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Environmental Fatigue Evaluation of Reactor Recirculation Inlet Nozzle and Vessel Shell/Bottom Head

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U.S. NUCLEAR REGULATORY COMMISSION

In the Matter of Entergy Nuclear Vermont Yankee LLC

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1.0 INTRODUCTION/STATEMENT OF PROBLEM/ OBJECTIVE

The purpose of this calculation is to perform a plant-specific evaluation of reactor water environmental effects for the reactor recirculation (RR) inlet nozzle and the reactor pressure vessel (RPV) shell/bottom head locations identified within NUREG/CR-6260 [1] for the older vintage General Electric (GE) plant for the Vermont Yankee Nuclear Power Plant (VY).

The water chemistry input used in this calculation covers several portions of the RPV, as well as the feedwater and recirculation lines. Although these regions encompass more areas than needed to address the two components of interest in this calculation, environmental fatigue multipliers are developed for all of these regions in this calculation for potential use in other evaluations associated with this project.

2.0 TECHNICAL APPROACH OR METHODOLOGY

Per Chapter X, "Time-Limited Aging Analyses Evaluation of Aging Management Programs Under 10 CFR 54.21(c)(1)(iii)," Section X.M1, "Metal Fatigue of Reactor Coolant Pressure Boundary," of the Generic Aging Lessons Learned (GALL) Report [2], detailed, vintage-specific, fatigue calculations are required for plants applying for license renewal for the locations identified for the appropriate vintage plant in NUREG/CR-6260.

In this calculation, detailed environmentally assisted fatigue (EAF) calculations are performed for VY for two of the locations associated with the older vintage GE plant in NUREG/CR-6260. The older-vintage GE plant is the appropriate comparison to VY since the original piping design at VY was in accordance with USAS B31.1 [3], as well as the fact that the older-vintage boiling water reactor (BWR) in NUREG/CR-6260 was a BWR-4 plant, which is the same as VY.

Entergy performed an initial assessment of EAF effects for VY in their License Renewal Application (LRA) that was submitted to the NRC in January 2006. Table 4.3-3 of the VY LRA provides the results of those evaluations. All but two of the VY locations evaluated for EAF in the LRA did not yield acceptable results for 60 years of operation. Further refined analyses are currently underway in other calculations associated with this project to address those components. This calculation documents the EAF evaluation for the RR inlet nozzle and RPV shell/bottom head locations, where it is expected that acceptable EAF results can be achieved based on the existing analyses without the need for additional refined evaluations.

3.0 ASSUMPTIONS / DESIGN INPUTS

Per Section X.M1 of the GALL Report [2], the EAF evaluation must use the appropriate F_{en} relationships from NUREG/CR-6583 [4] (for carbon/low alloy steels) and NUREG/CR-5704 [5] (for stainless steels), as appropriate for the material for each location. These expressions are:

For Carbon Steel [4, p. 69]: $F_{en} = \exp(0.585 - 0.00124T' - 0.101 S^* T^* O^* \dot{\varepsilon}^*)$

Substituting T' = 25°C in the above expression, as required by NUREG/CR-6583 to relate room temperature air data to service temperature data in water [6], the following is obtained:

$$F_{en} = \exp(0.585 - 0.00124(25°C) - 0.101\, S^*\, T^*\, O^*\, \dot{\varepsilon}^*)$$
$$= \exp(0.554 - 0.101\, S^*\, T^*\, O^*\, \dot{\varepsilon}^*)$$

For Low Alloy Steel [4, p. 69]: $F_{en} = \exp(0.929 - 0.00124T' - 0.101 S^* T^* O^* \dot{\varepsilon}^*)$

Substituting T' = 25°C in the above expression, as required by NUREG/CR-6583 to relate room temperature air data to service temperature data in water [6], the following is obtained:

$$F_{en} = \exp(0.929 - 0.00124(25°C) - 0.101\, S^*\, T^*\, O^*\, \dot{\varepsilon}^*)$$
$$= \exp(0.898 - 0.101\, S^*\, T^*\, O^*\, \dot{\varepsilon}^*)$$

where [4, pp. 60 and 65]: F_{en} = fatigue life correction factor
S^* = S for $0 < \text{sulfur content, } S \leq 0.015$ wt. %
= 0.015 for $S > 0.015$ wt. %
T^* = 0 for $T < 150°C$
= $(T - 150)$ for $150 \leq T \leq 350°C$
T = fluid service temperature (°C)
O^* = 0 for dissolved oxygen, $DO < 0.05$ parts per million (ppm)
= $\ln(DO/0.04)$ for $0.05 \text{ ppm} \leq DO \leq 0.5$ ppm
= $\ln(12.5)$ for $DO > 0.5$ ppm
$\dot{\varepsilon}^*$ = 0 for strain rate, $\dot{\varepsilon} > 1\%/\text{sec}$
= $\ln(\dot{\varepsilon}^*)$ for $0.001 \leq \dot{\varepsilon} \leq 1\%/\text{sec}$
= $\ln(0.001)$ for $\dot{\varepsilon} < 0.001\%/\text{sec}$

For Types 304 and 316 Stainless Steel [5, p. 31]: $F_{en} = \exp(0.935 - T^* \dot{\varepsilon}^* O^*)$

where [5, pp. 25 and 31]:
F_{en} = fatigue life correction factor
T^* = 0 for $T < 200°C$
= 1 for $T \geq 200°C$
T = fluid service temperature (°C)
$\dot{\varepsilon}^*$ = 0 for strain rate, $\dot{\varepsilon} > 0.4\%/\text{sec}$
= $\ln(\dot{\varepsilon}/0.4)$ for $0.0004 \leq \dot{\varepsilon} \leq 0.4\%/\text{sec}$
= $\ln(0.0004/0.4)$ for $\dot{\varepsilon} < 0.0004\%/\text{sec}$
O^* = 0.260 for dissolved oxygen, DO < 0.05 parts per million (ppm)
= 0.172 for DO ≥ 0.05 ppm

Bounding F_{en} values are determined or, where necessary, computed for each load pair in the detailed fatigue calculation for each component. The environmental fatigue is then determined as $U_{env} = (U)(F_{en})$, where U is the original fatigue usage and U_{env} is the environmentally assisted fatigue (EAF) usage factor. All calculations can be found in Excel spreadsheet "*VY-16Q-303 (Env. Fat. Calcs).xls*" associated with this calculation.

From Reference [7], for the BWR, typical DO levels range from just over 200 ppb for normal water chemistry (NWC) conditions to less than 10 ppb for hydrogen water chemistry (HWC) conditions. Typical HWC system availabilities are greater than 90%. Based on VY-specific water chemistry input for Entergy [8], which is also contained in Appendix A of this calculation, the input shown in Table 1 is defined for use in this calculation.

The water chemistry input covers several portions of the RPV, as well as the feedwater and recirculation lines. Although these regions encompass more areas than needed to address the two components of interest in this calculation, environmental fatigue multipliers are developed for all of these regions in this calculation for potential use in other evaluations associated with this project.

Therefore, based on Table 1 and for the purposes of this calculation, the following is assumed:

- Over the 60-year operating life of the plant, HWC conditions exist for 47% of the time, and NWC conditions exist for 53% of the time.
- All operation through 11/1/2003 was assumed as NWC using the dissolved oxygen values from the "Pre-NMCA" column in Appendix A, and all operation after 11/1/2003 was assumed as HWC using the maximum oxygen values from the "Post-NMCA + HWC (OLP)", "Post-NMCA + HWC (EPU)", and "Future Operation" columns in Appendix A.
- Recirculation line DO is 122 ppb pre-HWC and 48 ppb post-HWC.
- Feedwater line DO is 40 ppb for pre-HWC and 40 ppb for post-HWC conditions.
- RPV Upper Region DO is 114 ppb pre-HWC and 97 ppb post-HWC.
- RPV Beltline DO is 123 ppb pre-HWC and 46 ppb post-HWC.
- RPV Bottom Head Region DO is 128 ppb pre-HWC and 69 ppb post-HWC.

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Based on the above typical DO levels, bounding F_{en} multipliers for each of the three applicable materials (carbon, low alloy, and stainless steels) are shown in Tables 2 through 6 for the various RPV and piping regions.

The projected number of cycles used in this calculation is based on the number of cycles actually experienced by the plant in the past and forward-projected with some additional margin for 60 years of operation, as documented in Reference [9]. In addition, the latest governing stress analysis for each location was utilized, and any relevant effects of Extended Power Uprate (EPU) operation were incorporated as necessary. With these assumptions, the cumulative usage factor (CUF) values documented in this calculation are considered applicable for sixty years of operation including all relevant EAF and EPU effects.

4.0 CALCULATIONS

The analyses for the NUREG/CR-6260 locations identified in Section 2.0 are provided in this section. As previously noted, the fatigue calculations for 60 years for all locations make use of the 60-year projected cycles for VY from Reference [9], and incorporate EPU effects.

Since the F_{en} methodology documented in References [4] and [5] is relatively "new" technology, it is intended to apply to "modern-day" fatigue analyses, i.e., applied to fatigue analyses that use current ASME Code fatigue curves, etc. Therefore, to be consistent with this approach, the evaluation for the all locations will also utilize modern-day fatigue calculation methodology using the 1998 Edition, 2000 Addenda of the ASME Code [11]. This involves applying a Young's Modulus correction factor (i.e., $E_{fatigue\ curve}/E_{analysis}$) to the calculated stresses, applying K_e where appropriate, and utilizing the 2000 Addenda fatigue curve.

NOTE: *It is recognized that some of the references used in this calculation are not the latest revision; for example, Reference [12] (VYC-378, Revision 0) has been revised. However, the details necessary to perform the evaluations in this calculation are not necessarily contained in the latest revision of all documents. Therefore, wherever necessary, the appropriate revision of the governing document is referenced in order to obtain all appropriate inputs necessary to perform the EAF calculations. So, it should be recognized that, despite using what appear to be outdated revisions of some references, use of these references is for input data use only. All calculations represent the latest available analyses for all locations.*

NOTE: *Hand calculations may yield results slightly different than the values shown in the tables of this calculation due to round-off based on the significant figures utilized by the spreadsheet used for these calculations.*

4.1 RPV Lower Head

The 60-year CUF value (without EAF effects) for the RPV shell/bottom head location was reported in Table 4.3-3 of the VY LRA submittal to be 0.400. The EAF CUF estimated by Entergy for this location was 0.98, based on an overall F_{en} of 2.45. Based on this result, further refined analysis would not normally be necessary to show acceptable EAF CUF results for this component. However, the calculation for this location is updated in this section to reflect the updated water chemistry information supplied for this project.

The CUF value reported in the VY LRA for the RPV shell/bottom head location is 0.400. This value is the original design basis CUF from the RPV Stress Report, as noted on page B8 of Reference [12]. However, as noted on page A61 of Reference [12], this CUF corresponds to Point 8, which is located on the outside surface of the RPV bottom head at the junction with the support skirt. Therefore, this location is not exposed to the reactor coolant, and EAF effects do not apply. Based on this, evaluation of the limiting location along the inside surface of the RPV bottom head was performed.

Based on a review of the primary plus secondary stresses tabulated for all locations along the bottom head on page A52 of Reference [12], Point 14 was selected for EAF evaluation. Per Section 3.2.1.2 of Reference [13], none of the CUF values for the RPV bottom head region were evaluated for the effects of EPU, as the CUF values are below the EPU screening criteria value of 0.5. Therefore, as a part of the evaluation for this location, EPU effects were included. Per References [14] and [19], the RPV shell material is low alloy steel (A-533, Grade B).

The new CUF calculation for Point 14 for 40 years, which includes the use of updated methodology and incorporates EPU effects [14], is shown at the top portion of Table 7. The CUF for 40 years (without EAF effects) is 0.0057.

The fatigue calculation for 60 years for the RPV shell/bottom head location is also shown in Table 7. The results show a CUF (without EAF effects) of 0.0085 for 60 years. The fatigue calculation for 60 years makes use of the 60-year projected cycles for VY from Reference [9].

The resulting environmental fatigue calculation for the RPV shell/bottom head location is shown in Table 7. Bounding F_{en} multipliers were applied in the calculations. RPV bottom head water chemistry conditions from Tables 1 and 6 are used for this location. The results show an EAF adjusted CUF of 0.0809 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0).

The CUF determined for Point 14 is very low. Comparison to other locations of the RPV shell/bottom head region indicates it is not the limiting location from a fatigue perspective. Review of the CUF values in Table 3-1 of Reference [15] reveals that the shroud support (at vessel wall junction) location is potentially more limiting, so EAF evaluation of that location is also performed.

Per page S3-99f of Reference [16], the design basis CUF of 0.06 is for Point 9. Page S3-85 of Reference [16] reveals that this point is on the RPV shell at the junction of the shroud support plate. Per References [14] and [19], the RPV shell material is low alloy steel (A-533, Grade B).

The revised and updated CUF calculation for Point 9 for 40 years, which includes the use of updated methodology and incorporates EPU effects, is shown at the top portion of Table 8. The CUF for 40 years (without EAF effects) is 0.0549. This CUF value is more limiting than the RPV shell/bottom head location evaluated in Table 7, so it is considered to be the governing location for VY with respect to the equivalent NUREG/CR-6260 RPV shell/bottom head location.

The fatigue calculation for 60 years for the RPV shell/shroud support location is also shown in Table 8. The results show a CUF (without EAF effects) of 0.0774 for 60 years. The fatigue calculation for 60 years makes use of the 60-year projected cycles for VY from Reference [9].

The resulting environmental fatigue calculation for the RPV shell/shroud support location is shown in Table 8. Bounding F_{en} multipliers were applied in the calculations. RPV bottom head water chemistry conditions from Table 6 are used for this location. The results show an EAF adjusted CUF of 0.7364 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0).

4.2 RR Inlet Nozzle

For conservatism due to the different materials involved, two locations are evaluated for the RR inlet nozzle: (1) the limiting location in the nozzle forging, and (2) the limiting location in the safe end.

The 60-year CUF value (without EAF effects) for the RR inlet nozzle in the VY LRA submittal is 0.610. However, that analysis used conservative transient definitions and cyclic projections for 60 years of operation that have since been updated. The applicable CUF values are those shown in Table 3-1 of Reference [15] (0.1058 for the safe end, and 0.03 for the nozzle for 40-years), except that these values are pre-EPU.

For the RR inlet nozzle forging, the governing CUF calculation is shown on page B28 of Reference [12], where a value of 0.03 was obtained. From pages A269 and A270 of Reference [12], the CUF calculation corresponds to Point 12 in the nozzle forging, which is on the outside surface of the nozzle on the outboard end of the nozzle transition. Although this location is not exposed to the reactor coolant, it will be conservatively evaluated for EAF effects as it is the bounding fatigue location in the nozzle forging. As a part of the evaluation for this location, EPU effects were included. Per page I-S8-4 of Reference [17], the RR inlet nozzle material is low alloy steel (A-508 Class II).

The new CUF calculation for Point 12 for 40 years, which includes the use of updated methodology and incorporates EPU effects [14], is shown at the top portion of Table 9. The CUF for 40 years (without EAF effects) is 0.0433.

The fatigue calculation for 60 years for the RR inlet nozzle forging location is also shown in Table 9. The results show a CUF (without EAF effects) of 0.0650 for 60 years. The fatigue calculation for 60 years makes use of the 60-year projected cycles for VY from Reference [9].

The resulting environmental fatigue calculation for the RR inlet nozzle forging location is shown in Table 9. Bounding F_{en} multipliers were applied in the calculations. RPV beltline water chemistry conditions from Table 5 are used for this location. The results show an EAF adjusted CUF of 0.5034 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0)

For the RR inlet nozzle safe end, the governing CUF calculation is shown on page B27 of Reference [12], where a value of 0.1058 was obtained. From pages A257 and A259 of Reference [12], the CUF calculation corresponds to Line 6 at the inside surface of the safe end. Page A238 of Reference [12] reveals that this location is location at the nozzle-to-safe end weld. Per Section 3.2.1.2 of Reference [13], the CUF value for the RR inlet nozzle safe end was evaluated for the effects of EPU, since the original CUF calculated in Reference [18] was 0.551 (which was adjusted downward to 0.1058 by Entergy in Reference [12] based on further refined evaluation). Therefore, as a part of the evaluation for this location, EPU effects were included. Per page 8 of Reference [18], the RR inlet nozzle safe end material is 316L stainless steel.

The new CUF calculation for the RR inlet nozzle safe end for 40 years, which includes the use of updated methodology and incorporates EPU effects [14], is shown at the top portion of Table 10. The CUF for 40 years (without EAF effects) is 0.0017.

The fatigue calculation for 60 years for the RR inlet nozzle safe end location is also shown in Table 10. The results show a CUF (without EAF effects) of 0.0017 for 60 years. The fatigue calculation for 60 years makes use of the 60-year projected cycles for VY from Reference [9].

The resulting environmental fatigue calculation for the RR inlet nozzle safe end location is shown in Table 10. Bounding F_{en} multipliers were applied in the calculations. Recirculation line water chemistry conditions from Table 2 are used for this location. The results show an EAF adjusted CUF of 0.0199 for 60 years, which is acceptable (i.e., less than the allowable value of 1.0)

5.0 RESULTS OF ANALYSIS

The final environmental fatigue results contained in Sections 4.1 and 4.2 (and associated Tables 7 through 10) for the RPV shell/bottom head and RR inlet nozzle locations are summarized in Table 11.

6.0 CONCLUSIONS AND DISCUSSION

In this calculation, EAF calculations were performed in accordance with the GALL Report [2] for the following VY locations:

- RR inlet nozzle, consisting of the following bounding locations:
  - Nozzle forging (low alloy steel)
  - Safe end (stainless steel)
- RPV shell/bottom head, consisting of the following bounding locations:
  - Limiting bottom head shell inside surface location (low alloy steel)
  - Limiting RPV shell/shroud support location (low alloy steel)

The above locations were selected based on the locations identified in NUREG/CR-6260 for the older vintage GE plant and plant-specific fatigue calculations that determined the limiting locations for VY. Calculations for the remaining NUREG/CR-6260 locations will be documented in other analyses performed under this project.

The EAF results for the locations identified above are shown in Table 11. These results indicate that the fatigue usage factors, including environmental effects, are within the allowable value for 60 years of operation for all locations evaluated. The calculations for all locations make use of the 60-year projected cycles for VY and incorporate EPU effects. Therefore, no additional evaluation is required for these components, and the GALL requirements are satisfied.

7.0 REFERENCES

1. NUREG/CR-6260 (INEL-95/0045), "Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components," March 1995.

2. NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report," U. S. Nuclear Regulatory Commission, September 2005.

3. USAS B31.1.0 – 1967, USA Standard Code for Pressure Piping, "Power Piping," American Society of Mechanical Engineers, New York.

4. NUREG/CR-6583 (ANL-97/18), "Effects of LWR Coolant Environments on Fatigue Design Curves of Carbon and Low-Alloy Steels," March 1998.

5. NUREG/CR-5704 (ANL-98/31), "Effects of LWR Coolant Environments on Fatigue Design Curves of Austenitic Stainless Steels," April 1999.

6. EPRI/BWRVIP Memo No. 2005-271, "Potential Error in Existing Fatigue Reactor Water Environmental Effects Analyses," July 1, 2005.

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8. "Vermont Yankee Dissolved Oxygen (DO) Levels for Use in EAF Evaluations," page 11 of Entergy Design Input Record (DIR) EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/3/07, SI File No. VY-16Q-209.

9. "Reactor Thermal Cycles for 60 Years of Operation," Attachment 1 of Entergy Design Input Record (DIR) EC No. 1773, Revision 0, "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/3/07, SI File No. VY-16Q-209.

10. VY LRA, page 1-4 (*included as Appendix B to this calculation*).

11. American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section III, Rules for Construction of Nuclear Facility Components, and Section II, Materials, Part D, "Properties (Customary)," 1998 Edition including the 2000 Addenda.

12. Yankee Atomic Electric Company Calculation No. VYC-378, Revision 0, "Vermont Yankee Reactor Cyclic Limits for Transient Events," 10/16/85, SI File No. VY-05Q-211.

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14. GE Nuclear Energy Certified Design Specification No. 26A6019, Revision 1, "Reactor Vessel – Extended Power Uprate," June 2, 2003, SI File No. VY-05Q-236.

15. Structural Integrity Associates Report No. SIR-01-130, Rev. 0, "System Review and Recommendations for a Transient and Fatigue Monitoring System at the Vermont Yankee Nuclear Power Station," February 2002, SI File No. W-VY-05Q-401.

16. CB&I RPV Stress Report, Section S3, Revision 4, "Stress Analysis, Shroud Support, Vermont Yankee Reactor Vessel, CB&I Contract 9-6201," 2-3-70, SI File No. VY-16Q-203.

17. CB&I RPV Stress Report, Section S8, Revision 4, "Stress Analysis, Recirculation Inlet Nozzle, Vermont Yankee Reactor Vessel, CB&I Contract 9-6201," 2-3-70, SI File No. VY-16Q-203.

18. GE Nuclear Energy Certified Stress Report No. 23A4292, Revision 4, "Reactor Vessel – Recirculation Inlet Safe End Nozzle," March 12, 1986, SI File No. VY-16Q-203.

19. Entergy Drawing No. 5920-5752, Revision 3 (CB&I Drawing No. R15, Revision 1), "Vessel & Attachments Mat'l. Identifications," 1/20/88, SI File No. VY-16Q-209.

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Table 1: Water Chemistry Calculations

Date of HWC Implementation:	11/01/2003	*(see Appendix A)*
Availability of HWC System Since HWC Implementation:	98.54%	*(see Appendix A)*
Projected Future HWC System Availability:	98.5%	*(see Appendix A, assume same as recent experience)*
Recirculation Line DO		
pre-HWC:	122	ppb *(see Appendix A)*
post-HWC:	48	ppb *(see Appendix A)*
Feedwater Line DO		
pre-HWC:	40	ppb *(see Appendix A)*
post-HWC:	40	ppb *(see Appendix A)*
RPV Upper Region DO		
pre-HWC:	114	ppb *(see Appendix A)*
post-HWC:	97	ppb *(see Appendix A)*
RPV Beltline Region DO		
pre-HWC:	123	ppb *(see Appendix A)*
post-HWC:	46	ppb *(see Appendix A)*
RPV Bottom Head Region DO		
pre-HWC:	128	ppb *(see Appendix A)*
post-HWC:	69	ppb *(see Appendix A)*
Plant Startup Date:	03/22/1972	*(see Appendix B)*
Time at pre-HWC Conditions:	31.61	years *(calculated, includes leap years.)*
Date of Calculations:	04/30/2007	
Time Since HWC Implementation:	3.49	years *(calculated, includes leap years.)*
Projected Future Time for HWC Operation:	24.90	years *(calculated, includes leap years.)*
Overall HWC Availability:	47%	

Note: All operation through 11/1/2003 was assumed as NWC using the dissolved oxygen values from the "Pre-NMCA" column in Appendix A, and all operation after 11/1/2003 was assumed as HWC using the maximum oxygen values from the "Post-NMCA + HWC (OLP)", "Post-NMCA + HWC (EPU)", and "Future Operation" columns in Appendix A.

Table 2: Bounding F_{en} Multipliers for Recirculation Line

Low Alloy Steel:

$F_{en} = \exp(0.898 - 0.101 S^* T^* O^* \varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ *(minimum)*

For a BWR with HWC environment (post-HWC implementation):
DO = 48 ppb = 0.048 ppm
DO < 0.050 ppm, so $O^* = 0$
Thus:

T (°C)	T (°F)	F_{en}
0	32	2.45
50	122	2.45
100	212	2.45
150	302	2.45
200	392	2.45
250	482	2.45
288	550	2.45

Thus, maximum F_{en} = 2.45

[T^* = (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 122 ppb = 0.122 ppm, so $O^* = \ln(0.122/0.04) = 1.115$
Thus:

T (°C)	T (°F)	F_{en}
0	32	2.45
50	122	2.45
100	212	2.45
150	302	2.45
200	392	4.40
250	482	7.89
288	550	12.29

Thus, maximum F_{en} = 12.29

Carbon Steel:

$F_{en} = \exp(0.554 - 0.101 S^* T^* O^* \varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 48 ppb = 0.048 ppm
DO < 0.050 ppm, so $O^* = 0$
Thus:

T (°C)	T (°F)	F_{en}
0	32	1.74
50	122	1.74
100	212	1.74
150	302	1.74
200	392	1.74
250	482	1.74
288	550	1.74

Thus, maximum F_{en} = 1.74

[T^* = (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 122 ppb = 0.122 ppm, so $O^* = \ln(0.122/0.04) = 1.115$
Thus:

T (°C)	T (°F)	F_{en}
0	32	1.74
50	122	1.74
100	212	1.74
150	302	1.74
200	392	3.12
250	482	5.59
288	550	8.71

Thus, maximum F_{en} = 8.71

Stainless Steel:

$F_{en} = \exp(0.935 - T^* \varepsilon^* O^*)$

For a BWR with HWC environment (post-HWC implementation):
DO = 48 ppb = 0.048 ppm < 0.050 ppm, so $O^* = 0.260$
Conservatively use $T^* = 1$ for $T > 200$°C
Thus:

For a BWR with NWC environment (pre-HWC implementation):
DO = 122 ppb = 0.122 ppm > 0.05 ppm, so $O^* = 0.172$
Conservatively use $T^* = 1$ for $T > 200$°C
Thus:

		HWC		NWC
$\varepsilon^* = 0$ for $\varepsilon > 0.4$%/sec	so F_{en} =	2.55	so F_{en} =	2.55
$\varepsilon^* = \ln(\varepsilon/0.4)$ for $0.0004 <= \varepsilon <= 0.4$%/sec	so F_{en} ranges from	2.55	so F_{en} ranges from	2.55
	to	15.35	to	8.36
$\varepsilon^* = \ln(0.0004/0.4)$ for $\varepsilon < 0.0004$%/sec	so F_{en} =	15.35	so F_{en} =	8.36
	Thus, maximum F_{en} =	15.35	Thus, maximum F_{en} =	8.36

Table 3: Bounding F_{en} Multipliers for Feedwater Line

Low Alloy Steel:

$F_{en} = \exp(0.898 - 0.101 S^* T^* O^* \varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 40 ppb = 0.040 ppm < 0.050 ppm so $O^* = 0$
Thus:

T (°C)	T (°F)	F_{en}
0	32	2.45
50	122	2.45
100	212	2.45
150	302	2.45
200	392	2.45
250	482	2.45
288	550	2.45

Thus, maximum F_{en} = 2.45

[T^* = (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 40 ppb = 0.040 ppm < 0.050 ppm so $O^* = 0$
Thus:

T (°C)	T (°F)	F_{en}
0	32	2.45
50	122	2.45
100	212	2.45
150	302	2.45
200	392	2.45
250	482	2.45
288	550	2.45

Thus, maximum F_{en} = 2.45

Carbon Steel:

$F_{en} = \exp(0.554 - 0.101 S^* T^* O^* \varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 40 ppb = 0.040 ppm < 0.050 ppm so $O^* = 0$
Thus:

T (°C)	T (°F)	F_{en}
0	32	1.74
50	122	1.74
100	212	1.74
150	302	1.74
200	392	1.74
250	482	1.74
288	550	1.74

Thus, maximum F_{en} = 1.74

[T^* = (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 40 ppb = 0.040 ppm < 0.050 ppm so $O^* = 0$
Thus:

T (°C)	T (°F)	F_{en}
0	32	1.74
50	122	1.74
100	212	1.74
150	302	1.74
200	392	1.74
250	482	1.74
288	550	1.74

Thus, maximum F_{en} = 1.74

There is no stainless steel in the Class 1 feedwater line.

Table 4: Bounding F_{en} Multipliers for RPV Upper Region

Low Alloy Steel:

$F_{en} = \exp(0.898 - 0.101S^*T^*O^*\varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 97 ppb = 0.097 ppm, so $O^* = \ln(0.097/0.04) = 0.886$

Thus:

T (°C)	T (°F)	F_{en}
0	32	2.45
50	122	2.45
100	212	2.45
150	302	2.45
200	392	3.90
250	482	6.20
288	550	8.82

Thus, maximum F_{en} = 8.82

[T^* = (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 114 ppb = 0.114 ppm, so $O^* = \ln(0.114/0.04) = 1.047$

Thus:

T (°C)	T (°F)	F_{en}
0	32	2.45
50	122	2.45
100	212	2.45
150	302	2.45
200	392	4.25
250	482	7.35
288	550	11.14

Thus, maximum F_{en} = 11.14

Carbon Steel:

$F_{en} = \exp(0.554 - 0.101S^*T^*O^*\varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 97 ppb = 0.097 ppm, so $O^* = \ln(0.097/0.04) = 0.886$

Thus:

T (°C)	T (°F)	F_{en}
0	32	1.74
50	122	1.74
100	212	1.74
150	302	1.74
200	392	2.77
250	482	4.40
288	550	6.25

Thus, maximum F_{en} = 6.25

[T^* = (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 114 ppb = 0.114 ppm, so $O^* = \ln(0.114/0.04) = 1.047$

Thus:

T (°C)	T (°F)	F_{en}
0	32	1.74
50	122	1.74
100	212	1.74
150	302	1.74
200	392	3.01
250	482	5.21
288	550	7.90

Thus, maximum F_{en} = 7.90

Stainless Steel:

$F_{en} = \exp(0.935 - T^*\varepsilon^*O^*)$

For a BWR with HWC environment (post-HWC implementation):
DO = 97 ppb = 0.097 ppm > 0.050 ppm, so $O^* = 0.172$
Conservatively use $T^* = 1$ for T > 200°C

For a BWR with NWC environment (pre-HWC implementation):
DO = 114 ppb = 0.114 ppm > 0.05 ppm, so $O^* = 0.172$
Conservatively use $T^* = 1$ for T > 200°C

	HWC: Thus:		NWC: Thus:	
$\varepsilon^* = 0$ for $\varepsilon > 0.4\%/\text{sec}$	so F_{en} =	2.55	so F_{en} =	2.55
$\varepsilon^* = \ln(\varepsilon/0.4)$ for $0.0004 <= \varepsilon <= 0.4\%/\text{sec}$	so F_{en} ranges from	2.55	so F_{en} ranges from	2.55
	to	8.36	to	8.36
$\varepsilon^* = \ln(0.0004/0.4)$ for $\varepsilon < 0.0004\%/\text{sec}$	so F_{en} =	8.36	so F_{en} =	8.36
	Thus, maximum F_{en} =	8.36	Thus, maximum F_{en} =	8.36

Table 5: Bounding F_{en} Multipliers for RPV Beltline Region

Low Alloy Steel:

$F_{en} = \exp(0.898 - 0.101 S^* T^* O^* \varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 46 ppb = 0.046 ppm
DO < 0.050 ppm, so $O^* = 0$
Thus:

T (°C)	T (°F)	F_{en}
0	32	2.45
50	122	2.45
100	212	2.45
150	302	2.45
200	392	2.45
269.45	517.01	2.45
288	550	2.45

Thus, maximum F_{en} = 2.45

[T^* = (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 123 ppb = 0.123 ppm, so $O^* = \ln(0.123/0.04) = 1.123$
Thus:

T (°C)	T (°F)	F_{en}
0	32	2.45
50	122	2.45
100	212	2.45
150	302	2.45
200	392	4.42
269.45	517.01	10.00
288	550	12.43

Thus, maximum F_{en} = 12.43

Carbon Steel:

$F_{en} = \exp(0.554 - 0.101 S^* T^* O^* \varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 46 ppb = 0.046 ppm
DO < 0.050 ppm, so $O^* = 0$
Thus:

T (°C)	T (°F)	F_{en}
0	32	1.74
50	122	1.74
100	212	1.74
150	302	1.74
200	392	1.74
250	482	1.74
288	550	1.74

Thus, maximum F_{en} = 1.74

[T^* = (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 123 ppb = 0.123 ppm, so $O^* = \ln(0.123/0.04) = 1.123$
Thus:

T (°C)	T (°F)	F_{en}
0	32	1.74
50	122	1.74
100	212	1.74
150	302	1.74
200	392	3.13
250	482	5.64
288	550	8.81

Thus, maximum F_{en} = 8.81

Stainless Steel:

$F_{en} = \exp(0.935 - T^* \varepsilon^* O^*)$

For a BWR with HWC environment (post-HWC implementation):
DO = 46 ppb = 0.046 ppm < 0.050 ppm, so $O^* = 0.260$
Conservatively use $T^* = 1$ for T > 200°C
Thus:

For a BWR with NWC environment (pre-HWC implementation):
DO = 123 ppb = 0.123 ppm > 0.05 ppm, so $O^* = 0.172$
Conservatively use $T^* = 1$ for T > 200°C
Thus:

$\varepsilon^* = 0$ for $\varepsilon > 0.4\%/\text{sec}$	so F_{en} =	2.55	so F_{en} =	2.55
$\varepsilon^* = \ln(\varepsilon/0.4)$ for $0.0004 <= \varepsilon <= 0.4\%/\text{sec}$	so F_{en} ranges from	2.55	so F_{en} ranges from	2.55
	to	15.35	to	8.36
$\varepsilon^* = \ln(0.0004/0.4)$ for $\varepsilon < 0.0004\%/\text{sec}$	so F_{en} =	15.35	so F_{en} =	8.36
	Thus, maximum F_{en} =	15.35	Thus, maximum F_{en} =	8.36

Table 6: Bounding F_{en} Multipliers for RPV Bottom Head Region

Low Alloy Steel:

$F_{en} = \exp(0.898 - 0.101 S^* T^* O^* \varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 69 ppb = 0.069 ppm, so $O^* = \ln(0.069/0.04) = 0.545$
Thus:

T (°C)	T (°F)	F_{en}
0	32	2.45
50	122	2.45
100	212	2.45
150	302	2.45
200	392	3.27
250	482	4.34
288	550	5.39

Thus, maximum F_{en} = 5.39

[T^* = (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 128 ppb = 0.128 ppm, so $O^* = \ln(0.128/0.04) = 1.163$
Thus:

T (°C)	T (°F)	F_{en}
0	32	2.45
50	122	2.45
100	212	2.45
150	302	2.45
200	392	4.51
250	482	8.29
288	550	13.17

Thus, maximum F_{en} = 13.17

Carbon Steel:

$F_{en} = \exp(0.554 - 0.101 S^* T^* O^* \varepsilon^*)$

Assume $S^* = 0.015$ (maximum)
Assume $\varepsilon^* = \ln(0.001) = -6.908$ (minimum)

For a BWR with HWC environment (post-HWC implementation):
DO = 69 ppb = 0.069 ppm, so $O^* = \ln(0.069/0.04) = 0.545$
Thus:

T (°C)	T (°F)	F_{en}
0	32	1.74
50	122	1.74
100	212	1.74
150	302	1.74
200	392	2.31
250	482	3.08
288	550	3.82

Thus, maximum F_{en} = 3.82

[T^* = (T-150) for T > 150°C]

For a BWR with NWC environment (pre-HWC implementation):
DO = 128 ppb = 0.128 ppm, so $O^* = \ln(0.128/0.04) = 1.163$
Thus:

T (°C)	T (°F)	F_{en}
0	32	1.74
50	122	1.74
100	212	1.74
150	302	1.74
200	392	3.20
250	482	5.88
288	550	9.34

Thus, maximum F_{en} = 9.34

Stainless Steel:

$F_{en} = \exp(0.935 - T^* \varepsilon^* O^*)$

For a BWR with HWC environment (post-HWC implementation):
DO = 69 ppb = 0.069 ppm > 0.050 ppm, so $O^* = 0.172$
Conservatively use $T^* = 1$ for T > 200°C
Thus:

For a BWR with NWC environment (pre-HWC implementation):
DO = 128 ppb = 0.128 ppm > 0.05 ppm, so $O^* = 0.172$
Conservatively use $T^* = 1$ for T > 200°C
Thus:

$\varepsilon^* = 0$ for $\varepsilon > 0.4\%/\text{sec}$	so F_{en} =	2.55	so F_{en} =	2.55
$\varepsilon^* = \ln(\varepsilon/0.4)$ for $0.0004 <= \varepsilon <= 0.4\%/\text{sec}$	so F_{en} ranges from	2.55	so F_{en} ranges from	2.55
	to	8.36	to	8.36
$\varepsilon^* = \ln(0.0004/0.4)$ for $\varepsilon < 0.0004\%/\text{sec}$	so F_{en} =	8.36	so F_{en} =	8.36
	Thus, maximum F_{en} =	8.36	Thus, maximum F_{en} =	8.36

Table 7: EAF Evaluation for RPV Shell/Bottom Head Location

Component: RPV Shell/Bottom Head
NUREG/CR-6260 CUF: 0.032 *(for reference only)*
Reference: NUREG/CR-6260, p. 5-102
Stress Report CUF: 0.0057 *(for Point 14, see below)*
Material: Low Alloy Steel *(Material = A-533 Gr. B per References [14] and [19])*

Design Basis CUF Calculation for 40 years:

$E_{fatigue\ curve}/E_{analysis}$ = 1.149 *Conservatively used minimum E of 26.1 from Section S2 Appendix of RPV Stress Report.*
Power Uprate = 1.0067 *=(549 - 100) / (546 - 100) per 4.4.1.b of 26A6019, Rev. 1 [14]*
K_t = 1.000 *stress concentration factor*
m = 2.0 *NB-3228.5 of ASME Code, Section III [11]*
n = 0.2 *NB-3228.5 of ASME Code, Section III [11]*
S_m = 26,700 psi *(ASME Code, Section II, Part D [11])*

P_L+P_B+Q *(see Note 1)*	K_e *(see Note 2)*	S_{alt} *(see Note 3)*	n *(see Note 4)*	N *(see Note 5)*	U
44,526	1.00	25,762	200	35,300	0.0057
				Total, U_{40} =	0.0057

Notes:
1. *P_L+P_B+Q is obtained for Point 14 from p. A52 of VYC-378, Rev. 0.*
2. *K_e computed in accordance with NB-3228.5 of ASME Code, Section III.*
3. *$S_{alt} = 0.5 \cdot K_e \cdot K_t \cdot E_{fatigue\ curve}/E_{analysis} \cdot$ Power Uprate $\cdot (P_L+P_B+Q)$.*
4. *n for 40 years is the number of Heatup-Cooldown cycles, per p. B8 of VYC-378, Rev. 0.*
5. *N obtained from Figure I-9.1 of Appendix I of ASME Code, Section III.*
6. *n for 60 years is the projected number of Heatup-Cooldown cycles.*

Revised CUF Calculation for 60 Years:

P_L+P_B+Q *(see Note 1)*	K_e *(see Note 2)*	S_{alt} *(see Note 3)*	n *(see Note 6)*	N *(see Note 4)*	U
44,526	1.00	25,762	300	35,300	0.0085
				Total, U_{60} =	0.0085

Environmental CUF Calculation for 60 Years:

Maximum $F_{en\text{-}HWC}$ Multiplier for HWC Conditions = 5.39 *(from Table 6)*
Maximum $F_{en\text{-}NWC}$ Multiplier for NWC Conditions = 13.17 *(from Table 6)*

$U_{env\text{-}60} = U_{60} \times F_{en\text{-}NWC} \times 0.53 + U_{60} \times F_{en\text{-}HWC} \times 0.47 =$ 0.0809
Overall Multiplier = $U_{env\text{-}60}/U_{60}$ = 9.51

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Table 8: EAF Evaluation for Limiting RPV Shell/Shroud Support Location

Component: RPV Shell at Shroud Support
NUREG/CR-6260 CUF: 0.032 *(for reference only)*
Reference: NUREG/CR-6260, p. 5-102
Stress Report CUF: 0.0549 *(for Point 9, see below)*
Material: Low Alloy Steel *(Material = A-533 Gr. B per References [14] and [19])*

Design Basis CUF Calculation for 40 years:

Hydrotest σ_ϕ = 26,240 psi *(p. S3-97 of RPV Stress Report)*
Hydrotest σ_r = -1,250 psi *(p. S3-97 of RPV Stress Report)*
Stress Concentration Factor, K_1 = 2.40 *(p. S3-99d of RPV Stress Report)*
Hydrotest $K_1\sigma_\phi$ = 62,976 psi *(p. S3-97 of RPV Stress Report)*
Improper Startup σ_ϕ = 28,060 psi *(p. S3-98 of RPV Stress Report)*
Improper Startup σ_r = -1,025 psi *(p. S3-98 of RPV Stress Report)*
Improper Startup Skin Stress = 156,099 psi *(p. S3-98 of RPV Stress Report)*
Improper Startup $K_1\sigma_\phi$ + Skin Stress = 223,443 psi *(p. S3-98 of RPV Stress Report)*
Warmup σ_ϕ = -5,707 psi *(p. S3-99a of RPV Stress Report)*
Warmup σ_r = -102 psi *(p. S3-99a of RPV Stress Report)*
Warmup $K_1\sigma_\phi$ = -13,696 psi *(p. S3-99a of RPV Stress Report)*
$E_{fatigue\ curve}/E_{analysis}$ = 1.0417 *30.0 / 28.6 per S3-99f of RPV Stress Report and ASME Code fatigue curve*
Power Uprate = 1.0067 *=(549 - 100) / (546 - 100) per 4.4.1.b of 26A6019, Rev. 1 [14]*
m = 2.0 *NB-3228.5 of ASME Code, Section III [11]*
n = 0.2 *NB-3228.5 of ASME Code, Section III [11]*
S_m = 26,700 psi *(ASME Code, Section II, Part D [11])*

P_L+P_B+Q *(see Note 1)*	Events	K_e *(see Note 2)*	S_{alt} *(see Note 3)*	n *(see Note 4)*	N *(see Note 5)*	U
34,690	Improper Startup - Warmup	1.00	124,825	5	332	0.0151
33,095	Hydrotest - Warmup	1.00	40,804	322	8,095	0.0398
					Total, U_{40} =	0.0549

Notes:

1. P_L+P_B+Q is computed for Point 9 based on the $[(\sigma_\phi - \sigma_r)_{Event\ 1} - (\sigma_\phi - \sigma_r)_{Event\ 2}]$ stress intensity.
2. K_e computed in accordance with NB-3228.5 of ASME Code, Section III.
3. $S_{alt} = 0.5 * K_e * E_{fatigue\ curve}/E_{analysis} * \text{Power Uprate} * [(K_1\sigma_\phi - \sigma_r)_{Event\ 1} - (K_1\sigma_\phi - \sigma_r)_{Event\ 2}]$.
4. n for 40 years is the number of cycles as follows per p. S3-99e and S3-99f of the RPV Stress Report:
   Improper Startup = 5 cycles
   Hydrotest = 2 cycles
   Isothermal at 70°F and 1,000 psi = 120 cycles (same as number of Startup events)
   Warmup-Cooldown = 199 cycles
   Warmup-Blowdown = 1 cycle
   TOTAL = 327 cycles
5. N obtained from Figure I-9.1 of Appendix I of ASME Code, Section III.
6. n for 60 years is the projected number of cycles as follows:
   Improper Startup = 1 cycles
   Hydrotest = 1 cycles
   Isothermal at 70°F and 1,000 psi = 300 cycles (same as number of Startup events)
   Warmup-Cooldown = 300 cycles
   Warmup-Blowdown = 1 cycle
   TOTAL = 603 cycles

Revised CUF Calculation for 60 Years:

P_L+P_B+Q *(see Note 1)*		K_e *(see Note 2)*	S_{alt} *(see Note 3)*	n *(see Note 6)*	N *(see Note 4)*	U
34,690	Improper Startup - Warmup	1.00	124,825	1	332	0.0030
33,095	Hydrotest - Warmup	1.00	40,804	602	8,095	0.0744
					Total, U_{60} =	0.0774

Environmental CUF Calculation for 60 Years:

Maximum $F_{en\text{-}HWC}$ Multiplier for HWC Conditions = 5.39 *(from Table 6)*
Maximum $F_{en\text{-}NWC}$ Multiplier for NWC Conditions = 13.17 *(from Table 6)*

$U_{env\text{-}60} = U_{60} \times F_{en\text{-}NWC} \times 0.53 + U_{60} \times F_{en\text{-}HWC} \times 0.47$ = 0.7364
Overall Multiplier = $U_{env\text{-}60}/U_{60}$ = 9.51

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Table 9: EAF Evaluation for RR Inlet Nozzle Forging Location

Component: Recirculation Inlet Nozzle Forging
NUREG/CR-6260 CUF: 0.310 *(for reference only)*
Reference: NUREG/CR-6260, p. 5-105
Stress Report CUF: 0.0433 *(updated for Point 12, see below)*
Material: Low Alloy Steel *(Material = A-508 Cl. II per p. I-S8-4 of CBIN Stress Report Section S8)*

Design Basis CUF Calculation for 40 years:

$E_{fatigue\ curve}/E_{analysis}$ = 1.1278 *= 30.0 / 26.6 (per p. I-S8-24 of CBIN Stress Report Section S8 and ASME Code fatigue curve)*
Power Uprate = 1.0067 *=(549 - 100) / (546 - 100) per 4.4.1.b of 26A6019, Rev. 1 [14]*
K_t = 1.660 *stress concentration factor (p. A270 of VYC-378, Rev. 0 [12])*
m = 2.0 *NB-3228.5 of ASME Code, Section III [11]*
n = 0.2 *NB-3228.5 of ASME Code, Section III [11]*
S_m = 26,700 psi *(ASME Code, Section II, Part D [11])*

P_L+P_B+Q *(see Note 1)*	Skin Stress *(see Note 2)*	K_e *(see Note 3)*	S_{alt} *(see Note 4)*	n *(see Note 5)*	N *(see Note 6)*	U
43,110	15,145	1.00	49,224	200	4,614	0.0433
					Total, U_{40} =	0.0433

Notes:
1. *P_L+P_B+Q is obtained for Point 12 from p. A270 of VYC-378, Rev. 0.*
2. *Skin Stress is obtained for Point 12 from p. A270 of VYC-378, Rev. 0.*
3. *K_e computed in accordance with NB-3228.5 of ASME Code, Section III.*
4. *$S_{alt} = 0.5 * K_e * E_{fatigue\ curve}/E_{analysis}$ * Power Uprate * [$(P_L+P_B+Q)\ K_t$ + Skin Stress].*
5. *n for 40 years is the number of Heatup-Cooldown cycles, per p. B28 of VYC-378, Rev. 0.*
6. *N obtained from Figure I-9.1 of Appendix I of ASME Code, Section III.*
7. *n for 60 years is the projected number of Heatup-Cooldown cycles.*

Revised CUF Calculation for 60 Years:

P_L+P_B+Q *(see Note 1)*	Skin Stress *(see Note 2)*	K_e *(see Note 3)*	S_{alt} *(see Note 4)*	n *(see Note 7)*	N *(see Note 6)*	U
43,110	15,145	1.00	49,224	300	4,614	0.0650
					Total, U_{60} =	0.0650

Environmental CUF Calculation for 60 Years:

Maximum $F_{en\text{-}HWC}$ Multiplier for HWC Conditions = 2.45 *(from Table 5)*
Maximum $F_{en\text{-}NWC}$ Multiplier for NWC Conditions = 12.43 *(from Table 5)*

$U_{env\text{-}60} = U_{60} \times F_{en\text{-}NWC} \times 0.53 + U_{60} \times F_{en\text{-}HWC} \times 0.47$ = 0.5034
Overall Multiplier = $U_{env\text{-}60}/U_{60}$ = 7.74

Table 10: EAF Evaluation for RR Inlet Nozzle Safe End Location

Component:	Recirculation Inlet Nozzle Safe End	
NUREG/CR-6260 CUF:	0.310	*(for reference only)*
Reference:	NUREG/CR-6260, p. 5-105	
Stress Report CUF:	0.0017	*(updated for Location 6-I, see below)*
Material:	Stainless Steel	*(316L per p. 8 of 23A4292, Rev. 4)*

Design Basis CUF Calculation for 40 years:

$E_{fatigue\ curve}/E_{analysis}$ =	1.1076	*= 28.3 / 25.55 (per p. 62 of Reference [18] and ASME Code fatigue curve)*
Power Uprate =	1.0067	*=(549 - 100) / (546 - 100) per 4.4.1.b of 26A6019, Rev. 1 [14]*
K_t =	1.280	*stress concentration factor (p. B27 of VYC-378, Rev. 0 [12])*
m =	1.7	*NB-3228.5 of ASME Code, Section III [11]*
n =	0.3	*NB-3228.5 of ASME Code, Section III [11]*
S_m =	16,600	psi *(ASME Code, Section II, Part D [11])*

P_L+P_B+Q *(see Note 1)*	P+Q+F *(see Note 2)*	K_e *(see Note 3)*	S_{alt} *(see Note 4)*	n *(see Note 5)*	N *(see Note 6)*	U
47,183	36,972	1.00	26,385	2,076	1,242,266	0.0017
					Total, U_{40} =	0.0017

Notes:

1. *P_L+P_B+Q is obtained for Surface I (after weld overlay) from p. 117 of Reference [18].*
2. *P+Q+F is obtained for Point 6-I from p. 118 of Reference [18] (BEFORE weld overlay).*
3. *K_e computed in accordance with NB-3228.5 of ASME Code, Section III.*
4. *$S_{alt} = 0.5 * K_e * E_{fatigue\ curve}/E_{analysis}$ * Power Uprate * [(P+Q+F) K_t].*
5. *n for 40 years is the number of cycles as follows per p. B26 of VYC-378, Rev. 0:*

Design Hydrotest =	*130*	
Loss of Feedpumps Composite:		
Startup/Shutdown =	*290*	
SRV Blowdown =	*8*	
Loss of Feedwater Pumps	*30*	*10 events x 3 up/down cycles per event*
SCRAM =	*270*	
Normal +/- Seismic =	*11*	*10 cycles of upset seismic, plus 1 Level C seismic event*
Normal =	*739*	*= Sum of all of above events*
Zeroload =	*598*	*= Startup/Shutdown + SRV Blowdown + Scram + LOFP*
Total number of cycles =	*2,076*	

6. *N obtained from Figure I-9.2 of Appendix I of ASME Code, Section III.*
7. *n for 60 years is the projected number of cycles as follows:*

Design Hydrotest =	*120*	
Loss of Feedpumps Composite:		
Startup/Shutdown =	*300*	
SRV Blowdown =	*1*	
Loss of Feedwater Pumps	*30*	*10 events x 3 up/down cycles per event*
SCRAM =	*289*	*All remaining scrams*
Normal +/- Seismic =	*11*	*Assume the same*
Normal =	*751*	*= Sum of all of above events*
Zeroload =	*620*	*= Startup/Shutdown + SRV Blowdown + Scram + LOFP*
Total number of cycles =	*2,122*	

Revised CUF Calculation for 60 Years:

P_L+P_B+Q *(see Note 1)*	P+Q+F *(see Note 2)*	K_e *(see Note 3)*	S_{alt} *(see Note 4)*	n *(see Note 5)*	N *(see Note 7)*	U
47,183	36,972	1.00	26,385	2,122	1,242,266	0.0017
					Total, U_{60} =	0.0017

Environmental CUF Calculation for 60 Years:

Maximum $F_{en\text{-}HWC}$ Multiplier for HWC Conditions =	15.35	*(from Table 2)*
Maximum $F_{en\text{-}NWC}$ Multiplier for NWC Conditions =	8.36	*(from Table 2)*
$U_{env\text{-}60} = U_{60} \times F_{en\text{-}NWC} \times 0.53 + U_{60} \times F_{en\text{-}HWC} \times 0.47$ =	0.0199	
Overall Multiplier = $U_{env\text{-}60}/U_{60}$ =	11.64	

Table 11: Summary of EAF Evaluation Results for VY

No.	Component	Material	40-Year Design CUF (1)	60-Year CUF (2)	Overall Environmental Multiplier	60-Year Environmental CUF (2,3)
1	RPV Shell/Bottom Head	Low Alloy Steel	0.0057	0.0085	9.51	0.0809
2	RPV Shell at Shroud Support	Low Alloy Steel	0.0549	0.0774	9.51	0.7364
3	Recirculation Inlet Nozzle Safe End	Stainless Steel	0.0017	0.0017	11.64	0.0199
4	Recirculation Inlet Nozzle Forging	Low Alloy Steel	0.0433	0.0650	7.74	0.5034

Notes:
1. Updated 40-year CUF calculation based on recent ASME Code methodology and design basis cycles.
2. CUF results using updated ASME Code methodology and actual cycles accumulated to-date and projected to 60 years.
3. An F_{en} multiplier was used for each respective component with the following conditions:
    - + 47% HWC conditions and 53% NWC conditions

APPENDIX A

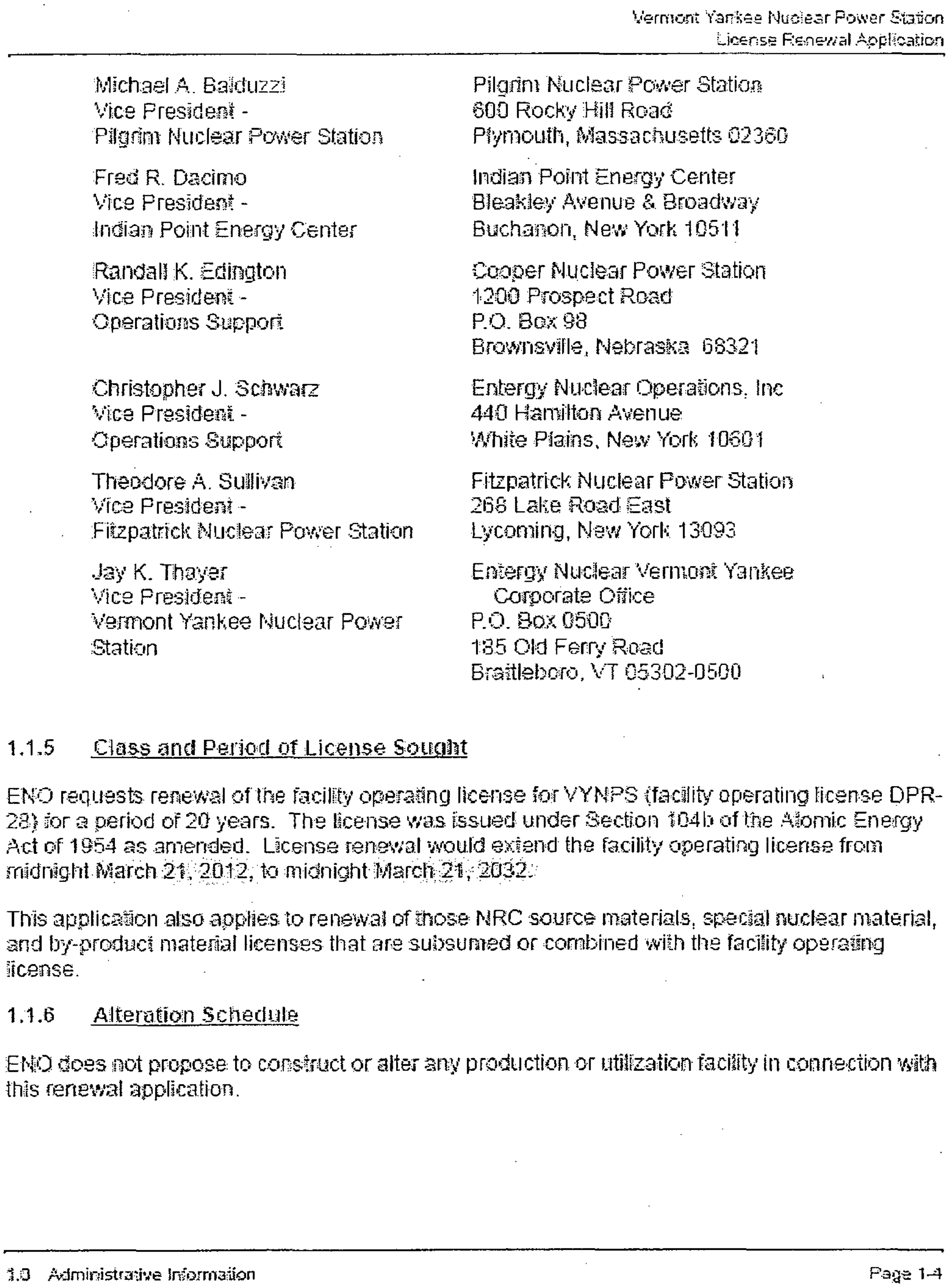
VY WATER CHEMISTRY INFORMATION [8]

Location	Pre-NMCA 1593 MWth (OLP)	Post-NMCA + HWC 1593 MWth (OLP)	Post-NMCA + HWC 1912 MWth (EPU)	Future Operation Post-NMCA + HWC 1912 MWth (EPU)
	---	Average Availability 98.5%	Average Availability 98.5%	Average Availability 99%
	Implementation Date = 11/1972	NMCA Application Date = 04/27/2001 HWC Implementation Date = 11/01/2003	EPU Implementation Date = 5/2006	---
FW Line	40 ppb	40 ppb	40 ppb	40 ppb
Recirc. Line	122 ppb	48 ppb	34 ppb	34 ppb
RPV Bottom Head **	128 ppb	69 ppb	55 ppb	55 ppb
RPV Upper Region	114 ppb	97 ppb	90 ppb	90 ppb
RPV Beltline Region	123 ppb	46 ppb	31 ppb	31 ppb

** RPV Bottom head at "Lower Plenum, Downflow" (i.e. outside core support columns)

APPENDIX B

VY LICENSE DATE [10]



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1.1.5 Class and Period of License Sought

ENO requests renewal of the facility operating license for VYNPS (facility operating license DPR-28) for a period of 20 years. The license was issued under Section 104b of the Atomic Energy Act of 1954 as amended. License renewal would extend the facility operating license from midnight March 21, 2012, to midnight March 21, 2032.

This application also applies to renewal of those NRC source materials, special nuclear material, and by-product material licenses that are subsumed or combined with the facility operating license.

1.1.6 Alteration Schedule

ENO does not propose to construct or alter any production or utilization facility in connection with this renewal application.