) | (ksi-in$^{1/2}$) | (in-lb/in$^2$) |
| 0.69 | 0.00 | 0.923 | 55.09 | 0.31 | 5.86 | 0.758 | 0.928 | 56.08 | 0.32 | 5.57 | 61.97 | 125.26 |
| 0.74 | 0.05 | 0.927 | 55.88 | 0.32 | 5.63 | 0.810 | 0.931 | 56.73 | 0.33 | 5.36 | 62.43 | 127.11 |
| 0.79 | 0.10 | 0.930 | 56.54 | 0.33 | 5.43 | 0.861 | 0.935 | 57.28 | 0.34 | 5.18 | 62.80 | 128.65 |
| 0.84 | 0.15 | 0.933 | 57.10 | 0.34 | 5.24 | 0.911 | 0.938 | 57.74 | 0.36 | 5.02 | 63.12 | 129.94 |
| 0.89 | 0.20 | 0.937 | 57.59 | 0.35 | 5.07 | 0.962 | 0.942 | 58.14 | 0.37 | 4.87 | 63.38 | 131.00 |
| 0.94 | 0.25 | 0.940 | 58.00 | 0.36 | 4.92 | 1.013 | 0.945 | 58.48 | 0.38 | 4.73 | 63.59 | 131.89 |
| 0.99 | 0.30 | 0.944 | 58.36 | 0.37 | 4.78 | 1.063 | 0.949 | 58.77 | 0.39 | 4.61 | 63.76 | 132.61 |
| 1.04 | 0.35 | 0.948 | 58.66 | 0.38 | 4.66 | 1.114 | 0.953 | 59.01 | 0.40 | 4.49 | 63.90 | 133.18 |
| 1.09 | 0.40 | 0.951 | 58.92 | 0.39 | 4.54 | 1.164 | 0.957 | 59.20 | 0.41 | 4.39 | 64.00 | 133.58 |
| 1.14 | 0.45 | 0.955 | 59.13 | 0.41 | 4.43 | 1.214 | 0.961 | 59.34 | 0.42 | 4.29 | 64.05 | 133.81 |
| 1.19 | 0.50 | 0.959 | 59.29 | 0.42 | 4.33 | 1.264 | 0.965 | 59.43 | 0.43 | 4.19 | 64.06 | 133.83 |
| 1.24 | 0.55 | 0.963 | 59.40 | 0.43 | 4.23 | 1.314 | 0.969 | 59.45 | 0.44 | 4.11 | 64.00 | 133.60 |
| 1.29 | 0.60 | 0.967 | 59.45 | 0.44 | 4.14 | 1.364 | 0.973 | 59.40 | 0.45 | 4.03 | 63.88 | 133.08 |
| 1.34 | 0.65 | 0.971 | 59.43 | 0.45 | 4.06 | 1.414 | 0.977 | 59.25 | 0.46 | 3.95 | 63.66 | 132.19 |
| 1.39 | 0.70 | 0.975 | 59.32 | 0.46 | 3.98 | 1.464 | 0.981 | 58.99 | 0.47 | 3.88 | 63.34 | 130.87 |
| 1.44 | 0.75 | 0.980 | 59.11 | 0.47 | 3.91 | 1.513 | 0.986 | 58.61 | 0.48 | 3.81 | 62.90 | 129.05 |
| 1.49 | 0.80 | 0.984 | 58.78 | 0.48 | 3.84 | 1.562 | 0.990 | 58.07 | 0.49 | 3.74 | 62.31 | 126.64 |
| 1.54 | 0.85 | 0.988 | 58.30 | 0.49 | 3.77 | 1.611 | 0.994 | 57.37 | 0.50 | 3.68 | 61.55 | 123.57 |
| 1.59 | 0.90 | 0.993 | 57.64 | 0.50 | 3.71 | 1.660 | 0.999 | 56.46 | 0.51 | 3.63 | 60.60 | 119.77 |
| 1.64 | 0.95 | 0.997 | 56.79 | 0.51 | 3.65 | 1.708 | 1.003 | 55.33 | 0.52 | 3.57 | 59.42 | 115.17 |

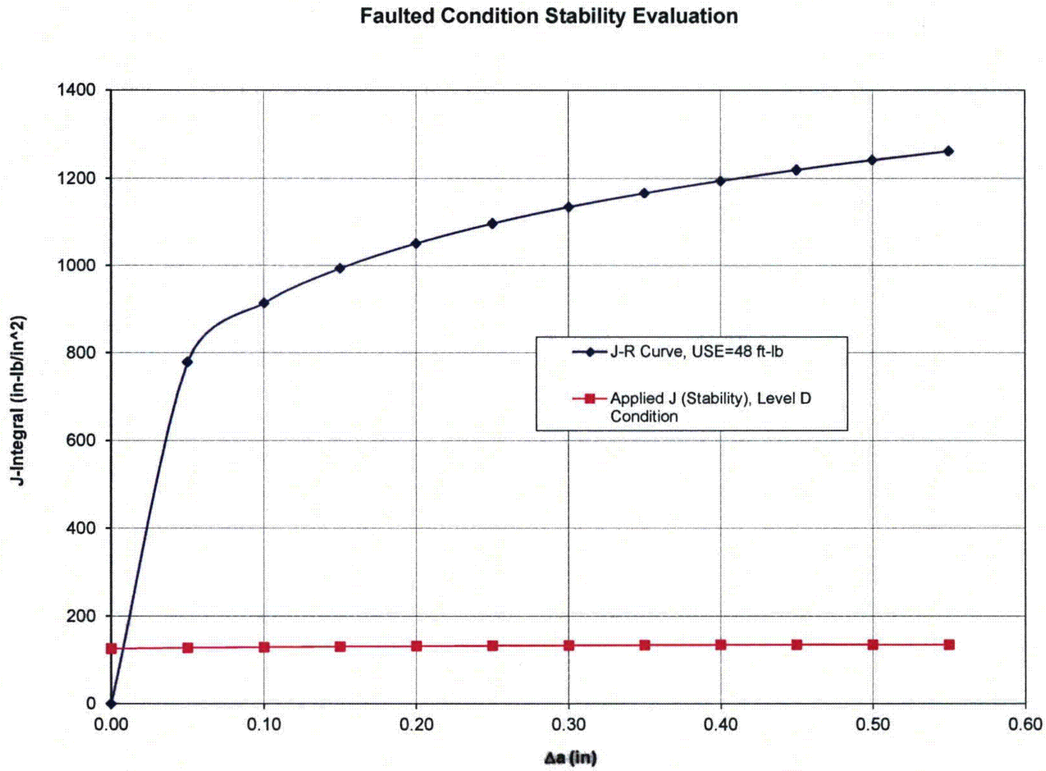


**Figure 8-5: Crack Growth Stability Criterion Evaluation for Level D Condition**

## 9.0 SUMMARY & CONCLUSIONS

10CFR50 Appendix G states that the RPV must maintain USE of no less than 50 ft-lbs throughout its life, unless it is demonstrated in a manner approved by the Director, Office of Nuclear Reactor Regulation, that lower values of USE will provide margins of safety against fracture equivalent to those required by Appendix G of Section XI the ASME Code.

For the MNGP EPU evaluation for 60 years (54 EFPY), the beltline plate material was evaluated using RG 1.99, Revision 2 [6]; the minimum predicted EOL USE value (48 ft-lbs) did not meet the required value of 50 ft-lbs defined in [1] or the acceptance criterion provided in BWRVIP-74-A [4]. Therefore, the calculation in this report documents a plant-specific evaluation that was conducted to show compliance with the USE requirements using RG 1.161 [10] and ASME Appendix K [9].

This MNGP plate USE evaluation followed the methodology outlined in ASME Code Case N-512-1 [8], Appendix K of ASME Section XI [9], and RG 1.161 [10]. The evaluation shows that the Level A and B Condition is governing.

Based on the results of this plant-specific evaluation, it is concluded that the plate materials in the MNGP RPV meet the margins of safety against fracture equivalent to those required by Appendix G of Section XI the ASME Code.

## 10.0REFERENCES

1. "Fracture Toughness Requirements," Appendix G to Part 50 of Title 10, the Code of Federal Regulations, July 1983.
2. ASME, "Fracture Toughness Criteria for Protection Against Failure," Appendix G to Section XI of the ASME Boiler & Pressure Vessel Code, 2004 Edition.
3. GE Nuclear Energy, "10CFR50 Appendix G Equivalent Margin Analysis for Low Upper Shelf Energy in BWR/2 through BWR/6 Vessels," NEDO-32205-A, Revision 1, February 1994.
4. EPRI, "BWRVIP-74-A: BWR Vessel and Internals Project BWR Reactor Pressure Vessel Inspection and Flaw Evaluation Guidelines for License Renewal," 1008872, June 2003.
5. EPRI, "BWRVIP-135, Revision 2 BWR Vessel and Internals Project Integrated Surveillance Program (ISP) Data Source Book and Plant Evaluations," 1020231, October 2009.
6. USNRC, "Radiation Embrittlement of Reactor Vessel Materials," Regulatory Guide 1.99, Revision 2, May 1988.
7. USNRC, Branch Technical Position - MTEB 5-2, "Fracture Toughness Requirements", Revision 1, July 1981.
8. Code Case N-512-1, "Assessment of Reactor Vessels with Low Upper Shelf Charpy Impact Energy Levels," Section XI, Division 1 Code, August 24, 1995.
9. American Society of Mechanical Engineers, "Assessment of Reactor Vessels with Low Upper Shelf Charpy Impact Energy Levels," Appendix K, A93, pp. 482.1-482.15, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components", 1992 Edition, 1993 Addenda, New York, December 1993.
10. USNRC, "Evaluation of Reactor Pressure Vessels with Charpy Upper-Shelf Energy Less Than 50 ft-lb," Regulatory Guide 1.161, June 1995.
11. Code Case N-512, "Assessment of Reactor Vessels with Low Upper Shelf Charpy Impact Energy Levels," Section XI, Division 1 Code, February 12, 1993.
12. James T. Wiggins (US NRC) to Lesley A. England (Gulf States), "Acceptance for Referencing of Topical Report NEDO-32205, Revision 1, '10CFR50 Appendix G Equivalent Margin Analysis for Low Upper Shelf Energy in BWR/2 through BWR/6 Vessels'," December 08, 1993.
13. GE Hitachi Nuclear Energy, "Monticello Neutron Flux and Fluence Evaluation for Extended Power Uprate," 0000-0076-7052-R0, Revision 0, December 2007.

14. GE Hitachi Nuclear Energy, "Pressure-Temperature Curves for Nuclear Management Company LLC Monticello Nuclear Generating Plant," NEDC-33307P, Revision 0, February 2008.

15. GE Nuclear Energy, "Information on Reactor Vessel Material D Surveillance Program prepared for Northern States Power Company," NEDO-24197, Revision 1, October 1979.

16. GE Nuclear Energy, "Monticello Reactor Pressure Vessel Purchase Specification," 21A1112, Revision 6, March 1969

17. GE Hitachi Nuclear Energy, "Certified Design Specification for Monticello, "Reactor Vessel – Extended Power Uprate," 26A7209, Revision 0, March 2008.

# ENCLOSURE 6

## SUPPLEMENTAL INFORMATION

This Enclosure provides Supplemental information related to statements made in the Power Uprate Safety Analysis Report (PUSAR) to document replacement of equipment.

Discussion

The PUSAR (Reference 6-1, Enclosure 5) indicated that pressure transmitters would be replaced due to EPU conditions. The purpose of this supplement is to clarify that the transmitters to be replaced are actually level transmitters instead of pressure transmitters, and to report that this replacement has been completed.

In Reference 6-1, Enclosure 5, NSPM indicated that two pressure transmitters will be replaced due to EPU conditions outside of containment affecting the qualification of the pressure transmitters. In Reference 6-2, Enclosure 1, Item 27, NSPM indicated that level transmitters LT-7338A/B were replaced for compliance with the Equipment Qualification (EQ) program under EPU conditions.

In a recent discussion, the NRC staff requested NSPM clarify that the proposed modification was completed.

Description of change

NSPM has completed the replacement of LT-7338A/B. The level transmitters use a differential pressure signal to determine level in the Torus. Therefore, the level transmitters stated as being replaced in Reference 6-2, Enclosure 1, Item 27 are the pressure transmitters originally described as requiring replacement in Reference 6-1, Enclosure 5. Attached is a marked-up page from Reference 6-1, Enclosure 5 indicating completion of the replacement.

References

6-1 Letter from T J O'Connor (NSPM) to Document Control Desk (NRC), "License Amendment Request: Extended Power Uprate (TAC MD9990)," L-MT-08-052, dated November 5, 2008. (ADAMS Accession No. ML083230111)

6-2 Letter from M A Schimmel (NSPM) to Document Control Desk (NRC), "Monticello Extended Power Uprate: Supplement for Gap Analysis Updates (TAC MD9990)," L-MT-12-114, dated January 21, 2013. (ADAMS Accession No. ML130390220)

**Inside Containment**

EQ for safety-related electrical equipment located inside the containment is based on MSLB and/or DBA/LOCA conditions and their resultant temperature, pressure, humidity, and radiation consequences, and includes the environments expected to exist during normal plant operation. Normal temperatures are expected to increase slightly, but remain bounded by the normal temperatures used in the EQ analyses. The post-accident peak and long-term temperature and pressure for CLTP conditions increase slightly for EPU. However, the increase was determined not to adversely affect the qualification of safety-related electrical equipment.

The current radiation levels under normal plant conditions were evaluated to increase in proportion to the increase in RTP. The accident radiation levels increase above the levels used in the current EQ Program. The total integrated doses (normal plus accident) for EPU conditions were determined not to adversely affect qualification of the equipment located inside containment.

**Outside Containment**

Accident temperature, pressure, and humidity environments used for qualification of equipment outside containment result from an MSLB, or other HELBs, whichever is limiting for each plant area. The temperature, pressure and humidity profiles that are not bounded by the CLTP conditions were evaluated and do not adversely affect the qualification of safety related electrical equipment.

level were

The accident temperature resulting from a LOCA/MSLB inside containment increased for some Reactor Building areas due to the additional heat load resulting from the increase in drywell and wetwell temperatures. However, the increase in long-term post-accident temperatures was evaluated and determined not to adversely affect the qualification of safety-related electrical equipment with the exception of two ~~pressure~~ transmitters that ~~will be~~ replaced. The normal temperature, pressure, and humidity conditions do not change significantly as a result of EPU. The current normal and post-accident radiation levels were evaluated to increase. The total integrated doses (normal plus accident) for EPU conditions were evaluated and determined not to adversely affect qualification of the EQ equipment located outside of containment with the exception of the two ~~pressure~~ transmitters that ~~will be~~ replaced. The evaluation of the environmental parameter changes for EPU is provided separately.

**Conclusion**

NSPM has evaluated the effects of the proposed EPU on the environmental conditions for the qualification of electrical equipment. The evaluation indicates that the electrical equipment will continue to meet the relevant requirements of 10 CFR 50.49 following implementation of the proposed EPU. Therefore, the proposed EPU is acceptable with respect to the EQ of electrical equipment.