Enclosure
Relief Request 52 Proposed Alternative in Accordance with 10 CFR 50.55a(a)(3)(i)

ATTACHMENT 6

Natural Frequency and Structural Integrity Analysis

AREVA

CALCULATION SUMMARY SHEET (CSS)

Document No. 32 - 9220624 - 000 Safety Related: ☒Yes ☐ No

Title Natural Frequency and Structural Integrity Analysis for PVNGS3 RV BMI Nozzle Repair (Non-Proprietary)

PURPOSE AND SUMMARY OF RESULTS:

AREVA Inc. Proprietary information in the document is indicated by pairs of braces " [ ]."

Purpose

The purpose of this analysis is to find the natural frequency and analyze the structural integrity of the Palo Verde Nuclear Generating Station, Unit 3 (PVNGS3) Reactor Vessel Bottom Mounted Instrumentation (BMI) Remnant Nozzle after repair.

Summary of Results

As presented in Section 6.2, the remnant nozzle's natural frequencies are compared with the vortex shedding and other primary excitations on nozzle #3. There is no potential of excitation of the nozzle with the vortex shedding, nor with other dynamic loads analyzed herein.

As discussed in Section 6.3, the Limit Load Analysis per NB-3228.1 as performed through the finite element analysis with ANSYS indicates that the lower bound collapse has not been reached even with a factor of 2 being applied to the internal pressure and all primary nozzle loads. It is concluded that the remnant nozzle and the weld with a flawed region as analyzed herein retains its structural integrity through the plant normal operation.

This is the non-proprietary version of 32-9216967-001.

The total number of pages in this calculation is 33. This includes pages 1-26 and Appendix A (A-1 to A-7).

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT:

CODE/VERSION/REV	CODE/VERSION/REV
ANSYS 14.5.7/Windows 7 x64	
ANSYS 14.0 (See Section 5.1.2)	

THE DOCUMENT CONTAINS ASSUMPTIONS THAT SHALL BE VERIFIED PRIOR TO USE

☐Yes
☒ No

Enclosure Attachment 6

Review Method: ☒ Design Review (Detailed Check)

☐ Alternate Calculation

Signature Block

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Record of Revision

Revision No.	Pages/Sections/Paragraphs Changed	Brief Description / Change Authorization
000	All	Initial Issue

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1.0 PURPOSE

An inspection of Alloy 600 Bottom Mounted Instrument (BMI) nozzles in 2013 identified potential coolant leakage between the interface of the RVBH (reactor vessel bottom head) penetration #3 and the BMI nozzle at Palo Verde Nuclear Station Unit 3 (PVNS3). Although a half-nozzle repair performed on nozzle #3 moved the primary pressure boundary from the original J-groove partial penetration weld at the inner surface of the vessel to a new J-groove partial penetration weld at an outer surface weld pad, there remains a concern that cracks in the remnant nozzle may propagate over the remaining life of the plant .

The remaining function of the remnant nozzle consists of two parts:

1. Provide a path for the incore instrumentation cable.
2. Maintain structural integrity so as to limit the size of a DBA break under a hypothetical failure of the J-groove weld on the new external pad pressure boundary. That is, the size of the break opening would remain the same as that of the attached [ ] ID tubing, which is the same as the current design of the other internal welded BMI nozzles that use the anti-ejection feature.

These design functions are accomplished by demonstrating structural stability of the remnant nozzle and weld joint. The effect of the cracks in the nozzle and degraded weld on the structural stability of the remnant nozzle are conservatively evaluated to calculate the potential reduction in stiffness and its corresponding natural frequency to ensure that a resonant condition does not exist when subjected to the flow induced vibratory loads of the RCS system.

AREVA Document 51-9220420 (latest revision) provides a road map of the AREVA analyses for the Palo Verde BMI Nozzle.

The purpose of this calculation is to determine the natural frequency of the remnant nozzle and evaluate its structural integrity, considering any circumferential extension of the lack of fusion zone and flawed material due to crack growth. The natural frequency will be compared to the excitation of primary dynamic loads to determine if resonance may occur. The structural integrity of the nozzle will be determined by demonstrating there is no collapse mechanism formed by loads as high as 1.5 times maximum primary loads using ASME Code Limit Analysis (Reference [1]) as a guide. Although the remnant nozzle is no longer considered to be a primary pressure boundary component, it is convenient to use ASME Code Section III as a guideline for determining the structural integrity of the nozzle. Primary loads imposed on the remnant nozzle at penetration #3 that need to be addressed include deadweight, pressure, seismic, pump excitation, white noise excitation, and hydraulic flow.

2.0 ANALYTICAL METHODOLOGY

The general methodology of model development and analysis consists of:

1) Use the three-dimensional model developed for the Section III analysis (Reference [2]) and modify to include the lack of fusion between the weld and remnant nozzle due to the cracking found. The cracks identified in BMI nozzle 3 were contained within a circumferential arc of approximately [ ] (See Appendix A), centered approximately at the uphill side of the nozzle. This circumferential region of cracking will be assumed to exhibit a complete loss of fusion between the nozzle and remnant J-groove weld over the full axial depth of the weld. The model is also conservatively considered to have a complete loss of material in the flawed zone within a window of the size [ ] by [ ] (see Section 4.1 and Appendix A for details). It will also consider corrosion between the BMI remnant nozzle #3 and the RVBH.
2) The natural frequencies of the remnant nozzle will be calculated using the finite element model developed to reflect the loss of fusion at the interface between the nozzle and J-groove weld. This

frequency will be compared to the vortex shedding frequency and the excitation of other primary dynamic loads.

3) Use primary loadings on the BMI nozzle #3 including deadweight, pressure, seismic, pump excitation, white noise excitation, and hydraulic flow and apply to the finite element model as developed in the Section III analysis. These will be modified as necessary based on the frequency found in Step 2.

4) Run a limit load analysis to obtain the total strains for the nozzle and J-groove weld material. Ensure no collapse mechanism forms at the nozzle to weld junction for loadings up to 1.5 times the maximum primary loads.

3.0 ASSUMPTIONS

3.1 Unverified Assumptions

There are no unverified assumptions within this calculation.

3.2 Justified Assumptions

This circumferential region of cracking is conservatively assumed to exhibit a complete loss of fusion between the nozzle and remnant J-groove weld over the full axial depth of the weld over the flawed region identified in Reference [3].

3.3 Modeling Simplifications

One boat sample is included in the finite element model. The boat excavation will be modeled at the plane of symmetry on the uphill side (i.e., most critical location). This modeling simplification allows a 180 degree finite element model in lieu of 360 degrees.

To account for the flaws in the remnant nozzle a "window" is cut in the nozzle with the size calculated in Appendix A. This window bounds the flawed area in the remnant nozzle and the area where there is loss of fusion between the nozzle and remnant J-groove weld. It is conservative to consider the loss of material for the flawed region while in reality there is only a loss of rigidity due to crack propagation.

4.0 DESIGN INPUT

4.1 Dimensions

Major nominal dimensions are the same as Reference [2] and are summarized below:

RVBH inside radius to base metal = [ ]

RVBH base metal thickness (min.) = [ ]

Cladding Thickness = [ ]

Buttering Thickness = [ ]

BMI Remnant Nozzle OD at weld = [ ]

BMI Remnant Nozzle ID at weld = [ ]

BMI Repair Nozzle OD = [ ]

BMI Repair Nozzle ID = [ ]

Weld Pad Height = [ ]

The cracks identified in BMI nozzle 3 were contained within a circumferential arc of approximately [ ] (See Appendix A based on Reference [3] and calculation in Section 6.1), centered approximately at the uphill side of the nozzle. This circumferential region of cracking is assumed to exhibit a complete loss of fusion between the nozzle and remnant J-groove weld over the full axial depth of the weld.

The window cut out to simulate the portion of nozzle having flawed material starts at [ ] above the horizontal datum (where the nozzle ID tapers to [ ]), and the bottom of the window is [ ]. It has a total height of [ ] and is [ ] wide circumferentially. See Appendix A for dimension details.

4.2 Materials

Material designations are listed in Section 6.0 of Reference [4]. For existing materials, material properties to be used in the finite element analysis are taken from Reference [5]. For replacement materials, material properties are taken from Reference [6]. Material properties for each component are tabulated in Reference [2].

RVBH	[ ]	Existing
BMI Remnant Nozzle	[ ]	Existing
Cladding	[ ]	Existing (non-structural)
Buttering	[ ]	Existing, use [ ]
J-Groove Weld	[ ]	Existing, use [ ]
Repair Weld Filler	[ ]	Replacement, use [ ]
Replacement Half Nozzle	[ ]	Replacement

4.3 Primary Loads for Structural Integrity Analysis (Section 6.3)

4.3.1 Internal Pressure

Per Reference [4], the design temperature and pressure are [ ] and [ ], respectively. The design pressure is used as the maximum normal operating pressure.

Since secondary stress due to thermal is self-relieving and not considered part of the analysis a uniform temperature of [ ] (Tunif=Tref in ANSYS, no differential thermal growth) is applied throughout the model and a uniform pressure of [ ] (conservative) on all surfaces in contact with the primary coolant. These surfaces include the RVBH interior, the original J-groove weld, the head bore, the weld pad bore, the remaining and replacement BMI nozzle inside diameter and the remaining and replacement BMI nozzle outside diameter which is inside the head bore. In addition, the bottom end of the replacement BMI nozzle also has the pressure applied to represent the hydrostatic end cap pressure.

4.3.2 Remnant Nozzle Loadings

Per Reference [7] the remnant nozzle inside the vessel experiences the following external loads, which described on Pages A-582 to A-585 of Reference [7]:

Fluid Flow Pressure (HF)
Pump Periodic Excitation (PPE)
Seismic Accelerations (SSE)
Mechanical White Noise Excitation (WN)

The nozzle loadings used in Reference [2] based on References [7] and [8] are reviewed for resonance based on the natural frequency found and are used or updated as necessary. Since the nozzle loads are reversible, they will all be applied in the same direction at the same time. Two cases will be considered, one in the positive x direction and one in the negative x direction. See Figure 6-2 for the coordinates.

5.0 COMPUTER SOFTWARE

All computer files generated for this analysis and the Installation Test files have been uploaded to AREVA ColdStor found in the following directory: "\cold\General-Access\32\32-9000000\32-9216967-000\official". All files are listed in Table 5-1.

5.1 Software

5.1.1 Main Body Computer Software

ANSYS Release 14.5.7 (Reference [9]) is used in this calculation. Verification tests are listed as follows:

- Computer programs tested: ANSYS Release 14.5.7.
- Verification Tests: VM246 for SOLID186 and SOLID187 elements.
- Computer hardware used: DELL Precision (Service Tag# 5VM76S1, computer name "KBARNES3") with Windows 7 Enterprise Service Pack 1, 64 bit Operating System with 8 GB of RAM available.
- Name of person running the tests: Kristine Barnes.
- Date of tests: 2/7/2014.

5.1.2 Appendix A Computer Software

ANSYS Release 14.0 (Reference [10]) is used in this calculation. The software was used for determining the size and position of the flaws in the welds and it is acceptable to use the earlier version. Verification tests are listed as follows:

- Computer programs tested: ANSYS Release 14.0.
- Verification Tests: VM111 for the PLANE55 element (element type is arbitrary for the purpose of Appendix A).
- Computer hardware used: DELL Precision (Service Tag# 5VN36S1, computer name "DKILLIAN4") with Windows 7 Enterprise Service Pack 1, 64 bit Operating System with 8 GB of RAM available.
- Name of person running the tests: Doug Killian.
- Date of tests: 2/11/2014.

5.2 Computer Files

The following table lists the computer files associated with the natural frequency and structural integrity of the PV3 RV BMI Nozzle Repair.

Table 5-1: Computer Files

File Name	Date	Description
Geometry		
Geom_cut.dat	01/14/2014	FEM nodes/elements written from ANSYS Workbench for frequency and structural analysis.
Geom_cut_Modal.out	01/16/2014	Output creating model .db file for frequency analysis (Section 6.2).
Geom_cut_Str.out	01/16/2014	Output creating model .db file for structural integrity analysis (Section 6.3).

File Name	Date	Description
Boundary Conditions/Materials		
matDef_modal.mac	01/16/2014	Material definitions for frequency analysis (read by Geom_cut_Modal, Section 6.2).
matDef_LL.mac	01/31/2014	Material definitions for structural integrity analysis (read by Geom_cut_str, Section 6.3).
bc_st_symm.mac	01/14/2014	Structural boundary conditions written from ANSYS Workbench (read by each analysis).
Natural Frequency Analysis (Section 6.2)		
Modal_Cut.out	01/16/2014	Output documenting modal natural frequency analysis. Reads database from Geom_cut_Modal.
Structural Integrity Analysis (Section 6.3)		
Load_Limit_SSEPos.out	03/06/2014	Output documenting the structural analysis with loads for the structural integrity determination. Reads database from Geom_cut_Str.
Load_Limit_SSEPos_Post.out	03/06/2014	Post Processing for Load_Limit_SSEPos.out
Load_Limit_SSENeg.out	03/06/2014	Output documenting the structural analysis with loads for the structural integrity determination. Reads database from Geom_cut_Str.
Load_Limit_SSENeg_Post.out	03/06/2014	Post Processing for Load_Limit_SSENeg.out
LC1_SSENeg_Post.dat	03/06/2014	Stress and Strain Results from the Load Limit Analyses.
LC1_SSEPos_Post.dat	03/06/2014	
LC2_SSENeg_Post.dat	03/06/2014	
LC2_SSEPos_Post.dat	03/06/2014	
LC3_SSENeg_Post.dat	03/06/2014	
LC3_SSEPos_Post.dat	03/06/2014	
LC4_SSENeg_Post.dat	03/06/2014	
LC4_SSEPos_Post.dat	03/06/2014	
LC5_SSENeg_Post.dat	03/06/2014	
LC5_SSEPos_Post.dat	03/06/2014	
Appendix A		
Flaws.out	03/04/2014	Draws lines between the end points of each flaw indication and then extends the skewed flaws until they intersect the extended axial flaws.
Flaws.output	03/04/2014	
Flaw Indications.xlsx	01/29/2014	Determines the size and position of the cracked region from Flaws.output.
Verification Files		
VM246.out	02/07/2014	Verification run for SOLID186 and SOLID187 elements.
vm111.vrt	02/11/2014	Verification run for PLANE 55 used in Appendix A.

6.0 CALCULATIONS

6.1 Model

The 3-D solid model simulates a [ ] section of BMI Nozzle #3 and a portion of the adjacent Reactor Vessel Bottom Head. The model is similar to the model used in Reference [2], with the major difference being the window cut out to account for the actual cracks on the nozzle and weld.

The window is located [ ] above the horizontal datum (where the nozzle ID tapers to [ ]) and the bottom of the window is [ ] as shown in Figure 6-1. It has a total height of [ ] and is [ ] wide circumferentially (see Appendix A).

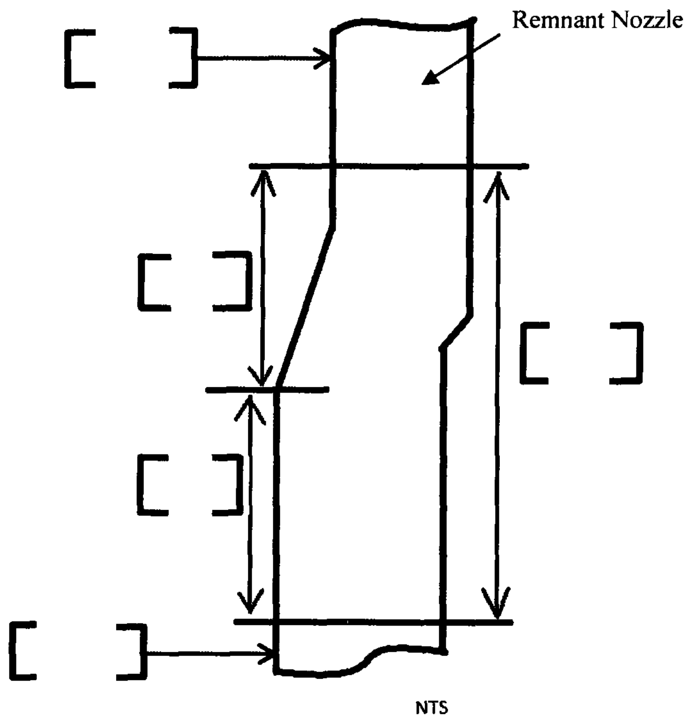

Figure 6-1: Window Location

For modeling the cutout in a half model, half of the total circumferential width is considered [ ] [ ] due to symmetry). With an OD of [ ] , the total circumference of the remnant nozzle is:

[ ]

The angle of the window for the half model is:

[ ]

Therefore, the window will be modeled for a [ ] portion of the nozzle. This is in the same location that the existing weld is unfused from the nozzle and bounds the flawed weld locations.

No contact elements are included in the model to account for the corrosion between the pipe and the RVBH. The corrosion rate was found to be [ ] over [ ] of operation (Reference [11]). The maximum displacement for the entire nozzle at design loadings is [ ] (LC1_SSENeg_Post.dat, See Section 6.3). Therefore, the remnant nozzle will not interact with the RVBH head.

The model geometry is built with ANSYS Workbench [9] and is shown in Figure 6-2. The model is meshed within the ANSYS Workbench environment. The meshed FEA model is shown in Figure 6-3. The meshed Workbench model is written to Geom_cut.dat which is used to create the two models for the frequency and structural analysis (Geom_cut_Modal.out and Geom_cut_Str.out).

[ ]

Figure 6-2: 3-D Solid Model Geometry with Window

[ ]

Figure 6-3: Meshed FEA Model

6.1.1 Structural Boundary Conditions

Symmetric boundary conditions are applied to the nodes that lie on the plane of symmetry of the model via ANSYS file bc_st_symm.mac. These symmetric boundary conditions allow in-plane displacements (i.e., radial growth) while restricting all out-of-plane displacements.

6.1.2 Primary Load Application for Structural Integrity Analysis

Inside surfaces which are in contact with the fluid are loaded with the appropriate internal pressure. These surfaces include: RVBH interior, remnant nozzle OD and top surface within the vessel, remnant nozzle and replacement nozzle ID, remnant nozzle and replacement nozzle within the head bore, RVBH bore, and cut ends of remnant and replacement nozzle within the bore. In addition, an end-cap pressure is applied to the external end of the repair nozzle to simulate the hydrostatic pressure which is present in the full system. The exterior of the RVBH and repair nozzle are not loaded by pressure.

EndCapPress= Pressure x $(\text{Inside Radius})^2 / ((\text{Outside Radius})^2 - (\text{Inside Radius})^2)$

The remnant nozzle loads are applied as a concentrated load at the mid-height of the nozzle. Since the model only includes 180 degrees of the nozzle and weld, the loads are divided by 2 when applied. For the Pump Periodic Excitation (PPE) and White Noise Excitation (WN), the resultant of the force calculated in Reference [2] is used:

[ ]

The seismic loads are also calculated based on a resultant force in the horizontal direction in Reference [2]:

[ ]

The Fluid Flow Pressure or Hydrolic Flow Load (HF) is a single load in the horizontal direction and does not need to use a resultant of two directions: [ ] as calculated in Reference [2].

6.2 Natural Frequency Analysis

The bottom mounted nozzles are subjected to hydraulic loads as the reactor coolant emerges from the downcomer region and turns to flow through the fuel assemblies. Of particular concern are cross flows that could potentially excite vortex shedding vibration modes or pump excitation modes for the remnant nozzle. The natural frequencies of the remnant nozzle must be calculated to ensure no resonance with the vortex shedding or excitation of other dynamic loads.

To perform the frequency analysis, the material for the nozzle was modified to account for the water mass in the nozzle and displaced by the nozzle as done previously in Reference [7]. In Reference [7] on pg. A-524, the volumes of the solid nozzle and void space are calculated for nozzle #1. The nozzle is similar in size to nozzle #3, and it is acceptable to use the volumes calculated previously to find the necessary increase in material density to account for water mass. The window cut out is not considered in the following density calculation since it is a fictitious window and the material is still present in reality.

Per Reference [7], the solid volume is [ ] and the void volume is [ ]. Therefore, the total volume of water that must be accounted for is:

[ ]

Therefore the weight of water is (water density = [0.0266 lb/in^3], Reference [7]):

[ ]

The total weight of steel is (steel density = [0.304 lb/in^3], Reference [7]):

[ ]

Therefore, the increase in weight is:

[ ]

When the cut model is run with a factor of 1.111 for the nozzle density, the modal analysis produces the first few frequencies as registered in the output file "Modal_Cut.out." The lowest frequency is found to be:

[ ] with [ ] mass participation in the [ ], first mode shown in Figure 6-4.

The next lowest frequency of [ ] does not demonstrate participation from the nozzle. The next mode that shows participation from the nozzle is the 3rd mode with a frequency of [ ].

Figure 6-4: Remnant Nozzle First Mode

6.2.1 Remnant Nozzle Load Evaluation

Based on the new natural frequency, each remnant nozzle load listed in Section 6.1.2 is evaluated to ensure there is no resonance:

Fluid Flow Pressure (HF): The vortex shedding frequency for nozzles #1-40 is [ ] (Reference [7], pg. A-527). This is much lower than the first natural frequency of nozzle #3, therefore, there will be no excitation of the nozzle due to the vortex sheading frequency.

Pump Periodic Excitation (PPE): The frequency is not close to either of the pump excitations at [ ] ([ ] separation either way). Therefore, the previous load used at [ ] (Reference [7]) is still acceptable.

Seismic Accelerations (SSE): The seismic accelerations used are peak values as calculated in Reference [2]. Therefore, the natural frequency has no effect on the load.

Mechanical White Noise Excitation (WN): The white noise band covers frequencies up to [ ]. Therefore, the natural frequency has no effect on the load.

6.3 Structural Integrity Analysis

Although the remnant nozzle is no longer considered to be a primary pressure boundary component, it is convenient to use ASME Code Section III (Reference [1]) as a guideline. As such the Limit Analysis detailed in Section NB-3228.1 is used as a guideline for determining if the remnant nozzle and J-groove weld will remain structurally intact during plant operation. Per Section NB-3228.1, the maximum loadings should not be greater than 2/3 of the lower bound collapse load. Thus, 1.5 times all primary loadings will be checked to ensure no collapse mechanism forms. Since the analysis is only concerned about the remnant nozzle becoming a loose part, and not concerned with maintaining an ASME pressure boundary, fatigue evaluation on the remnant nozzle is not performed herein. The crack growth evaluation of the remnant nozzle is performed in AREVA Document 32-9217241 (latest revision).

The material properties are updated for this model so that the materials are all elastic-perfectly plastic in matDef_LL.mac. The yield strength used is $1.5S_m$ as prescribed by NB-3228.1 of Reference [1].

Yield Stress for remnant nozzle ([ ]) is 23.3 ksi x 1.5 = 34.95 ksi Reference [5]

Yield Stress for the RVBH ([ ]) is 26.7 ksi x 1.5 = 40.05 ksi Reference [5]

Yield Stress for the cladding (non-structural, [ ]) is 16.7 ksi x 1.5 = 25.05 ksi Reference [5]

Yield Stress for the replacement nozzle and weld [ ] is 23.3 ksi x 1.5 = 34.95 ksi Reference [6]

For the limit analysis, the applied primary loads including deadweight, pressure ([ ]), seismic ([ ]), pump excitation ([ ]), white noise excitation ([ ]), and hydraulic flow ([ ]) are taken from Reference [2] and applied at mid-height of the remnant nozzle as a concentrated load. The loads are increased incrementally using a multiplier from 1 to 2 by an increment of 0.25 (numbered as Load Cases 1-5). Note that even with a factor of 2, ANSYS still provides a converged solution indicating the lower bound collapse loads have not been reached. The analysis is run for the two worst case scenarios: (1) all loads applied in the positive x-direction (Load_Limit_SSEPos.out) and (2) all loads applied in the negative x-direction (Load_Limit_SSENeg.out). The external loads along with the pressure ensure that all load combinations are bounded. See Figure 6-2 for the coordinates.

The limit analysis is documented in Load_Limit_SSEPos.out and Load_Limit_SSENeg.out. Stresses and strains are printed to files LC(x)_SSEPos_Post.out and LC(x)_SSENeg_Post.out where (x) is the load case number as.

Based on a yield strength of $1.5S_m$, the maximum elastic strain where [ ] for [ ] is:

[ ]

Anything above this is considered plastic. All plots are based on the SSENeg run as it was judged to be worst case. Figure 6-5 and Figure 6-6 show strain contours for the applied loads with a multiplier of 1.0, with gray areas indication strain above [ ] . Figure 6-9 shows stress contours for the applied loads with a multiplier of 1.0, where the maximum stress is 34.95 ksi as calculated above. Figure 6-7 and Figure 6-8 show strain contours for the applied loads with a multiplier of 1.5. Figure 6-10 shows stress contours for the applied loads with a multiplier of 1.5. For loads with a multiplier of 1.0, the plastic portions of the remnant nozzle are near the edge of the window and along the crevice where the remnant nozzle is attached to the J-groove weld with no collapse mechanism formed as shown in Figure 6-5 and Figure 6-6. The plastic portions expands through a majority of the nozzle and weld at a multiplier of 1.5, as shown in Figure 6-7 and Figure 6-8, however a collapse mechanism has still not formed completely through the nozzle and weld. Per NB-3228.1 (Reference [1]), the model should be run until collapse and the loadings should not exceed 2/3 of the collapse load. Since the model does not collapse at 1.5 times all primary loads as shown by ANSYS convergence, it is concluded that a sufficient portion of the remnant nozzle and J-groove weld remains stable up to 1.5 times all primary loads, the nozzle will remain structurally intact through normal operation.

[ ]

Figure 6-5: Strain Results at 1 x Primary Loads (Remnant Nozzle and Weld)

[ ]

Figure 6-6: Strain Results at 1 x Primary Loads (Remnant Nozzle Only)

[ ]

Figure 6-7: Strain Results at 1.5 x Primary Loads (Remnant Nozzle and Weld)

[ ]

Figure 6-8: Strain Results at 1.5 x Primary Loads (Remnant Nozzle Only)

[ ]

Figure 6-9: Stress Results at 1 x Primary Loads (Remnant Nozzle and Weld)

[

]

Figure 6-10: Stress Results at 1.5 x Primary Loads (Remnant Nozzle and Weld)

7.0 CONCLUSION

As found in Section 6.2, the remnant nozzle's lowest natural frequency is much higher than the vortex shedding frequency near nozzle #3. Excitation by other primary dynamic loads is also evaluated. There is no excitation of the nozzle due to the vortex sheading or other dynamic loads.

As discussed in Section 6.3, the Limit Load Analysis per NB-3228.1 as performed through the finite element analysis with ANSYS indicates that the lower bound collapse has not been reached even with a factor of 2 being applied to the internal pressure and all primary nozzle loads. It is concluded that the remnant nozzle with a flawed region as analyzed herein remains its structural integrity through the plant normal operation.

8.0 REFERENCES

References identified with an (*) are maintained within Palo Verde Nuclear Generating Station Records System and are not retrievable from AREVA Records Management. These are acceptable references per AREVA Administrative Procedure 0402-01, Attachment 8. See page 2 for Project Manager Approval of customer references.

1. ASME B&PV Code, Section III, "Rules for Construction of Nuclear Facility Components," Division 1, 1998 Edition, including Addenda through 2000.
2. AREVA Inc. Document 32-9215084-001, "ASME Section III End of Life Analysis of PVNGS3 RV BMI Nozzle Repair."
3. *Palo Verde Unit 3 U3R17, Reactor Vessel Bottom Mounted Instrumentation ID Examinations, Wesdyne Report WDI-PJF-1312161-FSR-001, Rev. 0, October 2013.
4. AREVA Inc. Design Specification 08-9212780-001, "Palo Verde Unit 3 Reactor Vessel Bottom Mounted Instrument Nozzle Modification."
5. ASME B&PV Code, Section III, "Nuclear Power Plant Components," Division 1, 1971 Edition including Addenda through Winter 1973.
6. ASME B&PV Code, Section II, Part D, Materials, "Properties," 1998 Edition, including Addenda through 2000.
7. *APS Report N001-0301-00214, Revision 7, "Reactor Vessel, Unit 3, Analytical Report, V-CE-30869, 30AU84."
8. *APS Specification MN742-A00179, Revision 4, "Project Specification for a Reactor Vessel Assembly for Arizona Nuclear Power Project Units 1, 2, and 3."
9. ANSYS and ANSYS Workbench, Release 14.5.7, ANSYS Inc., Canonsburg, Pa.
10. ANSYS, Release 14.0, ANSYS Inc., Canonsburg, Pa.
11. AREVA Inc. Document 51-9213061-001, "Corrosion Evaluation for Palo Verde Unit 3 Reactor Vessel Bottom Mounted Instrument Nozzle Modification."

APPENDIX A: NOZZLE CRACKED REGION

A.1 Purpose

Non-destructive examination (NDE) of the Palo Verde Unit 3 bottom mounted instrumentation (BMI) nozzle #3 by ultrasonic inspection (UT) revealed ten flaw indications in the nozzle in the vicinity of the partial penetration J-groove weld that attaches the nozzle to the reactor vessel bottom head. The purpose of this appendix is to define a rectangular window, or cutout, to represent a region of potentially degraded material due to future extension of cracks in the nozzle. This is used to evaluate the remaining structural integrity and natural frequency of the degraded nozzle.

A.2 Definition of Flaw Indications and Calculation of Nozzle Cutout

The NDE inspection report (Reference [3]) describes ten part-through wall flaw indications in BMI nozzle #3 located on the outside surface of the nozzle near the J-groove weld. Flaw indications 1 through 4 are oriented primarily in the axial direction (with respect to the nozzle) while flaw indications 5 through 10 are slightly skewed. It is postulated that over time the "axial" flaws and the skewed flaws will increase in depth and length until they link up to form a region of degraded material that will potentially affect the structural integrity of the nozzle. To account for this degraded region in the structural models, a volumetric section of the nozzle will be removed, or cutout, to form a window in the nozzle wall. Using data from the UT inspection report (Reference [3]) to define the initial flaw orientations, the size of the nozzle cutout and its location are calculated by extending the defined flaws indications until they intersect.

Table A-1 and Table A-2 are taken from the UT inspection report (Reference [3]). Table A-1 presents the inspection data for flaw indications 1 through 4 and Table A-2 provides similar data for flaw indications 5 through 10. Each flaw indication is defined by linear (L1/L2) and angular (ϕ1/ϕ2) positions of its two end points relative to horizontal and vertical datum lines. The vertical position of the weld at the location of the flaw indication is defined by the linear dimensions L3 and L4. The reference positions for these parameters are explained below, with the aid of Figure A-1.

Distance is measured in inches.

Angular position is measured in degrees.

Horizontal datum: [ ]

Azimuthal datum: [ ]

[ ]

[ ]

Figure A-1: Reference Positions for UT Inspection Data

The UT data in Table A-1 and Table A-2 are rearranged and processed in Table A-3 and Table A-4 to determine bounding flaw characteristics. This data is further processed by "rolling out" the outer surface geometry onto a flat plane to produce linear arc lengths (ArcLen1/ArcLen2) to the end positions of each flaw indication. These flaw indications are then extended upward and downward to determine where the skewed flaws intersect the axial flaws, using the ANSYS (Reference [10]) computer code as a graphical interpreter. The ANSYS input is echoed in the output file (Flaws.out) and creates the output file (Flaws.output). Both are included in the list of computer files that have been placed on the ColdStor server (see Section 5.2). The input file takes linear dimensions from Table A-3 and Table A-4 to draw lines between the end points of each flaw indication and then extends the skewed flaws until they intersect the extended axial flaws. The end points of the extended flaws, obtained from the ANSYS output file, are passed to the EXCEL spreadsheet "Flaw Indications.xlsx", where they are used to determine the size and position of the cracked region, as shown in Table A-4.

Table A-1: UT Data for Flaw Indications 1 through 4

[ ]

Table A-2: UT Data for Flaw Indications 5 through 10

[ ]

Table A-3: Calculation of Nozzle Cutout (1)

Table A-4: Calculation of Nozzle Cutout (2)

A.3 Summary of Nozzle Cutout

The nozzle cutout is defined pictorially in Figure A-2. From Table A-4, the overall size of the window is [ ] wide by [ ] high. The window starts at [ ] above the horizontal datum and stops at [ ] below the datum line.

[

]

Figure A-2: Nozzle Cracked Region