ENCLOSURE 2

COOPER NUCLEAR STATION CORE PLATE BOLT STRESS ANALYSIS REPORT (NON-PROPRIETARY)

HITACHI

GE Hitachi Nuclear Energy

NEDO-33674

Revision 0

DRF Section 0000-0133-3268 R2

October 2011

Non-Proprietary Information – Class I (Public)

COOPER NUCLEAR STATION
CORE PLATE BOLT
STRESS ANALYSIS REPORT

Copyright 2011 GE-Hitachi Nuclear Energy Americas LLC

All Rights Reserved

INFORMATION NOTICE

This is a non-proprietary version of the document NEDC-33674P, Revision 0, which has the proprietary information removed. Portions of the document that have been removed are identified by an open and closed bracket, as shown here [[ ]].

IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT

Please Read Carefully

The design, engineering, and other information contained in this document is furnished for the purpose of supporting Nebraska Public Power District in proceedings before the U.S. Nuclear Regulatory Commission. The only undertakings of GEH with respect to information in this document are contained in the contracts between GEH and its customers or participating utilities, and nothing contained in this document shall be construed as changing that contract. The use of this information by anyone for any purpose other than that for which it is intended is not authorized; and with respect to any unauthorized use, GEH makes no representation or warranty, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

Term	Definition
A-ΔP	Faulted Condition RIPD Load
ASME	American Society of Mechanical Engineers
ASTM	American Socicty for Testing and Materials
B&PVC	Boiler and Pressure Vessel Code
BWR	Boiling Water Reactor
BWRVIP	Boiling Water Reactor Vessel and Internals Project
CNS	Cooper Nuclear Station
DCB	Double Cantilever Beam
dpa	Displacements Per Atom (Proportional to Fluence)
DW	Deadweight
EFPY	Effective Full Power Year
EPRI	Electric Power Research Institute
FCC	Face-Centered Cubic
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)
MeV	Mega Electron Volts
N-ΔP	Normal Condition RIPD Load
N/A	Not Applicable
NPPD	Nebraska Public Power District
OBE	Operating Basis Earthquakc
RIPD	Reactor Internal Pressure Difference (psi)
SS	Stainless Steel
SSE	Safe Shutdown Earthquake
U-ΔP	Upset Condition RIPD load
USAR	Updated Safety Analysis Report

1.0 Introduction

Nebraska Public Power District (NPPD) has requested a plant-specific core plate bolt evaluation for Cooper Nuclear Station (CNS). This plant-specific analysis performed by GE-Hitachi Nuclear Energy Americas LLC (GEH) is consistent with Electric Power Research Institute's (EPRI's) Boiling Water Reactor Vessel and Internals Project (BWRVIP)-25 Appendix A (Reference 1) and CNS's current licensing basis. This analysis shows that the core plate bolts in CNS meet American Society of Mechanical Engineers (ASME) code allowable limits. This demonstrates that CNS 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 this evaluation is to demonstrate the structural adequacy of the CNS core plate bolts and aligner pins if subjected to the three scenarios listed in BWRVIP-25 Appendix A. Plant-specific data is used in the analysis. The CNS core plate is not an ASME code component. However, ASME code criteria are used as a guideline. 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. Results for the core plate bolt stress levels are presented in this report.

This analysis only reports whether 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 CNS 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.
2. Shear load on the aligner pins with no credit for horizontal bolt restraint.
3. Loads on the core plate bolts with no credit for aligner pin and also with the stiffener-beam-to-rim weld cracked.

4.0 Structural Acceptance Criteria

The acceptance criteria are consistent with the CNS Updated Safety Analysis Report (USAR) (Reference 2), as shown in Table 4-1. The material properties were taken from the 1971 ASME Boiler and Pressure Vessel Code (B&PVC) (Reference 3). After analyzing Normal/Upset, Emergency, and Faulted Conditions, it was determined that the limiting load combinations are for Service Level C (Emergency Condition). The results are reported in Section 8.0.

4.1 Allowable Stress Limits

Table 4-1 Allowable Stress Limits

Stress Category	Service Level B Allowable Limit[1]	Service Level C Allowable Limit[1]	Service Level D Allowable Limit[1]
Membrane Stress (P_m)	*1.0 Sm*	*1.5 Sm*	*2.0 Sm*
Membrane (P_m) + Bending (P_b) Stress	*1.5 Sm*	*2.25 Sm*	*3.0 Sm*
Shear Stress	*0.6 Sm*	*0.9 Sm*	*1.2 Sm*

Note: [1] Reference 2 (page C-3-16); $Sm = 16{,}925\ psi$.

5.0 Stress Relaxation Evaluation

5.1 Scope

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

A. Relaxation of core plate hold down bolts due to irradiation. The report will discuss the basis for the stress relaxation evaluation, including the following:

- Discuss stress – linear, primary plus secondary creep law form in relation to stepwise multiple regression data
- Describe the stress relaxation curves, including the loads used to develop the stress relaxation curves
- Analyze the effect of austenitic material type on stress relaxation from neutron radiation and provide information to document that the GEH design curves apply to Type 304SS, to include the effect of test temperature and neutron flux on stress relaxation

B. Determination of the fraction of remaining stress.

5.2 Evaluation

A. Discuss the basis for the stress relaxation evaluation.

Stress-relaxation properties of irradiated austenitic steels and nickel alloys were studied extensively by GE in the late 1970s and early 1980s, and mean and 95-95 limit curves for use in design were developed and issued in the GE BWR Materials Handbook. [[

]]

[[ ]] (1)

[[

]]

[[ ]] (2)

[[

]]

[[ ]] (3)

[[ ]]

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

[[

]]

[[

]]

[[ ]] (4)

[[

]]

High-energy radiation produces a number of simultaneous effects in materials, mostly 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.

[[

]]

To further support this observation, see Figure 7-17 in the BWRVIP-99-A report (Reference 4), "Crack Growth Rates in Irradiated Stainless Steels in BWR Internal Components" (repeated here as Figure 5-2).

Figure 5-2 Stress Relaxation Data

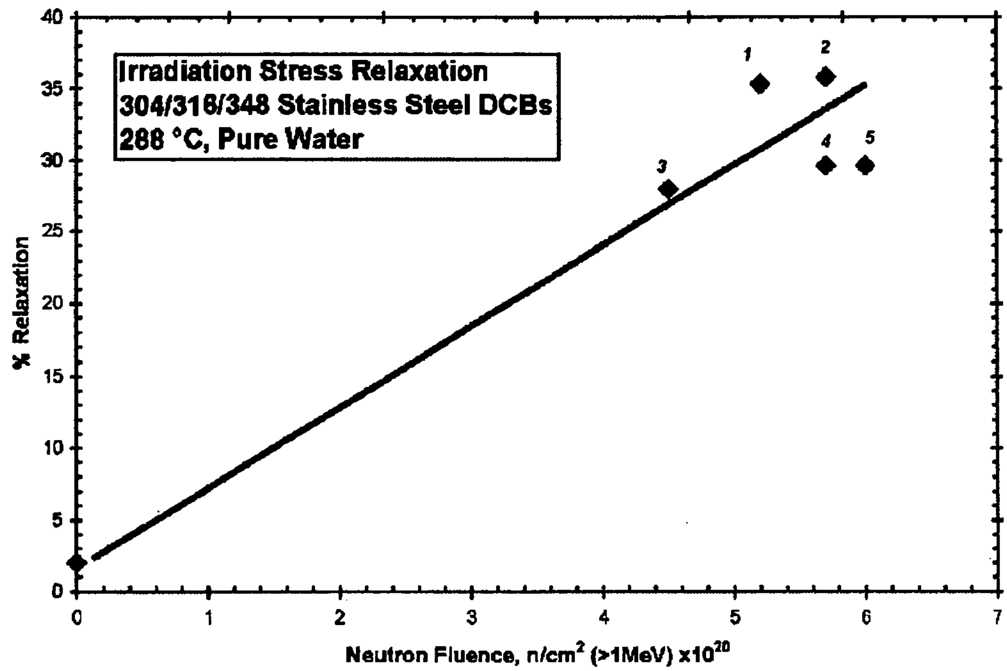


Figure 5-2 shows stress relaxation data from wedge loaded double cantilever beam (DCB) specimens in 288°C water that are exposed to neutron fluences of approximately 4.4 to 6 x 10^{20} n/cm^2 (>1 MeV) (i.e., approximately 0.6 to 0.9 dpa). This data shows stress relaxation levels clustered between 28%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

[[

]]

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

[[

]]

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.

B. ***Determine fraction of remaining stress.***

Core plate bolts experience a stress relaxation due to fluence exposure. In this analysis, [[

]]

6.0 Loads and Load Combinations

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

Table 6-1 Loads Considered for Analysis

Load	Value
[[	
	]]

According to the USAR for CNS, the following load combinations shown in Table 6-2 apply. The allowable stress limits are determined from the USAR (Reference 2, pages C-3-16 and C-3-13) and the material properties for Type 304SS plate (SA-240) as defined in Table I-1.1 of the 1971 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	25.388 ksi
Emergency	C	DW + Normal RIPD + SSE	38.081 ksi
Faulted	D	DW + Faulted RIPD + SSE	50.775 ksi

All load combinations were considered in the evaluation and the Upset condition (Level B) was found to be the most limiting.

6.1 Load Combinations

The total horizontal load is effectively equal to the horizontal seismic (OBE or SSE) load. The vertical loads on the core plate bolts are caused primarily by the pressure differential across the core plate. The vertical seismic load (a_{vert}) also contributes to the vertical load on the core plate bolts. The DW opposes the vertical load. DW includes core plate weight and peripheral fuel weight. [[

]]

6.2 Horizontal Seismic Loads

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

6.3 Vertical Seismic Loads

Plant-specific vertical direction accelerations 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 and peripheral fuel, and it opposes the vertical loads.

6.5 Preload

Preload on the core plate bolts is considered a secondary load to the calculated secondary stress. 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. 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 a 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" (Reference 8) uses a friction factor range of 0.2 to 0.8, with a mean value of 0.5. A value of 0.2 for the friction factor is used to be conservative in this analysis.

The use of the 0.2 friction factor is more realistic than assuming no friction, but is still conservative. Without friction, all the lateral loads on the core plate will be resisted only by the core plate bolts through the bending and shear of the core plate bolts. With this small friction factor (0.2), nearly all 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.

The original preload in the bolts was reduced due to fluence and thermal relaxation (see Sections 6.7 and 6.8). This reduced preload, when combined with the vertical loads applied (which act to reduce the normal force at the interface), resulted in a minimum normal force at the interface of the core plate rim and shroud ledge [[

]]

6.7 Fluence

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

]]

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. [[

]]

7.0 Structural Analysis

7.1 Components

Figure 7-1 shows the components of a generic core plate (Reference 1). The CNS core plate has 72 core plate bolts, each with a diameter of 1.125 inches. The original preload in each bolt was 300±25 ft-lbf. This preload is reduced due to fluence and thermal relaxation, as described in Sections 6.5 through 6.8. The CNS core plate also has four aligner pins, each with a diameter of 2.99 inches. Figure 7-2 shows the configuration of core plate bolt, aligner pin and shroud ledge and core plate core plate rim contact.

Figure 7-1 Generic Core Plate Assembly Component Names

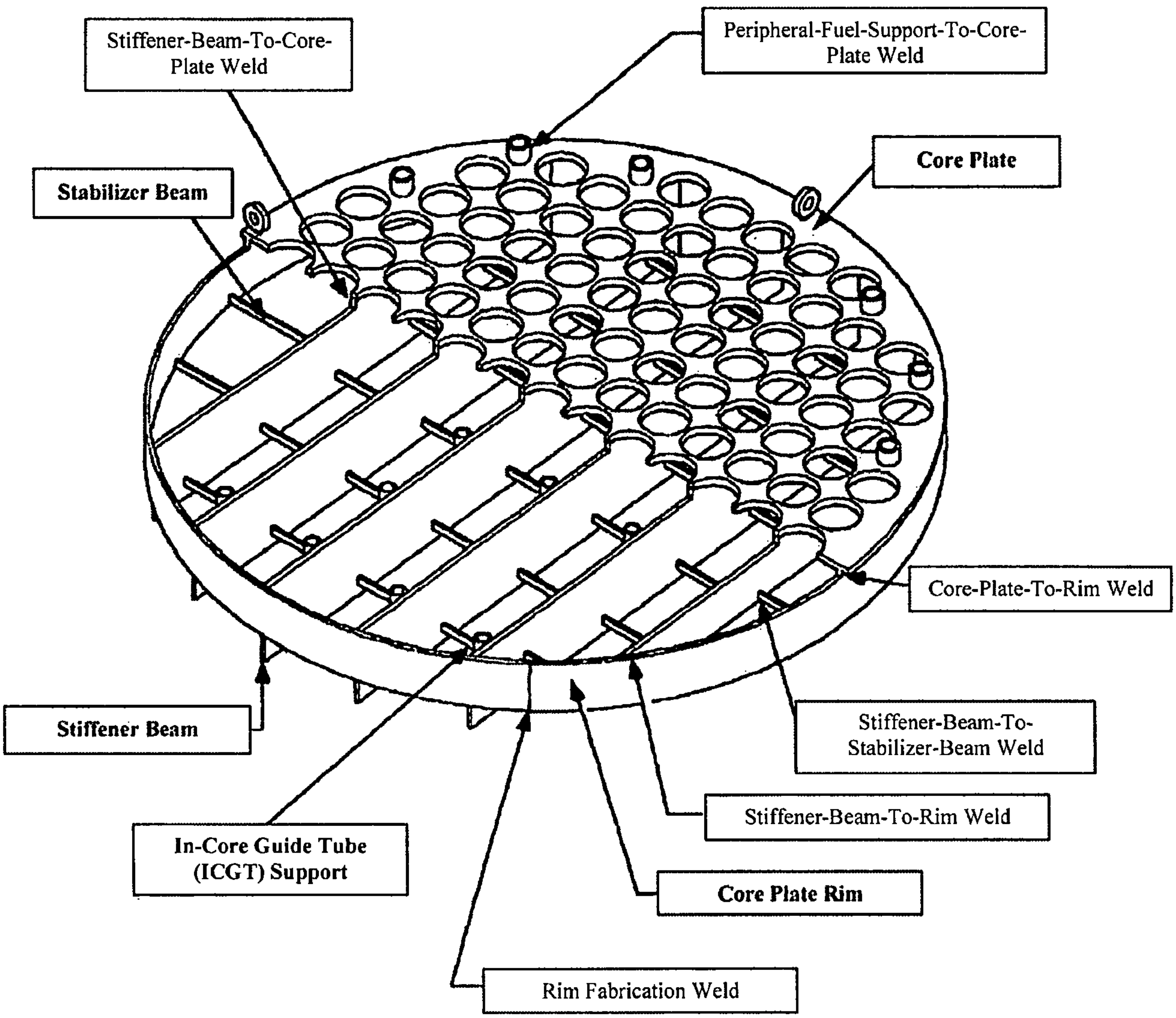
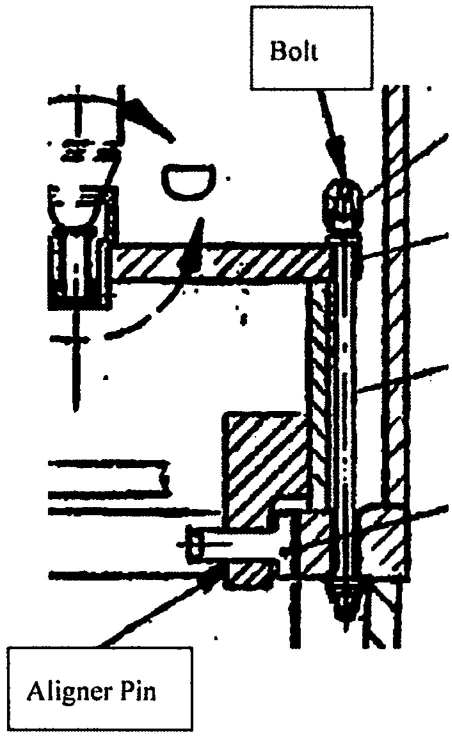


Figure 7-2 shows the configuration of the core plate bolts and aligner pins (Reference 1).

Figure 7-2 Core Plate Bolt and Aligner Pin Configuration



7.2 Scenario Descriptions

7.2.1 Scenario 1

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. Aligner pins are not included for this scenario.

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 horizontal loads imparted on the core plate are resisted by the shearing of the aligner pins. The core plate bolts take only the vertical loads, not the lateral loads.

BWRVIP-25 Appendix A determined the maximum of the horizontal loads calculated on all four aligner pins and calculated the shear stress on a single aligner pin by applying this maximum horizontal load. [[

]]

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. 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.

[[

]]

8.0 Analysis Results

8.1 Comparison of Core Plate Bolt Stresses to ASME Allowable Limits

This analysis shows that the CNS 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 the following differences:

1. This analysis uses plant-specific loading and geometry for CNS.
2. This analysis takes credit for a conservative amount of friction (0.2 friction factor) between the core plate rim and the shroud ledge.
3. This analysis used the pre-load in the secondary stress calculation.
4. An additional bending load due to the bending of core plate rim is added to the core plate bolts.
5. This analysis calculates the shear loads on the aligner pins using a different method due to having a different aligner pin configuration.

The Normal/Upset condition is found to be the most limiting condition. Results for the limiting condition (Normal/Upset) are presented in Table 8-1.

Table 8-1 Stresses Compared to ASME Allowable Limits

[[									
									]]

[[

]]

9.0 Conclusion

This analysis shows that the CNS 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). The effects of preload relaxation due to thermal effects and fluence for a 60-year plant life are considered in the analysis.

10.0 References

1. "BWRVIP-25: BWR Vessel and Internals Project, BWR Core Plate Inspection and Flaw Evaluation Guidelines." EPRI, Palo Alto, CA: 1996. 107284.
2. Updated Safety Analysis Report for CNS.
3. American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section III, 1971 Edition with No Addenda.
4. "BWRVIP-99-A: BWR Vessel and Internals Project, Crack Growth Rates in Irradiated Stainless Steels in BWR Internal Components." EPRI, Palo Alto, CA: 2008. 1016566.
5. J. P. Foster, "Analysis of In-Reactor Stress Relaxation Using Irradiation Creep Models," Irradiation Effects on the Microstructure and Properties of Metals, American Society for Testing and Materials (ASTM) STP611, page 32, 1976.
6. Nebraska Public Power District, "Cooper Nuclear Station Core Support Plate Rim Bolt Axial Fluence Evaluation," NPP-FLU-003R-008, Revision 0, 2011 (NEDC07-032, Revision 1C1).
7. "BWRVIP-51-A: BWR Vessel and Internals Project, Jet Pump Repair Design Criteria." EPRI, Palo Alto, CA: 2005. 1012116.
8. GE Hitachi Nuclear Energy, "Dynamic, Load-Drop and Thermal-Hydraulic Analyses for ESBWR Fuel Racks," NEDO-33373-A, Revision 5, September 2010.