Attachment 3

Westinghouse Calculation CN-PAFM-15-20-NP, Rev. 2, *Palo Verde Unit 3 RCS Cold Leg Alloy 600 Small Bore Nozzle Repair Transient Stress and Fracture Mechanics Evaluation for One Cycle Operation*

WESTINGHOUSE ELECTRIC COMPANY LLC

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Palo Verde Unit 3 RCS Cold Leg Alloy 600 Small Bore Nozzle Repair Transient Stress and Fracture Mechanics Evaluation for One Cycle Operation

Author Name(s)	Signature / Date	Scope
Nathan L. Glunt	*Electronically Approved**	Non-Proprietary Class 3
Matthew T. Coble	*Electronically Approved**	Non-Proprietary Class 3
Verifier Name(s)	**Signature / Date**	**Scope**
Anees Udyawar	*Electronically Approved**	Non-Proprietary Class 3
Justin D. Webb	*Electronically Approved**	Non-Proprietary Class 3
Manager Name	**Signature / Date**	**Scope**
John L. McFadden	*Electronically Approved**	Non-Proprietary Class 3
Carl J. Gimbrone	*Electronically Approved**	Non-Proprietary Class 3

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1	April 17, 2015	Removed sentence in Section 5.1.2 per customer request. Change is marked by a revision bar in the left hand margin.
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2	See EDMS	This –NP version adds proprietary brackets and the proprietary information has been redacted.

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1.0 Background and Purpose

During the 3R18 spring 2015 refueling outage at Palo Verde Nuclear Generating Station (PVNGS) Unit 3, visual examinations of the reactor coolant pump (RCP) suction safe end revealed evidence of leakage in the annulus between the outer surface of the Inconel 600 instrument nozzle and the bore on the suction safe end. The most likely location of the flaw(s) is in the primary water stress corrosion cracking (PWSCC)-susceptible Alloy 82/182 weld and Inconel 600 instrument nozzle, along their fusion line inside the safe end bore. The Alloy 600 instrument nozzle is attached with a partial penetration weld to the inside of the RCP suction safe end.

The "half-nozzle" repair method will be used to replace a portion of the Alloy 600 one-inch instrument nozzle. The repair will be made with an Inconel 690 PWSCC-resistant material half-nozzle, which will be attached to the Palo Verde Unit 3 RCP suction safe end outside diameter. This is an alternative to the ASME Section XI [1] requirement, IWB-3142.3, to correct the observed leakage. For the half-nozzle repair, the instrument nozzle is severed on the outside of the RCP suction safe end. The remaining lower portion of the instrument nozzle is removed by boring into the suction safe end. The removed portion of the Alloy 600 instrument nozzle is then replaced with a section (half-nozzle) of a more PWSCC-resistant
Rev. 2 Alloy 690 material, which will then be welded to the outside surface of the suction safe end using a 52M weld filler (see Figure 1). The inner portion of the original instrument nozzle, including the partial penetration weld, is left in place.

The half-nozzle repair has been successfully implemented on 63 Alloy 600 small-bore reactor coolant system hot leg nozzles (i.e., pressure taps, sampling line, and resistive temperature device thermowell nozzles) for Palo Verde Units 1, 2, and 3 [5 and 14]. Additionally, the half-nozzle method has been used at many other Combustion Engineering (CE) designed nuclear steam supply system plants.

Westinghouse has previously performed a technical justification and a fracture mechanics investigation into the feasibility of small diameter Alloy 600/690 half-nozzle repairs in WCAP-15973-P-A [2]. The NRC has issued a final safety evaluation (SE) [3] that found WCAP-15973-P to be acceptable for referencing in licensing applications for CE designed pressurized water reactors as long as information required by the SE in is submitted as a relief request. The NRC SE [3] is incorporated into WCAP-15973-P-A [2], and this WCAP report was submitted to the NRC in [18]. The flaw evaluation performed in this report will follow guidance from the technical basis and the NRC SE to demonstrate that a flaw(s) in the partial penetration weld will not grow to an unacceptable size in the suction safe end base metal, for up to 18 months of operation.

The purpose of this report is to demonstrate the acceptability of the half-nozzle repair for the flawed RCP suction safe end instrument nozzle at Palo Verde Unit 3 based on a the following assessments:

1. corrosion evaluation
2. ASME Section XI crack growth evaluation
3. stress corrosion cracking assessment

The flaw evaluation will demonstrate that any flaws in the penetration weld that remain after the half-nozzle repair will not grow to an unacceptable flaw size into the suction safe end carbon steel metal

within the next cycle of operation (18 months). The fracture mechanics justification will be consistent with revision 1 of Relief Request 31, which was previously submitted and approved for the Palo Verde Units 1, 2, and 3 small-bore hot leg Alloy 600 nozzles [5 and 14].

This calculation note was created and verified in accordance with Westinghouse Level II Procedures WEC 3.2.6, WEC 3.3.3 and Level III Procedure ES 3.2.1.

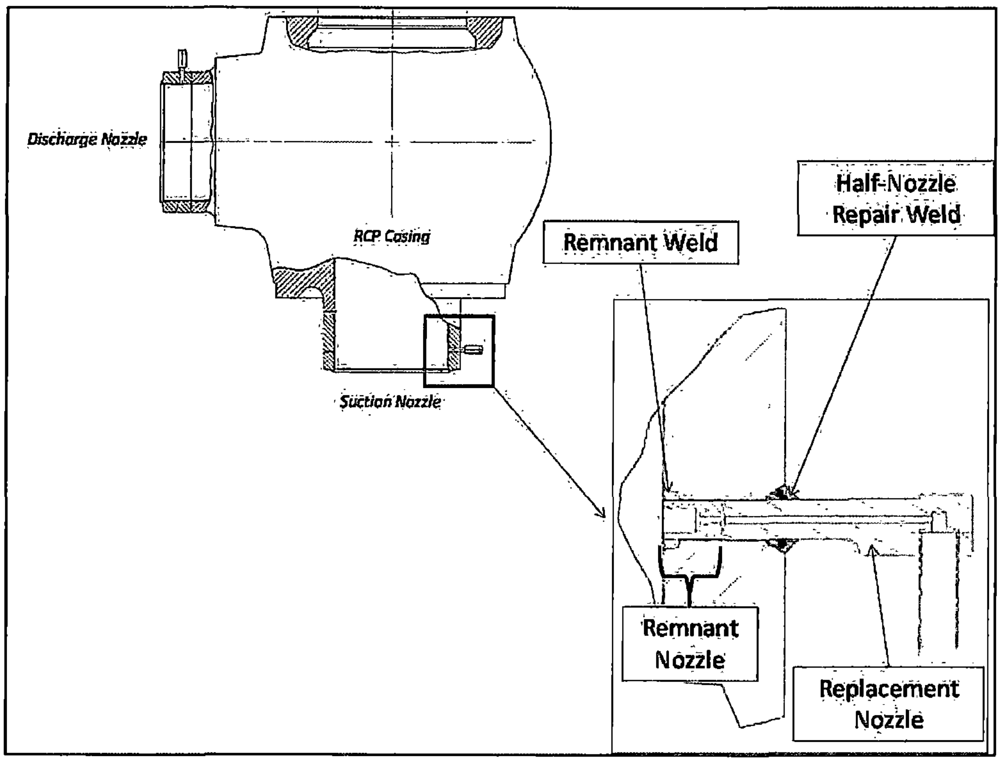

Figure 1: RCP Instrumentation Nozzle Repair Schematic

2.0 Summary of Results and Conclusions

During the spring 2015 refueling outage at Palo Verde Unit 3, visual examinations of the RCP suction safe end revealed evidence of leakage in the annulus between the outer surface of the Inconel 600 instrument nozzle and the bore on the suction safe end. The most likely location of the flaw(s) is in the PWSCC-susceptible Alloy 82/182 weld and Inconel 600 instrument nozzle, along their fusion line inside the safe end bore. The Alloy 600 instrument nozzle is attached with a partial penetration weld to the inside diameter of the RCP suction safe end.

The half-nozzle repair method will be used to replace a portion of the Alloy 600 one-inch instrument nozzle with an Inconel 690 PWSCC-resistant material half-nozzle, attached to the Palo Verde Unit 3 RCP suction safe end outside diameter. The ASME Class 1 pressure boundary and associated nozzle attachment weld will be relocated to the outside surface of the suction safe end. The (assumed) flawed partial penetration weld and a portion of the existing nozzle will be abandoned in place.

Westinghouse has previously performed a technical justification and a fracture mechanics investigation into the feasibility of small diameter Alloy 600/690 half-nozzle repairs WCAP-15973-P-A [2] and CN-CI-02-71 [6], which the NRC has found acceptable for referencing in licensing applications for CE designed pressurized water reactors as long as information required by the SE is submitted as a relief request. The flaw evaluation performed in this report follows their guidance and demonstrates that a flaw in the partial penetration weld will not grow to an unacceptable size in the suction safe end base metal, for up to 18 months of operation.

The evaluation performed in this report demonstrates the acceptability of the half-nozzle repair for the flawed RCP suction safe end instrument nozzle at Palo Verde Unit 3 based on a corrosion evaluation, on an ASME Section XI crack growth evaluation, and on a flaw stability analysis.

The corrosion rate around the instrumentation nozzle bore was determined based on the operating mode corrosion rates of [2] and the plant operating history. Based on the overall corrosion rate, the instrumentation nozzle bore diameter remains acceptable for the end of life at Palo Verde Unit 3.

A comparison was made between the ASME Section XI Code evaluation of hot leg nozzle repairs [2 and 6] and the Palo Verde Unit 3 RCP instrumentation nozzle repair, and it was determined that the evaluation in [2 and 6], which was for 40 years of operation, would bound the repair condition for the instrumentation nozzle and the suction safe end of Palo Verde Unit 3 for at least 18 months. Furthermore, it was demonstrated that the previous relief request and the subsequent NRC SEs [5 and 14], documenting approval for the Palo Verde Units 1, 2, and 3 small-bore hot leg nozzles, are bounding and applicable for the RCP suction safe end instrumentation nozzle half-nozzle repair. Therefore, the half-nozzle repair for the RCP suction safe end is acceptable per Section XI of the ASME Code for at least the next 18 months of operation.

3.0 References

1. ASME Boiler and Pressure Vessel Code, Section XI, 2001 Edition with 2003 Addenda.

2. Westinghouse Report, WCAP-15973-P-A, Rev. 0, "Low-Alloy Steel Component Corrosion Analysis Supporting Small-Diameter Alloy 600/690 Nozzle Repair/Replacement Programs," February 2005. (Westinghouse Proprietary Class 2)

3. NRC Letter, "Final Safety Evaluation for Topical Report WCAP-15973-P, Revision 01, "Low-Alloy Steel Component Corrosion Analysis Supporting Small-Diameter Alloy 600/690 Nozzle Repair/Replacement Program" (TAC No. MB6805)," January 12, 2005.

4. Combustion Engineering Report, A-CEOG-9449-1242, Rev. 00, "Evaluation of the Corrosion Allowance for Reinforcement and Effective Weld to Support Small Alloy 600 Nozzle Repairs," June 13, 2000. (Westinghouse Proprietary Class 2)

5. APS Letter, "Palo Verde Nuclear Generating Station (PVNGS) Units 1, 2, 3, Docket No. STN 50-528/529/530, 10 CFR 50.55a(a)(3)(i) Alternative Repair Request for Reactor Coolant System Hot Leg Alloy 600 Small-Bore Nozzles (Relief Request 31, Revision 1)." August 16, 2005. (ML Accession No. ML052550368)

6. Westinghouse Calculation Note, CN-CI-02-71, Rev. 2, "Summary of Fatigue Crack Growth Evaluation Associated with Small Diameter Nozzles in CEOG Plants," March 31, 2004. (Westinghouse Proprietary Class 2)

7. Combustion Engineering Specification, 00000-PE-140, Rev. 04, "General Specification for Reactor Coolant Pipe and Fittings," May 25, 1977. (Westinghouse Proprietary Class 2)

8. Combustion Engineering Report, CENC-1642, Rev. 0, "Analytical Report for Arizona Unit No. 3 Piping," May 1984. (Westinghouse Proprietary Class 2)

9. Combustion Engineering Specification, SYS80-PE-480, Rev. 02, "Specification for Standard Plant for Reactor Coolant Pumps," May 2, 1978. (Westinghouse Proprietary Class 2)

10. Palo Verde Nuclear Generating Station Units 1, 2, and 3 Updated Final Safety Analysis Report, Rev. 17B, January 2015.

11. Westinghouse Calculation Note, A-GEN-PS-0003, Rev. 3, "Evaluation of Fatigue Crack Growth Associated with Small Diameter Nozzles in CEOG Plants," December 9, 2005. (Westinghouse Proprietary Class 2)

12. Westinghouse Design Specification, 14273-PE-140, Rev. 15, "Project Specification for Reactor Coolant Piping and Fittings for Arizona Nuclear Power Project," June 25, 2007. (Westinghouse Proprietary Class 2)

13. CE – KSB Pump Co. Inc. Drawing, E-8111-101-2002, Rev. 00, "Pump Casing – A."

14. NRC Letter, "Palo Verde Nuclear Generating Station, Units 1, 2, and 3 – Relief Request No. 31, Revision 1, Re: Proposed Alternative Repair for Reactor Coolant System Hot-Leg Alloy 600 Small-Bore Nozzles (TAC Nos. MC9159, MC9160, and MC9161). ML Accession No. ML062300333.

15. Westinghouse Calculation Note, CN-MRCDA-15-13, Rev. 0, "Qualification of Palo Verde Unit 3 Reactor Coolant Pump Replacement Instrumentation Nozzle," April 16, 2015. (Westinghouse Proprietary Class 2)

16. Palo Verde Nuclear Generating Station Document 13-MS-B041, "Alloy Steel Corrosion Analysis Supporting Alloy 600/690 Nozzle Repair/Replacement."

17. Westinghouse Policy/Procedure WEC 3.6.5, Rev. 1, "External Computer Software," effective July 13, 2013.

18. Westinghouse Owners Group Letter, "Westinghouse Owners Group Transmittal of NRC-Approved Topical Report WCAP-15973-P-A (Proprietary) and WCAP-15973-NP-A, Rev 0, (Non-Proprietary) "Low-Alloy Steel Component Corrosion Analysis Supporting Small-Diameter Alloy 600/690 Nozzle Repair/Replacement Programs," (TAC MB6805) (Task 1170)," March 16, 2005.

4.0 Calculations

4.1 Limits of Applicability

This calculation note is applicable to the fracture mechanics evaluation of the Palo Verde Unit 3 RCP suction safe end instrumentation nozzle half-nozzle repair.

4.2 Open Items

There are no open items in this calculation note.

4.3 Method Discussion

The purpose of the evaluation contained herein is to demonstrate the acceptability of the RCP suction safe end instrumentation nozzle half-nozzle repair for an operation duration of 18 months (1 cycle). The technical basis for the half nozzle repairs in the hot leg and pressurizer has been performed in WCAP-15973-P-A [2], which has been accepted by the NRC in Reference 3. Furthermore, Palo Verde specific hot leg half nozzle repairs have been performed per [5] for a plant operation duration of 40 years, and has been approved by the NRC as discussed in Reference 14. The approved half-nozzle repair evaluation for Palo Verde 1, 2, and 3 for the hot leg nozzle [5 and 14] will be used as a basis for justification that the Palo Verde Unit 3 RCP suction safe end will remain acceptable for one cycle of operation based on the fracture mechanics evaluation herein. The complete details and results of the evaluation are provided in Section 5.0 of this document.

4.4 Discussion of Significant Assumptions

All assumptions are identified in Section 5.0 of this calculation note.

4.5 Acceptance Criteria

The evaluation of a postulated flaw in Palo Verde Unit 3 RCP suction safe end instrumentation nozzle attachment weld is performed in accordance with the ASME Section XI Code [1], WCAP-15793-P [2], CN-CI-02-71 [6], and the NRC SE [3].

4.6 Input

The specific input required for this calculation note are described in the detailed evaluation contained in Section 5.0.

5.0 Evaluations, Analysis, Detailed Calculations and Results

5.1 General Corrosion Assessment

According to WCAP-15973-P-A [2], the crevices between the safe end bore and the instrument nozzle material will fill with borated water if a half-nozzle replacement/repair is implemented. When used as primary pressure boundary materials, carbon and low alloy steels are clad with corrosion-resistant materials (generally weld-deposited stainless steels) to isolate these materials from the primary coolant, thereby minimizing corrosion and corrosion product release to the coolant. The inside diameters of holes, such as those used for instrumentation nozzles, are not clad because, in the as-built condition, they are not exposed to borated water. During the time when the plant returns to operation from a shutdown condition (i.e., refueling), the crevice region may be filled with aerated water. The oxygen in the water will be consumed by corrosion of the steel; however, the corrosion rate will be high for the relatively short time when the temperature is at a low-to-moderate level. When the plant is operating, the crevice region will be de-aerated, and the corrosion rate is much less than that during the time immediately after startup.

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5.1.1 Maximum Allowable Bore Size

The first step in the corrosion evaluation is the determination of the allowable increase in the diameter of the carbon steel nozzle bore. The allowable increase in the diameter (because of corrosion) was determined by subtracting the original bore diameter from the maximum allowable diameter. The maximum allowable hole size was determined in Section 2.4 of WCAP-15973-P-A [2] based on (1) the reduction in the effective weld shear area, and (2) the required area of reinforcement for the nozzle bore holes.

A value of [ ]^{a,c} inches of corrosion allowance was determined for the hot leg nozzle per A-CEOG-9449-1242 [4], which is Reference 12 of the WCAP-15973-P-A. Westinghouse Calculation CN-MRCDA-15-13 [15] determined that the actual Palo Verde Unit 3 suction safe end nozzle repair corrosion allowance would be larger than the hot leg nozzle corrosion allowance of [ ]^{a,c} inches. For conservatism, a corrosion allowance of [ ]^{a,c} inches was used herein for the Palo Verde Unit 3 suction safe end for the small Alloy 600 nozzle repair. The allowable diametrical hole increase of [ ]^{a,c} inches can be compared to the corrosion growth of the bore hole calculated for 40 years, as shown below.

Therefore, the hot leg nozzle corrosion allowance can be conservatively used for the RCP suction safe end. Similar trends for the other applications of fracture mechanics (i.e., flaw stability and crack growth), as described later in this report, will also demonstrate that the hot leg nozzle evaluations performed for Palo Verde Unit 3 in WCAP-15973-P-A [2] and the relief requests [4 and 15] are bounding for the RCP suction safe end bore region.

5.1.2 General Corrosion Rate

The corrosion rate for a carbon steel material (such as that of SA-508, Class 1) for the Palo Verde Unit 3 RCP suction safe end is provided in [2]. The corrosion rate in [2], applicable to the half-nozzle crevice region, is provided 600 small-bore nozzle repairs [5] in order to provide assurance that the allowable hole

diameter for three separate operating conditions: full power operation, startup mode (assumed to be at intermediate temperature with aerated primary coolant), and refueling mode (100°F with aerated primary coolant). The corrosion rates for each mode of operation are shown in Table 1 in mils per year (mpy). The percentage of time spent in each mode of operation based on [2] is also shown.

Rev. 2 Arizona Public Service (APS) has committed to track the time at cold shutdown in the previous relief requests for hot leg Alloy 600 small-bore nozzle repairs [5] in order to provide assurance that the allowable hole diameter is not exceeded over the life of the plant. The case herein for 18 months is more than sufficient, as demonstrated below. Based on a review of Palo Verde Unit 3 operation data shown in Appendix A, the percentage of time spent in startup and cold shutdown conditions is bounded by the values used in [2].

Table 1: Corrosion Based on Mode of Operation

Mode of Operation	Growth Rate [2]	Percent Time in Mode [2]
Normal Operations	0.4 mpy	88%
Startup Conditions	19.0 mpy	2%
Cold Shutdown Conditions	8.0 mpy	10%

An overall corrosion rate is then determined based on the corrosion rates of the individual operating modes and the percentage of time spent in each mode. Using Table 1, the calculated corrosion rate (CR) for Palo Verde Unit 3 is:

$$CR = (0.88)(0.4\text{ mpy}) + (0.02)(19.0\text{ mpy}) + (0.10)(8.0\text{ mpy}) = 1.53\text{ mpy}$$

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5.1.3 General Corrosion for One Fuel Cycle

For a conservative operation period of 40 years, the total corrosion of the nozzle bore would be:

$$\begin{aligned}\text{Corrosion} &= (1.53\text{ mpy})(40\text{ years}) = (0.00153\text{ in/yr})(40\text{ yrs}) \\ &= 0.0612\text{ inches (radially, relative to penetration)} \\ &= 0.1224\text{ inches (diametrically, relative to penetration)}\end{aligned}$$

As previously discussed, the allowable increase in hole diameter to the Palo Verde Unit 3 instrumentation nozzle bore is [ ]^{a,c} inches. Since the expected corrosion in 40 years is only 0.1224 inches diametrically, the diameter of the bore would remain acceptable beyond the next 40 years of operation.

5.2 Stress Evaluation and Transient Consideration

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In [6], for the technical basis for the hot leg half-nozzle repairs, postulated bounding flaws encompassing the entire partial penetration weld at small-bore penetration welds in the hot leg piping were assessed for flaw growth and flaw stability as specified in ASME Code Section XI for a plant life of 40 years. This is the basis for the WCAP-15973-P-A allowable flaw size and crack growth evaluations in [2]. These evaluations demonstrated that the postulated bounding flaws, which could have been left in place in the weld remnant after small-bore nozzle repairs, are acceptable. The small-bore instrument nozzle repairs evaluated for the hot leg are similar to the Palo Verde Unit 3 RCP suction safe end small-bore instrument nozzle repair. Any differences will be assessed herein to justify that the fracture mechanics evaluation performed for the hot leg nozzle repair would bound the RCP suction safe end small-bore instrument nozzle repair for the next 18 months of plant operation.

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The weld size and bore diameter used in the hot leg half-nozzle repair evaluation are similar to that of the Palo Verde Unit 3 instrumentation nozzle half-nozzle repair in the suction safe end. The thickness used in the hot leg nozzle repair evaluation is 3.75 inches, as compared to the 3.00-inch thickness for the RCP suction safe end for Palo Verde Unit 3. This difference is evaluated in Section 5.3 of this report, and is shown to have an insignificant impact on the fracture mechanics analysis.

5.2.1 Thermal Transient Evaluation

The RCP suction safe end transients are the same as the cold leg transients documented in [7]. Based on [8], the usage factor for the hot leg piping is [ ]^{a,c} and the usage factor for the cold leg piping is [ ]^{a,c}. These usage factors are sufficiently small, and the difference between the two usage factors is considered to be insignificant; therefore, the transient effects on the RCP suction safe end are expected to be similar to those on the hot leg.

Based on a comparison of the hot leg transient definitions in [7] and the RCP nozzle transients in [9], all transients except for the Loss of Secondary Pressure (faulted condition) transient are more severe and limiting for the hot leg than for the RCP suction safe end as shown in Appendix B. The Loss of Secondary Pressure transient is not required to be considered for the fatigue crack growth because only the Level A/B and test transients are considered. However, for the flaw stability evaluation, the Loss of Secondary Pressure transient should be considered. For the flaw stability evaluation performed in [6], it was determined that the Loss of Secondary Pressure transient was not the limiting transient used in the maximum allowable flaw size calculation; furthermore, it had a margin of approximately [ ]^{a,c} between the applied stress intensity factor and the allowable stress intensity factor (see Section 3.5 of [2] and Section 2.1 of [6]). The difference in the delta temperature and the ramp time of the temperature change for the cold leg, as compared to the hot leg transient, is not so severe that it would result in very large changes in the existing thermal stresses for the hot leg nozzle. Therefore, the severity of the RCP suction safe end Loss of Secondary Pressure transient is not sufficient to significantly reduce the margin of [ ]^{a,c} between the applied and allowable stress intensity factors. Therefore, the flaw stability calculation for the hot leg nozzle is sufficient and representative for the RCP suction safe end location.

5.2.2 Mechanical Load Considerations

An additional consideration in the calculation of the stress field in the vicinity of the crack is the stress due to mechanical loads. The mechanical load stresses used in [6] and discussed in [2] for the hot leg piping are evaluated in Appendix C of [11]. It is demonstrated by comparison, as illustrated in Table 2 and Table 3, that the mechanical load stresses evaluated for the hot leg piping conservatively bound the mechanical load stresses in the RCP suction safe end.

The pressure load applied to the hot leg and RCP suction safe end is identical. Therefore, the stress in each is based on the pipe geometry. From Appendix C of [11], the stress in the pipe, based on thick-wall theory, can be calculated as:

$$\sigma = P\left(\frac{R_i^2}{R_o^2 - R_i^2}\right)$$

In the previous equation:
P = operating pressure (2,250 psi)
R_i = inner radius of the pipe
R_o = outer radius of the pipe

The radii can be calculated by dividing the diameter values given in Table 3 by a factor of two. The resulting operating pressure stress values are [ ]^{a,c} ksi for the hot leg and [ ]^{a,c} ksi for the RCP suction safe end. The stress in the hot leg pipe due to operating pressure conservatively bounds the RCP suction safe end stress.

The piping mechanical loads used to evaluate the piping stress are the pipe axial load and the bending moment. The mechanical loads applied to the hot leg piping and RCP suction safe end are compared in Table 2. The comparison shows that the axial load on the hot leg piping is [ ]^{a,c} times greater than the axial load on the RCP suction safe end. The axial stress area ratios are compared in Table 3. This comparison shows that the axial stress area ratio of [ ]^{a,c} is much less than the axial load ratio of [ ]^{a,c}. A similar comparison can be made for the applied bending moments. Table 2 shows that the hot leg bending moment is [ ]^{a,c} times greater for normal operating conditions and [ ]^{a,c} times greater for operating basis earthquake (OBE). A comparison of the section modulus in Table 3 shows that the section modulus ratio of [ ]^{a,c} is less than the minimum bending moment ratio of [ ]^{a,c}. These comparisons show that the mechanical loads applied to the hot leg piping, and the resulting stress field evaluated in [2 and 6], provide bounding results when compared to the mechanical loads applied to the RCP suction safe end and the stress field that would result from these loads.

Table 2: Comparison of Hot Leg Piping and RCP Suction Safe End Loads

Load Type	Condition	Hot Leg Loads(2)	RCP Suction Nozzle Loads(3)	Load Ratio (Hot Leg/ RCP Suction Nozzle)
Axial (kips)	NO_4(1)	[ ]a,c	[ ]a,c	[ ]a,c
	OBE	[ ]a,c	[ ]a,c	[ ]a,c
Bending (ft-kips)	NO_4(1)	[ ]a,c	[ ]a,c (4)	[ ]a,c
	OBE	[ ]a,c	[ ]a,c	[ ]a,c

Notes:
1) The NO_4 condition corresponds to the loads due to deadweight, normal operating thermal expansion, and friction.
2) Loads are from [11].
3) Loads are from [12], reported for Assembly P-4 at the "B" end of piping.
4) Equal to the square root sum of the squares of M_x and M_z moments in [12].

Table 3: Comparison of Hot Leg and RCP Suction Safe End Geometric Properties

Dimension	Hot Leg(1)	RCP Suction Nozzle(2)	Ratio (Hot Leg/ RCP Suction Nozzle)
Inner Diameter (in)	[ ]a,c	[ ]a,c	-
Outer Diameter (in)	[ ]a,c	[ ]a,c	-
Area (in^2)(3)	[ ]a,c	[ ]a,c	[ ]a,c
Section Modulus (in^3)(4)	[ ]a,c	[ ]a,c	[ ]a,c

Notes:
1) Dimensions are from [11].
2) Dimensions are from [13]; the inner diameter is based on the minimum wall thickness of 76.2 mm (3.0 inches).
3) Area is calculated as: π*diameter^2/4.
4) Section modulus is calculated as: [π*(outer diameter^4 - inside diameter^4)/64]/(outer diameter/2).

5.3 Fracture Mechanics Evaluation

An overall transient stress comparison performed in Section 5.2 determined that the stress evaluation in [2 and 6] envelops the Palo Verde Unit 3 suction safe end instrumentation nozzle half-nozzle repair. Therefore, the hot leg transient stresses used in the allowable flaw size determination and fatigue crack growth evaluation [2], and used in the basis document [6], would bound the Palo Verde Unit 3 RCP suction safe end transient stresses.

The stress field, geometry, and flaw size are the major contributors to the calculation of stress intensity factors. Based on the discussion in Section 5.2, the hot leg transient stresses used in the allowable flaw size determination and fatigue crack growth evaluation [2], and used in the basis document [6], would bound the Palo Verde Unit 3 RCP suction safe end transient stresses.

The stress intensity factor model used in the hot leg nozzle flaw evaluation is based on a hole in a flat plate, with two cracks emanating from the corners. The bounding axial and circumferential flaw geometries are shown in Figure 2 and Figure 3; the stress intensity model is shown in Figure 4. The hole diameter used in the hot leg nozzle repair evaluation (diameter = [ ]^{a,c} inches) from [6] is similar in size to the suction safe end instrumentation nozzle hole diameter (diameter = [ ]^{a,c} inches) in [13]. This slight difference would have an insignificant effect of the calculated stress intensity factors. Additionally, the difference in the thickness of the hot leg nozzle of 3.75 inches, as compared to the cold leg nozzle thickness of 3.0 inches, will have an insignificant impact on the fracture mechanics analysis and the stress intensity factor calculation. This is because, based on a review on the stress intensity factor database used in [6], the influence coefficients used in the stress intensity factor calculation do not significantly change between flaw depth-to-wall thickness ratios of a/t = 0.2 to a/t = 0.5. The flaw depth to wall thickness ratio (a/t) of both the hot leg and cold leg is approximately 0.3. Furthermore, according to Section 3.5 of [2] and Section 2.1 of [6], there is ample margin between the calculated stress intensity factors and the allowables to account for any small changes in component geometries.

According to Section 3.5 of [2] and Section 2.1 of [6], the limiting transient (with respect to allowable circumferential flaw size) was the cooldown transient, particularly the end of the cooldown transient. The end of cooldown is generally limiting due to the low temperature that affects the fracture toughness of the component. The fracture mechanics evaluations in [2] and in its supporting document, [6], were performed according to the 1992 Edition of the ASME Section XI Code, where IWB-3612 determined acceptability for normal and upset condition transients based on the following criterion:

$$K_I < K_{Ia}/\sqrt{10}$$

However, for Palo Verde Unit 3, the 2001 Edition with 2003 Addenda Section XI ASME Code is the Code of record. The acceptance criterion for normal and upset condition transients in IWB-3612 in the 2001 Edition with 2003 Addenda Section XI ASME Code is based on the following criterion:

$$K_I < K_{Ic}/\sqrt{10}$$

Since K_{Ic} is less limiting than K_{Ia}, the calculated axial and circumferential flaw stress intensity factors for the End of Cooldown transient in Section 3.5 of [2] (and Table 2-2 of [6]) would have additional margin over the allowables based on the current Palo Verde Unit 3 ASME Section XI Code year. As documented in Section 3.5 of [2] and Section 2.1 of [6], an RT_{NDT} value of 60°F was utilized in the allowable stress intensity factor calculation for the hot leg base metal. The use of an RT_{NDT} value of 60°F in [2 and 6] was confirmed based on a review of the allowable stress intensity factor for the End of Cooldown transient. For the RCP suction safe end, the RT_{NDT} is 40°F or less according to the RCP suction safe end Certified Material Test Report and UFSAR Table 5.2-29B [10]. Therefore, the lower RT_{NDT} value of 40°F for the Palo Verde Unit 3 cold leg nozzle would result in a less limiting allowable flaw size than the hot leg nozzle RT_{NDT} of 60°F. As such, the allowable flaw size evaluation performed in [2 and 6] for a hot leg nozzle repair would be conservatively representative for the Palo Verde Unit 3 RCP suction safe end instrumentation nozzle since stress intensity factors for the same size flaws would be similar.

Therefore, the allowable flaw size evaluation performed in WCAP-15973-P for a hot leg nozzle repair would be conservatively representative for the Palo Verde Unit 3 RCP suction safe end instrumentation nozzle since stress intensity factors for the same size flaws would be similar.

The fatigue crack growth evaluation performed in [2 and 6] demonstrated that crack growth for 40 years was small, and that the axial and circumferential flaws remained within the allowables. Table 4 and Table 5 show the crack growth for 40 years of operation to compare with the allowable flaw sizes from the generic hot leg piping evaluation (Section 3.4 of [2] and Section 2.1 of [6]) and the Palo Verde-specific hot leg piping evaluation from [5]. Since the stresses, stress intensity factors, and allowable flaw sizes used in [2 and 6] are considered bounding for the Palo Verde Unit 3 suction safe end instrumentation nozzle repair, the amount of fatigue crack growth tabulated in Table 4 and Table 5 for 40 years is expected to far exceed the anticipated fatigue crack growth for an 18-month duration in the Palo Verde Unit 3 suction safe end instrumentation nozzle.

Table 4: Hot Leg Piping Fatigue Crack Growth from [2] and [6]

Depth or Length	Initial (in.)	Axial Final (in.)	Axial Allowable (in.)	Circumferential Final (in.)	Circumferential Allowable (in.)
Depth	0.938	0.984	1.3	1.001	1.3
Length	0.762	0.791	1.1	0.802	1.1

Table 5: Hot Leg Piping Fatigue Crack Growth Using PVNGS Dimensions [5]

Depth or Length	Initial (in.)	Axial Final (in.)	Axial Allowable (in.)	Circumferential Final (in.)	Circumferential Allowable (in.)
Depth	0.950	0.999	1.3	1.017	1.3
Length	0.762	0.793	1.1	0.805	1.1

Since the fracture mechanics evaluation in [2 and 6] concluded that the half-nozzle repair was acceptable with respect to Section XI of the ASME Code for 40 years of operation, and since the fracture mechanics evaluation in [2 and 6] has been found to be bounding for the Palo Verde Unit 3 suction safe end instrumentation nozzle half-nozzle repair, it is concluded that the flawed Palo Verde Unit 3 suction safe end instrumentation nozzle weld will remain acceptable with respect to fatigue crack growth though the suction safe end for an operating duration of 18 months.

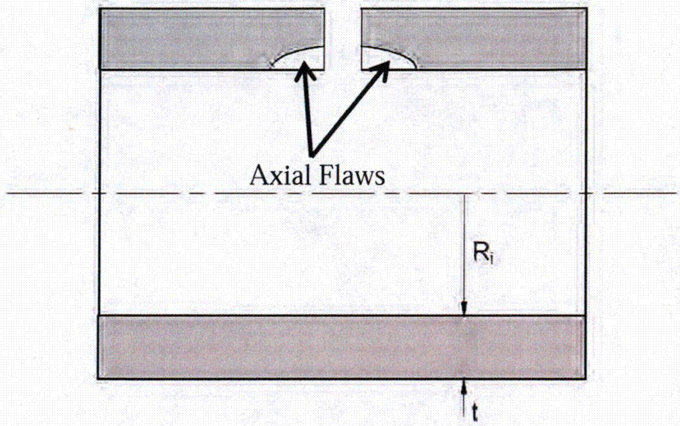

Figure 2: Axial Flaw Geometry

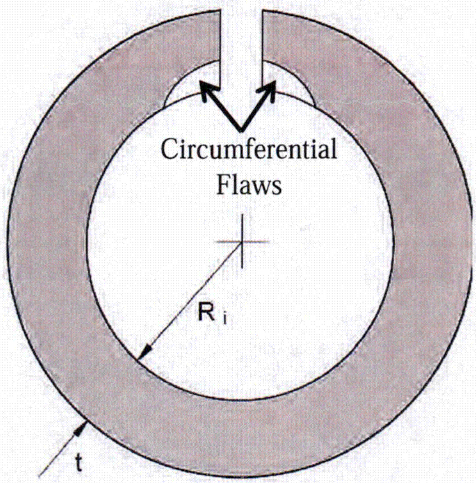

Figure 3: Circumferential Flaw Geometry

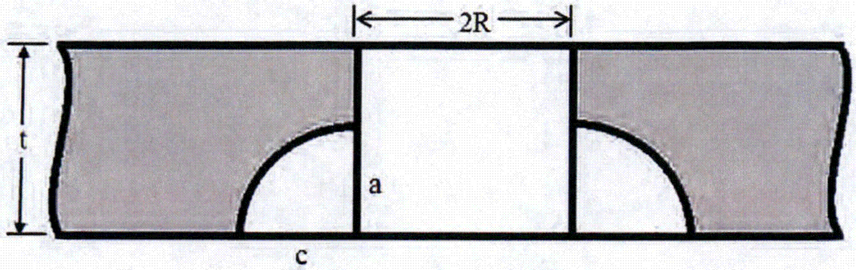

Figure 4: Stress Intensity Factor Model

5.4 Stress Corrosion Cracking Assessment

According to the NRC SE for WCAP-15973-P-A [3], the stress corrosion assessment in [2] may be used in the relief request as long as a review of plant chemistry is conducted to ensure that flaws in the carbon steel base metal material will not grow by stress corrosion. Stress corrosion and plant chemistry evaluations were previously conducted in [5]. The hot leg nozzle repair relief request determined, through a review of chemistry records and chemistry control procedures, that the plant chemistry was within the bounds of the standards of [2] and that the stress corrosion cracking conclusion reached in [2] also applies to the Palo Verde Unit 3 RCP suction safe end. Provided below is an excerpt from the Palo Verde relief request for the hot leg nozzle and the NRC SE [14], which is still applicable for the RCP suction safe end region.

NRC Requirement 1

Conduct appropriate plant chemistry reviews and demonstrate that a sufficient level of hydrogen overpressure has been implemented for the RCS, and that the contaminant concentrations in the reactor coolant have been typically maintained at levels below 10 part per billion (ppb) for dissolved oxygen, 150 ppb for halide ions, and 150 ppb for sulfate ions.

APS Response

A review of plant chemistry records show that the halide /sulfate concentration levels have been maintained below 150 ppb for chloride, fluoride, and sulfate over the two operating cycles prior to the repair. Oxygen levels are maintained below 10 ppb during power operation and below 100 ppb during plant startups (RCS temperature >250°F). There is no oxygen limit when the RCS temperature is below 250°F.

An RCS hydrogen overpressure of > 15 cc/kg is established prior to criticality (hard hold point) and is maintained in a range of 25 to 50 cc/kg in Modes 1 and 2. In Modes 1 and 2, RCS hydrogen is a Control Parameter with Action Level 1 outside the range of 25 - 50 cc/kg, an Action Level 2, less than 15 cc/kg, and an Action Level 3 less than 5 cc/kg. Chemistry administrative control procedures do not allow critical reactor operation with the RCS hydrogen concentration less than 15 cc/kg without immediate corrective action. The nominal operating band for RCS hydrogen is 25 to 50 cc/kg.

Thus the conclusion reached in the Westinghouse TR with respect to stress corrosion cracking, applies to PVNGS.

The plant chemistry is expected to be within the standards of [2] for the next fuel cycle; therefore, the conclusion reached in [2] would apply to Palo Verde Unit 3 for that period.

6.0 Listing of Computer Codes Used and Runs Made In Calculation

Microsoft Excel®[1] is used in this calculation to calculate the SIFs to determine the allowable pressure-temperature limit curves. Excel is considered to be a "general utility program" per Westinghouse Policy/Procedure WEC 3.6.5, "External Computer Software," Section 7.6 (Reference 17).

Table 6-1
Summary of Computer Codes Used in Calculation

Code No.	Code Name	Code Ver.	Configuration Control Reference	Basis (or reference) that supports use of code in current calculation
1	MS Excel	N/A	See note above	See note above

[1] Microsoft Excel is the registered trademark of Microsoft Corporation in the United States and/or other countries.

Table 6-2
Electronically Attached File Listing

Run No.	Table 6-1 Code No.	Computer Run Description	Machine Name Run Date/Time	File Type	EDMS File Name or File Location
N/A	N/A	N/A	N/A	N/A	N/A

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[ ] a,c

Computer Code Checklist 6-1

(Completed By Author)

No.	Self Review Topic	Yes	No	N/A
1	Are macros, scripts, calculational worksheets, or single-application programs used in the analysis?		X	
2	Have the requirements in WEC 3.6.1 and WEC 3.6.6, if applicable, for the documentation and qualification of the macros, scripts, calculational worksheets, or single-application computer programs been met?			X
3	Has the range of use for the macros, scripts, calculational worksheets, or single-application programs been verified and documented in the calculation note?			X
4	Have all macros, scripts, calculational worksheets, or single-application program limitations been identified and documented within the calculation note?			X
5	In the case of finite element analysis models, scripts and macros: Are there any commands or element type limitations identified that apply to this analysis?			X
6	In the case of finite element analysis models, scripts and macros: Have macros (e.g., ANSYS APDL) used in the analysis, been documented in accordance with WEC 3.6.1 and WEC 3.6.6?			X

Appendix A: Supporting Documentation

A.1 Palo Verde Unit 3 Operating Mode History (Reference 16)

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Cycle	Date Begin	Date End	Mode of Operation (Days)			Total Days
			Normal	Startup	Shutdown	

Cycle	Date Begin	Date End	Mode of Operation (Days)			Total Days
			Normal	Startup	Shutdown	
		Total Days				

a,c

a,c

Appendix B: Comparison of RCS Piping Transients

This appendix contains the plots of the hot and cold leg RCS piping transients from [7]. For all transients, the RCS pressure is identical for the hot and cold leg piping. Therefore, only the differences in transient temperature profiles need to be considered. The transient list is shown in Figure B-1. The thermal transients are compared by evaluating the maximum temperature difference and the rate of change of the temperatures for the hot and cold leg temperatures. The comparison of these values is shown in Table B-1. As can be seen in Table B-1 and Figure B-2 through Figure B-7, all transients are bounded except for the faulted Loss of Secondary Pressure Transient.

Table B-1: Comparison of Transient Temperatures(1, 2)

Transient	**ΔT_{hot} (°F)**	**$\delta T_{hot}/\delta t$ (°F/minute)**	**ΔT_{cold} (°F)**	**$\delta T_{cold}/\delta t$ (°F/minute)**		**Disposition**
Heatup					a,c	bounded
Cooldown						bounded
Loading						bounded
Unloading						bounded
Step Increase Step Decrease Plant Variation						no difference
Reactor Trip Loss of Flow Loss of Load						bounded
Loss of Secondary Pressure						**not bounded**
Plant Leak Test						no difference

Notes:
1) ΔT = maximum difference in temperature for the hot or cold leg temperature
2) $\delta T/\delta t$ = maximum rate of change for the hot or cold leg temperature

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Calculation Note Number	Revision	Page
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Checklist A: Proprietary Class Statement Checklist

Directions (this section is to be completed by authors): Authors are to determine the appropriate proprietary classification of their document. Start with the Westinghouse Proprietary Class 1 category and review for applicability, proceeding to Westinghouse Proprietary Class 2 – Non-Releasable and finally to Westinghouse Proprietary Class 2 – Releasable. The proprietary classification is established when the first criterion is satisfied.

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☐ If the document contains highly sensitive information such as commercial documents, pricing information, legal privilege, strategic documents, including business strategic and financial plans and certain documents of the utmost strategic importance, it is Proprietary Class 1. Check the box to the left and see Appendix B of Procedure 1.0 in WCAP-7211, Revision 5, for guidance on the use of Form 36 and the distribution of this document. This document can be found at:

http://george.westinghousenuclear.com/work/polproc/Documents/E3_WCAP-7211.pdf

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Review the questions below for applicability to this calculation, checking the box to the left of each question that is applicable. If one or more boxes are checked, the calculation is considered a Westinghouse Proprietary Class 2 – Non-Releasable document. See Appendix B of Procedure 1.0 in WCAP-7211, Revision 5, for guidance on the use of Form 36 and the distribution of this document.

☐ Does the document contain one or more of the following: detailed manufacturing information or technology, computer source codes, design manuals, priced procurement documents or design reviews?

☐ Does the document contain sufficient detail of explanation of computer codes to allow their recreation?

☐ Does the document contain special methodology or calculation techniques developed by or for Westinghouse using a knowledge base that is not available in the open literature?

☐ Does the document contain any cost information or commercially or legally sensitive data?

☐ Does the document contain negotiating strategy or commercial position justification?

☐ Does the document contain Westinghouse management business direction or commercial strategic directions?

☐ Does the document contain third party proprietary information?

☐ Does the document contain information that supports Westinghouse patented technologies, including specialized test data?

☐ Does the document contain patentable ideas for which patent protection may be desirable?

Westinghouse Proprietary Class 2 – Releasable

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Checklist B: Calculation Note Methodology Checklist

(Completed By Author)

No.	Self Review Topic	Yes	No	N/A
1	Was the latest version of the calculation note template used?	X		
2	Is all information in the cover page header block provided appropriately?	X		
3	Are all the pages sequentially numbered, and are the calculation note number, revision number, and appropriate proprietary classification listed on each page? Are the page numbers in the Table of Contents provided and correct?	X		
4	Does this calculation note fulfill the customer requirements?	X		
5	Is the Summary of Results and Conclusions provided in Section 2.0 consistent with the purpose stated in Section 1.0 and calculations contained in Section 5.0?	X		
6	Is sufficient information provided for all References in Section 3.0 to facilitate their retrieval (e.g., from EDMS, SAP, CAPs, NRC's ADAMS system, open literature, etc.), or has a copy been provided in Appendix A?	X		
7	Are Section 4.2 and the open items box on the calculation note cover sheet consistent and, are all open items documented in Section 4.2 tracked in an open items database and include an estimated scheduled date for closure?	X		
8	Are all computer outputs documented in Table 6-2 and consistent with Table 6-1?	X		
9	Are all computer codes used under Configuration Control and released for use?	X		
10	Are the computer codes used applicable for modeling the physical and/or computational problem contained in this calculation note?			X
11	Have the latest and/or most appropriate versions of all computer codes been used?	X		
12	Have all open computer code errors identified in Software Error Reports been addressed?	X		
13	Are the units of measure clearly identified?	X		
14	Are approved design control practices (e.g., Level 3 procedures, guidebooks, etc.) followed without exception?	X		
15	Are all hand-annotated changes to the calculation note initialed and dated by author and verifier? Has a single line been drawn through any changes with the original information remaining legible?			X
16	Was a Pre-Job Brief held prior to beginning the analysis?	X		
17	Was a Self Check performed prior to submitting the analysis for Peer Checks and/or final verification?	X		
18	Was a Peer Check performed to review inputs documented in Section 4.6 prior to performing analyses?	X		
19	Was a Peer Check performed to review results before documenting them in Section 5.0?	X		
20	If required, have computer files been transferred to archive storage? Provide page number for list of files if not included in Table 6-2. Page			X
21	If applicable, have the results of any previous assessments on the analysis of record been incorporated in this calculation note?	X		
22	If this calculation note requires a change to a safety analysis database (e.g., SAIK), has the change been submitted such that the database will be updated?			X
23	If this calculation note used FEA methods, were the guidelines discussed in WCAP-16904-P used?			X
24	Has an editorial review been performed on this calculation note?	X		
25	Are all trademark symbols and the trademark attribution statement correctly identified in the calculation note?	X		

Checklist C: Verification Method Checklist

(Completed By Verifier(s))

Verification Method (One or more must be completed by each verifier)		**Initial If Performed**
1	Independent review of document. (Briefly explain method of review below or attach.)	AU, JDW
2	Verification performed by alternative calculations as indicated below.[(1)]	
	a. Comparison to a sufficient number of simplified calculations which give persuasive support to the original analysis.	
	b. Comparison to an analysis by an alternate verified method.	
	c. Comparison to a similar verified design or calculation.	
	d. Comparison to test results.	
	e. Comparison to measured and documented plant data for a comparable design.	
	f. Comparison to published data and correlations confirmed by experience in the industry.	
3	Completed Group-Specific Verification Checklist. (Optional, attach if used.)	
4	Other (Describe)	

(1) For independent verification accomplished by comparisons with results of one or more alternate calculations or processes, the comparison should be referenced, shown below, or attached to the checklist.

Verification: The verifier's signature (or Electronic Approval) on the cover sheet indicates that all comments or necessary corrections identified during the review of this document have been incorporated as required and that this document has been verified using the method(s) described above. For multiple verifiers, appropriate methods are indicated by initials. If necessary, technical comments and responses (if required) have been made on the "Additional Verifier's Comments" page.

Additional Details of Verifier's Review

Verified that the background and purpose, summary of results and conclusions, references, limits of applicability, open items, calculation methods, assumptions, acceptance criteria, inputs, evaluations, and analysis results are clearly stated, appropriate and reasonable (AU, JDW).

Checklist D: 3-Pass Verification Methodology Checklist

(Completed by Verifier(s))

No.	3-Pass Verification Review Topic	Yes	No	N/A
	First Pass			
1	Were the general theme, scope of document, and scope of review clear?	X		
	Second Pass			
2	Do the references appear to be documented correctly? Is there enough information present to ensure the referenced document is retrievable?	X		
3	Do the acceptance criteria seem appropriate?	X		
4	Does the technical content of the calculation note make sense from a qualitative standpoint and are appropriate methods used?	X		
	Third Pass			
5	Do the results and conclusions meet the acceptance criteria? Do the results and conclusions make sense and support the purpose of the calculation note?	X		
6	Has the technical content of the document been verified in adequate detail? Examples of technical content include inputs, models, techniques, output, hand calculations, results, tables, plots, units of measure, etc.	X		
7	Does the calculation note provide sufficient detail in a concise manner? Note that sufficient detail is enough information such that a qualified person could understand the analysis and replicate the results without consultation with the author.	X		
8	Is the calculation note acceptable with respect to spelling, punctuation, and grammar?	X		
9	Are the references accurate? Do the references to other documents point to the latest revision? If not, are the reasons documented? Are the references retrievable?	X		
10	Are computer code names spelled correctly? If applicable, are numerals included in the official code name as appropriate?	X		
11	Has the calculation note been read word-for-word, cover-to-cover?	X		
12	Have all differences between the documented and the verifier-calculated results been resolved, justified if applicable, and documented?	X		

If 'NO' to any of the above, provide page number of justification or provide additional explanation here or on subsequent pages.

Additional Verifier's Comments

The signatures of the Author(s) and Verifier(s) on the cover page (or Electronic Approval) indicate acceptance of the comments and responses.

No.	Verifier's Comments	Author's Response (If Required)
	None (AU, JDW)	None Required (NLG, MTC)