ENCLOSURE 3 CONTAINS INFORMATION REQUESTED TO BE WITHHELD FROM PUBLIC DISCLOSURE UNDER 10 CFR 2.390. UPON SEPARATION FROM ENCLOSURE 3, THIS LETTER IS DECONTROLLED.

April 13, 2022

L-2022-046
10 CFR 54.17
10 CFR 2.390

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
11545 Rockville Pike
One White Flint North
Rockville, MD 20852-2746

St. Lucie Nuclear Plant Units 1 and 2
Dockets 50-335 and 50-389
Facility Operating Licenses DPR-67 and NPF-16

SUBSEQUENT LICENSE RENEWAL APPLICATION REVISION 1 – DOCUMENTS WCAP-18623-P/NP REVISION 1 SUBMITTAL

References:

1. FPL Letter L-2021-192 dated October 12, 2021 – Subsequent License Renewal Application – Revision 1 (ADAMS Accession No. ML21285A107)
2. U.S. Nuclear Regulatory Commission (NRC) Letter dated September 24, 2021, St. Lucie Plant, Units 1 and 2 – Aging Management Audit Plan Regarding the Subsequent License Renewal Application Review (ADAMS Accession No. ML21245A305)

FPL, owner and licensee for St. Lucie Nuclear Plant (PSL) Units 1 and 2, has submitted a revised subsequent license renewal application (SLRA) for the Facility Operating Licenses for PSL Units 1 and 2 (Reference 1). During NRC's aging management audit of the SLRA with FPL (Reference 2), FPL agreed to docket Westinghouse Electric Company LLC (Westinghouse) proprietary (P) document WCAP-18623-P, *St. Lucie Units 1 & 2 Subsequent License Renewal: Fracture Mechanics Assessment of Reactor Pressure Vessel Structural Steel Supports* (December 2021 Revision 1). This proprietary document, its non-proprietary (NP) version, and accompanying withholding Affidavit are enclosed.

Enclosure 3 contains information proprietary to Westinghouse supported by an Affidavit executed by Westinghouse, the owner of the information. The Enclosure 1 Affidavit sets forth the basis on which the Enclosure 3 information may be withheld from public disclosure by the NRC, and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR 2.390. Accordingly, it is respectfully applied for that the information that is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR 2.390. Correspondence with respect to the copyright or proprietary aspects of the information or Affidavit should be addressed to the Westinghouse representative identified in their Affidavit.

Should you have any questions regarding this submittal, please contact me at (561) 304-6256 or William.Maher@fpl.com.

ENCLOSURE 3 CONTAINS INFORMATION REQUESTED TO BE WITHHELD FROM PUBLIC DISCLOSURE UNDER 10 CFR 2.390. UPON SEPARATION FROM ENCLOSURE 3, THIS LETTER IS DECONTROLLED.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on the 13th day of April 2022.

Sincerely,

William Maher

Digitally signed by William Maher
DN: cn=William Maher, o=Nuclear, ou=Nuclear Licensing Projects, email=william.maher@fpl.com, c=US
Date: 2022.04.13 08:56:51 -04'00'

William D. Maher
Licensing Director - Nuclear Licensing Projects

Cc: (w/o Enclosure 3)

Regional Administrator, USNRC, Region II
Senior Resident Inspector, USNRC, St. Lucie Plant
Chief, USNRC, Division of New and Renewed Licenses
Senior Project Manager, USNRC, Division of New and Renewed Licenses
Chief, Bureau of Radiation Control, Florida Department of Health

Enclosures:

Enclosure 1	Westinghouse Affidavit CAW-22-011 Supporting Withholding Proprietary Information from Public Disclosure Pursuant to 10 CFR 2.390
Enclosure 2	WCAP-18623-NP, St. Lucie Units 1 & 2 Subsequent License Renewal: Fracture Mechanics Assessment of Reactor Pressure Vessel Structural Steel Supports (December 2021 Revision 1) [Public Version]
Enclosure 3	WCAP-18623-P, St. Lucie Units 1 & 2 Subsequent License Renewal: Fracture Mechanics Assessment of Reactor Pressure Vessel Structural Steel Supports (December 2021 Revision 1) [Contains Information Requested to be Withheld From Public Disclosure Under 10 CFR 2.390]

ENCLOSURE 1

Westinghouse Affidavit CAW-22-011 Supporting Withholding Proprietary Information from Public Disclosure Pursuant to 10 CFR 2.390

(4 total pages including this cover sheet)

Commonwealth of Pennsylvania:
County of Butler:

(1) I, Camille Zozula, Manager, Regulatory Compliance and Corporate Licensing, have been specifically delegated and authorized to apply for withholding and execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse).

(2) I am requesting the proprietary portions of WCAP-18623-P Revision 1 be withheld from public disclosure under 10 CFR 2.390.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged, or as confidential commercial or financial information.

(4) Pursuant to 10 CFR 2.390, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse and is not customarily disclosed to the public.

(ii) The information sought to be withheld is being transmitted to the Commission in confidence and, to Westinghouse's knowledge, is not available in public sources.

(iii) Westinghouse notes that a showing of substantial harm is no longer an applicable criterion for analyzing whether a document should be withheld from public disclosure. Nevertheless, public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar technical evaluation justifications and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

(5) Westinghouse has policies in place to identify proprietary information. Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage (e.g., by optimization or improved marketability).

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

(6) The attached documents are bracketed and marked to indicate the bases for withholding. The justification for withholding is indicated in both versions by means of lower-case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower-case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (5)(a) through (f) of this Affidavit.

I declare that the averments of fact set forth in this Affidavit are true and correct to the best of my knowledge, information, and belief. I declare under penalty of perjury that the foregoing is true and correct.

Executed on: 3/3/2022

Signed electronically by
Camille Zozula
Regulatory Compliance &
Corporate Licensing

ENCLOSURE 2

WCAP-18623-NP, St. Lucie Units 1 & 2 Subsequent License Renewal: Fracture Mechanics Assessment of Reactor Pressure Vessel Structural Steel Supports (December 2021 Revision 1)

[Public Version]

(111 total pages including this cover sheet)

WCAP-18623-NP
Revision 1

December 2021

St. Lucie Units 1 & 2 Subsequent License Renewal: Fracture Mechanics Assessment of Reactor Pressure Vessel Structural Steel Supports

Westinghouse

WCAP-18623-NP
Revision 1

St. Lucie Units 1 & 2 Subsequent License Renewal: Fracture Mechanics Assessment of Reactor Pressure Vessel Structural Steel Supports

December 2021

Alexandria M. Scott*
RV/CV Design and Analysis

Gordon Z. Hall*
Structural Design and Analysis

Verifier: George J. Demetri*
RV/CV Design and Analysis

Reviewers: Nicholas M. Bisceglia*
J. Brian Hall*
Andrew E. Hawk*

Approved: Lynn A. Patterson*, Manager
RV/CV Design and Analysis

*Electronically approved records are authenticated in the electronic document management system.

Westinghouse Electric Company LLC
1000 Westinghouse Drive
Cranberry Township, PA 16066, USA

FOREWORD

This document contains Westinghouse Electric Company LLC proprietary information and data which has been identified by brackets. Coding (a,c,e) associated with the brackets sets forth the basis on which the information is considered proprietary.

The proprietary information and data contained in this report were obtained at considerable Westinghouse expense and its release could seriously affect our competitive position. This information is to be withheld from public disclosure in accordance with the Rules of Practice 10CFR2.390 and the information presented herein is to be safeguarded in accordance with 10CFR2.390. Withholding of this information does not adversely affect the public interest.

This information has been provided for your internal use only and should not be released to persons or organizations outside the Directorate of Regulation and the ACRS without the express written approval of Westinghouse Electric Company LLC. Should it become necessary to release this information to such persons as part of the review procedure, please contact Westinghouse Electric Company LLC, which will make the necessary arrangements required to protect the Company's proprietary interests.

The proprietary information in the brackets is provided in the proprietary version of this report (WCAP-18623-P Revision 1).

RECORD OF REVISIONS

Revision	Date	Revision Description
0	November 2021	Original Issue
1	December 2021	Incorporate customer comment responses and close the open item in Revision 0.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

As plants apply for 80-year licensure (Subsequent License Renewal-SLR), the United States (U.S.) Nuclear Regulatory Commission (NRC) has queried the nuclear power plant industry to investigate the impact of neutron embrittlement (radiation effects) on the reactor pressure vessel (RPV) supports due to extended plant operation past 60 years. The U.S. NRC has released Generic Aging Lessons Learned (GALL) SLR report NUREG-2191 [1] which provides information regarding license renewal for 80 years. This report does not include guidance for analysis of loss of fracture toughness due to irradiation embrittlement for structural steel support components in the vicinity of the RPV; however, recent U.S. NRC meetings have provided preliminary guidance on evaluating irradiation embrittlement of RPV steel supports [2]. The radiation effects on RPV supports were previously investigated and resolved as part of GSI-15 in NUREG-0933, Revision 3 [3], NUREG-1509 (published in May 1996) [4] and NUREG/CR-5320 (published in 1989) [5]. The conclusions in NUREG-0933, Revision 3 [3] stated that the supports were acceptable for continued operation and GSI-15 was resolved. However, for plants applying for 80 year life licensure, the U.S. NRC has requested a re-assessment of the RPV structural steel supports based on a fracture mechanics evaluation to account for neutron embrittlement (radiation effects).

As part of St. Lucie Units 1 and 2 SLR application (which has recently been submitted to the U.S. NRC), an assessment of the structural steel RPV supports as it pertains to the irradiation aging effects for 80 years was completed in LTR-SDA-21-021 [6]. The assessment included a technical justification to support an inspection-based approach, which is permitted by the pre-decisional draft interim staff guidance [2] as an appropriate means of managing the irradiation aging concerns through the subsequent period of extended operation. The assessment was a comparative analysis to the Point Beach RPV structural steel supports analysis [7]. For Point Beach, it was concluded that the ASME Section XI In-Service Inspection (ISI) program is a sufficient approach to manage the radiation embrittlement effects on the RPV support for 80 calendar years (72 effective full power year (EFPY)). Based on the comparative assessment in LTR-SDA-21-021, it was determined that continued inspections in accordance with the ASME Section XI [8] ISI program to address the irradiation aging effects for the RPV supports are justifiable for the subsequent period of extended operation and no additional inspection is required beyond the current ASME Section XI ISI program at St. Lucie Units 1 and 2.

The report herein provides a plant-specific defense-in-depth fracture mechanics analysis of the structural steel RPV supports and investigation of the impact of neutron embrittlement (radiation effects) of the supports due to extended plant operation past 60 years to support the assessment that was completed in LTR-SDA-21-021 [6] for St. Lucie Units 1 and 2. A detailed fracture mechanics evaluation is performed on St. Lucie Units 1 and 2 RPV structural steel supports to calculate the critical flaw sizes following the general guidance of ASME Section XI [8] to investigate brittle fracture of the structural steel supports per NUREG-0933, Revision 3 and NUREG-1509. Five separate structural steel components within the St. Lucie Units 1 and 2 RPV support system were evaluated. These components are the 4" horizontal plate and 5" vertical plate at the top of the horizontal support, the 4" horizontal plate at the bottom of the horizontal support, the bolts which connect the column and bottom of the horizontal support, and the bolts at the socket/slide restraining plates. The critical flaw sizes are determined by equating the applied stress intensity factor to the material-specific fracture toughness. The stress intensity factors were determined for the various loading combinations for the St. Lucie Units 1 and 2 RPV supports and for an array of flaw shapes. The impact of neutron embrittlement on the RPV structural steel supports material-specific fracture toughness was determined at 80 calendar years (72 EFPY) and also at 40 years as a sensitivity study for with and without analytical uncertainties associated with the methodology used to calculate embrittlement.

Based on the magnitude of the calculated critical flaw sizes discussed in Section 8 of this report, it can be demonstrated that the calculated critical flaw sizes based on 80 calendar years (72 EFPY) of neutron embrittlement are sufficiently large (i.e., flaw tolerant) as compared to [

]^{a,c,e}

For the five components within the RPV support system, it was concluded that there was enough margin between the [

]^{a,c,e} Based on the detailed conclusions in Section 8, the RPV support systems at St. Lucie Units 1 and 2 are structurally stable (i.e., flaw tolerant) considering 80 years of radiation embrittlement effects on the supports, and a sufficient level of flaw tolerance is demonstrated to justify continuing the current examinations of the RPV structural steel supports.

1 INTRODUCTION

As plants apply for 80-year licensure (Subsequent License Renewal-SLR), the United States (U.S.) Nuclear Regulatory Commission (NRC) has queried the nuclear power plant industry to investigate the impact of neutron embrittlement (radiation effects) on the reactor pressure vessel (RPV) supports due to extended plant operation past 60 years. The radiation effects on the RPV supports were previously investigated and resolved as part of GSI-15 in NUREG-0933, Revision 3 [3], NUREG-1509 (published in May 1996) [4] and NUREG/CR-5320 (published in 1989) [5]. The conclusions in NUREG-0933, Revision 3 stated that the supports were acceptable for continued operation and GSI-15 was resolved, as follows:

> The preliminary conclusion indicated that the potential problem [embrittlement of supports due to radiation effects] did not pose an immediate threat to public health and safety… The above tentative results indicated that plant safety could be maintained despite RVSS [reactor vessel support structures] radiation damage… In order to encompass the uncertainties in the various analyses and provide an overall conservative assessment, several structural analyses conducted demonstrated the following:
>
> 1. Postulating that one of the four RPV supports was broken in a typical PWR, the remaining supports would carry the reactor vessel load even under SSE [safe-shutdown earthquake] seismic loads;
> 2. If all supports were assumed to be totally removed (i.e., broken), the short span of piping between the vessel and the shield wall would support the load of the vessel.
>
> The results of the analyses virtually eliminated the concern for both radiation embrittlement and significant structural damage from a postulated RPV failure… Based on the staff's regulatory analysis, the issue was resolved with no new requirements. Consideration of a license renewal period of 20 years did not change this conclusion.

Based on conclusions in NUREG-0933 and U.S. NRC Memorandums on GSI-15 [9], it was concluded that the RPV supports were not a concern for the entirety of its plant life (i.e., 40 and 60 years); even in the extreme case where all the supports were totally removed (i.e., broken), the piping has acceptable margin to carry the load of the vessel. However, for plants applying for 80-year life licensure, the U.S. NRC has recently requested a re-assessment of the RPV structural steel supports based on a fracture mechanics evaluation to account for neutron embrittlement [2]. The U.S. NRC Generic Aging Lessons Learned (GALL) Subsequent License Renewal (SLR) report NUREG-2191 [1] for 80-year license renewal does not include guidance for analysis of loss of fracture toughness due to irradiation embrittlement for structural steel support components in the vicinity of the RPV. However, recent U.S. NRC meetings have provided preliminary guidance in [2] which states that NUREG-1509 provides general guidance and an acceptable approach for the evaluation of the loss of fracture toughness of the RPV supports due to radiation effects for long term operation.

There are two potential fracture mechanics strategies that are identified to resolve the radiation embrittlement concern based on NUREG-0933 and NUREG-1509. One approach is to compare the lowest service temperature (LST) with the material adjusted reference temperature considering irradiation effects. If the LST is higher than the material adjusted reference temperature, then the RPV supports are acceptable. Historically, it was determined that the LST method would not provide sufficient margin, hence this methodology will not be used for the St. Lucie RPV structural steel supports.

The second approach used to investigate brittle fracture of the structural steel supports per NUREG-1509 is to perform a detailed fracture mechanics evaluation in order to calculate the critical flaw sizes, similar to the general guidance of ASME Section XI Appendix A. The evaluation could be used to demonstrate that the calculated critical flaw sizes based on 80 years of neutron embrittlement are sufficiently large (i.e., flaw tolerant) as compared to [

]a,c,e

Note that current ASME Section XI IWF in-service inspection for supports requires only a visual examination (VT-3). As discussed in Section 8.1, magnetic particle testing (MT) is required for one of the three RPV nozzle support feet for St. Lucie Units 1 and 2. The objective of the analysis is to demonstrate a sufficient level of flaw tolerance to justify continuing the current visual examinations (VT-3).

It should be noted that, as part of the overall resolution of GSI-15 in NUREG-1509, a detailed fracture mechanics evaluation was performed in 1989 for one of the pilot plants in NUREG/CR-5320, namely, Turkey Point Unit 3 (the other plant was Trojan). The conclusions in NUREG/CR-5320 indicated that, for the most severe credible loading (deadweight plus large break LOCA) at 32 effective full power years (EFPY) (i.e., 40 years), the best-estimate minimum critical flaw size depth is 0.3 inch for the structural support beams. Furthermore, the study had concluded that calculated flaw size is insensitive to reactor operating time after ~10 EFPY, and at startup (0 EFPY) the size is 0.6 inch. The study in NUREG/CR-5320 also demonstrated that considering uncertainties in the fracture toughness, initial nil-ductility transition temperature ($NDTT_o$), and the operating temperature of the support components, the $\pm 1\sigma$ (one standard deviation) values of the critical flaw size at 32 EFPY are ~0.2 and 0.6 inch. For the loading case of deadweight plus safe shutdown earthquake, the critical flaw size is substantially larger (1.1 inches as compared with 0.3 inch) at 32 EFPY.

Even though the fracture mechanics study performed for Turkey Point Unit 3 and Trojan in NUREG/CR-5320 (conducted in 1989) had calculated small critical flaw sizes that could be a source of concern for brittle fracture, the U.S. NRC staff in 1996 had reviewed several other structural analyses in addition to the fracture mechanics evaluation. Based on the U.S. NRC's review of other structural consequence analysis, a final conclusion (as stated in NUREG-0933 of GSI-15) was reached that even if one of the RPV supports was broken in a pressurized water reactor (PWR), the remaining supports would safely carry the RPV load under seismic events. The structural analyses also concluded that even if all the RPV supports were broken, the short span of piping between the vessel and the shield wall would support the load of the RPV.

As a result, the fracture mechanics evaluation in NUREG/CR-5320 can be considered a defense-in-depth study of the structural integrity of the RPV supports, as supplemented by the structural analysis which demonstrated that the piping can withstand the load of the RPV after failure of all vessel supports. It should be noted that the flaw sizes postulated in the NUREG/CR-5320 would have been identified during original fabrication (pre-service inspection) of the support welds either by dye penetrant testing, magnetic particle or even ultrasonic equipment as required by AISC (American Institute of Steel Construction) and AWS (American Welding Society).

The goal of the analysis herein for St. Lucie Units 1 and 2 for the 80-year SLR is to keep consistent with the overall methodology that had been previously accepted by the industry and U.S. NRC in NUREG-0933, NUREG-1509, and NUREG/CR-5320, while at the same time demonstrate that the RPV supports, with consideration of neutron embrittlement, are structurally safe for plant life extension to 80 years.

Thus, the evaluation in this report for St. Lucie Units 1 and 2 determines the critical flaw sizes based on a fracture mechanics evaluation of the RPV structural steel supports to investigate the impact of neutron embrittlement (radiation effects) for an operating life of 80 years. The general methodology of the fracture mechanics evaluation is described in Section 2. The St. Lucie support configuration, materials, and geometry are provided in Section 3 of this report. Section 4 describes the plant-specific loading conditions and the stresses used in the evaluation, while Section 5 provides information regarding fracture toughness, plant-specific neutron embrittlement, and postulation of flaw sizes. Section 6 describes the allowable flaw sizes which are compared to the critical flaw sizes. Section 7 provides the calculated critical flaw sizes that were determined for the supports to demonstrate structural stability based on the linear elastic fracture mechanics evaluations, and Section 8 provides the final conclusions of the fracture mechanics evaluations. All cited references are provided in Section 9.

Revision 1 of this report addresses customer comments. Revision 1 changes are marked by change bars. Additionally, all design input transmittals are official. The open item in Revision 0 of this report is closed.

2 GENERAL METHODOLOGY

The goal of the fracture mechanics evaluation is to demonstrate that brittle fracture is not a concern for the RPV structural support steels at St. Lucie Units 1 and 2 (i.e., the calculated critical flaw sizes are sufficiently large or flaw tolerant) based on 80 years (72 EFPY) of neutron embrittlement. Linear elastic fracture mechanics (LEFM) will be used as a conservative methodology to evaluate the structural integrity of the supports. The LEFM methodology is illustrated in a flow chart format (see Figure 2-1) based on the guidance provided in NUREG-1509 [4] for a fracture mechanics approach to account for radiation effects on RPV support steels. The LEFM methodology is briefly described in the following paragraphs.

The limiting component for the fracture mechanics analysis is based on a combination of component geometry, operating conditions, stresses, material properties, and neutron embrittlement. The St. Lucie support configuration, materials, and geometry are provided in Section 3 of this report. The critical flaw size will be calculated by equating the material-specific fracture toughness to the applied stress intensity factors for various postulated flaw sizes in the support components based on normal, upset, and faulted conditions (note that the test and emergency conditions are not in the RPV supports analysis of record and are not analyzed in this report). All applicable loading conditions, such as deadweight, seismic, loss of coolant accident, welding residual stresses and thermal stresses are considered in the analysis as described in Section 4 of this report. [

]^{a,c,e}

Based on the component geometry and loading types, stress intensity factors for various flaw conditions will be considered as described in Section 5.2 of this report. Stress intensity factors based on semi-elliptical postulated flaws with various aspect ratios (AR, flaw length over flaw depth) will be considered at the RPV support components with plate-like structures; these AR will range from 2:1 to infinity. For bolts, the stress intensity factors will be based on a postulated 360° continuous circumferential flaw, a straight front flaw, and a semi-circular front flaw in a bar model. The stress intensity factors are then compared to the material-specific fracture toughness to determine critical flaw size.

The material-specific fracture toughness will be [

]^{a,c,e} A detailed description of the allowable flaw sizes is provided in Section 6 of this report.

Section 7 and Section 8 provide the calculated critical flaw sizes for the RPV structural steel supports and compare them to the allowable flaw sizes to demonstrate structural stability based on the linear elastic fracture mechanics evaluations.

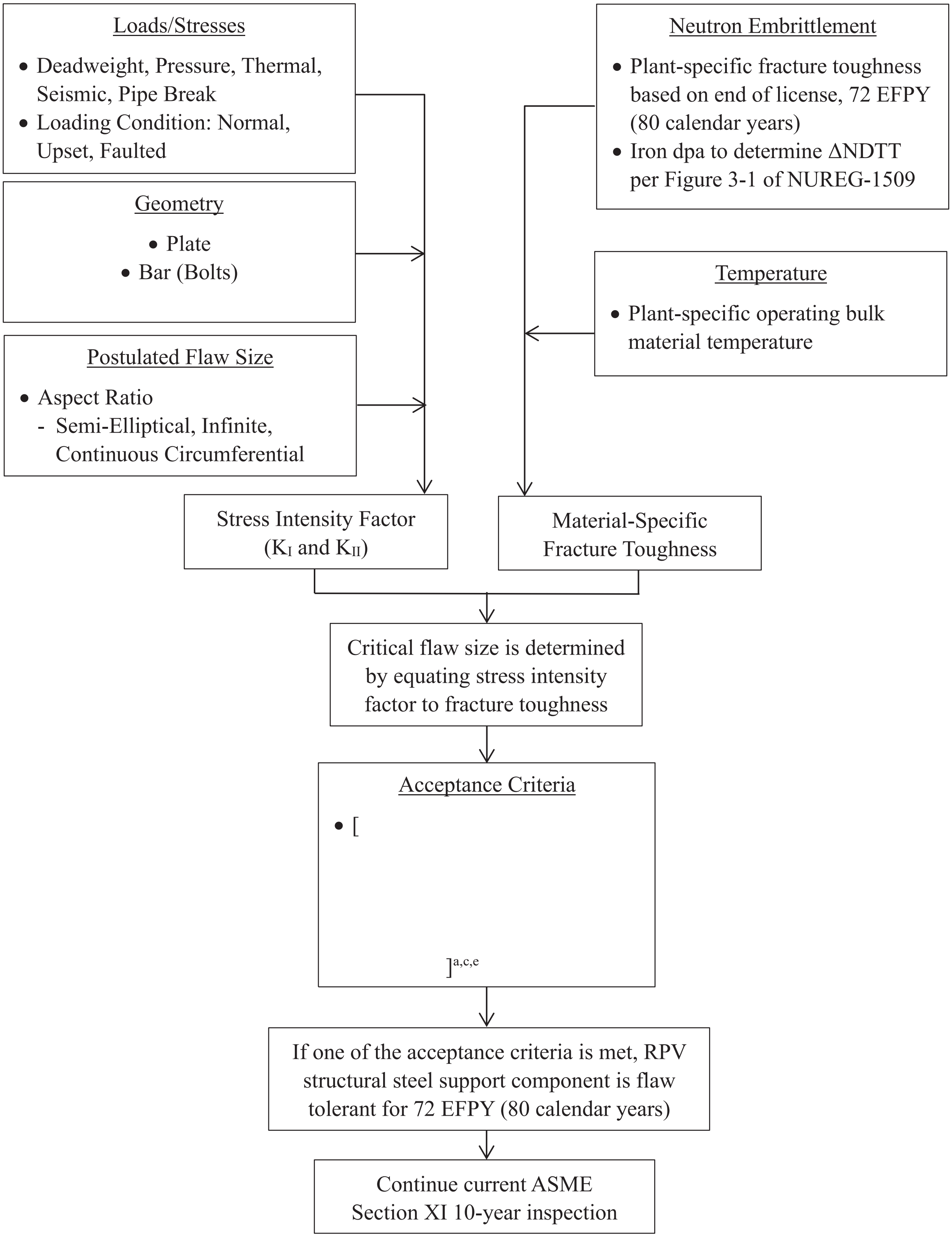


Figure 2-1: Fracture Mechanics Approach Flowchart

*** This record was final approved on 12/17/2021, 9:08:48 AM. (This statement was added by the PRIME system upon its validation)

3 SUPPORT CONFIGURATION, MATERIAL, AND GEOMETRY

This section of the report describes the general St. Lucie RPV support configuration, material designation and geometry.

The St. Lucie RPV support structure consists of three long steel columns extending 23 feet downward to the interior concrete structure below the RPV. The three columns support three reactor vessel nozzles, one column supports the vessel under the hot leg nozzle, while the other two columns support the vessel under the two cold leg nozzles on the loop opposite the hot leg nozzle support as shown in Figure 3-1. The top of each long column is bolted to a horizontal support in a “T-shaped” structure as shown in Figure 3-2. The horizontal support, bottom of the column/base plate, and anchor bolts at the base plate and horizontal support are shown in more detail in Figure 3-3. A close-up view of the horizontal support is provided in Figure 3-4. The horizontal support consists of plates joined by welds and bolts. The top of the horizontal support is bolted to shoe-type support stiffener plates (i.e., the restraining bracket plate shown in Figure 3-5) which restrain the socket/slide assembly of the RPV nozzle support. The socket plate of the socket/slide assembly is bolted to the nozzle support foot and sits on the dome-shaped slide. The slide is lubricated on both sides and is held in place on the support structure by two restraining plates as illustrated in Figure 3-5.

The RPV supports are designed and fabricated in accordance with Specification FLO-8770-761 [10.a] and addendum [10.b] for St. Lucie Unit 1 and Specification FLO-2998-761 [10.c] for St. Lucie Unit 2. The following five RPV support steel components were considered for the critical flaw size calculations since these locations could experience large tensile stresses and/or high embrittlement effects: the 4” horizontal plate and 5” vertical plate at the top of the horizontal support, the 4” horizontal plate at the bottom of the horizontal support, the bolts which connect the column and the bottom of the horizontal support, and the bolts at the socket/slide restraining plates. Note that “top of the horizontal support” and “bottom of the horizontal support” are defined in Figure 3-4. The other components such as the base plate, anchor bolts, column, and other welded plates within the RPV support system are subject to compressive or lower tensile stress and lower irradiation, and thus will be bounded by the results and conclusions for the five analyzed components mentioned previously. The specifications also state that the welding process and electrodes shall be AWS-5.1 low hydrogen Class E70 for manual shielded metal-arc welding (SMAW) or AWS 5.17 F7X for submerged arc welding (SAW). The St. Lucie Unit 2 specification included the option for AWS A5.20 Class E70T-1 or E70T-5 for flux cored arc welding (FCAW). The geometry of interest for the five components and the type of material provided in the following paragraphs is based on the RPV support drawings [11].

Top of Horizontal Support – 4” Horizontal Plate (Figure 3-4)

The top of the horizontal support consists of plates of various sizes welded together with butt welds including full penetration, partial penetration, and fillet welds. [

]^{a,c,e}

Material: ASTM A-441 [12]

Thickness (t) = 4”

Width = 21”

Top of Horizontal Support – 5" Vertical Plate (Figure 3-4)

The top of the horizontal support consists of plates of various sizes welded together with butt welds including full penetration, partial penetration, and fillet welds. [

]a,c,e

Material: ASTM A-533 Class 2, Grade B [13]

Thickness (t) = 5"

Width = 21"

Bottom of Horizontal Support – 4" Horizontal Plate (Figure 3-4)

The bottom of the horizontal support consists of various sized plates welded together with butt welds including full penetration, partial penetration, and fillet welds. [

]a,c,e

Material: ASTM A-441 [12]

Thickness (t) = 4"

Width = 21"

Bolts Connecting Column and Bottom of Horizontal Support (Figure 3-4)

There are eight bolts which connect the top of the column to the bottom of the horizontal support.

Material: ASTM A-325 [14]

Diameter = 1.25"

Bolts at Socket/Slide Restraining Plates (Figure 3-5)

There are eight bolts that fasten two restraining plates to the horizontal surface of the socket/slide assembly.

Material: Not Specified

Diameter = 0.875"

In addition to the five aforementioned components, the base plate, anchor bolts and columns are reviewed in Section 7. The column consists of ASTM A-441 plates with thickness ranging from 3" to 4". The base plate (thickness = 4") and surrounding welded plate near the bottom of the column (thickness ranges from 1" to 4") are ASTM A-441. The anchor bolts at the base plate (diameter = 1.25") and anchor bolts at the horizontal support (diameter = 2.75") are ASTM A-325.

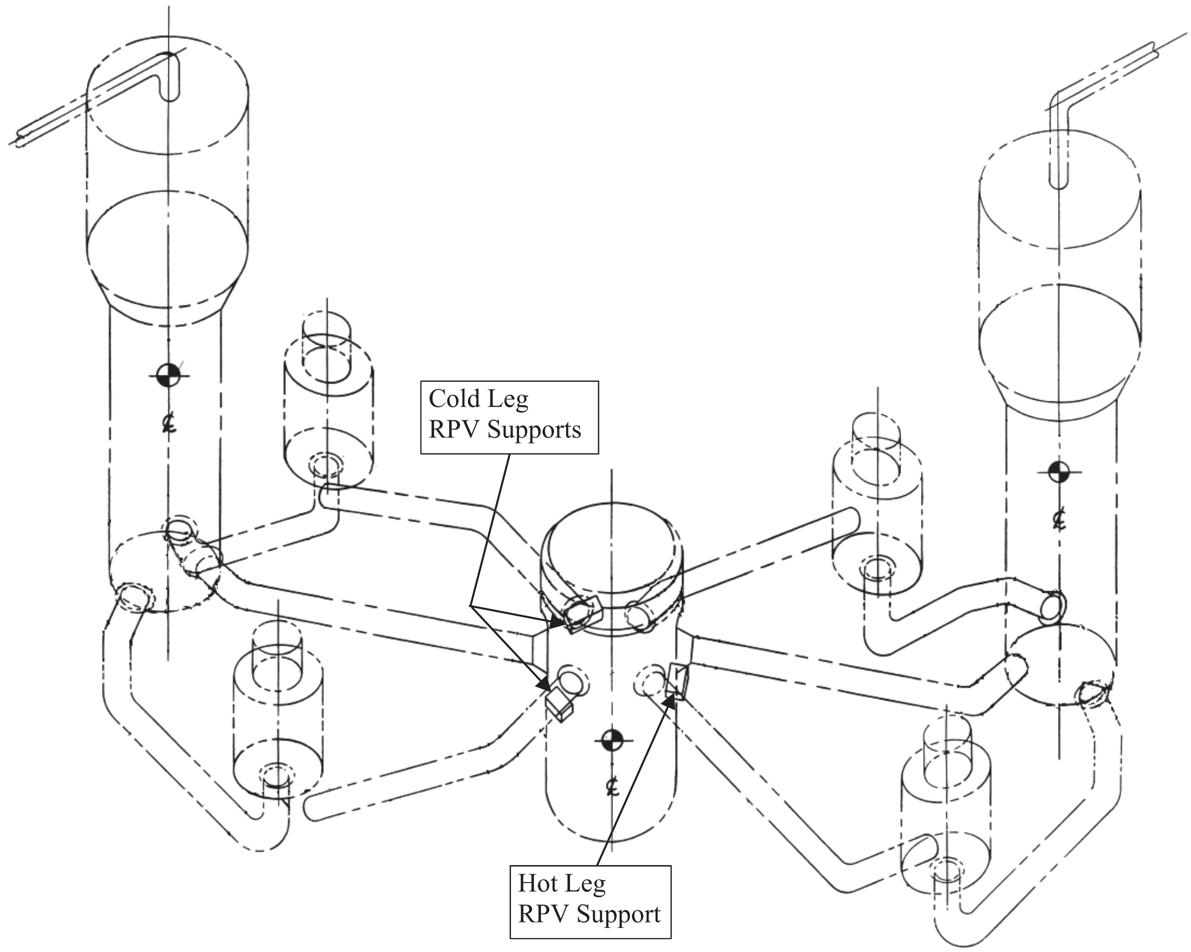


Figure 3-1: Reactor Coolant Loops, Reactor Pressure Vessel, and Location of RPV Supports Excerpt of References [11.g] and [11.h]

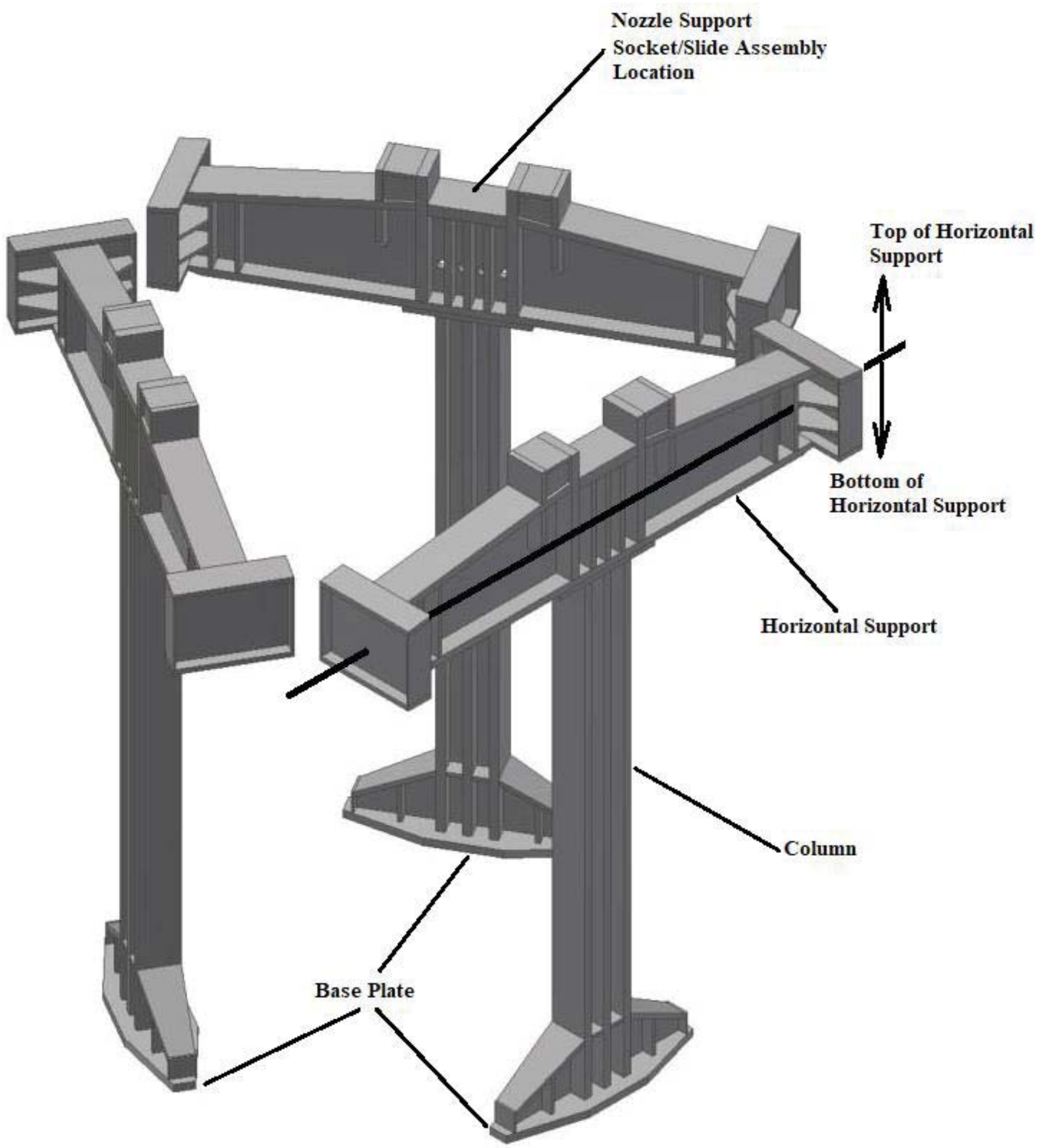


Figure 3-2: St. Lucie RPV Support Arrangement Illustration

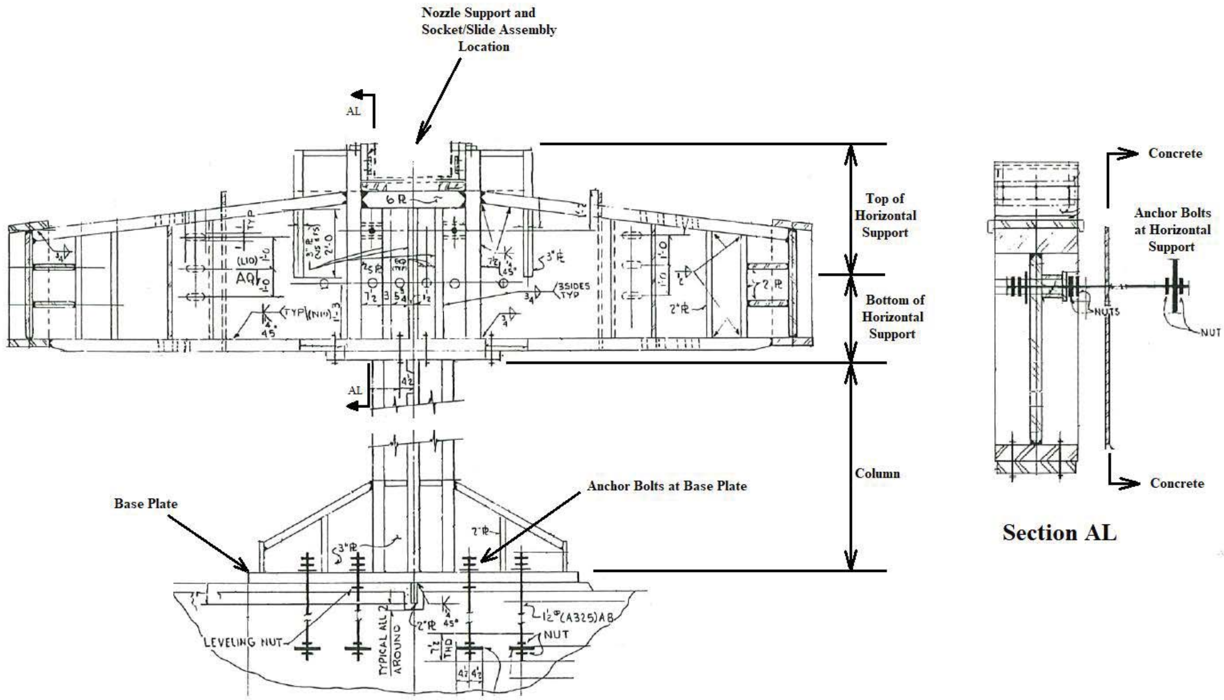


Figure 3-3: St. Lucie RPV Support System

Excerpt of References [11.a] and [11.b]

a,c,e

Figure 3-4: Close-up View of St. Lucie RPV Support System

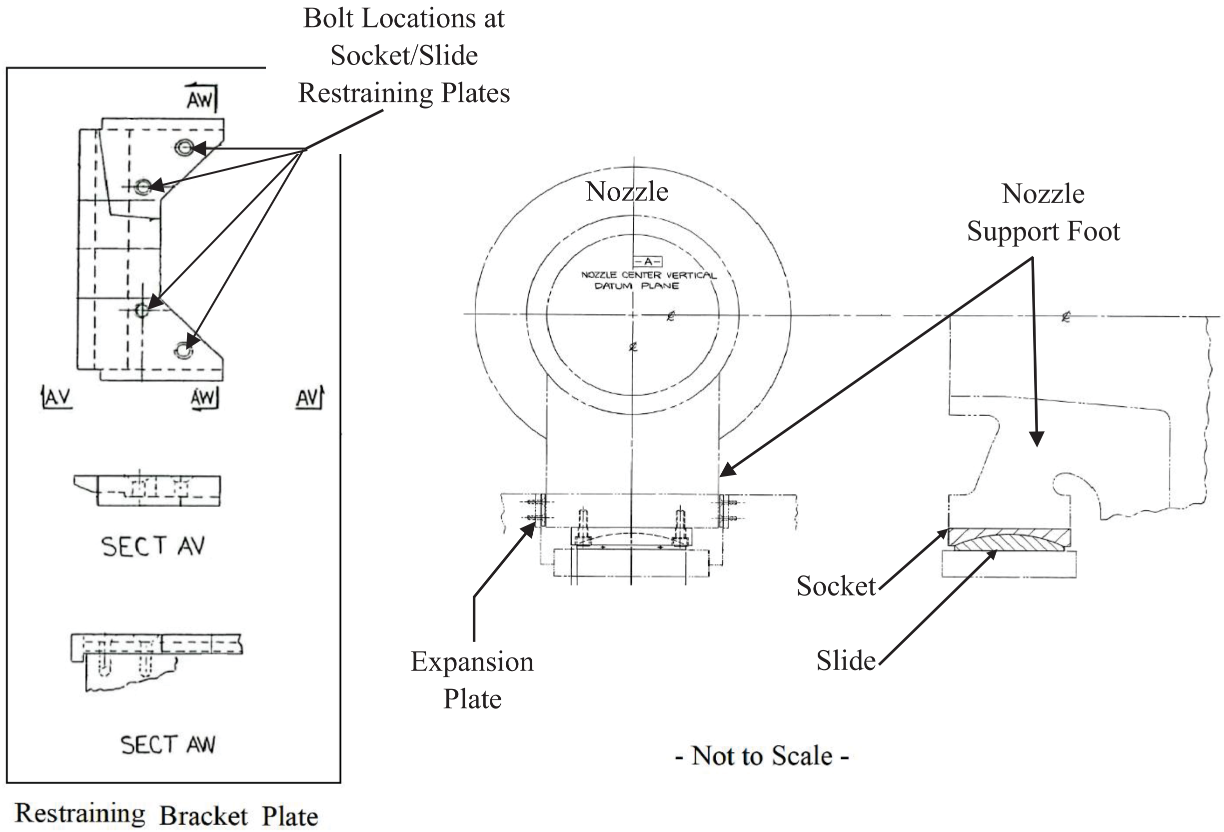


Figure 3-5: St. Lucie RPV Support Shoe Socket and Slide at Nozzle Support

Excerpt of References [11.a] through [11.d]

4 LOADING CONDITIONS AND STRESS ANALYSIS

The critical flaw sizes are determined by equating the applied stress intensity factor to the material-specific fracture toughness. The stress intensity factor is determined for the various loading combinations applicable to the St. Lucie Units 1 and 2 RPV supports. The design basis load combinations for the St. Lucie RPV supports are based on the analysis of record [15] [16] and are as follows:

[

]a,c,e

Representative stress contour plots for the St. Lucie Units 1 and 2 RPV Supports are illustrated in Figure 4-1 through Figure 4-13 for normal, upset, and faulted conditions. There are five components within the St. Lucie Units 1 and 2 RPV support systems that are evaluated in this report. The five components are the 4” horizontal plate and 5” vertical plate at the top of the horizontal support, the 4” horizontal plate at the bottom of the horizontal support, the bolts which connect the column and bottom of the horizontal support, and the bolts at the socket/slide restraining plates. These support components represent the locations of highest stresses within the RPV support system and/or are located near the RPV active core and subjected to high neutron irradiation. The other components such as the base plate, anchor bolts, column, and other welded plates within the RPV support system will be bounded by the five components evaluated herein (the other components are discussed in the various subsections of Section 7). The plant-specific normal, upset, and faulted loading combination stresses used to evaluate the five components are provided in Table 4-1 through Table 4-5. [

]a,c,e

The typical stress components considered [

]a,c,e

[

]a,c,e The stress intensity factor methodology for each of the five support components is described in Section 5.2 of this report.

Welding residual stress (WRS) is also considered for the welded components within the RPV support structure. Based on drawings for St. Lucie Unit 1 and Unit 2, the welded connections are made with full penetration, partial penetration, and fillet welds. [

]a,c,e

The following sections in this report provide the stress applied to each of the five components and a figure of the postulated flaws that are analyzed to determine the critical flaw sizes:

- Section 4.1: Top of Horizontal Support – 4” Horizontal Plate
- Section 4.2: Top of Horizontal Support – 5” Vertical Plate
- Section 4.3: Bottom of Horizontal Support – 4” Horizontal Plate
- Section 4.4: Bolts Connecting Column and Bottom of Horizontal Support
- Section 4.5: Bolts at Socket/Slide Restraining Plates

[

]a,c,e A discussion of stress as well as fracture toughness is provided in the various subsections of Section 7 to determine that these components will be bounded by or represented by the five components mentioned previously.

a,c,e

Figure 4-1: Representative Stress Intensity for Normal Operating Conditions

a,c,e

Figure 4-2: Representative Stress Intensity Detail for Normal Operating Conditions

a,c,e

Figure 4-3: Representative Upper Support Bottom Plate Stress Intensity Detail for Normal Operating Conditions

a,c,e

Figure 4-4: Representative Stress Intensity for Upset Conditions

a,c,e

Figure 4-5: Representative Stress Intensity Detail for Upset Conditions

a,c,e

Figure 4-6: Representative Upper Support Bottom Plate Stress Intensity Detail for Upset Conditions

a,c,e

Figure 4-7: Representative Stress Intensity for Faulted Conditions

a,c,e

Figure 4-8: Representative Stress Intensity Detail for Faulted Conditions

a,c,e

Figure 4-9: Representative Upper Support Bottom Plate Stress Intensity Detail for Faulted Conditions

a,c,e

Figure 4-10: Representative Column Maximum Principal Stress for Upset Conditions

a,c,e

Figure 4-11: Representative Column Minimum Principal Stress for Upset Conditions

a,c,e

Figure 4-12: Representative Column Maximum Principal Stress for Faulted Conditions

a,c,e

Figure 4-13: Representative Column Minimum Principal Stress for Faulted Conditions

4.1 TOP OF HORIZONTAL SUPPORT – 4" HORIZONTAL PLATE STRESS

The applied stresses on the 4" horizontal plate located at the top of the horizontal support are provided in Table 4-1 for the normal, upset, and faulted loading combinations. The applied stresses are based on [ ][a,c,e] Welding residual stress is added to the operating stress for the postulated flaws located near the welded portion of the horizontal plate. The postulated semi-elliptical flaws with aspect ratios (AR, flaw length over flaw depth) of 6:1 and 2:1, as well as a postulated infinitely long edge flaw are analyzed as a parametric study. A rendition of the horizontal plate and the postulated flaws is shown in Figure 4-14.

Table 4-1: Applied Stresses for Top of Horizontal Support – 4" Horizontal Plate

[ ]a,c,e

a,c,e

Figure 4-14: Postulated Flaws in the Top of Horizontal Support – 4” Horizontal Plate

4.2 TOP OF HORIZONTAL SUPPORT – 5” VERTICAL PLATE STRESS

The applied stresses on the 5” vertical plate located at the top of the horizontal support are provided in Table 4-2 for the normal upset, and faulted loading combinations. The applied stresses are based on [ ]a,c,e Welding residual stress is added to the operating stress for the postulated flaws located near the welded portion of the vertical plate. The postulated semi-elliptical flaws with aspect ratios (AR, flaw length over flaw depth) of 6:1 and 2:1, as well as a postulated infinitely long edge flaw are analyzed as a parametric study. A rendition of the vertical plate and the postulated flaws is shown in Figure 4-15. Note that the difference of stress trend between St. Lucie Unit 1 and Unit 2 load conditions is due to the St. Lucie units having different load-source calculations due to various updates made to the units over the years.

Table 4-2: Applied Stresses for Top of Horizontal Support – 5” Vertical Plate

[ ]a,c,e

a,c,e

Figure 4-15: Postulated Flaws in the Top of Horizontal Support – 5” Vertical Plate

4.3 BOTTOM OF HORIZONTAL SUPPORT – 4" HORIZONTAL PLATE STRESS

The applied stresses on the 4" horizontal plate located at the bottom of the horizontal support are provided in Table 4-3 for the normal, upset, and faulted loading combinations. The applied stresses are based on [ ]a,c,e Welding residual stress is added to the operating stress for the postulated flaws located near the welded portion of the horizontal plate. The postulated semi-elliptical flaws with aspect ratios (AR, flaw length over flaw depth) of 6:1 and 2:1, as well as a postulated infinitely long edge flaw are analyzed as a parametric study. A sketch of the horizontal plate and the postulated flaws is shown in Figure 4-16.

It is noted that the stresses for the normal condition exceed those for the upset and faulted conditions. The reason for this has to do with the fact that throughout the development of the calculations, the upset and faulted condition models were extensively refined with regard to stress locations due to the high stresses imposed by the higher loads. One of the refinements made was at the location of the bottom plate. The location of high stress is where the bolt element is attached to the plate element via rigid links. This attachment point between the bolt and the plate represents a discontinuity in the mesh where extremely high stresses develop that are not related to the input loading. In the upset and faulted condition runs, the stresses at this discontinuity were so high that the linearization path that was applied to produce stresses was moved to be very close to the discontinuous location, but just outside of it, so that a more accurate representation of the stress field was developed by the linearization.

For the normal operating condition, the stresses were generally low enough that such refinement was not necessary. For the bottom plate case in particular, the linearization path was kept at a location that cuts directly through the discontinuity, hence the high stress represented in the results.

Table 4-3: Applied Stresses for Bottom of Horizontal Support – 4" Horizontal Plate

[ ]a,c,e

a,c,e

Figure 4-16: Postulated Flaws in the Bottom of Horizontal Support – 4” Horizontal Plate

4.4 BOLTS CONNECTING COLUMN AND BOTTOM OF HORIZONTAL SUPPORT FORCES AND MOMENTS

The applied forces and moments on the bolts which connect the column to the bottom of the horizontal support are provided in Table 4-4 for normal, upset, and faulted loading combinations. [

][a,c,e] A sketch of the bolt and the postulated flaws is shown in Figure 4-17. Pre-load was examined, and the values used in the analysis were far greater than a reasonable snug-fit value; ergo, the analysis is conservative.

Table 4-4: Forces and Moments for Bolts Connecting Column and Bottom of Horizontal Support

a,c,e

a,c,e

Figure 4-17: Postulated Flaws and Loads in Bolts Connecting Column and Bottom of Horizontal Support

4.5 BOLTS AT SOCKET/SLIDE RESTRAINING PLATES STRESS

The applied shear stress on the bolts located at socket/slide restraining plates is provided in Table 4-5 and is conservatively applied to all loading combinations. [

]a,c,e A sketch of the bolt and the postulated flaws is shown in Figure 4-18.

Table 4-5: Applied Shear Stress for Bolts at Socket/Slide Restraining Plates
St. Lucie Units 1 and 2

a,c,e

a,c,e

Figure 4-18: Postulated Single Edge Flaw and Shear Stress in Bolts at Socket/Slide Restraining Plates

5 FRACTURE MECHANICS METHODOLOGY

As discussed in Section 2, the linear elastic fracture mechanics methodology is used to evaluate the structural integrity of the St. Lucie Units 1 and 2 RPV structural steel supports. The goal of the evaluation in this report is to demonstrate that the calculated critical flaw sizes based on 80 years of neutron embrittlement are sufficiently large (i.e., flaw tolerant) as compared to [

]a,c,e A detailed description of the allowable flaw sizes is provided in Section 6.

The critical flaw sizes are calculated based on equating the stress intensity factor to the material-specific fracture toughness with consideration of neutron embrittlement. The discussion for stress intensity factor methodology is provided in Section 5.2, while the determination of material-specific fracture toughness values is discussed in Section 5.1.

5.1 FRACTURE TOUGHNESS DETERMINATION

The critical flaw size is determined by equating the applied stress intensity factor to fracture toughness. For pressure vessel steels, it would be appropriate to use the K_{Ic} or K_{IR} fracture toughness curves in ASME Section XI [8] and ASME Section III Appendix G-2000 [17], respectively. However, some St. Lucie RPV support materials (high strength bolts or carbon steels) were not part of the specifications that were tested to generate the ASME Section XI and Section III curves (i.e., SA-533 Grade B Class 1 and SA-508 Class 1, 2, and 3). [

]a,c,e

[

]a,c,e

5.1.1 Neutron Embrittlement and Nil-Ductility Transition Temperature of RPV Supports

A Westinghouse Owners Group (WOG) (now known as Pressurized Water Reactor Owners Group [PWROG]) program was performed in WCAP-14422, Revision 2-A [21] during the late 1990s and completed in the year 2000 that reassessed the aging effects from neutron embrittlement on the RPV supports for the first license renewal program (60 years). The assessment in WCAP-14422 referenced the extensive industry research and plant-specific evaluations performed in NUREG-1509, NUREG/CR-5320 and the resolution of GSI-15 in NUREG-0933 to conclude that aging management is not a concern for the RPV supports for 60 years of plant life operation.

In the final U.S. NRC safety evaluation for WCAP-14422, the U.S. NRC staff concluded "the staff considers that neutron embrittlement is not a concern for the supports, and does not warrant an aging management program" [21]. The conclusion was based on an evaluation that shows that if all the supports failed, the short span of piping between the vessel and the shield wall would support the load of the vessel. This eliminated the staff's concern with RPV support embrittlement.

The embrittlement prediction models developed in NUREG/CR-5320 and used in the fracture mechanics analysis of Trojan and Turkey Point were discussed in Section 2.3 of NUREG-1509. The major issue of the embrittlement curve in NUREG/CR-5320 was that only fast neutron fluence (E >1.0 MeV) was considered to cause embrittlement damage. Sections 2 and 3 of NUREG-1509 concluded that low-energy neutron irradiation (below 1 MeV) could potentially make a significant contribution to the observed embrittlement. Therefore, the guidance provided in the NUREG-0933 GSI-15 resolution is to utilize Figure 3-1 of NUREG-1509 (reproduced herein as Figure 5-1) to calculate the change in nil-ductility transition temperature (ΔNDTT) based on dpa for the energy spectrum E > 0.1 MeV.

[

]a,c,e

[

]a,c,e

The impact of neutron embrittlement (radiation effects) on the St. Lucie Units 1 and 2 RPV supports was determined for 80 calendar years (72 EFPY) and 40 calendar years (approximately 37.7 EFPY for St. Lucie Unit 1 and 36 EFPY for St. Lucie Unit 2) of operation. The neutron embrittlement is defined as a function of iron displacement per atom (dpa) consistent with Figure 3-1 of NUREG-1509 (reproduced herein as Figure 5-1) to determine change in ΔNDTT. The neutron transport methodology used to generate the iron dpa data followed the guidance of U.S. NRC Regulatory Guide 1.190 [24], and was consistent with the U.S. NRC approved methodology described in WCAP-18124-NP-A [25]. Although this methodology has not been approved by the U.S. NRC for the RPV supports, the methodology has been generically approved for calculations of exposure of the RPV beltline (generally, RPV materials opposite the active fuel). The following paragraphs describe the neutron transport methodology for St. Lucie Units 1 and 2.

[

]a,c,e

[

]a,c,e

The impact of neutron embrittlement (radiation effects) on the RPV supports, defined as iron dpa values from all energy levels, are provided in Table 5-1 and Table 5-2 for St. Lucie Units 1 and 2, respectively. The St. Lucie RPV supports locations of interests for the evaluation herein are on four elevations:

(1) Top of the support column has the maximum iron dpa of the entire column.
(2) Top of the 6” plate under nozzle support foot (top of the support structure).
(3) Bottom of the horizontal support which is the same elevation as (1)
(4) Support column bottom

The iron dpa values include contributions of neutrons above 0.1 MeV as well as neutrons below 0.1 MeV and include a +10% bias on the peripheral and re-entrant corner assembly relative powers. Therefore, the full spectrum dpa values are conservatively used to determine the ΔNDTT in accordance with Figure 3-1 of NUREG-1509. Note that as a study of fracture toughness, iron dpa is increased by 25% to account for analytical uncertainties associated with the methodology used to calculate embrittlement of the St. Lucie RPV support structure. The ΔNDTT calculated based on the upper bound curve in Figure 5-1 (Figure 3-1 of NUREG-1509) for the aforementioned elevations are provided in Table 5-3 and Table 5-4 for 80 calendar years (72 EFPY) and 40 calendar years (approximately 37.7 EFPY for St. Lucie Unit 1 and 36 EFPY for St. Lucie Unit 2).

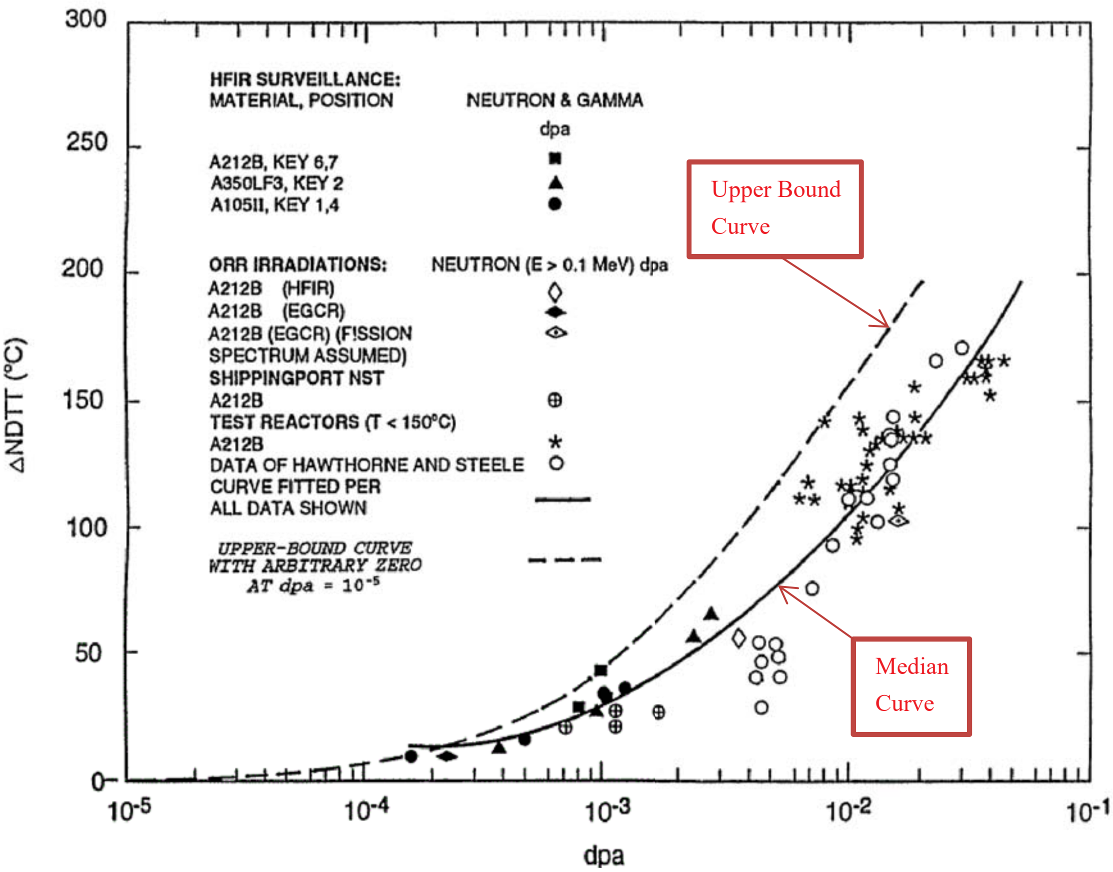


Figure 5-1: Change in Nil-Ductility Transition Temperature, ΔNDTT as a Function of dpa per Figure 3-1 of NUREG-1509 [4]

a,c,e

Figure 5-2: Top View of the Reactor Geometry at the Core Midplane – with Thermal Shield St. Lucie Unit 1 Cycles 1–5

a,c,e

Figure 5-3: Oblique View of the Reactor Geometry – with Thermal Shield, St. Lucie Unit 1 Cycles 1–5

a,c,e

Figure 5-4: Top View of the Reactor Geometry at the Core Midplane – Without Thermal Shield, St. Lucie Unit 1 Cycle 6+

a,c,e

Figure 5-5: Oblique View of the Reactor Geometry – Without Thermal Shield, St. Lucie Unit 1 Cycles 6+

a,c,e

Figure 5-6: Top View of Reactor Geometry at the Core Midplane – St. Lucie Unit 2

a,c,e

Figure 5-7: Oblique View of Reactor Geometry – St. Lucie Unit 2

Table 5-1: St. Lucie Unit 1 Iron dpa (All Neutron Energies) at the RPV Support Structure – +10% Bias on the Peripheral and Re-Entrant Corner Assembly Relative Powers

Elevation [(a)] (cm)	Iron Atom Displacements – All Neutron Energies (dpa) [(d)]						
	37.66 EFPY[(b)]	42 EFPY	48 EFPY	54 EFPY	60 EFPY	66 EFPY	72 EFPY
218.81[(c)]	7.61E-04	8.68E-04	1.02E-03	1.16E-03	1.31E-03	1.46E-03	1.61E-03
213.36	8.89E-04	1.01E-03	1.19E-03	1.36E-03	1.53E-03	1.71E-03	1.88E-03
198.12	1.27E-03	1.45E-03	1.69E-03	1.94E-03	2.19E-03	2.44E-03	2.69E-03
182.88	1.71E-03	1.95E-03	2.29E-03	2.62E-03	2.96E-03	3.30E-03	3.63E-03
167.64	2.27E-03	2.60E-03	3.05E-03	3.50E-03	3.95E-03	4.40E-03	4.85E-03
152.40	2.90E-03	3.31E-03	3.88E-03	4.46E-03	5.03E-03	5.61E-03	6.18E-03
137.16	3.49E-03	3.99E-03	4.68E-03	5.37E-03	6.05E-03	6.74E-03	7.43E-03
121.92	4.00E-03	4.56E-03	5.35E-03	6.13E-03	6.91E-03	7.70E-03	8.48E-03
106.68	4.39E-03	5.01E-03	5.86E-03	6.72E-03	7.57E-03	8.43E-03	9.28E-03
91.44	4.71E-03	5.37E-03	6.29E-03	7.20E-03	8.12E-03	9.03E-03	9.95E-03
76.20	5.05E-03	5.75E-03	6.73E-03	7.71E-03	8.68E-03	9.66E-03	1.06E-02
60.96	4.91E-03	5.60E-03	6.54E-03	7.49E-03	8.44E-03	9.38E-03	1.03E-02
45.72	4.89E-03	5.57E-03	6.51E-03	7.45E-03	8.39E-03	9.33E-03	1.03E-02
30.48	4.86E-03	5.54E-03	6.48E-03	7.41E-03	8.35E-03	9.28E-03	1.02E-02
15.24	4.84E-03	5.51E-03	6.44E-03	7.37E-03	8.30E-03	9.23E-03	1.02E-02
0.00	4.83E-03	5.50E-03	6.42E-03	7.35E-03	8.28E-03	9.20E-03	1.01E-02
-15.24	4.83E-03	5.50E-03	6.42E-03	7.35E-03	8.28E-03	9.21E-03	1.01E-02
-30.48	4.82E-03	5.49E-03	6.42E-03	7.34E-03	8.27E-03	9.19E-03	1.01E-02
-45.72	4.79E-03	5.45E-03	6.37E-03	7.30E-03	8.22E-03	9.14E-03	1.01E-02
-60.96	4.73E-03	5.39E-03	6.30E-03	7.21E-03	8.12E-03	9.04E-03	9.95E-03
-76.20	4.64E-03	5.29E-03	6.18E-03	7.08E-03	7.97E-03	8.87E-03	9.76E-03
-91.44	4.48E-03	5.11E-03	5.98E-03	6.85E-03	7.72E-03	8.58E-03	9.45E-03
-106.68	4.23E-03	4.83E-03	5.65E-03	6.48E-03	7.30E-03	8.12E-03	8.95E-03
-121.92	3.87E-03	4.42E-03	5.18E-03	5.94E-03	6.69E-03	7.45E-03	8.21E-03
-137.16	3.40E-03	3.88E-03	4.55E-03	5.22E-03	5.88E-03	6.55E-03	7.22E-03
-152.40	2.83E-03	3.23E-03	3.79E-03	4.35E-03	4.91E-03	5.46E-03	6.02E-03
-167.64	2.21E-03	2.53E-03	2.96E-03	3.40E-03	3.84E-03	4.27E-03	4.71E-03
-182.88	1.63E-03	1.86E-03	2.18E-03	2.50E-03	2.82E-03	3.14E-03	3.46E-03
-198.12	1.14E-03	1.31E-03	1.53E-03	1.75E-03	1.98E-03	2.20E-03	2.42E-03
-213.36	7.94E-04	9.05E-04	1.06E-03	1.21E-03	1.36E-03	1.52E-03	1.67E-03
-228.60	5.58E-04	6.35E-04	7.42E-04	8.48E-04	9.55E-04	1.06E-03	1.17E-03
-243.84	4.06E-04	4.61E-04	5.38E-04	6.14E-04	6.91E-04	7.67E-04	8.44E-04
-259.08	3.04E-04	3.46E-04	4.02E-04	4.59E-04	5.16E-04	5.73E-04	6.30E-04
-274.32	2.34E-04	2.66E-04	3.09E-04	3.53E-04	3.96E-04	4.39E-04	4.83E-04
-289.56	1.88E-04	2.14E-04	2.48E-04	2.83E-04	3.18E-04	3.53E-04	3.88E-04
-304.80	1.55E-04	1.75E-04	2.04E-04	2.32E-04	2.60E-04	2.89E-04	3.17E-04

Notes:

(a) Elevations are given with respect to the midplane of the active fuel.

(b) Value listed is the projected EFPY at the end of Cycle 30.

(c) This elevation corresponds to the top of the 6-inch-thick horizontal plate at the top-center of the RPV support structure.

(d) Linear interpolation between the EFPY values listed in this table may be performed as necessary.

Table 5-2: St. Lucie Unit 2 Iron dpa (All Neutron Energies) at the RPV Support Structure – +10% Bias on the Peripheral and Re-Entrant Corner Assembly Relative Powers

Elevation[(a)] (cm)	Iron Atom Displacements – All Neutron Energies (dpa) [(d)]							
	32.30 EFPY[(b)]	36 EFPY	42 EFPY	48 EFPY	54 EFPY	60 EFPY	66 EFPY	72 EFPY
231.16[(c)]	5.25E-04	6.01E-04	7.26E-04	8.50E-04	9.74E-04	1.10E-03	1.22E-03	1.35E-03
228.60	5.62E-04	6.44E-04	7.77E-04	9.10E-04	1.04E-03	1.18E-03	1.31E-03	1.44E-03
213.36	8.17E-04	9.36E-04	1.13E-03	1.32E-03	1.52E-03	1.71E-03	1.90E-03	2.09E-03
198.12	1.10E-03	1.26E-03	1.52E-03	1.78E-03	2.04E-03	2.30E-03	2.56E-03	2.82E-03
182.88	1.50E-03	1.73E-03	2.08E-03	2.44E-03	2.80E-03	3.16E-03	3.52E-03	3.88E-03
167.64	2.00E-03	2.30E-03	2.79E-03	3.27E-03	3.75E-03	4.23E-03	4.72E-03	5.20E-03
152.40	2.53E-03	2.91E-03	3.53E-03	4.15E-03	4.77E-03	5.38E-03	6.00E-03	6.62E-03
137.16	3.02E-03	3.48E-03	4.22E-03	4.97E-03	5.71E-03	6.45E-03	7.20E-03	7.94E-03
121.92	3.43E-03	3.95E-03	4.80E-03	5.65E-03	6.50E-03	7.34E-03	8.19E-03	9.04E-03
106.68	3.76E-03	4.33E-03	5.27E-03	6.20E-03	7.14E-03	8.07E-03	9.01E-03	9.94E-03
91.44	4.14E-03	4.77E-03	5.81E-03	6.84E-03	7.87E-03	8.90E-03	9.94E-03	1.10E-02
76.20	4.08E-03	4.71E-03	5.73E-03	6.75E-03	7.77E-03	8.79E-03	9.81E-03	1.08E-02
60.96	4.07E-03	4.70E-03	5.72E-03	6.73E-03	7.75E-03	8.77E-03	9.79E-03	1.08E-02
45.72	4.08E-03	4.71E-03	5.73E-03	6.75E-03	7.77E-03	8.80E-03	9.82E-03	1.08E-02
30.48	4.08E-03	4.71E-03	5.73E-03	6.75E-03	7.77E-03	8.80E-03	9.82E-03	1.08E-02
15.24	4.07E-03	4.70E-03	5.72E-03	6.74E-03	7.76E-03	8.78E-03	9.80E-03	1.08E-02
0.00	4.06E-03	4.69E-03	5.71E-03	6.73E-03	7.75E-03	8.77E-03	9.78E-03	1.08E-02
-15.24	4.06E-03	4.69E-03	5.70E-03	6.72E-03	7.74E-03	8.76E-03	9.78E-03	1.08E-02
-30.48	4.04E-03	4.67E-03	5.68E-03	6.70E-03	7.71E-03	8.72E-03	9.74E-03	1.08E-02
-45.72	4.01E-03	4.63E-03	5.63E-03	6.64E-03	7.65E-03	8.65E-03	9.66E-03	1.07E-02
-60.96	3.96E-03	4.57E-03	5.56E-03	6.55E-03	7.55E-03	8.54E-03	9.54E-03	1.05E-02
-76.20	3.88E-03	4.48E-03	5.45E-03	6.43E-03	7.40E-03	8.37E-03	9.35E-03	1.03E-02
-91.44	3.75E-03	4.33E-03	5.27E-03	6.21E-03	7.16E-03	8.10E-03	9.04E-03	9.98E-03
-106.68	3.54E-03	4.09E-03	4.98E-03	5.87E-03	6.76E-03	7.65E-03	8.55E-03	9.44E-03
-121.92	3.25E-03	3.75E-03	4.57E-03	5.38E-03	6.20E-03	7.02E-03	7.83E-03	8.65E-03
-137.16	2.87E-03	3.31E-03	4.02E-03	4.74E-03	5.46E-03	6.18E-03	6.89E-03	7.61E-03
-152.40	2.40E-03	2.77E-03	3.37E-03	3.96E-03	4.56E-03	5.15E-03	5.75E-03	6.35E-03
-167.64	1.89E-03	2.18E-03	2.64E-03	3.11E-03	3.57E-03	4.04E-03	4.50E-03	4.96E-03
-182.88	1.39E-03	1.60E-03	1.94E-03	2.28E-03	2.62E-03	2.96E-03	3.30E-03	3.64E-03
-198.12	9.80E-04	1.13E-03	1.36E-03	1.60E-03	1.84E-03	2.08E-03	2.32E-03	2.55E-03
-213.36	6.76E-04	7.77E-04	9.41E-04	1.10E-03	1.27E-03	1.43E-03	1.60E-03	1.76E-03
-228.60	4.73E-04	5.44E-04	6.58E-04	7.73E-04	8.88E-04	1.00E-03	1.12E-03	1.23E-03
-243.84	3.40E-04	3.91E-04	4.74E-04	5.57E-04	6.40E-04	7.22E-04	8.05E-04	8.88E-04
-259.08	2.53E-04	2.91E-04	3.52E-04	4.14E-04	4.76E-04	5.38E-04	6.00E-04	6.62E-04
-274.32	1.99E-04	2.29E-04	2.78E-04	3.27E-04	3.76E-04	4.25E-04	4.74E-04	5.23E-04
-289.56	1.63E-04	1.88E-04	2.28E-04	2.68E-04	3.08E-04	3.48E-04	3.88E-04	4.28E-04

Notes:
(a) Elevations are given with respect to the midplane of the active fuel.
(b) Value listed is the projected EFPY at the end of Cycle 25.
(c) This elevation corresponds to the top of the 6-inch-thick horizontal plate at the top-center of the RPV support structure.
(d) Linear interpolation between the EFPY values listed in this table may be performed as necessary.

Table 5-3: Iron Displacement per Atom and Corresponding ΔNDTT for St. Lucie Unit 1

Item	Location	EFPY	Iron dpa	Upper Bound Curve ΔNDTT [(b)]			
1	Support Column – Maximum (Table 5-1 Elevation: 76.20 cm)	72	1.06E-02	283	°F	157	°C
		72+25%dpa	1.33E-02	302	°F	168	°C
		37.7	5.05E-03	208	°F	116	°C
		37.7+25%dpa	6.31E-03	231	°F	128	°C
2	Top of 6" Plate under Nozzle Foot (Table 5-1 Elevation: 218.81 cm)	72	1.61E-03	108	°F	60	°C
		72+25%dpa	2.01E-03	126	°F	70	°C
		37.7	7.61E-04	63	°F	35	°C
		37.7+25%dpa	9.51E-04	76	°F	42	°C
3	Bottom of Horizontal Support Top of Column (Table 5-1 Elevation: 76.20 cm)	72	1.06E-02	283	°F	157	°C
		72+25%dpa	1.33E-02	302	°F	168	°C
		37.7	5.05E-03	208	°F	116	°C
		37.7+25%dpa	6.31.E-03	231	°F	128	°C
4	Support Column Bottom (Table 5-1 Elevation: -304.80 cm)	All	<<3.17E-04 [(a)]	<<33[(a)]	°F	<<18[(a)]	°C

Notes:

(a) This is the iron dpa at the lowest elevation reported in Table 5-1 (219 + 304 cm below top of support = 17 feet). The bottom of the support column is over 10 feet below this reported iron dpa elevation (28 ft from the top to bottom of support [11.a]). The top of the support column bottom foot is 7 feet below this reported iron dpa elevation. Therefore, iron dpa and any associated embrittlement at these locations is negligible. Embrittlement need not be considered in the support bottom components.

(b) The conversion of delta temperature (T) in degrees Celsius to Fahrenheit is ΔT°F = 9/5 ΔT°C.

Table 5-4: Iron Displacement per Atom and Corresponding ΔNDTT for St. Lucie Unit 2

Item	Location	EFPY	Iron dpa	Upper Bound Curve ΔNDTT (b)	
1	Support Column – Maximum (Table 5-2 Elevation: 91.44 cm)	72	1.10E-02	286 °F	159 °C
		72+25%dpa	1.38E-02	306 °F	170 °C
		36	4.77E-03	202 °F	112 °C
		36+25%dpa	5.96E-03	224 °F	125 °C
2	Top of 6” Plate under Nozzle Foot (Table 5-2 Elevation: 231.16 cm)	72	1.35E-03	96 °F	53 °C
		72+25%dpa	1.69E-03	111 °F	62 °C
		36	6.01E-04	54 °F	30 °C
		36+25%dpa	7.51.E-04	62 °F	35 °C
3	Bottom of Horizontal Support Top of Column (Table 5-2 Elevation: 91.44 cm)	72	1.10E-02	286 °F	159 °C
		72+25%dpa	1.38E-02	306 °F	170 °C
		36	4.77E-03	202 °F	112 °C
		36+25%dpa	5.96E-03	224 °F	125 °C
4	Support Column Bottom (Table 5-2 Elevation: -289.56 cm)	All	<<4.28E-04 (a)	<<40(a) °F	<<22(a) °C

Notes:

(a) This is the iron dpa at the lowest elevation reported in Table 5-2 (231 + 290 cm below top of support = 17 feet). The bottom of the support column is over 10 feet below this reported iron dpa elevation (28 ft from the top to bottom of support [11.b]). The top of the support column bottom foot is 7 feet below this reported iron dpa elevation. Therefore, iron dpa and any associated embrittlement at these locations is negligible. Embrittlement need not be considered in the support bottom components.

(b) The conversion of delta temperature (T) in degrees Celsius to Fahrenheit is ΔT°F = 9/5 ΔT°C.

5.1.2 Strain Rate Effects

Per the guidance in Section 4.3.3.1 of NUREG-1509 [4], strain rates associated with dynamic loading for earthquake or pipe break scenarios should be addressed (i.e., the rate of load application). Per [

]^{a,c,e}

[

]^{a,c,e}

a,c,e

Figure 5-8: [ ]^{a,c,e}

5.1.3 Bulk Material Temperature

The bulk material temperature or normal operating temperature of the RPV supports is an input for the fracture toughness determination. Figure 1 in the St. Lucie Unit 1 UFSAR, Appendix 3H [26] provides a temperature distribution during steady-state normal operating conditions for the hot leg support. The temperature distribution during steady-state normal operating conditions for the cold leg RPV supports is not available. As illustrated in Figure 5-9, the hot leg reactor support foot location is 189°F. [

]a,c,e Fracture toughness is determined for both the hot and cold leg support normal operating temperatures and reported in Table 5-10 for St. Lucie Unit 1. The limiting cold leg RPV support fracture toughness is conservatively used for the allowable flaw size evaluation.

There is no available thermal analysis of the normal operating conditions for the St. Lucie Unit 2 RPV supports. [

]a,c,e

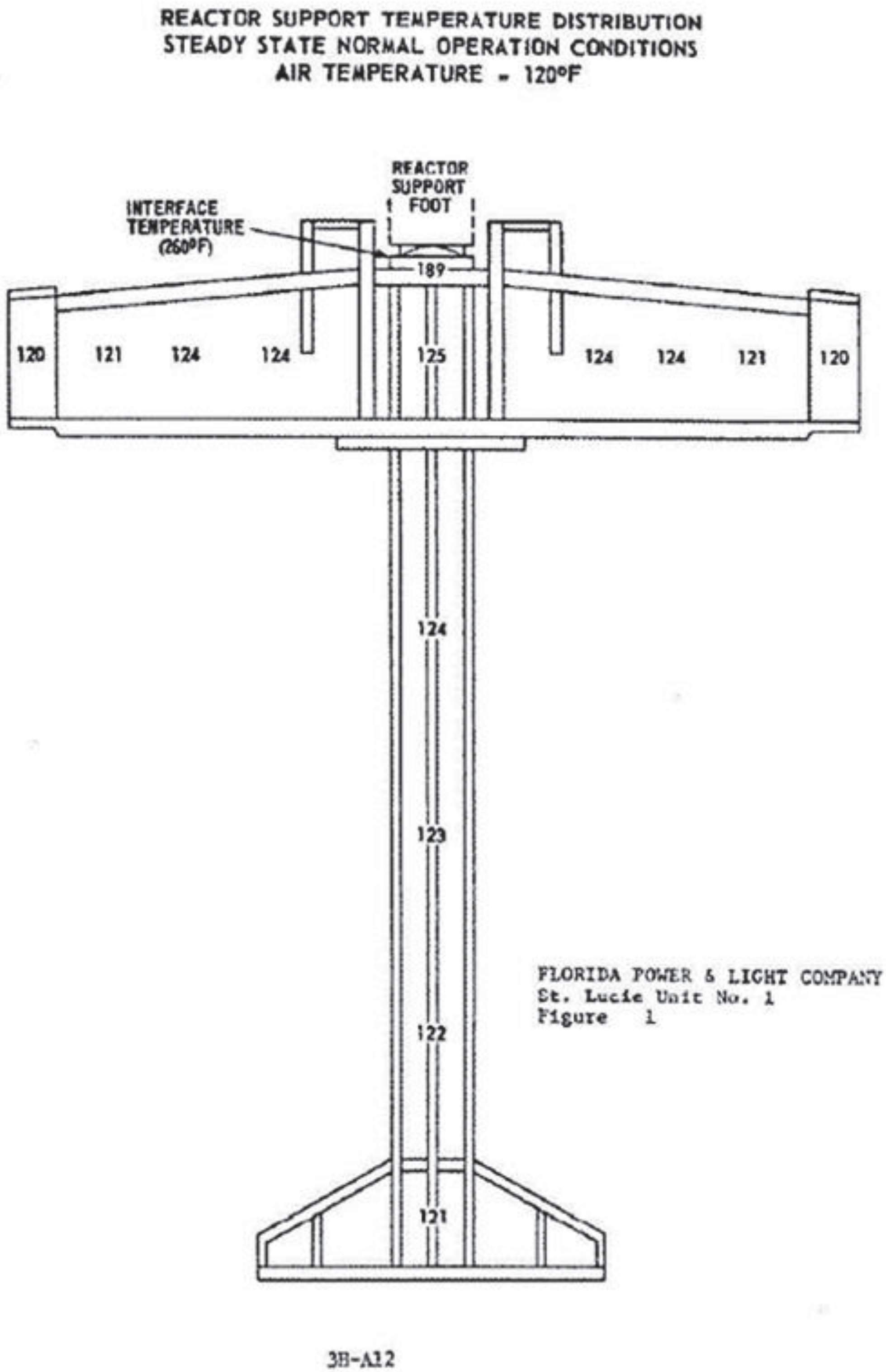


Figure 5-9: St. Lucie Unit 1 RPV Support Normal Operation Temperature [26]

5.1.4 Initial Nil-Ductility Transition Temperature

St. Lucie Unit 1 RPV supports are detailed, fabricated and delivered per Specification FLO-8770-761 [10.a] and its addendum [10.b] and Unit 2 per Specification FLO-2998-761 [10.c]. The specifications state that unless otherwise specified on the drawings, structura1steel shall be in accordance with ASTM Specification A36. However, the RPV supports drawings, Sheet 1 of [11.a] and Sheet 2 of [11.b], specify that steel shall be ASTM A-441 unless otherwise noted. Therefore, the ASTM A36 material is not applicable to the St. Lucie Units 1 and 2 RPV supports fracture mechanics evaluation herein. For both units, some component pieces are welded plate ASTM A-533, Class 2, Grade B per drawings [11.a] and [11.b].

[

]a,c,e

Table 5-5: [ ]a,c,e

a,c,e

5.1.5 St. Lucie CMTR Review

No CMTRs with [ ]a,c,e for the structurally significant support steels were obtained for St. Lucie Unit 1, [ ]a,c,e The available St. Lucie Unit 2 CMTRs have been reviewed and are summarized in this section.

Weld

The available St. Lucie Unit 2 weld CMTR sheets were reviewed with the [ ]a,c,e

Table 5-6: [ ]a,c,e

a,c,e

ASTM A-441 Steel Plates

The ASTM A-441 CMTRs for St. Lucie Unit 2 were reviewed with the [ ]a,c,e

Table 5-7: [ ]a,c,e

a,c,e

ASTM A-533, B2 Steel Plates

The ASTM A-533 CMTRs for St. Lucie Unit 2 were reviewed with the [

]a,c,e

Table 5-8: [ ]a,c,e

a,c,e

5.1.6 Estimation of Unirradiated Fracture Toughness

[

]a,c,e

Table 5-9: [

]a,c,e

a,c,e

a,c,e

Figure 5-10: [ ][a,c,e]

5.1.7 Example of Fracture Toughness Determination by Curve Shift ASTM A-441 for St. Lucie Unit 2

The determination of fracture toughness is described in detail in this section for the St. Lucie Unit 2 ASTM A-441 material [

]a,c,e

The fracture toughness values for all St. Lucie Unit 2 support steels, including ASTM A-533 and weld material, is provided in Table 5-11.

a,c,e

Figure 5-11: ASTM A-441 Thin Plates Fracture Toughness – Highest Fluence at 72 EFPY

a,c,e

Figure 5-12: ASTM A-441 Thin Plate Fracture Toughness – Top of Horizontal Support Fluence at 72 EFPY

5.1.8 ASTM A-441 (Column and Horizontal Support Components for St. Lucie Unit 1)

The columns and horizontal support in the RPV support system are largely made of ASTM A-441 plates per the specification [10.a] and drawing [11.a]. [

]a,c,e

The fracture toughness values for all St. Lucie Unit 1 support steels, including ASTM A-533 material (which is described in Section 5.1.9) and weld material, are provided in Table 5-10.

5.1.9 ASTM A-533 B2 (St. Lucie Unit 1)

[

]a,c,e

The fracture toughness values for all St. Lucie Unit 1 support steels, including ASTM A-441 material (which is described in Section 5.1.8) and weld material, are provided in Table 5-10.

5.1.10 ASTM A-325 (Bolts for St. Lucie Units 1 and 2)

The bolts at the top of the columns of the RPV support systems are made of A-325 material. The diameter of the St. Lucie bolts is 1.25”. [

]a,c,e

[

]a,c,e

The fracture toughness values for the St. Lucie Units 1 and 2 bolt material (ASTM A-325) are provided in Table 5-10 and Table 5-11.

5.1.11 Fracture Toughness Results

The adjusted reference temperature and applicable fracture toughness of the RPV supports at St. Lucie Units 1 and 2 are shown in Table 5-10 and Table 5-11, respectively, using the methodology and inputs discussed in Section 5.1.1 through Section 5.1.10.

The iron dpa values from Section 5.1.1 are used to determine the embrittled fracture toughness. The ΔNDTT is based on Figure 3-1 of NUREG-1509 using the conservatively biased full spectrum fluence embrittlement effects resulting from 40 calendar years, 40 calendar years +25% dpa, 72 EFPYs (80 calendar years) and 72 EFPY +25% dpa of radiation. The +25% in iron dpa accounts for analytical uncertainties associated with the methodology used to calculate embrittlement of the St. Lucie RPV support structure. Bounding initial reference temperatures are used with adjustment for dynamic effects on fracture toughness.

Table 5-10: Fracture Toughness for St. Lucie Unit 1 Material Components

a,c,e

Table 5-11: Fracture Toughness for St. Lucie Unit 2 Material Components

a,c,e

5.2 STRESS INTENSITY FACTORS AND POSTULATED FLAWS

A wide range of stress intensity factor methodologies were considered in the analysis of linear elastic fracture mechanics to account for the support geometry (bolt and flat plate models) and for flaw shapes (infinitely long edge flaws and semi-elliptical flaws). The prevalent crack-opening stress components are the stresses normal to the crack face; however, shear stresses are also present in the supports. [

]a,c,e

are then used to calculate the Mode I stress intensity factors, which can be equated to the fracture toughness of the material to back-calculate the critical flaw sizes (discussed in Section 7). Stress intensity factors for Mode II crack opening, also denoted as K_{II}, are considered for the bolts located at the socket/slide restraining plates where the main load is based on shear stress. A general description of the stress intensity factor methodologies is provided in Table 5-12 for each of the five RPV support components and the following sections provide more detail for each stress intensity factor correlation.

The crack tip stress intensity factors are determined based on the stress intensity factor expressions from API-579 2016 Edition [31] and Tada [32]. The stress intensity factor databases are industry accepted solutions and have been used frequently for previous fracture mechanics projects. [

]a,c,e

A variety of flaw shapes are considered in the fracture mechanics analysis based on the previously mentioned stress intensity factor databases to provide a parametric study of critical flaw sizes within each of the RPV support components. The flaw shapes which are appropriate for the various support geometry (bolt and flat plate models) are described in Table 5-12. These flaw shapes include infinitely long edge flaws in plates and semi-elliptical flaws with aspect ratios (AR, flaw length/flaw depth) of 2 and 6 as discussed in Section 5.2.1. Note that the welded plate components are subjected to welding residual stress as described in Section 4. The bar shaped components are analyzed with 360° continuous circumferential, straight front, and semi-circular front flaw shapes as discussed in Section 5.2.2.

5.2.1 Plate Model

The welded plates within the RPV horizontal support are modeled as a flat plate. The first postulated flaw case in the flat plate model is a semi-elliptical flaw with aspect ratios (flaw length / flaw depth) of 2 and 6 as a parametric study of critical flaw sizes. A graphical representation of a semi-elliptical flaw in a plate model is provided in Figure 5-13.a. The stress intensity factor is calculated at the surface point ($\phi = 0°$, see Figure 5-13.a) and the deepest point ($\phi = 90°$) along the postulated crack front, and the limiting critical flaw sizes are reported in Section 7. The stress provided in Section 4.1, Section 4.2 and Section 4.3 is conservatively applied as constant through the wall thickness (i.e., as a pure membrane stress). The semi-elliptical flaws included welding residual stress since the flaws are postulated near the welds of the plate components. The stress intensity factor correlation for the semi-elliptical flaw with pure membrane stress is provided in API-579 [31] Section 9B.3.4 as follows:

$$K_I = \mathrm{M}_m \sigma_m \sqrt{\frac{\pi a}{Q}}$$

Where:

K_I = stress intensity factor (ksi-in$^{0.5}$)

M_m = factor to account for flaw size, aspect ratio, and geometry

σ_m = membrane stress (ksi)

a = flaw depth or size (in.)

$Q = 1 + 1.464(a/c)^{1.65}$ for a/c < 1

c = half flaw length (in.)

The welded plate components also considered an infinitely long edge flaw. A graphical representation of an infinitely long edge flaw in a plate model is provided in Figure 5-13.b. The stress provided in Section 4.1, Section 4.2 and Section 4.3 is conservatively applied as constant through the wall thickness (i.e., as a pure membrane stress). The infinitely long edge flaws included welding residual stress since the flaws are postulated near the welds of the plate components. The stress intensity factor for the infinitely long edge flaw in a plate with pure membrane stress is provided in API-579 [31] Section 9B.3.2 as follows:

$$K_I = G_o \sigma_o \sqrt{\pi a}$$

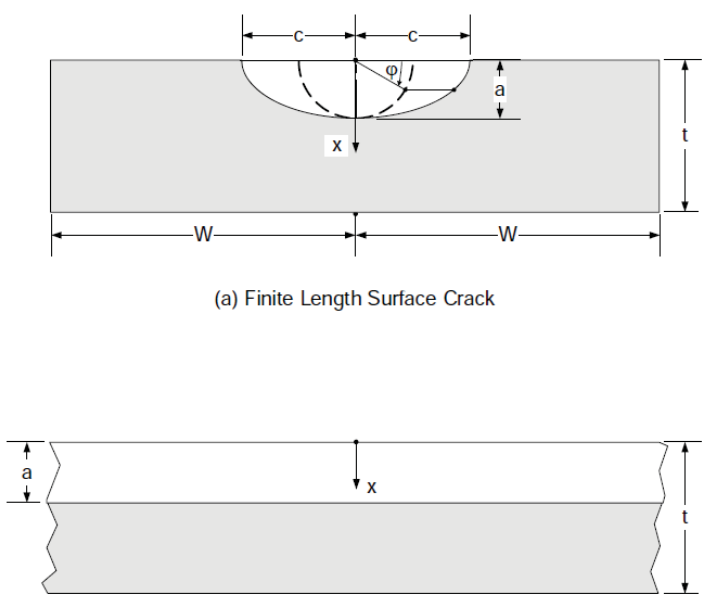
Where:

K_I = stress intensity factor (ksi-in$^{0.5}$)

G_o = influence coefficient to account for flaw size and geometry

σ_o = membrane stress (ksi)

a = flaw depth or size (in.)



(a) Finite Length Surface Crack

(b) Infinitely Long Surface Crack (c>>a)

Figure 5-13: Postulated Surface Flaws in a Plate Model

5.2.2 Round Bar Model (for Bolts)

The bolts which connect the column to the bottom of the horizontal support were conservatively assumed to have completely 360° circumferential flaws oriented perpendicular to the bolt centerlines and therefore responsive to bolt tensile loading. In addition, the straight front and semi-circular crack models are postulated as a parametric study and for less limiting critical flaw size results. A graphical representation of the three flaw types in a bar model is provided in Figure 5-14. The axial force, shear stress, and moments on the bar components are provided in Section 4.4. The stress intensity factor for the bolts is based on API-579 [31] Sections 9B.11.1, 9B.11.2, and 9B.11.3 for round bar surface circumferential crack – 360°, straight front crack, and semi-circular front crack, respectively, with through-wall membrane stress as follows:

$$K_I = \mathrm{M}_m \sigma_m \sqrt{\pi a}$$

Where:

K_I = stress intensity factor (ksi-in$^{0.5}$)

M_m = influence factor to account for flaw size and geometry

σ_m = membrane stress (ksi)

a = flaw depth or size (in.)

The bolts located at the socket/slide restraining plates are subjected to shear stress which causes Mode II and Mode III stress intensity factors (see Figure 5-15 for a graphical representation of a single edge flaw in a plate model). The Mode II and Mode III stress intensity factors for a single edge crack in the bolt are provided based on Section 2.31 of Tada [32] as follows:

$$K_{II} = \mathrm{F}_{II(a/b)} \tau \sqrt{\pi a}$$

$$K_{III} = \mathrm{F}_{III(a/b)} \tau_l \sqrt{\pi a}$$

Where:

K_{II} and K_{III} = Mode II and Mode III stress intensity factors (ksi-in$^{0.5}$)

$F_{II(a/b)}$ and $F_{III(a/b)}$ = influence coefficient to account for flaw size (a) and geometry (thickness)

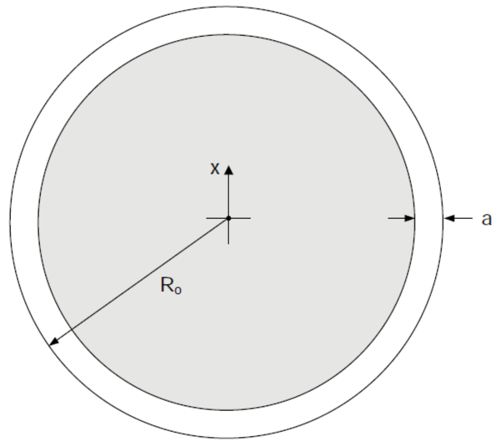
τ and τ_l = shear stress (ksi)

a = flaw depth or size (in.)

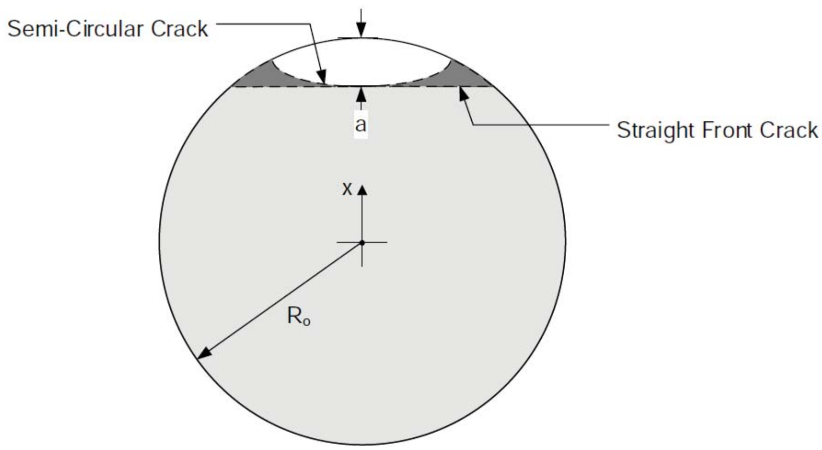
b = thickness of component (in.)

A review of Mode II and Mode III influence coefficients determined that $F_{II(a/b)}$ will provide a more limiting critical flaw size; thus, critical flaw size is only calculated and reported based on the Mode II stress intensity factor. The Mode II stress intensity factor is based on a [

]^{a,c,e}



(a) 360° Continuous Surface Flaw



(b) Straight Front and Semi-Circular Surface Crack

Figure 5-14: Postulated Flaws in a Round Bar Model

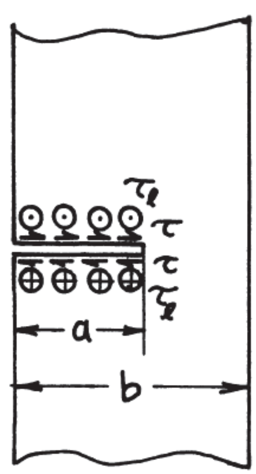


Figure 5-15: Postulated Single Edge Flaw with Shear Stress in a Plate Model

Table 5-12: Mode I and II Stress Intensity Factor Model Description

Component	Model Shape	Flaw Configuration	Stress Intensity Factor Reference and Section No.	Figure of Postulated Flaw Shape
All Welded Plates	Plate [(a)] Mode I Stress Intensity Factor	Semi-Elliptical	API-579 Section 9B.3.4 [31]	Figure 5-13.a
		Infinite	API-579 Section 9B.3.2 [31]	Figure 5-13.b
Bolts Connecting Column and Bottom of Horizontal Support	Bar Mode I Stress Intensity Factor	360° Continuous Circumferential	API-579 Section 9B.11.1 [31]	Figure 5-14
		Straight Front	API-579 Section 9B.11.2 [31]	
		Semi-Circular Front	API-579 Section 9B.11.3 [31]	
Bolts at Socket/Slide Assembly	Rectangular Bar [(b)] Mode II Stress Intensity Factor	Single Edge Crack	Tada Part 2.31 Section A [32]	Figure 5-15

Notes:

a,c,e

6 ALLOWABLE FLAW SIZES

The goal of the fracture mechanics analysis is to demonstrate that the calculated critical flaw sizes based on 80 years of neutron embrittlement are sufficiently large as compared to [

]a,c,e

[

]a,c,e

The allowable flaw sizes in Table 6-1 are compared against the calculated critical flaw sizes in Section 7 to demonstrate that the St. Lucie Units 1 and 2 RPV supports are flaw tolerant for 80 years of service.

Table 6-1: Allowable Flaw Sizes

a,c,e

Table 6-1 Continued: Allowable Flaw Sizes

a,c,e

Table 6-1 Continued: Allowable Flaw Sizes

a,c,e

7 CRITICAL FLAW SIZE CALCULATION RESULTS

As discussed in several previous sections of this report, the goal of the fracture mechanics analysis for St. Lucie Units 1 and 2 RPV supports is to justify that plant life extension to 80 years does not cause a structural integrity concern based on radiation embrittlement. One technique used to demonstrate continued operability of the RPV supports past 60 years is to compare the critical flaw sizes calculated in the analysis herein to [

]a,c,e These previously mentioned allowable flaw sizes are described in detail in Section 6 of this report.

Per Section 4.2.4 of NUREG-1509, the supports would demonstrate safe operation with consideration of neutron radiation embrittlement if the following criteria are met:

1. The initial nil-ductility transition temperature of the RPV supports is well below the minimum operating temperature.
2. The radiation exposure at the supports is low.
3. The peak tensile stresses are 6 ksi or less.

However, as shown in Section 4, [

]a,c,e Thus, a fracture mechanics evaluation is completed for the 4” horizontal plate and 5” vertical plate at the top of the horizontal support, the 4” horizontal plate at the bottom of the horizontal support, the bolts which connect the column and bottom of the horizontal support, and the bolts at the socket/slide restraining plates. The other components such as the base plate, anchor bolts, column, and other welded plates within the RPV support system will be bounded by, or are represented by, the five components mentioned previously (these other components are discussed in the various subsections of Section 7).

This section provides the critical flaw sizes for each of the five components based on the latest plant-specific stresses, welding residual stress, operating condition temperatures, neutron embrittlement for 80 calendar years (72 EFPY) and 40 years (approximately 37.7 EFPY for St. Lucie Unit 1 and 36 EFPY for St. Lucie Unit 2), shift in NDTT based on Figure 3-1 of NUREG-1509 (reproduced as Figure 5-1 herein), and the latest stress intensity factors used in the industry. [

]a,c,e

[

]a,c,e The ΔNDTT based on the neutron embrittlement at 40 and 80 years is calculated in Table 5-3 and Table 5-4 for various locations around the St. Lucie RPV supports. The ΔNDTT for each component is conservative based on a representative location to account for embrittlement effects.

It should be noted that the RPV supports experience various loading conditions (normal, upset, and faulted) as discussed in Section 4. [

]a,c,e

[

]a,c,e

Even with the previously mentioned conservatisms, many components in the fracture mechanics analysis have large margin between the allowable flaw size and the critical flaw size as discussed in Section 7.1 through Section 7.5.

7.1 TOP OF HORIZONTAL SUPPORT –4" HORIZONTAL PLATE

The 4" horizontal plate (ASTM A-441) at the top of the horizontal support and the associated welds are subjected to moderate embrittlement resulting in the minimum fracture toughness values as shown below (see Table 5-10 and Table 5-11). Note that, as a study of fracture toughness, iron dpa is increased by 25% to account for analytical uncertainties associated with the methodology used to calculate embrittlement of the St. Lucie RPV support structure.

St. Lucie Unit 1

[

]a,c,e

St. Lucie Unit 2

[

]a,c,e

In addition to the applied stresses on the horizontal plate (see Table 4-1), welding residual stress is considered per Section 4 for the postulated semi-elliptical flaws and infinitely long edge flaw in the welded portion of the plate. Based on Section 4, [

]a,c,e

Various postulated flaw shapes in a plate model were analyzed, including a study of semi-elliptical flaws with aspect ratios (flaw length over flaw depth) of 6 and 2 and an infinite length flaw in the weld. The aspect ratios of 6 and 2 for the semi-elliptical flaws, as well as the infinitely long flaw shape are provided as a parametric study of critical flaw sizes. The calculated critical flaw sizes are shown in Table 7-1.a and Table 7-1.b for the previously mentioned postulated flaw shapes, as well as the [

]a,c,e

[

]a,c,e thus, the horizontal plate at the top of the horizontal support and associated welds continue to be structurally stable considering 80 years of radiation embrittlement effects on the supports.

As shown in Table 7-1.a and Table 7-1.b, the change in embrittlement from 40 to 80 years results in critical flaw sizes that vary by approximately 2% to 10% for St. Lucie Unit 1 and approximately 4% to 16% for St. Lucie Unit 2. The upper range of change in critical flaw sizes (10% and 16%) is based on the postulated semi-elliptical flaw size with aspect ratio of 2 and is mostly due to the [

]a,c,e The magnitude of the critical flaw sizes between 40 and 80 years is more similar (in the range of approximately 2% to 6% for St. Lucie Unit 1 and approximately 4% to 9% for St. Lucie Unit 2) for the postulated semi-elliptical flaw size with aspect ratio of 6 and the infinitely long edge flaw. [

]a,c,e In addition, the difference in critical flaw size results between embrittlement with and without analytical uncertainties ranges from 1% to 4% (i.e., the magnitude of the critical flaw sizes is similar). Thus, the horizontal plate at the top of the horizontal support and the associated welds are considered to be flaw tolerant for 80 years and there is no concern for structural instability due to radiation embrittlement.

7.1.1 Base Plate

[

]a,c,e Thus, the bottom of the column/base plate and associated welds are considered to be flaw tolerant for 80 years and there is no concern for structural instability due to radiation embrittlement. [

]a,c,e

Table 7-1.a: Summary of Top of Horizontal Support – 4" Horizontal Plate Critical Flaw Size St. Lucie Unit 1

Component	Fracture Toughness	Loading Combination	Critical Flaw Size (a/t), % (a)		
			Semi-Elliptical (AR = 2) (b)	Semi-Elliptical (AR = 6) (b)	Infinite Edge (b)
4" Horizontal Plate	[ ]a,c,e for 37.7 EFPY (without analytical uncertainties)	Normal	24.7	13.7	10.0
		Upset	16.8	9.2	6.9
		Faulted	24.8	13.8	10.0
	[ ]a,c,e for 72 EFPY (without analytical uncertainties)	Normal	14.8	8.1	6.1
		Upset	9.9	5.4	4.1
		Faulted	14.8	8.1	6.1
	[ ]a,c,e for 37.7 EFPY (with analytical uncertainties)	Normal	21.0	11.6	8.6
		Upset	14.2	7.7	5.9
		Faulted	21.1	11.6	8.6
	[ ]a,c,e for 72 EFPY (with analytical uncertainties)	Normal	12.9	7.1	5.4
		Upset	8.6	4.7	3.6
		Faulted	13.0	7.1	5.4
Section XI Allowable Flaw Size			5.2	2.6	1.9

Notes:

(a) The critical flaw sizes are determined by setting the applied stress intensity factor equal to the fracture toughness and back-calculating flaw size. Plate thickness = 4".

(b) The welds within the entire RPV structural steel supports at St. Lucie Unit 1 [

]a,c,e

Table 7-1.b: Summary of Top of Horizontal Support – 4” Horizontal Plate Critical Flaw Size St. Lucie Unit 2

Component	Fracture Toughness	Loading Combination	Critical Flaw Size (a/t), % (a)		
			Semi-Elliptical (AR = 2) (b)	Semi-Elliptical (AR = 6) (b)	Infinite Edge (b)
4” Horizontal Plate	[ ]^{a,c,e} for 36 EFPY (without analytical uncertainties)	Normal	34.8	19.6	13.8
		Upset	27.5	15.3	11.1
		Faulted	41.8	23.8	16.2
	[ ]^{a,c,e} for 72 EFPY (without analytical uncertainties)	Normal	21.7	12.0	8.9
		Upset	16.7	9.2	6.9
		Faulted	26.9	15.0	10.8
	[ ]^{a,c,e} for 36 EFPY (with analytical uncertainties)	Normal	31.7	17.8	12.6
		Upset	24.9	13.8	10.1
		Faulted	38.3	21.7	15.0
	[ ]^{a,c,e} for 72 EFPY (with analytical uncertainties)	Normal	18.2	10.0	7.5
		Upset	13.9	7.6	5.8
		Faulted	22.6	12.5	9.2
Section XI Allowable Flaw Size			5.2	2.6	1.9

Notes:

(a) The critical flaw sizes are determined by setting the applied stress intensity factor equal to the fracture toughness and back-calculating flaw size. Plate thickness = 4”.

(b) The welds within the entire RPV structural steel supports at St. Lucie Unit 2 [

]^{a,c,e}

7.2 TOP OF HORIZONTAL SUPPORT – 5” VERTICAL PLATE

The 5” vertical plate (ASTM A-533 Class 2, Grade B) at the top of the horizontal support and the associated welds are subjected to moderate embrittlement resulting in the minimum fracture toughness values as shown below (see Table 5-10 and Table 5-11). Note that as a study, iron dpa is increased by 25% to account for analytical uncertainties associated with the methodology used to calculate embrittlement of the St. Lucie RPV support structure.

St. Lucie Unit 1

[

]a,c,e

St. Lucie Unit 2

[

]a,c,e

In addition to the applied stresses on the vertical plate (see Table 4-2), welding residual stress is considered per Section 4 for the postulated semi-elliptical flaw and infinitely long edge flaw in the welded portion of the plate. Based on Section 4, [

]a,c,e

Various postulated flaw shapes in a plate model were analyzed, including a study of semi-elliptical flaws with aspect ratios (flaw length over flaw depth) of 6 and 2 and an infinite length flaw in the weld. The aspect ratios of 6 and 2 for the semi-elliptical flaws, as well as the infinitely long flaw shape are provided as a parametric study of critical flaw sizes. The calculated critical flaw sizes are shown in Table 7-2.a and Table 7-2.b for the previously mentioned postulated flaw shapes, as well as the [

]a,c,e

[ ]a,c,e thus, the vertical plate at the top of the horizontal support and associated welds continue to be structurally stable considering 80 years of radiation embrittlement effects on the supports.

As shown in Table 7-2.a and Table 7-2.b, the change in embrittlement from 40 to 80 years results in critical flaw sizes that vary by approximately 2% to 13% for St. Lucie Units 1 and 2. The upper range of change in critical flaw sizes (13%) is based on the postulated semi-elliptical flaw size with aspect ratio of 2 and is mostly due to the [ ]a,c,e The magnitude of the critical flaw sizes between 40 and 80 years is more similar (on the range of approximately 2% to 8% for St. Lucie Units 1 and 2) for the postulated semi-elliptical flaw size with aspect ratio of 6 and the infinitely long edge flaw. [ ]a,c,e In addition, the difference in critical flaw size results between embrittlement with and without analytical uncertainties ranges from 1% to 5% (i.e., the magnitude of the critical flaw sizes is similar). Thus, the vertical plate at the top of the horizontal support and the associated welds are considered to be flaw tolerant for 80 years and there is no concern for structural instability due to radiation embrittlement.

Table 7-2.a: Summary of Top of Horizontal Support – 5” Vertical Plate Critical Flaw Size St. Lucie Unit 1

Component	Fracture Toughness	Loading Combination	Critical Flaw Size (a/t), % [(a)]		
			Semi-Elliptical (AR = 2) [(b)]	Semi-Elliptical (AR = 6) [(b)]	Infinite Edge [(b)]
5” Vertical Plate	[ ][a,c,e] for 37.7 EFPY (without analytical uncertainties)	Normal	31.7	17.8	12.7
		Upset	17.2	9.4	7.1
		Faulted	11.8	6.4	4.9
	[ ][a,c,e] for 72 EFPY (without analytical uncertainties)	Normal	18.9	10.4	7.8
		Upset	9.7	5.3	4.1
		Faulted	6.6	3.6	2.8
	[ ][a,c,e] for 37.7 EFPY (with analytical uncertainties)	Normal	27.1	15.1	10.9
		Upset	14.4	7.9	6.0
		Faulted	9.8	5.3	4.1
	[ ][a,c,e] for 72 EFPY (with analytical uncertainties)	Normal	15.5	8.5	6.4
		Upset	7.9	4.3	3.3
		Faulted	5.4	2.9	2.2
Section XI Allowable Flaw Size			5.2	2.6	1.9

Notes:

(a) The critical flaw sizes are determined by setting the applied stress intensity factor equal to the fracture toughness and back-calculating flaw size. Plate thickness = 5”.

(b) The welds within the entire RPV structural steel supports at St. Lucie Unit 1 [

]a,c,e

Table 7-2.b: Summary of Top of Horizontal Support – 5" Vertical Plate Critical Flaw Size St. Lucie Unit 2

Component	Fracture Toughness	Loading Combination	Critical Flaw Size (a/t), % (a)		
			Semi-Elliptical (AR = 2) (b)	Semi-Elliptical (AR = 6) (b)	Infinite Edge (b)
5" Vertical Plate	[ ]a,c,e for 36 EFPY (without analytical uncertainties)	Normal	34.8	19.6	13.8
		Upset	28.2	15.7	11.3
		Faulted	33.9	19.0	13.5
	[ ]a,c,e for 72 EFPY (without analytical uncertainties)	Normal	21.8	12.0	8.9
		Upset	17.2	9.4	7.1
		Faulted	21.1	11.7	8.6
	[ ]a,c,e for 36 EFPY (with analytical uncertainties)	Normal	31.7	17.8	12.7
		Upset	25.5	14.2	10.3
		Faulted	30.8	17.3	12.3
	[ ]a,c,e for 72 EFPY (with analytical uncertainties)	Normal	18.2	10.0	7.5
		Upset	14.3	7.8	5.9
		Faulted	17.7	9.7	7.3
Section XI Allowable Flaw Size			5.2	2.6	1.9

Notes:

(a) The critical flaw sizes are determined by setting the applied stress intensity factor equal to the fracture toughness and back-calculating flaw size. Plate thickness = 5".

(b) The welds within the entire RPV structural steel supports at St. Lucie Unit 2 [

]a,c,e

7.3 BOTTOM OF HORIZONTAL SUPPORT – 4” HORIZONTAL PLATE

The 4” horizontal plate (ASTM A-441) at the bottom of the horizontal support and the associated welds are subjected to high embrittlement resulting in the minimum fracture toughness values as shown below (see Table 5-10 and Table 5-11). Note that as a study of fracture toughness, iron dpa is increased by 25% to account for analytical uncertainties associated with the methodology used to calculate embrittlement of the St. Lucie RPV support structure. It is shown that the change in neutron embrittlement over time is not significant (i.e., the change in fracture toughness is small from 40 years to 80 years) since the bottom of the horizontal support is close to the vicinity of the RPV active core.

St. Lucie Unit 1

[

]a,c,e

St. Lucie Unit 2

[

]a,c,e

In addition to the applied stresses on the horizontal plate (see Table 4-3), welding residual stress is considered per Section 4 for the postulated semi-elliptical flaws and infinitely long edge flaw in the welded portion of the plate. Based on Section 4, [

]a,c,e

Various postulated flaw shapes in a plate model were analyzed, including a study of semi-elliptical flaws with aspect ratios (flaw length over flaw depth) of 6 and 2 and an infinite length flaw in the weld. The aspect ratios of 6 and 2 for the semi-elliptical flaws, as well as the other flaw shapes are provided as a parametric study of critical flaw sizes. The calculated critical flaw sizes are shown in Table 7-3.a and Table 7-3.b for the previously mentioned postulated flaw shapes, as well as the [

]a,c,e

[

]a,c,e thus, the horizontal plate at the bottom of the horizontal support and associated welds continue to be structurally stable considering 80 years of radiation embrittlement effects on the supports.

As shown in Table 7-3.a and Table 7-3.b, the change in embrittlement from 40 to 80 years results in critical flaw sizes that vary up to approximately 3% (i.e., the magnitude of the critical flaw sizes is similar) for St. Lucie Units 1 and 2. It is determined that the effect of the change in embrittlement on the critical flaw sizes over time is minor. In addition, the difference in critical flaw size results between embrittlement with and without analytical uncertainties varies up to approximately 1% (i.e., the magnitude of the critical flaw sizes is similar). Thus, the horizontal plate at the bottom of the horizontal support and the associated welds are considered to be flaw tolerant for 80 years and there is no concern for structural instability due to radiation embrittlement.

7.3.1 Column

[

]a,c,e Thus, the column and associated welds are considered to be flaw tolerant for 80 years and there is no concern for structural instability due to radiation embrittlement. [

]a,c,e

Table 7-3.a: Summary of Bottom of Horizontal Support – 4” Horizontal Plate Critical Flaw Size St. Lucie Unit 1

Component	Fracture Toughness	Loading Combination	Critical Flaw Size (a/t), % [a]		
			Semi-Elliptical (AR = 2) [b]	Semi-Elliptical (AR = 6) [b]	Infinite Edge [b]
4” Horizontal Plate	[ ]a,c,e for 37.7 EFPY (without analytical uncertainties)	Normal	8.5	4.6	3.5
		Upset	14.4	7.9	6.0
		Faulted	9.4	5.1	3.9
	[ ]a,c,e for 72 EFPY (without analytical uncertainties)	Normal	7.2	3.9	3.0
		Upset	12.3	6.7	5.1
		Faulted	8.1	4.4	3.4
	[ ]a,c,e for 37.7 EFPY (with analytical uncertainties)	Normal	7.9	4.3	3.3
		Upset	13.4	7.3	5.5
		Faulted	8.7	4.7	3.6
	[ ]a,c,e for 72 EFPY (with analytical uncertainties)	Normal	7.2	3.9	3.0
		Upset	12.3	6.7	5.1
		Faulted	8.1	4.4	3.4
Section XI Allowable Flaw Size			5.2	2.6	1.9

Notes:

(a) The critical flaw sizes are determined by setting the applied stress intensity factor equal to the fracture toughness and back-calculating flaw size. Plate thickness = 4”.

(b) The welds within the entire RPV structural steel supports at St. Lucie Unit 1 [

]a,c,e

Table 7-3.b: Summary of Bottom of Horizontal Support – 4" Horizontal Plate Critical Flaw Size St. Lucie Unit 2

Component	Fracture Toughness	Loading Combination	Critical Flaw Size (a/t), % (a)		
			Semi-Elliptical (AR = 2) (b)	Semi-Elliptical (AR = 6) (b)	Infinite Edge (b)
4" Horizontal Plate	[ ]^{a,c,e} for 36 EFPY (without analytical uncertainties)	Normal	9.8	5.3	4.1
		Upset	16.2	8.9	6.7
		Faulted	13.0	7.1	5.4
	[ ]^{a,c,e} for 72 EFPY (without analytical uncertainties)	Normal	7.9	4.3	3.3
		Upset	13.0	7.1	5.4
		Faulted	10.4	5.7	4.3
	[ ]^{a,c,e} for 36 EFPY (with analytical uncertainties)	Normal	9.1	5.0	3.8
		Upset	15.1	8.3	6.3
		Faulted	12.1	6.6	5.0
	[ ]^{a,c,e} for 72 EFPY (with analytical uncertainties)	Normal	7.2	3.9	3.0
		Upset	12.0	6.6	5.0
		Faulted	9.6	5.2	4.0
Section XI Allowable Flaw Size			5.2	2.6	1.9

Notes:

(a) The critical flaw sizes are determined by setting the applied stress intensity factor equal to the fracture toughness and back-calculating flaw size. Plate thickness = 4".

(b) The welds within the entire RPV structural steel supports at St. Lucie Unit 2 [

]^{a,c,e}

7.4 BOLTS CONNECTING COLUMN AND BOTTOM OF HORIZONTAL SUPPORT

There are eight bolts (ASTM A-325) which connect the top of the column to the bottom of the horizontal support. These bolts are subjected to high embrittlement resulting in fracture toughness values as shown below (see Table 5-10 and Table 5-11). Note that as a study of fracture toughness, iron dpa is increased by 25% to account for analytical uncertainties associated with the methodology used to calculate embrittlement of the St. Lucie RPV support structure. It is shown that the change in neutron embrittlement over time is not significant (i.e., the change in fracture toughness is small from 40 years to 80 years) since the bottom of the horizontal support/top of the column is close to the vicinity of the RPV active core.

<u>St. Lucie Unit 1</u>

[

]a,c,e

<u>St. Lucie Unit 2</u>

[

]a,c,e

The [

]a,c,e the bolts continue to be structurally stable considering 80 years of radiation embrittlement effects on the supports.

As shown in Table 7-4.a and Table 7-4.b, the change in embrittlement from 40 to 80 years results in critical flaw sizes that vary by approximately 1% to 4% (i.e., the magnitude of the critical flaw sizes is similar). It is determined that the effect of the change in embrittlement over time is minor on the critical flaw sizes. In addition, the difference in critical flaw size results between embrittlement with and without analytical uncertainties is 1% to 2% (i.e., the magnitude of the critical flaw sizes is similar). Thus, the bolts that connect the column to the bottom of the horizontal supports are considered to be flaw tolerant for 80 years and there is no concern for structural instability due to radiation embrittlement.

7.4.1 Anchor Bolts

[

]^{a,c,e}

The anchor bolts at the base plates are embedded in concrete. Additionally, the irradiation embrittlement effect is insignificant for the base plate anchor bolts; thus, [ ]^{a,c,e} These anchor bolts are included in the FEA model, and the boundary conditions are set up such that the anchor bolts resist any lateral loads that would cause the baseplate to slide along the concrete. Due to the rigidity of the upper part of the support, the anchor bolts at the base experience insignificant shear load. Stresses for the base plate anchor bolts are bounded by the bolts connecting the top of the column and the horizontal support. [ ]^{a,c,e} Thus, these anchor bolts are considered to be flaw tolerant for 80 years and there is no concern for structural instability due to radiation embrittlement.

The anchor bolts at the horizontal supports are not entirely embedded in concrete but partially exposed. Due to their relative flexibility compared to the rest of the upper support, which is embedded in concrete at its ends, and the clearance holes, these anchor bolts will not provide any significant load resistance in the directions normal to the bolt axis. All of the loads are transmitted through the body of the support to the concrete embedment at the ends of the upper support and to the column. As a result, the St. Lucie RPV horizontal support anchor bolts are not limiting. These anchor bolts are considered to be flaw tolerant for 80 years and there is no concern for structural instability due to radiation embrittlement.

Table 7-4.a: Summary of Bolts Connecting Column and Bottom of Horizontal Support Critical Flaw Size St. Lucie Unit 1

Component	Fracture Toughness	Loading Combination	Critical Flaw Size, % (a)		
			Circumferential 360° Continuous, a/Radius	Straight Front a/D	Semi-Circular Front a/D
Bolts	[ ]a,c,e for 37.7 EFPY (without analytical uncertainties)	Normal	11.1	13.8	21.5
		Upset	10.7	13.1	20.7
		Faulted	20.4	41.5	49.5
	[ ]a,c,e for 72 EFPY (without analytical uncertainties)	Normal	10.1	12.1	19.3
		Upset	9.7	11.5	18.5
		Faulted	19.4	39.0	47.2
	[ ]a,c,e for 37.7 EFPY (with analytical uncertainties)	Normal	10.6	12.9	20.4
		Upset	10.2	12.3	19.6
		Faulted	19.9	40.3	48.4
	[ ]a,c,e for 72 EFPY (with analytical uncertainties)	Normal	10.1	12.1	19.3
		Upset	9.7	11.5	18.5
		Faulted	19.4	39.0	47.2
Section XI Allowable Flaw Size			See Note (c)	1.0 (b)	1.0 (b)

Notes:

(a) The critical flaw sizes are determined by setting the applied stress intensity factor equal to the fracture toughness and back-calculating flaw size. Bolt Diameter (D) = 1.25".

(b) The Section XI allowable flaw size based on [

]a,c,e

(c) The Section XI allowable flaw size based on [

]a,c,e

Table 7-4.b: Summary of Bolts Connecting Column and Bottom of Horizontal Support Critical Flaw Size St. Lucie Unit 2

Component	Fracture Toughness	Loading Combination	Critical Flaw Size, % (a)		
			Circumferential 360° Continuous, a/Radius	Straight Front a/D	Semi-Circular Front a/D
Bolts	[ ]^{a,c,e} for 36 EFPY (without analytical uncertainties)	Normal	11.6	14.6	22.5
		Upset	12.0	15.7	24.0
		Faulted	18.2	35.7	44.2
	[ ]^{a,c,e} for 72 EFPY (without analytical uncertainties)	Normal	10.1	12.1	19.3
		Upset	10.6	13.1	20.7
		Faulted	16.7	31.6	40.5
	[ ]^{a,c,e} for 36 EFPY (with analytical uncertainties)	Normal	11.1	13.8	21.5
		Upset	11.5	14.9	22.9
		Faulted	17.7	34.4	43.0
	[ ]^{a,c,e} for 72 EFPY (with analytical uncertainties)	Normal	10.1	12.1	19.3
		Upset	10.6	13.1	20.7
		Faulted	16.7	31.6	40.5
Section XI Allowable Flaw Size			See Note (c)	1.0 (b)	1.0 (b)

Notes:

(a) The critical flaw sizes are determined by setting the applied stress intensity factor equal to the fracture toughness and back-calculating flaw size. Bolt Diameter (D) = 1.25".

(b) The Section XI allowable flaw size based on [

]^{a,c,e}

(c) The Section XI allowable flaw size based on [

]^{a,c,e}

7.5 BOLTS AT SOCKET/SLIDE RESTRAINING PLATES

There are eight bolts that fasten two restraining plates to the horizontal surface of the socket/slide assembly, near the top of the RPV support assembly. These bolts are away from the vicinity of the RPV active core and subjected to a moderate amount of embrittlement; however, since the material of these bolts is unknown, the largest amount of embrittlement on the entire RPV supports is applied to these bolts resulting in fracture toughness values as shown below (see Table 5-10 and Table 5-11). The fracture toughness values used to calculate critical flaw size are nearly on the lower shelf of the 95% lower tolerance bound Master Curve. Note that as a study of fracture toughness, iron dpa is increased by 25% to account for analytical uncertainties associated with the methodology used to calculate embrittlement of the St. Lucie RPV support structure.

St. Lucie Unit 1

[

]a,c,e

St. Lucie Unit 2

[

]a,c,e

The bolts are only subjected to the [

]a,c,e

thus, the bolts continue to be structurally stable considering 80 years of radiation embrittlement effects on the supports.

[

]a,c,e

As shown in Table 7-5.a and Table 7-5.b, the change in embrittlement from 40 to 80 years results in critical flaw sizes that vary by approximately 1% to 4% (i.e., the magnitude of the critical flaw sizes is similar). It is determined that the effect of the change in embrittlement over time on the critical flaw sizes is minor. In addition, the difference in critical flaw size results between embrittlement with and without analytical uncertainties is approximately 2% (i.e., the magnitude of the critical flaw sizes is similar). Thus, the bolts that fasten two restraining plates to the horizontal surface of the socket/slide assembly are considered to be flaw tolerant for 80 years and there is no concern for structural instability due to radiation embrittlement.

Table 7-5.a: Summary of Bolts at Socket/Slide Restraining Plate Critical Flaw Size St. Lucie Unit 1

Component	Fracture Toughness	Loading Combination	Critical Flaw Size (a/D), % (a) Single Edge Flaw K_{II} Model
Bolt	[ ]a,c,e for 37.7 EFPY (without analytical uncertainties)	All	19.2
	[ ]a,c,e for 72 EFPY (without analytical uncertainties)	All	16.5
	[ ]a,c,e for 37.7 EFPY (with analytical uncertainties)	All	17.8
	[ ]a,c,e for 72 EFPY (with analytical uncertainties)	All	16.5
Section XI Allowable Flaw Size			2.1 (b)

Notes:

(a) The critical flaw sizes are determined by setting the applied stress intensity factor equal to the fracture toughness and back-calculating flaw size. Bolt Diameter = 0.875".

(b) The Section XI allowable flaw size based on [

]a,c,e

Table 7-5.b: Summary of Bolts at Socket/Slide Restraining Plate Critical Flaw Size St. Lucie Unit 2

Component	Fracture Toughness	Loading Combination	Critical Flaw Size (a/D), % [(a)] Single Edge Flaw K_{II} Model
Bolt	[ ][a,c,e] for 36 EFPY (without analytical uncertainties)	All	20.5
	[ ][a,c,e] for 72 EFPY (without analytical uncertainties)	All	16.5
	[ ][a,c,e] for 36 EFPY (with analytical uncertainties)	All	19.2
	[ ][a,c,e] for 72 EFPY (with analytical uncertainties)	All	16.5
Section XI Allowable Flaw Size			2.1 [(b)]

Notes:

(a) The critical flaw sizes are determined by setting the applied stress intensity factor equal to the fracture toughness and back-calculating flaw size. Bolt Diameter = 0.875".

(b) The Section XI allowable flaw size based on [

]a,c,e

8 DISCUSSION OF CONCLUSIONS

8.1 EVALUATION OF CURRENT CONDITIONS

Per Section 4.3.1 of NUREG-1509 [4], physical examination of the structural components is essential to the reevaluation completed herein and an assessment of the overall condition of the RPV support structure. For St. Lucie Unit 2, the inspection records indicate that all rejectable defects discovered during visual inspection, magnetic testing, and ultrasonic testing records were repaired. Rejectable defects discovered per radiographic inspections are characterized as slag inclusions, lack of fusion and surface irregularities; however, no cracks were recorded or marked as rejectable. Although inspection records for St. Lucie Unit 1 were not identified, the specifications for both St. Lucie Unit 1 and Unit 2 state that the components of the RPV supports were to be inspected during initial fabrication and that welds were to be carefully examined to ensure that there are no slag inclusions, craters, cracks or undercuts and that defects are to be removed by chipping or grinding and then rewelded. In addition, the specifications state that all finished work shall be of good quality and have a neat appearance without warpage. The ASTM A-533 and ASTM A-441 standards and related ASTM standards generally state that plates shall be free of injurious defects and shall have a workmanlike finish. Visual inspection requirements for bolts per ASTM A-325 state that any bolt which contains a burst would be considered defective and removed/destroyed. Thus, it is expected that components analyzed are free from cracks after initial fabrication and after an extended period of time since crack growth mechanism are not present at the RPV supports.

The following text was based on LTR-SDA-21-021 [6]:

St. Lucie Unit 1 RPV supports were inspected in April 2021 based on VT-3 per 2007 Edition and 2008 Addenda ASME Section XI, IWF requirements. The Unit 1 RPV supports were also inspected in 2012. Based on the visual examination, all Unit 1 accessible support components were acceptable, there was no deformation or structural degradation, there were no cracks in welds, there were no loose/missing/detached items, and no recordable corrosion was observed (except for light rust). In addition, the Unit 1 RPV support at the "B" hot leg was examined in 2018 with VT-3 and magnetic particle examination of the nozzle support foot. The results were also acceptable.

The St. Lucie Unit 2 RPV supports were inspected in 2012. Based on the visual examination, all Unit 2 accessible support components were acceptable, there was no deformation or structural degradation, there were no cracks in welds, there were no loose/missing/detached items, and no recordable corrosion was observed. The Unit 2 inspection report identified boric acid residue on the supports; however, the structural integrity of the supports was not impacted. In addition, all Unit 2 RPV supports are scheduled for examination in the Fall of 2021.

The following describes the current St. Lucie Units 1 and 2 ISI programs pertaining to the RPV supports. St. Lucie Units 1 and 2 have similar configurations and accessibility regarding inspection of the RPV supports. For the upper support area where stress is limiting, VT-3 is performed for the A1 cold leg and the A2 cold leg. Additionally, magnetic particle testing is required for one of the three RPV nozzle support feet. VT-3 and MT are performed for the "B" hot leg RPV support. These inspections are implemented once every ten years as part of the ISI program.

To date, the St. Lucie Units 1 and 2 RPV support locations have shown acceptable inspection results over past inspection intervals and no gross deformation has been detected.

8.2 CHANGE IN EMBRITTLEMENT OVER TIME

[

]a,c,e

8.3 CRITICAL FLAW SIZE CONCLUSIONS

Based on the conclusions in NUREG-0933, it was determined that the RPV supports were not a concern for the entirety of the plant's life (i.e., 40 or 60 years). Even if all the supports were totally removed (i.e., broken), the piping has acceptable margin to carry the load of the vessel. Nevertheless, for plants applying for long term life extension (i.e., beyond 60 years) the U.S. NRC has recently been requesting a re-assessment of the RPV structural steel supports, based on a fracture mechanics evaluation, to account for neutron embrittlement.

The goal of the fracture mechanics analysis in this report for St. Lucie Units 1 and 2 was to demonstrate that the calculated critical flaw sizes based on 80 years of neutron embrittlement are sufficiently large (i.e., flaw tolerant) as compared to [

]a,c,e

[ ]a,c,e These previously mentioned allowable flaw sizes were described in detail in Section 6 of this report.

There are five components within the St. Lucie RPV support system that were analyzed via the fracture mechanics approach described in NUREG-1509. The five components are the 4” horizontal plate and 5” vertical plate at the top of the horizontal support, the 4” horizontal plate at the bottom of the horizontal support, the bolts which connect the column and bottom of the horizontal support, and the bolts at the socket/slide restraining plates. These five components were considered for the critical flaw size calculations because these locations could experience tensile stresses and high embrittlement effects. The other components such as the base plate, anchor bolts, column, and other welded plates within the RPV support system will be bounded by, or are represented by, the five components mentioned previously (these other components were discussed in the various subsections of Section 7). The critical flaw sizes for each of the five components are based on the latest plant-specific stresses, welding residual stress, operating condition temperatures, neutron embrittlement for 40 and 80 calendar years of operation, shift in NDTT based on Figure 3-1 of NUREG-1509 (reproduced as Figure 5-1 herein), and the latest stress intensity factors used in the industry. [

]a,c,e

The critical flaw sizes for the RPV support components are determined for 40 and 80 calendar years of operation in Section 7.1 through Section 7.5 for various flaw shapes; the limiting critical flaw size for each component is provided in Table 8-1.a and Table 8-1.b. A summary of conservatisms included in the calculation of the critical flaw sizes are provided in Section 7. The critical flaw size represents the largest flaw size that results from equating the applied stress intensity factor to the component-specific material fracture toughness, and this flaw size is compared against [

]a,c,e

For the welded plates that were analyzed, the critical flaw sizes for the range of postulated flaw sizes (aspect ratios of 2, 6 and infinitely long edge flaws) are larger than the [

]a,c,e Even with all these conservatisms, these critical flaw sizes are deemed to be acceptable.

For the single edge flaw in the bolts at the socket/slide assembly and the straight front and semi-circular front circumferential postulated flaws in the bolts which connect the column to the bottom of the horizontal support, the critical flaw sizes are all above the [

]a,c,e Even with all these conservatisms, these critical flaw sizes are deemed to be acceptable. [

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[

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Generally stated, all calculated critical flaw sizes in this report would [

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Based on the discussions above and the results provided in this report, it is concluded that the RPV supports at St. Lucie Units 1 and 2 are structurally stable (i.e., flaw tolerant) considering 80 calendar years (72 EFPY) of radiation embrittlement effects, and a sufficient level of flaw tolerance is demonstrated to justify continuing the current examination of the RPV structural steel supports. In conclusion, the loss of fracture toughness due to neutron embrittlement over 80 years is not significant and, therefore, the St. Lucie Units 1 and 2 RPV structural steel supports do not require more frequent inspections than those required by the current ASME Section XI inspection program.

Table 8-1.a: Summary of St. Lucie Unit 1 RPV Support Critical Flaw Sizes

Fracture Toughness	Loading Condition	Critical Flaw Size (a)				
		Top of Horizontal Support – Horizontal Plate (a/t) (b)	Top of Horizontal Support – Vertical Plate (a/t) (b)	Bottom of Horizontal Support – Horizontal Plate (a/t) (b)	Bolts Connecting Column and Bottom of Horizontal Support (a/R)	Bolts at Socket/Slide Restraining Plate (a/D)
Fracture Toughness for 37.7 EFPY (without Analytical Uncertainties)	Normal	10.0	12.7	3.5	11.1	19.2
	Upset	6.9	7.1	6.0	10.7	
	Faulted	10.0	4.9	3.9	20.4	
Fracture Toughness for 72 EFPY (without Analytical Uncertainties)	Normal	6.1	7.8	3.0	10.1	16.5
	Upset	4.1	4.1	5.1	9.7	
	Faulted	6.1	2.8	3.4	19.4	
Fracture Toughness for 37.7 EFPY (with Analytical Uncertainties)	Normal	8.6	10.9	3.3	10.6	17.8
	Upset	5.9	6.0	5.5	10.2	
	Faulted	8.6	4.1	3.6	19.9	
Fracture Toughness for 72 EFPY (with Analytical Uncertainties)	Normal	5.4	6.4	3.0	10.1	16.5
	Upset	3.6	3.3	5.1	9.7	
	Faulted	5.4	2.2	3.4	19.4	
Section XI Allowable Flaw Size		1.9	1.9	1.9	Note (c)	2.1

Notes for Table 8-1.a:

(a) The critical flaw sizes are determined by setting the applied stress intensity factor equal to the fracture toughness and back-calculating flaw size. The critical flaw size is a/t (flaw depth over thickness ratio) for plates and a/D (flaw depth over diameter ratio) and a/R (flaw depth over radius ratio) for bolts. There are no significant transients or thermal cycling that would cause any crack growth over time. The calculated critical flaw sizes are compared against the Section XI allowable flaw sizes (permissible per Section 4.3.4.1 of NUREG-1509). In all cases, the critical flaw sizes are larger than the Section XI allowable flaw sizes; thereby concluding that the St. Lucie RPV support components continue to be structurally stable (i.e., flaw tolerant) considering 80 years of radiation or embrittlement effects on the supports. Also, these flaws would have been detected during initial fabrication and repaired.

(b) This location considers welding residual stress.

(c) The Section XI allowable flaw size based on surface examination of bolts is limited to 0.25” in length for a circumferential flaw; thus, a 360° continuous circumferential flaw is inherently not allowed.

Table 8-1.b: Summary of St. Lucie Unit 2 RPV Support Critical Flaw Sizes

Fracture Toughness	Loading Condition	Critical Flaw Size [a]				
		Top of Horizontal Support – Horizontal Plate (a/t) [b]	Top of Horizontal Support – Vertical Plate (a/t) [b]	Bottom of Horizontal Support – Horizontal Plate (a/t) [b]	Bolts Connecting Column and Bottom of Horizontal Support (a/R)	Bolts at Socket/Slide Restraining Plate (a/D)
Fracture Toughness for 36 EFPY (without Analytical Uncertainties)	Normal	13.8	13.8	4.1	11.6	20.5
	Upset	11.1	11.3	6.7	12.0	
	Faulted	16.2	13.5	5.4	18.2	
Fracture Toughness for 72 EFPY (without Analytical Uncertainties)	Normal	8.9	8.9	3.3	10.1	16.5
	Upset	6.9	7.1	5.4	10.6	
	Faulted	10.8	8.6	4.3	16.7	
Fracture Toughness for 36 EFPY (with Analytical Uncertainties)	Normal	12.6	12.7	3.8	11.1	19.2
	Upset	10.1	10.3	6.3	11.5	
	Faulted	15.0	12.3	5.0	17.7	
Fracture Toughness for 72 EFPY (with Analytical Uncertainties)	Normal	7.5	7.5	3.0	10.1	16.5
	Upset	5.8	5.9	5.0	10.6	
	Faulted	9.2	7.3	4.0	16.7	
Section XI Allowable Flaw Size		1.9	1.9	1.9	Note (c)	2.1

Notes for Table 8-1.b:

(a) The critical flaw sizes are determined by setting the applied stress intensity factor equal to the fracture toughness and back-calculating flaw size. The critical flaw size is a/t (flaw depth over thickness ratio) for plates and a/D (flaw depth over diameter ratio) and a/R (flaw depth over radius ratio) for bolts. There are no significant transients or thermal cycling that would cause any crack growth over time. The calculated critical flaw sizes are compared against the Section XI allowable flaw sizes (permissible per Section 4.3.4.1 of NUREG-1509). In all cases, the critical flaw sizes are larger than the Section XI allowable flaw sizes; thereby concluding that the St. Lucie RPV support components continue to be structurally stable (i.e., flaw tolerant) considering 80 years of radiation or embrittlement effects on the supports. Also, these flaws would have been detected during initial fabrication and repaired.

(b) This location considers welding residual stress.

(c) The Section XI allowable flaw size based on surface examination of bolts is limited to 0.25" in length for a circumferential flaw; thus, a 360° continuous circumferential flaw is inherently not allowed.

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c. [ ]a,c,e

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