Attachment 2

Vermont Yankee Nuclear Power Station
License No. DPR-28 (Docket No. 50-271)

Vermont Yankee Core Plate Bolt Stress Analysis Report

(Non-proprietary Version)

HITACHI

GE Hitachi Nuclear Energy

NEDO-33618

Revision 0

DRF Section 0000-0125-3751-R3

March 2011

Non-Proprietary Information – Class I (Public)

VERMONT YANKEE
CORE PLATE BOLT
STRESS ANALYSIS REPORT

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ACRONYMS AND ABBREVIATIONS

Term	Definition
ABS	Absolute Value
ASME	American Society of Mechanical Engineers
B&PVC	Boiler and Pressure Vessel Code
BWR	Boiling Water Reactor
BWRVIP	Boiling Water Reactor Vessel and Internals Project
DCB	Double Cantilever Beam
dpa	Displacements Per Atom (Proportional to Fluence)
DW	Deadweight
Entergy	Entergy Nuclear Operations, Inc.
EPRI	Electric Power Research Institute
FCC	Face-Centered Cubic
FE	Finite Element
FL	Fuel Lift
GEH	GE-Hitachi Nuclear Energy Americas, LLC
ICGT	In-Core Guide Tube
kips	Kilo-pounds (1000 x lbf): a unit of force
ksi	Kilo-pounds-per-square-inch (1000 x psi): a unit of mechanical stress (or pressure)
LOCA	Loss-of-Coolant Accident
MeV	Mega Electron Volts
MWt	Megawatts, Thermal
NRC	Nuclear Regulatory Commission
OBE	Operating Basis Earthquake
RG	Regulatory Guide
RIPD	Reactor Internal Pressure Difference (psi)
SRV	Safety Relief Valve
SS	Stainless Steel
SRSS	Square Root Sum of Squares

SSE	Safe Shutdown Earthquake
UFSAR	Updated Final Safety Analysis Report
VYNPS	Vermont Yankee Nuclear Power Station

1.0 Introduction

Entergy Nuclear Operations, Inc. (Entergy) has requested a plant-specific core plate[1] hold-down bolt stress analysis for Vermont Yankee Nuclear Power Station (VYNPS). This plant-specific analysis performed by GE-Hitachi Nuclear Energy Americas, LLC (GEH) is consistent with Electric Power Research Institute's (EPRI) Boiling Water Reactor Vessel and Internals Project (BWRVIP)-25 Appendix A (Reference 1) and VYNPS's current licensing basis. This analysis shows that the core plate bolts in VYNPS meet American Society of Mechanical Engineers (ASME) code allowable limits. This demonstrates that VYNPS core plate bolts can withstand Normal, Upset, Emergency, and Faulted loads, considering the effects of stress relaxation on the bolts until the end of the 60-year period of plant operation.

2.0 Scope

The purpose of the stress calculations performed herein is to demonstrate the structural adequacy of the VYNPS core plate bolts and aligner pins if subjected to the three scenarios listed in BWRVIP-25 Appendix A. Plant-specific data is applied in the analysis, and ASME Boiler and Pressure Vessel Code (B&PVC) Section III is used as a guide for the allowable stress limits. The methodology contained within this report also scales some results from the BWRVIP-25 Appendix A data where plant-specific data is not available. This analysis includes stress relaxation due to 60-year fluence and thermal effects. This report also includes a stress relaxation evaluation. Results for the core plate bolt stress levels are presented.

This analysis only reports whether or not the stresses in the core plate bolts will remain under ASME allowable values for the scenarios listed in BWRVIP-25 and associated loading conditions.

3.0 Summary of Analysis Results

This analysis shows that the VYNPS core plate bolts meet the ASME Code allowable stresses for the loading conditions and assumptions made for all three scenarios analyzed in BWRVIP-25 Appendix A throughout a 60-year period of plant operation. A summary of these results can be found in Table 8-1 and details of the analysis results can be found in Section 8.0. The three scenarios are:

1. Loads on the core plate bolts with no credit for aligner pins (the bolts take all of the horizontal and vertical loads)
2. Shear load on the aligner pins with no credit for horizontal bolt restraint (the bolts take the vertical loads and the aligner pins take all of the horizontal loads)

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[1] The proper component terminology is *core support*, but *core plate* has been used almost universally and will be used in this report.

3. Loads on the core plate bolts with no credit for aligner pin and also with the stiffener-beam-to-rim weld cracked (the core plate bolts take all of the horizontal and vertical loads)

4.0 Structural Acceptance Critiera

The acceptance criteria are consistent with VYNPS Updated Final Safety Analysis Report (UFSAR) (Reference 2) as shown in Table 4-1. The material properties were taken from the 1965 ASME B&PVC (Reference 3). After analyzing Normal/Upset, Emergency, and Faulted Conditions, it was determined that the limiting load combinations are for Service Level D (Faulted Condition). The Faulted Condition results are reported in Section 8.0.

4.1 Allowable Stress Limits

Table 4-1 Allowable Stress Limits

Stress Category	Service Level C Allowable Limit[1]	Service Level D Allowable Limit[1]
Membrane Stress (P_m)	*1.5 Sm*	*2.0 Sm*
Membrane (P_m) + Bending (P_b) Stress	*2.25 Sm*	*3.0 Sm*
Shear Stress	*0.9 Sm*	*1.2 Sm*

Note: [1] Reference 2 (page C.2-27 of 65)

5.0 Stress Relaxation Evaluation

5.1 Scope

This section of the report discusses the relaxation of VYNPS core plate bolt stress due to irradiation and the basis for the stress relaxation evaluation, including the following:

- GEH design curves (Figures 5-1 and 5-3) that are based on a model using stress-linear, primary plus secondary creep law form, and are fitted to the available data in Figure 5-1 using stepwise multiple regression data;
- Stress relaxation curves, including the loads used to develop the stress relaxation curves;
- An analysis of the effect of austenitic material type on stress relaxation from neutron radiation; and
- Results documenting that the GEH design curves apply to Type 304SS, including the effect of test temperature and neutron flux on stress relaxation.

5.2 Evaluation

Stress-relaxation properties of irradiated austenitic steels and nickel alloys have been studied extensively by GEH, and mean and 95-95 limit curves have been developed. [[

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[[ ]] (3)

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Figure 5-1 Relaxation of Irradiated Austenitic Steels & Ni-Alloys (GEH Mean Design Curve)

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[[ ]] (4)

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High-energy radiation produces a number of simultaneous effects in materials, primarily originating with the displacement of atoms from their original lattice position to relatively distant locations, usually as an interstitial. The interstitial atoms and the associated vacancies group into interstitial and vacancy clusters (hardening), migrate to grain boundaries, and relax constant displacement stresses due to the resulting interaction with dislocations. These radiation-induced effects in austenitic SSs are most strongly influenced by the face-centered cubic (FCC) structure of the materials, which is a common attribute of the materials used in developing the design curve.

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To further support this observation, see Figure 7-17 in the BWRVIP-99 report (Reference 4), shown below as Figure 5-2.

Figure 5-2 Stress Relaxation Data

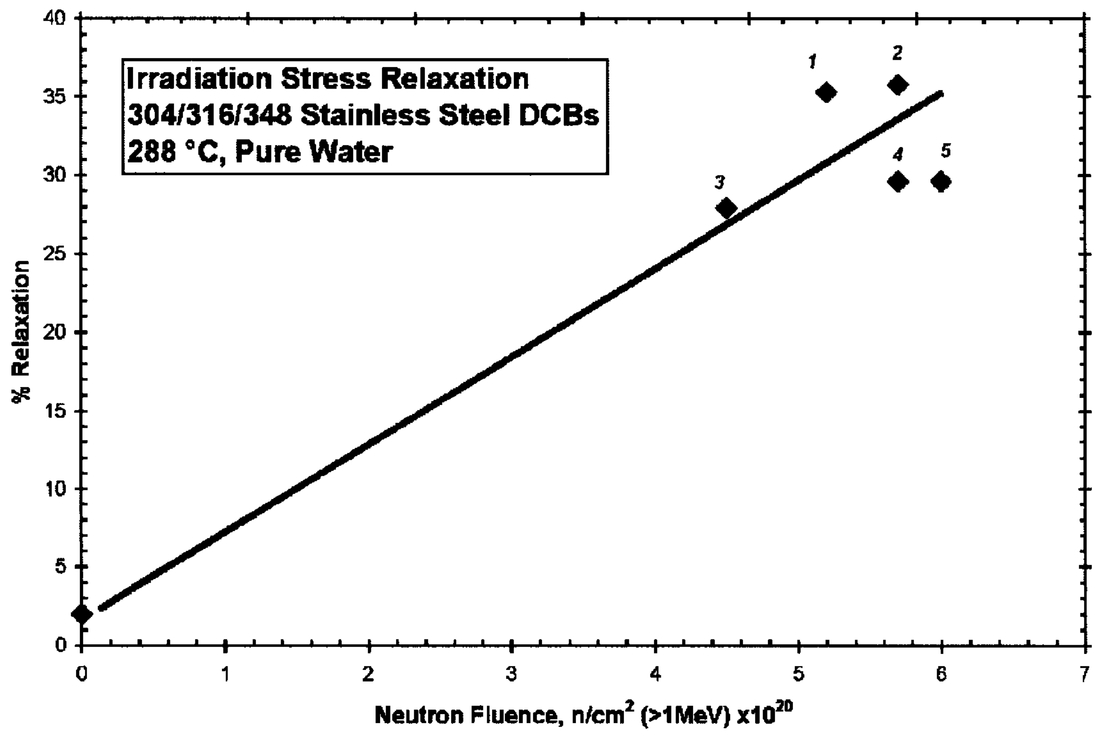

Figure 5-2 shows stress relaxation data from wedge loaded double cantilever beam (DCB) specimens in 288°C water that are exposed to neutron fluences of approximately 4.4 to 6 x 10^{20} n/cm^2 (>1 MeV) (i.e., approximately 0.6 to 0.9 dpa) (Reference 5). This data shows stress relaxation levels clustered between 28% and 36% for DCB specimens fabricated from 304/316/348 SSs. This data is for fluence levels nearly 10 times higher than that predicted for the VYNPS bolts, but the effects at lower fluences would be no more pronounced.

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Figure 5-3 Relaxation of Irradiated Austenitic Steels (GEH Mean Design Curve and Additional Data)

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The in-core specimen data used to establish this trend line (Figure 5-1) was irradiated at temperatures of approximately 550°F, which is equivalent to the temperatures experienced by the core plate bolts. Temperature effect is thus considered negligible.

6.0 Loads and Load Combinations

The loads shown in Table 6-1 were considered for this analysis. [[

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Table 6-1 Loads Considered for Analysis (Faulted Condition)

Load	Value	Reference
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According to the UFSAR for VYNPS, the following load combinations shown in Table 6-2 apply. The allowable stress limits are determined from the UFSAR (Reference 2, page C.2-27 of 65) and the material properties for Type 304SS plate (SA-240) as defined in Table N-421 of the 1965 Section III ASME B&PVC (Reference 3).

Table 6-2 Load Combinations

Service Level		Loads	Allowable $P_m + P_b$ Stress
Normal/Upset	A/B	DW + Normal RIPD + OBE	24 ksi
Emergency	C	DW + Normal RIPD + SSE	36 ksi
Faulted	D	DW + Faulted RIPD + SSE + FL	48 ksi

All load combinations were considered in the evaluation and the Faulted Condition (Level D) is the most limiting.

6.1 Load Combinations

The total horizontal load is effectively equal to the horizontal SSE load. The vertical loads on the core plate bolts are caused primarily by the pressure differential across the core plate. The SSE_{vert} also contributes to the vertical load on the core plate bolts. The DW opposes the vertical load. Peripheral fuel weight has conservatively not been included. FL also adds to the vertical load for the Faulted Condition. [[

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6.2 Horizontal Seismic Loads

Plant-specific horizontal direction accelerations and shear loads due to Operating Basis Earthquake (OBE) and SSE were used in this analysis. [[

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6.3 Vertical Seismic Loads

Plant-specific vertical direction accelerations and shear loads due to OBE and SSE were used in this analysis. [[ ]]

6.4 Fluid Drag and Deadweight Loads

The fluid drag was applied as a pressure to the bottom surface of the core plate. This pressure differential (RIPD) is caused by fluid flowing across the core plate. It results in an upward load on the core plate bolts. The DW of the core plate is the weight of the core plate assembly mass only, and it opposes the vertical loads.

6.5 Preload

Preload on the core plate bolts is accounted for by adding the membrane stress resulting from the preload to the calculated membrane stress, which is consistent with the approach used in BWRVIP-25 Appendix A. Preload relaxation due to fluence and temperature was considered in this analysis (see Sections 6.7 and 6.8).

6.6 Friction

For this analysis, 304SS is interacting with 304SS on a wetted interface. [[

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A friction factor of 0.2 has been suggested in BWRVIP-51-A Section 5.5 (Reference 7) for modeling the friction restraint for the evaluation of retained flaws unless a higher value can be technically justified. Typical jet pump material is also SS and the recommendation of friction factor of 0.2 should be applicable for the SS core plate rim and shroud ledge interface. Additionally, the Licensing Topical Report entitled "Dynamic, Load-Drop and Thermal-Hydraulic Analyses for ESBWR Fuel Racks" uses a friction factor range of 0.2 to 0.8, with a mean value of 0.5 (Reference 8). [[
]] for the analysis contained herein, a value of 0.2 for the friction factor is used to be conservative.

The use of the 0.2 friction factor, although still conservative, is more realistic than assuming no friction. Without friction, all the lateral loads on the core plate will be resisted by the core plate bolts through the bending and shear of the core plate bolts. With this small friction factor, some of the lateral loads are resisted by the friction at the rim and shroud ledge interface, which results in lower loads on the core plate bolts.

Friction was incorporated in the following manner: The original preload in the bolts was reduced due to fluence and thermal relaxation (see forthcoming sections). This reduced preload, when combined with the vertical loads applied (which act to reduce the normal force at the interface), resulted in a normal force at the interface of the core plate rim and shroud ledge [[

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6.7 Fluence

In 2003, GE performed a best-estimate flux evaluation for the EPU equilibrium core configuration of VYNPS using the Regulatory Guide (RG) 1.190 (Reference 9) compliant and Nuclear Regulatory Commission (NRC) approved GE fluence methodology. Based on that evaluation, best-estimate fast flux (E > 1 MeV) at a thermal power of 1,912 MWt was evaluated for the vessel inside surface, shroud inside surface, and surveillance capsule. The flux results from the 2003 flux calculation were used to estimate the flux and fluence for the core plate bolts at VYNPS. Cycle-dependent energy generation data were provided by Entergy and used to convert the flux into fluence for this analysis.

The fluence evaluation performed in support of this analysis resulted in a peak total fast fluence [[

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The core plate bolt preload will relax with fluence. [[

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6.8 Thermal Relaxation

The modulus of elasticity of the steel changes as the reactor is brought to operating temperature. This effect is included in this analysis by reducing the preload. [[

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7.0 Structural Analysis

7.1 Components

Figure 7-1 shows the components of a generic core plate (Reference 1). The zero of the azimuthal location, Θ, is located along the X-axis. The VYNPS core plate has 30 core plate bolts, each with a diameter of 2 inches. The original preload in each bolt was 900 ft-lbf. This preload is reduced due to fluence and thermal relaxation, as described in Sections 6.5 through 6.8.

Figure 7-1 Generic Core Plate Assembly Component Names

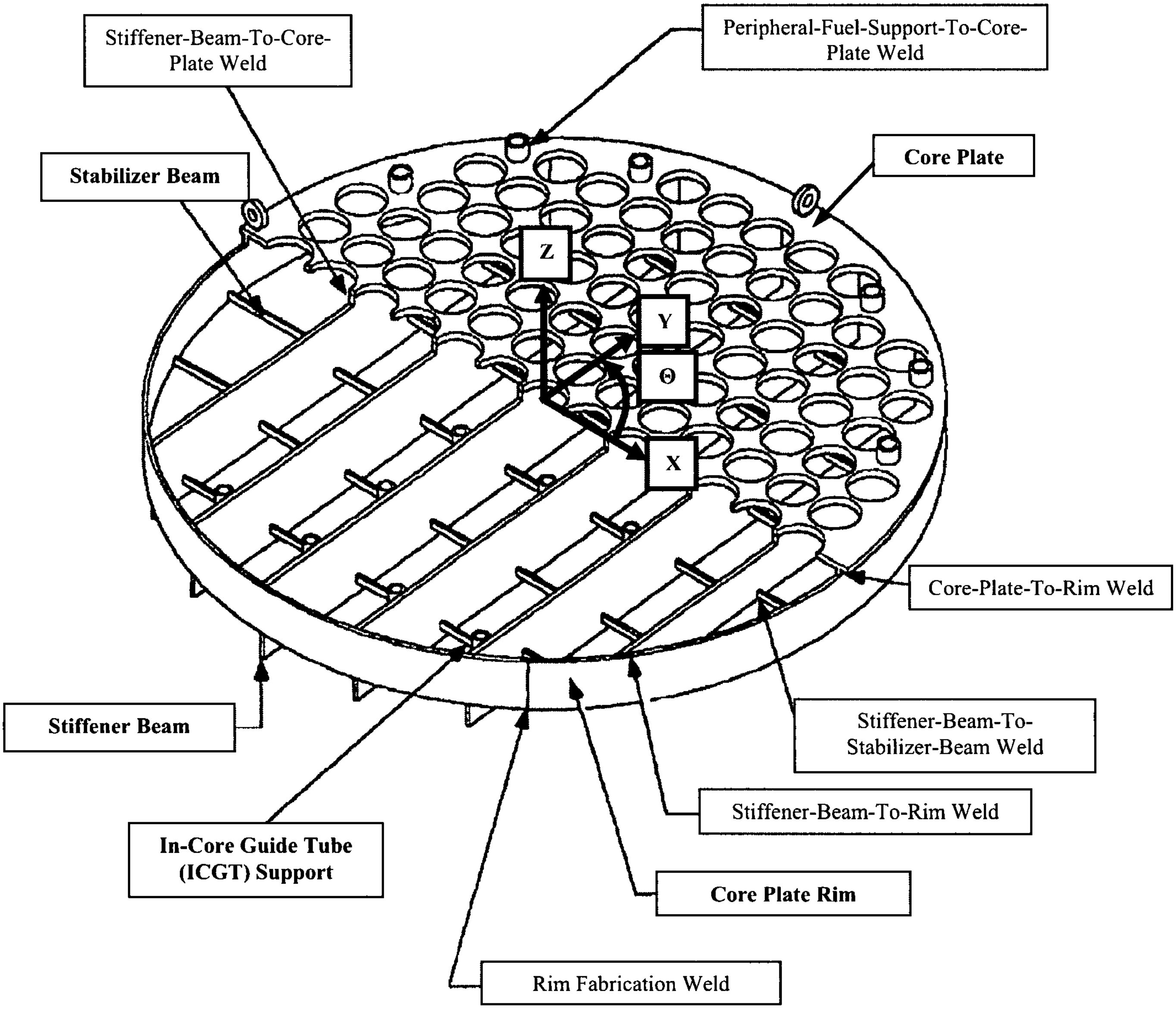
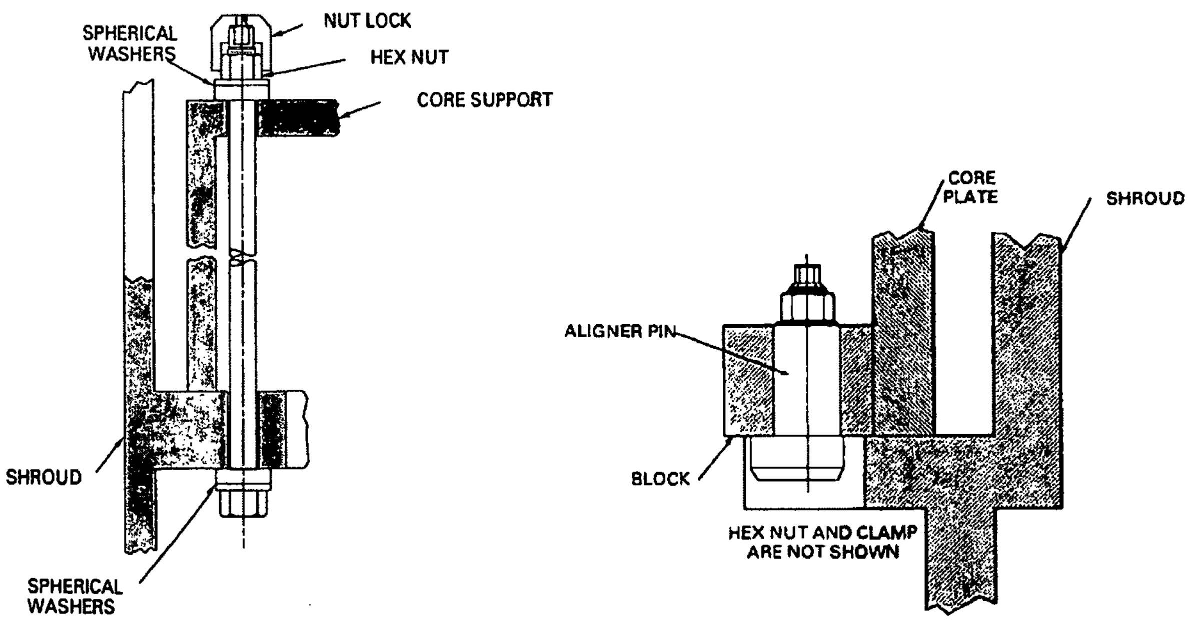


Figure 7-2 shows the configuration of the core plate bolts and aligner pins (Reference 1).

Figure 7-2 Core Plate Bolt and Aligner Pin Configuration



7.2 Scenario Descriptions

7.2.1 Scenario 1

Aligner pins are not included for this scenario. All vertical loading is supported by axial stretching of the core plate bolts. The horizontal loads imparted on the core plate are resisted by bending of the core plate bolts and by the friction between the core plate rim and the shroud ledge.

7.2.2 Scenario 2

Aligner pins are included for this scenario. All vertical loading is supported by the axial stretching of the core plate bolts. The aligner pins cannot support a vertical load. The horizontal loads imparted on the core plate are resisted by the shearing of the aligner pins and by the friction between the core plate rim and the shroud ledge. The core plate bolts take only the vertical loads, not the lateral loads.

BWRVIP-25 Appendix A determines the maximum of the horizontal loads calculated on all four aligner pins from the Finite Element (FE) model. Then the shear stress on a single aligner pin is calculated by applying this maximum horizontal load. [[

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7.2.3 Scenario 3

The difference between this scenario and Scenario 1 is the postulated complete failure of the weld between the stiffener beams and the rim. Aligner pins are not included for this scenario. All vertical loading is supported by axial stretching of the core plate bolts. The horizontal loads imparted on the core plate are resisted by bending of the core plate bolts and by the friction between the core plate rim and the shroud ledge.

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8.0 Analysis Results

8.1 Comparison of Core Plate Bolt Stresses to ASME Allowable Limits

As stated in Section 3.0, this analysis shows that the VYNPS core plate bolts meet the ASME allowable stresses for the loading conditions and assumptions made for all three scenarios analyzed in BWRVIP-25 Appendix A (Reference 1). This analysis follows the BWRVIP-25 Appendix A example analysis with three differences:

1. This analysis uses plant-specific loading and geometry for VYNPS and ASME allowable limits consistent with the licensing basis.
2. This analysis takes credit for a conservative amount of friction between the core plate rim and shroud ledge.
3. Because this analysis does not have a plant-specific FE model, some calculations use scaled values from BWRVIP-25 data.

Results for the Faulted Condition, which is the most limiting condition, have been included in Table 8-1.

Table 8-1 Stresses Compared to ASME Allowable Limits (Faulted Condition)

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9.0 Conclusion

Including the effects of preload relaxation due to thermal effects and fluence for a 60-year plant life, this analysis shows that the VYNPS core plate bolts meet the ASME allowable stresses for the most limiting load combinations and loads for all three scenarios analyzed in BWRVIP-25 Appendix A (Reference 1).

10.0 References

1. EPRI, "BWR Core Plate Inspection and Flaw Evaluation Guidelines," BWRVIP-25, December 1996.
2. Updated Final Safety Analysis Report for VYNPS, Revision 24.
3. 1965 American Society of Mechanical Engineers Boiler & Pressure Vessel Code Section III.
4. EPRI, "Crack Growth Rates in Irradiated Stainless Steels in BWR Internal Components," BWRVIP-99, December 2001.
5. R. Pathania, et al., "Crack Growth Rates in Irradiated Stainless Steels in BWR Internals," 14th International Conference on Environmental Degradation of Materials in Nuclear Power Systems, August 23-27, 2009, Virginia Beach, VA.
6. GE Nuclear Energy, "Safety Analysis Report for Vermont Yankee Nuclear Power Station Constant Pressure Power Uprate," NEDC-33090P, Revision 0, September 2003.
7. EPRI, "Jet Pump Repair Design Criteria," BWRVIP-51-A, September 2005.
8. GE Hitachi Nuclear Energy, "Dynamic, Load-Drop and Thermal-Hydraulic Analyses for ESBWR Fuel Racks," NEDO-33373-A, Revision 5, September 2010.
9. U.S. NRC, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence," Regulatory Guide 1.190, March 2001.