GE Nuclear Energy

Technical Services Business

NEDC-32148
Revision 2
DRF 137-0010-5,
Sec. 523-144-1092
Class 2
August 1995

REACTOR PRESSURE VESSEL POWER UPRATE STRESS REPORT RECONCILIATION FOR THE BRUNSWICK UNITS 1 AND 2 POWER PLANTS

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GE Nuclear Energy

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August 1995

REPORT CERTIFICATION

This design certification, with the documents listed below, constitutes the analysis of the Brunswick Units 1 and 2 Power Uprate Stress Report Reconciliation. I certify, to the best of my knowledge and belief, that the report listed below is correct, complete, and complies with the Design Specification listed below. I also hereby certify that I am a duly Registered Engineer under the laws of the State of California.

SUPPORTING DOCUMENTS

Document	Revision	Type of	Title
25A5062	1	Certified Design Specification	Reactor Vessel -- Power Uprate -- Brunswick
NEDC-32148	2	Analysis Report	Reactor Pressure Vessel Power Uprate Stress Report Reconciliation for the Brunswick Power Plants

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State: California Date: 8-16-95

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IMPORTANT NOTICE REGARDING

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ABSTRACT

An ASME Boiler and Pressure Vessel Code, Section III, analysis was conducted to assess the effects of changes in design bases operating conditions due to proposed increases in core thermal power levels (105% power uprate) on limiting components of the Brunswick Steam Electric Plant Unit 1 and Unit 2 reactor vessels. The components selected for stress and fatigue reevaluation are:

- Closure region bolts
- Feedwater nozzle
- Core spray nozzle
- Recirculation inlet nozzle

The results of the analysis show that structural integrity is maintained for all RPV components selected for the uprated conditions.

1. SUBJECT OF STUDY

An increase in the licensed thermal power of the Brunswick Steam Electric Plant is planned. Licensing analyses are being performed to support operation at power levels of up to 2558 MWt, which represents a 5% increase from the original licensed thermal power of 2436 MWt.

The purpose of this study is to determine whether modifications are required to existing systems and components to support this operational power increase.

The objectives of the study of the systems and components are to:

- Evaluate the impact on nuclear safety.
- Evaluate the influence on the availability and reliability of the system.

2. CONCLUSIONS

The results of the power uprate analysis show that structural integrity is maintained for the Brunswick Unit 1 and Unit 2 reactors at the increased temperatures and pressures. There is no effect on nuclear safety or the availability and reliability of the system.

3. INTRODUCTION

This report documents the ASME Boiler and Pressure Vessel Code, Section III, analysis of limiting Reactor Pressure Vessel (RPV) components for the Brunswick Steam Electric Plant. This analysis is based on proposed increases in core thermal power levels (power uprate) which will change some original design basis operating parameters such as coolant pressures, temperatures, and nozzle flow rates. These changes in pressures, temperatures and flows will, in general, increase the original stress values in the RPV components. This analysis constitutes the stress report reconciliation for validating the use of existing RPV components for the power uprate conditions.

4. POWER UPRATE CONDITIONS

4.1 Design Condition Changes

As noted in Paragraph 4.3 of the Design Specification for the Brunswick Power Uprate Program (Reference 1), the power uprate design requirements are unchanged from the original design requirements specified in the reactor vessel purchase documents (Reference 2).

4.2 Operating Condition Changes

As noted in Paragraph 4.4.1 of Reference 1, the changes to the Reactor Cycles document (Reference 3) are as follows:

- In Region A, the operating pressure shall be increased from 1000 to 1035 psig (1050 psia).
- In Regions A, B, and C, the operating temperature shall be increased from 546°F to 551°F when specified.
- In the "scram" transient, revise the following identified Region A pressures (by an increase of 35 psi) and the corresponding saturation temperatures as in Table 4-1.

Table 4-1
POWER UPRATE CHANGES FOR THE SCRAM TRANSIENT

Original Pressure (psig/psia)	**Power Uprate Pressure (psig/psia)**	**Original Sat. Temp. (°F)**	**Power Uprate Sat. Temp. (°F)**
1180/1195	1215/1230	567*	570
875/890	910/925	531	535
1125/1140	1160/1175	561	564
1000/1015	1035/1050	546	550
665/680	700/715	500	505
930/945	965/980	538	542

* The saturation temperature for a pressure of 1180 psig (1195 psia) is 567°F, <u>not</u> 573°F as written in Reference 3.

- In Regions B and C, the identified operating temperatures shall be increased as follows: 522 to 527°F, 538 to 543°F and 512 to 517°F.

As noted in Paragraph 4.4.2 of Reference 1, the changes to the Reactor Vessel Nozzle Thermal Cycles document (Reference 4) are as follows:

- On Sheet 1 (Recirculation Outlet) the 100% rated flow per nozzle increases from 43,500 to 47,800 GPM.
- On Sheet 2 (Recirculation Inlet) the 100% rated flow per nozzle increases from 8700 to 9560 GPM.
- On Sheet 3 (Steam Outlet) the 100% rated flow/nozzle increases from 2.43×10^6 to 2.84×10^6 lb/hr.
- On Sheets 4 and 5 (Feedwater) the feedwater inlet temperature increases from 376°F to 427°F.
- On Sheets 4 and 5 (Feedwater) the 100% rated flow/nozzle increases from 5550 to 6800 GPM (Unit 1) and 6380 GPM (Unit 2).
- On all sheets, the vessel bulk temperature, when specified, shall be increased from 546°F to 551°F.
- On all sheets, the vessel pressure shall be increased from 1000 psig to 1035 psig (1015 to 1050 psia) when specified.

As noted in Paragraph 4.4.3 of Reference 1, in the recirculation inlet specification (Table 1) change the thermal sleeve loads identified as "hydraulic and seismic" and "hydraulic normal operation" to the values tabulated.

As noted in Paragraph 4.4.4 of Reference 1, all other operating requirements are unchanged from those specified in Reference 2.

5. POWER UPRATE STRESS ANALYSIS FOR NON-BOLTING MATERIALS

5.1 ASME Code Stress Analysis

The power uprate stress analysis uses the guidelines and procedures of the ASME Boiler and Pressure Vessel Code, Section III (Code). For the component under consideration, the 1965 Code with addenda up to and including Summer 1967 (Reference 6), which is the Code of construction, shall be the governing Code. However, if a component underwent a design modification, the governing Code shall be the Code used in the stress analysis of the modified component.

5.2 Design Conditions

Since there are no changes in the design conditions due to power uprate, the design-based stresses (general primary membrane, primary membrane plus primary bending) remain unchanged and the Code requirements of Paragraphs N-414.1 through N-414.3 of Reference 6 and Section NB-3221 of Reference 7 are still met for all RPV components analyzed.

5.3 Normal and Upset Conditions

5.3.1 Effects of Changes in Pressure, Temperature, and Nozzle Flow Rates

In general, changes in normal operation pressures, temperatures and nozzle flow rates will increase the primary plus secondary (P+Q) stresses and the primary plus secondary plus peak (P+Q+F) stresses at a particular location on the RPV component.

The stress components [3 normal (σ_r, σ_θ, σ_z) and 3 shear (τ_{rz}, $\tau_{z\theta}$, $\tau_{\theta r}$)] of the P+Q stresses and the P+Q+F stresses consist of pressure stress components, thermal cycling stress components, and mechanical stress components (resulting from reaction loads from attached piping and/or a thermal sleeve, or from seismic loads).

The magnitude of the normal stress due to pressure is directly proportional to the coolant pressure, and the magnitude of the normal stress due to thermal cycling is proportional to the temperature change during a thermal transient (final transient temperature minus initial transient temperature).

In the case of nozzles, increases in coolant flow through the nozzle will increase the forced convection heat transfer coefficients on the inside (fluid side) surface of the nozzle. These increases in heat transfer coefficients will change the temperature distribution through the nozzle, thus changing the thermal stresses in the nozzle slightly. However, previous studies suggest that small changes in the heat transfer coefficient on the nozzle inside surface have a negligible effect on the temperature distribution through the nozzle.

5.3.2 Power Uprate Scaling Technique

A technique was developed to conservatively scale up the original stress report stresses to account for pressure and temperature increases due to power uprate.

In the pressure vessel calculations examined for Brunswick, the three stress directions of the orthogonal coordinate system (e.g., r, θ, and z) at a particular location on the component of interest are chosen such that the shear stress components are zero and, thus, the normal stress components are the principal stresses.

Therefore, the magnitude of the principal stress due to pressure is directly proportional to the coolant pressure, and the magnitude of the principal stress due to thermal cycling is proportional to the temperature change during a thermal transient, provided that the normal stress directions and the principal stress directions coincide. Since ΔT_{new} is in the same relative range as ΔT_{old}, changes in the coefficient of thermal expansion are insignificant and can be ignored. Since, for most components, there are no changes in the mechanical stresses due to power uprate, the new (power uprate) value for principal stress is:

$$\sigma_{total.new} = \sigma_{pressure.old}\left(\frac{P_{new}}{P_{old}}\right) + \sigma_{thermal.old}\left(\frac{\Delta T_{new}}{\Delta T_{old}}\right) + \sigma_{mechanical}$$

Or:

$$\sigma_{total.new} = \sigma_{pressure.old}(SCF)_P + \sigma_{thermal.old}(SCF)_T + \sigma_{mechanical}$$

where

$(SCF)_P$ = pressure scaling factor = (P_{new}/P_{old})
$(SCF)_T$ = thermal scaling factor = $(\Delta T_{new}/\Delta T_{old})$
ΔT = final thermal transient temp. - initial thermal transient temp.

Most stress reports do not explicitly report values for pressure stresses, thermal cycling stresses and mechanical stresses separately. Therefore, it is not possible to calculate power uprate principal stresses by scaling the original pressure stress by $(SCF)_P$ and the original thermal cycling stress by $(SCF)_T$ and combining them with the original mechanical stress.

Thus, a conservative scaling technique was developed where the original principal stress components are scaled up by the larger of $(SCF)_P$ and $(SCF)_T$. This is conservative because:

- The ***larger*** scaling factor, SCF, is used to scale up the stresses.
- The mechanical stress is scaled up as well.

In addition, if the scaling factor is less than unity, the power uprate principal stresses are not scaled down. In that case, an SCF value of 1.0 is used; that is, the original values are retained.

To further simplify the scaling technique, the larger scaling factor, SCF, can be applied directly to the original stress intensity values instead of applied to the original principal stresses. Stress intensity (or "stress difference") is determined by taking the algebraic difference between any pair of principal stresses. The following example illustrates why SCF can be applied to the stress intensities directly:

$$\begin{aligned} S_{12,new} &= \sigma_{1,new} - \sigma_{2,new} \\ &= (\sigma_{1,old} \times SCF) - (\sigma_{2,old} \times SCF) \\ &= (\sigma_{1,old} - \sigma_{2,old}) \times SCF \\ &= S_{12,old} \times SCF \end{aligned}$$

5.3.3 ASME Code Stress Limits for Normal and Upset Conditions

According to Paragraph N-414.4 of Reference 6 and Sections NB-3222 and NB-3223 of Reference 7, structural adequacy is met if the maximum primary plus secondary stress intensity range, S_n, at a location on the component is less than $3S_m$ of the material. If the $3S_m$ limit is not met, then plastic behavior is assumed and the simplified elastic-plastic analysis of Paragraph NB-3228.3 of Reference 7 can be used to determine structural adequacy.

For those components that do not meet the requirements of Paragraph N-415.1 of Reference 6 or Paragraph NB-3222.4(d) of Reference 7, a fatigue evaluation must be made to assure that the component does not fail by material fatigue. For adequacy, the cumulative fatigue usage factor must be less than 1.0.

5.3.4 Procedure for Calculating Power Uprate P+Q Stress Intensity Range

The following general procedure is used for calculating the power uprate P+Q stress intensity range, $S_{n,new}$, for the limiting location on the RPV component of interest. This power uprate value will then be compared with the ASME Code stress limit described in Paragraph 5.3.3 of this report:

1) Determine the pressure scaling factors, $(SCF)_P$, and the thermal scaling factors, $(SCF)_T$, for all stress cycles originally analyzed using the appropriate power uprate operating condition changes. For each stress cycle, determine the larger of the two scaling factors. This value is SCF.

2) Multiply SCF for each stress cycle by the original P+Q stress intensity values of the original governing stress report. The original governing stress report is the most recent stress report listed in Paragraph 2.1 of Reference 1.

3) Determine the maximum absolute value of the extremes of the range through which the power uprate stress intensities (calculated in step 2) fluctuate over time. This value is $S_{n,new}$. Note that there are two stress cycles associated with it.

4) Determine the allowable P+Q stress intensity range, $3S_{m,new}$, evaluated at the maximum temperature of the two limiting stress cycles of step 3. However, according to Note 1 of Figure N-414 of Reference 6, the average value of $3S_m$ for the highest and lowest temperatures of the metal during the transient can be used in the analysis if it can be shown that the secondary stress is due to thermal loads and not mechanical loads.

5) Compare $S_{n,new}$ with $3S_{m,new}$. If $S_{n,new} < 3S_{m,new}$, the ASME Code stress limit is met. If $S_{n,new} > 3S_{m,new}$, then the guidelines of Paragraph NB-3228.3 of Reference 7 must be followed, using power uprate values where applicable.

5.3.5 Procedure for Power Uprate Fatigue Evaluation

The following general procedure is used for calculating the power uprate cumulative fatigue usage factor, U_{new}, for the limiting location on the RPV component of interest. This power uprate value will then be compared with the ASME Code stress limit described in Paragraph 5.3.3 of this report.

1) Multiply SCF for each stress cycle by the original P+Q+F stress intensity values of the original governing stress report.

2) For each of the limiting stress cycle pairs used in the fatigue analysis of the original governing stress report, determine the absolute value of the difference of the power uprate P+Q+F stress intensities (calculated in part a). This value is $S_{P+Q+F,new}$.

3) Determine the power uprate alternating stress intensity, $S_{alt,new}$, for each of the original limiting stress cycle pairs as follows:

$$S_{alt,new} = \frac{1}{2} \times K_{e,new} \times \frac{E_c}{E_a} \times S_{P+Q+F,new}$$

where

$$\begin{aligned} K_{e,new} &= \text{simplified elastic - plastic factor} \\ &= 1.0,\ S_{n,new} \leq 3S_{m,new} \\ &= 1 + \frac{(1-n)}{(n(m-1))} \times \left[\frac{(S_{n,new})}{(3S_{m,new})} - 1 \right],\ 3S_{m,new} < S_{n,new} < 3mS_{m,new} \\ &= \frac{1}{n},\ S_{n,new} \geq 3mS_{m,new} \end{aligned}$$

$\frac{E_c}{E_a}$ = elastic modulus correction factor

E_c = elastic modulus of design fatigue curve

E_a = elastic modulus at actual temperature.

4) Use $S_{alt,new}$ as the value of the ordinate when entering the applicable design fatigue curve in Reference 6 or 7 to find the corresponding allowable number of cycles, $N_{i,new}$, for each of the limiting stress cycle pairs.

5) Calculate the power uprate incremental fatigue usage factor, $U_{i,new} = n_i/N_{i,new}$, for each of the limiting stress cycle pairs, where n_i is the lesser of the actual number of design cycles for each pair. The lesser number is used because the value of the P+Q+F stress intensity range for the limiting stress cycle pair is only experienced by the component over the lesser number of cycles.

6) Calculate the power uprate cumulative fatigue usage factor, $U_{new} = \sum U_{i,new}$. If $U_{new} < 1.0$, the ASME Code stress limit is met.

5.4 Emergency and Faulted Conditions

Maximum primary stresses due to emergency conditions and faulted conditions remain unchanged and the Code requirements of Sections NB-3224 and NB-3225 of Reference 7 are still met for all RPV components analyzed.

6. POWER UPRATE STRESS ANALYSIS FOR BOLTING MATERIALS

6.1 Design Conditions

Since there are no changes in the design conditions due to power uprate, the bolt design stresses remain unchanged and the ASME Code requirements of Section N-416 of Reference 6 and Section NB-3231 of Reference 7 are still met.

6.2 Normal, Upset, and Emergency Conditions

6.2.1 Effects of Changes in Pressure and Temperature

In general, changes in normal operation pressures and temperatures will increase the bolt service stresses, both averaged across the bolt cross section and at the periphery of the bolt cross section, and increase the peak bolt stresses.

6.2.2 ASME Code Stress Limits for Normal, Upset, and Emergency Conditions

According to Paragraph N-416.1 of Reference 6 and Paragraph NB-3232.1 of Reference 7, structural adequacy is met if the maximum value of service stress, averaged across the bolt cross section and neglecting stress concentrations, is less than $2S_m$ of the bolting material.

According to Paragraph N-416.1 of Reference 6 and Paragraph NB-3232.2 of Reference 7, structural adequacy is met if the maximum value of service stress at the periphery of the bolt cross section is less than $3S_m$ of the bolting material, except that the maximum value of service stress is limited to 2.7 S_m if the higher of the two fatigue curves in Figure N-416 of Reference 6 or Figure I-9-4 of Reference 7 is used (see Sheet 80 of Reference 14).

For those components that do not meet the requirements of Paragraph N-415.1 of Reference 6 or Paragraph NB-3222.4(d) of Reference 7, a fatigue evaluation must be made to assure that the bolts do not fail by material fatigue. For adequacy, the cumulative fatigue usage factor must be less than 1.0.

6.2.3 Procedure for Calculating Power Uprate Service Stresses

The general procedure for calculating the power uprate service stresses for the limiting location on the bolt, and comparing it to the ASME Code stress limits described in Paragraph 6.2.2 of this report, is as follows:

1) Determine the pressure scaling factors, $(SCF)_P$, and the thermal scaling factors, $(SCF)_T$, for all stress cycles originally analyzed using the appropriate power uprate operating condition changes. For each stress cycle, determine the larger of the two scaling factors. This value is SCF.

2) Multiply SCF for each stress cycle by the original service stress values, both averaged across the bolt cross section and at the bolt periphery, of the original governing stress report.

3) Determine the allowable service stress values, $2S_{m,new}$ for the service stress averaged across the bolt cross section, and $3S_{m,new}$ for the service stress at the bolt periphery, evaluated at the maximum temperature of the limiting stress cycles.

4) Compare the power uprate service stresses with their allowable values. If the allowable values are not exceeded, the ASME Code stress limits are met.

6.2.4 Procedure for Power Uprate Fatigue Evaluation

The general procedure for calculating the power uprate cumulative fatigue usage factor, U_{new}, for the limiting location on the bolt and comparing it to the ASME Code stress limit described in Paragraph 6.2.2 of this report, is as follows:

1) Multiply SCF for each stress cycle by the original peak bolt stress values of the original governing stress report.

2) For each of the limiting stress cycle pairs used in the fatigue analysis of the original governing stress report, determine the absolute value of the difference of the power uprate peak bolt stresses (calculated in step 1). This value is $S_{peak,new}$.

3) Determine the power uprate alternating stress intensity, $S_{alt,new}$, for each of the original limiting stress cycle pairs as follows:

$$S_{alt,new} = \frac{1}{2} \times \frac{E_c}{E_a} \times S_{peak,new}$$

where (E_c/E_a) = same factor as in Paragraph 3.3.5 of this Report.

4) Use $S_{alt,new}$ as the value of the ordinate when entering the design fatigue curve (Figure I-9.4) of Reference 7 to find the corresponding allowable number of cycles, $N_{i,new}$, for each of the limiting stress cycle pairs.

5) Calculate the power uprate incremental fatigue usage factor, $U_{i,new} = n_i / N_{i,new}$, for each of the limiting stress cycle pairs, where n_i is the lesser of the actual number of cycles for each pair. The lesser number is used because the value of the peak bolt stress range for the limiting stress cycle pair is only experienced by the bolt over the lesser number of cycles.

6) Calculate the power uprate cumulative fatigue usage factor, $U_{new} = \sum U_{i,new}$. If $U_{new} < 1.0$, the ASME Code stress limit is met.

6.3 Faulted Conditions

The stresses due to faulted conditions remain unchanged and the Code requirements of Section NB-3235 of Reference 7 are still met for all bolts analyzed.

7. COMPONENT ANALYSIS

7.1 Selection Criteria for Power Uprate Stress Analysis

RPV components were selected for the power uprate stress analysis based on original fatigue usage factors greater than 0.5 at the most limiting location on the component as calculated in the most recent stress report for that component. These selected components are considered to be the bounding components of the RPV. A summary of original fatigue usage factors for RPV components that did not meet the requirements of Paragraph N-415.1 (Vessels Not Requiring Analysis for Cyclic Operation) of Reference 6 or Paragraph NB-3222.4(d) of Reference 7 is shown in Table 7-1.

Thus, the components selected for power uprate stress analysis, based on the selection criteria, are:

- Closure Region Bolts, Units 1 and 2
- Feedwater Nozzle, Units 1 and 2
- Core Spray Nozzle, Units 1 and 2
- Recirculation Inlet Nozzle, Units 1 and 2

Table 7-1
SUMMARY OF PRE-POWER UPRATE FATIGUE USAGE FACTORS

RPV Component	**Pre-Power Uprate Cumulative Fatigue Usage Factor**
Skirt to Bottom Head Junction	0.0834
Feedwater Nozzle	0.747 (1), 0.73 (2)
Core Spray Nozzle	0.98 (3)
Recirculation Inlet Nozzle	0.81 (4)
Shroud Support	0.195
Closure Region Bolts	0.8
Recirc Outlet Nozzle	0.127 (5)

NOTES:

(1) Value for Brunswick Unit 1 is given in Reference 9.
(2) Value for Brunswick Unit 2 is given in Reference 10.
(3) Value is given in core spray nozzle modification stress report (Reference 11).
(4) Value is given in recirc inlet nozzle modification stress report (Reference 12).
(5) Value is given in recirc outlet nozzle modification stress report (Reference 13).

7.1.1 Table Temperature and Strength Ratio Checks

According to Paragraph NB-3228.3(e) of Reference 7, the temperature used in the analysis should not exceed the tabulated values of Paragraph NB-3228.3. The maximum temperature from this table is 800°F for austenitic stainless steel, and the maximum analysis temperature is 551°F for the components analyzed. Since 551°F < 800°F, this requirement is met.

According to Paragraph NB-3228.3(f), the ratio of the material's minimum specified yield strength, $S_{y,ms}$, to the minimum specified ultimate strength, $S_{u,ms}$, shall be less than 0.80. All component materials meet this requirement.

7.2 Closure Region Bolts

7.2.1 Results of Original Analysis

The highest original cumulative fatigue usage factor for the Closure Region Bolts is 0.8, as given in Reference 14.

The maximum original value of the service stress averaged across the bolt cross section is 55.2 ksi, and the maximum original value of the service stress at the bolt periphery is 89.6 ksi.

7.2.2 Power Uprate Service Stress Limit Check

The service stress limits of Paragraph 6.2.3 of this report must be met after applying the power uprate operating conditions to the original analysis.

The original values of the maximum service stresses that were affected by power uprate operating conditions are scaled up by the appropriate values. The combined stress cycles used in the original analysis are retained in this analysis.

The results of the power uprate maximum average service stress analysis are shown in Table 7-2. It can be seen that all power uprate values are below their allowable limits of $2S_m$, where S_m values are evaluated at power uprate conditions. The largest value of the service stress affected by the power uprate conditions, averaged across the bolt cross section, is 56.8 ksi due to the startup stress.

The results of the power uprate maximum periphery service stress analysis are shown in Table 7-3. The largest overall value of the service stress at the bolt periphery is 92.2 ksi (due to startup), and meets the allowable of 108.1 ksi.

7.2.2.1 Power Uprate Fatigue Usage Check

The fatigue usage limit of Paragraph 6.2.2 of this report must be met after applying the power uprate operating conditions to the original analysis. The original values of the peak bolt stresses are scaled up by the appropriate SCF values. These power uprate peak bolt stresses are used in the power uprate fatigue evaluation.

The only two stress cycle pairs affected by the power uprate conditions were the Startup - Normal Cooldown pair and the Scram cycles. The power uprate conditions increased the original fatigue usage for the Closure Region Bolts from 0.8 to 0.81.

Table 7-2
POWER UPRATE MAXIMUM SERVICE STRESS RESULTS AVERAGED OVER CROSS-SECTION FOR THE CLOSURE REGION BOLTS

Material: SA-540 Grade B24(B) Low Alloy Steel

Stress Component	**Startup Transient**	**Operating Steady State**	**Overload Steady State**
Original	55.2 ksi	41.3 ksi	42.8 ksi
Scaling Factor	1.03	1.03	1.01
Power Uprate	56.8 ksi	42.5 ksi	43.2 ksi
Allowable ($2S_m$)	80.1 ksi	73.5 ksi	73.5 ksi

Table 7-3
POWER UPRATE MAXIMUM SERVICE STRESS RESULTS AT BOLT PERIPHERY FOR THE CLOSURE REGION BOLTS

Material: SA-540 Grade B24(B) Low Alloy Steel

Stress Component	Startup Transient	Operating Steady State	Overload Steady State
Original	89.6 ksi	63.7 ksi	63.9 ksi
Scaling Factor	1.03	1.03	1.01
Power Uprate	92.2 ksi	65.6 ksi	64.5 ksi
Allowable (2.7S_m)	108.1 ksi	99.2 ksi	99.2 ksi

7.2.3 Discussion of Power Uprate Results

The power uprate analysis for the Closure Region Bolts shows that the Code stress limits are met and that the structural integrity is acceptable for the power uprate conditions.

7.3 Feedwater Nozzle Unit 1

7.3.1 Results of Original Analysis

The location of highest original cumulative fatigue usage on the feedwater nozzle is on Element 449 on the safe end. Note that the feedwater nozzle was modified to accept a new thermal sleeve after the original RPV vendor stress report was issued. Therefore, the governing stress report is Reference 9. The original fatigue usage factor calculated in Reference 9 is 0.747.

7.3.2 Power Uprate P+Q Stress Intensity Limit Check

The primary plus secondary stress intensity limit of Paragraph 5.3.3 of this report must be met after applying the power uprate operating conditions to the original analysis.

The power uprate scaling factors were applied to the P+Q stress intensity range values.

The maximum P+Q stress intensity range, S_n, which is equal to 126.3 ksi, exceeds the allowable 3S_m limit of 69.9 ksi. Thus, the simplified elastic-plastic analysis of Paragraph NB-3228.3 of Reference 7 must be performed.

7.3.2.1 Removal of Thermal Bending Stresses

According to Paragraph NB-3228.3(a) of Reference 7, the P+Q stress intensity range, after removing thermal bending stresses, shall be less than 3S_m. Power uprate P+Q stresses are recalculated (scaled up) after removing the thermal bending stresses from the stress components. These values are then used to determine the P+Q (minus thermal bending) stress intensity range for certain stress cycle pairs.

The maximum P+Q (minus thermal bending) stress intensity range is 37.3 ksi, which is less than the allowable $3S_m$ limit (for that pair) of 69.9 ksi. Thus, the requirement of Paragraph NB-3228.3(a) is met.

7.3.2.2 Calculation of the Cumulative Fatigue Usage Factor

Fatigue usage for power uprate was evaluated using the procedure outlined in Section 5.3.5. The results show that the power uprate fatigue usage factor is 0.856, which is below the allowable limit of 1.0.

7.3.2.3 Thermal Stress Ratchet Check

Per Paragraph NB-3228.3(d) of Reference 7, the thermal stress ratchet check of Paragraph NB-3222.5 of Reference 7 must be performed. The analysis shows that compliance is met, as follows:

Maximum general membrane stress due to pressure:

$(P_M)_\theta = 9.148$ ksi
(from p. 8 of Reference 8)

$$x = \frac{(P_M)_\theta}{1.5 \times S_m} = \frac{9.148 \text{ ksi}}{34.95 \text{ ksi}} = 0.262$$

where S_m is evaluated at the increased vessel temperature at Power Uprate of 551°F.

For $0 < x < 0.5$,

$$y = \frac{1}{x} \text{ and } y = \frac{S_n}{1.5 \times S_m}$$

$$S_n = \frac{1.5 \times S_m}{x} \text{ (max. allowable value for } S_n\text{)}$$

$$S_n = \frac{34.95 \text{ ksi}}{0.262} = 133.5 \text{ ksi}$$

The largest cyclic range of thermal stress occurring at the location of interest is 126.3 ksi. Therefore, since 133.5 ksi > 126.3 ksi, no thermal ratchet effect will be experienced at that location.

7.3.3 Discussion of Power Uprate Results

The power uprate analysis for the feedwater nozzle safe end shows that the Code stress limits are met and that the structural integrity is acceptable for the power uprate conditions.

7.4 Feedwater Nozzle Unit 2

7.4.1 Results of Original Analysis

The location of highest original cumulative fatigue usage is at the inside surface of the safe end (section 3, per page F4-61 of Reference 10). The original fatigue usage factor calculated in the governing stress report (Reference 10) is 0.73.

7.4.2 Power Uprate P+Q Stress Intensity Limit Check

The primary plus secondary stress intensity limit of Paragraph 5.3.3 of this report must be met after applying the power uprate operating conditions to the original analysis.

The power uprate scaling factors were applied to the P+Q stress intensity range values.

The maximum P+Q stress intensity range, S_n, which is equal to 60.0 ksi, exceeds the allowable $3S_m$ limit of 54.3 ksi. Thus, the simplified elastic-plastic analysis of Paragraph NB-3228.3 of Reference 7 must be performed.

7.4.2.1 Removal of Thermal Bending Stresses

According to Paragraph NB-3228.3(a) of Reference 7, the P+Q stress intensity range, after removing thermal bending stresses, shall be less than $3S_m$. Power uprate P+Q stresses are recalculated (scaled up) after removing the thermal bending stresses from the stress components. These values are then used to determine the P+Q (minus thermal bending) stress intensity range for certain stress cycle pairs. The maximum P+Q (minus thermal bending) stress intensity range is 44.3 ksi, which is less than the allowable $3S_m$ limit (for that pair) of 54.3 ksi. Thus, the requirement of Paragraph NB-3228.3(a) is met.

7.4.2.2 Calculation of the Cumulative Fatigue Usage Factor

Fatigue usage for power uprate was evaluated using the procedure outlined in Section 5.3.5. The power uprate fatigue usage factor is conservatively calculated as 0.96, which is below the allowable limit of 1.0.

7.4.2.3 Thermal Stress Ratchet Check

Per Paragraph NB-3228.3(d) of Reference 7, the thermal stress ratchet check of Paragraph NB-3222.5 of Reference 7 must be performed. The analysis shows that compliance is met, as follows:

Maximum power uprate general membrane stress due to pressure:

$$\sigma_{\theta M} = P_{old} \times \frac{R}{t},$$

where

P_{old} = original max. normal operating vessel pressure,
(from p. S4-97 of Reference 10)

Therefore,

$$\sigma_{\theta M,new} = \sigma_{\theta M,old} \times \frac{P_{new}}{P_{old}},$$

$$= 12.2 \text{ ksi} \times \frac{1260 \text{ psi}}{1475 \text{ psi}}$$

$$= 10.4 \text{ ksi}$$

$$x_{new} = \frac{\sigma_{\theta M,new}}{S_{y,new}}$$

$$= \frac{10.4 \text{ ksi}}{27.1 \text{ ksi}}$$

$$= 0.385$$

where $S_{y,new}$ is evaluated at the increased vessel temperature at power uprate of 551°F. **Note:** operating pressure is used instead of design pressure to remove excessive conservatism.

For $0 < x < 0.5$,

$$y' = \frac{1}{x} \text{ and } y' = \frac{S_n}{S_y}$$

$$S_n = \frac{S_{y,new}}{x} \text{ (max. allowable value for } S_n\text{)}$$

$$S_n = \frac{27.1 \text{ ksi}}{0.385}$$

$$= 70.5 \text{ ksi}$$

The largest cyclic range of thermal stress (mechanical stress conservatively included) is 67.9 ksi (Section F4-58 of Reference 10). Therefore, since 67.9 ksi < 70.5 ksi, no thermal ratchet effect will be experienced.

7.4.3 Discussion of Power Uprate Results

The power uprate analysis for the feedwater nozzle safe end shows that the Code stress limits are met and that the structural integrity is acceptable for the power uprate conditions.

7.5 Core Spray Nozzle Units 1 and 2

7.5.1 Results of Original Analysis

The highest original cumulative fatigue usage factor for the Core Spray Nozzle is 0.98 as given in Reference 11; the location of highest usage is at element 404 on the nozzle. Note that the nozzle was modified to accept a new safe end and thermal sleeve after the original RPV vendor stress report was issued. Therefore, the governing stress report is Reference 11.

7.5.2 Power Uprate P+Q Stress Intensity Limit Check

The primary plus secondary stress intensity limit of Paragraph 5.3.3 of this report must be met after applying the power uprate operating conditions to the original analysis.

The power uprate scaling factors were applied to the P+Q stress intensity range values.

The maximum P+Q stress intensity range exceeds the allowable 3S_m limit of 52.47 ksi. Thus, the simplified elastic-plastic analysis of Paragraph NB-3228.3 of Reference 15 must be performed.

7.5.2.1 Removal of Thermal Bending Stresses

According to Paragraph NB-3228.3(a) of Reference 15, the P+Q stress intensity range, after removing thermal bending stresses, shall be less than 3S_m. Power uprate P+Q stresses are recalculated (scaled up) after removing the thermal bending stresses from the stress components. These values are then used to determine the P+Q (minus thermal bending) stress intensity range for certain stress cycle pairs.

The maximum P+Q (minus thermal bending) stress intensity range is 52.3 ksi, which is less than the allowable 3S_m limit (for that pair) of 52.47 ksi. Thus, the requirement of Paragraph NB-3228.3(a) is met.

7.5.2.2 Calculation of the Cumulative Fatigue Usage Factor

Fatigue usage for power uprate was evaluated using the procedure outlined in Section 5.3.5. The results show that the power uprate fatigue usage factor is 0.96, which is below the allowable limit of 1.0. Usage factor went down due to removal of excessively conservative assumptions.

7.5.2.3 Thermal Stress Ratchet Check

Per Paragraph NB-3228.3(d) of Reference 15, the thermal stress ratchet check of Paragraph NB-3222.5 of Reference 15 must be performed. The analysis shows that compliance is met, as follows:

Maximum general membrane stress due to pressure:

$$(P_M)_q = \frac{pR_i^2\left(R_o^2 + R_m^2\right)}{R_m^2\left(R_o^2 - R_i^2\right)} = 6.412 \text{ ksi (from p. F-2 of Reference 11)}$$

$$\begin{aligned} x &= \frac{(P_M)_q}{1.5 \times S_m} \\ &= \frac{6.412 \text{ ksi}}{26.235 \text{ ksi}} \\ &= 0.2444 \end{aligned}$$

where S_m is evaluated at the increased vessel temperature at power uprate of 551°F.

For $0.0 < x < 0.5$,

$$\begin{aligned} \text{Allowable thermal } S_n &= 1.5\ S_m / x \\ &= 26.235/0.2444 = 107.3 \text{ ksi.} \end{aligned}$$

The largest cyclic range of thermal stress occurring at the location of interest is 75.6 ksi. Therefore, since 107.3 ksi > 75.6 ksi, no thermal ratchet effect will be experienced at that location.

7.5.3 Discussion of Power Uprate Results

The power uprate analysis for the Core Spray Nozzle safe end shows that the Code stress limits are met and that the structural integrity is acceptable for the power uprate conditions.

7.6 Recirculation Inlet Nozzle Units 1 and 2

7.6.1 Results of Original Analysis

The location of highest original cumulative fatigue usage on the Recirculation Inlet Nozzle is on Element 574 on the nozzle. Note that the Recirculation Inlet Nozzle was modified to accept a new safe end and thermal sleeve after the original RPV vendor stress report was issued. Therefore, the governing stress report is Reference 12. The original fatigue usage factor calculated in Reference 12 is 0.81.

7.6.2 Power Uprate P+Q Stress Intensity Limit Check

The primary plus secondary stress intensity limit of Paragraph 5.3.3 of this report must be met after applying the power uprate operating conditions to the original analysis.

The power uprate scaling factors were applied to the P+Q stress intensity range values.

The results of Table 7.3-1 show that the maximum P+Q stress intensity range, S_n, which is equal to 228.0 ksi, exceeds the allowable $3S_m$ limit of 52.47 ksi. Thus, the simplified elastic-plastic analysis of Paragraph NB-3228.3 of Reference 15 must be performed.

7.6.2.1 Removal of Thermal Bending Stresses

According to Paragraph NB-3228.3(a) of Reference 15, the P+Q stress intensity range, after removing thermal bending stresses, shall be less than $3S_m$. Power uprate P+Q stresses are recalculated (scaled up) after removing the thermal bending stresses from the stress components. These values are then used to determine the P+Q (minus thermal bending) stress intensity range for certain stress cycle pairs.

The maximum P+Q (minus thermal bending) stress intensity range is 46.0 ksi, which is less than the allowable $3S_m$ limit (for that pair) of 52.47 ksi. Thus, the requirement of Paragraph NB-3228.3(a) is met.

7.6.2.2 Calculation of the Cumulative Fatigue Usage Factor

Fatigue usage for power uprate was evaluated using the procedure outlined in Section 5.3.5. The results show that the power uprate fatigue usage factor is 0.86, which is below the allowable limit of 1.0.

7.6.2.3 Thermal Stress Ratchet Check

Per Paragraph NB-3228.3(d) of Reference 15, the thermal stress ratchet check of Paragraph NB-3222.5 of Reference 15 must be performed. The analysis shows that compliance is met, as follows:

Maximum general membrane stress due to pressure:

$(P_M)_\theta = pR/t = 14.431$ ksi
(from p. F-2 of Reference 12)

$$x = \frac{(P_M)_\theta}{1.5S_m} = \frac{14.431 \text{ ksi}}{25.4085 \text{ ksi}} = 0.5679$$

where S_m is evaluated at the increased vessel temperature at power uprate of 551°F.

For $0.5 < x < 1.0$,

$$\text{Allowable thermal } S_n = 1.5\, S_m\, [4(1 - x)],$$
$$= 25.4085\, [4(1 - 0.5679)] = 43.9 \text{ ksi.}$$

The largest cyclic range of thermal stress occurring at the location of interest is 33.8 ksi. Therefore, since 43.9 ksi > 33.8 ksi, no thermal ratchet effect will be experienced at that location.

7.6.3 Discussion of Power Uprate Results

The power uprate analysis for the Recirculation Inlet Nozzle safe end shows that the Code stress limits are met and that the structural integrity is acceptable for the power uprate conditions.

8. IMPACTED DESIGN DOCUMENTS

The design documents affected by this power uprate are the vessel and nozzle thermal cycle diagrams in References 3 and 4. The changes in the thermal cycle diagrams are called out by the Design Specification (Reference 1).

9. DESIGN RECORD FILE

Design Record File (DRF) No. 137-0010-5, Section GENE-523-144-1092, contains the documentation for this evaluation.

10. REFERENCES

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