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JAFP-12-0122
September 28, 2012

United States Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 20555

Subject: Core Plate Rim Hold Down Bolting, Plant Specific Analysis and Inspection Plan, License Renewal Commitment #23.
James A. FitzPatrick Nuclear Power Plant
Docket No. 50-333
License No. DPR-59

References:

1. Letter, Entergy to USNRC, "James A. FitzPatrick Nuclear Power Plant, License Renewal Application," JAFP-06-0109, dated July 31, 2006
2. Letter, Entergy to USNRC, "James A. FitzPatrick Nuclear Power Plant, License Renewal Application, Amendment 5," JAFP-07-0019, dated February 1, 2007
3. Letter, USNRC to Entergy, "Safety Evaluation Report Related to the License Renewal of James A. FitzPatrick Nuclear Power Plant," NUREG-1905, dated April, 2008

Dear Sir or Madam:

On July 31, 2006, Entergy Nuclear Operations, Inc. (ENO) submitted the License Renewal Application (LRA) for the James A. FitzPatrick Nuclear Power Plant (JAFNPP) [Reference 1]. On February 1, 2007, ENO submitted amendment 5 to the LRA in response to subsequent requests for additional information (RAI) and the results of the Aging Management Program (AMP) and Aging Management Review audits [Reference 2].

Specifically, Entergy commitment #23 of attachment 1 in reference 3 states the following:

Enhance the BWR Vessel Internals Program to perform inspections of the core plate rim hold down bolts.

Appendix A.2.2.7 Core Plate is revised to add that JAFNPP will perform one of the following:

1. Install core plate wedges prior to the period of extended operation, or,

2. Complete a plant-specific analysis to determine acceptance criteria for continued inspection of core plate rim hold down bolting in accordance with BWRVIP-25 and submit the inspection plan, along with acceptance criteria and justification for the inspection plan, to the NRC two years prior to the period of extended operation for NRC review and approval.

If Option 2 is selected, the analysis to determine acceptance criteria will address the information requested in RAIs 3.1.2-2A and 4.7.3.2-1.

How We Addressed the Commitment

JAF has chosen to complete a plant specific analysis to satisfy Option 2 of the commitment. JAF-RPT-12-00009 Rev. 0, "Proposed Core Plate Bolt Inspection Protocol and Technical Bases," summarizes the evaluations performed to show the susceptibility of the JAF core plate bolts to known degradation mechanisms, the relaxation of bolt preload over 60 years of operation, the flaw tolerance of the bolts, and the number of bolts required to prevent horizontal displacement of the core plate assembly assuming both no credit and credit for the aligner pin and bracket assemblies. Section 3 of the report, Inspection Protocol, concludes that no further inspections of the JAF core plate bolts are required during the period of extended operation.

JAF-RPT-12-00009 Rev. 0 is included as attachment 1 and provides justification for performing no further core plate bolt inspections during the period of extended operation.

What We Are Doing Currently

As documented in SEP-RVI-004 Rev. 1, JAF Reactor Vessel Internals (RVI) Inspection Plan, JAF has taken a variance from BWRVIP-25 guidance for Inspection of the core plate bolts. VT-3 exams of the bolting are being performed periodically as an alternative to the required BWRVIP-25 bolt inspections. This deviation will remain in place until December 31, 2015 or until the NRC approves revised BWRVIP guidance, whichever occurs first. Selected portions of SEP-RVI-004 Rev. 1 are included as attachment 2 to this letter.

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Questions concerning this submittal may be addressed to Mr. Kevin Irving, Programs & Components Engineering Manager, at 315-349-6294.

Sincerely,

Chris Adner
Licensing Manager - JAF

CA/jo

Attachments: 1. JAF-RPT-12-00009 Rev. 0, “Proposed Core Plate Bolt Inspection Protocol and Technical Bases.”

2. SEP-RVI-004 Rev. 1, “JAF Reactor Vessel Internals (RVI) Inspection Plan.”

cc:

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**JAFP-12- 0122**

**Attachment 1**

**JAF-RPT-12-00009 Rev. 0, “Proposed Core Plate Bolt Inspection Protocol and Technical Bases”**

**(37 Pages)**

Engineering Report No. JAF-RPT-12-00009 Rev 0
Page 1 of 46

Entergy

**ENTERGY NUCLEAR**
**Engineering Report Cover Sheet**

**Engineering Report Title:**
Proposed Core Plate Bolt Inspection Protocol and Technical Bases

**Engineering Report Type:**

New ☒ Revision ☐ Cancelled ☐ Superseded ☐
Superseded by: ________

**Applicable Site(s)**

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IP1 | ☐ | IP2 | ☐ | IP3 | ☐ | JAF | ☒ | PNPS | ☐ | VY | ☐ | WPO | ☐ |
| ANO1 | ☐ | ANO2 | ☐ | ECH | ☐ | GGNS | ☐ | RBS | ☐ | WF3 | ☐ | PLP | ☐ |

**EC No.** 36003

**Report Origin:** ☐ Entergy ☒ Vendor
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Prepared by: Structural Integrity Associates Date: ________
Responsible Engineer (Print Name/Sign)

Design Verified: R. Casella / R Casella Date: 9/10/12
Design Verifier (if required) (Print Name/Sign)

Reviewed by: N/R [signature] 9/10/12 Date: ________
Reviewer (Print Name/Sign)

Approved by: G. Foster / See AS EC 36003 Date: ________
Supervisor / Manager (Print Name/Sign)

| Revision | Record of Revision |
|---|---|
| 0 | Initial issue. |
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Report No. 1101291.401
Revision 0
Project No. 1101291
September 2012

**Proposed Core Plate Bolt Inspection Protocol and Technical Bases**

*Prepared for:*

James A. Fitzpatrick Nuclear Power Plant – Entergy Nuclear
Lycoming, NY
Contract No. 10340564

*Prepared by:*

Structural Integrity Associates, Inc.
San Jose, California

| | | | |
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| *Prepared by*: | Clark J. Oberembt, P.E. | Date: | 03SEP2012 |
| *Reviewed by*: | Terry J. Herrmann, P.E. | Date: | 03SEP2012 |
| *Approved by*: | Daniel V. Sommerville, P.E. | Date: | 03SEP2012 |

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**REVISION CONTROL SHEET**

Document Number: **1101291.401**

Title: Proposed Core Plate Bolt Inspection Protocol and Technical Bases

Client: James A. Fitzpatrick Nuclear Power Plant – Entergy Nuclear

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| 5.0 | 5-1 – 5-2 | | | |
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## REGISTERED PROFESSIONAL ENGINEER CERTIFICATION

I, Terry J. Herrmann, being a Licensed Professional Engineer Registered in the State of New York, hereby certify that the work in Structural Integrity Associates report 1101291.401 Revision 0 and all underlying calculation packages were prepared with my personal professional knowledge and under my supervisory control and responsibility. This report summarizes the work developed in the underlying calculation packages listed below.

| Calculation Number | Revision | PE Initials |
|---|---|---|
| 1101291.301 | 0 | |
| 1101291.302 | 0 | |
| 1101291.303 | 0 | |
| 1101291.304 | 0 | |
| 1101291.305 | 0 | |
| 1101291.306 | 0 | |


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# 1.0 INTRODUCTION

The James A. Fitzpatrick (JAF) nuclear power plant license renewal commitment number 23 [1, Attachment 1] states that Entergy will either install core plate wedges at JAF prior to the period of extended operation or complete a plant specific analysis to develop and justify a core plate bolt inspection plan. The inspection plan must include acceptance criteria that meet the requirements of BWRVIP-25 [2].

Figure 1-1 illustrates the main components of the core plate bolt assembly.

## 1.1 Background

After cracking was observed in core plate components in two Boiling Water Reactors (BWR's), inspection and evaluation guidelines were developed and presented in BWRVIP-25 [2]. The evaluation documented in BWRVIP-25 showed that most regions of the core plate assembly did not require any inspection. Further, this document summarized the results of a generic core plate stress analysis in which it was shown that the aligner pin and bracket assemblies provide a redundant load path and can support the lateral loading on the core plate assembly without presence of any core plate bolts and that there is margin in the total number of core plate bolts included in the General Electric (GE) core plate designs. Margin was demonstrated even considering the extremely conservative analysis approach in which no credit for friction between the core support plate and core plate was taken and the entire lateral load was assumed to be supported by the core plate bolting acting as cantilever beams. Despite this conservative analysis it was acknowledged that there are plant specific differences between the numbers and dimensions of the core plate bolts, the applied loading, and the type of aligner pin and bracket assemblies. Consequently, BWRVIP-25 [2] included a generic recommendation to either:

1. Inspect the core plate bolts.
2. Install core plate wedges.

The inspection strategies presented in BWRVIP-25 [2] require that either ultrasonic testing (UT) from the top of the bolts or enhanced VT-1 inspection from below the core plate be performed. To date there are no known techniques for performing the UT inspections on the core plate bolts.

BWRVIP-25 [2] also provides guidance that different inspection strategies may be acceptable based on the results of plant specific analysis and also introduced the possibility that additional inspections of the core plate bolts may not be necessary based on existing "good inspection results combined with the good operating experience of BWR bolts and the degree of redundancy of the hold down bolts…" [2, pg. 3-5], or , "For example, if a location for which inspection is required were shown for a specific plant to be solution annealed, a plant-specific evaluation would specify no inspection is required," [2, pg. 3-3]. Review of Table 3-2 of BWRVIP-25 [2] shows that the core plate bolt is the only component in the core plate assembly for which inspection is recommended.

## 1.2 Objective

The objective of the evaluation summarized in this report is to perform a plant specific core plate bolt evaluation for the James A. Fitzpatrick (JAF) nuclear power plant in order to develop and justify a core plate bolt inspection protocol which satisfies the requirements of BWRVIP-25 [2].

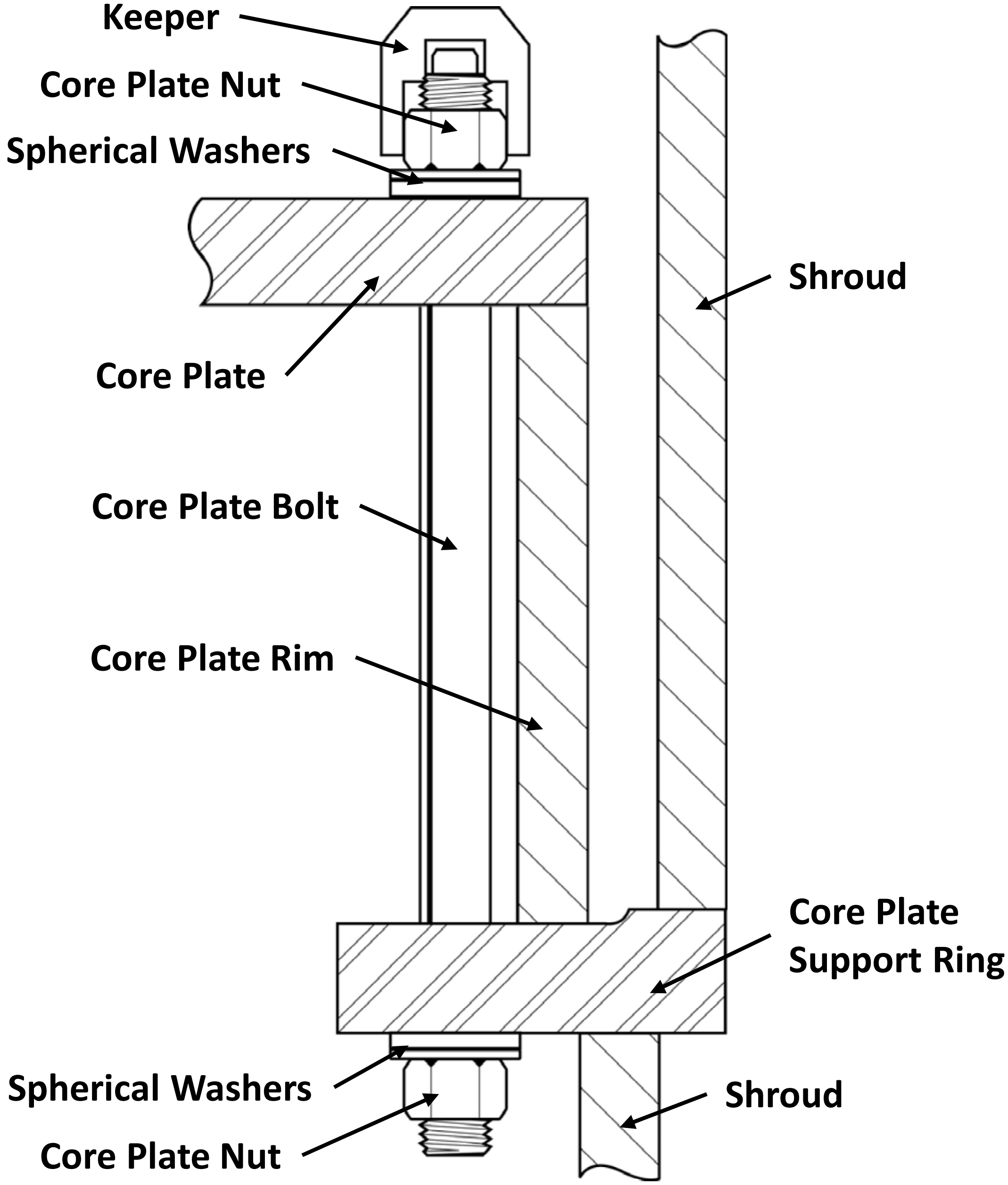



**Figure 1-1: Core Plate Bolt Assembly**

## 2.0 PLANT SPECIFIC ANALYSIS

The JAF plant specific analysis consists of five separate evaluations [3, 4, 5, 6, 7]. The design inputs used were tracked and approved by JAF in a Design Input Request (DIR) throughout the project [8]. These evaluations addressed:

1. The susceptibility of the JAF core plate bolts to known degradation mechanisms [3],
2. The relaxation of bolt preload over 60 years of operation [4],
3. Flaw tolerance of the bolts [5], and
4. The minimum number of bolts required to prevent horizontal displacement of the core plate assembly assuming:
    a. No credit for the aligner pin and bracket assemblies [6], and
    b. Credit for the aligner pin and bracket assemblies [7].

Conservative methods were used for each evaluation, and these conservatisms are compounding. The methodology and results for each of the separate evaluations are summarized in the following subsections.

Failure in this evaluation is generally defined as the loss of all preload. For the fracture mechanics evaluation [5] a "minimum" preload force was determined and used only to identify the point at which the iterative finite element analysis (FEA) was terminated; this was a measure taken to reduce total solution time for each crack configuration. Loss of all preload could result from permanent deformation in the core plate bolts or complete separation of the bolt cross section.

### 2.1 Core Plate Bolt Degradation Susceptibility

The core plate bolt degradation susceptibility evaluation and relevant assumptions are contained in Reference [3]. Known degradation mechanisms affecting BWR internals include:

- Intergranular Stress Corrosion Cracking (IGSCC)
- Irradiation Assisted Stress Corrosion Cracking (IASCC)
- Thermal fatigue (system cycling)
- Flow induced vibration fatigue

Although these mechanisms were considered during preparation of BWRVIP-25 [2], for completeness, each of these degradation mechanisms were addressed in this evaluation as well. A literature review was conducted to identify relevant data, both recent and historical, regarding the susceptibility of Type 304 stainless steel (SS) bolts to IGSCC and IASCC. The material manufacturing process, the service environment and the level of tensile stress were considered. Additionally, a review of relevant operating experience was conducted to ensure that the fleet operating experience was appropriately considered in the evaluation. Susceptibility to thermal and flow induced vibration (FIV) fatigue was assessed by review of the plant design documentation and startup test vibration report.

The core plate bolts were specified to be fabricated from solution heat treated descaled Type 304 SS [9]. Therefore, the material is not considered to be thermally sensitized. The threads were conservatively assumed to be machined. The machining process will impart some level of cold work; however, the purchase specification requires that any components that receive cold work, other than specified pipe bending operations, be solution annealed after cold working [9]. The honing process described in Reference [10] provides a smooth matte finish with little additional cold work.

The JAF water chemistry environment can be evaluated based on historical water chemistry data. The electrochemical corrosion potential (ECP) of stainless steel at the core plate bolt location and reactor water conductivity are of particular interest. Literature supports an IGSCC initiation "threshold" ECP, in the BWR environment, of -230 mV[SHE] in high purity water (i.e. < 0.15μS/cm) [11]. While values of ECP below this threshold are representative of environments which are unlikely to support IGSCC initiation, crack growth can still occur below -230 mV[SHE]. A summary of the historical water chemistry for JAF is provided in Reference [3]. Hydrogen Water Chemistry (HWC) was first implemented in 1989 at JAF which provided a reduction in average conductivity to a level regularly below 0.15μS/cm except for the years 1990, 2009 and 2010. The ECP was significantly improved in 1995; however, the ECP was not reduced to below the -230 mV[SHE] threshold until Noble Metals Chemical Addition (NMCA) was implemented in 1999. Subsequently, JAF has implemented On-line Noble Chemistry (OLNC) in 2011.

The nature of threaded fasteners provides a possible crevice condition that will locally produce more aggressive water chemistry due to the effects of the ECP difference between the exterior of the crevice and the interior of the crevice. However, HWC, which is effective at this location, will greatly reduce this corrosion potential difference driven effect [12]. Additionally, an anti-seize lubricant was used during the installation of the core plate bolts [13]. Anti-seize lubricants are used to provide a barrier between the contacting metal surfaces of fasteners and also the environment. Protecting the metal surfaces from the environment is intended to prevent corrosion and subsequently prevent seizing of the contacting surfaces. The presence of a high purity anti-seize could provide some benefit against IGSCC if it acts as a barrier separating the stainless steel from the environment. The lubricant would be expected to be more likely to remain effective early in life, which is also the time that the environment, based on water chemistry, was most conducive to IGSCC initiation.

The core plate bolts are subject to tensile stress due to preload and potential applied loads from the core plate. The calculated bolt stress is 22,845 psi based on a preload of 19,556 lbf [3]. This represents the initial tensile stress in the bolt due to preload. The stress concentration effect at the root of the threads could result in near yield stresses at these locations at ambient temperature. The effects of relaxation (i.e. loss of preload) are discussed in Section 2.2.

The core plate bolts may be susceptible to IGSCC due to possible cold work, the presence of a significant tensile stress, and an environment, early in plant operation, that would be more supportive of IGSCC. However, the probability of cracking is considered low since the material is not thermally sensitized because it was purchased to a specification requiring solution annealing following cold work, has a smooth surface finish, the environment has been mitigated, and a protective barrier may exist due to the presence of an anti-seize lubricant.

The Reference [14] test results suggest that a “threshold” fluence of $5 \times 10^{20}$ n/cm$^2$ and $2 \times 10^{21}$ n/cm$^2$ for “highly” and “lower” stressed components in the BWR normal water chemistry (NWC) environment, respectively. For components exposed to HWC characterized by a lower ECP, the “threshold” fluence may be approximately $3 \times 10^{21}$ n/cm$^2$ [14]. The core plate bolts can be considered a highly stressed component for this evaluation. During the first 14 years of operation, JAF operated at NWC conditions; therefore, the corresponding fluence “threshold” value is 5 x $10^{20}$ n/$cm^2$. This value for fluence "threshold" is also supported by other literature as discussed in Reference [3].

The bounding fluence values from Reference [15] indicate that the fluence "threshold" will not be exceeded prior to 54 EFPY. Additionally, after the introduction of HWC in 1989 and NMCA in 1999, the fluence "threshold" value would likely be much higher due to the associated reduction in stainless steel ECP. Consequently, the JAF core plate bolts are not considered to be susceptible to IASCC.

FIV was not identified as an issue for the core plate bolts in the JAF Updated Final Safety Analysis Report (UFSAR) [16, Section 3.3.6] or in the startup vibration test report (reviewed at site) [8]. Additionally, fatigue is not identified in BWRVIP-25 [2] as a degradation mechanism of concern for the core plate bolts. As long as the bolted joint has sufficient preload to resist the normal operating ΔP across the core plate then there will be no leakage flow passing through the bolt hole which could cause FIV and consequent fretting wear or fatigue accumulation. Bolt preload is further discussed in Section 2.2.

Due to the low probability of significant fatigue loading/cycling and the lack of evidence that FIV is an issue at JAF, thermal and FIV induced fatigue are not considered to be relevant degradation mechanisms for the core plate bolts.

Many US plants, including JAF, have inspected their core plate bolts using visual inspections from above the bolts, and no obvious signs of degradation have been found [8, 17, 18, 19]. A summary of the JAF inspections to date is provided in Table 2-1. While these examinations would not have been able to detect cracking in the threaded regions of the bolting, cracked keepers, rotated bolts, missing bolts or fretting wear due to bypass leakage caused by gross failures over the past 30+ years of operation would have been observable. No obvious signs of degradation have been observed. Additionally, as stated in Reference [18], and supported by BWRVIP-25 [2], no failures of core plate bolts have been observed in the US BWR fleet, which suggests that operating experience has been good to date.

## 2.2 Core Plate Bolt Preload Relaxation

The core plate bolt preload relaxation evaluation and relevant assumptions are contained in Reference [4]. A literature review was conducted to identify information regarding the relevant mechanisms of preload reduction and the associated analysis methods. The following mechanisms were identified as relevant to the JAF core plate bolts:

- Thermal Relaxation
- Stress Relaxation
- Radiation Relaxation

In this evaluation the term "thermal relaxation" will be used to describe the loss of preload associated with thermal effects on temperature dependent material properties. These effects will contribute to the reduction in preload at operating temperatures.

Thermal relaxation occurs due to thermal effects on temperature dependent material properties and can result in both a temporary (i.e. recoverable) reduction in preload due to a change in the modulus of elasticity and a permanent loss of preload due to a change in the yield strength and consequent yielding of the material at an elevated temperature. For this evaluation, the elevated temperature was taken as the operating temperature. Thermal relaxation was evaluated using representative stress-strain curves for Type 304 SS by identifying the strain due to the preload stress at room temperature and determining the equivalent stress for constant strain on an elevated temperature curve representing the operating temperature.

From Reference [4, Figure 5-1], the approximate preload stress, after thermal relaxation, was determined to be 17,500 psi. This value corresponds to a 23.4% reduction in preload due to thermal relaxation, and accounts for both the reduction in modulus and the effect of yielding.

Stress relaxation occurs due to a creep mechanism in the material. Stress relaxation was evaluated based on the temperature, stress, and time of operation. The potential relaxation effects of both primary and secondary creep were assessed for Type 304 SS, through evaluation of available information. Creep deformation of metals occurs in three stages: primary creep, secondary creep and tertiary creep. For the core plate bolts, primary creep is most relevant, and further stages of creep (i.e. secondary and tertiary) are considered negligible. Secondary (steady state) creep is typically considered a high temperature phenomenon, and the temperatures in an operating BWR are generally regarded to be outside of the secondary creep regime. Since secondary creep is negligible, tertiary creep is also negligible. However, at lower temperatures, stress relaxation does occur, and is the result of primary creep.

After thermal relaxation, the remaining preload stress is 17,500 psi. Taking 17,500 psi as the initial preload which will be affected by primary creep and considering the average curve in Reference [4, Figure 5-2] results in a relaxation stress of approximately 1,200 psi. This value corresponds to a 6.8% additional reduction in preload due to stress relaxation. In this evaluation, the thermal relaxation occurs over a short time scale (first heat-up); therefore, the primary creep affects the preload after thermal relaxation has occurred. Further, since this evaluation considers primary creep for all core plate bolts it is more appropriate to evaluate the average primary creep relaxation and apply this to all core plate bolts than to assume the maximum creep relaxation occurs for all core plate bolts.

Radiation relaxation, also referred to as irradiation creep, is a fluence (time) dependent deformation process which affects stainless steels in the light water reactor (LWR) environment. Fluence for energy > 0.1 MeV is considered for the evaluation of radiation relaxation. This is consistent with the approach in Reference [20], and is conservative compared to the use of fluence values for energy > 1.0 MeV. The maximum value of average fluence, along the loaded length of the core plate bolts, for all bolts around the core plate, is used to calculate the relaxation along each bolt. Therefore, this is bounding for all other azimuthal locations. Radiation relaxation is evaluated utilizing data from three different sources as discussed in Reference [4] and by comparing the results to develop a reasonable and bounding loss of preload.

The results of the three separate resources used to evaluate radiation relaxation in the 304 SS core plate bolts agreed well with each other. The range of average preload stress reduction due to radiation relaxation is approximately 3-8%. For this evaluation, the value of 8% was used.

The results for the thermal, stress and radiation relaxation evaluations are summarized in Table 2-2. The effects of the three different relaxation mechanisms are such that they occur in a sequential order. Thermal relaxation happens when the bolts first reach operating temperature, then stress relaxation occurs over a short period of time at temperature (less than 100 hours) [20], and radiation relaxation occurs over an extended period of time (many years). Therefore, the total equivalent percent reduction in preload is calculated as follows:

$$\text{Total \%} = 1 – (1 – 0.234) * (1 – 0.068) * (1 – 0.08) = 34.3\%$$

Based on an initial preload of 19,556 lbf, the remaining preload in each bolt at 54 EFPY is 12,844 lbf.

## 2.3 Core Plate Bolt Fracture Mechanics

The core plate bolt fracture mechanics evaluation and relevant assumptions are contained in Reference [5]. A linear elastic fracture mechanics evaluation (LEFM) was performed to evaluate the flaw tolerance of the JAF core plate bolt design. The LEFM evaluation considered various postulated crack locations and orientations, consistent with published data for IGSCC in threaded fasteners, to assess the flaw tolerance of the bolts. Further, the results of the LEFM evaluation were benchmarked against existing LEFM solutions for simpler configurations. The methodology selected for this evaluation was intended to address the limitations of previous evaluations performed for JAF and incorporate information presented in the open literature subsequent to the previous evaluations as described in detail in Reference [5]. The general methodology used for this evaluation is as follows:

1. Use 3-D FEA in order to simulate contact between the nut and bolt and to perform finite element (FE) linear elastic fracture mechanics (LEFM) evaluations of single and multiple crack cases of various crack configurations. The various crack cases considered are shown in Table 2-3. This method enables consideration of crack front turning, and the effects of non-uniform crack front stress intensity factor distribution on crack growth.
2. Use elastic plastic FEA to quantify compliance induced relaxation as the crack grows deeper into the cross-section of the core plate bolt.
3. Use BWRVIP-14-A [21] crack growth rate (CGR) correlations for K-dependent and environment dependent crack growth rates in the stainless steel core plate bolting.
    a. This CGR correlation provides crack growth rates representative of a 95% confidence interval “upper bound” on the data set used to develop the correlations.
    b. Plant specific water chemistry data is used for periods of prior operation and expected plant values are used for future operation.
    c. The FE LEFM results are used to provide the K versus crack depth relationships for each crack case considered.

4. Determine the residual life of a core plate bolt for various crack cases considering different assumed crack initiation times.
    a. Data presented in the open literature are used to identify crack locations, number of cracks, and crack shapes considered in the evaluations.
    b. Crack growth simulations are terminated once the retained preload becomes less than the normal operation applied loading on each bolt. At this time it is assumed that leakage flow may develop since the core plate assembly can lift off the core support ring. Since this condition is inconsistent with the design basis of the assembly it is not considered acceptable. Further, if there is zero net normal force between the core plate assembly and core support ring then there is no friction force available to resist the lateral loading on the core plate assembly caused by a seismic event. This would enable lateral core plate assembly movement which could impede control rod insertion which is also unacceptable.

The core plate bolt and nut were modeled in ANSYS [22] using 3-dimensional structural solid elements (SOLID185) and contact between the nut and bolt surfaces was simulated with contact elements (CONTA174 and TARGE170). A quarter-symmetry model was used for all crack cases to reduce model size. Symmetric boundary conditions were applied to the two cut planes. The top nut (i.e. the nut in contact with the top of the core plate) was explicitly modeled. The length of bolt was modeled to the interface of the bottom of the core plate support ring and the bottom nut. The bottom nut was simulated by fixing the bottom of the model in the axial direction. This treatment ensures that the proper axial displacement was considered in the FEA. Figure 2-1 and Figure 2-2 show the FEM. Figure 2-3 identifies the boundary conditions applied to the model. To determine the applied displacement on the bottom surface of the core plate nut, a preload force is applied to the model. The effects of radiation relaxation are conservatively ignored in the fracture mechanics evaluation [5]. Figure 2-4 shows a stress contour plot of the first principal stress at the threads. Notice that the root of the first engaged thread has the highest principal stress. The average axial displacement at the nut bottom surface was determined, and an equal uniform displacement was applied to the uncracked models to account for the bolt preload.

Generation of the cracked mesh, calculation of the fracture mechanics parameters, and incremental advance of the crack front was performed using the Zencrack program developed by Zentech [23]. Zencrack uses the magnitude and direction of maximum energy release rate for fracture mechanics calculations. Zencrack determines the energy release rate by using nodal displacements near the crack tip to calculate stress intensity factors, followed by conversion to energy release rate. In this method, the crack tip displacements and nodal displacements on the crack face near the crack front were used for calculating stress intensity factors. The crack growth direction was determined by the maximum energy release rate direction.

A "minimum" preload force was determined and used only to identify the point at which the iterative FEA was terminated; this was a measure taken to reduce total solution time for each crack configuration. The minimum bolt preload used in the fracture mechanics evaluation is the force below which the normal operation applied loading results in zero friction force between the core plate assembly and core support ring. To determine this preload value, only the reactor internal pressure difference (RIPD) across the core plate and the deadweight forces were considered. By using only these loads the fracture mechanics solutions inherently bound the case where larger residual preload would be required (i.e. a thicker remaining ligament would be necessary). In this case a residual life can be read from Figure 5-1 for any combination of initial or final flaw sizes.

Several different crack orientations and initiation scenarios have been analyzed. The crack shape and location were defined to be consistent with published data for IGSCC in threaded fasteners. Further, the results of this study have been benchmarked against existing LEFM solutions for simpler configurations. The results of this evaluation are consistent with related information in the literature and provide additional insight for complex crack orientations and multiple crack cases. Both single and multiple circumferential flaws have been analyzed with initiation times ranging from plant startup to 30 years after startup. Time-dependent water chemistry data for reactor conductivity and ECP were considered. The most important factor affecting the flaw tolerance of the JAF core plate bolting was the assumption used for crack initiation time. If crack initiation is assumed to occur in the first 20 years of plant operation (prior to 1995) then the core plate bolt exhibits little flaw tolerance. Conversely, if crack initiation is assumed to occur after the first 20 years of plant operation (subsequent to 1995) then the core plate bolt exhibits substantially improved flaw tolerance. If single or multiple IGSCC flaws initiated in the JAF core plate bolting subsequent to 1995 then the residual life of the core plate bolting is on the order of 40-50 years, as shown in Figure 2-5. Considering desired operation through 60 years, these results show adequate flaw tolerance of the core plate bolting through the period of extended operation if IGSCC is assumed to initiate after the first 20 years of operation.

The omission of radiation relaxation from the LEFM evaluation provided an upper bound driving force on the bolts when considering the effects of preload relaxation. The 95$^{th}$ percentile crack growth rates were used rather than the "best estimate" crack growth rates for all postulated flaws. A fully circumferential flaw was used rather than one or more discrete thumbnail flaws; resulting in a bounding flaw orientation. The thread form tolerance resulting in the maximum stress state was evaluated, rather than nominal dimensions. Because of these compounding conservatisms, the results of Reference [5] are considered to be a bounding assessment of the flaw tolerance of the core plate bolts.

### 2.4 Minimum Required Number of Core Plate Bolts

The minimum required numbers of core plate bolts evaluations and relevant assumptions are contained in References [6, 7]. If sufficient horizontal displacement of the core plate were to occur, the resulting misalignment could potentially prevent the control rods from inserting properly. Simplified calculations were performed to calculate the minimum number of required core plate bolts needed to ensure that horizontal displacement of the core plate would not occur during both Level A/B and Level C/D events. Two separate evaluations were performed. The first evaluation conservatively ignored the contribution of the aligner pin and bracket assemblies, and calculated the minimum number of bolts needed to ensure that the frictional force between the core plate and the support ring was sufficient to resist applied horizontal forces [6]. The second evaluation considered the load carrying capacity of the aligner pin and bracket assemblies, which provide an alternate load path to limit lateral motion of the core plate [7]. In both cases, the remaining core plate bolts are assumed to be evenly distributed around the core plate.

Adequacy of the core plate bolting design would have been required to be shown in the original design stress analyses for JAF. The plant specific analysis summarized in this report is not intended to be a Section III stress analysis; rather, it is essentially a flaw tolerance evaluation of the core plate bolting and core plate assembly. Accordingly, none of the present work invalidates the original stress analysis. Therefore, the original stress analysis performed for the core plate bolting and assembly is considered to remain applicable through 60 years of operation. Note that the design considerations for the original bolting design would have required that the cumulative vertical force applied to the core plate assembly by the preload in the core plate bolts would have been greater than the vertical loading contributed by buoyancy, reactor internal pressure differences, and seismic loads. This means that there would have been a net vertical load and reaction force between the core support ring and the core plate assembly. Since the acceptance criterion for this plant specific evaluation is that there remains sufficient normal force between the core plate and core support ring such that the resulting friction force prevents lateral movement of the core plate assembly, it inherently requires that the cumulative remaining preload (i.e. total cumulative preload in the remaining uncracked bolts) exceeds the vertical force applied to the core plate assembly. Consequently, the original stress analysis that would consider the preload at time equal to zero and at end of life would remain applicable for the present evaluation. Additionally, the use of spherical washers in the bolted joint helps to ensure loading remains axial and reduces the potential for bending induced loading in the unlikely event that multiple bolts failed in close proximity to each other creating an eccentric loading condition.

### *2.4.1 Without Consideration of Aligner Pins*

The core plate to core plate support ring bolted joint was evaluated as a static friction-type joint when considering horizontal displacement. No credit was taken for shear in the bolts due to mechanical contact between the bolts and the core plate. The amount of friction at the joint interface is proportional to the resultant normal force and the coefficient of friction. A conservative coefficient of friction value of 0.2 was used. The value of 0.2 is also consistent with the coefficient of static friction used in Reference [18, pg. 12], which also states that an experimentally determined coefficient closer to 0.5 was determined by GE Hitachi Nuclear Energy (GEH). Bounding loads are used for Service Levels A/B (Normal/Upset) and C/D (Emergency/Faulted). Figure 2-6 illustrates a free-body diagram of the core plate bolt to support plate joint. Applied forces acting on the friction joint include:

- Bolt preload force, including the effects of relaxation ($F_P$)
- Dead weight force, including the effects of buoyancy ($F_{DW}$)
- Core plate ΔP force, including the effects of bypass flow ($F_{\Delta P}$)
- Seismic forces, due to vertical and horizontal accelerations ($F_{SY}$ and $F_{SX}$)

The reaction forces acting on the friction joint include:

- Normal force, vertical ($F_N$)
- Static friction force, horizontal ($\mu F_N$)

The normal force is the reaction force equal and opposite to the sum of the applied vertical forces. The total preload force was calculated by multiplying the number of remaining core plate bolts by the preload force at 54 EFPY. The number of remaining core plate bolts is the primary variable which affects the normal force (i.e. all other forces are fixed). The number of remaining core plate bolts was iterated until the static friction force ($\mu F_N$) was just greater than the applied horizontal seismic force ($F_{SX}$) for Service Levels A/B and C/D. The Service Level C/D seismic accelerations produced the bounding horizontal seismic force ($F_{SX}$); thus, providing the minimum required number of bolts. The minimum required number of bolts at 54 EFPY, without considering the aligner pins, is 56 bolts. In other words, there are 16 more bolts in the core plate assembly design than are required to prevent lateral displacement of the core plate assembly during a Level C/D seismic event. The results of the Reference [6] evaluation are summarized in Table 2-4.

### *2.4.2 With Consideration of Aligner Pins*

The core plate aligner pin and bracket assemblies provide an additional, redundant, lateral support for the core plate. Figure 2-7 provides a general view of the aligner pin and bracket assembly as analyzed. If these assemblies are considered then a more accurate calculation of the number of core plate bolts required to prevent lateral displacement of the core plate assembly can be performed. Consideration of these assemblies results in fewer required core plate bolts.

Since the design of the aligner pin and bracket assemblies allow for a gap between the aligner pin and the core support ring it is possible that the core plate assembly would slide horizontally enough to close the gap before the aligner pin and bracket assembly were available to provide a reaction force against the applied seismic load. In this case a dynamic load exists; thus, the static methods described in Section 2.4.1 above are not adequate for this calculation. The potential for an impact loading against the aligner pin was accounted for by using an energy method which considers the kinetic energy of the core plate assembly, the elastic deformation of the aligner pin and bracket assembly, and energy lost by friction between the core plate rim and core support ring. Although plastic deformation could also occur, using a linear-elastic approach is conservative since it only considers energy absorbed up to the yield limit. This approach requires two criteria to be met:

1. All stresses must remain below the yield stress, Sy, of the material. This justifies the use of the elastic equations for spring energy.
2. ASME Code allowable stress criteria must be met for the aligner pin and bracket assemblies and AWS Code allowable stress criteria must be met for the welds. The applicable stress limits were conservatively applied to both Service Level A/B and Service Level C/D conditions. Service Level C/D in actuality has higher stress limits than for Service Level A/B and allows gross structural deformation, i.e., plastic analysis allowed by NB-3228, as long as the reactor can be brought to a cold shutdown condition.

Considering the initial gap between the aligner pin and the core support ring, the core plate assembly may accelerate from rest until the gap is closed. The aligner pin and bracket assembly will then absorb energy from the impact loading contributed by the contact between the core plate assembly and the core support ring (see Figure 2-8). The seismic load is the only relevant horizontal load for the core plate assembly; therefore, this was the only horizontal load considered in this analysis. Assuming the core plate starts at rest, the change in kinetic energy of the system was calculated. Using the work-energy principle, the change in kinetic energy of the system equals the work performed on the system. The aligner pin and bracket assembly was treated as an elastic spring with a determined stiffness. In addition to the stiffness of the aligner pin and bracket assembly, the friction force acting between the core plate assembly and the core support plate, contributed by the normal force provided by the core plate bolts, acts to resist the horizontal seismic force.

The energy of the core plate due to the seismic force must be absorbed by the friction at the core plate to core plate support ring (due to normal force) and the deformation of the bracket assembly. Considering the required stress limits discussed above, the displacement of the bracket assembly available to counteract the kinetic energy of the core plate can be calculated. The remaining horizontal force must be counteracted by the friction force at the core plate to core plate support ring interface. Similarly to the methods described in Section 2.4.1 above, the minimum required number of core plate bolts can be determined for Service Levels A/B and C/D.

Due to the orientation of the four aligner pin assemblies on the core plate rim, more than one aligner pin assembly will be loaded regardless of the direction of the seismic forces. For this analysis, it was conservatively assumed that only one aligner pin was in contact and was in pure compression. In this scenario, two additional aligner pins would be in shear; however, the shear strength of the pins was conservatively neglected here for simplicity. Elastic allowable stress limits were used in this evaluation; whereas, for the Level C/D condition, limiting strain in the aligner pin and bracket assembly to the elastic regime is not required (since following a Level D event, there is no expectation that the core plate assembly will need to be removed and reinstalled without significant inspections, repairs, and replacements). Consequently a plastic analysis could have been performed in which the acceptance criterion was rupture of the load carrying members in the aligner pin and bracket assembly. Consideration of plasticity and the associated increased strain energy capacity of the assembly would be expected to result in fewer required core plate bolts than as shown in Table 2-5.

It is important to note that the calculations described above assumed a worst case initial gap condition of 0.030 inches between the aligner pin and core support ring, as shown in Figure 2-8. Since the nominal design condition includes a 0.015 inch gap and since it is equally as probable for there to be a 0.000 inch gap as it is for there to be a 0.030 inch gap, additional calculations are performed to present the range of core plate bolts required to prevent lateral motion of the core plate assembly when the range of initial gap distance is considered. Further, the calculation assumes only one aligner pin and bracket assembly support the applied load. Additional insight can be obtained if two aligner pin and bracket assemblies are assumed to support the lateral load. To perform these sensitivity cases the gap size and the allowable equivalent force (proportional to the number of aligner pins) were varied. Several different cross sections were analyzed as shown in Figure 2-9.

The Service Level C/D seismic accelerations produced the bounding horizontal seismic force ($F_{SX}$). The maximum allowable gap between the aligner pin and bracket (based on tolerance specifications) combined with the limiting Level C/D conditions resulted in the highest number of required bolts at 48 bolts. The results of the sensitivity evaluation performed for the assumed gap between the aligner pin and bracket assembly and the core support ring, showed that if zero gap was assumed, the bounding required number of bolts could be as low as 16. The results of the Reference [7] evaluation are summarized in Table 2-5.

**Table 2-1: JAF Core Plate Bolt Inspection Summary**

| Outage | No. of Bolts | Method | Results |
|---|---|---|---|
| RO11 | 20 | VT-1 | No indications requiring evaluation |
| RO13 | 72 | VT-3 | No indications requiring evaluation |
| RO18 | 33 | VT-1 | No indications requiring evaluation |

**Table 2-2: Summary of Preload Relaxation Results**

| Mechanism | Reduction in Preload | Remaining Preload (lbf) |
|---|---|---|
| Thermal Relaxation | 23.4% | 14980 |
| Stress Relaxation | 6.8% | 13961 |
| Radiation Relaxation | 8.0% | 12844 |
| | | |
| **Total at 54 EFPY** | **34.3%** | **12844** |

**Table 2-3: Crack Cases Considered in the Fracture Mechanics Evaluation**

<table>
<tr><th>Name</th><th>Crack Locations</th><th>Initial Crack Orientation</th><th>Shape</th></tr>
<tr><td>Single</td><td>1 crack at high stressed thread</td><td rowspan="3">Horizontal at root of thread</td><td>Fully circumferential</td></tr>
<tr><td>Adj</td><td>2 cracks, one at highest stressed thread and the other at the adjacent thread</td><td>Fully circumferential</td></tr>
<tr><td>Far</td><td>2 cracks, one at highest stressed thread and the other at the thread furthest away</td><td>Fully circumferential</td></tr>
<tr><td>Single-Max</td><td>1 crack at high stressed thread</td><td>Normal to the direction of the maximum principal stress location</td><td>Fully circumferential</td></tr>
<tr><td>Thumbnail</td><td>1 crack at high stressed thread</td><td>Horizontal at root of thread</td><td>Semi-circular</td></tr>
</table>

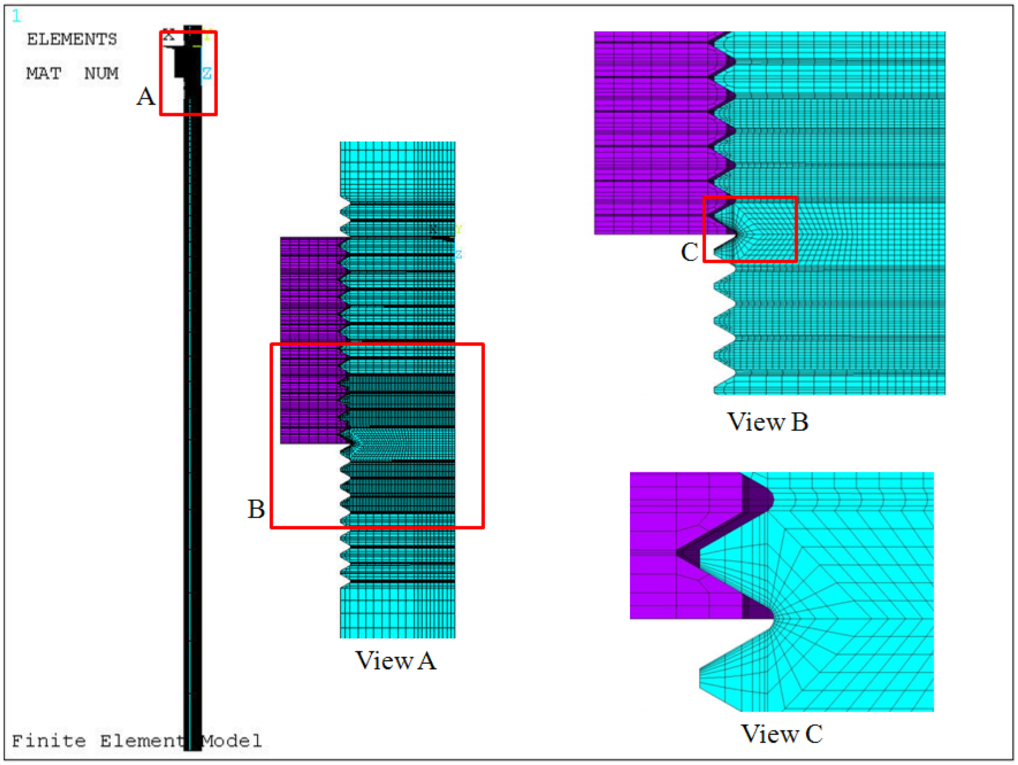
**Table 2-4: Minimum Required Number of Bolts, Without Consideration of Aligner Pins**

| Service Level | No. of Bolts | Friction Force (lbf) | Horizontal Force (lbf) |
|---|---|---|---|
| A/B | 72 | 135759 | 65250 |
| | 45 | 66402 | |
| C/D | 72 | 129311 | 87000 |
| | 56 | 88210 | |

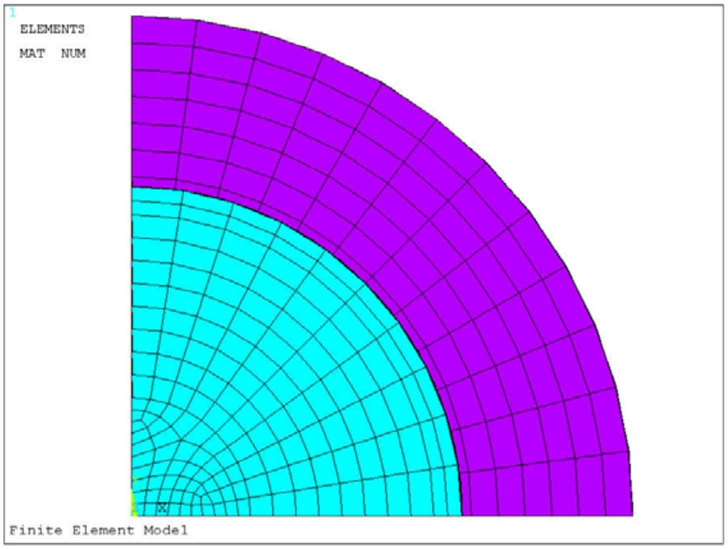
**Table 2-5: Minimum Required Number of Bolts, With Consideration of Aligner Pins**

| | # of Brackets Supporting Load | Initial Gap (in) | | |
|---|---|---|---|---|
| | | 0.03 | 0.015 | 0 |
| **Service Level A/B** | **1** | 39 | 34 | 14 |
| | **2** | 32 | 26 | 7 |
| **Service Level C/D** | **1** | 48 | 43 | 16 |
| | **2** | 40 | 33 | 10 |

Note: The initial gap value represents the assumed gap between the aligner pin and the core support ring as defined in Reference [7].

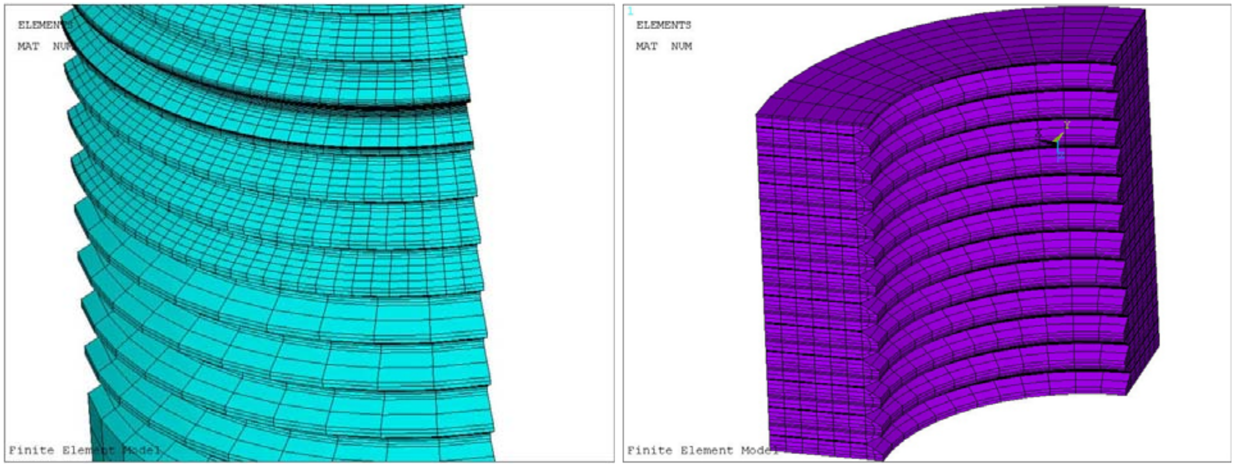



(Side View)




(Top View)

**Figure 2-1: 3-D Finite Element Model for the Fracture Mechanics Evaluation**




(Bolt) (Nut)

**Figure 2-2: 3-D Finite Element Model, Bolt and Nut Thread Detail View**

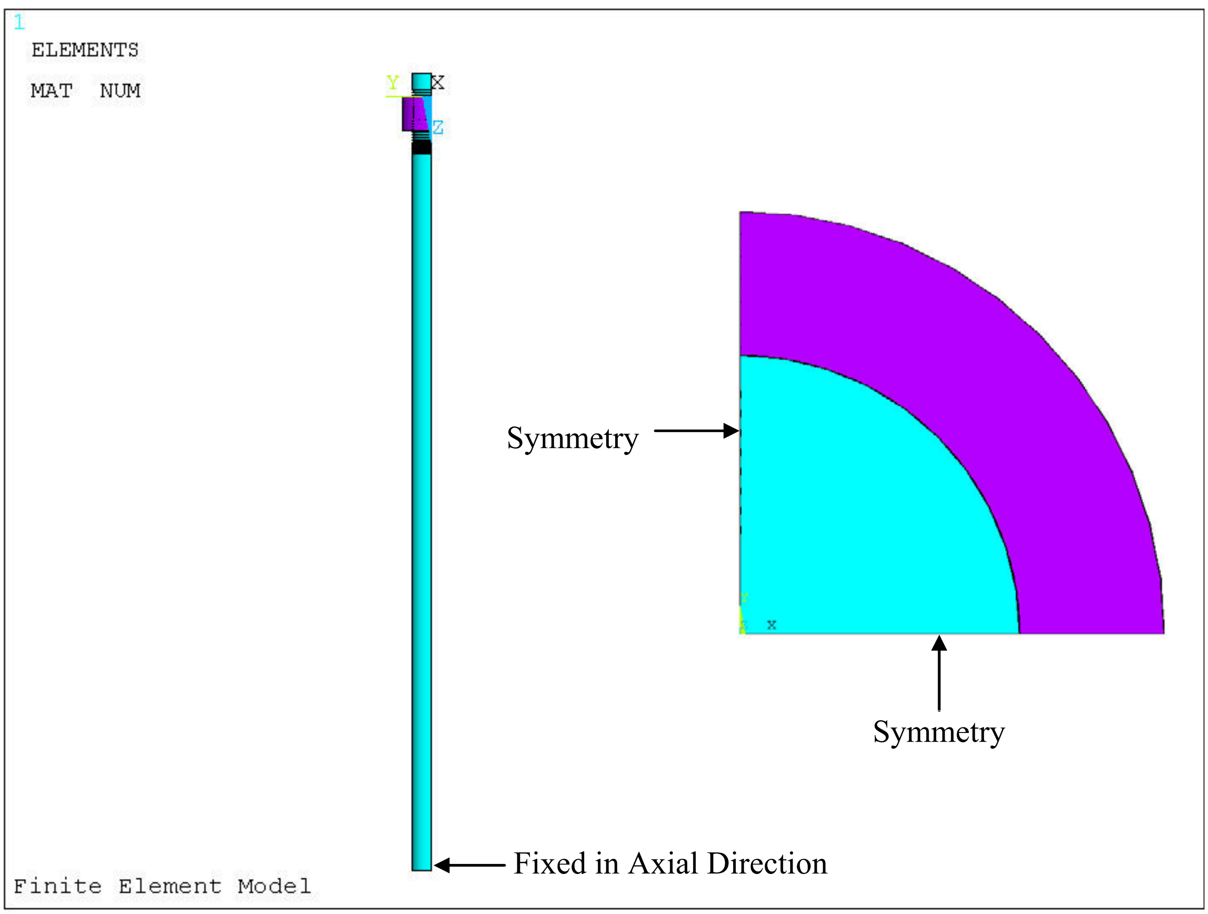



**Figure 2-3: Boundary Conditions Applied to Model**

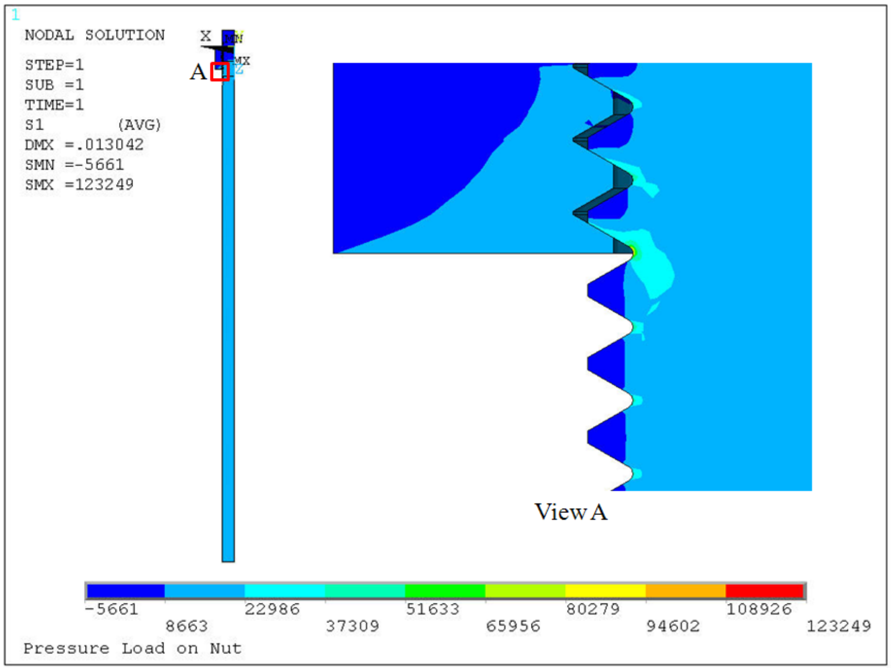



**Figure 2-4: First Principal Stress for Preload Analysis**

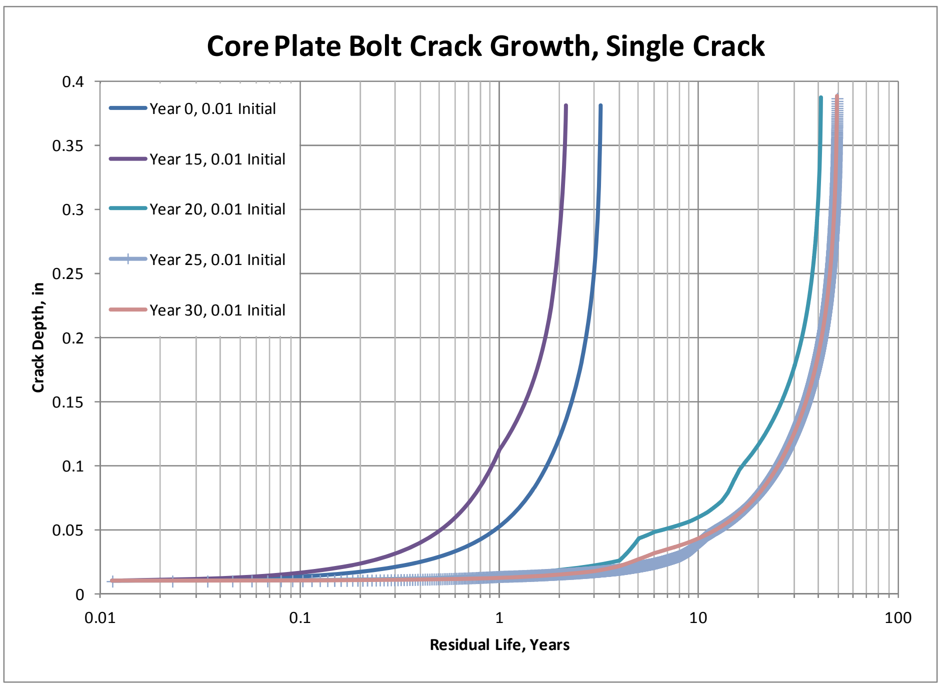



**Figure 2-5: Crack Growth Curves - Single Crack Case, Various Initiation Times**


Structural Integrity Associates, Inc.®

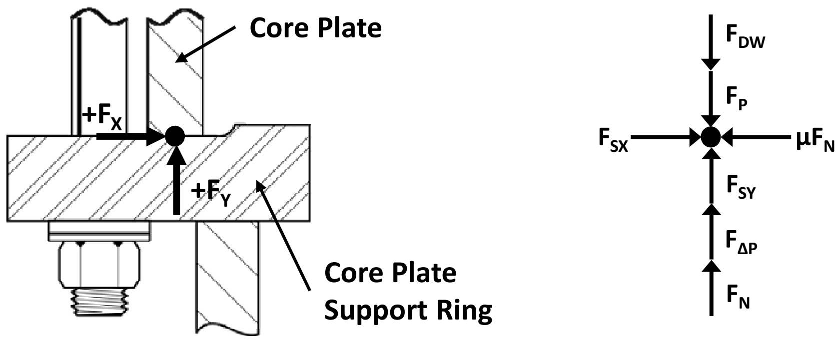



**Figure 2-6: Core Plate Bolt Free-body Diagram**

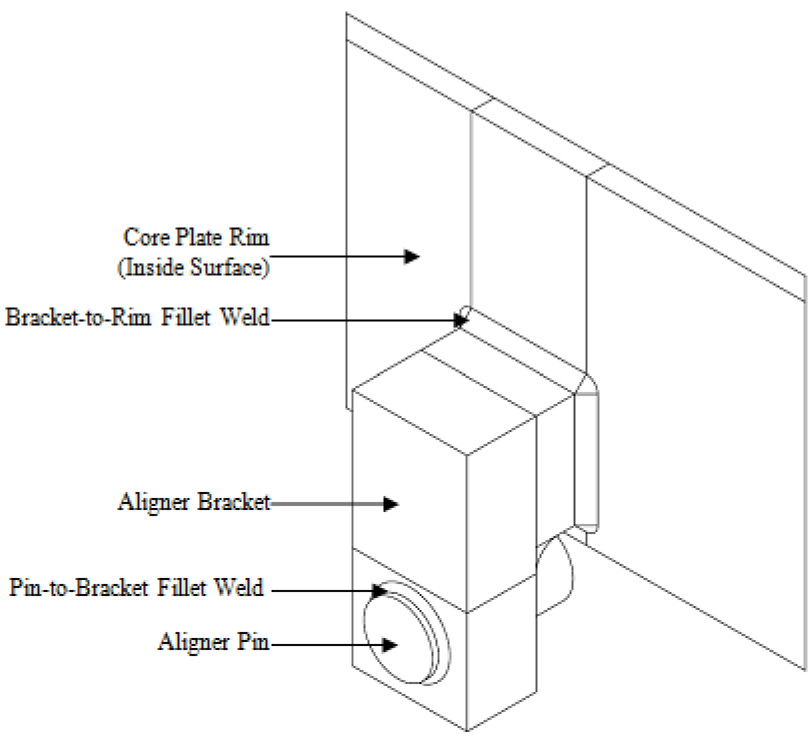



**Figure 2-7: General View of Aligner Pin and Bracket Assembly**

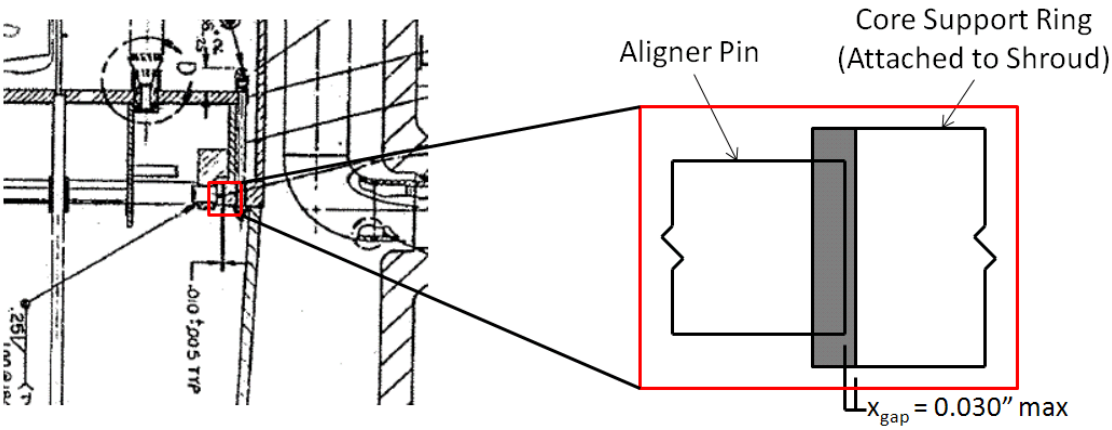



**Figure 2-8: Aligner Pin and Core Support Ring Interface**

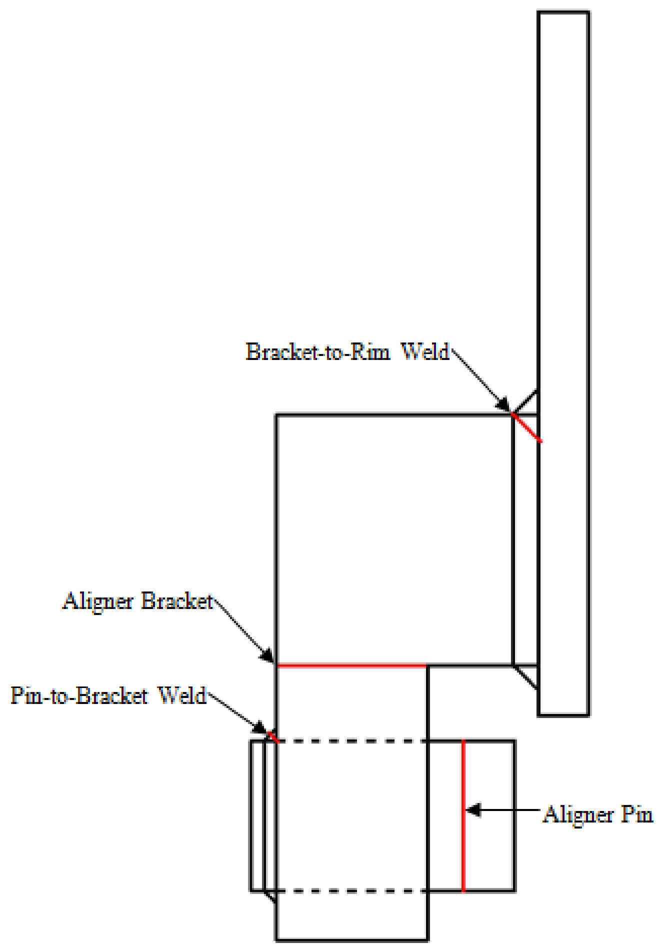



**Figure 2-9: Aligner Pin Assembly Cross Sections Analyzed**

## 3.0 INSPECTION PROTOCOL

The recommendations for a core plate bolt inspection protocol are contained in Reference [24]. As shown in Table 2-1, there have been no obvious signs of degradation, such as cracked keepers, rotated bolts, missing bolts, or fretting wear due to bypass leakage, in the 3 previous visual inspections, including the baseline VT-3 inspection of all 72 core plate bolts. The JAF core plate bolts are judged to have a low susceptibility to IGSCC due to the material and manufacturing specification requirements and the coating applied at installation [3]. IGSCC cracking in the core plate bolts is unlikely, and, furthermore, simultaneous cracking in multiple bolts is even less likely, due to the random nature of the parameters that influence crack initiation times. Review of water chemistry suggests that if IGSCC initiation were to occur, it would be more likely to occur early in plant life when the water chemistry was most conducive to IGSCC [3]. If an IGSCC flaw were to have initiated early in plant life, failure (i.e. complete loss of preload) would be expected to have occurred within a few years and signs of degradation (e.g. missing bolts, fretting wear or rotation due to bypass leakage flow, etc.) should have been observed during previous visual inspections. No signs of degradation have been observed during previous visual inspections at JAF. Additionally, no failed bolting has been observed in any U.S. BWR [18]. Since U.S. BWR core plate bolt design, reactor operation, and environment are similar, the absence of fleet experience of cracking is a good indicator of resistance to degradation in general.

Since 1995 JAF water chemistry is essentially mitigating which suggests that IGSCC initiation will not occur since that time and into the future as long as effective HWC and NMCA/OLNC continues. In the unlikely event that a flaw were to have initiated later in plant life, the bolts are much more flaw tolerant due to favorable water chemistry and the flaw would not be expected to grow to a size which would result in failure of the bolt during the period of extended operation.

The JAF core plate bolt design provides for at least 22% excess capacity (number of bolts required) when considering the relaxation of bolt preload over the 60 year life of the plant, limiting Level C/D load conditions, a conservative coefficient of friction, and not accounting for the aligner pin and bracket assemblies [6]. If credit for the aligner pin and bracket assemblies were taken, the margin would increase to at least 33% [7]. Even if 16 (or potentially more) of the existing 72 bolts exhibited IGSCC and failure in the period of extended operation, the joint would retain sufficient bolting capacity to prevent lateral movement of the core plate assembly. This would ensure the ability to insert the control rod drives (CRDs) and safely shut down the plant in a design basis seismic event.

GE test data shows that the CRDs can be inserted with core plate misalignment on the order of 0.5 inches or more [25]; whereas, the present analyses [3, 4, 5, 6, 7] did not allow any displacement (with the exception of the small elastic displacement considered in the aligner pin and bracket assembly on the order of thousands of an inch). For the core plate assembly to displace on the order of 0.5 inches, the assembly would have to experience substantial plastic deformation which would absorb significant energy. Therefore, there is further inherent margin in the system's ability to ensure CRD insertion which is also not being credited.

Consequently, considering the conservative evaluation used it can be reasonably concluded that the core plate bolts have a low susceptibility to IGSCC and are flaw tolerant. Further, the core plate assembly bolted joint design has demonstrated that the design includes more bolts than are necessary to prevent lateral movement of the core plate assembly, and the core plate assembly includes redundant load paths through the aligner pins and brackets. Finally, multiple visual inspections, including a 100% baseline inspection of the bolts, have been performed which identified no signs of degradation. The observed lack of degradation is consistent with industry-wide experience [18].

For these reasons, no further inspections are required for the JAF core plate bolts during the period of extended operation.

Additionally, this inspection protocol is supported by BWRVIP-25 [2, Section 3.2]. This section states that there may be plant-specific situations, such as required inspection locations that are shown to have been solution annealed, where a plant-specific evaluation would specify no inspection is required. Currently the core plate bolts are the only required inspection location per BWRVIP-25 [2], and the JAF core plate bolts were procured to a purchase specification requiring solution annealing after cold working processes [9].

## 4.0 CONCLUSIONS

A plant specific analysis was performed to evaluate the susceptibility of the JAF core plate bolts to known degradation mechanisms, calculate the relaxation of bolt preload over 60 years of operation, evaluate the flaw tolerance of the bolts, and calculate the minimum number of bolts required to prevent horizontal displacement. Conservative methods were used for each evaluation, and these conservatisms are compounding. This plant specific analysis supports the following conclusions:

- The JAF core plate bolts have a low susceptibility to IGSCC, and initiation is unlikely based on the material and manufacturing specification requirements.
- The core plate bolts are not considered susceptible to IASCC since the expected fluence at the core plate bolt location is below the relevant "threshold" value for IASCC considering the material type and water chemistry.
- The core plate bolts are not considered susceptible to degradation by thermal fatigue or FIV due to the absence of sufficient fatigue loading and cycles and the lack of evidence of FIV following the startup vibration testing.
- If IGSCC initiation had occurred early in plant life when plant water chemistry was most conducive of IGSCC, failures would be expected to have occurred within a few years of initiation due to very high crack growth rates.
- If single or multiple IGSCC flaws initiated in the JAF core plate bolting subsequent to 1995 then the residual life of the core plate bolting is on the order of 40-50 years.
- The minimum number of core plate bolts required to ensure no relative horizontal displacement of the core plate under bounding Service Level C/D seismic loading and without consideration of the aligner pins is 56 out of the original 72 bolts. Therefore, the JAF core plate design provides at least 22% excess number of bolts, even when considering the relaxation of bolt preload over the 60 year plant life; thus, ensuring the ability to insert the control rod drives (CRDs) and safely shut down the plant in a design basis seismic event. This excess capacity doesn't credit the aligner pins which would further increase margin.
- By taking structural credit for the aligner pin and bracket assembly, the minimum number of core plate bolts required to ensure negligible relative horizontal displacement of the core plate for Service Level C/D and assuming one aligner pin in contact and the maximum gap size is 48 bolts. However, if no gap was assumed for the same service level and same number of aligner pins in contact, the required number of bolts could be as low as 16.
- If core plate bolt failures had occurred, obvious signs of degradation (e.g. missing bolts, fretting wear or rotation due to bypass leakage flow, etc.) should have been observed

during previous inspections.  However, no obvious signs of degradation have been observed during the 3 previous visual inspections of the JAF core plate bolts, including a 100% baseline inspection of all 72 bolts.

Based on this plant specific evaluation, no further inspections of the JAF core plate bolts are required.

## 5.0 REFERENCES

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**JAFP-12-0122**

**Attachment 2**

**SEP-RVI-004 Rev. 1, JAF Reactor Vessel Internals (RVI) Inspection Plan**

**(7 Pages)**

# JAF REACTOR VESSEL INTERNALS (RVI) INSPECTION PROGRAM PLAN

*APPLICABLE SITES*

**All Sites:** ☐

**Specific Sites:** **ANO** ☐ **GGNS** ☐ **IPEC** ☐ **JAF** ☒ **PLP** ☐ **PNPS** ☐ **RBS** ☐ **VY** ☐ **W3** ☐ **HQN** ☐

Safety Related: ☒ Yes

☐ No

**ATTACHMENT 1**
**Deviations to BWRVIP Guidelines**
**(Technical Justifications)**

## Deviation Disposition: Variance from BWRVIP-25 Guidance for Inspection of Core Plate Bolts

### 1.0 Summary

BWRVIP-25 requires that core plate bolts be inspected by Ultrasonic (UT) or Visual (VT) methods for plants that do not have core plate wedges installed. Currently, UT has significant limitations due to bolt geometry and VT is not able to interrogate the susceptible threaded areas of the bolting. The BWRVIP is addressing this issue and intends to develop revised guidance. Until such guidance is developed, a VT-3 exam of the bolting will be performed periodically as an alternative to the required BWRVIP-25 bolt inspections. This deviation will remain in place until December 31, 2015 or until the NRC approves revised BWRVIP guidance, whichever occurs first.

### 2.0 Background

A typical BWR core plate bolt is shown in Figure 1. The bolt is threaded at its upper and lower ends and is unthreaded over the remainder of its length. Anywhere from 30 to 72 bolts (dependent on plant design) are used to secure the core plate to the core plate support ring. BWRVIP-25 [1] requires that the bolts be inspected using either visual methods (EVT-1) from below the core plate or with an ultrasonic (UT) technique. In spite of significant effort on the part of the BWRVIP Inspection Focus Group and the EPRI NDE Center, the development of UT techniques for this application has been unsuccessful. The only feasible location for delivering acoustic energy to the bolt is through its upper end and access to the upper end is restricted by the presence of a keeper that is fillet welded to the top of the bolt. The resulting geometry does not allow for effective wave transmission and, consequently, a UT inspection has not been possible (as is recognized in Reference 2).

Visual inspections are also problematic. As shown in Figure 1, an EVT-1 inspection may be able to examine the unthreaded shank of the bolt. However, the threaded portion which is theoretically more susceptible to IGSCC is surrounded by the core plate and the core plate support ring and is hidden from view. Thus, meaningful EVT-1 exams cannot be performed and, in hindsight, should not have been recommended in BWRVIP-25.

The BWRVIP is currently performing analyses that will result in revised guidance for managing potential degradation of core plate bolting. Until that guidance is issued, the alternative inspections described in Section 3 will be performed to ensure continued integrity of the bolting. This alternative approach is justified for the short term by a number of reasons that are discussed below in Section 4.

**ATTACHMENT 1**
**Deviations to BWRVIP Guidelines**
**(Technical Justifications)**

## 3.0 Interim Inspection Approach

Until such time as the BWRVIP provides additional guidance on inspection of core plate bolting, a random sample of 25% of the bolts will be inspected by VT-3 from the upper end by 2015. At least 10% of the bolts shall be inspected by *December 31, 2012*. Should any significant degradation be observed, a plan for scope expansion and enhanced inspections will be developed on a case-by-case basis. Credit may be taken for prior inspections performed during or after 2005.

## 4.0 Acceptability of Interim Approach

While the interim approach does not accomplish the thorough inspection intended by BWRVIP-25, it is considered to be acceptable for the short term for the reasons discussed in the remainder of this section.

### 4.1 Field Experience

JAF has (72) preloaded, 1.125" diameter, 304 stainless steel core plate bolts. VT-3 inspections have been performed on the core plate bolts from above the core plate since 1998 in accordance with GE SIL-588 Rev.1. Over the course of 13 years, all 72 bolts have been inspected with no indications noted. Although it is recognized this is a limited exam, the following excerpt from the GE SIL gives some assurance that a VT-3 inspection from above would identify a failure. "Consequently, the recommended inspection is only that necessary to show that the bolts have not loosened and rotated due to a combination of vibration and failure of the welds on the locking device (keeper). If this were to occur, it should be obvious by visual inspection (VT-3)."

Across the industry, extensive VT-3 exams of the upper portion of the bolting have also been performed in accordance with GE SIL-588. In addition, some plants have performed VT-3 exams as an alternative to the BWRVIP-25 requirements. Twenty-one plants have reported the results of these inspections to the BWRVIP and none have reported any degradation. It is likely that additional inspections, not reported to the BWRVIP, have also been conducted per the GE SIL and no degradation has been reported to the industry.

One plant was able to perform an EVT-1 of all bolts from below the core plate during an extended outage. No degradation was observed.

While these exams are not sufficient to completely rule out the possibility of minor cracking in areas that cannot be observed visually, they do indicate that no degradation of consequence has occurred.

**ATTACHMENT 1**
**Deviations to BWRVIP Guidelines**

**(Technical Justifications)**

### 4.2 Hardware Redundancy

BWR core plates are attached to the shroud with between 30 and 72 bolts. A generic analysis described in Reference 1 showed that only approximately 80-percent of the bolts are necessary to resist loads during faulted conditions. This indicates that a significant amount of cracking in the bolts can be tolerated before the ability of the core plate to maintain control rod alignment is compromised.

The aligner hardware (Figure 2) also provides redundant structural capability. The generic analysis in Reference 1 concludes that even with 100% of the bolting failed, the stress on the aligners is less than ASME Code allowables. Thus, the aligners by themselves are capable of maintaining the horizontal position of the core plate during a seismic event. The vertical motion of the core plate (in the event of complete failure of the bolts) is limited to an acceptable value by contact with the CRD guide tube alignment tabs.

The aligner hardware is inaccessible for inspection which could be used to ensure its complete integrity and, thus, its ability to provide redundant restraint. However, the probability that a sufficient number of bolts are failed AND significant degradation of the aligners exists is very small.

### 4.3 IGSCC Susceptibility

The bolts and nuts are typically finished with techniques that minimize susceptibility to IGSCC. The threads at the top of the bolt and the threads on the top nut are subjected to liquid honing and/or electro-polishing techniques to ensure smooth contact between the nut and bolt. These finishing techniques reduce surface stresses and greatly reduce the susceptibility of the components to crack initiation.

The bottom of the bolt and its accompanying nut may not receive such treatment. However, even absent this stress relief, the thread-form itself reduces the crack-susceptibility of the bolt. The threads are typically fabricated with a short flat region at the root of the thread. This flat region is usually rounded to blend with the thread angle. The resulting smooth transitions reduce the local stresses and thus the susceptibility of the component to cracking.

### 4.4 Mitigation

JAF has injected hydrogen since 1988 and has applied noble metals twice. The first application was performed in 1999 and a second in 2004 and is currently scheduled to apply a third application in August 2011. Radiolysis models show that plants with hydrogen water chemistry (HWC) or noble metal chemical application (NMCA) are provided some level of protection in the region of the core plate bolting. Thus, the susceptibility of the bolting to new initiation is much reduced. In addition, the growth rate of any cracking that pre-dated mitigation will be greatly retarded.

**ATTACHMENT 1**
**Deviations to BWRVIP Guidelines**

**(Technical Justifications)**

**4.5 Standby Liquid Control**

The discussion in Sections 4.1 through 4.4 demonstrates that there is a very low probability that a sufficient degradation of the bolting could occur such that the resultant displacement of the core plate during a seismic event would inhibit or slow control rod insertion. However, in the unlikely case that such degradation did occur and control rods could not be inserted, the reactor could be brought to a safe shutdown using the standby liquid control (SLC) system.

**5.0 Conclusion**

Inspection techniques are not currently available to perform the core plate bolt inspections required by BWRVIP-25. However, as described in Section 4, there is reason to believe that the bolting has a relatively low susceptibility to cracking. Even if significant cracking did occur in the bolting, redundant structural components will prevent adverse displacement of the core plate. And finally, even with the extremely conservative assumptions of failures of both the bolting and the redundant hardware, the SLC system could be used to bring the reactor to a safe shutdown.

Given the low likelihood that the function of the core plate will be compromised by bolting failures, there is little risk in postponing a detailed inspection of the bolts until such time as the BWRVIP develops revised guidance. In the interim, the only viable inspection is a VT-3 of the top portion of the bolts. Such an inspection will be performed as described in Section 3

**6.0 References**

1. "BWR Vessel and Internals Project, BWR Core Plate Inspection and Flaw Evaluation Guidelines (BWRVIP-25)," EPRI Report TR-107284, December 1996.

2. "BWRVIP-94, Revision 1: BWR Vessel and Internals Project, Program Implementation Guide," EPRI Technical Report 1011702, December 2005

3. James A. FitzPatrick Reactor Vessel Internals (RVI) Inspection Program Plan, SEP-RVI-004 Rev 0

**ATTACHMENT 1**
**Deviations to BWRVIP Guidelines**

**(Technical Justifications)**

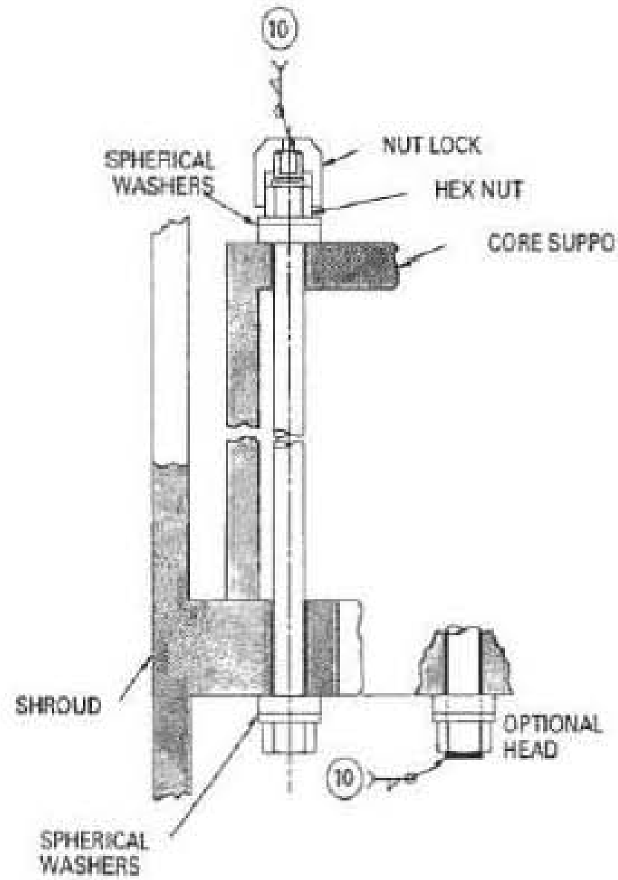


Figure 1: Typical Core Plate Bolt

**ATTACHMENT 1**
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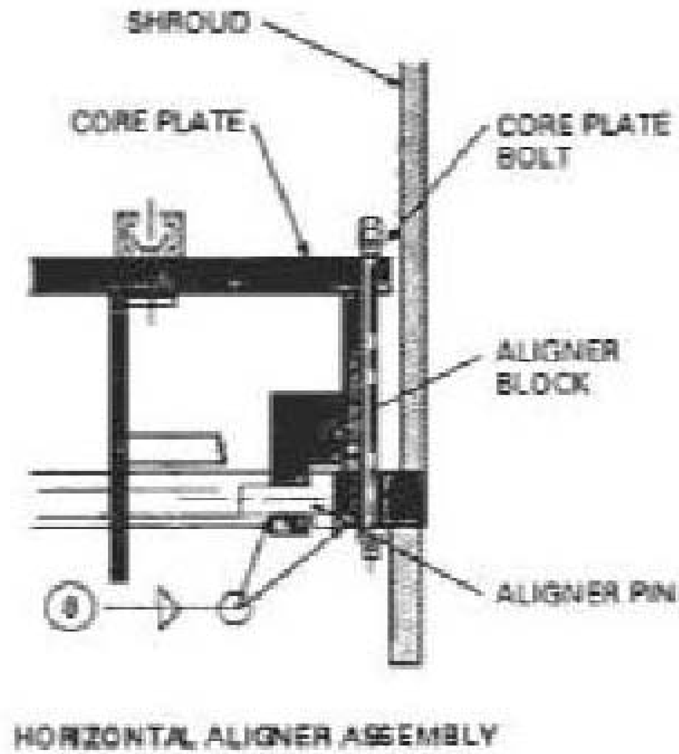


Figure 2: Core Plate Aligner Assembly