



PNP 2025-080

10 CFR 50.55a

November 26, 2025

ATTN: Document Control Desk  
U.S. Nuclear Regulatory Commission  
Washington, DC 20555-0001

Palisades Nuclear Plant  
NRC Docket No. 50-255  
Renewed Facility Operating License No. DPR-20

Subject: Response to Request for Additional Information for Relief Request RR 5-12,  
*Proposed Alternative to ASME Section XI Code for Full Structural Weld Overlays  
of Primary Coolant System Hot Leg, Cold Leg, and Pressurizer Nozzle Dissimilar  
Metal Welds*

Pursuant to Title 10 of the Code of Federal Regulations (10 CFR) 50.55a, *Codes and standards*, Holtec Palisades hereby provides the response to the Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI)(ADAMS Accession Number ML25310A225). This request is regarding the previously submitted Relief Request RR 5-12 for the Palisades Nuclear Plant (PNP) dated August 20, 2025 (ADAMS Accession Number ML25232A195).

Attachment 1 to this letter provides the NRC Questions and the Holtec Palisades Responses.

Attachment 2 contains a non-proprietary version of the documents requested by the NRC in question 1 of the Request for Additional Information.

Attachment 3 provides the Framatome Affidavit Proprietary Information Notice for each of the documents provided in Attachment 4.

Attachment 4 provides the requested four documents which contain information considered proprietary to Framatome. On behalf of Framatome, Holtec Palisades request that the NRC withhold this information in accordance with 10 CFR 2.390. Upon removal of the proprietary information in this attachment, the balance of this submittal is decontrolled.

This letter contains no new regulatory commitments.

Please refer any questions regarding this submittal to Kami Miller – Manager Emergency Preparedness and Regulatory Assurance, at (269) 764-2375.

Respectfully,

Jean A.  
Fleming

Digitally signed by Jean A. Fleming  
UN: cn=Jean A. Fleming, c=US,  
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Jean A. Fleming  
Vice President, Licensing and Regulatory Assurance  
Holtec International

- Attachments:
1. NRC Questions and Holtec Palisades Responses
  2. Non-Proprietary versions of the Framatome Documents listed in Attachment 4.
  3. Framatome Affidavits, Proprietary Information Notice for the documents listed in Attachment 4.
  4. Framatome Document No. 32-9373588-001, "Palisades Hot Leg Surge Nozzle FSWOL Calculation," November 2025;  
Framatome Document No. 32-9377011-001, "Palisades Hot Leg Surge Nozzle FSWOL Weld Residual Stress Analysis," November 2025;  
Framatome Document No.32-9390082-001, "Palisades Hot Leg Surge Nozzle FSWOL Crack Growth Appendix C Analysis," November 2025; and  
Framatome Document No.32-9383549-001, "ASME Section III Analysis - Palisades Hot Leg Surge Nozzle FSWOL," November 2025.  
**(Proprietary Information – Withhold Under 10 CFR 2.390)**

cc: NRC Region III Regional Administrator  
NRC Senior Resident Inspector – Palisades Nuclear Plant  
NRC Project Manager – Palisades Nuclear Plant

**ATTACHMENT 1**

**NRC Questions Followed by Palisades Responses**

## Questions and Responses

### **NRC Question # 1:**

Attachment 2 (Framatome Document 51-9392688-000) of the licensee's supplement dated September 16, 2025, indicates that the following documents describe the specific approaches, code provisions and demonstrations of the weld overlay sizing calculations, residual stress analyses, crack growth analyses, and ASME Code, Section III stress and fatigue analyses for the hot leg surge line weld overlay in detail (References: (1) Framatome 32-9373588-000, "Palisades Hot Leg Surge Nozzle FSWOL Calculation," November 2024; (2) Framatome 32-9377011-000, "Palisades Hot Leg Surge Nozzle FSWOL Weld Residual Stress Analysis," November 2024; (3) Framatome 32-9390082-000, "Palisades Hot Leg Surge Nozzle FSWOL Crack Growth Appendix C Analysis," June 2025; and (4) Framatome 32-9383549-000, "Palisades Hot Leg Surge Nozzle Full Structural Weld Overlay Section III Analysis," April 2025).

Even though these documents address the design analyses for the hot leg surge line weld overlay that is one of the weld overlays in the scope of the proposed alternative, these analyses can serve as examples that describe the design analyses for the weld overlays in the scope of the proposed alternative. Provide these documents containing the design analyses referenced above.

### **Holtec Palisades Response:**

The Framatome proprietary supporting documents listed below will be provided to support NRC review of Relief Request 5-12. Attachment 2 to this letter contains the non-proprietary version of the documents. Attachment 3 provides the Affidavit's for the documents. Attachment 4 contains the four proprietary documents, upon removal of the proprietary information in this attachment the balance of this submittal is decontrolled.

- Framatome Proprietary Document 32-9373588-001, "Palisades Hot Leg Surge Nozzle FSWOL Calculation"
- Framatome Proprietary Document 32-9377011-001, "Palisades Hot Leg Surge Nozzle FSWOL Weld Residual Stress Analysis"
- Framatome Proprietary Document 32-9390082-001, "Palisades Hot Leg Surge Nozzle FSWOL Crack Growth Appendix C Analysis"
- Framatome Proprietary Document 32-9383549-001, "ASME Section III - Palisades Hot Leg Surge Nozzle FSWOL"

The documents provided show the latest revision which was required to include the bracketed proprietary material.

**NRC Question # 2:**

Attachment 2 (Framatome Document 51-9392688-000) of the licensee's supplement dated September 16, 2025, indicates that except for the analysis performed for the pressurizer pilot-operated relief valve (PORV and also called power-operated relief valve) nozzle, where the original weld was partially removed and replaced in a previous repair, the weld residual analyses simulate a conservatively estimated 50 percent through-wall 360 degree full circumferential inner diameter repair at the Alloy 82/182 weld attaching the nozzles to the safe ends.

Explain why the conservatively estimated 50 percent through-wall inner diameter repair is not simulated in the residual stress analysis for the pressurizer PORV nozzle. As part of response, discuss how the residual stress analysis for the pressurizer PORV nozzle considers the potential effects of the previous repair on the residual stress.

**Holtec Palisades Response:**

For all of the repaired nozzles except the PORV, a 50 percent through-wall inside diameter (ID) weld repair on the nozzle to safe end weld is conservatively assumed in the absence of detailed fabrication records. This ensures that the residual stress analysis bounds the tensile stresses near the ID of this dissimilar metal (DM) weld.

However, in the case of the Pressurizer Power Operated Relief Valve (PORV), the safe end and the adjacent pipe were fully replaced in 1995. As part of this replacement, a stainless steel safe end was welded to the nozzle using Alloy 52 weld metal. A small remnant of the existing Alloy 82/182 butter and weld was left on the nozzle and encapsulated by an onlay on the ID with Alloy 52 weld metal prior to attaching the new safe end. This documented repair process effectively mitigates the need for a larger through-wall ID repair assumption.

As a result, a 50 percent through-wall ID weld repair scenario is not simulated for the PORV nozzle. The actual repair history, which considers the Alloy 52 replacement safe end butter and weld attaching the nozzle to the safe end, the Alloy 52 onlay encapsulating the Alloy 52 DM weld and the remnant original Alloy 82/182 DM weld and butter, and the full-structural weld overlay (FSWOL) provides a more representative residual stress condition of the PORV nozzle. Therefore, the residual stress analysis for the PORV nozzle reflects the as-repaired condition and does not require the additional conservative ID repair assumption applied to other nozzles.

**NRC Question # 3:**

With respect to the residual stress analyses for weld overlay design, discuss, if any, residual stress measurement data, other analysis results (e.g., benchmark or validation results), or conservatism associated with the analyses that support the adequacy of the analyses. As part of the response, clarify whether the residual stress analyses use the approaches in EPRI MRP-287, EPRI MRP-317 or NUREG-2162/2228.

**Holtec Palisades Response:**

The weld residual stresses (WRS) used as part of the applied stresses in the ASME B&PV Code Section XI Appendix C crack growth analyses are simulated using validated thermoplastic finite element (FE) methods. The FE analyses consist of sequential thermal and structural simulations that replicate multi-pass weld deposition. The transient thermal analyses employ temperature-dependent material properties and heat inputs representative of the actual weld parameters to generate the temperature history during welding. The resulting temperature history from the thermal analysis is then used as input to the multi-pass weld deposition in the subsequent structural analysis to predict the residual stress distribution in the welded components. The structural analysis uses the time dependent multi-linear kinematic stress-strain relation for the simulated materials. The finite element welding simulation procedure complies with the general recommendations of industry WRS modeling guidance documents such as MRP-317 (Reference [1]) and is consistent with MRP-287 (Reference [2]) residual stress modeling recommendations.

For WRS simulation validation purpose, Framatome (formerly known as AREVA NP Inc.) participated in the FE round robin study coordinated by the NRC and documented in NUREG-2228 (Reference [3]). Reference 3 provided FE modeling guidance aimed at reducing analyst-to-analyst scatter. The round robin study involved modeling a pressurizer surge nozzle dissimilar metal weld as representative geometry. WRS measurements were also performed using deep hole drilling. Participation in the NUREG-2228 (Reference [3]) round robin study demonstrated that the WRS prediction capability of Framatome's weld simulation procedure is consistent with other participants, and it provides assurance that the WRS simulation procedure follows the industry recommended practices.

**NRC Question # 4:**

Describe (a) the crack growth rate models for fatigue and stress corrosion cracking used in the crack growth analyses for the weld overlay design and (b) the adequacy of the crack growth rate models for the weld overlay design analyses.

**Holtec Palisades Response:**

(a) Crack Growth Rates Description

The fatigue and primary water stress corrosion cracking (PWSCC) crack growth rates (CGR) selected for the materials evaluated in the flaw growth analyses are described below:

i. Fatigue Crack Growth Rates

i.1 Alloy 82/182

The fatigue crack growth rate given in NUREG/CR-6907 (Reference [4]) is utilized. Framatome uses a value of 10 as a conservative constant multiplier over the Alloy-600 in-air equation as recommended in Reference 4, to obtain the crack growth rate of Alloy 82/182 in a PWR environment.

i.2 Stainless Steel

The fatigue crack growth rate for austenitic stainless steels in water environments is obtained from ASME Code Case N-809-1 (Reference [5]).

i.3 Alloy 52/52M

Flaw growth in Alloy 52/52M in a water environment due to cyclic loading is calculated using the crack growth model presented in References [6] and [7] which is based on the work that was presented in NUREG/CR-6721, Reference [8]. Reference 8 shows that Alloy 52 and 52M weldments behave similarly to Alloy 600 in PWR water. To be conservative, a multiplier of 2 is applied to the Alloy 600 crack growth rate in PWR water environment.

i.4 Low Alloy Steel

The crack growth rate given in Article A-4300 of ASME Section XI (Reference [9]) is utilized. Note, the differences between crack growth rate given in Article A-4300 from Reference [9] and [10] are reconciled within the applicable flaw growth evaluation with no impact to the acceptability of the analysis.

ii PWSCC Crack Growth Rates

ii.1 Alloy 82/182

The PWSCC crack growth rate given in Equation 6.5 of MRP-420, Revision 1 (Reference [11]) is utilized to model PWSCC crack growth in Alloy 82/182 material.

ii.2 Alloy 52/52M

The PWSCC crack growth rate given in the disposition Equation 4.5 from MRP-115 (Reference [12]) which is applicable for Alloy 82/182, is utilized with a factor of improvement (FOI) of 324, per MRP-386 (Reference [13]), to model PWSCC crack growth in Alloy 52/52M material.

(b) Description of Adequacy of the Crack Growth Rate Models for the Weld Overlay Design Analyses

The CGR models applied in the weld overlay design flaw growth analyses are consistent with the requirements and intent of ASME Section XI, Appendix C (Reference [10]), and reflect the required and/or available formulations for fatigue and PWSCC.

Per ASME Section XI, Appendix C, Article C-8430 (Reference [10]), when material-specific fatigue CGR not covered by C-8410 (austenitic steels) or C-8420 (ferritic steels), alternative technically justified sources may be used. Because C-8410 provides only in-air fatigue CGR for austenitic steels, environmentally adjusted rates from NRC accepted ASME Code Case N-809-1 (Reference [5]) are applied for austenitic stainless steels in PWR environment. Fatigue CGR for ferritic steels follow ASME Section XI, Article A-4300, as referenced by C-8420. Differences between crack growth rate given in Article A-4300 from References [9] and [10] are reconciled within the applicable flaw growth evaluation with no impact to the acceptability of the analysis.

Fatigue CGR for Alloy 82/182 is obtained from NUREG/CR-6907 (Reference [4]) and fatigue CGR for Alloy 52/52M is obtained from the model presented in References [6] and [7] which is based on the work presented in NUREG/CR-6721, Reference [8].

ASME Section XI, Article C-8500 (Reference [10]) does not specify CGRs for stress corrosion cracking for the materials evaluated; therefore, PWSCC rates are taken from EPRI MRP-420, Revision 1 (Reference [11]) for Alloy 82/182, and MRP-115/MRP-386 (References [12] and [13]) for Alloy 52/52M.

Each source of CGR selected for evaluation represents the most broadly used and accepted technical basis within the nuclear industry for characterizing fatigue and PWSCC crack growth behavior in PWR environments. The selected models, derived from ASME provisions, NRC reports, and EPRI Material Reliability Program guidance documents, are based on extensive experimental data and have been used in prior NRC reviewed analyses and licensing applications. Therefore, these models provide an appropriate and technically justified basis for assessing flaw growth of the weld overlay designs.

**NRC Question # 5:**

The proposed alternative does not include the licensee's plan to submit to the NRC staff the following information within a certain time period after the post-installation ultrasonic examination of the full structural weld overlays: (1) a listing of indications detected in the overlaid weld material; (2) the disposition of all indications using the acceptance criteria of ASME Code, Section XI, IWB-3514; and (3) a discussion of any repairs to the weld overlay or base material and the reason for the repair.

Please discuss the licensee's plan to submit the above information regarding the results of the

post-installation ultrasonic examination of the weld overlays and the dispositions of the examination results.

**Holtec Palisades Response:**

The following table summarizes the indications and associated dispositions in response to items (1) and (2) above:

Component	Nozzle Description	Weld ID		Disposition	* Report Number
		Nozzle-to-Safe End	Safe End-to-Pipe / Valve	Per Table IWB-3514-3 and IWB-3514-1	
Hot Leg	12" Hot Leg Surge (Loop 1)	PCS-12-PSL-1H1-8	PCS-12-PSL-1H1-7	(5) Acceptable Indications and (8) Rejectable Indications	HLS-360-00-UT-001
	12" Hot Leg Surge (Loop 1 after indication removal)	PCS-12-PSL-1H1-8	PCS-12-PSL-1H1-7	(9) Acceptable Indications	HLS-B90-00-UT-001 HLS-B90-00-UT-002
	12" Shutdown Cooling (Loop 2)	PCS-12-SDC-2H1-1	PCS-12-SDC-2H1-2	(1) Acceptable Base Material Indication	HLSC 360-00-UT-001 HLSC 370-00-UT-001
Cold Leg	12" Safety Injection (Loop 1A)	PCS-12-SIS-1A1-12	PCS-12-SIS-1A1-11	(2) Acceptable Base Material Indications	SI1A-360-00-UT-001 SI1A-370-00-UT-001
	12" Safety Injection (Loop 1B)	PCS-12-SIS-1B1-16	PCS-12-SIS-1B1-15	(2) Acceptable Indications	SI1B-360-00-UT-001 SI1B-370-00-UT-001
	12" Safety Injection (Loop 2A)	PCS-12-SIS-2A1-15	PCS-12-SIS-2A1-14	(4) Acceptable Indications	SI2A-360-00-UT-001 SI2A-370-00-UT-001
	12" Safety Injection (Loop 2B)	PCS-12-SIS-2B1-15	PCS-12-SIS-2B1-14	(11) Acceptable Indications	SI2B-360-00-UT-001 SI2B-370-00-UT-001
Pressurizer	12" Pressurizer Surge	PCS-12-PSL-1H1-1	PCS-12-PSL-1H1-2	(1) Acceptable Indication	PS-360-00-UT-001 PS-370-00-UT-001
	4" Power Operated Relief Valve (PORV)	PCS-4-PRS-1P1-1	N/A	No Recordable Indications	PRS-360-00-UT-001 PRS-370-00-UT-001

\* Reference component UT reports for detailed information.

Response to NRC Question 5 item (3) is that the initial weld overlay UT acceptance examination of the Hot Leg Surge Nozzle Weld Overlay revealed thirteen (13) procedurally recordable indications. Five were classified as lack of bond and were located at or near the weld overlay/base material interface. These five indications were determined to be acceptable per the acceptance criteria in ASME Section XI, Table IWB-3514-3. The remaining eight indications were classified as inter-bead lack of fusion and were located in the weld overlay material within the weld bead layers. Three of these eight indications were determined to be unacceptable based on the acceptance criteria in ASME Section XI, Table IWB-3514-1.

Two excavations were performed to remove the three rejectable indications. The excavations did not extend into the temper bead region or the base material. Each excavation was PT examined and rewelded to restore the final geometry of the weld overlay.

A final UT acceptance examination was performed after completing the local weld repairs, and the results showed that one of the rejectable indications was fully removed and the other two

were reduced to an acceptable size per ASME Section XI, Table IWB-3514-1. Three of the other inter-bead lack of fusion indications that were in close proximity to the rejectable indications were also cleared. All nine of the remaining indications are located within the PSI/ISI examination volume and were detected during the PSI examination of the weld overlay. No additional recordable indications were revealed.

**Additional Clarification of Information:**

By letter dated August 20, 2025 (ADAMS Accession Number ML25232A195) Palisades submitted Relief Request 5-12. During ensuing reviews it was determined that there was an error in the submittal in that in four instances in Attachment 1 and in two instances in Attachment 4 Palisades had stated that preservice inspections will be done in accordance with ASME Code Case N-770-7, which was inadvertently misleading because when the preservice inspections were performed they were done to the requirements of ASME Code Case N-770-5. Upon further review it was determined that there were no significant differences between the preservice inspection requirements of the two code cases. A Condition Report was written to address this issue, the resolution of which is this paragraph explaining the discrepancy.

**RAI Response References:**

1. Materials Reliability Program: Welding Residual Stress Dissimilar Metal Butt-Weld Finite Element Modeling Handbook (MRP-317, Revision 1). EPRI, Palo Alto, CA: 2015. 3002005499.
2. Materials Reliability Program: Primary Water Stress Corrosion Cracking (PWSCC) Flaw Evaluation Guidance,” (MRP-287), EPRI, Palo Alto, CA, December 2010, Report 1021023.
3. NUREG-2228, Weld Residual Stress Finite Element Analysis Validation Part II - Proposed Validation Procedure, Final Report, July 2020. (ADAMS Accession No. ML20212L592)
4. NUREG/CR-6907, “Crack Growth Rates of Nickel Alloy Welds in a PWR Environment”, U.S. Nuclear Regulatory Commission, May 2006.
5. ASME BPVC Code Cases, “Case N-809-1 Reference Fatigue Crack Growth Rate Curves for Austenitic Stainless Steels in Pressurized Water Reactor Environments Section XI, Division 1.”
6. NRC Letter from Richard Barrett, Director Division of Engineering, Office of NRR to Alex Marion of Nuclear Energy Institute, “Flaw Evaluation Guidelines,” April 11, 2003, ADAMS Accession Number ML030980322.
7. Enclosure 2 to Reference [6], “Appendix A: Evaluation of Flaws in PWR Reactor Vessel Upper Head Penetration Nozzles,” ADAMS Accession Number ML03098033.
8. NUREG/CR-6721, “Effects of Alloy Chemistry, Cold Work, and Water Chemistry on Corrosion Fatigue and Stress Corrosion Cracking of Nickel Alloys and Welds,” U.S. Nuclear Regulatory Commission (Argonne National Laboratory), April 2001.
9. ASME BPVC Section XI, Non-Mandatory Appendix C, “Evaluation of Flaws in Piping.” 1995 Edition with 1996 Addenda.
10. ASME BPVC Section XI, Non-Mandatory Appendix C, “Evaluation of Flaws in Piping.” 2007 Edition with Addenda through 2008.
11. Materials Reliability Program: Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick-Wall Alloy 600 Materials and Alloy 82, 182, and 132 Welds (MRP-420, Revision 1).
12. Materials Reliability Program: Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Alloy 82, 182, and 132 Welds (MRP-115).
13. Materials Reliability Program: Recommended Factors of Improvement for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) Growth Rates of Thick- Wall Alloy 690 Materials and Alloy 52, 152, and Variants Welds (MRP-386).

**ATTACHMENT 2**

**Framatome Document No. 32-9401205-000, "Palisades Hot Leg Surge Nozzle FSWOL Calculation," Non-Proprietary November 2025**

**Framatome Document No. 32-9401217-000, "Palisades Hot Leg Surge Nozzle FSWOL Weld Residual Stress Analysis," Non-Proprietary November 2025**

**Framatome Document No. 32-9401201-000, "Palisades Hot Leg Surge Nozzle FSWOL Crack Growth Appendix C Analysis," Non-Proprietary November 2025**

**Framatome Document No. 32-9401238-000, "ASME Section III Analysis - Palisades Hot Leg Surge Nozzle FSWOL," Non-Proprietary November 2025**

**(Non-Proprietary)**



# CALCULATION SUMMARY SHEET (CSS)

Document No. 32 - 9401205 - 000

Safety Related:  Yes  No

Title Palisades Hot Leg Surge Nozzle FSWOL Calculation – Non-Proprietary

### PURPOSE AND SUMMARY OF RESULTS:

Purpose:

The purpose of this calculation is to specify the minimum Full Structural Weld Overlay Length and Thickness required for the Hot Leg Surge Nozzle for Palisades Nuclear Power Plant in accordance with References [1], [4], [6], and [7].

Summary of Results:

Based upon the specified loadings, the minimum [ ] Full Structural Weld Overlay (FSWOL) thickness is [ ] over the surge nozzle and surge line pipe. The minimum Weld Overlay Length is [ ] full weld thickness beyond the projected flaw on the flaw end and [ ] from the toe of the weld on the unflawed end, with an end transition slope not exceeding 30°, per Code Case N-740-2 (2)(b)(2) Reference [7]. The FSWOL sizing performed in this document does not include any allowance for fatigue crack growth, weld material dilution or the final machining. Crack growth evaluation will be performed in a separate document to add allowance to the FSWOL thickness for crack growth. The FSWOL sizing does not consider any NDE inspection requirements.

Export Classification US EC:  N  Part 810  EAR

ECCN: N/A

**If the computer software used herein is not the latest version per the EASI list, AP 0402-01 requires that justification be provided.**

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT:

CODE/VERSION/REV	CODE/VERSION/REV
_____	_____
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THE DOCUMENT CONTAINS ASSUMPTIONS THAT SHALL BE VERIFIED PRIOR TO USE

Yes

No

Palisades Hot Leg Surge Nozzle FSWOL Calculation – Non-Proprietary

Review Method:  Design Review (Detailed Check)

Alternate Calculation

Does this document establish design or technical requirements?  YES  NO

Does this document contain Customer Required Format?  YES  NO

**Signature Block**

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Kim Jones Project Manager	<i>KM JONES</i> 11/24/2025	PM	Please see Section 7. There are some documents with “*”. These are not in Framatome records system.

**Role Definitions:**

- P/R/A designates Preparer (P), Reviewer (R), Approver (A);
- LP/LR designates Lead Preparer (LP), Lead Reviewer (LR);
- M designates Mentor (M);
- PM designates Project Manager (PM)



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Palisades Hot Leg Surge Nozzle FSWOL Calculation – Non-Proprietary

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**1.0 PURPOSE**

The purpose of this calculation is to specify the minimum Full Structural Weld Overlay Length and Thickness (FSWOL) required for the hot leg surge nozzle for the Palisades Nuclear Power Plant in accordance with References [1], [4], [6], and [7].

The FSWOL sizing performed in this document does not include any allowance for fatigue crack growth, weld material dilution or the final machining. Crack growth evaluation is performed in a separate document to add allowance to the FSWOL thickness for crack growth. The WOL sizing does not consider any NDE inspection requirements.

**2.0 ANALYTICAL METHODOLOGY**

Two dissimilar metal welds composed of [ ] were manufactured to join the hot leg surge nozzle composed of [ ] with the 90° elbow composed of [ ] Thus, the sizing of the WOL of dissimilar metals is based on Code Case N-740-2, Reference [7]. Per Code Case N-740-2 (b)(3) Reference [7], the assumed flaw in the weld shall be based on the limiting case of either (a) 100% through-wall circumferential flaw for the entire circumference or (b) 100% through-wall flaw with the length of 1.5" in the axial direction.

Code Case N-740-2 (2)(b)(1) and (2)(b)(2) specifies that the FSWOL full thickness length extends axially beyond the projected flaw on each end by at least  $0.75(Rt)^{1/2}$  (where  $R$  is the outside diameter of the pipe and  $t$  is the thickness) with an end transition slope not exceeding 30° (Reference [7]).

Code Case N-740-2 (b)(4) specifies that the WOL thickness meets IWB-3640. To be acceptable, IWB-3640 requires the pipe containing flaws to satisfy IWB-3642, IWB-3643 or IWB-3644. IWB-3642 states that the piping may be evaluated as described in Appendix C of Section XI, Division I Reference [1].

Section C-1200 (f) of Appendix C specifies the use of C-4000 to determine the failure mechanism for the material. Section C-4210 determines the failure mode for base material flaw, and Figure 4210-1 specifies the use of C-5000. An ambient-temperature temper bead machine GTAW welding process, per Section 7.5 of Reference [4] is used for the welding process. The provisions of C-5000 are used in this analysis (Reference [1]).

**2.1 FSWOL Thickness by Circumferential Crack Criteria**

The required thickness of a weld overlay repair is determined by formulas given in Appendix C (Reference [1]). The criterion is based on net section plastic collapse, which predicts adequate load capacity of flawed pipes repaired by weld overlays for given applied stresses,  $\sigma_m$  and  $\sigma_b$ . Here,  $\sigma_m$  is the pipe primary membrane stress and  $\sigma_b$  is the pipe primary bending stress. Note that only the applied loads such as pressure, deadweight, and seismic loads are needed in evaluating  $\sigma_m$  and  $\sigma_b$ . From Section C-2612 of Reference [1], Appendix C evaluates the flaw and FSWOL under primary loading. Secondary stresses due to temperature gradients and thermal expansion do not need to be considered; these loads cause stresses that are self-limiting, and therefore do not affect the net section plastic collapse.

For a circumferentially flawed pipe, the relation between the applied loads and the flaw depth at incipient plastic collapse per Reference [1], Section C-5321 is given by:

$$\sigma_b^c = \frac{2\sigma_f}{\pi} (2 - \frac{a}{t}) \sin\beta$$

Palisades Hot Leg Surge Nozzle FSWOL Calculation – Non-Proprietary

where  $t$  is the pipe thickness including the overlay,  $\beta$  is the angle that defines the location of the neutral axis (see Figure C-4310-1 of Reference [1] for details),  $a$  is the flaw depth,  $\sigma_f$  is the flow stress defined in C-8200 of Reference [1], and  $\sigma_b^c$  is the bending stress at the incipient plastic collapse.

The assumed circumferential through-wall flaw penetrates the compressive bending region such that  $(\theta + \beta) > \pi$ , where  $\theta$  is one-half of the flaw angle (180 degrees), and therefore the angle  $\beta$  per Reference [1] is given by:

$$\beta = \frac{\pi}{2 - \frac{a}{t}} \left( 1 - \frac{a}{t} - \frac{\sigma_m}{\sigma_f} \right)$$

where  $\sigma_m$  is the pipe primary membrane stress in the axial direction in the unflawed section of the pipe. The allowable pipe bending stress is given by:

$$S_c = \frac{\sigma_b^c}{SF_b} - \sigma_m \left( 1 - \frac{1}{SF_m} \right)$$

where  $SF_m = 2.7$  for normal conditions, 2.4 for upset conditions, and 1.3 for faulted conditions;  $SF_b = 2.3$  for normal condition, 2.0 for upset conditions and 1.4 for faulted conditions (see C-2621 of Ref. [1]).

In addition, the allowable membrane stress ( $S_t$ ) in the flawed pipe is determined by the following formulas:

$$S_t = \frac{\sigma_m^c}{SF_m}$$

$$\sigma_m^c = \sigma_f \left[ 1 - \left( \frac{a}{t} \right) \left( \frac{\theta}{\pi} \right) - \frac{2\Phi}{\pi} \right]$$

$$\Phi = \arcsin \left( 0.5 \left( \frac{a}{t} \right) \sin \theta \right)$$

Additionally, C-5322 and C-5420 of Reference [1] states that in no case shall the resulting flaw depth be greater than  $a = 0.75t$ , and the weld overlay thickness should be adjusted to satisfy this criterion if necessary.

## 2.2 FSWOL Thickness by axial Flaw Criteria

The required thickness of the weld overlay repairs subjected to the axial flaw is determined by formula given in Appendix C-5420 of Ref. [1]. The allowable hoop stress  $\sigma_{h-allowable}$  is given by:

$$\sigma_{h-allow} = \frac{\sigma_f}{SF_m} \left[ \frac{1 - \frac{a}{t}}{1 - \left( \frac{a}{t} \right) / M_2} \right]$$

where,

$$M_2 = \left[ 1 + \left( \frac{1.61}{4R_m t} \right) l_f^2 \right]^{\frac{1}{2}}$$

with  $R_m$  as the mean radius of the overlaid pipe,  $t$  as the nominal thickness (pipe + FSWOL), and  $l_f$  as the end-of evaluation-period flaw length that is assumed to be  $1.5'' < l_{allow}$  (refer to Table 3 FSWOL Thickness Calculation,  $l_{allow}$  is per C-5410 of Reference [1]). Per Code Case N-740-2 (b)(3) of Reference [7], the flaw depth is assumed to be 100% through wall thickness.

Palisades Hot Leg Surge Nozzle FSWOL Calculation – Non-Proprietary

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With  $R_m$  as the mean pipe radius of the overlaid pipe, the applied hoop stress under internal pressure of  $P$  is calculated by:

$$\sigma_h = \frac{PR_m}{t}$$

The upper bounds on applicability of the above equation are limited to a flaw depth less than or equal  $a = 0.75t$ .

**2.3 FSWOL Length**

As mentioned in Section 2.0, Code Case N-740-2 of Reference [7], for the purpose of sizing, the length of the weld overlay should extend at least  $0.75(Rt)^{1/2}$  beyond the projected flaw on each end where  $R$  and  $t$  are the outside radius and the wall thickness of the pipe prior to depositing the weld overlay. Weld shear stress check is also performed, refer to Section 6.3.

**3.0 ASSUMPTIONS**

**3.1 Unjustified Assumptions**

There are no assumptions that need verification.

**3.2 Justified Assumptions**

- Circumferential cracks are assumed 100% thru wall thickness for the entire circumference of the pipe (flaw angle of 360 degrees) based on Code Case N-740-2 (b)(3) (Reference [7]). This is demonstrated in Section 4.1.
- The analysis assumes 1.5" axial crack per Reference [7]. This conservatism is acceptable as it does not drive the size of the weld overlay (FSWOL).
- The design pressure and temperature of [ ] and [ ] per 5.3.1 and 5.3.2 respectively (Ref. [4]), are used in the sizing of the FSWOL; this is acceptable since these values bound the normal conditions and since the upset and faulted conditions have a large margin.
- The hot leg surge nozzle orientation is assumed to be oriented along the [ ] axis; Reference [6] dictates a coordinate system such that the [ ] axis is oriented [ ]
- Reference [6] does not explicitly state where the external loads are applied on the model. [ ]

]

- [

]

#### 4.0 DESIGN INPUT

##### 4.1 Geometry

Figure 4-1 details the DMW1 connecting the surge nozzle and safe end with an ID of [ ] and an OD of [ ] (Reference [3]). The circumference of the nozzle [ ]



Figure 4-1 Drawing [ ]

##### 4.2 Material and Material Properties

The existing material of the hot leg surge nozzle is composed of [ ] (Reference [4]). The new weld filler material is [ ] per Section 6.3.2 (Reference [4]). The material properties of the new weld filler [ ] at the design operating temperature of [ ] are provided in Table 1 (Reference [5]).

Table 1 Material Properties [ ]

Palisades Hot Leg Surge Nozzle FSWOL Calculation – Non-Proprietary

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**4.3 Applied Loads**

Identified in Reference [1], only primary stresses ( $\sigma_m$  – maximum applied pipe primary membrane stress,  $\sigma_b$  – maximum applied pipe primary bending stress and  $\sigma_h$  – maximum applied hoop stress) are needed to determine the acceptability of a flawed pipe for continued service. The primary stresses considered in this application result from [ ] Forces and moments due to normal operating and seismic conditions are provided in Table 2 (Reference [6]).

**Table 2 Surge Nozzle Forces and Moments Due to Normal Operating and Seismic Conditions**

[ ]
-----

**5.0 COMPUTER USAGE**

No engineering software is used in the sizing calculation. All calculations were completed in excel file [ ]

**6.0 CALCULATION**

**6.1 FSWOL Thickness**

[

]

The final calculation is included in Table 3. C-5322 and C-5420 of Reference [1] also states that in no case shall the resulting flaw depth be greater than  $a = 0.75t$ , and the weld overlay thickness should be adjusted to satisfy this criterion if necessary. The measured thickness of the pipe will be used to satisfy this criterion as it results in higher thickness for the WOL (refer to Section 4.1 and Table 3).

**6.2 Axial Flaw Evaluation**

Although no axial flaw was detected, the calculation conservatively assumes an axial crack with an end-of-life length of 1.5" per Section 2 (a) (2) (Reference [7]). This conservative assumption is acceptable [

]

Axial flaw evaluation to ensure acceptability of the FSWOL for axial flaw criteria (Section 2.2) is also included in Table 3.

Palisades Hot Leg Surge Nozzle FSWOL Calculation – Non-Proprietary

**Table 3 FSWOL Thickness Calculation**

	Symbol	Equation	Normal	Upset	Faulted	Unit	Reference/Note
weld overlay thickness	$t_{weld}$					inch	iterative calculation
original pipe wall thickness	$t_n$	$(d_o - d_i)/2$				inch	
end-of-life crack depth <sup>1</sup>	$a$	$t_n + \text{crack growth}$				inch	
design pressure	$P$					ksia	Ref [4]
total thickness	$t$	$t_n + t_{weld}$				inch	
pipe ID	$d_i$					inch	Ref [3]
pipe OD	$d_o$					inch	Ref [3]
overlay OD	$D_o$	$d_o + 2*t_{weld}$				inch	
sectional area	$A$	$\pi(D_o^2 + d_i^2)/4$				inch <sup>2</sup>	
moment of inertia	$I$	$\pi(D_o^4 + d_i^4)/64$				inch <sup>4</sup>	
section modulus	$Z$	$I/(D_o/2)$				inch <sup>3</sup>	
mean radius	$R_m$	$(d_i + D_o)/4$				inch	
general flaw length	$l_{assumed}$					inch	Section 2(a)(2) (Ref [7])
bulging factor for axial flaw	$M_2$	$[1+(1.61/4R_m t)(l_{assumed})^2]^{1/2}$					C-4312 Ref [1]
moment arm <sup>5</sup>	$L_{arm}$	Distance from safe end to DMW				inch	Ref [3]
moment from $F_x^5$	$M_1$	$F_x * L_{arm}$				inch-kips	
moment from $F_y^5$	$M_2$	$F_y * L_{arm}$				inch-kips	
moment from $F_z^5$	$M_3$	$F_z * L_{arm}$				inch-kips	
total moment – $x^5$	$M_{x\ tot}$	$M_1+M_x$				inch-kips	
total moment – $y^5$	$M_{y\ tot}$	$M_2+M_y$				inch-kips	
total moment – $z^5$	$M_{z\ tot}$	$M_3+M_z$				inch-kips	
resultant bending moment <sup>4</sup>	$M_b$	$[M_{x\ tot}^2 + M_{y\ tot}^2 + M_{z\ tot}^2]^{1/2}$				inch-kips	
axial force	$F_a$	$[P*\pi*d_i^2/4] + [F_y]$				kips	
calculated membrane stress <sup>2</sup>	$\sigma_m$	$F_a/A$				ksi	C-2500 Ref [1] <sup>2</sup>
flow stress	$\sigma_f$	$1/2 (S_y+S_u)$				ksi	C-8200 Ref [1]
collapse membrane stress	$\sigma_m^c$	$\sigma_f [1-(a/t)*(\theta/\pi)-2\phi/\pi]$				ksi	C-5321 Ref [1]
safety factor (membrane)	$SF_m$					ksi	C-2622 Ref [1]
allowable membrane stress <sup>3</sup>	$S_t$	$\sigma_m^c / SF_m$				ksi	C-5321 Ref [1]
calculated bending stress <sup>3</sup>	$\sigma_b$	$M_b/Z$				ksi	C-2500 Ref [1]
angle (neutral axis)	$\beta$	$\pi/(2-a/t)*(1-a/t-\sigma_m/\sigma_f)$					p358 2013 BPVC
	$\theta$	$1/2$ (flaw angle)				rad	flaw angle = 360 deg
	$\phi$	$\sin^{-1} (1/2*a/t*\sin\theta)$					C-5321 Ref [1]
collapse bending stress	$\sigma_b^c$	$2\sigma_f*\pi*(2-a/t)*\sin\beta$				ksi	C-5321 Ref [1]
safety factor (bending)	$SF_b$						C-2621 Ref [1]
allowable bending stress <sup>3</sup>	$S_c$	$\sigma_b^c/SF_b-\sigma_m*[1-1/SF_m]$				ksi	C-5321 Ref [1]
calculated hoop stress <sup>3</sup>	$\sigma_h$	$P*R_m/t$				ksi	C-2500 Ref [1]
allowable hoop stress <sup>3</sup>	$\sigma_h$	$\sigma_f/SF_m*[(1-a/t)/(1-a/t)/M_2]$				ksi	C-5420 Ref [1]
allowable flaw length	$l_{allow}$	$1.58(R_m t)^{1/2} [(\sigma_f/\sigma_h)^2-1]^{1/2}$				inch	C-5430 Ref [1]
flaw depth ratio <sup>3</sup>	$a/t$						

(1) Assuming 100% crack through wall

(2) Simplifies from [ ]

(3) Normal, Upset, and Faulted conditions are deemed acceptable because the a/t ratio is  $\leq 0.75$ , and because the calculated stresses are less than the allowable stresses (Table 4 Summary Table).

(4) [

]

Palisades Hot Leg Surge Nozzle FSWOL Calculation – Non-Proprietary

(5) [ ] ]

(6) Figure 4-1 details the value of  $L_{arm} = [ ]$

**Table 4 Summary Table of Stresses**

	Normal	Upset	Faulted
weld overlay thickness	[ ]	[ ]	[ ]
calculated membrane stress	[ ]	[ ]	[ ]
allowable membrane stress	[ ]	[ ]	[ ]
calculated bending stress	[ ]	[ ]	[ ]
allowable bending stress	[ ]	[ ]	[ ]
calculated hoop stress	[ ]	[ ]	[ ]
allowable hoop stress	[ ]	[ ]	[ ]
calculated a/t	[ ]	[ ]	[ ]
allowable a/t	[ ]	[ ]	[ ]

**6.3 FSWOL Length**

With  $R = [ ]$  and thickness =  $[ ]$  (refer to Section 4.1), the full thickness weld overlay length shall be extended from the crack end to at least:

$$[ ]$$

The length of  $[ ]$  is the FSWOL length in full thickness beyond the projected flaw on the flaw end and  $[ ]$  from the toe of the weld on the unflawed end.

The minimum length required to transfer the axial load from the pipe to the weld and back to the other side of the pipe is evaluated in this section as follows:

$$\text{Total length required} = 2 \times \text{axial load} / (\text{circumference of the pipe} \times \text{weld shear allowable})$$

The faulted load from Table 3 FSWOL Thickness Calculation is used along with the allowable shear stress for the weld under normal condition.

Shear allowable of the weld is considered as  $0.6S_m$  of the base metal per NB-3227.2 of Reference [8].

$$\text{Total length} = [ ]$$

where  $[ ]$  is the axial load to be transferred through the weld,  $[ ]$  is the circumference (refer to Section 4.1),  $S_m$  of the base metal is per Table 1 Material Properties  $[ ]$  Since  $[ ]$  the FSWOL required length is acceptable.

**6.4 Results, Summary, and Conclusion**

In accordance with Reference [1], [4] & [6], the full structural weld overlay size is calculated as follows:

Thickness of  $[ ]$  measured from the pipe outside surface.

Palisades Hot Leg Surge Nozzle FSWOL Calculation – Non-Proprietary

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Length of [ ] in full thickness beyond the projected flaw on the flaw end and [ ] from the toe of the weld on the unflawed end, with an end transition slope not exceeding 30° per Code Case N-740-2 (2)(b)(2) Reference [7].

The FSWOL sizing performed in this document does not include any allowance for fatigue crack growth, weld material dilution or the final machining. Crack growth evaluation is performed in a separate document to add allowance to the FSWOL thickness for crack growth. The FSWOL sizing does not consider any NDE inspection requirements.

**7.0 REFERENCES**

References identified with an (\*) are maintained within Palisades Records System and are not retrievable from Framatome Records Management. These are acceptable references per Framatome Administrative Procedure 0402-01, Attachment 7.

1. ASME Boiler and Pressure Vessel Code, 2007 Edition including Addenda through 2008, Section XI, Division 1, Appendix C.
2. [ ]
3. [ ]
4. Framatome Document [ ]
5. ASME Boiler and Pressure Vessel Code, 2019 Edition, Section II, Part D, Customary Properties.
6. [ ]
7. Code Case N-740-2, “Full Structural Dissimilar Metal Weld Overlay for Repair or Mitigation of Class 1, 2, and 3 Items, Section XI, Division 1.”
8. ASME Boiler and Pressure Vessel Code, 2019 Edition, Section III A, Division 1, XIII-3710 (b).



# CALCULATION SUMMARY SHEET (CSS)

Document No. 32 - 9401217 - 000

Safety Related:  Yes  No

Title Palisades Hot Leg Surge Nozzle FSWOL Weld Residual Stress Analysis – Non-Proprietary

**PURPOSE AND SUMMARY OF RESULTS:**

**PURPOSE:**

The purpose is to perform the weld residual stress finite element analysis of the Hot Leg (HL) surge nozzle Alloy 82/182 welds mitigated by a full structural weld overlay (FSWOL) at Palisades Nuclear Power Plant. The analysis includes simulations of the existing nozzle butter weld, the existing Alloy 82/182 weld attaching the nozzle to safe end, the existing dissimilar weld (DMW) attaching the safe end to the elbow, and the proposed FSWOL mitigation of the HL surge nozzle. The analysis also includes simulation of a conservatively assumed 50% through-wall 360-degree full circumferential ID repair at the Alloy 82/182 weld attaching the nozzle to safe end.

**RESULTS:**

The state of stress after the application of FSWOL as predicted by the ANSYS finite element analysis, are summarized in Section 8.0 to support subsequent fracture mechanics evaluation of postulated flaws in the susceptible materials.

Proprietary information in the document is identified by bold brackets ( [ ... ] ). The content of this document is identical to 32-9377011-001, except that proprietary information is redacted.

Export Classification

US EC:  N  Part 810  EAR

ECCN: N/A

**If the computer software used herein is not the latest version per the EASI list, AP 0402-01 requires that justification be provided.**

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT:

CODE/VERSION/REV	CODE/VERSION/REV
ANSYS 19.2 (see Section 6.1)	

THE DOCUMENT CONTAINS ASSUMPTIONS THAT SHALL BE VERIFIED PRIOR TO USE

Yes  
 No

Palisades Hot Leg Surge Nozzle FSWOL Weld Residual Stress Analysis – Non-Proprietary

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Review Method:  Design Review (Detailed Check)

Alternate Calculation

Does this document establish design or technical requirements?  YES  NO

Does this document contain Customer Required Format?  YES  NO

**Signature Block**

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**Role Definitions:**

P/R/A designates Preparer (P), Reviewer (R), Approver (A);

LP/LR designates Lead Preparer (LP), Lead Reviewer (LR);

M designates Mentor (M);

PM designates Project Manager (PM)



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**1.0 INTRODUCTION**

Primary water stress corrosion cracking (PWSCC) of Alloy 600/82/182 materials is a well-documented phenomenon in the nuclear power industry. High temperature components such as those associated with the Reactor Coolant System (RCS) show the highest risk to PWSCC.

Framatome plans to mitigate the Palisades Hot Leg (HL) Alloy 82/182 dissimilar metal weld (DMWs) at the surge nozzle as well as the safe end with a full structural weld overlay (FSWOL). The planned modification using a FSWOL is a preemptive measure to reduce susceptibility of the DMWs to PWSCC and to enhance the configuration such that improved coverage using ultrasonic examination of the nozzle to safe end DMW is accomplished. The full specification of the repair is described in Reference [1].

**2.0 PURPOSE**

The purpose of this document is to report results of the weld residual stress (WRS) developed by finite element analysis (FEA) of the HL surge nozzle locations with Alloy 82/182 weld at Palisades Nuclear Plant.

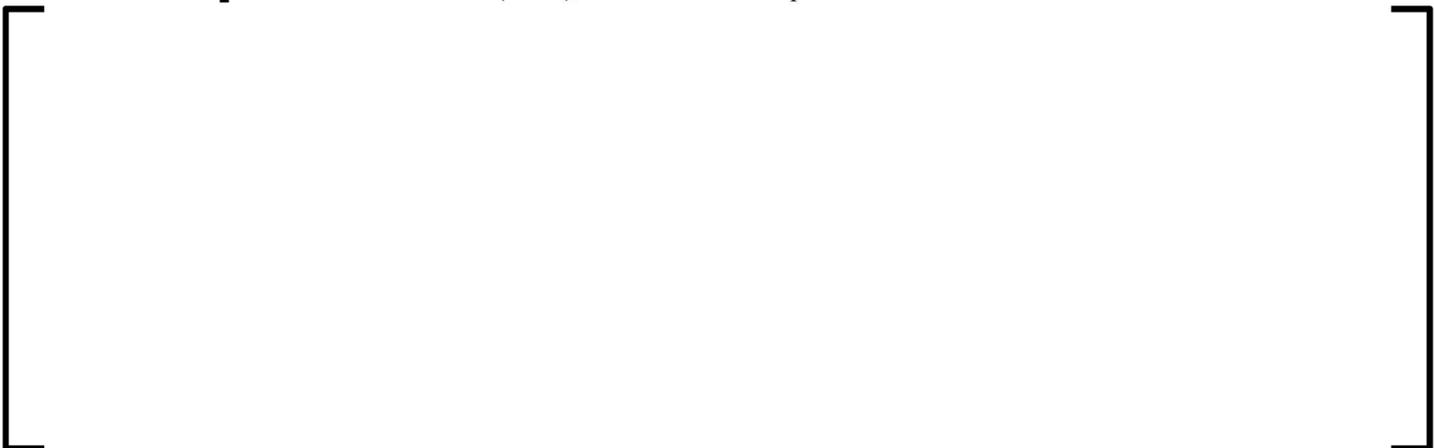
This analysis includes simulation of the nozzle butter weld, the DMW attaching the nozzle to the safe end and the safe end to the elbow, and the proposed FSWOL mitigation of the PZR Surge nozzle. The analysis also includes simulation of a conservatively assumed 50% through-wall 360-degree full circumferential ID repair at the DMW attaching the nozzle to the safe end as specified in Reference [1].

The state of stress after the application of FSWOL as predicted by the FEA, is summarized in this report to support subsequent fracture mechanics evaluation of postulated flaws in the degraded materials.

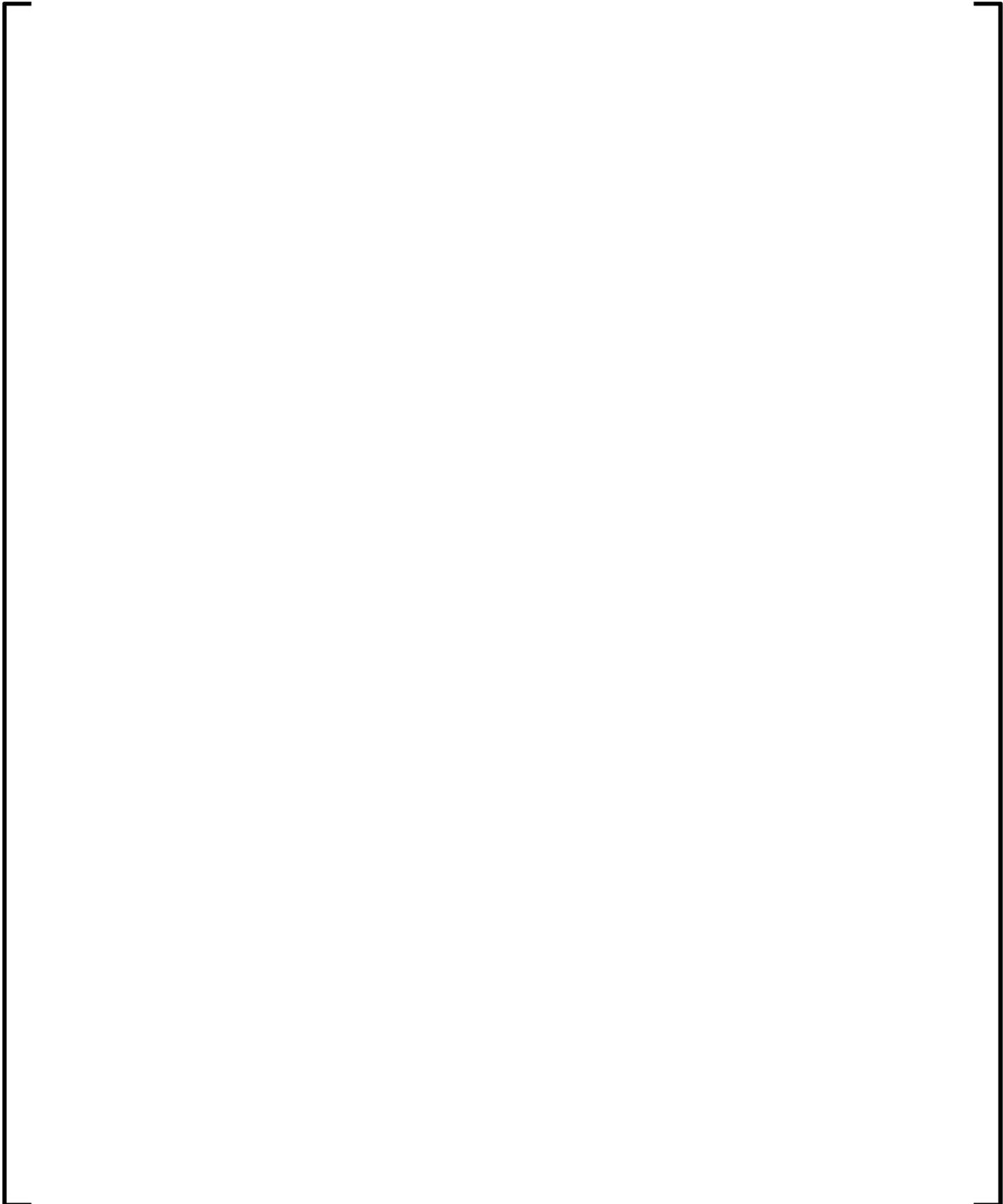
**3.0 ANALYTICAL METHODOLOGY**

The methodology used to perform the WRS FEA employed herein is consistent with the methods described in the WRS analysis procedure, Reference [2], and with the general recommendations of industry WRS modeling guidance MRP-317, Reference [3]. The general-purpose finite element code ANSYS, Reference [4], is used to perform the WRS FEA. The stages of the welding processes are simulated using a [

] finite element model (FEM), with the basic steps listed as follows:



Palisades Hot Leg Surge Nozzle FSWOL Weld Residual Stress Analysis – Non-Proprietary



**4.0 ASSUMPTIONS**

**4.1 Unverified Assumptions**

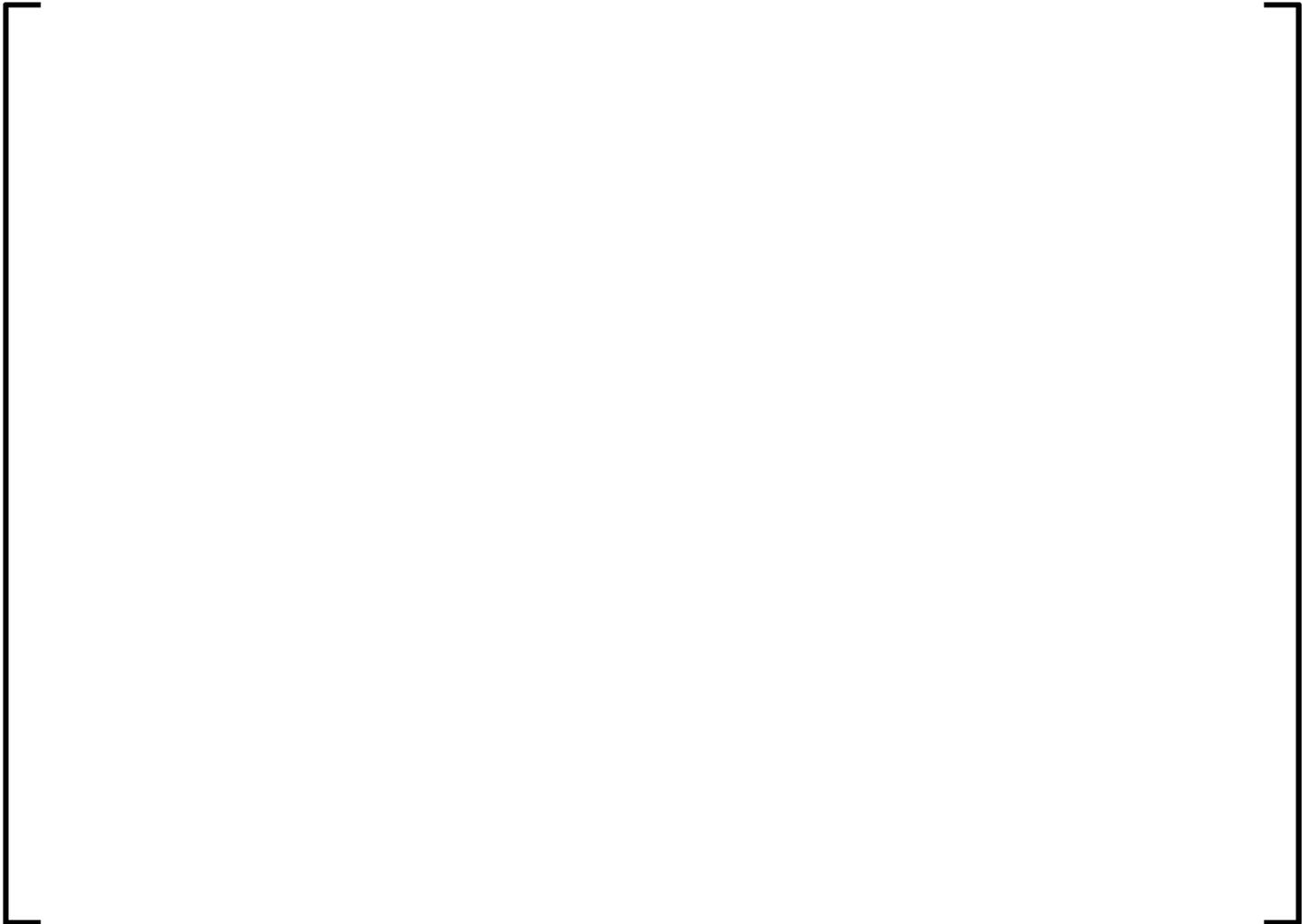
The calculation contains no assumptions that require verification prior to use on safety-related work.

**4.2 Justified Assumptions**

### 4.3 Modeling Simplifications

The following is a list of modeling simplifications that are used in this document:





**5.0 DESIGN INPUTS**

**5.1 Geometry**

The detailed dimensions of the HL surge nozzle and FSWOL modeled in the WRS finite element analysis are obtained from References [10], [11] and [8]. The key dimensions are shown in Table 5-1.

**Table 5-1: Hot Leg Surge Nozzle and FSWOL Key Dimensions**

Table content is missing
--------------------------

**5.2 Materials**

The material designations for the FEA components are obtained from References [1], [6] and [8] as listed in Table 5-2. The analysis herein uses the physical properties (thermal conductivity, specific heat, mean coefficient of thermal expansion, density, Young’s modulus, and Poisson’s ratio) and the stress-strain curves from Reference [7] that are representative of the materials (see Section 4.3, item 3). All of the physical and mechanical properties are temperature dependent, except Poisson’s ratio.

Table content is missing
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**Table 5-2: Component Material Designations**

Component	Material Designation	Physical Properties, Table in Reference [7]	Stress-Strain Curve, Table in Reference [7]
HL surge nozzle	SA-508 Cl. 1	Table 5-14	Table 5-15
Nozzle cladding	Stainless Steel Type 304	Table 5-1	Table 5-2
Nozzle butter weld	Alloy 82/182	Table 5-7	Table 5-9
Nozzle to safe end weld <sup>(1)</sup>	Alloy 82/182	Table 5-7	Table 5-9
Safe end	SB-166 (Alloy 600)	Table 5-7	Table 5-8
Safe end to elbow weld	Alloy 82/182	Table 5-7	Table 5-9
Elbow	Stainless Steel Type 316	Table 5-4	Table 5-5
Full structural weld overlay	Alloy 690	Table 5-10	Table 5-11
FSWOL buffer layer	ER309L <sup>(2)</sup>	Table 5-1	Table 5-2
FSWOL bridge layer	Alloy 82	Table 5-7	Table 5-9
FSWOL dilution layer	Alloy 52M/52MSS	Table 5-10	Table 5-11

Notes:

- (1) Alloy 82/182 is selected for the conservatively assumed nozzle to safe end ID repair weld.
- (2) Compatible material properties of stainless steel Type 304L are selected for the FSWOL buffer layer material.

### 5.3 Welding Parameters

The welding parameters used for modeling the welding simulation processes are listed in Table 5-3. For the existing Alloy 82/182 butter, surge nozzle-to-safe end weld and safe end-to elbow weld and the surge nozzle-to-safe end repair, typical values per Reference [2] are used (see Section 4.3, item 6). For FSWOL, the heat input varies and the maximum value is [ ] per Reference [12].

**Table 5-3: Welding Parameters**

**5.4 Post Weld Heat Treatment**

The post-weld heat treatment temperature [ ] is assumed for the evaluation, as described in Section 4.2, item 2.

**5.5 Loading Conditions**

The loading conditions for the static structural analyses described in Section 3.0 are listed in Table 5-4, per References [1] and [13].

**Table 5-4: Steady State Loading Conditions**

--	--

**6.0 COMPUTER USAGE**

**6.1 Software**

This calculation uses the following software:

- Controlled installation of software ANSYS Mechanical Enterprise 19.2 (Reference [4]), at controlled currently maintained as a controlled container at “/opt/shared/containers/rhel72\_ansys192.sif” on the approved platform Lynchburg HPCv2, Reference [14].
  - ANSYS verification tests documented in Reference [15] demonstrate that ANSYS Version 19.2 meets the requirements to be used on the HPC as a controlled-access code. Note that Version 19.2 is not the most recent approved version of ANSYS listed on EASI (Engineering Applications Software Index). However, the use of this version of ANSYS is acceptable since all error notices up to date have been reviewed and it is concluded that none of the errors may create erroneous results for the intent of this calculation.
  - The container image file “rhel72\_ansys192.sif” has been verified using the public key provided in Reference [15]
  - Operating System: Red Hat Enterprise Linux release 8.2; Kernel: 4.18.0-193.el8.x86\_64

The software is being used within its specified range of applicability as defined by validation and verification requirements defined in References [14] and [15].

## 6.2 Computer Files

The computer input and output files are stored in ColdStor at the following directory:

[ ]

**Table 6-1: List of Computer Files**



**7.0 FINITE ELEMENT ANALYSIS**

**7.1 Finite Element Model**

The finite element model is a [ ] model. The finite element mesh consists of [ ]

[ ] Files are listed in Table 6-1. The solid model is shown in Figure 7-1, and finite element model is shown in Figure 7-2.

The weld passes employed in the welding simulations for the different component welds are shown in Figure 7-3 through Figure 7-8, with the order of the weld passes noted on the figures (See Section 4.2, Items 4 and 5).



**Figure 7-1: [ ] Solid Model**

Palisades Hot Leg Surge Nozzle FSWOL Weld Residual Stress Analysis – Non-Proprietary



**Figure 7-2: [ ] Finite Element Model**



**Figure 7-3: Buttering Weld Pass Sequence [ ]**

Palisades Hot Leg Surge Nozzle FSWOL Weld Residual Stress Analysis – Non-Proprietary



**Figure 7-4: Nozzle DM Weld Pass Sequence [     ]**



**Figure 7-5: DMW ID Repair Weld Pass Sequence [     ]**



**Figure 7-6: Safe End DM Weld Pass Sequence**



**Figure 7-7: FSWOL Prepare Layer Weld Pass Sequences**



**Figure 7-8: FSWOL Overlay Layer Weld Pass Sequences**

**7.1.1 Welding Analysis**

**7.1.1.1 Thermal Boundary Conditions**



**7.1.1.2 Structural Boundary Conditions**





**Figure 7-9: Boundary Conditions in Welding Analysis**

**7.1.2 Post Weld Heat Treatment**



**7.1.3 Static Structural Analysis**

The steady state conditions include the cold shutdown condition (room temperature with no internal pressure) and the hot steady state conditions during a normal operation (operating temperature and pressure). Hydrotest as a static condition is also a steady state condition. [

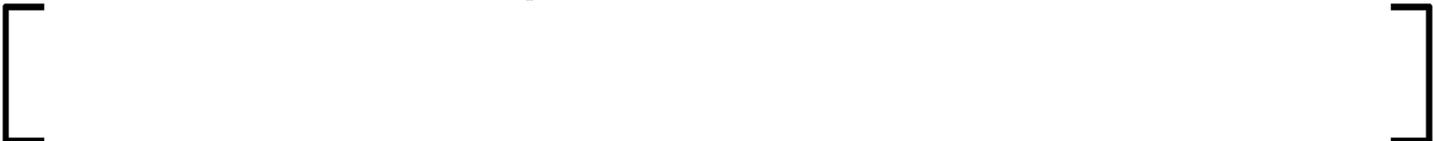
]

The end-cap pressure is calculated as follows:

$P$  = pressure (psi)

$R_i$  = inside radius of the end-cap cross-section

$R_o$  = outside radius of the end-cap cross-section



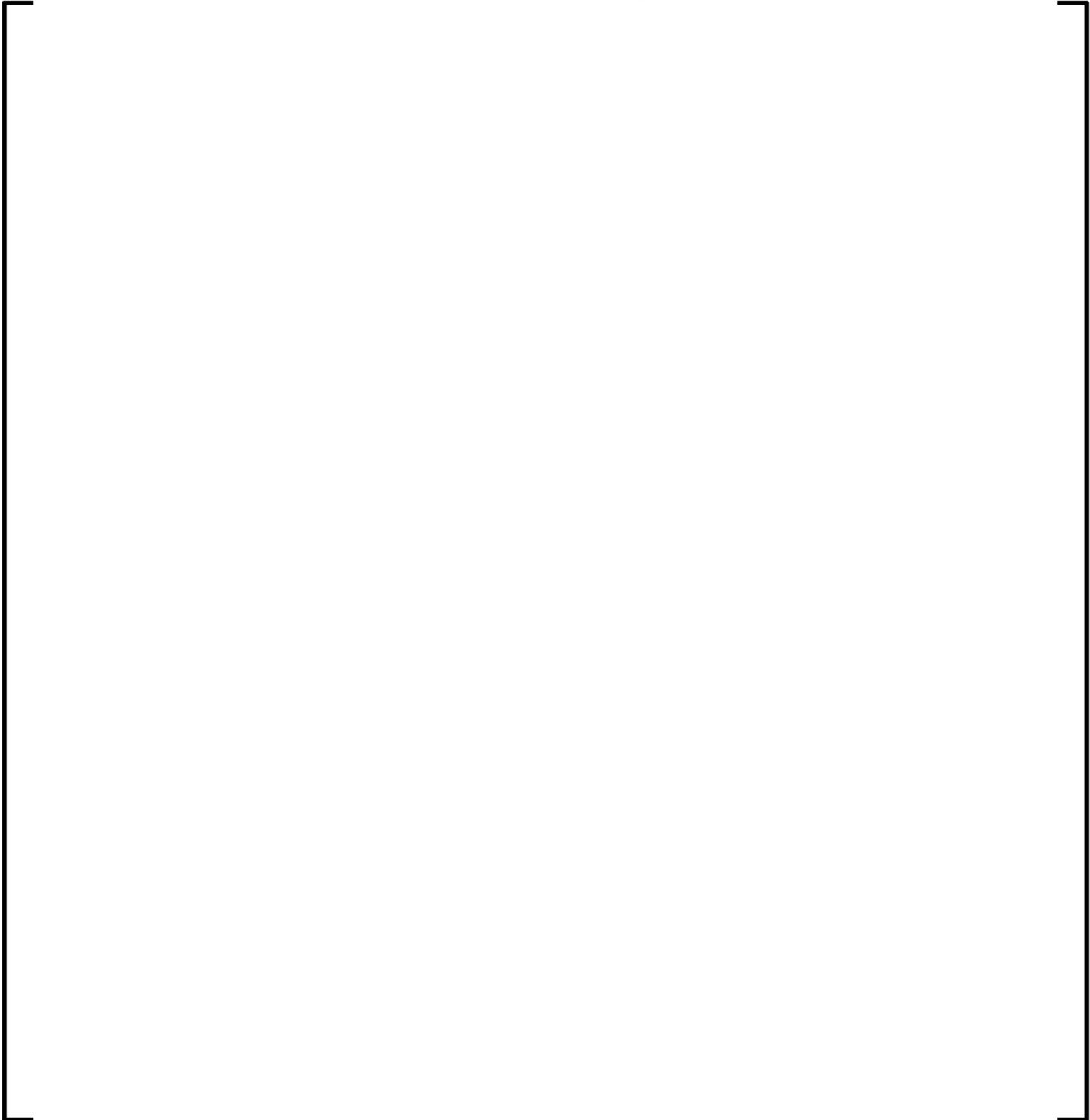


**Figure 7-10: Boundary Condition in Steady State Structural Analysis**

**7.2 Finite Element Analysis Run Sequence**

The various steps of the welding simulation methodology described in Section 3.0 are executed using the files described in Table 7-1. These files are listed in Table 6-1.

**Table 7-1: FEA Run Sequence**



### 7.3 Finite Element Analysis Post-Processing

Paths are defined in the DM weld regions as shown in Figure 7-11. The path line properties for the stress results are listed in Table 7-2. Stresses are extracted along these paths, which are listed in global coordinate system

[  
] (Table 6-1). The hoop and axial stresses are listed at [  
] along the paths for the cold shutdown condition, and the steady state operating conditions at 100% power. The stress results are printed in output files [  
] (Table 6-1).



**Figure 7-11: Path Lines for Stress Results**

**Table 7-2: Path Line Node Numbers**

**8.0 SUMMARY OF RESULTS**

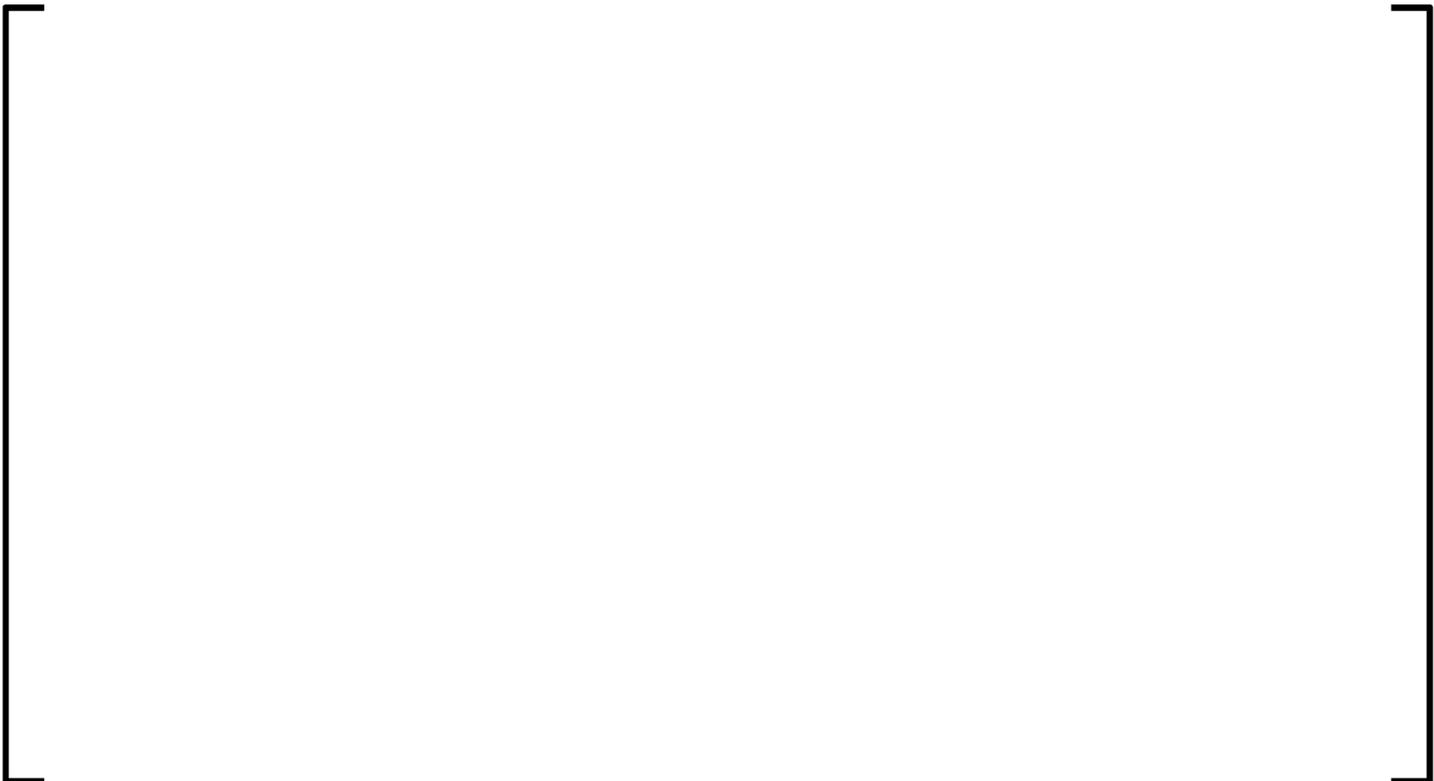
As discussed in Section 3.0, following the completion of the FSWOL repair simulation, five steady state loading cycles are applied to the finite element model to obtain a stable state of stresses after shakedown. This stress state is referred to as residual stresses at cold shutdown conditions. [ ] stress contours are shown in Figure 8-1 through Figure 8-4 for cold shutdown conditions and steady state operating conditions at 100% power.

The hoop and axial stresses are stored in the output files [ ] that are generated by ANSYS as documented in the output file [ ] (Table 6-1) for the path lines illustrated in Figure 7-11.

Plots along the normalized distance of each path are shown in Figure 8-5 and Figure 8-6 for the cold shutdown condition and in Figure 8-7 and Figure 8-8 for the steady state operating condition at 100% power. These axial and hoop stress distributions also tabulated in Table 8-1 and Table 8-2.

The results summarized in this section are presented in global coordinate system with the [ ]

[ ]



**Figure 8-1: Cold Shutdown Residual Stress – Axial [ ]**

Palisades Hot Leg Surge Nozzle FSWOL Weld Residual Stress Analysis – Non-Proprietary



**Figure 8-2: Cold Shutdown Residual Stress – Hoop [ ]**



**Figure 8-3: Residual + 100% Power Steady State Stress – Axial [ ]**

Palisades Hot Leg Surge Nozzle FSWOL Weld Residual Stress Analysis – Non-Proprietary



**Figure 8-4: Residual + 100% Power Steady State Stress – Hoop [ ]**



**Figure 8-5: Cold Shutdown Residual Stress Distribution – Axial [ ]**

Palisades Hot Leg Surge Nozzle FSWOL Weld Residual Stress Analysis – Non-Proprietary



**Figure 8-6: Cold Shutdown Residual Stress Distribution – Hoop [ ]**



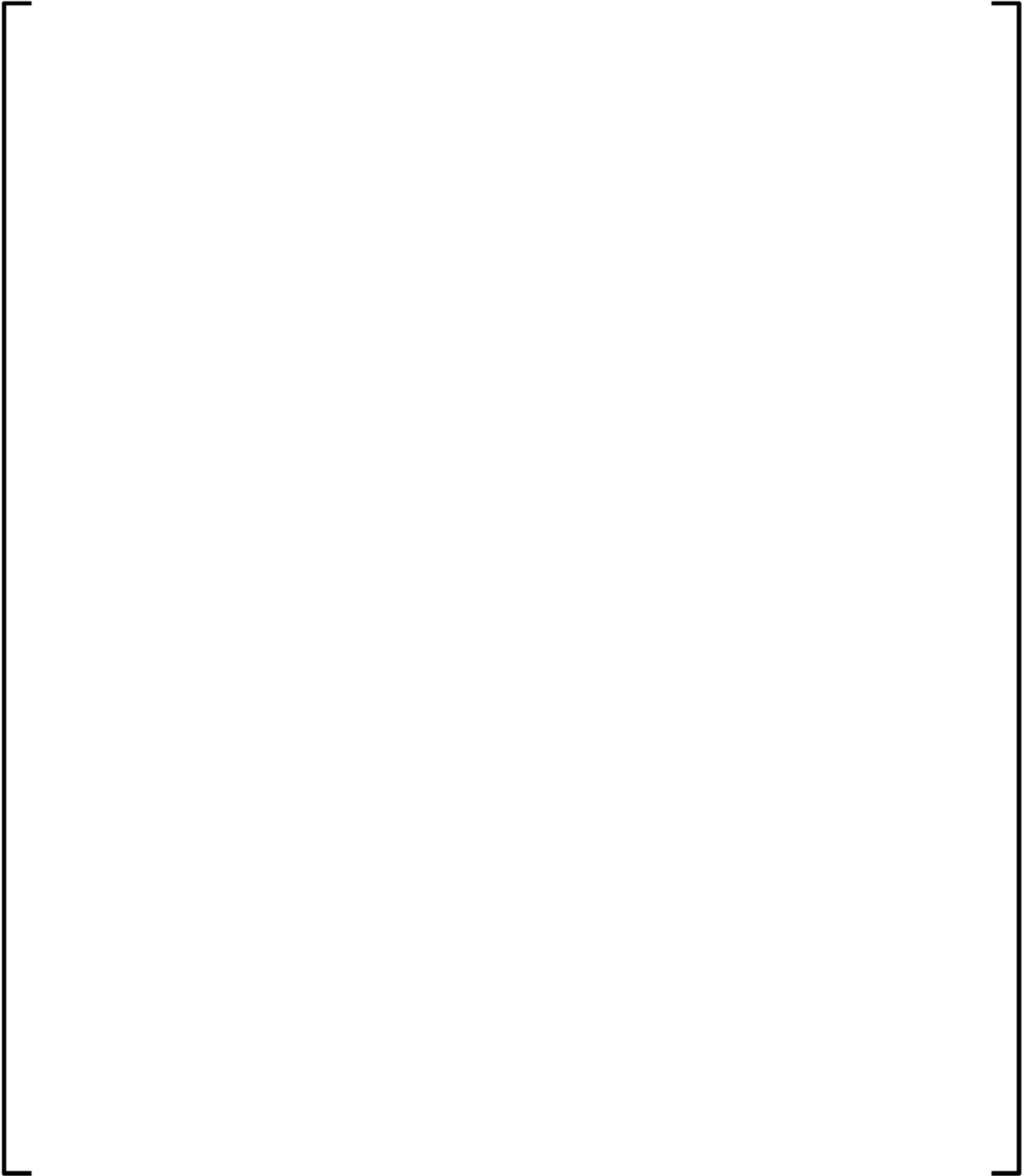
**Figure 8-7: Residual + 100% Power Steady State Stress Distribution – Axial [ ]**

Palisades Hot Leg Surge Nozzle FSWOL Weld Residual Stress Analysis – Non-Proprietary



**Figure 8-8: Residual + 100% Power Steady State Stress Distribution – Hoop [     ]**

**Table 8-1: Cold Shutdown Residual Stress Distribution**



**Table 8-2: Residual + 100% Power Steady State Stress Distribution**



**9.0 REFERENCES**

References identified with an (\*) are maintained within Holtec Records System and are not retrievable from Framatome Records Management. These are acceptable references per Framatome Administrative Procedure 0402-01, Attachment 7. See page 2 for Project Manager Approval of customer references.

- 1 Framatome Design Specification [ ]
- 2 Framatome Document [ ]
- 3 Materials Reliability Program: Welding Residual Stress Dissimilar Metal Butt-Weld Finite Element Modeling Handbook (MRP-317, Revision 1). EPRI, Palo Alto, CA: 2015. 3002005499.
- 4 ANSYS Finite Element Computer Code, Version 19.2, ANSYS Inc., Canonsburg, PA.
- 5 ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, 1965 Edition including Addenda through Winter 1966.
- 6 Framatome Document [ ]
- 7 Framatome Document [ ]
- 8 Framatome Drawing [ ]
- 9 Lee Fredette and Paul Scott, “Evaluation of the Mechanical Stress Improvement Process (MSIP) as a Mitigation Strategy for Primary Water Stress Corrosion Cracking in Pressurized Water Reactors,” Battelle Columbus, September 2009. (ADAMS Accession Number ML092990646)
- 10 \*Palisades Drawing VEN-M1-D SH. 106, Rev. 10, “Piping Assembly & Details.” (CE Dwg 232-673 Rev. 7)
- 11 \*Palisades Drawing VEN-M1-D SH. 109, Rev. 10, “Nozzle Details.” (CE Dwg. 232-676 Rev. 7)
- 12 Framatome Document [ ]
- 13 \*Combustion Engineering Specification No. 0070P-006 Rev. 2, “Engineering Specification for Primary Coolant Pipe and Fittings for Consumers Power Company,” Specification M1-D Effective March 17, 1994.
- 14 Framatome Document [ ]
- 15 Framatome Document [ ]



## CALCULATION SUMMARY SHEET (CSS)

Document No. 32 - 9401201 - 000

Safety Related:  Yes  No

Title Palisades Hot Leg Surge Nozzle FSWOL Crack Growth Appendix C Analysis – Non-Proprietary

### PURPOSE AND SUMMARY OF RESULTS:

**Purpose:** The purpose of this calculation is to evaluate the fatigue and primary water stress corrosion crack growth of postulated, inside surface-connected, 360° circumferential and semi-elliptical axial flaws in the weld overlaid Hot Leg Surge nozzle at Palisades in order to establish the acceptable period of operation between inspections based on the predicted crack growth calculated by the guidelines of Non-Mandatory Appendix C of the ASME Code Section XI.

The purpose of Revision 001 is to add proprietary bracketing. The results and conclusions of the analysis are not affected.

**Results/Conclusion:** The results from the fracture mechanics analysis performed to evaluate the worst-case flaws in the overlaid configuration and to establish the acceptable period of operation between inspections based on the predicted crack growth show that the acceptance criteria of ASME Section XI Appendix C are met for [ ] years of plant operation following the installation of the full structural weld overlay (FSWOL) [ ]. The actual period of plant operation between inspections for this component will be based on using the results of this evaluation in consultation with ASME Code Case N-770-7 (as modified by 10 CFR 50.55a and any limitations imposed by the NRC).

Export Classification

US EC:  N  Part 810  EAR

ECCN: N/A

**If the computer software used herein is not the latest version per the EASI list, AP 0402-01 requires that justification be provided.**

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT:

CODE/VERSION/REV	CODE/VERSION/REV
<u>AREVACGC v6.0</u>	

THE DOCUMENT CONTAINS ASSUMPTIONS THAT SHALL BE VERIFIED PRIOR TO USE

Yes

No

Palisades Hot Leg Surge Nozzle FSWOL Crack Growth Appendix C Analysis – Non-Proprietary

Review Method:  Design Review (Detailed Check)

Alternate Calculation

Does this document establish design or technical requirements?  YES  NO

Does this document contain Customer Required Format?  YES  NO

**Signature Block**

<b>Name and Title</b>	<b>Signature and Date</b>	<b>Role</b>	<b>Scope / Comments</b>
Nicholas Grummon, Engineer I	<i>N GRUMMON</i> 11/20/2025	P	All
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Jennifer Nelson, Principal Engineer	<i>JA NELSON</i> 11/21/2025	R	All
Bogdan Wasiluk, Engineering Supervisor	<i>BS WASILUK</i> 11/21/2025	A	All
Kimberly Jones, Project Manager	<i>KM JONES</i> 11/21/2025	PM	Approval of customer references.

**Role Definitions:**

- P/R/A designates Preparer (P), Reviewer (R), Approver (A);
- LP/LR designates Lead Preparer (LP), Lead Reviewer (LR);
- M designates Mentor (M);
- PM designates Project Manager (PM)





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**1.0 INTRODUCTION AND PURPOSE**

Framatome, Inc. has been contracted by Holtec Palisades, LLC (Owner of Palisades Nuclear Plant) to mitigate dissimilar metal welds (DMWs) with full structural weld overlays (FSWOLs) at multiple nozzle locations on the hot legs, cold legs, and pressurizer. Per the Certified Design Specification (Reference [1]), the purpose of this calculation is to establish an acceptable period of operation between inspections for the overlaid Hot Leg Surge (HLS) nozzle at Palisades, based on the predicted flaw growth determined by the guidelines of Non-Mandatory Appendix C of the ASME Code Section XI, Reference [2]. The time between inspections is determined to satisfy Note 10 in Table 1 of ASME Code Case N-770-7 (Reference [3]) which requires that inspections be performed within the mitigation evaluation period.

Time between inspections is investigated to address the possibility of primary water stress corrosion cracking (PWSCC) and fatigue crack growth of a postulated 360° circumferential flaw and a postulated semi-elliptical axial flaw in the [ ] weld-overlay region, as required, using Non-Mandatory Appendix C of the ASME BP&V Code Section XI, [ ] (Reference [2]) with use of applicable operating transients and associated cycles. Note, crack growth is not investigated in the underlying [ ] due to the application of the [ ]

[ ] That is, postulated flaws are assumed to propagate [ ] material.

This evaluation considers sustained and normal, upset, and test transient stresses from Reference [4] with the associated number of transient cycles, weld residual stresses from Reference [5], and sustained stresses due to pipe external loads and pressures from Reference [6] to predict the final flaw sizes at the end of the subsequent life renewal (SLR) period of extended plant operation at Palisades Nuclear Generating Station, which equates to [ ] starting from the FSWOL installation in [ ] and continuing to the end of life in 2054 for an 80 year license, or the acceptable period of operation if [ ]

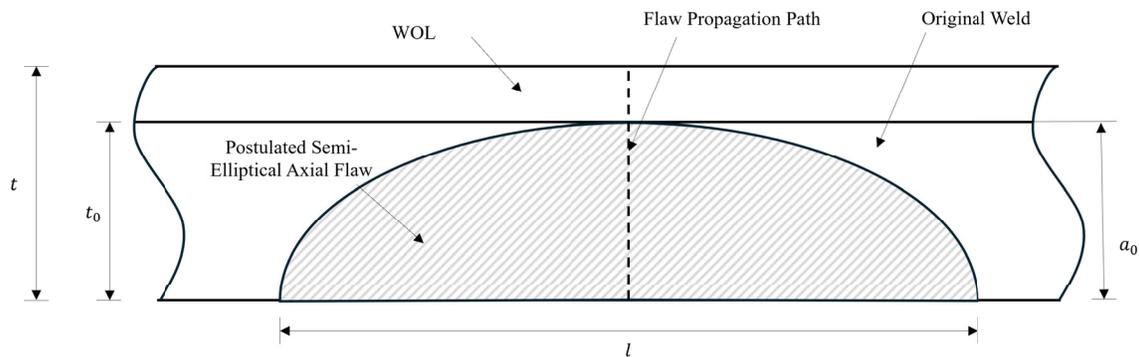
**2.0 ANALYTICAL METHODOLOGY**

This section presents several aspects of the fracture mechanics analysis that form the basis of the present flaw evaluation. The flaw growth analysis addresses the growth of the postulated flaws by primary water stress corrosion, cyclic and weld residual stresses, and sustained loads.

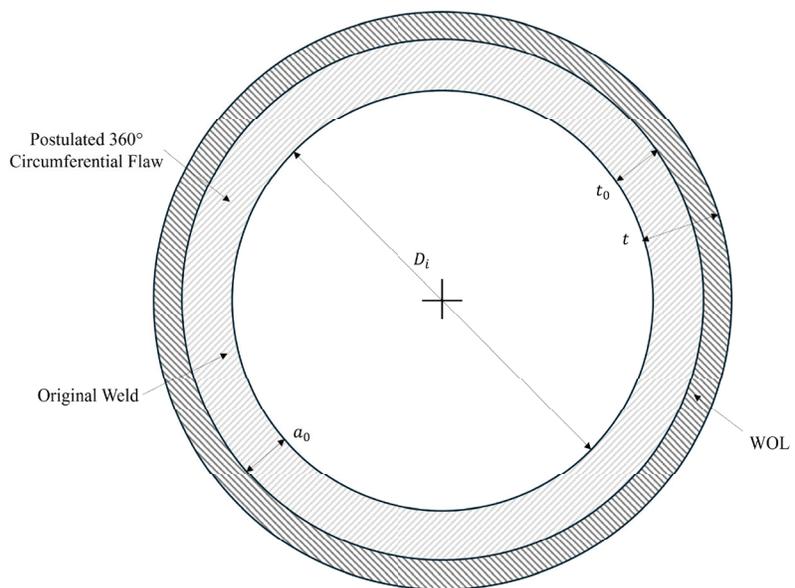
**2.1 Postulated Flaws**

An inside surface-connected, partial through-wall, semi-elliptical axial flaw, as shown in Figure 2-1, and an inside surface-connected, partial through-wall, full (360°) circumferential flaw in a cylinder, as shown in Figure 2-2, are postulated to exist at the time the weld overlay is applied. [

] In this analysis, a flaw aspect ratio (flaw length to depth) of [ ] is used to represent the postulated axial flaws. This is considered to be reasonably conservative based on the dimensions of the DMW given in Reference [8].



**Figure 2-1: Inside Surface-Connected, Partial Through-Wall, Semi-Elliptical Axial Flaw**



**Figure 2-2: Inside Surface-Connected, Partial Through-Wall, 360° Circumferential Flaw**

**2.2 Stress Intensity Factor (SIF) Solutions**

[  
 ]  
 This is a well-established fracture mechanics methodology which Framatome has implemented in a Microsoft Excel macro. The technical basis for this implementation is given in References [9] and [10]. The [ methodology is used [ ] for the postulated flaws and nozzle geometries considered in this analysis.

**2.3 Fatigue Crack Growth Mechanisms in [ ]**

Flaw growth in the [ ] in water environment due to cyclic loading is calculated using the fatigue crack growth model presented in [

] This equation is presented below and implemented by AREVACGC.



**2.4 PWSCC Crack Growth Mechanisms in [ ]**

The PWSCC crack growth rate given in [

to model PWSCC crack growth in [ ] material. This equation is presented below and implemented by AREVACGC.

**2.5 Methodology for Flaw Growth Analysis**

For the crack growth analysis, the applied stress intensity factor is driven by axial stresses for the 360° circumferential flaws, and by hoop stress for the axial flaws. The relevant sources of stress for fatigue and PWSCC crack growth are summarized in Table 2-1, below.

**Table 2-1: Relevant Sources of Stress for Fatigue and PWSCC Flaw Growth Analysis**

Inside Surface-Connected, Partial Through-Wall, 360° Circumferential Flaw	
Fatigue Crack Growth	
PWSCC Crack Growth	
Inside Surface-Connected, Partial Through-Wall, Semi-Elliptical Axial Flaw	
Fatigue Crack Growth	
PWSCC Crack Growth	

The number of cycles for each transient are assumed to be uniformly distributed over the HLS nozzle’s entire design life of 80 years. The cycles from all transients are sorted based on the time that they are assumed to occur. Fatigue flaw growth is calculated by considering the assumed sequence of total transient stresses which may consist of a collection of sub-cycles (peaks and valleys) within any transient.

The PWSCC and fatigue crack growth mechanisms are considered to be active simultaneously. Following the guidance of ASME Code Section XI Appendix C, Article C-3230 (Reference [2]), the PWSCC and fatigue crack growths are coupled in an incremental manner at selected time points throughout the service life (i.e. in approximate chronological order).

The PWSCC and fatigue crack growth of the inside surface-connected, partial through-wall, semi-elliptical axial flaw is controlled by the values of [ ]

The coupled PWSCC and fatigue crack growth calculations in the [ ] FSWOL are performed by the Framatome Excel-based macro code AREVACGC (Reference [9]).

**2.6 Acceptance Criteria for Crack Growth in [ ] SWOL Material**

The objective of the flaw growth analysis is to establish the acceptable period of operation between inspections based on the predicted crack growth calculated by the guidelines of ASME BPVC Non-Mandatory Appendix C (Reference [2]).

Per C-2610 of ASME BPVC, Section XI (Reference [2]), analytical evaluation procedures can be used to demonstrate acceptability for continued service during the evaluation period if the flaw parameters satisfy either the Final Flaw Depth Criteria in C-2611 or the Applied Stress Criteria in C-2612.

Palisades Hot Leg Surge Nozzle FSWOL Crack Growth Appendix C Analysis – Non-Proprietary

---

The Applied Stress Criteria of C-2612 of Reference [2] requires the calculated pipe stresses to be less than the allowable stresses for the flawed pipe which are a function of pipe stresses, required structural factors, pipe material properties, end-of-evaluation-period flaw length and depth, flaw orientation, and pipe failure mode. In addition, for axially oriented flaws, C-2613 requires that the final flaw length  $l_f$  shall not exceed the corresponding allowable flaw length  $l_{allow}$ . [

]

According to C-4210 (Reference [2]), the sequence used to determine the failure mode and analysis method for austenitic piping is given in Figure C-4210-1 which shows that for a flaw in austenitic/Ni-Cr-Fe weld material, Sections C-5000 and C-6000 of Reference [2] are to be used as the analysis methods for non-flux and flux welds, respectively.

The [ ] material in the existing DMW as well as in the FSWOL in the Palisades HLS nozzle is considered to be [ ] Therefore, for the postulated flaws that propagate into the [ ] weld material (per assumption), allowable stresses and flaw lengths are determined from the analysis method defined in [ ] of Reference [2].

**3.0 ASSUMPTIONS**

**3.1 Unverified Assumptions**

There are no unverified assumptions in the analysis.

**3.2 Justified Assumptions**

**3.3 Modeling Simplifications**

**4.0 DESIGN INPUTS**

**4.1 Geometry**

Crack growth analyses are performed along four path lines through the overlaid weld region, as shown in Figure 4-1. These path lines are selected from those used in the transient stress analysis (Reference [4]) and the residual stress analysis (Reference [5]). Note, these analyses differ slightly in both the model construction and the location of selected path lines. [



**Figure 4-1: Path Lines for Stress Results**

Path lines P1, P3, P4, and P5 from Reference [5] are chosen to correspond with path lines “btr”, “DM1”, “FR3”, and “DM2” respectively, from Reference [4]. That is, the stress results from the corresponding path lines are super-positioned in the present analysis as if the path lines coincide. This choice is made based on path line proximity and based on determination of the most severe stress profiles reported for each WRS path line in Reference [5]. The path lines are renamed PL\_1 (P1 and “btr”), PL\_2 (P3 and “DM1”), PL\_3 (P4 and “FR3”), and PL\_4 (P5 and “DM2”) respectively, in the present analysis. Stress results are extracted and combined at each of the angles of inclination [

]

[

]

Basic dimensions for the selected path lines shown in Figure 4-1 are presented below in Table 4-1. [

] Note, Reference [8] provides the Design Drawing for the HLS nozzle that the finite element model constructed in Reference [5] is based on.

**Table 4-1: Path Line Geometry Parameters**

Param	Description	PL_1	PL_2	PL_3	PL_4
$D_{o,orig}$	Diameter of outside surface prior to weld overlay				
$D_o$	Diameter of outside surface including weld overlay, $D_{o,orig} + 2 \times w$				
$D_i$	Diameter of inside surface				
$t_0$	Wall thickness prior to weld overlay, $(D_{o,orig} - D_i)/2$				
$t$	Overall wall thickness including weld overlay, $t_0 + w$				
$w$	Minimum weld overlay thickness, (reduced by 0.06 inches to exclude bridge layer thickness [8])				
$A$	Cross-sectional area, $\pi(D_o^2 - D_i^2)/4$				
$I$	Moment of inertia, $\pi(D_o^4 - D_i^4)/64$				
$S_o$	Section modulus at OD, $2I/D_o$				
$S_i$	Section modulus at ID, $2I/D_i$				

Reference [6] does not explicitly state where the external loads are applied on the model. [

]

[ These external loads are transformed to the dissimilar metal weld (DMW) region for the present analysis by the moment arm,  $h$ , representing the distance between the SSW and each DMW path line. [

] Table 4-2, below, reports this value along with several crack parameters used by the AREVACGC solver, determined from the dimensions given in Table 4-1.

**Table 4-2: AREVACGC Crack Parameters**

Parameter	Formula	PL_1	PL_2	PL_3	PL_4
$a_0$	$1.00 * t_0$				
$l_{0,axial}$	$4 * a_0$				
$l_{0,circ}$	$2\pi * (R_i + a_0)$				
$R_i$	$D_i/2$				
$h$	Arm from SSW to DMW (distance to PL5)				

**4.2 Material Properties**

The Framatome Certified Design Specification (Reference [1]) provides the material specifications pertinent for the flaw evaluation assessment in this document. [

]

**Table 4-3: Material Strength**

Material	Temperature	Yield Strength, $\sigma_y$ [psi]	Ultimate Strength, $\sigma_u$ [psi]
	100		
	500		
	600		
	650		
	700		

**4.3 Applied Stresses**

The categories of applied stresses that need be considered are discussed in this section.

**4.3.1 Transient Stresses**

The transients and transient cycle counts defined in Reference [6] required to be used for the flaw tolerance evaluations of the HLS nozzle FSWOL are reported in Table 4-4, below. The listed number of cycles is in accordance with Reference [1] which states that the design life of the modification shall minimally span the remainder of the 60-year licensed life of the plant (until 2031), plus an additional 20-year operational cycle extension (to 2054), [ ] Per Reference [1], the total cycle count through 2054 shall be calculated by [ ]

[ ] The number of cycles listed for stratification transients is [ ]

Note, the [ ] Only the Level A, Level B, and Test transients are applicable for analysis herein. Also note, the terminologies [ ] are used in the Design Specification (Reference [1]) to refer to the [ ] as defined in Reference [6].

**Table 4-4: Applicable Operating Transients and Cycles**

Case	Title	Category	Occurrences	Reference
		A		Section 4.2.4, [6]
		A		Section 5.4.1, [6]
		A		Section 5.4.1, [1]
		A		Section 5.4.1, [1]
		A		Section 5.4.1, [1]
		B		Section 4.2.4, [6]
		B		Section 4.2.4, [6]
		B		Section 4.2.4, [6]
		B		Section 4.2.4, [6]
		Test		Section 4.2.7, [6]
		Test		Section 4.2.7, [6]
				Section 4.2.4.1 [6]
				Section 4.2.4.1 [6]
				Section 4.2.4.1 [6]
				Section 4.2.4.1 [6]
				Section 4.2.4.1 [6]
				Section 4.2.4.1 [6]
				Section 4.2.4.1 [6]
				Section 4.2.4.1 [6]
				Section 4.2.4.1 [6]

The cyclic operating stresses that are needed to calculate fatigue crack growth are obtained from the [ ] Reference [4]. These cyclic stresses are developed for all applicable transients at a number of time points to capture the maximum and minimum stresses due to fluctuations in pressure and temperature.

The transient stresses, temperatures, and pressures on path lines PL\_1 (btr), PL\_2 (DM1), PL\_3 (FR3) and PL4 (DM2) are [ ]

The stress data applicable for each of the [ ] path lines is then extracted into [ ]

**4.3.2 Residual Stresses**

The residual stress profile through the thickness of the HLS nozzle is determined in the analysis performed in Reference [5]. [

] These results are then transferred into the appropriate AREVACGC solver workbook, as outlined in Table 2-1, above. [

]

**4.3.3 Pressure Loads**

[

] For PWSCC crack growth analysis, the sustained steady state normal operating pressure load of [ ] (Reference [6]) is applied to the crack faces. For the fatigue crack growth analysis, time dependent pressure is applied so that the pressure fluctuations can be accurately captured and factored into the fatigue crack growth.

The time dependent pressure is taken from the definition of transients as given in Reference [4] (the fatigue analysis). [

] The time dependent pressures are reported for each transient in the [ ] tab of the AREVACGC solver spreadsheets listed in COLDSTOR. [

]

The maximum pressures for normal, upset, emergency, and faulted conditions are required for the determination of allowable stresses and allowable flaw size, as discussed in Section 3.2(4). The maximum normal and upset pressure of [ ] (occurring at [ ]) is used for the normal and upset conditions. For emergency and faulted conditions, [

] Therefore, a maximum vessel pressure of [ ] is selected for the emergency and faulted conditions (see Assumption 3.2(4)).

Note, all pressure values are converted to units of [ ] before being entered into the AREVACGC solver sheets. Gauge pressure is considered to be zero at 15 psia.

**4.3.4 Piping Applied External Loads**

The external loads applied to the HLS nozzle are obtained from Reference [6] and presented in Table 4-5, below. Section 4.1 discusses the location of the load application point which is at the SSW. Per Reference [6], [

]

**Table 4-5: Hot Leg Surge Nozzle External Loads (at SSW)**

These external loads are transformed to the DMW region (PL\_1, PL\_2, PL\_3) by the moment arm,  $h$ , defined in Section 4.1 according to the equations below.

$$M_{X(DMW)} = M_{X(SSW)} + F_{Z(SSW)} \times h$$

$$M_{Y(DMW)} = M_{Y(SSW)}$$

$$M_{Z(DMW)} = M_{Z(SSW)} + F_{X(SSW)} \times h$$

The applicable loading combinations are defined for the Pressurizer HLS in Figure 11, Sheet 1 of Reference [6] as follows. [

]

The below load cases are selected from the above service levels and discussed in the following sections:

- Sustained Loads – [ ]
- Seismic OBE – [ ]
- Primary Bending Loads – [ ]
- Secondary Bending Loads – [ ]

**4.3.4.1 Sustained Stresses Due to Piping Loads**

Sustained loads include [ ] selected from every service level discussed in Section 4.3.4. The results of transforming the [ ] external loads to the DMW region for each path line, as discussed in Section 4.3.4, are reported below in Table 4-6.

**Table 4-6: Sustained Loads at DMW Path Lines**

Path Line	Normal Loading Conditions <sup>(1)</sup>						
	Fx (lb)	Fy (lb)	Fz (lb)	Mx (in-lb)	My (in-lb)	Mz (in-lb)	SRSS <sub>bending</sub> (in-lb) <sup>(2)</sup>
PL_1							
PL_2							
PL_3							

Note(s):

(1) Normal is defined as [ ] per Reference [6].

(2)  $SRSS_{bending} = [ ]$

These sustained loads are converted to axial stresses according to Equation 1.

$$[ ] \quad (1)$$

The resulting axial stresses due to sustained loads are reported in Table 4-7, below. These stresses are

[ ] as indicated in Table 2-1, into the [ ] columns in the [ ] tab in AREVACGC. [ ]

**Table 4-7: Axial Stresses Due to Sustained Loads**

$(r - R_i)(in)/t$	PL_1 (psi)	PL_2 (psi)	PL_3 (psi)	PL_4 (psi)
0.00				
0.05				
0.10				
0.15				
0.20				
0.25				
0.30				
0.35				
0.40				
0.45				
0.50				
0.55				
0.60				
0.65				
0.70				
0.75				
0.80				
0.85				
0.90				
0.95				
1.00				

**4.3.4.2 Thermal Stratification**

The effect of thermal stratification loads on fatigue crack growth is addressed by modeling [ ] For the thermal stratification events listed in Table 4-4, loads applied [ ] are listed in Table 4-8 which are obtained from Figure 11 Sheet 2 of Reference [6]. [ ]

**Table 4-8: Loads due to Thermal Stratification**

The loads applied at the safe end are transformed to the path lines in the [ ] dissimilar metal weld (DMW) region by the moment arm  $h$ , per Table 4-1 (distance to PL\_5) according to the equations below.

$$M_{X(DMW/Butter)} = M_{X(SSW)} + F_{Z(SSW)} \times h$$

$$M_{Y(DMW/Butter)} = M_{Y(SSW)}$$

$$M_{Z(DMW/Butter)} = M_{Z(SSW)} + F_{X(SSW)} \times h$$

The thermal stratification loads per Table 4-5 are transformed to the appropriate path lines using Equation 1 (from Section 4.3.4.1), [

] The axial stresses are calculated at every subpoint along the path lines. The results are given in Table 4-9 through Table 4-12, below.

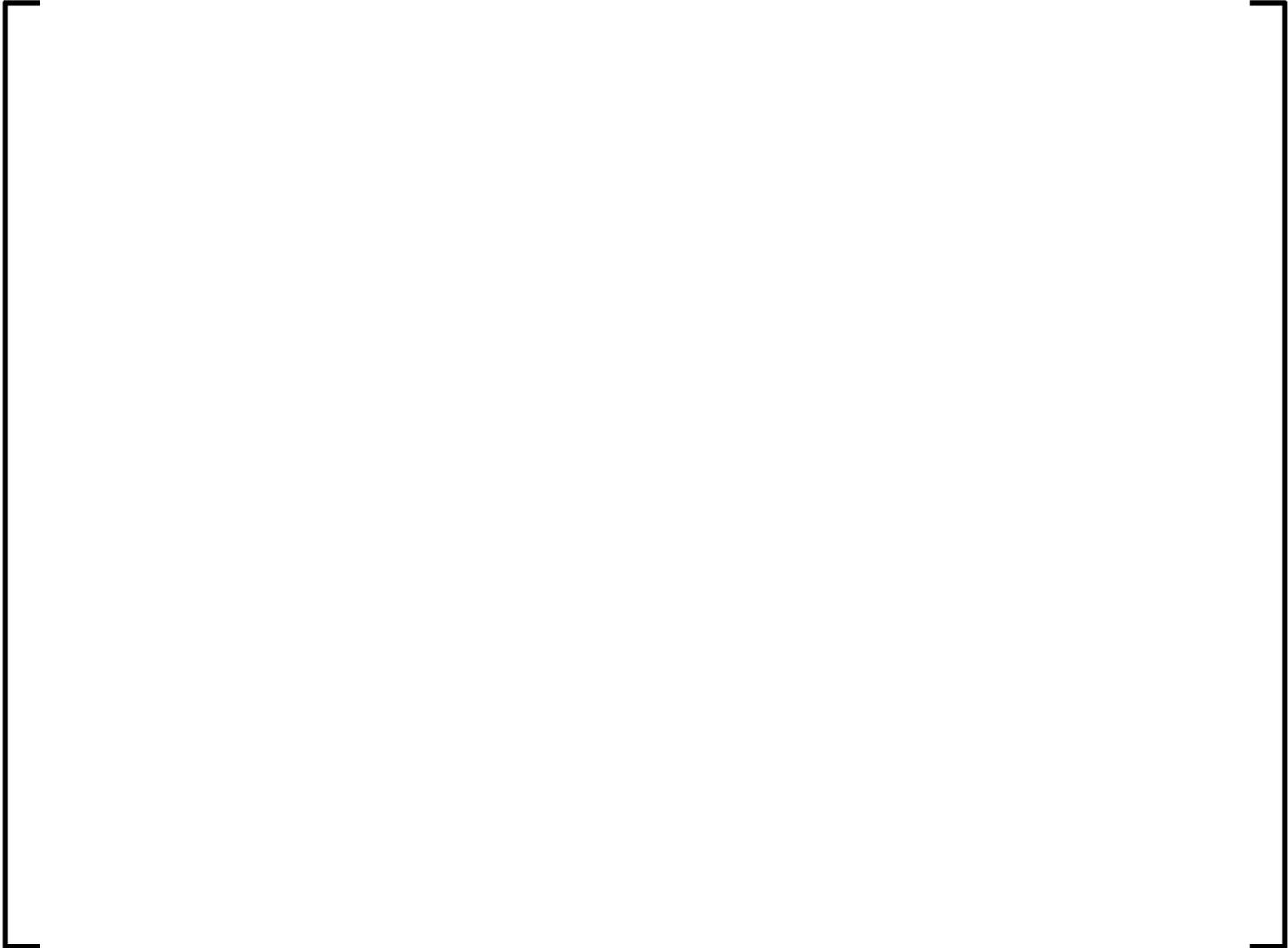
**Table 4-9: Axial Stresses (psi) Due to Thermal Stratification Loads in PL\_1 (Rounded)**

--

**Table 4-10: Axial Stresses (psi) Due to Thermal Stratification Loads in PL\_2 (Rounded)**



**Table 4-11: Axial Stresses (psi) Due to Thermal Stratification Loads in PL\_3 (Rounded)**



**Table 4-12: Axial Stresses (psi) Due to Thermal Stratification Loads in PL\_4 (Rounded)**

Table content is redacted
---------------------------

The stratification events are then modeled [ ] The number of cycles for each stratification event is listed in Table 4-4 for eighty years of operation.

The thermal stratification events occur during [ ] Therefore, in order to obtain the limiting baseline through-wall axial stress distribution, the [ ]

[ ] For each path line the time point where [ ]

[ ] See the [ ] tabs in the AREVACGC solver sheets listed in COLDSTOR for a detailed definition.

Note, the thermal stratification transients are [ ]

**4.3.4.3 Seismic Event**

The effect of seismic loads on fatigue crack growth is addressed by modeling the [ ] The forces and moments reported in Table 4-5 are first transformed from the SSW to the DMW region for each path line. The axial stress is then evaluated at the outer diameter of the HLS, according to Equation 1. Note, [ ] therefore, Equation 1 may be simplified to the following.

$$[ ]$$

This yields the axial seismic stress presented in Table 4-13 for each path line.

**Table 4-13: Axial Stress Due to Seismic [ ] Loads**

[ ]	[ ]
-----	-----

The seismic event is then modeled as [ ]

]

The baseline through-wall axial stress distribution for each path line is obtained for steady state conditions. This corresponds to [ ]

]

Note, the seismic transient is [ ]

]

**4.3.4.4 Primary and Secondary Bending Loads**

Per Article C-5000 and C-6000 of Reference [2], information on primary and secondary bending moments acting on the cross-section of interest under normal, upset, emergency, and faulted conditions are required to determine the allowable stresses for circumferential flaws. The primary and secondary bending moments for all service levels are based on the external loads given in Section 4.3.4, with the forces and moments first being transferred to the DMW region (PL\_1, PL\_2, and PL\_3) using the moment arm, *h*, as discussed.

The calculated primary and secondary bending moments at each path line are tabulated in Table 4-14 and Table 4-15, respectively. The loads included for each service level are defined as “Notes” beneath each table.

**Table 4-14: Primary Bending Loads at DMW Path Lines**

Path Line	Normal/Upset Loading Conditions <sup>(2)</sup>						
	Fx (lb)	Fy (lb)	Fz (lb)	Mx (in-lb)	My (in-lb)	Mz (in-lb)	SRSS <sub>bending</sub> (in-lb) <sup>(1)</sup>
PL_1							
PL_2							
PL_3							
PL_4							
Path Line	Emergency/Faulted Loading Conditions <sup>(2)</sup>						
	Fx (lb)	Fy (lb)	Fz (lb)	Mx (in-lb)	My (in-lb)	Mz (in-lb)	SRSS <sub>bending</sub> (in-lb) <sup>(1)</sup>
PL_1							
PL_2							
PL_3							
PL_4							

Note(s):

<sup>(1)</sup>  $SRSS_{bending} = [ \quad ]$

<sup>(2)</sup> Normal/Upset Load Combination = [  $\quad$  ]

<sup>(1)</sup> Emergency/Faulted Load Combination = [  $\quad$  ]

**Table 4-15: Secondary Bending Loads at DMW Path Lines**

Path Line	Normal/Upset Loading Conditions <sup>(2)</sup>						
	Fx (lb)	Fy (lb)	Fz (lb)	Mx (in-lb)	My (in-lb)	Mz (in-lb)	SRSS <sub>bending</sub> (in-lb) <sup>(1)</sup>
PL_1							
PL_2							
PL_3							
PL_4							

Note(s):

<sup>(1)</sup>  $SRSS_{bending} = [ \quad ]$

<sup>(2)</sup> Normal/Upset Load Combination = [  $\quad$  ]

**5.0 COMPUTER USAGE**

**5.1 Software**

The Framatome software verification process for this calculation included the execution of test cases which exercised features of the software which are applicable to the actual analysis done in the calculation. These test cases and the actual analysis were done using the same version of AREVACGC v6.0, Reference [9], executed on the same hardware and operating system, the applicable software version, and the results of the test cases, demonstrating that the correct results are achieved.

To validate the installation of AREVACGC v6.0, Reference [9], Test Cases [ ] provided in Reference [9] are executed. The installation of the software on a [ ] is documented below and verification tests of similar applications are listed as follows.

**Computer Program Tested:** AREVACGC v6.0

**Computer Hardware Used:** The hardware used is [ ] and the operating system is [ ]

**Responsible Engineer:** N. Grummon

**Date of Tests:** 5/11/2025 (before all runs)  
6/16/2025 (after all runs)

**Acceptability:** Results agree with those documented for the corresponding test cases in Reference [9]. Test case runs are documented in Table 5-1.

**5.2 Computer Files**

The computer files pertinent to Revision 000 of this document are listed in Table 5-1 and located in the following ColdStor directory:

[ ]

**Table 5-1: List of Computer Files for Revision 000**



**6.0 CALCULATIONS**

The following subsections provide the fatigue and PWSCC crack growth analyses and final flaw size evaluations for the postulated circumferential and axial flaws. For every postulated flaw type and path line, a crack growth analysis is conducted to establish the acceptable period of operation between inspections based on the predicted crack growth. The analysis considers path lines rotated about the HLS nozzle at [ ]

The final flaw depth is determined by either reaching [ ] of operation from the weld overlay installation date [ ] to the end of life for an 80 year license period (i.e. through 2054), or by reaching the allowable stresses and/or final flaw configurations established by the flaw acceptance criteria outlined in Section 2.6. Per Assumption 3.2(3), the flaw is postulated to initiate in the [ ] FSWOL material as opposed to the [ ] due to the [ ] to the HLS nozzle.

**6.1 Circumferential Flaw**

**6.1.1 Propagation of Circumferential Flaw into [ ] FSWOL Crack Growth Analysis Summary (PL\_1, PL\_2, PL\_3)**

This section details the crack growth of a postulated circumferential flaw developed in the [ ] FSWOL portion of the Palisades HLS nozzle, along all path lines selected for the analysis. AREVACGC (Reference [9]) is used to determine the final flaw depth due to combined fatigue and PWSCC crack growth in the [ ] FSWOL material joining the nozzle to the safe end. A summary of the flaw growth in the [ ] weld material for the postulated circumferential flaw is presented in Table 6-1 through Table 6-4.

**Table 6-1: Summary of Crack Growth for Circumferential Flaws on [ ] Path Lines**

Item	PL_1 <sup>(1)</sup>	PL_2 <sup>(1)</sup>	PL_3 <sup>(1)</sup>	PL_4 <sup>(2)</sup>
Initial Flaw Depth, $a_i$ , [inch]				
Initial $a_i/t$ ratio				
Final Flaw Depth, $a_f$ , [inch]				
Final $a_f/t$ ratio				
Total amount of Fatigue + PWSCC Crack Growth, $\Delta a$ , [inch]				
Acceptable Operating Period, $P$ , [year]				

Notes:

- (1) Crack growth results obtained from [ ]
- (2) Crack growth results obtained from [ ]

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**Table 6-2: Summary of Crack Growth for Circumferential Flaws on [ ] Path Lines**

Item	PL_1 <sup>(1)</sup>	PL_2 <sup>(1)</sup>	PL_3 <sup>(1)</sup>	PL_4 <sup>(2)</sup>
Initial Flaw Depth, $a_i$ , [inch]				
Initial $a_i/t$ ratio				
Final Flaw Depth, $a_f$ , [inch]				
Final $a_f/t$ ratio				
Total amount of Fatigue + PWSCC Crack Growth, $\Delta a$ , [inch]				
Acceptable Operating Period, $P$ , [year]				

Notes:

- (1) Crack growth results obtained from [ ]
- (2) Crack growth results obtained from [ ]

]

**Table 6-3: Summary of Crack Growth for Circumferential Flaws on [ ] Path Lines**

Item	PL_1 <sup>(1)</sup>	PL_2 <sup>(1)</sup>	PL_3 <sup>(1)</sup>	PL_4 <sup>(1)</sup>
Initial Flaw Depth, $a_i$ , [inch]				
Initial $a_i/t$ ratio				
Final Flaw Depth, $a_f$ , [inch]				
Final $a_f/t$ ratio				
Total amount of Fatigue + PWSCC Crack Growth, $\Delta a$ , [inch]				
Acceptable Operating Period, $P$ , [year]				

Notes:

- (1) Crack growth results obtained from [ ]
- (2) Crack growth results obtained from [ ]

]

**Table 6-4: Summary of Crack Growth for Circumferential Flaws on [ ] Path Lines**

Item	PL_1 <sup>(1)</sup>	PL_2 <sup>(1)</sup>	PL_3 <sup>(1)</sup>	PL_4 <sup>(1)</sup>
Initial Flaw Depth, $a_i$ , [inch]				
Initial $a_i/t$ ratio				
Final Flaw Depth, $a_f$ , [inch]				
Final $a_f/t$ ratio				
Total amount of Fatigue + PWSCC Crack Growth, $\Delta a$ , [inch]				
Acceptable Operating Period, $P$ , [year]				

Notes:

- (1) Crack growth results obtained from [ ]
- (2) Crack growth results obtained from [ ]

]

**6.1.2 Limiting Location Circumferential Flaw Individual Transient Contribution**

Contribution of the individual transients and PWSCC to the crack growth is reported below, in Table 6-5, for the postulated flaw in the limiting path line which is determined from Section 6.1.1 to be along [ ]

]

**Table 6-5: Individual Transient Contribution to Crack Growth for Circumferential Flaw in [ ] Path Line**

Table content is redacted
---------------------------

**6.1.3 Limiting Location Circumferential Flaw Acceptance Criteria**

The final flaw depth is found to be [ ] in PL\_1, [ ] in PL\_2, [ ] in PL\_3, and [ ] in PL\_4. ASME BPVC Section XI, Non-Mandatory Appendix C (Reference [2]), [ ] outlines the acceptance criteria for these results, per the discussion in Section 2.6. Table 6-6, below, demonstrates satisfaction of the acceptance criteria per the applicable subsections of the ASME Code for the most limiting path line [ ] Therefore, the period of acceptable operation between inspection of crack growth in the [ ] material is determined to be [ ]

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**Table 6-6: End of Life Evaluation for 360° Circumferential Planar Surface Flaw in [ ] FSWOL [ ] Path Lines**

Allowable Applied Stress for [ ]	Level A	Level B	Level C	Level D	Reference
Service level max pressure, p, (psi)					
Service level max temperature, T, (°F)					
Service level flow stress, $\sigma_f$ , (psi)					
Total thickness, t, (in)					
Outside diameter, $D_o$ , (in)					
Sectional area, A, (in <sup>2</sup> )					
Moment of inertia, I, (in <sup>4</sup> )					
Section modulus, S, (in <sup>3</sup> )					
Primary bending moment, Mb, (in-lbs)					
Membrane stress factor, SF <sub>m</sub>					
Bending stress factor, SF <sub>b</sub>					
Calculated primary membrane stress, $\sigma_m$ , (psi) <sup>(2)</sup>					
Calculated primary bending stress, $\sigma_b = M_b/S$ , (psi)					
Final flaw depth, a <sub>f</sub> , (in)					
Calc. final flaw depth to thickness ratio, a <sub>f</sub> /t					
Flaw half-angle, q, (rad)					
Angle to neutral axis of flawed pipe, b, (rad)					
$j = \arcsin[ 0.5(a_f/t) \sin q ]$ , (rad)					
Bending stress at incipient plastic collapse, $\sigma_b^c$ , (psi) <sup>(3)</sup>					
Membrane stress at incipient plastic collapse, $\sigma_m^c$ , (psi) <sup>(4)</sup>					
Allowable pipe bending stress, S <sub>c</sub> , (psi) <sup>(5)</sup>					
Allowable pipe membrane stress, S <sub>t</sub> , (psi) <sup>(6)</sup>					
Ratio $\sigma_b / S_c$					
Ratio $\sigma_m / S_t$					
Conclusion	<b><math>S_c &lt; \sigma_b, S_t &lt; \sigma_m</math> and <math>a_f/t = 0.75</math></b>				

Note(s):

Palisades Hot Leg Surge Nozzle FSWOL Crack Growth Appendix C Analysis – Non-Proprietary

6.2 Axial Flaw

6.2.1 Propagation of Axial Flaw into [ ] FSWOL Crack Growth Analysis Summary (PL\_1, PL\_2, PL\_3) Along All Path Lines

This section details the crack growth of a postulated axial flaw developed in the [ ] FSWOL portion of the Palisades HLS nozzle, along all path lines selected for the analysis. AREVACGC (Reference [9]) is used to determine the final flaw depth due to combined fatigue and PWSCC crack growth in the [ ] FSWOL material joining the nozzle to the safe end.

The analysis is repeated with the [ ] The flaw growth is found to be [ ] The results for the deepest point are presented below for each path line.

Table 6-7: Summary of Crack Growth for Axial Flaws on [ ] Path Lines

Item	PL_1 <sup>(1)</sup>	PL_2 <sup>(1)</sup>	PL_3 <sup>(1)</sup>	PL_4 <sup>(1)</sup>
Initial Flaw Depth, $a_i$ , [inch]				
Initial $a_i/t$ ratio				
Final Flaw Depth, $a_f$ , [inch]				
Final $a_f/t$ ratio				
Total amount of Fatigue + PWSCC Crack Growth, $\Delta a$ , [inch]				
Acceptable Operating Period, $P$ , [year]				

Notes:

<sup>(2)</sup> Crack growth results obtained from [ ]

Table 6-8: Summary of Crack Growth for Axial Flaws on [ ] Path Lines

Item	PL_1 <sup>(1)</sup>	PL_2 <sup>(1)</sup>	PL_3 <sup>(1)</sup>	PL_4 <sup>(1)</sup>
Initial Flaw Depth, $a_i$ , [inch]				
Initial $a_i/t$ ratio				
Final Flaw Depth, $a_f$ , [inch]				
Final $a_f/t$ ratio				
Total amount of Fatigue + PWSCC Crack Growth, $\Delta a$ , [inch]				
Acceptable Operating Period, $P$ , [year]				

Notes:

<sup>(3)</sup> Crack growth results obtained from [ ]

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**Table 6-9: Summary of Crack Growth for Axial Flaws on [ ] Path Lines**

Item	PL_1 <sup>(1)</sup>	PL_2 <sup>(1)</sup>	PL_3 <sup>(1)</sup>	PL_4 <sup>(1)</sup>
Initial Flaw Depth, $a_i$ , [inch]				
Initial $a_i/t$ ratio				
Final Flaw Depth, $a_f$ , [inch]				
Final $a_f/t$ ratio				
Total amount of Fatigue + PWSCC Crack Growth, $\Delta a$ , [inch]				
Acceptable Operating Period, $P$ , [year]				

Notes:

<sup>(1)</sup> Crack growth results obtained from [ ]

**Table 6-10: Summary of Crack Growth for Axial Flaws on [ ] Path Lines**

Item	PL_1 <sup>(1)</sup>	PL_2 <sup>(1)</sup>	PL_3 <sup>(1)</sup>	PL_4 <sup>(1)</sup>
Initial Flaw Depth, $a_i$ , [inch]				
Initial $a_i/t$ ratio				
Final Flaw Depth, $a_f$ , [inch]				
Final $a_f/t$ ratio				
Total amount of Fatigue + PWSCC Crack Growth, $\Delta a$ , [inch]				
Acceptable Operating Period, $P$ , [year]				

Notes:

<sup>(1)</sup> Crack growth results obtained from [ ]

**6.2.2 Limiting Location Axial Flaw Individual Transient Contribution**

Contribution of the individual transients and PWSCC to the crack growth is reported below, in Table 6-5, for the postulated flaw in the limiting path line which is determined from Section 6.2.1 to be along [ ]

**Table 6-11: Individual Transient Contribution to Crack Growth for Axial Flaw in [ ] Path Line**

[ ]
-----

**6.2.3 Limiting Location Axial Flaw Acceptance Criteria**

The final flaw depth is found to be [ ] in PL\_1, [ ] in PL\_2, [ ] in PL\_3, and [ ] in PL\_4. ASME BPVC Section XI, Non-Mandatory Appendix C (Reference [2]), [ ] outlines the acceptance criteria for these results, per the discussion in Section 2.6. Table 6-12, below, demonstrates satisfaction of the acceptance criteria per the applicable subsections of the ASME Code for the limiting path line [ ] Therefore, the period of acceptable operation between inspection of crack growth in the [ ] FSWOL material is determined to be [ ]

Palisades Hot Leg Surge Nozzle FSWOL Crack Growth Appendix C Analysis – Non-Proprietary

**Table 6-12: End of Life Evaluation for Axial Flaw Propagated into [ ] Path Lines**

Allowable Crack Length for [ ]	Level A	Level B	Level C	Level D	Reference
Service level maximum pressure, $p$ , (psi)					
Service level maximum temperature, $T$ , (°F)					
Service level flow stress, $\sigma_f = (\sigma_y + \sigma_u)/2$ , (psi)					
Total thickness, $t$ , (in)					
Outside diameter, $D_o$ , (in)					
Mean pipe radius, $R_m$ , (in)					
Membrane stress factor, $SF_m$					
Calculated pipe hoop stress, $\sigma_h = pR_m/t$ , (psi)					
Final flaw depth, $a_f$ , (in)					
Final flaw length, $l_f$ , (in)					
Calculated final flaw depth to thickness ratio, $a_f/t$					
Ratio of allowable flaw depth to thickness, $a_{allow} / t$ <sup>(4)</sup>					
Allowable flaw length limit, $l_{allow}$ , (in) <sup>(5)</sup>					
Ratio $a_f / a_{allow}$					
Ratio $l_f / l_{allow}$					
<b>Conclusion</b>	<b><math>a_{allow} &gt; a_f</math> and <math>l_{allow} &gt; l_f</math></b>				

Note(s):

**7.0 RESULTS**

The results from the fracture mechanics analysis performed to evaluate the bounding case flaws in the overlaid configuration and to establish the acceptable period of operation between inspections based on the predicted crack growth, show that the acceptance criteria of ASME Section XI Appendix C (Reference [2]) are met for [ ] of plant operation following the installation of the FSWOL [ ] (i.e. until the end of the SLR).

A summary of the ASME Section XI Appendix C flaw evaluations is shown in Table 7-1. The most limiting flaw orientation and path line is a [ ] located in the [ ] FSWOL region of the DMW, [ ]

**Table 7-1: ASME Section XI Appendix C Flaw Evaluation Summary**

360° Circumferential Flaws				
	PL_1	PL_2	PL_3	PL_4
Total wall thickness, $t$ [inch] =				
Initial flaw depth, $a_i$ [inch] =				
Final flaw depth, $a_f$ [inch] =				
Flaw growth, $\Delta a$ [inch] =				
Bending stress ratio, $\sigma_b/S_c$ =				
Membrane stress ratio, $\sigma_m/S_t$ =				
Acceptable operating period, $P$ , [year] =				
References:	Table 6-3	Table 6-3	Table 6-3	Table 6-1
Semi-Elliptical Axial Flaws				
	PL_1	PL_2	PL_3	PL_4
Total wall thickness, $t$ [inch] =				
Initial flaw depth, $a_i$ [inch] =				
Final flaw depth, $a_f$ [inch] =				
Flaw growth, $\Delta a$ [inch] =				
Final flaw depth to allowable flaw depth ratio, $a_f/a_{allow}$ =				
Final flaw length to allowable ratio, $l_f/l_{allow}$ =				
Acceptable operating period, $P$ , [year] =				
References:	Table 6-8	Table 6-8	Table 6-8	Table 6-8

**8.0 REFERENCES**

References identified with an (\*) are maintained within the Palisades Records System and are not retrievable from Framatome Records management. These are acceptable references per Framatome Administrative Procedure 0402-01, Attachment 7. See Page 2 for Project Manager Approval of customer References.

1. Framatome Document [ ]
2. ASME BPVC Section XI, Non-Mandatory Appendix C, "Evaluation of Flaws in Piping." [ ]
3. ASME Code Case N-770-7, "Alternative Examination Requirements and Acceptance Standards for Class 1 PWR Piping and Vessel Nozzle Butt Welds Fabricated with UNS N06082 or UNS W86182 Weld Filler Material with or without Application of Listed Mitigation Activities, Section XI, Division 1" (as modified by 10 CFR 50.55a).
4. Framatome Document [ ]
5. Framatome Document [ ]
6. \* Combustion Engineering Document 0070P-006 Rev 2, "Engineering Specification for Primary Coolant Pipe and Fittings for Consumers Power Company."
7. ASME BPVC Code Cases, "Case N-740-2 Full Structural Dissimilar Metal Weld Overlay for Repair or Mitigation of Class 1, 2, and 3 Items Section XI, Division 1." [ ]
8. Framatome Drawing [ ]
9. Framatome Document [ ]
10. Framatome Document [ ]
11. NRC Letter from Richard Barrett, Director Division of Engineering, Office of NRR to Alex Marion of Nuclear Energy Institute, "Flaw Evaluation Guidelines," April 11, 2003, ADAMS Accession Number ML030980322.
12. Enclosure 2 to Reference [11], "Appendix A: Evaluation of Flaws in PWR Reactor Vessel Upper Head Penetration Nozzles," ADAMS Accession Number ML030980333.
13. NUREG/CR-6721, "Effects of Alloy Chemistry, Cold Work, and Water Chemistry on Corrosion Fatigue and Stress Corrosion Cracking of Nickel Alloys and Welds," U.S. Nuclear Regulatory Commission (Argonne National Laboratory), April 2001.
14. Materials Reliability Program: Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Alloy 82, 182, and 132 Welds (MRP-115).
15. Materials Reliability Program: Recommended Factors of Improvement for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) Growth Rates of Thick- Wall Alloy 690 Materials and Alloy 52, 152, and Variants Welds (MRP-386).
16. U.S. Nuclear Regulatory Commission, Standard Review Plan, Section 3.7.3, "Seismic Subsystem Analysis," ADAMS Accession Number ML070640313.
17. \* Combustion Engineering Specification 70P-001 Rev. 3. "Engineering Specification for a Pressurizer Assembly for Palisades Nuclear Plant."
18. ASME BPVC Section II, "Materials," Part C, [ ]



# CALCULATION SUMMARY SHEET (CSS)

Document No. 32 - 9401238 - 000

Safety Related:  Yes  No

Title ASME Section III Analysis – Palisades Hot Leg Surge Nozzle FSWOL – Non-Proprietary

**PURPOSE AND SUMMARY OF RESULTS:**

The purpose of this engineering calculation is to perform an evaluation of the Palisades Hot Leg Surge Nozzle Weld Overlay in accordance with those requirements specified in the Framatome Design Specification (Reference [1]) and the Palisades Engineering Specification for Primary Coolant Pipe (Reference [2]). Primary plus secondary stress and cumulative fatigue usage criteria as prescribed by the ASME Code Section III Subsection NB (Reference [3]), and Section III Appendices (Reference [4]), have been evaluated for the structural weld overlay and associated component/regions overlaid.

The analysis of primary plus secondary stress and cumulative fatigue usage in the Hot Leg Surge Nozzle and [ ] Full Structural Weld Overlay (FSWOL) has demonstrated all criteria as prescribed by the ASME Code Section III Subsection NB (Reference [3]) has been met. For the minimum thickness of the [ ] FSWOL configuration, the maximum cumulative fatigue usage (CUF) calculated for 80 years of operation is [ ] located at the [ ]. For the maximum thickness of the Alloy 690 FSWOL configuration, the maximum cumulative fatigue usage (CUF) calculated for 80 years of operation is [ ]

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_____ SATB 1.0	_____ SATB 1.1							
_____ ANSYS 19.2	_____							

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Review Method:  Design Review (Detailed Check)

Alternate Calculation

Does this document establish design or technical requirements?  YES  NO

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## List of Acronyms

### Optional Content for Calculation (ID=32) per 0402-01 Attachment 3

**FSWOL**

Full Structural Weld Overlay

**RCS**

Reactor Coolant System

**HUCD**

Operational Transient- Heatup and Cooldown (Cold condition to 0% Power)

**PLPU\_0\_100 (or PLPU\_0)**

Operational Transient- Plant Loading and Unloading (0% to 100% Power)

**PLPU\_50\_100 (or PLPU\_50)**

Operational Transient- Plant Loading and Unloading (50% to 100% Power)

**SI**

Step Increase 10% (Plant Load Change 10% Full Load Step)

**SD**

Step Decrease 10% (Plant Load Change 10% Full Load Step)

**RT**

Reactor Trip

**LOL**

Loss of Load

**LPCF**

Loss of Primary Coolant Flow

**SVO**

Safety Valve Operations

**SPR**

Steam Pipe Rupture

**PWSCC**

Primary water stress corrosion cracking

**FEA**

Finite element analysis

**OBE**

Operational Basis Earthquake

**SSE**

Safe Shutdown Earthquake

**DMW**

Dissimilar metal weld

**MSIP**

Mechanical stress improvement process

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# 1 Analytical Methodology

## 1.1 Introduction

Primary water stress corrosion cracking (PWSCC) of [ ] materials is a well documented phenomenon in the nuclear power industry. High temperature components, such as those associated with the primary coolant system of pressurized water reactors have high risk of PWSCC occurrence. The design specification (Reference [1]) has identified that mechanical stress improvement process (MSIP) was applied to the Hot Leg Surge Nozzle in 1995 to mitigate PWSCC. Holtec has plans to further the defense against PWSCC in the reactor coolant system for [ ] dissimilar metal welds (DMW) with [ ] full structural weld overlays (FSWOL) prior to the restart of Palisades Nuclear Power Plant.

## 1.2 Purpose and Scope

The weld overlay is designed to cover the PWSCC susceptible [ ] DMWs. Application of weld overlays alters the local stress distribution. A detailed finite element analysis (FEA) is therefore conducted to investigate stress conditions under various operational transients. The purpose of this calculation is to provide an evaluation of both primary plus secondary stress and cumulative fatigue usage criteria specified by ASME Code Section III Subsection NB (Reference [3]) in accordance with the FSWOL Design Specification requirements (Reference [1]).

The analysis is focused on the FSWOL and overlaid component regions for requirements on both stress distribution and fatigue failure criterion. The nozzle repair configuration is shown in Figure 1–1 and it includes the hot leg pipe, surge nozzle, cladding, butter, safe end, surge line pipe, dissimilar metal weld (DMW) between the surge nozzle/safe end, DMW between the safe end/surge line, and FSWOL. The detailed finite element analyses performed herein evaluates the FSWOL modeled at the minimum and maximum thickness.

It should be noted that primary stress criteria are not evaluated in this calculation. [ ]

]

The cumulative fatigue usage factors calculated in this document assume the surge nozzle FSWOL has been in place since the plant conception. Per Reference [1], applicable transients and cycles are specified in Reference [2] for the original 40-year design life, and the number of cycles for each applicable transient bounds the current renewed license period for a total of 60 years of operation. To obtain the number of cycles to be evaluated for the proposed 80-year design life, the number of cycles shall be multiplied by a factor of [ ] . However, the normal step power changes (PLPU) transients shall be reduced to [ ] cycles per Reference [1].

Validation that the Full Structural Weld Overlay (FSWOL) sizing is sufficient to provide redistribution of loads in the event a 100% through wall flaw exists at either of the two DMWs is provided in Reference [7].

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**Figure 1–1: Hot Leg Surge Nozzle**

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**1.3 Methodology**

The following is the general methodology of model development and stress analysis used for the Hot Leg Surge Nozzle minimum and maximum thickness FSWOL calculations.

- 1) Building a [ ] of the hot leg surge nozzle and attached hot leg and surge line pipe. [ ]

**1.4 ASME Section III Design By Analysis**

The calculated stresses are evaluated per the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code “Design by Analysis” Criteria in Section III, Division 1, Subsection NB, Reference [3] (and by reference ASME Section III Appendices Reference [4]) in accordance with the Certified Design Specification (CDS), Reference [1].

Table 1–1 defines the variables used for the qualification with the Code.

**Table 1–1: Stress Definitions**

Paragraph, [4]	Description	Symbolic
XIII-2300 Step 1	Component Stresses	$\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{yz}, \tau_{xz}$
XIII-2300 Step 2	Assign Stress Categories	<i>P<sub>m</sub></i> : general primary stress * <i>P<sub>L</sub></i> : local primary stress <i>P<sub>b</sub></i> : primary bending stress <i>P<sub>e</sub></i> : expansion stress <i>Q</i> : secondary stress <i>F</i> : peak stress
XIII-2300 Step 3	Load combinations	Algebraically sum component stresses from load cases to be combined.

continues on next page

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Table 1-1 – continued from previous page

Paragraph, [4]	Description	Symbolic
XIII-2300 Step 4	Principal Stresses	Rotate the component stresses into an $(x', y', z')$ coordinate system such that $\tau'_{xy} = \tau'_{yz} = \tau'_{xz} = 0$ and then $\sigma_1 = \sigma'_x, \sigma_2 = \sigma'_y, \sigma_3 = \sigma'_z$
XIII-2300 Step 5	Stress Differences	$S_{12} = \sigma_1 - \sigma_2, S_{23} = \sigma_2 - \sigma_3, S_{31} = \sigma_3 - \sigma_1$
XIII-2300 Step 5	Stress Intensity	$S = \max( S_{12} ,  S_{23} ,  S_{31} )$

\*Membrane stress intensity is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the component stress level.

1.4.1 Primary + Secondary Stresses

Table 1-2 defines the Level A and B requirements for Primary + Secondary Stresses per per Reference [4].

Table 1-2: Primary + Secondary Stress Limits - (Level A and Level B)

Paragraph, [4]	Description	Symbolic
XIII-3420	Primary + Secondary Stress Limits	$((P_L \text{ or } P_m) + P_b + P_e + Q)_{max} \leq 3S_m$

1.4.2 Cyclic Stresses

Table 1-3 defines the Testing Limit requirements for Cyclic Stresses per Reference [4].

Table 1-3: Cycling Loading Requirements

Paragraph, [4]	Description	Symbolic
XIII-3520	Fatigue from Level A and Level B Loadings	See Table 1-5, Table 1-7.
XIII-3430	Thermal Stress Ratchet from Level A and Level B Loadings	See Table 1-4

continues on next page

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Table 1–3 – continued from previous page

Paragraph, [4]	Description	Symbolic
XIII-3600(e)	Fatigue from Test Loadings	<p>Tests, with the exception of either the first 10 hydrostatic tests in accordance with NB-6220, the first 10 pneumatic tests in accordance with NB-6320, or any combination of 10 such tests, shall be considered in the fatigue evaluation of the component.</p> <p>When at least one extreme of the stress intensity range is determined by the Test Loadings:  <math>*S_n = \max(3S_m, 2S_y)</math></p> <p>*<math>S_n</math>: Primary + Secondary Stress Intensity Limits</p>

**Table 1–4: Maximum Cyclic Thermal Stress Limit**

Case	$x =$ maximum general membrane stress due to pressure divided by the yield strength $S_y$ or $1.5S_m$ , whichever is greater	$y' =$ maximum allowable range of thermal stress computed on an elastic basis divided by the yield strength $S_y$ or $1.5S_m$ , whichever is greater
1: Linear variation of temperature through the wall	$0 < x < 0.5$	$y' = 1/x$
1: Linear variation of temperature through the wall	$0.5 < x < 1.0$	$y' = 4(1 - x)$
2: Parabolic constantly increasing or constantly decreasing variation of temperature through the wall	$0.615 < x < 1.0$	$y' = 5.2(1 - x)$
2: Parabolic constantly increasing or constantly decreasing variation of temperature through the wall	$x < 0.615$	$y'_{@x=0.3} = 4.65$ $y'_{@x=0.4} = 3.55$ $y'_{@x=0.5} = 2.70$

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1.4.2.1 Elastic Methodology

Table 1–5 defines the evaluation to qualify cyclic loads, using the elastic fatigue methodology.

**Table 1–5: Cyclic Requirements: Regular Fatigue**

Reference [4] Paragraph	Description	Symbolic
XIII-3520(a)	Stress Differences	Determine stress differences and alternating stress intensity $S_{alt}$ in accordance with XIII-2400 (Table 1–6)
XIII-3520(b)	Level Local Structural Discontinuities	Determine: (a) Stress Concentration Factors (b) Experimental Fatigue Strength Reduction Factors ( $K_f$ ), if $K_f < 5$
XIII-3520(c)	Design Fatigue Curves	Use applicable fatigue design curves (FDC) as contained in mandatory Appendix I, where the strength value is the minimum room temperature
XIII-3520(d)	Effect of Elastic Modulus	Enter FDC with $S_a = S_{alt} \cdot E_{FDC} / E_{analysis}$
XIII-3520(e)	Cumulative Damage	<ol style="list-style-type: none"> <li>1. Designate number of times of each type of stress cycle</li> <li>2. For each type of stress cycle, compute <math>S_{alt}</math> (Table 1–6), yielding <math>S_{alt1}, S_{alt2}, \dots, S_{altn}</math>.</li> <li>3. For each <math>S_{alt}</math>, use the FDC to determine allowable cycles, <math>N</math>, yielding <math>N_1, N_2, \dots, N_n</math>.</li> <li>4. For each type of stress cycle, calculated Partial Usage Factor, <math>U = S_{alt}/N</math>, yielding <math>U_1, U_2, \dots, U_n</math>.</li> <li>5. Calculate the cumulative usage factor, <math>U = U_1 + U_2 + \dots + U_n</math>.</li> <li>6. The Cumulative Usage Factor, U, shall not exceed 1.0.</li> </ol>

**Table 1–6:  $S_{alt}$  Calculation for Varying Principal Stress Direction**

Reference [4] Paragraph	Description	Symbolic
XIII-2420 Step 1	Consider 6 stress components vs. time, accounting for varying gross and local discontinuities, and thermal effects during the stress cycle	$\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{yz}, \tau_{xz}$

continues on next page

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Table 1-6 – continued from previous page

Reference [4] Paragraph	Description	Symbolic
XIII-2420 Step 2	Choose a point in time, $t_i$ , where conditions are at an extreme, denote the stress components at this time with subscript $i$	
XIII-2420 Step 3	At each point in time in the Stress Cycle, calculate the change in Component Stresses from this extreme timepoint	$\begin{aligned} \sigma_x - \sigma_{xi} &= \sigma'_x \\ \sigma_y - \sigma_{yi} &= \sigma'_y \\ \sigma_z - \sigma_{zi} &= \sigma'_z \\ \tau_{xy} - \tau_{xyi} &= \tau'_{xy} \\ \tau_{yz} - \tau_{yzi} &= \tau'_{yz} \\ \tau_{xz} - \tau_{xzi} &= \tau'_{xz} \end{aligned}$
XIII-2420 Step 4	At each point in time in the Stress Cycle, calculate Principal Stresses derived from the changes in the six Component Stresses from the extreme timepoint	$\sigma'_1, \sigma'_2, \sigma'_3 = \text{Eigenvalues of } \sigma'_x, \sigma'_y, \sigma'_z, \tau'_{xy}, \tau'_{yz}, \tau'_{xz}$
XIII-2420 Step 5	At each point in time in the Stress Cycle, Determine the Stress Differences. The alternating Stress Intensity, $S_{alt}$ is	$S_{alt} = S_r/2$ where $S_r = \max( S_{12}  =  \sigma'_1 - \sigma'_2 ,  S_{23}  =  \sigma'_2 - \sigma'_3 ,  S_{31}  =  \sigma'_3 - \sigma'_1 )$ vs. time

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1.4.2.2 Simplified Elastic-Plastic Methodology

If the conditions of Table 1–2 are not satisfied, Table 1–7 provides an alternate method to qualify Cyclic Stresses. This alternate method is a Simplified Elastic-Plastic methodology to determine the CUF, with additional limitations on Primary + Secondary stress range, Thermal Ratcheting, and Material Properties.

**Table 1–7: Cyclic Requirements: Simplified Elastic-Plastic**

Reference [4] Paragraph	Description	Symbolic
XIII-3450	Simplified Elastic-Plastic Analysis	If P+Q Stress Intensity range, $S_n > 3S_m$ ... the Simplified Elastic-Plastic Analysis method may be used and requires that XIII-3450(a)-(f) are satisfied.
XIII-3450(a)	P+Q SI Range	excluding thermal bending stresses, the range of P+Q membrane plus bending stress intensity shall be $\leq 3S_m$
XIII-3450(b)	Determine the factor $K_e$	for... $\dots S_n \leq 3S_m, K_e = 1.0$ $\dots 3S_m < S_n \leq 3mS_m, K_e = 1.0 + \left[ \frac{1-n}{n(m-1)} \left( \frac{S_n}{3S_m} - 1 \right) \right]$ $\dots S_n \geq 3mS_m, K_e = 1/n$ where the values of the material parameters $m$ and $n$ for the various classes of permitted materials are as given in Table 1–8
XIII-3450(c)	Cumulative Fatigue Damage	(a) The rest of the fatigue evaluation stays the same as required in Table 1–5, <i>except</i> that the procedure of applications of elastic analysis for stresses beyond the yield strength  (b) cumulative fatigue usage factor, $U = 1.0$
XIII-3450(d)	Thermal Ratchet Requirements	The component meets the thermal ratcheting requirement of Thermal Stress Ratcheting, as described in Table 1–4, and follow that if $S_y > 2S_a$ , for the maximum number of cycles on the applicable fatigue curve of Figs. I-9.0 for the material, the latter value shall be used if there is to be a large number of cycles because strain softening may occur
XIII-3450(e)	Temperature Limit	Transients must obey $T_{max} < 700F^\circ$
XIII-3450(f)	Yield to ultimate strength ratio	$\frac{S_y}{S_u} < 0.80$

**Table 1–8: Values of m, n, and maximum Temperature for Various Classes of Permitted Materials.**

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Materials	m	n	Tmax °F (°C)
Carbon steel	3	0.2	700 (370)
Low alloy steel	2	0.2	700 (370)
Martensitic stainless steel	2	0.2	700 (370)
Austenitic stainless steel	1.7	0.3	800 (425)
Nickel–chromium–iron	1.7	0.3	800 (425)
Nickel–copper	1.7	0.3	800 (425)

## 2 Assumptions

All assumptions pertain to both the minimum and maximum FSWOL configurations.

### 2.1 Unverified Assumptions

1. There are no unverified assumptions.

### 2.2 Justified Assumptions

2. The outside ambient condition for the Hot Leg Surge Nozzle analysis is assumed to be [ ] applied in conjunction with an heat transfer film coefficient representative of [ ] is approximately [ ] the value calculated by equation 9.34 of Reference [9].

5. Additional minor justified assumptions may be stated throughout the calculation as needed.

### 2.3 Modeling Simplifications

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**Figure 2-1: Hot Leg Model Simplification**

### 3 Design Inputs

All design inputs pertain to both the minimum and maximum FSWOL configurations.

#### 3.1 Material Properties

The materials specified components and welds within the scope of this analysis are listed in Table 3-1:

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**Table 3–1: Material Specifications**

Component	Material	Specification	Reference
Hot Leg	Carbon Steel		[10]
Hot Leg Surge Nozzle	Carbon Steel		[10]
Butter, DM Welds, Safe End	Nickel Alloy		[10]
Surge Line Pipe	Stainless Steel		[10] <sup>(1)</sup>
Hot Leg Cladding, Nozzle Cladding	Stainless Steel		[10] <sup>(2)</sup>
Weld Overlay (FSWOL)	Nickel Alloy		[1]

Notes:

<sup>(1)</sup> The physical material properties for hot leg surge line have been assumed equivalent to [ ] Reference [10]

<sup>(2)</sup> The physical material properties for cladding on hot leg and surge nozzle have been assumed equivalent to [ ] Reference [10]

**3.1.1 Physical Material Properties**

All material properties used in this analysis are defined for temperature range from 70 °F to 700 °F.

The 1986 ASME Code Section III Appendices, Reference [11], has been used to define the following material properties for the existing component materials: thermal conductivity (and thermal diffusivity), mean coefficient of expansion, and modulus of elasticity.

The 2019 ASME Code Section II Part D, Reference [12], has be used to define the material properties and stress limits for the FSWOL.

The existing material properties; thermal conductivity, thermal diffusivity, mean coefficient of thermal expansion and young’s modulus have been sourced from Reference [11]. All other properties (specific heat, poisson’s ratio and density) and properties for the deposited FSWOL have been taken or derived from Reference [12].

Materials have been identified in Figure 1–1. Properties for these materials are reported below in Table 3–2 through Table 3–7.

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**Figure 3–1:** Physical Properties

**Table 3–2:** Physical Properties for [ ]

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Temperature, °F	Young's Modulus, psi	Poisson's Ratio	Density, lb/in <sup>3</sup>	Coefficient of Thermal Expansion, 1/°F	Thermal Conductivity, Btu/hr * in * °F	Specific Heat, Btu/lb * °F
70.0	29500000.0	0.3	0.28	5.42e-06	1.9667	0.1074
100.0	29300000.0	0.3	0.2799	5.53e-06	1.9917	0.1116
200.0	28800000.0	0.3	0.2793	5.89e-06	2.0333	0.1198
300.0	28300000.0	0.3	0.2788	6.26e-06	2.0333	0.1247
400.0	27700000.0	0.3	0.2781	6.61e-06	2.0167	0.1304
500.0	27300000.0	0.3	0.2775	6.91e-06	1.975	0.1358
600.0	26700000.0	0.3	0.2768	7.17e-06	1.925	0.1396
650.0	26100000.0	0.3	0.2764	7.3e-06	1.8917	0.1427
700.0	25500000.0	0.3	0.2761	7.41e-06	1.8667	0.1467

**Table 3-3: Physical Properties for [ ] Surge Nozzle**

Temperature, °F	Young's Modulus, psi	Poisson's Ratio	Density, lb/in <sup>3</sup>	Coefficient of Thermal Expansion, 1/°F	Thermal Conductivity, Btu/hr * in * °F	Specific Heat, Btu/lb * °F
70.0	29300000.0	0.3	0.28	5.6e-06	2.5	0.1065
100.0	29100000.0	0.3	0.2799	5.73e-06	2.4917	0.109
200.0	28600000.0	0.3	0.2793	6.09e-06	2.4333	0.1161
300.0	28100000.0	0.3	0.2788	6.43e-06	2.3667	0.1226
400.0	27500000.0	0.3	0.2781	6.74e-06	2.3	0.1285
500.0	27100000.0	0.3	0.2775	7.06e-06	2.2167	0.134
600.0	26500000.0	0.3	0.2768	7.28e-06	2.1333	0.139
650.0	25900000.0	0.3	0.2764	7.4e-06	2.0917	0.142
700.0	25300000.0	0.3	0.2761	7.51e-06	2.05	0.1453

**Table 3-4: Physical Properties for [ ] DM Welds, Safe End, Butter**

Temperature, °F	Young's Modulus, psi	Poisson's Ratio	Density, lb/in <sup>3</sup>	Coefficient of Thermal Expansion, 1/°F	Thermal Conductivity, Btu/hr * in * °F	Specific Heat, Btu/lb * °F
70.0	31000000.0	0.31	0.3	6.76e-06	0.7167	0.1077
100.0	30800000.0	0.31	0.2998	6.9e-06	0.725	0.109
200.0	30200000.0	0.31	0.2992	7.2e-06	0.7583	0.1128
300.0	29900000.0	0.31	0.2985	7.4e-06	0.8	0.1163
400.0	29500000.0	0.31	0.2978	7.57e-06	0.8417	0.119
500.0	29000000.0	0.31	0.297	7.7e-06	0.8833	0.1208
600.0	28700000.0	0.31	0.2963	7.82e-06	0.925	0.1246
650.0	28500000.0	0.31	0.2959	7.88e-06	0.9417	0.1249
700.0	28200000.0	0.31	0.2955	7.94e-06	0.9667	0.1269

**Table 3-5: Physical Properties for [ ] Surge Line**

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Temperature, °F	Young's Modulus, <i>psi</i>	Poisson's Ratio	Density, <i>lb/in<sup>3</sup></i>	Coefficient of Thermal Expansion, <i>1/°F</i>	Thermal Conductivity, <i>Btu/hr * in * °F</i>	Specific Heat, <i>Btu/lb * °F</i>
70.0	28300000.0	0.31	0.29	8.42e-06	0.6417	0.1147
100.0	28100000.0	0.31	0.2898	8.54e-06	0.6583	0.116
200.0	27600000.0	0.31	0.289	8.76e-06	0.7	0.1193
300.0	27000000.0	0.31	0.2882	8.97e-06	0.75	0.1246
400.0	26500000.0	0.31	0.2874	9.21e-06	0.7917	0.1267
500.0	25800000.0	0.31	0.2865	9.42e-06	0.833	0.1294
600.0	25300000.0	0.31	0.2856	9.6e-06	0.875	0.1313
650.0	25100000.0	0.31	0.2852	9.69e-06	0.8917	0.1324
700.0	24800000.0	0.31	0.2847	9.76e-06	0.9167	0.1339

**Table 3–6: Physical Properties for [ ] Cladding**

Temperature, °F	Young's Modulus, <i>psi</i>	Poisson's Ratio	Density, <i>lb/in<sup>3</sup></i>	Coefficient of Thermal Expansion, <i>1/°F</i>	Thermal Conductivity, <i>Btu/hr * in * °F</i>	Specific Heat, <i>Btu/lb * °F</i>
70.0	28300000.0	0.31	0.29	8.46e-06	0.7167	0.1137
100.0	28100000.0	0.31	0.2898	8.55e-06	0.725	0.1143
200.0	27600000.0	0.31	0.289	8.79e-06	0.775	0.1194
300.0	27000000.0	0.31	0.2882	9e-06	0.8167	0.123
400.0	26500000.0	0.31	0.2874	9.19e-06	0.8667	0.1269
500.0	25800000.0	0.31	0.2865	9.37e-06	0.9083	0.1295
600.0	25300000.0	0.31	0.2856	9.53e-06	0.9417	0.1316
650.0	25100000.0	0.31	0.2852	9.61e-06	0.9667	0.133
700.0	24800000.0	0.31	0.2848	9.69e-06	0.9833	0.134

**Table 3–7: Physical Properties for [ ] FSWOL**

Temperature, °F	Young's Modulus, <i>psi</i>	Poisson's Ratio	Density, <i>lb/in<sup>3</sup></i>	Coefficient of Thermal Expansion, <i>1/°F</i>	Thermal Conductivity, <i>Btu/hr * in * °F</i>	Specific Heat, <i>Btu/lb * °F</i>
70.0	30300000.0	0.31	0.293	7.7e-06	0.5667	0.1074
100.0	30100000.0	0.31	0.2928	7.8e-06	0.5833	0.1089
200.0	29600000.0	0.31	0.2921	7.9e-06	0.6333	0.1124
300.0	29200000.0	0.31	0.2914	7.9e-06	0.6833	0.1155
400.0	28800000.0	0.31	0.2907	8e-06	0.7333	0.1192
500.0	28300000.0	0.31	0.29	8.1e-06	0.7833	0.1218
600.0	27900000.0	0.31	0.2892	8.2e-06	0.8333	0.1251
650.0	27700000.0	0.31	0.2888	8.3e-06	0.8583	0.1258
700.0	27500000.0	0.31	0.2885	8.3e-06	0.8833	0.1273

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3.1.2 Material Stress Allowable

The 1965 ASME Code Section III Appendices with Addenda through Winter 1967, Reference [13], has been used to define the stress limits for existing materials per Reference [10].

The 2019 ASME Code Section II Part D, Reference [12], has been used to define the stress limits for the FSWOL.

Figure 3–2: Material Strength

Table 3–8: Stress Limits for [ ] Hot Leg

Temperature, °F	Design Stress Intensity, psi	Yield Stress, psi	Ultimate Stress, psi
70.0	23300.0	38000.0	70000.0
100.0	23300.0	38000.0	70000.0
200.0	23100.0	34650.0	70000.0
300.0	22500.0	33700.0	70000.0
400.0	21700.0	32600.0	70000.0
500.0	20500.0	30750.0	70000.0
600.0	18700.0	28100.0	70000.0
650.0	18400.0	27600.0	70000.0
700.0	18300.0	27400.0	70000.0

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**Table 3–9: Stress Limits for [ ] Surge Nozzle**

Temperature, °F	Design Stress Intensity, <i>psi</i>	Yield Stress, <i>psi</i>	Ultimate Stress, <i>psi</i>
70.0	23300.0	35000.0	70000.0
100.0	23300.0	35000.0	70000.0
200.0	21300.0	31900.0	70000.0
300.0	20700.0	31000.0	70000.0
400.0	20000.0	30000.0	70000.0
500.0	18900.0	28300.0	70000.0
600.0	17300.0	25900.0	70000.0
650.0	17000.0	25400.0	70000.0
700.0	16800.0	25200.0	70000.0

**Table 3–10: Stress Limits for [ ] DM Welds, Safe End, Butter**

Temperature, °F	Design Stress Intensity, <i>psi</i>	Yield Stress, <i>psi</i>	Ultimate Stress, <i>psi</i>
70.0	23300.0	35000.0	80000.0
100.0	23300.0	35000.0	80000.0
200.0	23300.0	32700.0	80000.0
300.0	23300.0	31000.0	80000.0
400.0	23300.0	29800.0	80000.0
500.0	23300.0	28800.0	80000.0
600.0	23300.0	27900.0	80000.0
650.0	23300.0	27400.0	80000.0
700.0	23300.0	27000.0	80000.0

**Table 3–11: Stress Limits for [ ] Surge Line**

Temperature, °F	Design Stress Intensity, <i>psi</i>	Yield Stress, <i>psi</i>	Ultimate Stress, <i>psi</i>
70.0	20000.0	30000.0	75000.0
100.0	20000.0	30000.0	75000.0
200.0	20000.0	25800.0	75000.0
300.0	20000.0	23400.0	75000.0
400.0	19400.0	21600.0	75000.0
500.0	18200.0	20100.0	75000.0
600.0	17100.0	19000.0	75000.0
650.0	16700.0	18500.0	75000.0
700.0	16200.0	18050.0	75000.0

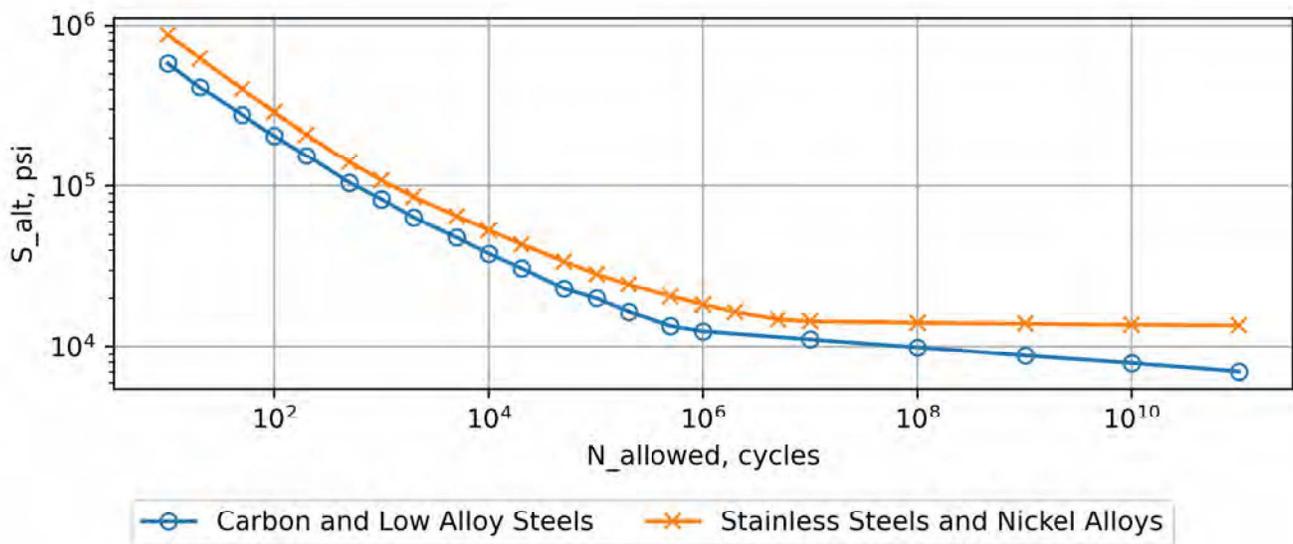
**Table 3–12: Stress Limits for [ ] Cladding**

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Temperature, °F	Design Stress Intensity, <i>psi</i>	Yield Stress, <i>psi</i>	Ultimate Stress, <i>psi</i>
70.0	20000.0	30000.0	75000.0
100.0	20000.0	30000.0	75000.0
200.0	20000.0	25600.0	75000.0
300.0	19800.0	22000.0	75000.0
400.0	17600.0	19600.0	75000.0
500.0	16400.0	18200.0	75000.0
600.0	15600.0	17300.0	75000.0
650.0	15300.0	17000.0	75000.0
700.0	15100.0	16800.0	75000.0

**Table 3–13: Stress Limits for [ ] FSWOL**

Temperature, °F	Design Stress Intensity, <i>psi</i>	Yield Stress, <i>psi</i>	Ultimate Stress, <i>psi</i>
70.0	23300.0	35000.0	85000.0
100.0	23300.0	35000.0	85000.0
200.0	23300.0	31700.0	85000.0
300.0	23300.0	29800.0	84000.0
400.0	23300.0	28600.0	82000.0
500.0	23300.0	27900.0	80800.0
600.0	23300.0	27600.0	80200.0
650.0	23300.0	27500.0	80000.0
700.0	23300.0	27500.0	79800.0



**Figure 3–3: Fatigue Curves**

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**Table 3–14:** Design Fatigue Curve for Low Alloy Material Hot Leg Surge Nozzle Analysis

E_curve, <i>psi</i>	30.0e6
N_allowed, cycles	S_alt, <i>psi</i>
10.0	580000
20.0	410000
50.0	275000
100.0	205000
200.0	155000
500.0	105000
1000.0	83000
2000.0	64000
5000.0	48000
10000.0	38000
20000.0	31000
50000.0	23000
100000.0	20000
200000.0	16500
500000.0	13500
1000000.0	12500
10000000.0	11100
100000000.0	9900
1000000000.0	8800
10000000000.0	7900
100000000000.0	7000

**Table 3–15:** Design Fatigue Curve for Stainless and Nickel Alloy Material Hot Leg Surge Nozzle Analysis

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E_curve, <i>psi</i>	28.3e6
N_allowed, cycles	S_alt, <i>psi</i>
10.0	870000
20.0	624000
50.0	399000
100.0	287000
200.0	209000
500.0	141000
1000.0	108000
2000.0	85600
5000.0	65300
10000.0	53400
20000.0	43500
50000.0	34100
100000.0	28400
200000.0	24400
500000.0	20600
1000000.0	18300
2000000.0	16400
5000000.0	14800
10000000.0	14400
100000000.0	14100
1000000000.0	13900
10000000000.0	13700
100000000000.0	13600

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**3.2 Geometry**

Major dimensions from the Hot Leg Surge Nozzle have been defined as parameters for use in this analysis. The dimensions include the existing component geometry and those parameters defined in cross section planes normal to the nozzle axis at which locations have been evaluated in this calculation. The variable names and locations have been illustrated below in Figure 3–4. Values and units for the geometry parameters provided in Table 3–16 are based on the cited references and analysis model for the minimum FSWOL configuration. Values and units for the geometry parameters provided in Table 3–17 are based on the cited references and analysis model for the maximum FSWOL configuration.



**Figure 3–4: Geometry Parameters**

**Table 3–16: Major Dimensions - Minimum FSWOL**

continues on next page

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Table 3-16 – continued from previous page

**Table 3-17: Major Dimensions - Maximum FSWOL**

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Table 3-17 – continued from previous page

**3.3 Loads**

**3.3.1 Design Conditions**

The Palisades Hot Leg Surge Nozzle is designed to satisfy the applicable ASME Code criteria at the design pressure of [ ] and temperature of [ ] per the original equipment specification (Reference [2]).

**3.3.2 Transient Loads**

Reference [2] provides all transient data for the hot leg piping and surge line piping. Only the Level A, Level B, and Test transients are applicable for analysis herein. The secondary stresses are not required for the evaluation of Level C or D (Faulted) transients. The transients used in this analysis are summarized in Table 3-20. [ ]

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Parameter descriptions and units for the values in the tables and figures in this section are shown below in Table 3–19.

**Table 3–19: Loading Parameters**

Parameter	Title	Units
TIME	Time	hr
FLOWRATE	Flow	gpm
T_FLUID	Fluid Temperature	$^{\circ}F$
T_AMB	Ambient Temperate	$^{\circ}F$
T_REF	Reference Temperature	$^{\circ}F$
T_UNIF	Uniform Temperature	$^{\circ}F$
T_SURGE	Surge Temperature	$^{\circ}F$
HTC_ID	Heat Transfer Coefficient on Inside Surface of Vessel	$BTU/hr \cdot in^2 \cdot ^{\circ}F$
HTC_OD	Heat Transfer Coefficient on Outside Surfaces	$BTU/hr \cdot in^2 \cdot ^{\circ}F$
HTC_a	Heat Transfer Coefficient of annulus region	$BTU/hr \cdot in^2 \cdot ^{\circ}F$
P_ID	Internal Pressure	psia
FX_N	Force in X direction (parallel to vessel axis, horizontal) - North Nozzle	lbf
FY_N	Force in Y direction (perpendicular to vessel axis, vertical) - North Nozzle	lbf
N_MAX_TH	Maximum Number of Substeps for Thermal Transient Solver	

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**3.4 Static Load Cases**

The design pressure/temperature static load case has been evaluated to serve as model behavior validation.

**3.5 Transient Load Cases**

**Table 3–20: Transient Load Cases**

The cumulative fatigue usage factors calculated in this document assume the surge nozzle FSWOL has been in place since the plant conception. Per Reference [1], applicable transients and cycles are specified in Reference [2] for the original 40-year design life, and the number of cycles for each applicable transient bounds the current renewed license period for a total of 60 years of operation. To obtain the number of cycles to be evaluated for the proposed 80-year design life, the number of cycles shall be multiplied by a factor of [ ]. However, the normal step power changes (PLPU) transients shall be reduced to [ ] cycles per Reference [1].

**Table 3–21: Applied Loads for Transient Case Heatup Cooldown (HUCD)**

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**Figure 3-5:** Applied Loads for Transient Case Heatup Cooldown (HUCD)

**Table 3-22:** Applied Loads for Transient Case Plant Loading and Unloading 0-100% (PLPU\_0\_100)

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**Figure 3–6:** Applied Loads for Transient Case Plant Loading and Unloading 0-100% (PLPU\_0\_100)

**Table 3–23:** Applied Loads for Transient Case Plant Loading and Unloading 50-100% (PLPU\_50\_100)

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**Figure 3-7:** Applied Loads for Transient Case Plant Loading and Unloading 50-100% (PLPU\_50\_100)

**Table 3-24:** Applied Loads for Transient Case Step Increase 10% (SI)

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**Figure 3–8:** Applied Loads for Transient Case Step Increase 10% (SI)

**Table 3–25:** Applied Loads for Transient Case Step Decrease 10% (SD)

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**Figure 3-9:** Applied Loads for Transient Case Step Decrease 10% (SD)

**Table 3-26:** Applied Loads for Transient Case Reactor Trip and Loss of Load (RT)

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**Figure 3–10:** Applied Loads for Transient Case Reactor Trip and Loss of Load (RT)

**Table 3–27:** Applied Loads for Transient Case Loss of Load (LOL)

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**Figure 3–11:** Applied Loads for Transient Case Loss of Load (LOL)

**Table 3–28:** Applied Loads for Transient Case Loss of Primary Coolant Flow (LPCF)

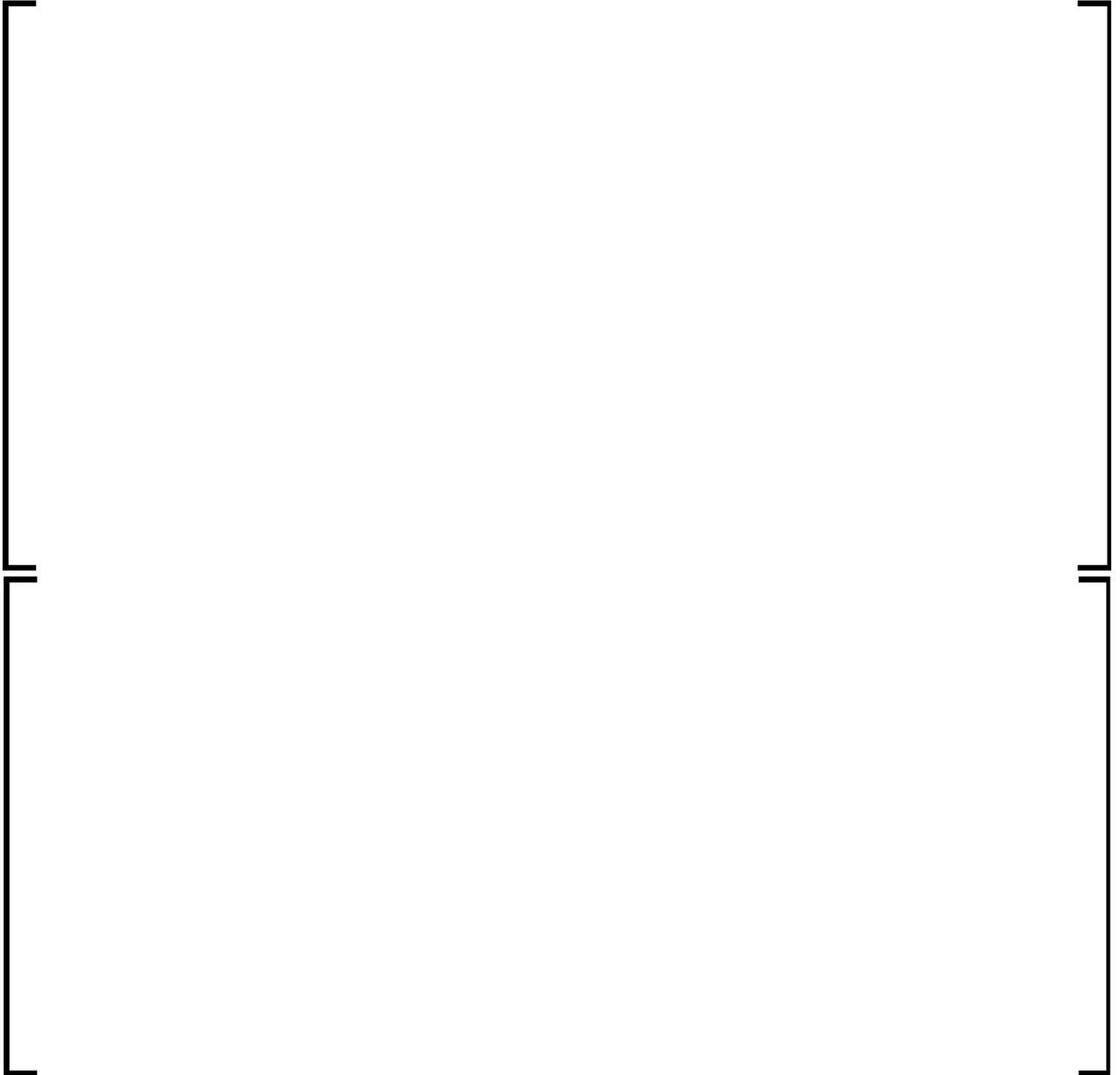
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**Figure 3–12:** Applied Loads for Transient Case Loss of Primary Coolant Flow (LPCF)

**Table 3–29:** Applied Loads for Transient Case Safety Valve Operation (SVO)

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**Figure 3–13:** Applied Loads for Transient Case Safety Valve Operation (SVO)

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**Table 3–30:** Applied Loads for Transient Case Hydrostatic Test (Hydro)



**Figure 3–14:** Applied Loads for Transient Case Hydrostatic Test (Hydro)

**Table 3–31:** Applied Loads for Transient Case Leak test (Leak)



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**Figure 3–15:** Applied Loads for Transient Case Leak test (Leak)

## 4 Computer Usage

The analysis herein uses the structural analysis tool box (Reference [15]). Documentation of the process is still under development. The directories associated with the analyses from model input to stress results output are contained within a standard directory structure. That structure is provided below.

**Listing 4.1:** General Project Analysis Directory Structure Overview



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Required Content for Calculation (ID=32) per 0402-01 Attachment 3

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**4.1 Software**

This calculation uses the following software:

- Controlled installation of ANSYS Mechanical APDL Version 19.2 on controlled platform rhe172\_ansys192.sif per Reference [16].
- Controlled installation of SCIPYENV, Version 2024.07.3 at /nfs/system/miniforge3/envs/scipyenv\_2024.07.3 on controlled platform Lynchburg HPCv2 per Reference [17].
- Controlled installation of SATB, Version 1.0 at /nfs/system/miniforge3/envs/scipyenv\_2024.07.3/bin/satb on controlled platform Lynchburg HPCv2 per Reference [15].

The software is being used within its specified range of applicability as defined by validation and verification requirements defined in References [16], [17] and [15]. All software errors notices applicable to these software have been reviewed and found to have no effect on this document.

**4.2 Data Pipeline**

The flow of data and calculation stages is shown in Figure 4–1.



**Figure 4–1: Directed Acyclic Graph (DAG) of Computation Steps**

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**4.3 Computer Files**

The computer files used in this analysis can be found below for the minimum WOL configuration:



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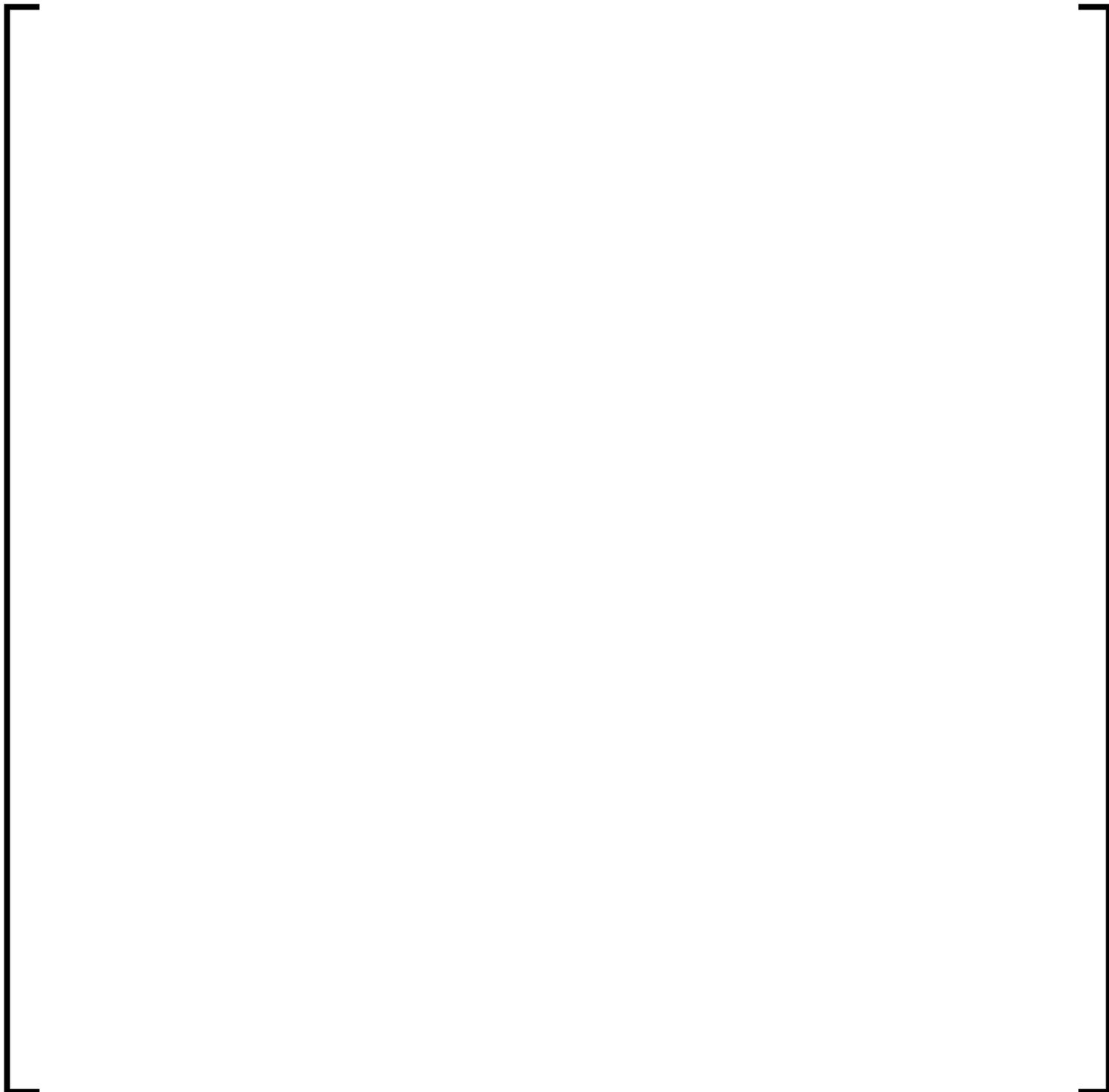
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The computer files used in this analysis can be found below for the maximum WOL configuration:



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## **5 Calculations**

### **5.1 Hot Leg Surge Nozzle - Minimum and Maximum FSWOL Configurations**

Figures of the minimum FSWOL configuration are shown in the following sections; however the descriptions provided are applicable to both the minimum and maximum FSWOL configurations evaluated in this calculation.

#### **5.1.1 Finite Element Model**



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**Figure 5–1:** Finite Element Model Mesh

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**5.1.2 Boundary Conditions**

**5.1.2.1 Thermal Boundary**



**Figure 5–2: Finite Element Model Thermal Boundary Conditions**

Additional boundary conditions are applied to the annulus region as seen in Figure 5–3.

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**Figure 5-3:** Finite Element Model Thermal Boundary Conditions Annulus Region

**5.1.2.2 Structural Boundary**

The structural boundary is shown in Figure 5-4. [



**Figure 5-4:** Finite Element Model Structural Boundary Conditions

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**5.2 Design Condition**

The design condition evaluated in the calculation includes only pressure and temperature. Per Reference [2], the surge nozzle was designed to satisfy the ASME Code Criteria at a pressure of [ ] and temperature [ ]. These design conditions are simulated by setting a uniform temperature of [ ] and a pressure of [ ]

[ ]

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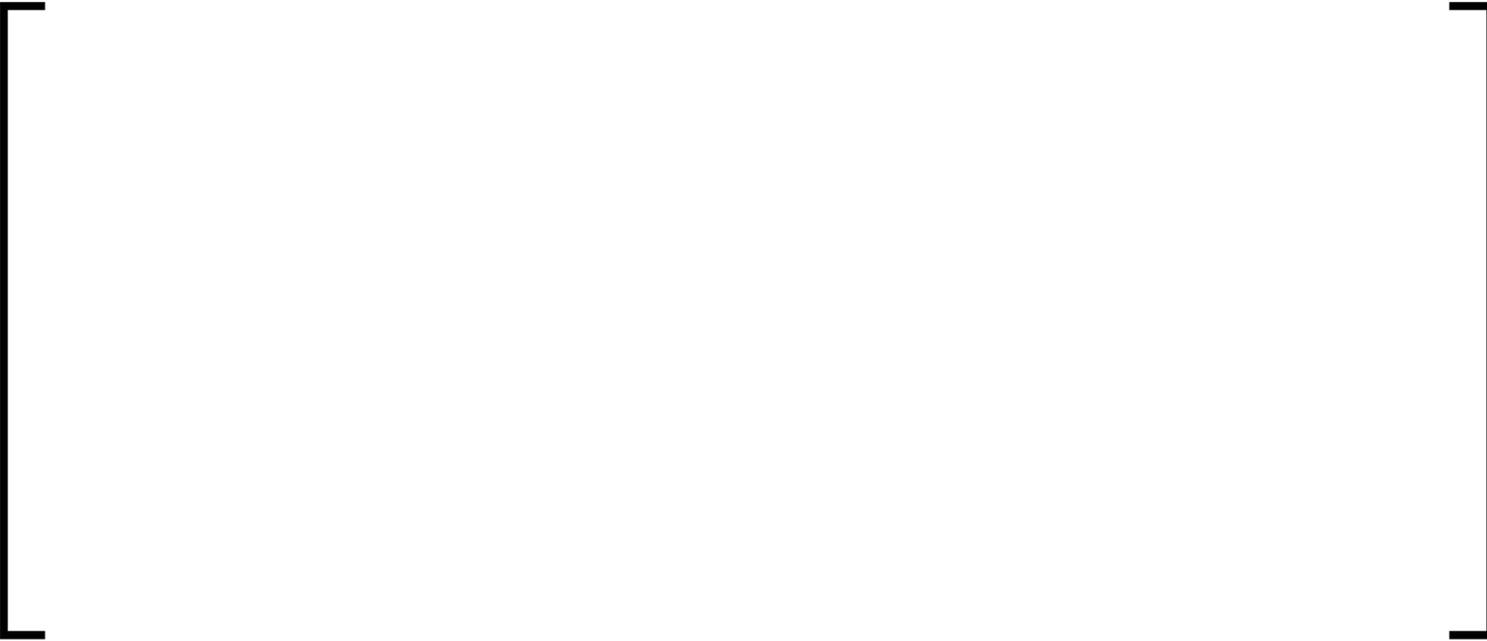
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**Figure 5-5:** Design Condition Displacements - Minimum FSWOL



**Figure 5-6:** Design Condition Stress Intensity - Minimum FSWOL

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**Figure 5–7:** Design Condition Displacements - Maximum FSWOL



**Figure 5–8:** Design Condition Stress Intensity - Maximum FSWOL

The stress intensity calculated for the safe end [ ] aligns with the stress intensity found in the ANSYS model at the safe end location. Therefore, the boundary conditions applied are valid.

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**5.3 Thermal Analysis**

The detailed thermal loading due to transients described in Section 3.5 are applied to the thermal finite element model in the form of fluid temperature versus time. An example of the thermal field in the Hot Leg Surge Nozzle during the initial steady-state condition of the the heatup and cooldown transients is shown in Figure 5–10 and Figure 5–11 for the minimum and maximum FSWOL configurations respectively.

The results of the thermal analyses are evaluated by examining the magnitude of temperature differences between key locations of the model (Figure 5–9). [

] The temperature and temperature gradients are plotted in Figure A–1 through Figure A–9 for the minimum FSWOL model and Figure A–13 through Figure A–21 for the maximum FSWOL model. These figures are provided in the document only to show the trend. Specific data are taken from computer files.



**Figure 5–9:** Thermal Gradient Paths of Interest

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**Figure 5-10:** Thermal Solution During Heatup and Cooldown Transient - Minimum FSWOL Model



**Figure 5-11:** Thermal Solution During Heatup and Cooldown Transient - Maximum FSWOL Model

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**5.4 Transient Elastic Analysis**

Stress analyses are performed at the time points listed in Table A–1 through Table A–9 for the minimum FSWOL configuration and Table A–12 through Table A–20 for the maximum FSWOL configuration. A sample plot of stress intensity during the Reactor Trip transient is shown in Figure 5–12 and Figure 5–13.

The time points identified by thermal gradient extrema are combined with those time points used to define the transient (see Section 3.5) and comprise the transient time points evaluated in the structural evaluations.



**Figure 5–12:** Structural Solution During Reactor Trip Transient - Minimum FSWOL

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**Figure 5–13:** Structural Solution During Reactor Trip Transient - Maximum FSWOL

**5.5 Stresses Due To External Loads**

The surge nozzle is exposed to the external loads documented in Table 3–18. [

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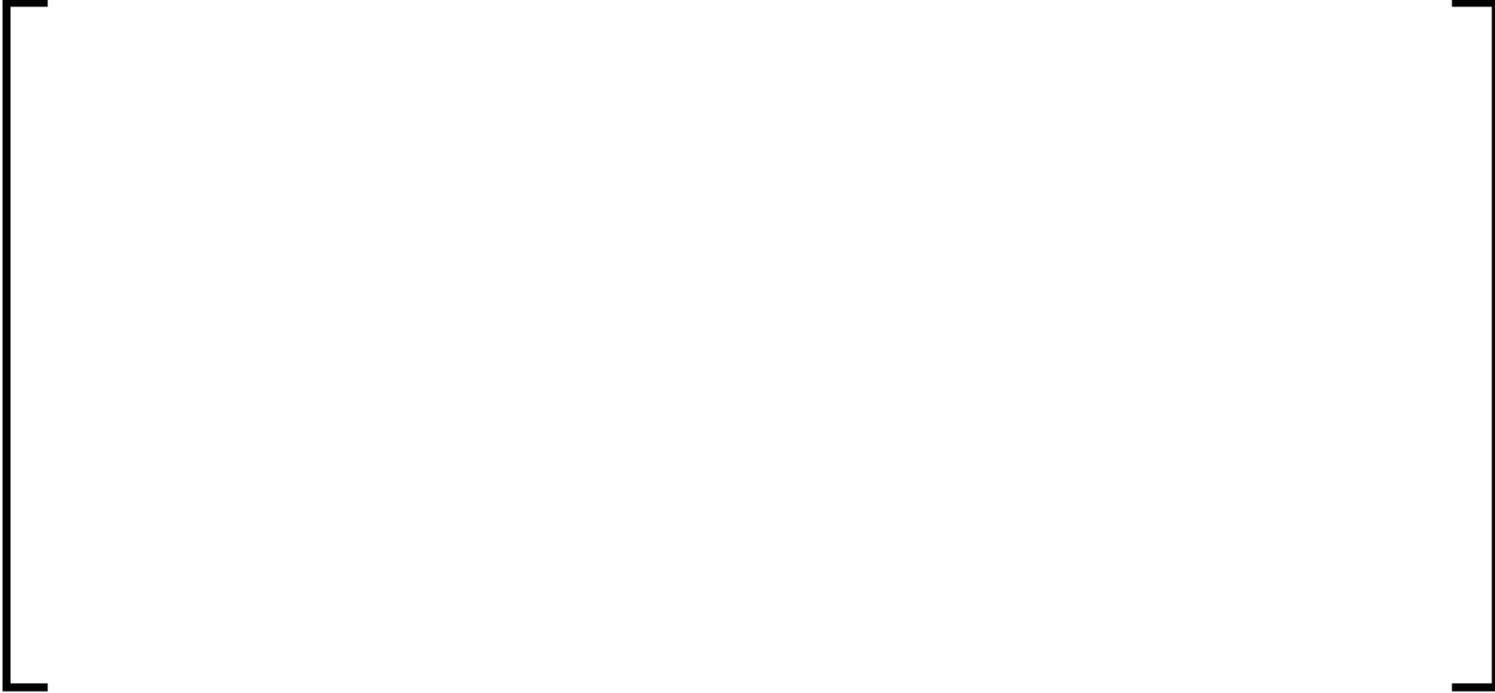
**5.5.1 Nozzle Cross Sections**

The cross sectional characteristics are calculated for the path locations as shown for the axial locations presented in Figure 5–14 for the minimum FSWOL model and Figure 5–15 for the maximum FSWOL model. [

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**Figure 5-14:** Structural Pathline Locations Evaluated for Minimum FSWOL Model



**Figure 5-15:** Additional Structural Pathline Evaluated for Maximum FSWOL Model

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**5.5.2 Stress Intensity**

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## **6 ASME Code Qualification**

### **6.1 Primary Stress Criteria**

Per XIII-3100 of Reference [4], the primary stresses are those normal or shear stresses developed by an imposed loading such as internal pressure and external loadings. The primary stress intensity criteria are the basic requirements in calculating the weld overlay size, wherein an assumption is made that a 360° circumferential flaw has grown completely through the original weld. Loading conditions in each service level have been considered in the weld overlay sizing calculation ([7]). The nozzle to pipe region has been reinforced by the weld overlay by adding materials to the nozzle outside region. This relieves the primary stress burden resulting from internal pressure and external loads. Therefore, the primary stress intensity requirements for the nozzle, welds, safe end and pipe have been satisfied for all service levels without the need for further evaluation. Related criteria include the minimum required pressure thickness and reinforcement area were addressed in the original design. Adding weld overlay will increase the nozzle wall thickness, and therefore, these requirements are satisfied.

### **6.2 Primary Plus Secondary Stress Criteria**

The analyses of stresses for transient conditions are required to satisfy the requirements for the secondary SI range and repetitive loadings. The following discussion describes the primary + secondary SI range evaluation and fatigue analysis process employed herein for the design.

Overall stress levels are reviewed and assessed to determine which locations require detailed stress/fatigue analysis. The objective is to assure that: 1) The highly stressed locations affected by implementation of FSWOL are evaluated. 2) The specified region is quantitatively qualified. Once specific locations for detailed stress evaluation are established, the related pathlines can be defined with ANSYS. A post-processing routine is then conducted to convert the component stresses along the selected path lines into the SI categories (i.e., membrane, membrane + bending, total) that correlate to the specific ASME Code criteria (Section 1.4.2).

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**6.2.1 Cladding Evaluation**

Per NB-3122.3 presence of cladding shall be considered for both the thermal analysis and the stress analysis.

therefore, the cladding must meet the primary plus secondary stress and fatigue criteria defined in XIII-3400 and XIII-3500 of Reference [4].

Per NB- 3122.1 of Reference [3], no structural strength is attributed to cladding for primary stress. In doing so, primary loads applied to a component with cladding imparts secondary stresses (self-limiting) within the cladding. Table-XIII-2600-1 of Reference [4] classifies both membrane stress due to pressure and bending due to thermal as secondary stress (Q) within the cladding.

**6.2.1.1 Cladding Evaluation of Primary Plus Secondary Stress**

As categorized by the ASME Code (References [3],[4]), the use of hand calculations can be used to prove that the KE factor applied in the analysis is conservative.

**6.2.1.1.1 Cladding Secondary Stress due to Thermal Gradient**

Thermal stress in the cladding itself is approximated assuming only a thin walled cylinder equal to the nominal dimensions of the cladding. Using equations from Reference [19] (Article 15.6) stress are calculated as follows:

$$\sigma_{hoop} = \sigma_{axial} = \frac{\Delta T \cdot \gamma \cdot E_x}{2 \cdot (1 - \nu)}$$

If the cladding stress ranges result in a full reversal of the assumed thermal gradient, the associated stress range would multiply the thermal equation by a factor of 2. The following is applied to the hot leg surge nozzle using the conservative maximizing stress:

1. Young's modulus at 70°F
2. CTE at 700°F
3. Maximum thermal gradient in the cladding

The secondary stress range due to thermal is calculated below.

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**6.2.1.1.2 Cladding Secondary Stress due Pressure**

The maximum stress intensity due to pressure is calculated using the equations for thick wall vessels and considering the full thickness of the component. The maximum stress intensity range will consider the maximum transient pressure defined and a pressure = [ ]

Using thickwall equations defined in Reference [19]. The principal stresses are evaluated at the inside surface (cladding) using the following equations. Given:

**6.2.1.1.3 Cladding Secondary Stress due to External Loads**

Including the stresses due to external loads (Section 5.5) is consistent with the ASME Code categorizations of pressure imposing secondary stress within the cladding. The maximum stress intensity due to external loads for

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those pathlines through the nozzle base metal should be combined with the stress intensities for thermal loads and pressure. The combined secondary stresses can then be compared directly to the  $3S_m$  limit.

**6.2.1.1.4 Cladding Exempt from Thermal Stress Ratchet Criteria**

Per XIII-3430 of Reference [4], determination of the maximum allowable cyclic thermal stress requires the general primary membrane stress due to pressure. Per the ASME Code, the cladding is not subjected to any stress that is categorized as primary stress. This interpretation is supported by the Code’s requirement that no structural strength due to cladding be credited in the primary stress evaluations.

As such, in the absence of primary stress, thermal stress ratcheting is not a valid failure mechanism. Pathlines through cladding should be excluded from the thermal stress ratchet criteria.

**6.2.1.1.5 Cladding Evaluation of Fatigue Criteria**

Per XIII-2500 of Reference [4], the  $3S_m$  criterion ensures structures will shakedown to elastic regime within a limited number of cycles except at regions with significant local discontinuities or local thermal stress.

Local thermal stress has been defined in XIII-1300(aj)(2) of Reference [4] as stress associated with almost complete suppression of differential expansion and thus produces no significant distortion (differential thermal stress in the cladding). Such stresses shall be considered only from the fatigue standpoint and are therefore classified as peak stresses.

Per XIII-2500 of Reference [4], in evaluating local thermal stresses for fatigue the elastic equations shall be used, except that the numerical value substituted for Poisson’s ratio shall be determined from the following expression:

$$\nu = 0.5 - 0.2 \frac{S_y}{S_a}$$

Assuming a large  $S_a$  would result in a maximum modified Poisson’s ratio of 0.5. The stresses obtained from the model are based on the nominal Poisson’s ration. The stress must then be scaled to account for the larger modified Poisson’s ratio. This would result in a maximum Poisson’s correction factor ( $K_\nu$ ) applied to stress obtained from the model.

$$\nu = 0.500 \text{ (Maximum modified poisson’s ratio)}$$

$$\nu_o = 0.310 \text{ (Specified Poisson’s ratio for the cladding material)}$$

$$K_\nu = \frac{1 - \nu_o}{1 - \nu} = \frac{1 - 0.310}{1 - 0.500} = 1.380$$

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This correction factor technically only applies to stress classified as “local thermal stress”. It is conservative to apply the  $K_v$  to all stresses in the fatigue calculations in the form of a FSRF applied to the total stresses.

The fatigue evaluation herein has placed pathlines through the cladding. Total stress is evaluated with the application of a  $K_v = 1.38$ . Additionally,  $K_e$  is calculated based on Membrane plus Bending stress and applied to  $S_{att}$ . If the  $K_e$  factor is greater than 1.0, the  $K_v$  factor is not applied per XIII-3450 of Reference [4].

**6.2.2 Path Definitions and Stress Evaluation**

The ANSYS Post Processor is used to linearize the stresses along predetermined paths and classify them in accordance with the ASME Code Criteria (i.e., membrane, membrane plus bending, total and peak stress). The selection of the paths is based on a review of stress levels which are obtained from the FE stress analysis described in Section 5.4. The paths go through highly stressed locations in the plane of symmetry. The stress contours in the nozzles for [ ] at time [ ] are shown in Figure 5–12 and Figure 5–13 for the minimum and maximum FSWOL configurations respectively. It can be seen that the highest stresses occur at the toe end of the FSWOL and the inner surface of the cladding below the FSWOL toe end.

Pathlines selected for evaluation in this analysis are detailed in Figure 5–14 and Figure 5–15.

**6.2.3 Maximum Primary plus Secondary Stress Intensity Range**

The P+Q stress ranges have been calculated within the Structural Analysis Tool Box. Stress intensity ranges are calculated in accordance with the methodology specified in paragraph XIII-2400 of the ASME Code Reference [4]. The calculation is performed at each node of selected path lines in Figure 5–14 and Figure 5–15 for all transients.

The maximum membrane + bending (P+Q) stress intensity ranges are conservatively combined with the maximum stress intensity ranges due to external loads and stratification loads(see Section 5.5). External loads are comprised of the loads due to OBE and the piping thermal extension. Note, that stresses due to external loads are calculated only for the through-wall paths. Stratification loads are only applied during heatup and cooldown transients as specified in Section 5.5 (Reference [2]). The maximum membrane + bending (P+Q) stress intensity ranges are conservatively combined with the maximum stress intensity ranges due to external loads (see Section 5.5). External loads are comprised of the loads due to OBE and the piping thermal extension. Note, that stresses due to external loads are calculated only for the through-wall paths. The SI from the outside node of these paths is conservatively used for all pathline locations at a given cross section plane.

The sum of the maximum transient SI Range and the stress intensity due to external loads is compared directly to the primary + secondary stress intensity range criterion of the ASME Code. Table 6–2 provides a detailed summary of the maximum P+Q SINT ranges and allowable limits along with the transient’s combinations. For any location which exceeds the  $3S_m$  criterion, it will be demonstrated to meet the acceptance criteria for Simplified Elastic-Plastic outlined in Section 1.4.2.2.

The ratio of calculated P+Q and P+Q[ntb] to 3Sm allowable has been provided as a column in the table. Values less than 1.0 indicate the criterion has been met.

The following tables provide the Ke factor assigned the appropriate cladding pathline but does not include the P+Q/3Sm, as that was resolved in Section 6.2.1.1 where the maximum P+Q/3Sm for cladding locations is calculated to be [ ]

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**Table 6–1:** Maximum P+Q Stress Intensities at Inside and Outside Pathline Locations for Minimum FSWOL Configuration



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**Table 6–2:** Maximum P+Q Stress Intensities at Inside and Outside Pathline Locations for Maximum FSWOL Configuration



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**6.2.4 Thermal Stress Ratchet**

Per XIII-3430 of Reference [4], the maximum thermal stresses are evaluated to ensure progressive distortion will not occur when the nozzle is subjected to a primary membrane stress due to internal pressure and cyclic thermal loading. The criteria and methodology for calculation of maximum allowable thermal cyclic stress are laid out in Table 1-4.

The thermal stress ratchet criteria summary for each pathline location has been provided in Table 6-3 and Table 6-4 for the minimum FSWOL configuration and Table 6-5 and Table 6-6 for the maximum FSWOL configuration.

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**Table 6-3:** Thermal Stress Ratchet At Inside Pathline Locations for Minimum FSWOL Configuration

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Table 6-3 – continued from previous page

**Table 6-4:** Thermal Stress Ratchet At Outside Pathline Locations for Minimum FSWOL Configuration

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**Table 6-5:** Thermal Stress Ratchet At Inside Pathline Locations for Maximum FSWOL Configuration

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**Table 6-6:** Thermal Stress Ratchet At Outside Pathline Locations for Maximum FSWOL Configuration

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**6.3 Cumulative Fatigue Usage**

The fatigue usage factor calculation is performed at critical locations with regards to peak stress and the application of the FSWOL. It includes the FSWOL, nozzle, DMWs, safe end, and pipe materials. All locations and corresponding fatigue parameters are listed in Table 6–8 and Table 6–9 for the minimum FSWOL model and Table 6–16 and Table 6–17 for the maximum FSWOL model. The path locations on the component have been depicted in Figure 5–14 and Figure 5–15.

The SATB (Reference [15]) is used to calculate fatigue based on the method prescribed in paragraph XIII-3520 of the ASME Code Reference [4] at the nodal locations for each pathline endpoint for all transients (See Table 1–7).

The fatigue usage factor at a location is usually calculated based on the total stress intensity range.

The stress category used in the fatigue evaluation for each node is listed in Table 6–8 and Table 6–9 for the minimum FSWOL model and Table 6–16 and Table 6–17 for the maximum FSWOL model.

If the membrane + bending SI range is over the  $3S_m$  limit, the SI range is also multiplied by the  $K_e$  factor.  $K_e$  factors are calculated using equation shown in Section 1.4.2.2, Table 1–7 where the  $S_m$  value for a particular combination is evaluated at the maximum temperatures between the time points being ranged. External load SI from Table A–23 and Table A–24 (for the minimum and maximum FSWOL configurations respectively) are combined with SI ranges evaluated for the fatigue calculation.

The load cases of all transients are combined for the maximum SI range. The number of cycles of the corresponding transient listed in Table 3–20 is used in the fatigue usage factor calculation.

The FSWOL material is conservatively evaluated for 80 years.

A summary of the cumulative fatigue usage values calculated at all locations in the minimum FSWOL model is provided in Table 6–7. Detailed listings in subsequent tables include the maximum evaluated  $S_{alt}$ , corresponding time points, maximum in-range temperatures, and applicable  $K_e$  factors for the following locations:

- Maximum fatigue usage in the FSWOL material- Table 6–10
- Maximum fatigue usage in the existing material- Table 6–12
- Maximum fatigue usage in the cladding material- Table 6–14
- Maximum fatigue usage in the surge line pipe material- Table 6–13