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U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
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South Texas Project
Unit 1
Docket No. STN 50-498
Summary of ASME Code Calculations Performed for
Repair of Bottom Mounted Instrumentation Penetrations

STP repaired two bottom mounted instrumentation (BMI) leaking penetrations with a "half-nozzle" design that relocated the pressure boundary to the outside of the reactor vessel. The repair is in accordance with the ASME Code as required by 10CFR50.55a.

To facilitate the NRC staff's review of the BMI repair, STPNOC is providing the attached summary of the ASME Code required analyses performed for the repair/replacement activity.

Please call me at (361) 972-7162 if you have any questions.

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Manager,
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Awh

Attachments:

1. BMI Guide Tube and BMI Nozzle Weld Analysis Summary
2. BMI Half Nozzle Repair/Replacement Stress Analysis Summary
3. BMI Nozzle Original J-Groove Weld Residual Stress Analysis Summary
4. BMI Nozzle Flow Induced Vibration Analysis Summary

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BMI Guide Tube and BMI Nozzle Weld Analysis Summary

ASME Stress and Fatigue Analysis
BMI GUIDE TUBE-TO-NOZZLE SOCKET WELD CONNECTION
Summary of Framatome Proprietary Calculation 32-5028839-00

Purpose

The half-nozzle repair of BMI penetrations #1 and #46 on the South Texas Project Unit 1 reactor pressure vessel included a new weld to connect the stainless steel guide tubes to the new half nozzle. The connection consists of a socket weld as shown on the attached figure. This document summarizes Framatome proprietary calculation 32-5028839-00, STP BMI Nozzle to Tube Connection Analysis and Qualification. Framatome performed the safety analysis of the weld connection in accordance with ASME Code Criteria of Section III, Article NB – 3220 (Stress Limits). The calculation demonstrates that the weld connection meets the ASME code requirements for design, test, and faulted conditions and for repetitive (fatigue) loading.

Scope

South Texas Project Unit 1 reactor vessel bottom head contains 58 BMI nozzles. The nozzles are aligned vertically and are located at various radial distances from the vertical centerline of the hemisphere. Based on the distance from the center of the hemispherical head, the length between the bottom head and the insulation varies. This distance has a significant effect on thermal and structural analysis.

Three BMI nozzle conditions were modeled and analyzed. Calculated models conservatively assume the worst location of the nozzle with respect to bottom head-to-insulation length. Verification of the BMI nozzle coupling necessitated the creation of 2D axi-symmetric finite element model and stress analyses of the BMI nozzle repair configurations. Although the repair configuration is only applicable to nozzles 1 and 46, the calculation performs bounding analysis to envelop other nozzles.

Methodology

The general methodology of model development and stress analysis consists of:

1. Building of two-dimensional model containing a portion of the BMI nozzle in the connection region. The model incorporates the geometry of the replacement BMI nozzle, the guide tube and new weld. Appropriate materials and boundary conditions were applied to the model. Two finite element models consist of thermal and structural elements, respectively, to support the thermal and structural analysis.

2. Applying the design pressure and temperature to the structural model and obtaining the deformation and stresses in the model.

3. Applying the thermal loads and run steady state thermal finite element analysis.

4. Applying the corresponding mechanical load (pressure) and thermal load (temperature distribution calculated in step 3) on the structural finite element model and run structural finite element analysis.

5. Perform ASME Code stress evaluation to demonstrate that failure does not occur due to application of design loads or due to repetitive loading.

The welded connection location with respect to the insulation varies depending on the nozzle radial location with respect to the center of the head. A socket weld located below the insulation (hypothetical case) will experience smaller thermal transients and minimum thermal stresses. A socket weld located between the insulation and the bottom head will experience larger thermal transients during heatup/cooldown cycles and correspondingly larger thermal stresses.

This calculation performs three analyses:

1. Nozzle with the weld closest to the insulation, but below the insulation (Model A).
2. Nozzle with the weld closest to the insulation, but above the insulation (Model B).
3. The furthest away nozzle: this connection is the closest to the head and is expected to have the highest temperature. (Model C)

Finite Element Model (FEM)

The FEM consists of 8279 nodes and 2544 elements. PLANE82 (2-D 8-node Structural Element) element was used in structural analysis. This element was converted to PLANE77 (2-D 8-node Thermal Element) for thermal analysis. The "mapped" meshing procedure was mostly applied to the model.

Thermal Loads

The possible nozzle configurations were enveloped by three models:

Analysis A:	The weld is below the insulation and very close to the insulation.
Analysis B:	The weld is above the insulation and very close to the insulation.
Analysis C:	The weld is above the insulation and very close to the head.

The thickness of insulation is neglected.

The surface of the BMI nozzle above the insulation exposed to ambient temperature was assumed completely insulated and a 0.0 BTU/hr-in^2-F heat transfer coefficient was applied from the bottom head to the insulation. A heat transfer coefficient of 0.0 BTU/hr-ft^2-F was applied on the inner surface of BMI nozzle assuming conservatively no flow condition inside the nozzle. The model, therefore, assumed only conduction heat transfer in the nozzle between the bottom head and the insulation. The outside surface of the BMI nozzle below the insulation is exposed to forced air convection; therefore 0.31 BTU/hr-in^2-F heat transfer coefficient was applied. The small gap between the BMI replacement nozzle ID and guide tube was modeled as "temperature coupling" representing the original configuration.

The nozzle is exposed to transient loads. These transient loads were approximated by 20,650 cycles with maximal applied pressure 2371 psia and temperature range from 120°F to 570.8°F. Temperatures of 120°F and 570.8°F were applied at the end of nozzle connected to RPVBH. Temperature of 70°F was applied on the bottom line of remaining pipe in FEM Model.

For Design Condition analysis a uniform temperature of 650°F was applied.

Mechanical Loads

The connection between BMI nozzle and remaining pipe was exposed to external loads caused by seismic accelerations and operating pressure. Operating pressure creates the Cap Load, which is also applied to the FEM model. The pressure was applied to inner surfaces of the nozzle and remaining pipe. The Cap Load was applied on the bottom line of remaining guide tube in FEM model.

Results

A fatigue cumulative usage factor (CUF) is calculated in accordance with NB-3200 is 0.35 for the fillet weld between the guide tube and the nozzle and the 0.07 for the guide tube. The CUF is negligible compared to the ASME Code allowable value of 1.0.

BMI Half Nozzle Repair/Replacement Stress Analysis Summary

ASME Stress and Fatigue Analysis
BMI HALF NOZZLE DESIGN
Summary of Framatome Proprietary Calculation 32-5028841-02

Purpose:

The BMI nozzle repair requires application of an Alloy 52 weld pad on the outside wall of the RVBH around the nozzle, removal of the nozzle to an elevation within the penetration, and replacement with a new Alloy 690 half nozzle. The new half nozzle is attached to the weld pad with a J-groove partial penetration weld using Alloy 52 weld filler metal.

This document summarizes the Framatome proprietary calculation 32-5028841-02, STP BMI Connection Analysis and Qualification. Framatome performed the safety analysis of the new BMI half nozzle design in accordance with ASME Code Criteria of Section III, Subsection NB, 1971 Edition, through Summer 1973 Addenda. The calculation demonstrates that the design meets the ASME code requirements for design and faulted conditions and for repetitive (fatigue) loading.

Scope:

The BMI nozzles are located at various radial distances from the vertical centerline of the RVBH hemisphere. Based on the distance from the center of the hemispherical head, the relative angle of the nozzle vertical centerline and the plane of the head curvature vary. This angle is referred to herein as the "hillside angle". Experience has shown that the larger the hillside angle, the more severe the stress level. In addition, subparagraph NB-3338.2 discusses the use of stress index method for pressure stresses in openings and NB-3338.2 (d)(1) magnifies the stress index resulting in higher stresses for obliquely increasing openings. Therefore, the model herein represents the largest hillside angle of any of the BMI housing nozzle locations (the outermost nozzle).

Methodology:

1. Building a three-dimensional model of a portion of the RV Bottom Head containing the outermost BMI nozzle. The model incorporates the geometry of the head, penetration, remnant of the original nozzle, replacement nozzle, weld & buttering and weld pad & weld pad J-groove, appropriate materials, and boundary conditions. The 3-D solid model is converted into a 3-D finite element model by 'meshing' the solid model into small elements. There are two finite element models consisting of thermal and structural elements respectively so as to perform the thermal and structural analyses.

2. Applying STP design conditions of pressure and temperature to the structural finite element model and obtaining the deformation and stresses in the model. The deformation field is used to verify the correct behavior of the model and correct modeling of boundary and load conditions.

3. Applying the thermal loads resulting from the plant operating transients (in the form of transient temperatures and corresponding heat transfer coefficients versus time). Each of the major power transients requires a separate run on the thermal finite element model.

4. Evaluating the results of the thermal analysis by examining the magnitude of temperature differences between key locations of the model at corresponding times (for example between nozzle and head). The time points of the maximum temperature gradient are the time points at which the maximum thermal stresses develop.

5. Applying the corresponding mechanical (pressure) and thermal loads (temperature gradients) at each significant time point.

6. Performing the ASME Code stress evaluation, which includes assurance that failure does not occur due to application of design loads and assurance that failure does not occur due to repetitive loading.

7. Documenting stresses for the original J-groove weld for Fracture Mechanics Analysis (FMA) use.

Boundary Conditions:

The model simulates, in three-dimensional space, a 180-degree section of the outermost BMI nozzle and part of the adjacent reactor vessel bottom head. The vertical plane containing the vertical central axis of the reactor vessel and the vertical central axis of the nozzle itself forms the plane of symmetry for the modeled portion of the nozzle. The thermal and structural boundary conditions are reflective in this plane. The outside surface of the bottom head exposed to ambient temperature was assumed to be almost completely insulated and small heat transfer coefficient (HTC) was applied. The small gap between the nozzle OD and penetration bore is modeled as "coupled temperatures" to best represent the actual condition.

As for structural behavior of the RVBH, the model vertical plane boundaries are allowed only to deflect in the direction that is radial to the bottom head center of curvature.

For thermal transient type loads (heat transfer coefficient and bulk fluid temperature), the appropriate surfaces are loaded. A film coefficient of 100 Btu/hr-ft^2-F is used in this analysis for the inner surfaces of the BMI, a film coefficient of 6737 Btu/hr-ft^2-F is used for the top and the outer surfaces of the BMI nozzle located inside the RVBH up to where the weld fillet ends. Finally, a film coefficient of 703 Btu/hr-ft^2-F is used for the RVBH ID.

During operation, the inside of the RVBH and the inside bore of the BMI nozzles are filled with reactor coolant fluid. The temperature and pressure of this fluid corresponds to those of the reactor coolant inlet. The fluid temperatures versus time are applied as loads to the model in conjunction with heat transfer coefficients (HTC).

For pressure, those surfaces in contact with primary coolant water (i.e., wetted) are loaded. These 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 at that part which is inside RVBH bore. The interface gap between the remaining and replacement BMI nozzle and the penetration bore are also loaded by pressure. The exterior of the RVBH is not loaded by pressure.

Finite Element Model:

The 3D Finite Element model is comprised of approximately 121000 nodes and approximately 80000 elements. The element type chosen is the ANSYS SOLID92 (3D 10-Node Tetrahedral Structural Solid) for the structural solutions. This element is converted to element type SOLID87 (3D 10-Node Tetrahedral Thermal Solid) for the thermal analysis.

Results:

Design Condition

As part of the developmental process for the subject FE model of the BMI nozzle attachment weld region, a run is made for the design conditions. The results of this run are used in evaluating the Primary Stresses to ASME Code Criteria. The results of this run are also used to assess the overall behavior of the model (i.e., displacements, deformations, stresses, etc.).

Thermal Results:

The results of the thermal analyses were evaluated to identify the maximum and minimum temperature gradients between different key locations in the model and the corresponding time points. These temperature gradients generate maximum and minimum thermal stresses, which in turn contribute to maximum range of stress intensities in the model. These gradients for the transients and the nodes of interest for evaluation of temperature and temperature gradient are defined in calculation output. These nodes are situated at RVBH, original weld, repair weld remaining nozzle and replacement nozzle.

Stress Results

Stress analysis is performed at approximately 80 time points. Nodal temperatures (thermal gradients) and internal pressures are loaded in the model. The analyses for transients are performed.

Minimal gap between remaining and replacement nozzle:

Due to different coefficient of thermal expansion of remaining and replacement nozzle material, the ends of these nozzles can come close to each other in the RVBH bore. Displacement between these ends was calculated for the maximum operating temperature 567° F. It is approx. 0.0025 inch. Minimal gap of repair design is 1/16 = 0.0625 inch. Since during operation, the ends move toward each other by 0.0025 inch and the minimal initial gap is 0.0625 inch, the remaining gap is still 0.06 inch.

ASME Code Criteria

The ASME code stress analysis involves two basic sets of criteria to:

1. Assure that failure does not occur due to a single application of the design loads.
2. Assure that failure does not occur due to repetitive loading.

In general, the Primary Stress Intensity criteria of the ASME code demonstrate that the design is adequate for the application of design loads.

Also, the ASME Code criteria for cumulative fatigue usage factor assure that the design is adequate for repetitive loading.

ASME Code Primary Stress Intensity (SI) Criteria

RV Bottom Head

The ANSYS post Processor was used to tabulate the stresses along paths through the head and classify them in accordance to the ASME Code criteria. Two paths were analyzed. Path "Head 1" is taken away from the discontinuity and represents the general membrane stresses in the head. Path "Head 2" is taken about one radius away from the penetration and represents the local stresses. The results from stress classification post processing runs calculated the stress components (membrane, bending, and peak) for each of the stress paths.

Primary Stress Intensities for Design Conditions

The analysis of primary stress intensities for design conditions is made to satisfy the requirements for the application of design loads in accordance NB-3221.

Other related criteria include the design limits for minimum required pressure thickness (NB-3324) and reinforcement area (NB-3330). The requirements for minimum required pressure thickness and the reinforcement area be effectively addressed by meeting NB-3221.1, NB-3221.1 and NB-3221.3.

NB-3221.1 – General Primary Membrane Stress Intensity ($P_m \leq 1.0S_m$)

$P_m = 20.17$ ksi vs. $1.0S_m = 26.7$ ksi

NB-3221.2 – Local Primary Membrane Stress Intensity ($P_l \leq 1.5S_m$)

$P_l = 25.24$ ksi vs. $1.5S_m = 40.05$ ksi

NB-3221.3 – Local Membrane + Primary Bending Stress Intensity ($P_l + P_b \leq 1.5S_m$)

$(P_l + P_b) = 29.19$ ksi vs. $1.5S_m = 40.05$ ksi

Primary Stress Intensities for Emergency Conditions

The emergency condition transients result in a maximum pressure of 2432 psia and maximum temperature of approximately 567 °F. Therefore, the primary stresses for these emergency condition transients are well represented (as well as bounded by) those previously determined for the design condition. Since the emergency condition stresses are bounded by the design stresses and the emergency allowable is greater than that of the design condition, the emergency condition primary stress intensity criteria are met.

Primary Stress Intensities for Faulted Conditions

The faulted condition transients result in a maximum pressure of 3112 psia (= 3097 psig) and maximum temperature of approximately 670 °F. Thus the pressure-induced primary stresses are greater than the design condition. The stresses due to faulted condition are calculated by ratio of the design condition. Since all faulted stresses are lower than the faulted allowable, the faulted stress criteria are met.

Primary Stress Intensities for Test Conditions

The test condition transients result in a maximum pressure of 3107 psig at temperature of approximately 120 °F. Thus the pressure-induced primary stresses are greater than the design condition. The stresses due to test condition are calculated by ratio of the design condition based on the stress and the elastic modulus. Since all test condition stresses are lower than the test allowable stresses, the test stresses are acceptable.

Replacement Nozzle

Primary Stress Intensities for Design, Emergency, Faulted and Test Conditions

For the qualification of the primary stresses in the replacement nozzle, the maximum stresses from the design, emergency, faulted and test conditions are compared to the design allowable stresses (these allowable stresses are the lowest of all of these considered conditions). If the stresses are less than the design allowable stresses no further justification is required. Note that the test condition has approximately the same pressure as the faulted case but with no external loads. Therefore, the faulted stresses will envelop all other stresses and are used in this section.

NB-3221.1, NB-3221.2 and NB-3221.3 – Local Membrane + Primary Bending Stress Intensity ($P_l + P_b \leq 1.0\ S_m$)

The maximum stress intensity is calculated as 11.3 ksi. This stress is compared with the general membrane allowable for the design condition 1.0*Sm for Alloy 690 = 23.3 ksi. Since the maximum faulted stress is lower than the design allowable these service levels are collectively satisfied thus no further qualification is required.

Remaining Nozzle

Primary Stress Intensities for Design, Emergency, Faulted and Test Conditions

For the qualification of the primary stresses in the remaining nozzle, the maximum stresses from the design, emergency, faulted and test conditions are compared to the design allowable stresses (these allowable stresses are the lowest of all of these considered conditions). If the stresses are less than the design allowable stresses no further justification is required. Note that the test condition has approximately the same pressure as the faulted case. Therefore, the faulted stresses will envelop all other stresses and are used in this section.

NB-3221.1, NB-3221.2 and NB-3221.3 – Local Membrane + Primary Bending Stress Intensity ($P_l + P_b \leq 1.0\ S_m$)

The maximum stress intensity is calculated for design and faulted conditions as **7.4 ksi**. This stress is compared with the general membrane allowable for the design condition 1.0*Sm for Alloy 600 = 23.3 ksi. Since the maximum faulted stress is lower than the design allowable these service levels are collectively satisfied thus no further qualification is required.

Partial Penetration Weld Size

The repair configuration includes partial penetration weld connection – replacement nozzle to weld pad. The required geometry of this weld is specified in paragraph 3352.4(d) and Figure NB-3352.4-4. The partial penetration J-Groove weld meets the ASME Code requirements.

ASME Code Primary + Secondary Stress Intensity Criteria

As stated previously, the analyses of stresses for transient conditions are required to satisfy the requirements for the repetitive loading. The following discussion describes the fatigue analysis process employed herein for the repair design.

Overall stress levels are reviewed and assessed to determine which model locations require detailed stress/fatigue analysis. The objective is to assure that:

1. The most severely stressed locations are evaluated.
2. The specified region is quantitatively qualified.

Once the specific locations for detailed stress evaluation are established, the ANSYS paths are defined. Post-processing runs for these paths are made to convert the stress components along these paths into Stress Intensity (SI) categories that correlate to the criteria of the ASME Code (i.e., membrane, membrane + bending, total).

The transient analysis of the model indicates that the locations of prime importance are the area around the original and repair weld and around the head bore.

The ANSYS post processor was used to tabulate the stresses along predetermined paths and classify them in accordance with the ASME Code criteria. These paths are defined at the original weld and the remaining nozzle area (material Alloy 600), the repair weld, the weld pad and the replacement nozzle area (material Alloy 690) and the head area (material SA-533) to allow stresses evaluation in all these materials separately. Review of the stress results and experience with analyses of similar configurations indicates that these sections include the location of the maximum stress/usage.

Fatigue Usage Factor Calculation

For consideration of the fatigue usage, the peak stress intensity ranges are calculated. These values must include the 'total' localized stresses. The geometry of the original and the repaired design results in a crevice-like configuration between the BMI nozzle OD and the penetration bore diameter. Therefore, the linearized 'membrane + bending' stress intensity range at the weld location is multiplied by a Fatigue Strength Reduction Factor (FSRF) of 4.0 (NB-3352.4(d), to represent the peak stress intensity range.

The geometry of the original and the repair weld and the penetration bore can produce peak stresses at local geometrical discontinuities. Also corrosion in RV bottom head penetration bore could result in irregular contours which will increase the peak stresses. The model used in the analysis may not depict all of the potential peak stresses for the fatigue analysis. Therefore to bound the potential effect of these considerations, the other locations used in fatigue analysis are conservatively also multiplied by a FSRF of 4.0, although a much smaller FSRF could be applied at some of these locations.

Repair weld, weld pad and replacement nozzle:

Upon reviewing the stress range results for this area it is determined that the SI Ranges produce the highest usage factor for Alloy 690.

The usage factor for 50 years of operation:

Usage = 0.060 < 1.0. Therefore, the ASME Code requirement has been met for this location.

Original weld and remaining nozzle:

The maximum existing usage factor for the original BMI nozzle is 0.1095 for 40 years. Therefore, this calculation considers the existing usage factor in repair design additional life calculation. Conservatively the 0.1095 usage factor for 40 years is added to the usage calculated from this analysis without adjusting for the years in service.

Upon reviewing the stress range results for this area it is determined that the SI ranges produce the highest usage factor for Alloy 600.

The usage factor for 50 years of operation.

Usage = 0.230 + 0.1095 = 0.3395 < 1.0. Therefore, the ASME Code requirement has been met for this location.

Consideration of Corrosion of RV Head Low -Alloy Material

The design configuration of the BMI nozzle repair results in a small area of the RV bottom head base material (low alloy; SA 533 Gr. B) being exposed to continuous contact with reactor coolant water. The chemistry of the reactor coolant combined with the properties of the RV Head material result in corrosion of the wetted surface.

The corrosion rate is determined to be 0.0018 inch per year. At this rate, the total surface corrosion after 30 years of plant life is only 0.054 inch. This small amount of corrosion volume loss will not have a significant impact on the analysis.

Note that the loss of metal is expected to be much smaller in the annulus between the nozzle OD the bore. However, for conservatism, the loss of metal is assumed to be through the thickness of the low alloy material. The 0.054" increase in radius has a negligible effect on the stress levels and stress distributions in the head. From a theoretical point of view, the stress concentration effect of a hole in a plate (that is subjected to a bi-axial stress field) is a function of the general plate stress and not of the size of the whole. Therefore, the larger radius shifts this peak stress field slightly outward to the new surface but does not increase it in magnitude. In addition, based on the diameter and thickness of the nozzle as well as the corrosion rate, the corrosion will not have any appreciable effect on the nozzle stresses and will not cause any denting. Thus, the larger bore diameter does not impact the stress / fatigue usage for the assembly and is acceptable.

Fatigue effect due to potentially irregular contour has been included in fatigue by applying the conservative FSRF of 4.0.

In addition, note that the weld pad added on the outside of the head is much larger volume than the metal volume lost due to corrosion even after considering that the weld material has lower allowable.

In conclusion, the corrosion of the exposed low-alloy material has negligible impact on the response of the BMI nozzle repair and is therefore acceptable.

Conclusions

The calculation has analyzed the South Texas Unit 1 Bottom Mounted Instrumentation nozzle repair and demonstrated that the repair design meets the stress and fatigue requirements of the ASME Code Section III, Subsection NB, 1971 through Addenda Summer 1973.

The ASME fatigue analysis indicates that the repair design is acceptable for 50 additional years of operation with a conservatively calculated fatigue usage factor of 0.4 compared to the Code maximum allowed value of 1.0.

BMI Nozzle Original J-Groove Weld Residual Stress Analysis Summary

BMI NOZZLE STRESS ANALYSIS
Summary of Dominion Proprietary Calculation C-3714-00-1

Purpose

The STP Bottom Mounted Instrumentation (BMI) nozzles are attached at the inside of the reactor vessel bottom head by a partial penetration J-groove weld. This document summarizes Dominion proprietary calculation C-3714-00-1, STP BMI Nozzle Stress Analysis. Dominion performs the calculation to document the results of finite element stress analyses of the BMI nozzle penetrations in the reactor vessel bottom head. In this analysis, a number of nozzle geometries spanning the range of penetration angles in the South Texas Project head are investigated.

Assumptions

The following modeling assumptions were used for the BMI nozzle modeling described in this calculation:

1. The range of clearance fits for the STP BMI nozzles may be calculated to be 0.5 to 2.5 mils radial. For the analysis, a 1.0 mil radial clearance fit was used.

2. Based on experimental stress-strain data and certified mill test report data for the materials, the room-temperature and 600°F elastic limit values were used in association with the elastic-perfectly plastic hardening laws.

The elastic limit values for the base materials (head shell and cladding), which undergo small strains during the analysis, are based on the 0.2% offset yield strength for the material. The elastic limit values for the weld materials, which undergo large strains during the analysis, are based on an average of the reported yield and tensile strengths.

3. Based on elevated temperature property data for Alloy 600, the 600°F yield strength value used in defining the multi-linear isotropic hardening curve for the nozzle material is 87.7% of the input room temperature value.

4. After the weld butter step is performed in the model but before the nozzle or J-groove welds are introduced, a stress relief pass at 1,100°F is performed by applying a uniform temperature to the model. The yield strength of the head, butter, and stainless cladding have been selected such that stresses in the low alloy steel material relax to 25 ksi or lower, while the other materials relax to 30 ksi.

5. For the J-groove weld simulation, two passes of welding were performed: an inner pass and an outer pass. The model geometry was designed such that each weld pass is approximately the same volume.

6. The model geometries for each of the BMI nozzle cases were based on nominal as-designed dimensions.

Methodology

ANSYS finite element analyses were performed using a model developed for commercial customers and described in a 1994 EPRI TR-103696 report on the subject of PWSCC of Alloy 600 components in PWR primary system service. The finite element model has been improved and refined since it was described in EPRI Report.

Finite Element Mesh

The model geometry used in this calculation makes use of approximately four times the mesh refinement in the J-groove weld areas relative to that shown in EPRI TR-103696 report. Additionally, the current model uses greater mesh refinement in other areas such as the nozzle, where five elements are used through the nozzle wall. Greater axial refinement through the head shell region above the J-groove weld was also used.

Material Properties

While the material properties used for the nozzle material continue to make use of multi-linear isotropic hardening, the material properties for the weld and weld buttering, head shell, and stainless steel cladding are now modeled using elastic-perfectly plastic hardening laws. This assumption gives more realistic stresses in the portions of the model where a high degree of plastic strain occurs at elevated temperatures, such as within the J-groove welds. The elastic limit for the weld materials is based on an average of the yield and tensile strengths.

As discussed in further detail below, this analysis included steps for weld depositing the butter and stress relieving the head and butter prior to the J-groove welding steps. In order to accurately model the stress relaxation in the butter region due to time at elevated temperature, the elastic limit for the Alloy 182 and head shell materials at temperatures near 1,100°F are reduced by a greater amount than in EPRI TR-103696 analyses.

Weld Butter Deposition and Thermal Stress Relief

Because the analyses performed in EPRI TR-103696 report were primarily concerned with calculating nozzle stresses, the J-groove butter and head shell region near the J-groove weld prep were assumed to be stress-free at the start of performing the J-groove weld. In order to more accurately determine the stresses in the J-groove weld buttering and head shell region near the J-groove weld, the current analysis model simulates the butter weld deposition process and the 1,100°F thermal stress relief of the head shell and butter. The butter weld deposition process is simulated using a single pass; i.e., the entire butter region is deposited at once. After completion of the butter deposition, the entire model is uniformly raised to 1,100°F. As noted above, the elastic limit material properties of the head shell and butter at 1,100°F are reduced relative to those used in EPRI TR-103696 report in order to simulate the stress relaxation caused by a multiple hour stress relief at 1,100°F.

Analytical Results Summary

The summary shows the maximum hoop and axial stresses at the ID of the nozzle, at the "uphill" (closest to the top of the head) and "downhill" circumferential planes, as well as "above" the weld (axial portion of the nozzle including the weld region and extending through the head shell) and "below" the weld (axial portion of the nozzle extending into the RPV). The maximum hoop stresses in the BMI nozzles are in the vicinity of the J-groove weld, and are in excess of the corresponding axial stresses, suggesting that PWSCC cracking should be axially oriented. The results also show that operating plus residual stresses are influenced by penetration angle, with higher angles generally leading to higher maximum hoop and axial stresses. Examining the above cases, the maximum ID hoop and axial stresses tend to occur at the downhill side of the nozzle.

Analysis Cases and Selected Results

Nozzle Angle	Yield Strength (ksi)	Max Downhill ID Hoop Stress (ksi)	Max Uphill ID Hoop Stress (ksi)	Max Downhill ID Axial Stress (ksi)	Max Uphill ID Axial Stress (ksi)
5.5°	49.7	54.6	55.0	36.4	31.3
17.7°	49.7	55.3	54.9	43.7	33.1
35.7°	49.7	60.0	53.4	50.7	37.2
48.6°	49.7	66.2	55.0	49.1	40.1

BMI Nozzle Flow Induced Vibration Analysis Summary

FLOW INDUCED VIBRATION INVESTIGATION OF BMI NOZZLES

Summary of Altran Proprietary Calculation 03812-C-002

Purpose:

This document summarizes Altran proprietary calculation 03812-C-002, Flow Induced Investigation of BMI Nozzles. Altran provides an assessment of the vulnerability of the bottom mounted instrumentation (BMI) nozzles inside the STP Unit 1 reactor vessel to flow induced vibration caused by the flow of cooling water at the bottom of the vessel.

Summary of Results:

The vortex shedding frequency is much lower than the natural frequency of the structure. Therefore flow induced vibration due to vortex shedding is not a concern.

Methodology:

Calculate the natural frequency of the BMI nozzle projection as a cantilevered beam inside the reactor vessel. Calculate vortex shedding frequency (Flow Induced Vibration) of the BMI nozzle and demonstrate that the vortex shedding frequency is much lower than the natural frequency of the BMI nozzle; hence, the fluid flow over the nozzle will not cause the nozzle to vibrate and experience high cycle fatigue (HCF).

Assumptions;

1. The flow of all pumps is 4 x 110,000 gpm = 440,000 gpm. This is the mechanical design flow and represents the maximum flow. Additionally all flow is assumed to run down the barrel. No bypass flow is assumed.
2. Temperature = 550 °F. Note that the actual temperature of the vessel core inlet can be as high as 561.2 °F. This difference is negligible.
3. The added mass of the nozzle due to the entrained flow has an entrained flow coefficient of 1.2
4. The entire flow of the pumps is assumed to pass through the surface of a cylinder (no bypass flow is assumed) of the following dimensions:
5. The nozzle is assumed to be a cantilevered beam. The piping from the core barrel support plate has the potential to restrict motion of the nozzle. Conservatively, no credit was taken for this potential increase in stiffness.

Results:

A conservatively calculated natural frequency of the nozzle located in the worst location in the reactor vessel bottom head is 237 Hz. Similarly, a conservatively calculated vortex shedding frequency of the nozzle is 44 Hz.

BMI Penetration Figure

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Analyses Supporting Repair