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Waterford 3

10 CFR 50.55a

W3F1-2016-0024

May 19, 2016

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
11555 Rockville Pike
Rockville, MD 20852

Subject: Request for Alternative to 10 CFR 50.55a(c), Reactor Coolant Pressure Boundary ASME Section III Code Case 1361-1
Relief Request W3-ISI-024
Waterford Steam Electric Station, Unit 3 (Waterford 3)
Docket No. 50-382
License No. NPF-38

Dear Sir or Madam:

Pursuant to 10 CFR 50.55a(z)(1), "Codes and Standards," Entergy Operations, Inc. (Entergy) hereby requests NRC approval of the attached relief request.

Entergy is requesting relief from ASME Section III Code Case 1361-1, "Socket Welds, Section III," to allow a diametral clearance (cMAX) of 0.062-inch between pressurizer heater sleeves and heater sheaths instead of 0.045-inch as specified in the Code Case. The need for this relief request was identified during pressurizer heater repairs conducted during Refueling Outage 20 (RF20) when it was discovered that shims to maintain Code Case 1361-1 allowable limits had not been installed on all heaters when repairs were performed during RF16. The details of the relief request are provided within Attachment 1.

Entergy requests approval by May 20, 2017 to ensure time remains to plan shim installation during RF21 (spring 2017) in the event this request is denied.

This letter contains no new commitments.

If you have any questions or require additional information, please contact the Regulatory Assurance Manager, John P. Jarrell, at (504) 739-6685.

Sincerely,

JPJ/MMZ

Attachments:
1. Relief Request W3-ISI-024
2. Waterford 3 Steam Electric Station Drawing PDD-5817-13524, Sheet 1, “Heater Weld Repair Design W3 Pressurizer,” Rev. No. A, May 1, 2005
3. Structural Integrity Associates, Inc., File No.: 1501532.301, “ASME Code, Section III Evaluation of the Pressurizer Heater Sheath to Heater Sleeve Fillet Weld,” Revision 1, May 9, 2016

cc: Mr. Marc L. Dapas, Regional Administrator
U.S. NRC, Region IV
RidsRgn4MailCenter@nrc.gov

U.S. NRC Project Manager for Waterford 3
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Frances.Ramirez@nrc.gov
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Attachment 1

to

W3F1-2016-0024

Relief Request W3-ISI-024

Waterford 3 Steam Electric Station
10 CFR 50.55a Request No. W3-ISI-024
Request for Alternative to a 10 CFR 50.55a(c)
Reactor Coolant Pressure Boundary ASME Section III Code Case 1361-1 Parameter

Proposed Alternative in Accordance with 10 CFR 50.55a(z)(1)
Alternative Provides Acceptable Level of Quality and Safety

Entergy is requesting relief from ASME Section III, Code Case 1361-1, "Socket Welds, Section III." This code case specifies a diametral clearance (cMAX) of 0.045-inch between connecting parts. The need for this relief request was identified during pressurizer heater repairs conducted during the recent refueling outage (RF20) when it was discovered that shims to maintain Code Case 1361-1 allowable limits had not been installed on all heaters when repairs were performed during RF16. Entergy is proposing an alternative to allow a 0.062-inch diametral clearance between pressurizer heater sleeves and heater sheaths instead of 0.045-inch as specified in the Code Case.

Background

Waterford Steam Electric Station, Unit 3 (Waterford 3) has a pressurizer containing thirty (30) heater sleeves attached to the bottom head. Waterford 3 UFSAR Section 5.2.1.2, "Applicable Code Cases," identifies that ASME Section III, Code Case 1361-1 was applied for the original pressurizer assembly, allowing for a fillet weld on the heater sleeve to heater sheath weld. The original Waterford 3 pressurizer stress reports prepared by Combustion Engineering (CE) evaluated the integrity of the heater sleeve-to-heater sheath fillet weld applying internal pressure and the effects of steady state temperature. The original construction for the heater sleeve was Alloy 600. The original construction for the heater sheath was Type 316 Stainless Steel.

During RF16, the original Alloy 600 heater sleeves were replaced with SB-166 Alloy N0690 heater sleeves to address concerns with primary water stress corrosion cracking. A drawing showing this configuration is provided in Attachment 2. The material of the heater sheath has not changed (Type 316 stainless steel). The new heater sleeve design was based on information received from Palo Verde Nuclear Generating Station (PVNGS). Waterford 3 learned that PVNGS had experienced difficulties inserting the new heaters during their first (Unit 2) pressurizer repair outage. For the second PVNGS (Unit 3) pressurizer repair outage, the clearances were opened up to 0.060-inch maximum. The ease and efficiency with which the new heaters were installed was greatly increased. Using this lesson learned, Waterford 3 incorporated a larger clearance between the heater sleeve and heater sheath in the new design. The maximum diametral clearance between the replacement Alloy 690 heater sleeves and heater sheaths was therefore increased to 0.062-inch to facilitate the insertion and future removal if needed. A shim was installed to restore the diametral clearance (cMAX) to comply with Code Case 1361-1 between the connecting parts.

During RF20, some pressurizer heaters were replaced due to degraded electrical/thermal performance. Upon removal, it was identified that eight (8) of the ten (10) heaters that were identified for replacement did not have the shims in place (C-1, G-4, E-2, J-2, G-3, G-2, G-1, and H-3). Shims identified as missing at locations G-1 and H-3 were corrected via the proper installation of new heaters based on them being within the original planned repair scope. This condition was entered into the corrective action program. It was discovered that during the heater installation performed during RF16, work instructions directed the installation of the shims. Shims were issued; however, they were not properly installed as required. The shims were found resting against the heater receptacle (having been loaded on the heater before installation) but were never positioned in place before welding. There is no indication of issues on the remaining twenty (20) heaters.

Technical Specification (TS) 3.4.3.1 (Pressurizer) requires the pressurizer shall be OPERABLE with at least two groups of pressurizer heaters powered from class 1E buses each having a nominal capacity of 150 kW in MODES 1, 2, and 3. Technical Requirements Manual (TRM) 3.4.3.1 requires the pressurizer heaters shall be OPERABLE with at least 300 kW of nominal heater capacity available in addition to the heater capacity specified in TS 3.4.3.1 in MODE 1. An evaluation performed of the condition of the shim not being installed concluded that the heaters are able to perform their design function and are therefore OPERABLE; however, an ASME code non-conformance is indicated.

Analysis

The pressurizer heaters are capable of performing their safety function because of the following:

- The heater sheath to sleeve fillet weld shear stress, primary membrane stress, and primary membrane-plus-primary bending stress was evaluated. This evaluation was performed by Structural Integrity Associates, Inc. prior to restart of the reactor following RF20. This demonstrated that the configuration is functional with the non-conforming gap.

- The pressurizer heater sheath to sleeve fillet weld satisfies the requirements of the ASME Code, Section III for Class 1 components and is qualified for the specified number of cycles defined in the Waterford 3 pressurizer Design Specification. The evaluation was performed by Structural Integrity Associates, Inc. and is provided in Attachment 3. This evaluation is based on the following:

    - Linearized stress intensities were determined and were compared against ASME Code allowable values for primary and primary-plus-secondary stress effects. In all cases the reported values of stress intensity and stress intensity ranges are less than their corresponding allowable values.

    - A fatigue evaluation performed demonstrates that the fillet weld is exempt from a detailed fatigue analysis, per ASME Code requirements.

1. ASME Code Component(s) Affected

Waterford 3
Item Number: RC MPZR0001
Description: Pressurizer Heater Sleeves, 30 per Unit
Code Class: 1

2. Applicable Code Edition and Addenda

The construction code for the Waterford 3 pressurizer vessel is ASME Section III, 1971 Edition through Summer 1971 Addenda.

3. Applicable Code Requirement(s)

Code Case 1361-1 (approved April 27, 1967), states, in part:

"Appurtenances with outside diameter equal to that of 2-inch standard pipe size and less may be constructed using weld joints in accordance with Figure 1, provided all the following requirements are met:

1) The design of the joint shall be such that stresses will not exceed the limits described in NB-3220, N-417, and tabulated in Tables I-1.1 and I-1.2.

2) A fatigue strength reduction factor of not less than 4 shall be used in fatigue analyses of the joints.

3) The finished welds shall be examined by a magnetic particle method in accordance with NB-5000 or by a liquid penetrant method in accordance with NB-5000.

4) End closure connections may be made with fillet welds or partial penetration welds provided the conditions stated above are met."

Per Figure 1, "Weld Connections for Appurtenances 2-inch Pipe Size and Smaller which are Attached to Nozzles," where cMAX = diametral clearance between connecting parts, cMAX = 0.045 in. is specified.

4. Reason for Request

In Figure 1 of Code Case 1361-1, the diametral clearance (cMAX) between connecting parts is specified as 0.045-inch. It was identified during RF20 that the gap between the pressurizer heater sheath and sleeve is greater than allowed by this Code Case. Evaluation of the condition demonstrates that the pressurizer heaters are capable of performing their safety function; therefore, it is desired to maintain this larger clearance until it is necessary for the heaters to be reworked. When heaters are reworked they will be installed per the approved Waterford 3 design.

5. Proposed Alternative and Basis for Use

The new design replacement heater sleeve has an ID of 1.300-inch maximum (1.300 +0.000 / -0.005); the heater sheath OD is the same as the original construction at 1.245-inch (1.245 ±0.007). The fillet weld size connecting these parts is the same as the original construction, namely a 3/16-inch leg. The resulting maximum diametral clearance for the new design is therefore 0.062-inch (including tolerances).

The heater sheath to sleeve fillet weld shear stress, primary membrane stress, and primary membrane-plus-primary bending stress was evaluated. This evaluation was performed by Structural Integrity Associates, Inc. prior to restart of the reactor following RF20. This demonstrated that the configuration is functional with the non-conforming gap.

Subsequent analyses by Structural Integrity and Associates, provided as Attachment 3, evaluate the fillet weld with a maximum diametral clearance between the parts of 0.062-inch. The results of the evaluation demonstrate compliance with the ASME Code NB-3220 allowable for Primary Membrane, Primary Membrane plus Bending, Primary plus Secondary and Fatigue stresses. The other requirements specified in Code Case 1361-1 for joint configuration are met with the increased diametral clearance with no appreciable increase in stress. This evaluation is written using bounding dimensions (per the drawing provided in Attachment 2) and bounds all heaters that were replaced with the new design.

Code Case 1361-1 was approved in April 1967. At that time, the ASME Code did not prepare a basis document for their Code Case assumptions as is being done presently. Thus, the basis for the diametral clearance requirement of 0.045-inch in Code Case 1361-1 is not specified. However, by maintaining the clearance between the parts relatively small, the amount of bending stresses that can be imparted on the fillet weld due to deflection of the parts is negligible. Waterford 3 pressurizer heaters are fixed at one end by the fillet weld and supported at the other end by two consecutive heater support plates, thus minimizing bending stresses at the fillet weld. Based on the above discussion, the reconfigured weld joint is acceptable from a stress/fatigue perspective for the remaining plant life.

Pursuant to 10 CFR 50.55a(z)(1), Waterford 3 proposes an alternative to Code Case 1361-1 by using a maximum 0.062-inch diametral clearance between the pressurizer heater and heater sleeve in lieu of the Code Case requirement of 0.045-inch (cMAX). This relief request is not limited to only those heaters that were found during RF20 with missing shims but is needed to apply to all heaters in the event that additional heaters that were replaced during RF16 are identified with missing shims. This proposed alternative would provide an acceptable level of quality and safety and thus would meet the requirements of 10 CFR 50.55a(z)(1).

6. Duration of Proposed Alternative

Waterford 3 requests that the 10 CFR 50.55a(z)(1) relief for the alternative to the cMAX value in Code Case 1361-1 for the pressurizer sleeves be granted and that the relief remain in effect until it is necessary for the heaters to be reworked. When heaters are reworked they will be installed per the approved Waterford 3 design.

7. Precedents

Similar Relief Requests:

1. Palo Verde Nuclear Generating Station (PVNGS) Units 1, 2, and 3
   Docket Nos. STN 50-528, 50-529, and 50-530
   10 CFR 50.55a(a)(3)(i) Request for Alternative to a 10 CFR 50.55a(c) Reactor Coolant Pressure Boundary ASME Section III Code Case 1361-2 Parameter (ISI Relief Request 30)
   Submitted to the NRC: November 11, 2004; Approved by the NRC: November 19, 2004
   (TAC NOS. MC5080, MC5081, AND MC5082)

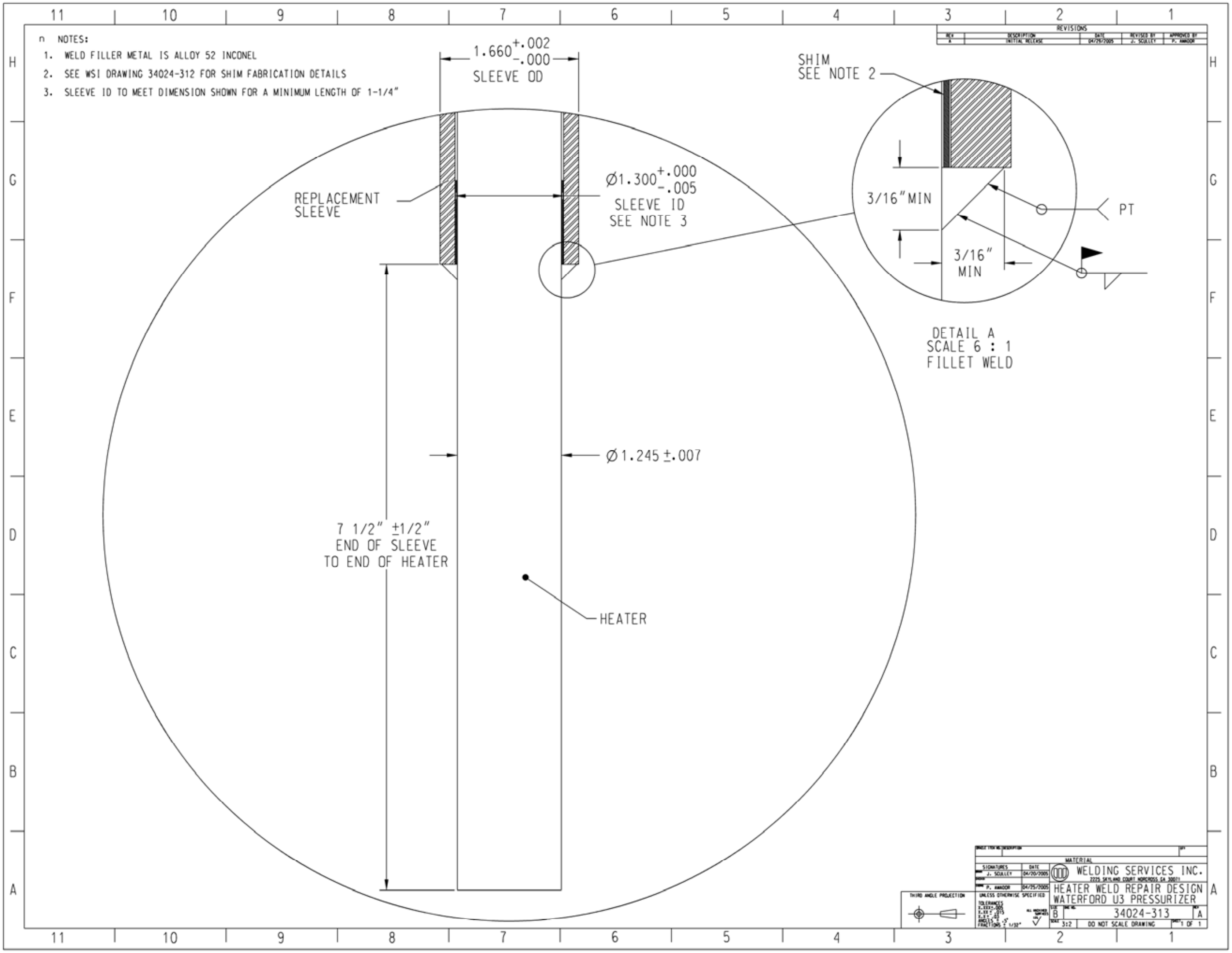
2. San Onofre Nuclear Generating Station (SONGS) Units 2 and 3
   Docket Nos. 50-361 and 50-362
   10 CFR 50.55a(a)(3)(i) Request for Alternative to a 10 CFR 50.55a(c) Reactor Coolant Pressure Boundary ASME Section III Code Case 1361-2 Parameter (Relief Request ISI-3-15)
   Submitted to the NRC: July 22, 2005; Approved by the NRC: February 8, 2006
   (TAC NOS. MC7977 AND MC7978)

Attachment 2

to

W3F1-2016-0024

Waterford 3 Steam Electric Station
Drawing PDD-5817-13524, Sheet 1
Heater Weld Repair Design W3 Pressurizer



☐ Before ☒ After DRN NO. 05-668			Page 1 of 1
DOC. * PDD-5817-13524	SHT. * 1	REV. A	
INIT. DOC. ER-W3-2004-0122-000	Superseded DRN*	-	
Control Room Drawing? YES ☐ NO ☒		Critical Change? YES ☐ NO ☒	
ICN Required? YES ☒ NO ☐		Eng App. of Rev. Doc.? YES ☒ NO ☐	
Prepared By:	V.PENACERRADA	Date	5-1-05
Reviewed By:	J.GOBELL	Date	5-1-05
CLOSURE:			
Incorp. on Rev.	Checker	DUE	Date
FILENAME: 135240la.dgn			

NO.	DATE	REVISION DESCRIPTION	BY	CH	APPROVED
A	05-01-05	REVISED PER DRN 05-668 . ER-W3-2004-0122-000	JAG		

WATERFORD 3 S.E.S.

LORAC NO. PDD-5817-13524 SH. 1 — REV. NO. A

TITLE: HEATER WELD REPAIR DESIGN
W3 PRESSURIZER

PRIMARY DISCIPLINE: ■M ☐C ☐E ☐I&C ☐OTHER
CROSS DISCIPLINE(S): ☐M ☐C ☐E ☐I&C ☐NA

P.O. NO. | IMPLEMENTING DOC. (I.E., DCP, ETC.) ER-W3-2004-0122-000

DRAWING REVIEW: NO COMMENTS ☐ FOR INFO ONLY ☐ COMMENTS AS SHOWN ☐
DRAWING STATUS: NO FURTHER REPRODUCIBLE REQUIRED ☐ SUBMIT REVISED REPRODUCIBLE ☐
FABRICATION: PROCEED ☐ DO NOT PROCEED ☐ PROCEED BASED ON COMMENTS ☐
DISTRIBUTION: APPROVED FOR DISTRIBUTION ☐ NOT APPROVED FOR DISTRIBUTION ☐
REVIEWED BY: DATE
THIS SECTION COMPLETED BY ENGINEERING UNLESS DCP RELATED.

THIS REVIEW IS FOR WATERFORD 3 INFORMATION REQUIREMENTS AND IN NO WAY RELIEVES THE CONTRACTOR FROM ENTIRE RESPONSIBILITY FOR ENGINEERING, DESIGN, WORKMANSHIP, MATERIAL, AND ALL OTHER LIABILITY UNDER THE CONTRACT.

SIGNATURES / APPROVALS ARE FOR:
■ PRELIMINARY DESIGN DRAWING AND / OR
■ APPLIQUE PLACEMENT & NUMBER ASSIGNMENT
NOTE: CHECK (1) OR BOTH AS APPLICABLE.

DATE	DRAFTER	CHECKER	APPROVALS
- -			

REMARKS:

FILENAME: 13524a.dgn

Attachment 3

to

W3F1-2016-0024

Structural Integrity Associates, Inc.
File No.: 150532.301
ASME Code, Section III Evaluation
of the
Pressurizer Heater Sheath to Heater Sleeve Fillet Weld

Structural Integrity Associates, Inc.® CALCULATION PACKAGE	File No.: 1501532.301 Project No.: 1501532 Quality Program: ☒ Nuclear ☐ Commercial

PROJECT NAME:
ASME Code, Section III Qualification of Pressurizer Heater Sheath to Heater Sleeve Fillet Weld

CONTRACT NO.:
10464601, Change Order No. 001

CLIENT:	**PLANT:**
Entergy Operations, Inc.	Waterford Steam Electric Station, Unit 3

CALCULATION TITLE:
ASME Code, Section III Evaluation of the Pressurizer Heater Sheath to Heater Sleeve Fillet Weld

Document Revision	Affected Pages	Revision Description	Project Manager Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1 - 45 A-1 - A-2 Computer Files	Initial Issue STATE OF LOUISIANA JOSEPH P. MACIEJCZYK License No. 39703 PROFESSIONAL ENGINEER IN MECHANICAL ENGINEERING May 9, 2016 After Rev1 complete	Richard Mattson 04/05/16	Preparer: Soo Bee Kok 04/05/16 Checker: Charles Fourcade 04/05/16
1	1 - 45 A-1 - A-2 Computer Files	Revise Reference List to replace References 4, 10, and 11 with new Reference 15. Revise calculation contents to suit. Replace Reference 6 with equivalent Entergy reference.	Richard Mattson 05/09/16	Preparer: Moses Taylor 05/09/16 Checker: Richard Mattson 05/09/16

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1.0 INTRODUCTION

The existing configuration for the Waterford Steam Electric Station (WSES), Unit 3 pressurizer heater sleeve, heater sheath and connecting fillet weld is different than the original design. Specifically, the existing configuration has a heater sleeve bore that is larger than the original design. The larger bore causes a gap between the heater sheath and the heater sleeve to be greater than allowed by ASME Code Cases 1361 / N-405, which were invoked for the heater installation. The gap was to be reduced with a shim to be Code Case compliant. However, some of the shims may not have been installed.

An evaluation using the guidelines in NRC Inspection Manual, Chapter 0326, 'Operability Determinations & Functionality Assessments for Conditions Adverse to Quality or Safety' [12] was performed by Structural Integrity Associates to show that the configuration is operable with the non-conforming gap. This non-conformance evaluation is documented in Reference 13.

As a follow-up to the non-conformance evaluation, this calculation documents the ASME Code, Section III [1] evaluation of the redesigned configuration of the pressurizer heater sheath to heater sleeve fillet weld.

2.0 KEY ASSUMPTIONS

1. The weld is remote from the fluid in the pressurizer and from the heating elements, so it is isothermal for all operating conditions [15]. Therefore, it is reasonable to assume that the temperature difference in the fillet weld region is small and insignificant.
2. The temperature range for all operating conditions varies from 70°F to 400°F [15]. Allowable stresses for all operating conditions are, therefore, based on material properties at the bounding temperature of 400°F.
3. Linearized stress intensities are computed along ten stress paths (see Figure 4). The allowable stresses are based on the weaker of the adjoining materials. Specifically, allowable stresses of Alloy 52 / Alloy 690 are used for stress paths 1, 2, 6 and 7, and allowable stresses of SA-213, TP316 stainless steel are used for stress paths 3, 4, 5, 8, 9, and 10.

3.0 DESIGN INPUT

3.1 Component Material and Material Properties

Heater Sleeve Material:	Alloy 690	[5]
Heater Sheath Material:	SA-213, TP316	[6]
Fillet Weld Material:	Alloy 52	[7]

Note that Alloy 52 and Alloy 690 have similar material properties: Alloy 52 designates the weld material and Alloy 690 designates the base metal. Material properties are listed in Table 2. Material properties for SA-213, TP316 are listed in Table 1.

3.2 Key Dimensions

The minimum heater sheath outside radius and the maximum heater sleeve inside radius are used to build a finite element model. These dimensions provide the largest gap between the heater sheath and sleeve, which is bounding for the analysis. In addition, minimum thicknesses are used for the heater sheath and sleeve. The fillet weld leg is modeled as the minimum dimension of 3/16" [7]. The key dimensions are listed below and shown in Figure 1.

Heater Sheath Outer Radius	=	(1.245-0.007)/2	in	[7]
	=	0.619	in	
Heater Sheath Inside Radius	=	0.619 – 0.180 + 0.015	in	[6, 7]
	=	0.454	in	
Heater Sleeve Outside Radius	=	1.660/2	in	[7]
	=	0.830	in	
Heater Sleeve Inside Radius	=	1.300/2	in	[7]
	=	0.650	in	
Fillet Weld Size	=	0.1875	in	[7]

3.3 Design Conditions

Design Pressure	=	2,500	psia	[15]
	=	2,485	psig	
Design Temperature	=	700	°F	[15]

3.4 Operating Conditions

Normal Operating Pressure	=	2,250	psia	[15]
	=	2,235	psig	
Upset Conditions Operating Pressure	=	2,550	psia	[15]
	=	2,535	psig	
Maximum Operating Temperature	=	400	°F	[See Assumption #2]

3.5 Test Conditions

Per Reference 15, there are two types of tests: hydrostatic test and plant leak test. The bounding hydrostatic test pressure is used.

Maximum Test Pressure	=	3,125	psia	[15]
	=	3,110	psig	
Maximum Test Temperature	=	400	°F	[15]

3.6 Mechanical Loads

The Operating Basis Earthquake (OBE) loads are taken from Reference 8 and the Design Basis Earthquake (DBE) loads are twice the OBE loads, as noted in Reference 9. The mechanical loads are listed below.

Dead Weight	=	40	lb	[8]
OBE Axial Force	=	30	lb	[8]
OBE Bending Moment	=	111	in-lb	[8]
DBE Axial Force	=	60	lb	[8, 9]
DBE Bending Moment	=	222	in-lb	[8, 9]

4.0 LOADS AND LOAD COMBINATIONS

Mechanical, pressure, and thermal loads applied to the finite element model (FEM) will be considered in the analysis of the fillet weld.

4.1 Mechanical Loads

The applied mechanical loads include Dead Weight, OBE, and DBE loads. The loads are listed in Section 3.6. Two load cases are analyzed: the Dead Weight and the DBE loads. The stress results from the DBE analysis is halved to obtain the OBE results.

4.2 Pressure Loads

The pressure loads considered are: (1) Design Pressure of 2,485 psig with a corresponding Design Temperature of 700°F, (2) Upset Conditions Operating Pressure of 2,535 psig with a corresponding Maximum Operating Temperature of 400°F, and (3) Maximum Test Pressure of 3,110 psig with a corresponding Maximum Test Temperature of 400°F.

The pressure analysis is performed for the Design Pressure of 2,485 psig. The linearized stress intensities for the Design Pressure load case are scaled to compute the corresponding stress intensities for the upset and test conditions.

4.3 Thermal Loads

Since the fillet weld is considered to be isothermal (see Assumption #1) and the maximum temperature for all operating conditions is 400°F (see Assumption #2), the thermal analysis is performed to evaluate the effects due to differential coefficients of expansion between the Alloy 52 (fillet weld), Alloy 690 (heater sleeve) and TP316 stainless steel (heater sheath) materials. The thermal analysis assumes a uniform temperature of 400°F with respective material properties at temperature.

4.4 Load Combinations

The following load combinations are considered:

1) Design Load Combination
2) Service Level A/B Load Combination
3) Service Level C/D Load Combination
4) Test Load Combination

The loads considered for each of the load combinations are summarized in Table 3.

5.0 STRESS CRITERIA AND ALLOWABLE STRESSES

5.1 Stress Criteria

The stress criteria for all load combinations are based on ASME Code, Section III, Division 1, Subsection NB for Class 1 Components [1]. A summary of the stress criteria is listed in Table 4.

5.2 Allowable Stresses

For the evaluation of the fillet weld, a joint efficiency factor (JEF) is taken as 0.5 per ASME Code, Subparagraph NB-3123.2 [2]. The JEF is used to decrease the allowable stresses. This guidance is taken from an older edition of Section III as it was removed from the newer versions.

The allowable stress intensities for SA-213, TP316 stainless steel and Alloy 52 / Alloy 690 are listed in Table 5 and Table 6, respectively.

6.0 FINITE ELEMENT MODEL

A finite element model is developed for the analysis of the pressurizer heater fillet weld using the ANSYS finite element software [14]. The model is developed using the three-dimensional (3-D) SOLID45 element type. A one-half symmetry model is created to perform the analysis. TARGE170 and CONTA175 element types are modeled at the bottom end of the heater sheath. These elements are used to impose moments on the model.

The temperature dependent material properties of the modeled components are listed in Table 1 and Table 2. The material properties are per Section III, Appendices of the ASME Code [1].

The key dimensions used for the model are listed in Section 3.2. The lengths of the heater sheath and heater sleeve are set at a reasonable distance away from the fillet weld so that the ends do not have any influence on the stresses in the weld region. The key dimensions used in the model are shown in Figure 1, and the finite element model mesh is shown in Figure 2. The dead weight, Design Pressure, DBE, and thermal applications are shown in Figure 5, Figure 6, Figure 7, and Figure 8, respectively.

In the 3-D half-symmetry model, the total numbers of elements and nodes are approximately 268,000 and 290,000, respectively.

6.1 ANSYS Element Types

The element types used in the ANSYS finite element model include:

- SOLID45

  SOLID45 is used for the 3-D modeling of solid structures. The element is defined by eight nodes having three degrees-of-freedom at each node: translations in the nodal x, y, and z directions. This element type is used to model the heater sleeve, fillet weld, and heater sheath.

- CONTA175

  CONTA175 is used to represent contact between a node and a surface. This element is located on the surfaces of solid elements. When used in conjunction with the associated TARGE170 element, the forces and moments imposed on the associated TARGE170 element are applied on the contact elements.

- TARGE170

  TARGE170 is used to represent various target nodes for the associated contact elements, CONTA175. The contact elements themselves overlay the solid elements describing the boundary of a solid body. The target node (TARGE170) is paired with its associated contact surface via a shared real constant set. Forces and moments can be imposed on target elements to transmit the loads to the associated contact surface.

6.2 Boundary Conditions

The nodes at the plane of symmetry (i.e., XZ plane) are restrained in the Y translation. The end nodes of the heater sleeve are restrained in the Z translation. To prevent instability, the middle row of nodes (i.e., from inside radius to outside radius at X = 0.0) at the end of the heater sleeve are restrained in the X translation. The finite element model boundary conditions are shown in Figure 3.

6.3 Linearized Stress Paths

A total of ten linearized stress paths are used, and they are shown in Figure 4. The first five paths are on one side of the symmetry plane, and the other five paths are at corresponding locations on the other side. Notably, the adjoining materials for the different paths are as follows:

- Paths 1 & 6; Adjoining materials are Alloy 52 and Alloy 690
- Paths 2 & 7; Adjoining materials are Alloy 52 and Alloy 690
- Paths 3 & 8; Adjoining materials are Alloy 52 and SA-213, TP316
- Paths 4 & 9; Adjoining materials are Alloy 52 and SA-213, TP316
- Paths 5 & 10; Adjoining materials are Alloy 52 and SA-213, TP316

7.0 STRESS ANALYSIS AND RESULTS

7.1 Dead Weight Analysis

The dead weight of 40 lb (see Section 3.6) is applied as end-cap pressure at the free surface of the heater sheath. The loading condition is shown in Figure 5. The reaction forces from the analysis are summed to confirm that the correct load is applied.

The dead weight analysis stress intensity plot is shown in Figure 9.

7.2 Pressure Analysis

The Design Pressure of 2,485 psi (see Section 3.3) is applied to the outside of the heater sheath in the annulus region, and the inside of the heater sleeve. The end-cap pressure acting on the heater sheath is applied at the end of the heater sheath. The loading conditions are shown in Figure 6. The reaction forces from the analysis are summed to confirm that the end-cap pressure is applied correctly.

The Design Pressure analysis stress intensity plot is shown in Figure 10.

7.3 DBE Analysis

The DBE loads consist of the axial force of 60 lb and the moment of 222 in-lb (see Section 3.6). The axial force is applied as end-cap pressure at the end of the heater sheath. The moment is applied at the

TARGE170 node, which transmits the moment to the associated CONTA175 surfaces located at the end of the heater sheath. The loading conditions are shown in Figure 7. The applied force and moment are checked at a surface remote from the application surface, using the ANSYS [14] FSUM command, to confirm the correct application of the DBE loads.

The DBE analysis stress intensity plot is shown in Figure 11.

7.4 Thermal Analysis

A uniform temperature of 400°F is applied to all nodes in the finite element model, and the reference temperature (i.e., stress free temperature) is set at 70°F. The application for the thermal analysis is shown in Figure 8.

The thermal analysis stress intensity plot is shown in Figure 12.

7.5 Linearized Stress Intensity Results

For the ASME Code, Section III evaluation, stress intensity results at ten paths are extracted from the model. Figure 4 shows the paths for the ASME Code, Section III evaluation. These linearized stress intensities are contained in *.OUT files as listed in Appendix A.

8.0 ASME CODE, SECTION III EVALUATION

The evaluation is performed in accordance with ASME Code, Section III, 1989 Edition [1]. The stress criteria are discussed in Section 5.1 and summarized in Table 4. The allowable stress intensities are discussed in Section 5.2 and tabulated in Table 5 and Table 6. Linearized stress intensities are evaluated through a total of ten paths (see Figure 4) for the heater sleeve, fillet weld and heater sheath. The comparisons of the calculated stresses and the allowable stresses are documented in the spreadsheet "1501532.301 Stresses.xlsx", as listed in Appendix A.

8.1 ASME Code Stress Limits Evaluation

8.1.1 Design Load Combination

For the design load combination, only primary stresses need to be evaluated. As shown in Table 3, the loads considered are the Design Pressure and the dead weight.

The general primary membrane stress due to pressure may be calculated via a hand calculation (i.e., Pr/t). Instead of performing a hand calculation for the general primary membrane stress intensity, the linearized membrane stress intensity from the ANSYS Design Pressure and dead weight results are used. This is conservative as the linearized results from ANSYS contain stress effects due to geometric discontinuities, and are more accurately treated as local primary membrane stresses, P_L. Table 7 contains the comparison of the calculated stresses to the allowable stresses. As shown in the table, the calculated stresses are less than the allowables.

8.1.2 Service Level A/B Load Combination

The load combination that must be considered for Service Levels A and B is shown in Table 3. As the allowable stress values for both service levels are the same, the Service Level A and B evaluations are combined into a single Service Level A/B evaluation. The bounding Service Level A/B stress range is a summation of thermal, dead weight, upset conditions pressure, and OBE stresses.

According to ASME Code, Section III, Subparagraph NB-3222.1 [1], '*there are no specific limits established on the primary stresses in the Level A Limits.'* However, the primary stresses for Service Level A/B are also evaluated using the allowable of 1.0 S_m for P_m, and the allowable of 1.5 S_m for P_L and $P_L + P_b$.

The evaluation of the Service Level A/B primary stress intensities is provided in Table 8, and the evaluation of the Service Level A/B primary-plus-secondary stress intensity range is provided in Table 9. As shown in the tables, the calculated stress intensities are less than the allowable stress intensities.

8.1.3 Service Level C/D Load Combination

The Service Level C and Service Level D evaluation are combined as one load combination by using the smaller allowable stress intensity values for Service Level C. Only primary stresses are evaluated for the Service Level C/D evaluation. As shown in Table 3, the loadings considered for the Service Level C/D evaluation include the dead weight, the upset conditions pressure, and the DBE loads.

Table 10 presents the evaluation of the primary stress intensities for the Service Level C/D evaluation. As shown in the table, all of the stress intensities are less than the allowables.

8.1.4 Test Load Combination

For the test load condition, only primary stresses need to be evaluated. As shown in Table 3, the loads considered are the test pressure and the dead weight.

Table 11 contains the comparison of the calculated stress intensities to the allowable stress intensities. As shown in the table, the calculated stress intensities are less than the allowables.

8.2 Fatigue Evaluation

Components may be exempted from a fatigue analysis provided the requirements of ASME Code, Subsubparagraph NB-3222.4 (d), conditions (1) through (6), are met [1]. The fatigue evaluation is performed for the current plant life of 40 years.

Exemption from a fatigue analysis involves the use of the appropriate ASME Code fatigue curves [1]. Adjustments are made to the curve values to account for differences in the elastic modulus (E) between the fatigue curve and the material being analyzed. The adjustment factor is: E-actual/E-curve.

The fatigue evaluation is performed for the pressurizer heater sleeve fillet weld. Note that the material properties are conservatively based on the Design Temperature (700ºF), which bounds the maximum operating temperature (400ºF). As the design consists of the fillet weld (Alloy 52), heater sleeve (Alloy 690) and heater sheath (TP316) materials, appropriate material properties are used for fatigue exemption evaluation.

Condition (1) Atmospheric to Service Pressure:

TP316:

The maximum alternating stress (S_a) [1, NB-3222.4(d)(1)] is computed as follows:

$S_a = 3S_m = 3 \times 16.3$ ksi = 48.9 ksi (S_m taken at 700ºF, See Table 1)

The corresponding number of allowable cycles (N) for $S_a = 48.9$ ksi is as follows:

E-actual = 24.8e6 psi at 700ºF (See Table 1)
E-curve = 28.3e6 psi [1, Figure I-9.2.1]
20,000 cycles is conservatively used for $S_a = 48.9$ ksi.
N = 20,000 × 24.8/28.3 cycles = 17,526 cycles [1, Figure I-9.2.1].

Alloy 690 / Alloy 52:

The maximum alternating stress (S_a) [1, NB-3222.4(d)(1)] is computed as follows:

$S_a = 3S_m = 3 \times 23.3$ ksi = 69.9 ksi (S_m taken at 700ºF, See Table 1)

The corresponding number of allowable cycles (N) for $S_a = 69.9$ ksi is as follows:

E-actual = 27.6e6 psi at 700ºF (See Table 1)
E-curve = 28.3e6 psi [1, Figure I-9.2.1]
5,000 cycles is conservatively used for $S_a = 69.9$ ksi.
N = 5,000 × 27.6/28.3 cycles = 4,876 cycles [1, Figure I-9.2.1]. (governs)

The specified number of times (n) that the pressure will be cycled from atmospheric pressure to service pressure and back to atmospheric pressure during design plant life corresponds to the number of heatup/cooldown and test conditions. Thus, the maximum number of cycles from Table 12 for these transients is 410 (i.e., 200 startup/cooldown, 200 leak test, and 10 hydrostatic test cycles) for the full design life of the plant.

Since 'n' is much less than 'N' (410 < 4,876), Condition (1) is satisfied.

Condition (2) Normal Service Pressure Fluctuation:

Significant pressure fluctuations [1, NB-3222.4(d)(2)] are those that exceed the following value:

P_f = 1/3 × Design Pressure × (S/S_m), where:

Design Pressure = 2,485 psig (Section 3.3), and S = S_a at 1 x 10^{11} cycles from the applicable fatigue curve.

TP316:

S_a = 13.6 ksi [1, Table I-9.2.2]

Thus, the significant pressure fluctuations are:

1/3 × 2,485 × (13.6/16.3) = 691 psi

Alloy 690 / Alloy 52:

S_a = 13.6 ksi [1, Table I-9.2.2]

Thus, the significant pressure fluctuations are:

1/3 × 2,485 × (13.6/23.3) = 483 psi (governs)

From Table 12, the number of cycles with normal service pressure fluctuations greater than 483 psi (limiting value) is 485 (i.e., 480 upset conditions, and 5 loss of secondary pressure) cycles.

The allowable number of cycles is calculated as follows:

P_f = 1/3 × Design Pressure × (S_a/S_m), where:

Design Pressure = 2,485 psig (Section 3.3), and S_a is the stress value from the fatigue curve for the applicable number of cycles that have significant pressure fluctuations.

TP316:

S_a = 148 ksi for 500 cycles (bounds 485 cycles) [1, Table I-9.2.1]

Thus, the allowable number of significant pressure fluctuations is:

1/3 × 2,485 × (148/16.3) = 7,521 cycles

Alloy 690 / Alloy 52:

S_a = 148 ksi for 500 cycles (bounds 485 cycles) [1, Table I-9.2.1]

Thus, the allowable number of significant pressure fluctuations is:

1/3 × 2,485 × (148/23.3) = 5,261 cycles (governs)

The number of significant pressure cycles is 485, which is much less than the allowable number of cycles of 5,261 (limiting value).

Hence, Condition (2) is satisfied.

Condition (3) Temperature Difference – Startup and Shutdown:

The allowable temperature difference [1, NB-3222.4(d)(3)] is given by:

$T_D = \frac{S_a}{2E\alpha}$, where:

S_a = maximum allowable alternating stress for number of startup and shutdown cycles
E = elastic modulus at the mean value of temperature between two adjacent points
α = instantaneous coefficient of thermal expansion at the mean value of temperature between two adjacent points

The specified number of startup and shutdown cycles, n = 200 (see Table 12).

TP316:

For 500 cycles (conservatively taken to bound 200 cycles):
S_a = 148 ksi [1, Table I-9.2.1]

As the temperatures vary between the transients, the values of E and instantaneous alpha will be taken at either 70ºF or 700ºF, whichever value yields a more conservative temperature difference. E*alpha at 70ºF is 8.42*28.3 = 238.29 while at 700ºF it is 10.76*24.8 = 266.85. Therefore, the values will be taken at 700ºF for the temperature difference calculations.

At 700ºF:
E = 24,800 ksi, α = 10.76E-6 in/in/ºF, E_{curve} = 28,300 ksi

$$T_D = \frac{148 \times 24.8 / 28.3}{2(24800)(10.76e^{-6})} = 243^{\circ}F \text{ (governs)}$$

Alloy 690 / Alloy 52:

For 500 cycles (conservatively taken to bound 200 cycles):
S_a = 148 ksi [1, Table I-9.2.1]

As the temperatures vary between the transients, the values of E and instantaneous alpha will be taken at either 70ºF or 700ºF, whichever value yields a more conservative temperature difference. E*alpha at 70ºF is 7.73*30.3 = 234.22 while at 700ºF it is 8.81*27.6 = 243.16. Therefore, the values will be taken at 700ºF for the temperature difference calculations.

At 700ºF:
E = 27,600 ksi, α = 8.81E-6 in/in/ºF, E_{curve} = 28,300 ksi

$$T_D = \frac{148 \times 27.6 / 28.3}{2(27600)(8.81e^{-6})} = 297^{\circ}F$$

Hence, the allowable temperature difference T_D is 243ºF.

It has been established that the weld is isothermal for all operating conditions (see Assumption #1). The maximum differences in temperatures for each path are expected to be small and insignificant, and, therefore, much less than 243°F. Hence, Condition (3) is satisfied.

Condition (4) Temperature Difference – Normal Service:

The allowable temperature difference [1, NB-3222.4(d)(4)] is given by:
$T_D = \frac{S_a}{2E\alpha}$, where:

S_a = maximum allowable alternating stress for total number of cycles for transients that have significant temperature differences
E = elastic modulus at the mean value of temperature between two adjacent points
α = instantaneous coefficient of thermal expansion at the mean value of temperature between two adjacent points

A temperature difference fluctuation shall be considered significant if its total algebraic range exceeds the quantity $\frac{S}{2E\alpha}$ [1, NB-3222.4(d)(4)], where S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

The values of E and alpha that were used for Condition (3) will be used for this calculation.

TP316:

At 700ºF:
E = 24,800 ksi, α = 10.76E-6 in/in/ºF, E_{curve} = 28,300 ksi

Significant temperature difference fluctuation = $\frac{13.6 \times 24.8/28.3}{2(24800)(10.76e^{-6})}$ = 22.3ºF

Alloy 690 / Alloy 52:

At 700ºF:
E = 27,600 ksi, α = 8.81E-6 in/in/ºF, E_{curve} = 28,300 ksi

Significant temperature difference fluctuation = $\frac{13.6 \times 27.6/28.3}{2(27600)(8.81e^{-6})}$ = 17.4ºF (governs)

Similar to Condition (3), it has been established that the weld is isothermal for all operating conditions (see Assumption #1). The maximum differences in temperatures for each path are expected to be small and insignificant, and, therefore, less than the conservatively calculated 17.4°F. Hence, Condition (4) is satisfied.

Condition (5) Temperature Difference – Dissimilar Materials:

The allowable temperature difference [1, NB-3222.4(d)(5)] is given by:

$T_D = \frac{S_a}{2(E_1\alpha_1 - E_2\alpha_2)}$, where:

S_a = maximum allowable alternating stress for total number of cycles for transients that have significant temperature differences
E_x = elastic modulus at the mean value of temperature of material x
α_x = instantaneous coefficient of thermal expansion at the mean value of temperature of material x

At 700ºF:

TP316:	E = 24,800 ksi, α = 10.76E-6 in/in/ºF
Alloy 690 / Alloy 52:	E = 27,600 ksi, α = 8.81E-6 in/in/ºF

$$\text{Significant temperature difference fluctuation} = \frac{13.6}{2(24{,}800 \cdot 10.76e^{-6} - 27{,}600 \cdot 8.81e^{-6})}$$

$$= 287^{\circ}\text{F}$$

Similar to Condition (3), it has been established that the weld is isothermal for all operating conditions (see Assumption #1). The maximum differences in temperatures for each path are expected to be small and insignificant, and, therefore, less than the calculated 287°F. Hence, Condition (5) is satisfied.

Condition (6) Mechanical Loads:

The full range of mechanical loads that act on the pressurizer heater fillet weld are from seismic loads. The seismic loads are listed in Section 3.6. The seismic loads are small and the maximum total stress intensity range for OBE is 3.1 ksi. The threshold S_a at 1 x 10^{11} cycles from the applicable fatigue curve is 13.6 ksi. Therefore, Condition (6) is satisfied.

8.3 Shear Stress Check

Per Subparagraph NB-3227.2 [1], a check of the pure shear stress across the fillet weld is performed. This shear stress is due to the dead weight, pressure, and DBE loads acting on the inside of the fillet weld and trying to shear the fillet weld from the heater sheath (Paths 3 & 8 in Figure 4). Per NB-3227.2(a), the shear stress shall be limited to $0.6S_m$ for all service level loadings.

Allowable shear stress = 0.6*16,300 = 9,780 psi [at 700°F]

The shear stresses due to dead weight, internal pressure, and the DBE are taken from the linearized shear stresses:

Shear Stress due to Dead Weight	=	54 psi	
Shear Stress due to Pressure	=	5,318 psi	(conservatively uses Test Pressure)
Shear Stress due to DBE	=	1,069 psi	
Resultant Shear Stress	=	6,441 psi	< 9,780 psi (OK)

The summed resultant shear stress value is less than the allowable of 9,780 psi. Therefore, the requirement for pure shear is met.

9.0 CONCLUSIONS

An evaluation of the pressurizer heater sheath to heater sleeve fillet weld has been performed in accordance with the requirements of the ASME Code, Section III [1], for Class 1 components.

Linearized stress intensities are determined for Design, Service Level A/B, Service Level C/D, and Test load combinations. These linearized stress intensities are compared against ASME Code allowable values for primary and primary-plus-secondary stress effects. In all cases the reported values of stress intensity and stress intensity ranges are less than their corresponding allowable values.

A fatigue evaluation is also performed, as discussed in Section 8.2, which demonstrates that the fillet weld is exempt from a detailed fatigue analysis, per ASME Code requirements.

In conclusion, the pressurizer heater sheath to heater sleeve fillet weld satisfies the requirements of the ASME Code, Section III, and is qualified for the specified number of cycles defined in the Waterford pressurizer Design Specification.

10.0 REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section III, Rules for Construction of Nuclear Power Plant Components, 1989 Edition with No Addenda.
2. ASME Boiler and Pressure Vessel Code, Section III, Rules for Construction of Nuclear Power Plant Components, 1983 Edition.
3. ASME Boiler and Pressure Vessel Code, Section II, Part D - Properties, 1995 Edition.
4. Not used.
5. SI Drawing No. 04139r0, 'Waterford Steam Electric Station, Unit 3, Pressurizer Bottom Head Heater Sleeve/Instrument Nozzle Repairs,' SI File No. WSES-10Q-501.
6. Entergy Waterford 3 S.E.S. Drawing No. 5817-13551 Sh.1, Rev. 1, 'Termocoax Pressurizer Heaters', SI File No. 1501504.204.
7. WSI Drawing No. 34024-313, Rev. A, 'Heater Weld Repair Design, Waterford U3 Pressurizer,' SI File No. 1501504.203.
8. Email from Chris Pickering (Entergy) to Moses Taylor (SI), dated 11/13/15 at 1:12 PM, Subject: 'FW: Pressurizer Input,' SI File No. 1501504.210.
9. Email from Michael Progler (Entergy) to Moses Taylor (SI), dated 11/14/15 at 11:52 AM, Subject: 'RE: SI Proposal No. 1501504 R0 for Evaluation of Fillet Weld between the Pressurizer Heater Sheath and Heater Sleeve at WSES, Unit 3,' SI File No. 1501504.211.
10. Not used.
11. Not used.
12. NRC Inspection Manual, Chapter 0326, 'Operability Determinations & Functionality Assessments for Conditions Adverse to Quality or Safety,' Issue Date 01/31/14.
13. SI Report No. 1501504.401, Rev. 0, 'Subject: Evaluation of the Fillet Weld between the Pressurizer Heater Sheath and Heater Sleeve at Waterford Steam Electric Station, Unit 3,' SI File No. 1501504.401.
14. ANSYS Mechanical APDL and PrepPost, Release 14.5 (w/ Service Pack 1 UP20120918), ANSYS, Inc., September 2012.
15. Entergy Design Input Record, EC 64156, Revision 0, EC Evaluation transmitted by E-mail from James W Hoss (Entergy) to Moses Taylor (SI), dated 5/4/16 at 12:49 PM, Subject: "RE: ASME Code, Section III Evaluation of the Pressurizer Heater Sheath to Heater Sleeve Fillet Weld Calculation 1501532.301," SI File No. 1501504.212.

Table 1: Material Properties for SA-213, TP316[1]

Temp (°F)	**E**[2] (10^3 ksi)	**S_m**[3] (ksi)	**S_y**[3] (ksi)	**S_u**[3] (ksi)	**α_{inst}**[4] (10^{-6} F^{-1})	**α_{avg}**[5] (10^{-6} F^{-1})
70	28.3	---	---	---	8.42	8.42
200	27.6	20.0	25.8	75.0	9.09	8.76
300	27.0	20.0	23.3	73.4	9.56	8.97
400	26.5	19.3	21.4	71.8	9.95	9.21
500	25.8	18.0	19.9	71.8	10.25	9.42
600	25.3	17.0	18.8	71.8	10.51	9.60
700	24.8	16.3	18.1	71.8	10.76	9.76

Notes: (1) All values are taken from Reference 1, Division 1 – Appendices.

(2) E denotes Young's modulus of elasticity.

(3) S_m, S_y, and S_u denote allowable stress, yield stress and ultimate tensile stress, respectively.

(4) α_{inst} denotes instantaneous coefficient of thermal expansion.

(5) α_{avg} denotes mean coefficient of thermal expansion.

Table 2: Material Properties for Alloy 690 / Alloy 52(1)

Temp (°F)	**E**(2) (10^3 ksi)	**S_m**(3) (ksi)	**S_y**(3) (ksi)	**S_u**(3, 6) (ksi	**α_{inst}**(4) (10^{-6} F^{-1})	**α_{avg}**(5) (10^{-6} F^{-1})
70	30.3	---	---	85.0	7.73	7.73
200	29.5	23.3	36.8	85.0	7.96	7.85
300	29.1	23.3	34.6	84.0	8.14	7.93
400	28.8	23.3	33.0	82.0	8.28	8.02
500	28.3	23.3	31.8	80.8	8.39	8.09
600	28.1	23.3	31.1	80.2	8.53	8.16
700	27.6	23.3	30.6	79.8	8.81	8.25

Notes: (1) All values, except S_u, are taken from Reference 1, Division 1 – Appendices.

(2) E denotes Young's modulus of elasticity.

(3) S_m, S_y, and S_u denote allowable stress, yield stress and ultimate tensile stress, respectively.

(4) α_{inst} denotes instantaneous coefficient of thermal expansion.

(5) α_{avg} denotes mean coefficient of thermal expansion.

(6) S_u values for Alloy 690 are not available in the ASME Code, 1989 Edition [1]. Therefore, the ASME Code, 1995 Edition [3] is used, as this is the first ASME Code Edition that includes Alloy 690 S_u material properties.

Table 3: Load Combinations

LOADS	Load Combinations			
	Design	Level A/B	Level C/D	Test
Pressure (psig)	2,485[(1)]	2,535[(2)]	2,535[(3)]	3,110[(4)]
Temperature (°F)	700[(1)]	400[(2)]	400[(3)]	400[(4)]
Dead Weight (lb)	40[(5)]	40[(5)]	40[(5)]	40[(5)]
Seismic Axial (lb)	N/A	30[(5)]	60[(5)]	N/A
Seismic Moment (in-lb)	N/A	111[(5)]	222[(5)]	N/A

Notes:
1. The Design Pressure and temperature are 2,485 psig and 700 ºF as in discussed Section 3.3.
2. The upset conditions pressure and temperature are 2,535 psig and 400°F, as discussed in Section 3.4, and are applied to Service Level A/B.
3. The upset conditions pressure and temperature are 2,535 psig and 400°F, as discussed in Section 3.4, and are applied to Service Level C/D.
4. The test pressure and temperature are 3,110 psig and 400°F, as discussed in Section 3.5.
5. The Dead Weight, OBE and DBE loads are listed in Section 3.6.

Table 4: Stress Criteria for ASME Code Class 1 Components

Load [5] Combination	P_m	P_L	$P_L + P_b$	$P_L + P_b + Q$
Design [1]	1.0 S_m	1.5 S_m	1.5 S_m	-
Level A/B [1, 2, 6]	1.0 S_m[6]	1.5 S_m[6]	1.5 S_m[6]	3.0 S_m
Level C [1, 4]	Greater of 1.0 S_y or 1.2 S_m	Greater of 1.5 S_y or 1.8 S_m	Greater of 1.5 S_y or 1.8 S_m	-
Level D [1, 3, 4]	Lesser of 0.7 S_u or 2.4 S_m	1.5 P_m Allowable	1.5 P_m Allowable	-
Test [1]	0.9 S_y	-	$1.35S_y$ (for $P_m \leq 0.67S_y$), or, $2.15S_y - 1.2P_m$ (for $0.67S_y < P_m \leq 0.9S_y$)	-

Notes:

1. Materials evaluated are shown in Table 1 and Table 2. The allowable used is dependent on the path evaluated.
2. The requirements of ASME Code, Section III, Subparagraph NB-3222.4 [1] for peak stresses and cyclic operation must be met.
3. Allowable requirements per ASME Code, Section III, Appendix F [1].
4. Service Level C and Service Level D are combined as one load combination, and the lower allowable values of Service Level C are used.
5. The allowable stresses for the design load combination are computed at the design temperature of 700°F, and the allowable stresses for other load combinations are computed at the maximum operating temperature of 400°F at the fillet weld location.
6. According to ASME Code, Section III, Subparagraph NB-3222.1, '*there are no specific limits established on the primary stresses in the Level A Limits.*' Conservatively, the primary stresses for Service Level A/B are evaluated using 1.0 S_m for P_m, and 1.5 S_m for P_L and $P_L + P_b$.

Table 5: Allowable Stress Intensities for SA-213, TP316[1, 4]

Load [3] Combination	P_m (psi)	P_L (psi)	$P_L + P_b$ (psi)	$P_L + P_b + Q$ (psi)
Design	8,150	12,225	12,225	-
Level A/B	9,650	14,475	14,475	28,950
Level C/D [2]	11,580	17,370	17,370	-
Test	9,630	-	14,445	-

Notes:

1. SA-213, TP316 allowable stresses are applicable to stress Paths 3, 4, 5, 8, 9 & 10, as shown in Figure 4.
2. Service Level C and Service Level D are combined as one load combination, and the lower allowable values of Service Level C are used.
3. The allowable stresses for the design load combination are computed at the design temperature of 700°F, and the allowable stresses for other load combinations are computed at the maximum operating temperature of 400°F at the fillet weld location.
4. The JEF of 0.5 is included in the calculation of the allowable stresses. The JEF is discussed in Section 5.2.

Table 6: Allowable Stress Intensities for Alloy 52 / Alloy 690[1, 4]

Load [3] Combination	P_m (psi)	P_L (psi)	$P_L + P_b$ (psi)	$P_L + P_b + Q$ (psi)
Design	11,650	17,475	17,475	-
Level A/B	11,650	17,475	17,475	34,950
Level C/D [2]	16,500	24,750	24,750	-
Test	14,850	-	22,275	-

Notes:

1. Alloy 52 / Alloy 690 allowable stresses are applicable to stress Paths 1, 2, 6, and 7, as shown in Figure 4.
2. Service Level C and Service Level D are combined as one load combination, and the lower allowable values of Service Level C are used.
3. The allowable stresses for the design load combination are computed at the design temperature of 700°F, and the allowable stresses for other load combinations are computed at the maximum operating temperature of 400°F at the fillet weld location.
4. The JEF of 0.5 is included in the calculation of the allowable stresses. The JEF is discussed in Section 5.2.

Table 7: Design Load Combination, Primary Stress Intensity Evaluation

Path (1)	General Primary Membrane						Primary Membrane-Plus-Bending					
	Stress Intensity (psi)						Stress Intensity (psi)					
	Pressure(2)	Dead(2) Weight	Total	Allowable (4)	Allowable (5) w/JEF	Accept	Pressure(3)	Dead(3) Weight	Total	Allowable (4)	Allowable (5) w/JEF	Accept
	P_m	P_m	P_m				$P_L + P_b$	$P_L + P_b$	$P_L + P_b$			
1 & 6	4,554	58	4,612	23,300	11,650	Yes	12,420	124	12,544	34,950	17,475	Yes
2 & 7	5,330	104	5,434	23,300	11,650	Yes	13,470	183	13,653	34,950	17,475	Yes
3 & 8	7,315	98	7,413	16,300	8,150	Yes	11,390	156	11,546	24,450	12,225	Yes
4 & 9	5,403	42	5,445	16,300	8,150	Yes	6,803	64	6,867	24,450	12,225	Yes
5 & 10	4,786	49	4,835	16,300	8,150	Yes	9,455	124	9,579	24,450	12,225	Yes

Notes:
1. Stress paths are shown in Figure 4.
2. The local stress intensity results, P_L, are conservatively used in place of P_m. P_L is obtained directly from the values of linearized membrane stress intensities.
3. The (inside or outside location) membrane-plus-bending stress intensity is obtained from the values of linearized membrane-plus-bending stress intensities, and conservatively classified as $P_L + P_b$. Note that the bending stress intensity is secondary, but is conservatively included.
4. Allowable stress criteria per Table 4, with properties taken from Table 1 and Table 2 at the Design Temperature of 700ºF.
5. To conservatively account for the fillet weld, a joint efficiency factor (JEF) is taken as 0.5 per Section 5.2.

Table 8: Service Level A/B Load Combination, Primary Stress Intensity Evaluation

Path [1]	General Primary Membrane							Primary Membrane-Plus-Bending						
	Stress Intensity (psi)							Stress Intensity (psi)						
	Pressure[2]	Dead[2] Weight	OBE[2]	Total	Allowable [4]	Allowable [5] w/JEF	Accept	Pressure[3]	Dead[3] Weight	OBE[3]	Total	Allowable [4]	Allowable [5] w/JEF	Accept
	P_m	P_m	P_m	P_m				$P_L + P_b$	$P_L + P_b$	$P_L + P_b$	$P_L + P_b$			
1 & 6	4,646	58	494	5,198	23,300	11,650	Yes	12,670	124	1,120	13,914	34,950	17,475	Yes
2 & 7	5,437	104	965	6,506	23,300	11,650	Yes	13,741	183	1,620	15,543	34,950	17,475	Yes
3 & 8	7,462	98	894	8,453	19,300	9,650	Yes	11,619	156	1,525	13,300	28,950	14,475	Yes
4 & 9	5,512	42	426	5,980	19,300	9,650	Yes	6,940	64	591	7,595	28,950	14,475	Yes
5 & 10	4,882	49	476	5,407	19,300	9,650	Yes	9,645	124	1,235	11,003	28,950	14,475	Yes

Notes:
1. Stress paths are shown in Figure 4.
2. The local stress intensity results, P_L, are conservatively used in place of P_m. P_L is obtained directly from the values of linearized membrane stress intensities. The stress intensity results due to pressure are scaled to correspond to the upset conditions pressure of 2,535 psig.
3. The (inside or outside location) membrane-plus-bending stress intensity is obtained from the values of linearized membrane-plus-bending stress intensities, and conservatively classified as $P_L + P_b$. Note that the bending stress intensity is secondary, but is conservatively included.
4. Allowable stress criteria per Table 4, with properties taken from Table 1 and Table 2 at the maximum operating temperature of 400°F.
5. To conservatively account for the fillet weld, a joint efficiency factor (JEF) is taken as 0.5 per Section 5.2.

Table 9: Service Level A/B Load Combination, Primary-Plus-Secondary Stress Intensity Range Evaluation

Path [1]	Primary-Plus-Secondary Membrane-Plus-Bending Stress Intensity Range (psi)							
	Pressure [2]	Dead Weight [3]	OBE [3, 6]	Thermal [3]	Total	Allowable [4]	Allowable [5] w/JEF	Accept
	$P_L + P_b$	$P_L + P_b$	$P_L + P_b$	Q	$P_L + P_b + Q$			
1 & 6	12,670	124	2,240	11,920	26,954	69,900	34,950	Yes
2 & 7	13,741	183	3,239	12,100	29,263	69,900	34,950	Yes
3 & 8	11,619	156	3,050	7,458	22,283	57,900	28,950	Yes
4 & 9	6,940	64	1,182	6,929	15,115	57,900	28,950	Yes
5 & 10	9,645	124	2,469	4,513	16,751	57,900	28,950	Yes

Notes:

1. Stress paths are shown in Figure 4.
2. The (inside or outside location) primary-plus-secondary membrane-plus-bending stress intensity due to pressure, $P_L + P_b$, is obtained from the values of linearized membrane-plus-bending stress intensities, and are scaled to correspond to the upset conditions pressure of 2,535 psig.
3. The (inside or outside location) primary-plus-secondary membrane-plus-bending stress intensity is obtained from the values of linearized membrane-plus-bending stress intensities.
4. Allowable stress criteria per Table 4, with properties taken from Table 1 and Table 2 at the maximum operating temperature of 400°F.
5. To conservatively account for the fillet weld, a joint efficiency factor (JEF) is taken as 0.5 per Section 5.2.
6. Full range of the seismic stress intensities are considered for the Service Level A/B primary-plus-secondary stress intensity range evaluation.

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Table 10: Service Level C/D Load Combination, Primary Stress Intensity Evaluation

Path (1)	General Primary Membrane							Primary Membrane-Plus-Bending						
	Stress Intensity (psi)							Stress Intensity (psi)						
	Pressure (2)	Dead (2) Weight	DBE (2)	Total	Allowable (4)	Allowable (5) w/JEF	Accept	Pressure (3)	Dead (3) Weight	DBE (3)	Total	Allowable (4)	Allowable (5) w/JEF	Accept
	P_m	P_m	P_m	P_m				$P_L + P_b$	$P_L + P_b$	$P_L + P_b$	$P_L + P_b$			
1 & 6	4,646	58	988	5,692	33,000	16,500	Yes	12,670	124	2,240	15,034	49,500	24,750	Yes
2 & 7	5,437	104	1,929	7,471	33,000	16,500	Yes	13,741	183	3,239	17,163	49,500	24,750	Yes
3 & 8	7,462	98	1,787	9,347	23,160	11,580	Yes	11,619	156	3,050	14,825	34,740	17,370	Yes
4 & 9	5,512	42	853	6,406	23,160	11,580	Yes	6,940	64	1,182	8,186	34,740	17,370	Yes
5 & 10	4,882	49	953	5,884	23,160	11,580	Yes	9,645	124	2,469	12,238	34,740	17,370	Yes

Notes:

1. Stress paths are shown in Figure 4.
2. The local stress intensity results, P_L, are conservatively used in place of P_m. P_L is obtained directly from the values of linearized membrane stress intensities. The stress intensity results due to pressure are scaled to correspond to the upset conditions pressure of 2,535 psig.
3. The (inside or outside location) membrane-plus-bending stress intensity is obtained from the values of linearized membrane-plus-bending stress intensities, and conservatively classified as $P_L + P_b$. Note that the bending stress intensity is secondary, but is conservatively included.
4. Allowable stress criteria per Table 4, with properties taken from Table 1 and Table 2 at the maximum operating temperature of 400°F.
5. To conservatively account for the fillet weld, a joint efficiency factor (JEF) is taken as 0.5 per Section 5.2.

Table 11: Test Load Combination, Primary Stress Intensity Evaluation

Path [(1)]	General Primary Membrane						Primary Membrane-Plus-Bending					
	Stress Intensity (psi)						Stress Intensity (psi)					
	Pressure[(2)]	Dead[(2)] Weight	Total	Allowable [(4)]	Allowable [(5)] w/JEF	Accept	Pressure[(3)]	Dead[(3)] Weight	Total	Allowable [(4)]	Allowable [(5)] w/JEF	Accept
	P_m	P_m	P_m				$P_L + P_b$	$P_L + P_b$	$P_L + P_b$			
1 & 6	5,699	58	5,758	29,700	14,850	Yes	15,544	124	15,667	44,550	22,275	Yes
2 & 7	6,671	104	6,775	29,700	14,850	Yes	16,858	183	17,041	44,550	22,275	Yes
3 & 8	9,155	98	9,252	19,260	9,630	Yes	14,255	156	14,410	28,890	14,445	Yes
4 & 9	6,762	42	6,804	19,260	9,630	Yes	8,514	64	8,578	28,890	14,445	Yes
5 & 10	5,990	49	6,038	19,260	9,630	Yes	11,833	124	11,957	28,890	14,445	Yes

Notes:
1. Stress paths are shown in Figure 4.
2. The local stress intensity results, P_L, are conservatively used in place of P_m. P_L is obtained directly from the values of linearized membrane stress intensities. The stress intensity results due to pressure are scaled to correspond to the hydrostatic test pressure of 3,110 psig.
3. The (inside or outside location) membrane-plus-bending stress intensity is obtained from the values of linearized membrane-plus-bending stress intensities, and conservatively classified as $P_L + P_b$. Note that the bending stress intensity is secondary, but is conservatively included.
4. Allowable stress criteria per Table 4, with properties taken from Table 1 and Table 2 at the maximum operating temperature of 400°F.
5. To conservatively account for the fillet weld, a joint efficiency factor (JEF) is taken as 0.5 per Section 5.2.

Table 12: Transient List for Fatigue Evaluation(1)

Transient	Cycles	Maximum Pressure (psia)	Minimum Pressure (psia)	Difference (psi)
Heatup	200	2,250	15	2,235
Cooldown	200	2,250	15	2,235
Normal Plant Variation	10^6	---	---	200
Upset Conditions	480	2,550	1,700	850
Loss of Secondary Pressure	5	2,250	150	2,100
Hydrostatic Test	10	3,125	15	3,110
Leak Test	200	2,250	15	2,235

Notes:

(1) All data are taken from Reference 15 except the minimum pressure for the Leak Test transient. The 15 psia value used is conservative compared to the 400 psia minimum pressure stated in Reference 15 since it results in a higher differential pressure for the test.

Table 13: ASME Code Fatigue Evaluation

(Per NB-3222.4(d))

NB-3222.4(d) [1] Condition	Determined Value	Allowable Value	Evaluation
1 – Atmospheric to Service Pressure Cycles	410 cycles	4,876 cycles	OK
2 – Normal Service Pressure Fluctuations	485 cycles	5,261 cycles	OK
3 – Temperature Difference – Startup and Shutdown	Insignificant (1)	243 °F	OK
4 – Temperature Difference – Normal Service	Insignificant (1)	17.4 °F	OK
5 – Temperature Difference – Dissimilar Materials	Insignificant (1)	287 °F	OK
6 – Mechanical Loads	4.0 ksi	13.6 ksi	OK

Note: (1) See Assumption #1.

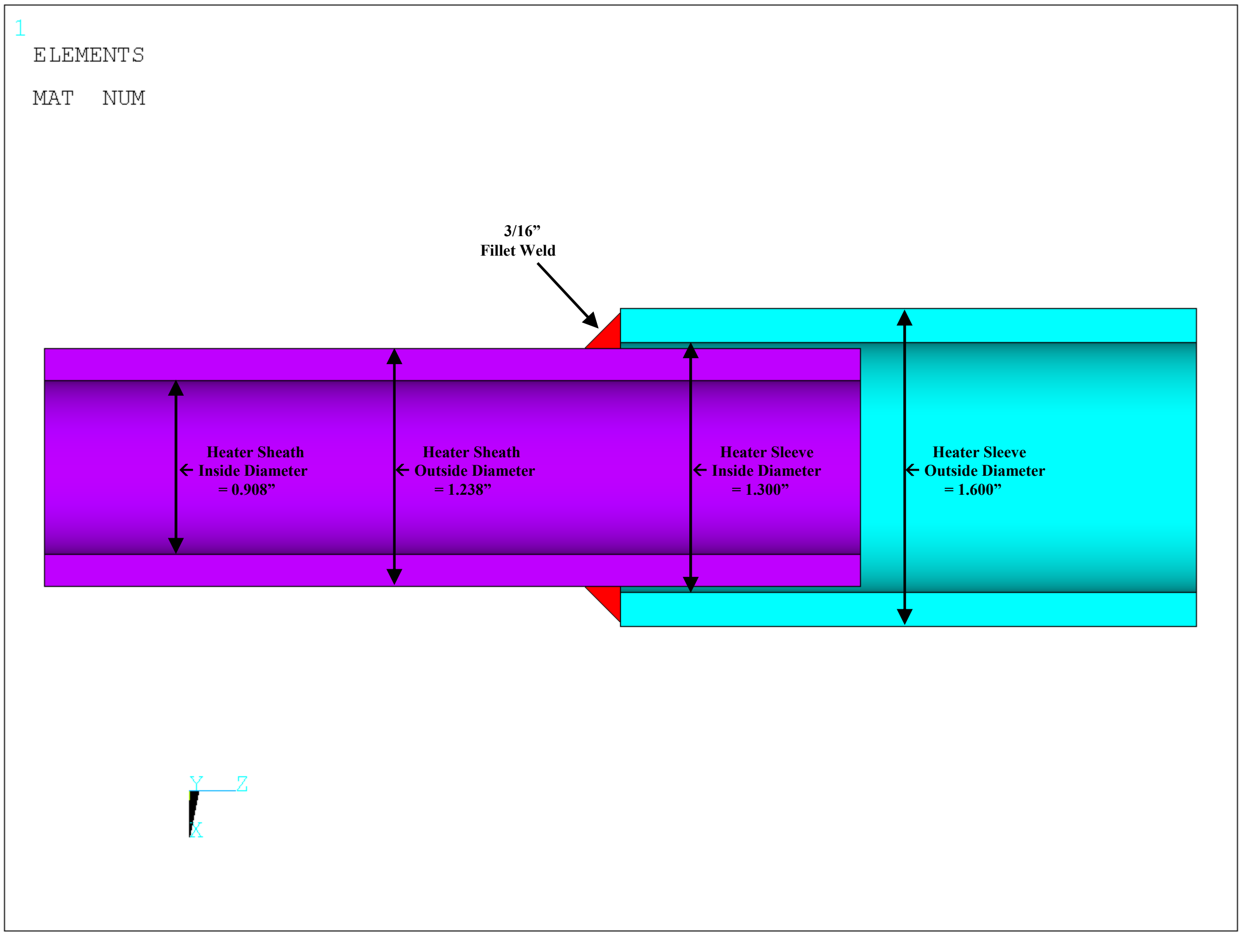

Figure 1. Finite Element Model Key Dimensions

(Note: Key model dimensions are listed in Section 3.2.)

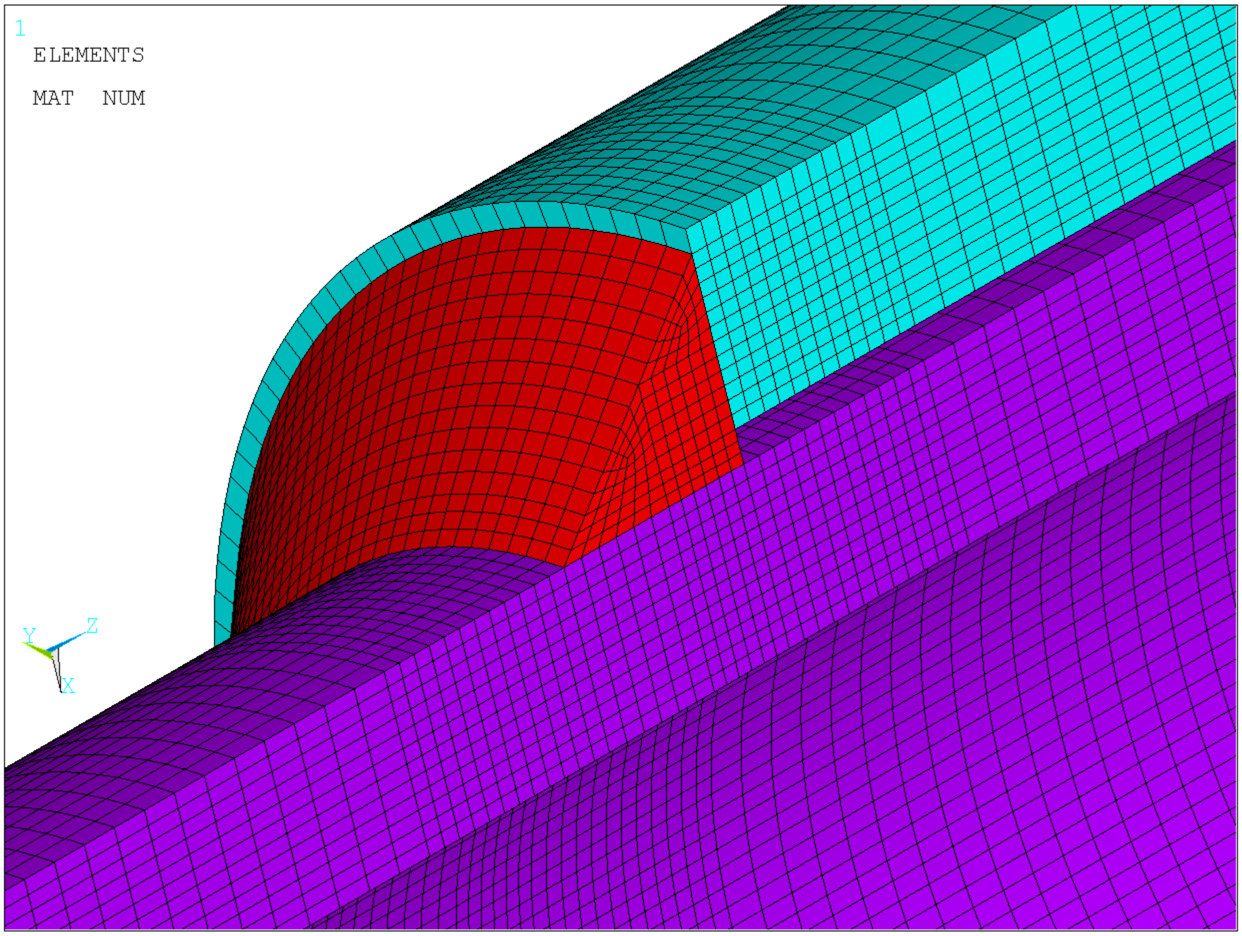

Figure 2. Finite Element Model Mesh

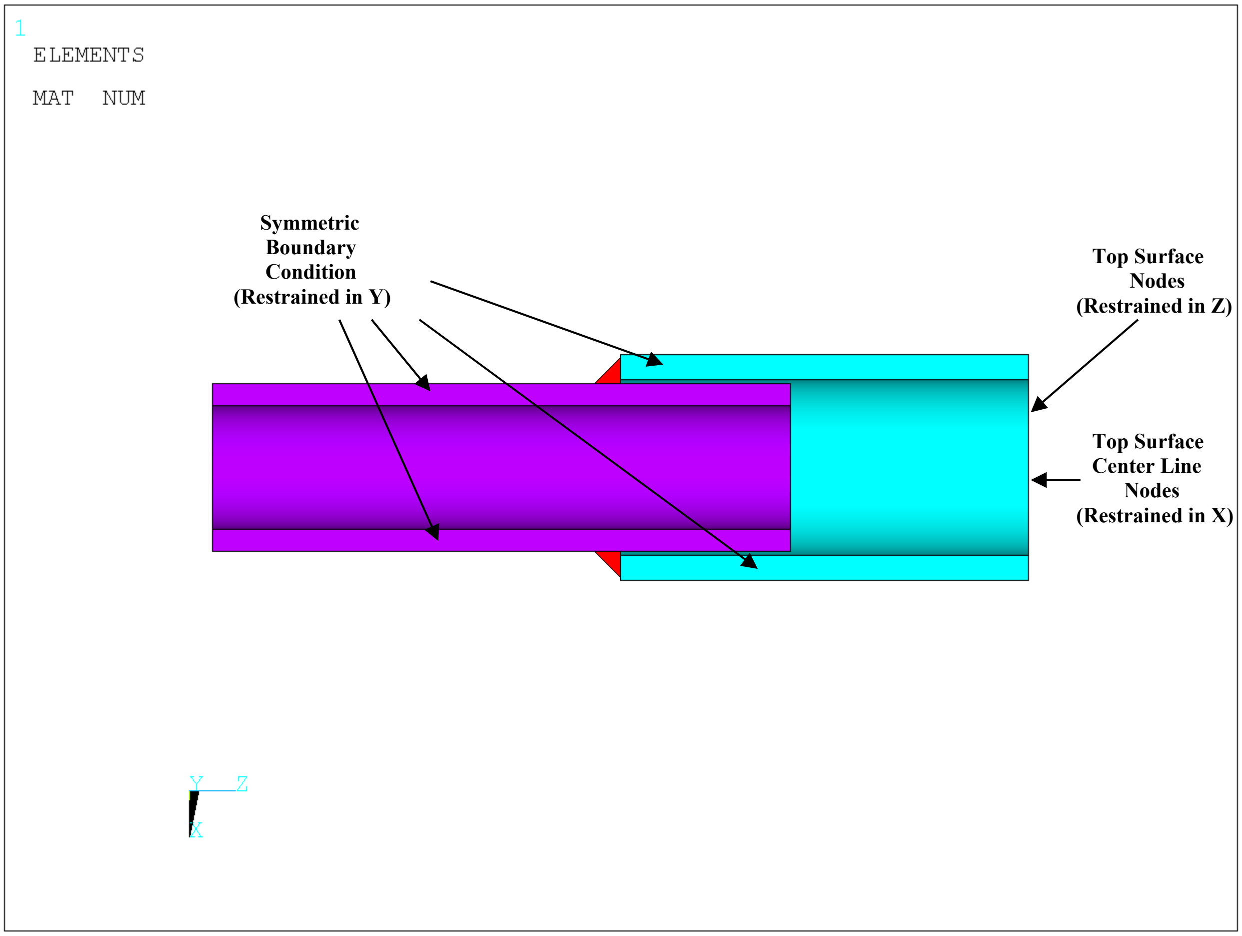

Figure 3. Finite Element Model Boundary Conditions

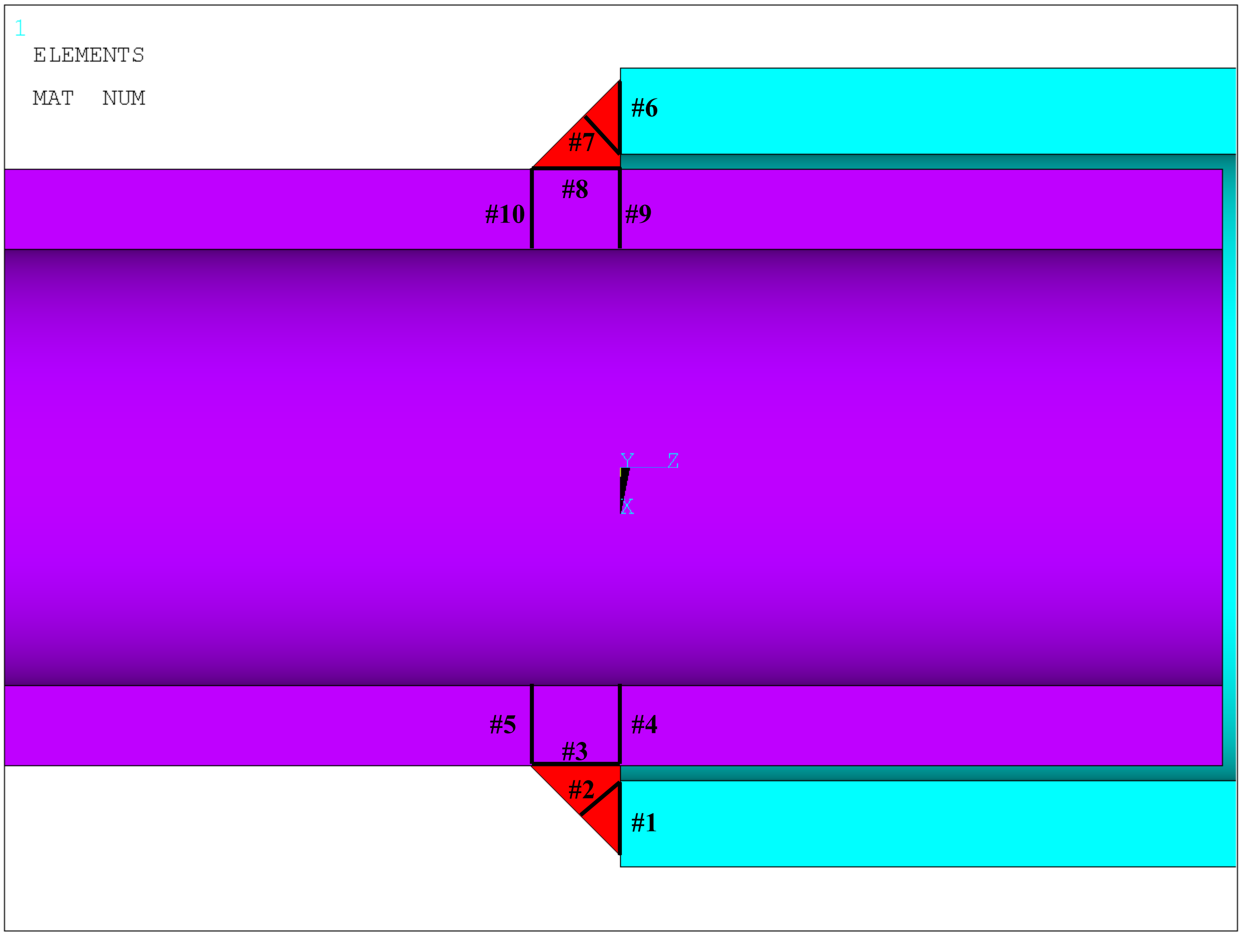

Figure 4. Linearized Stress Paths

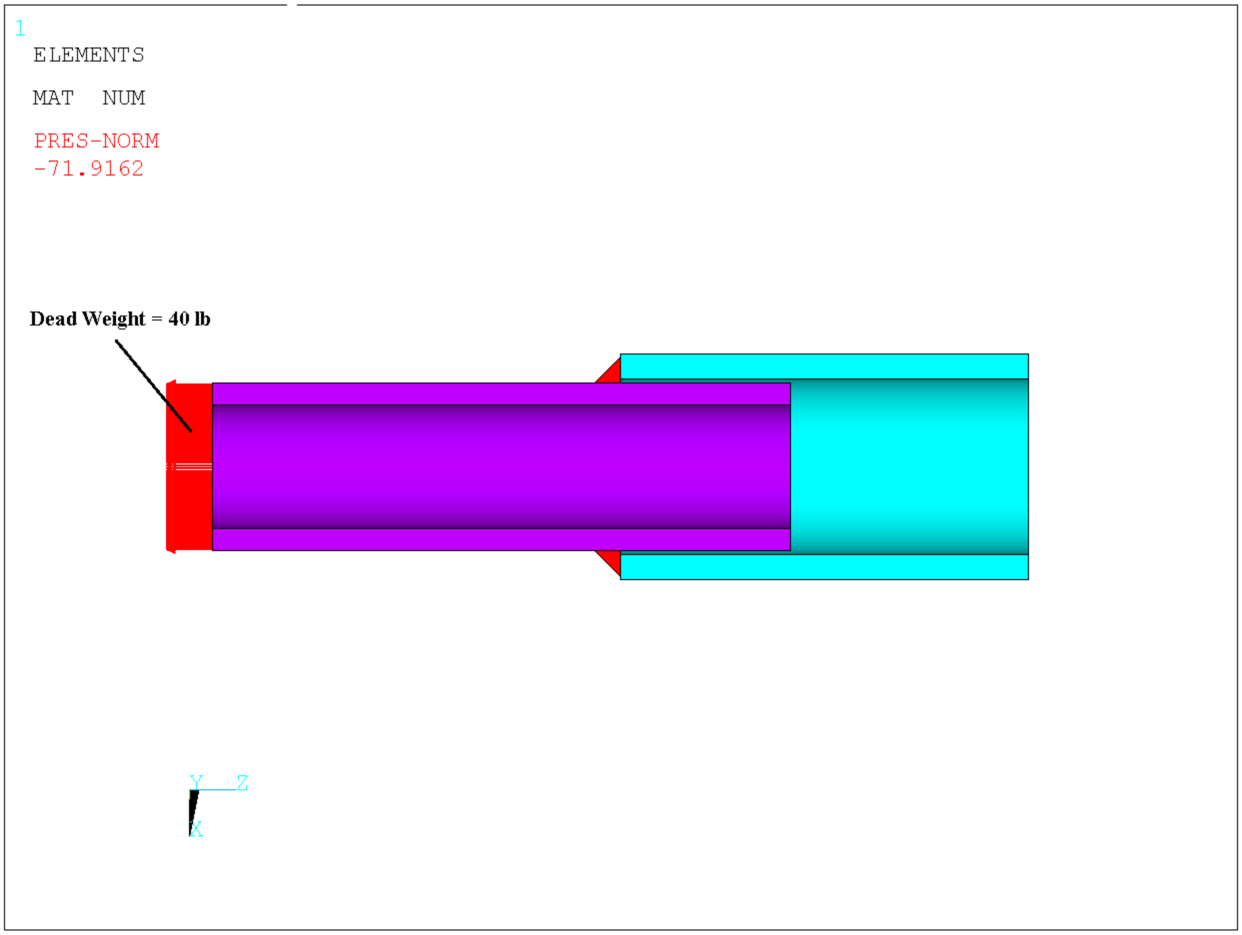

Figure 5. Dead Weight Application

(Units in figure are psi)

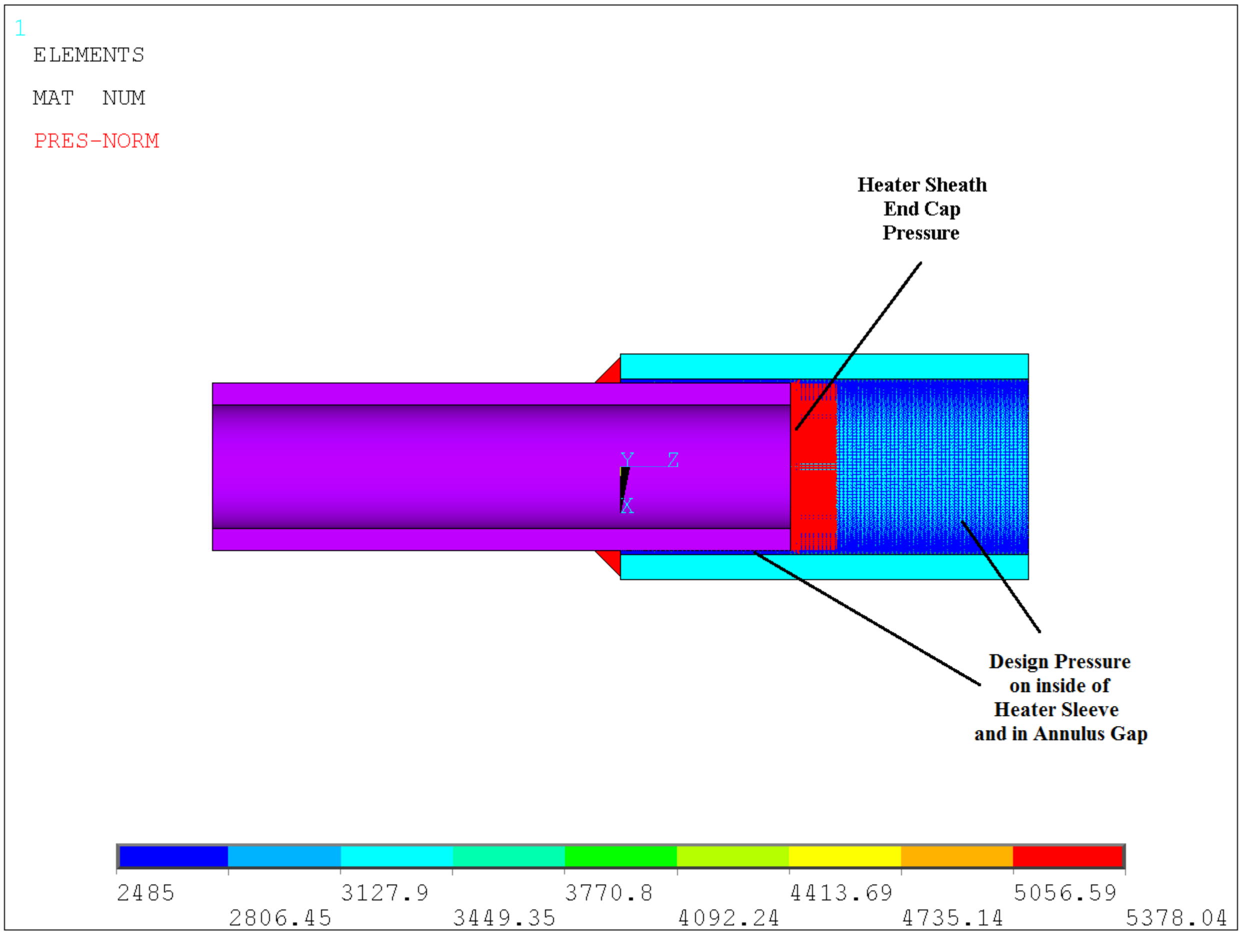

Figure 6. Design Pressure Application

(Units in figure are psi)

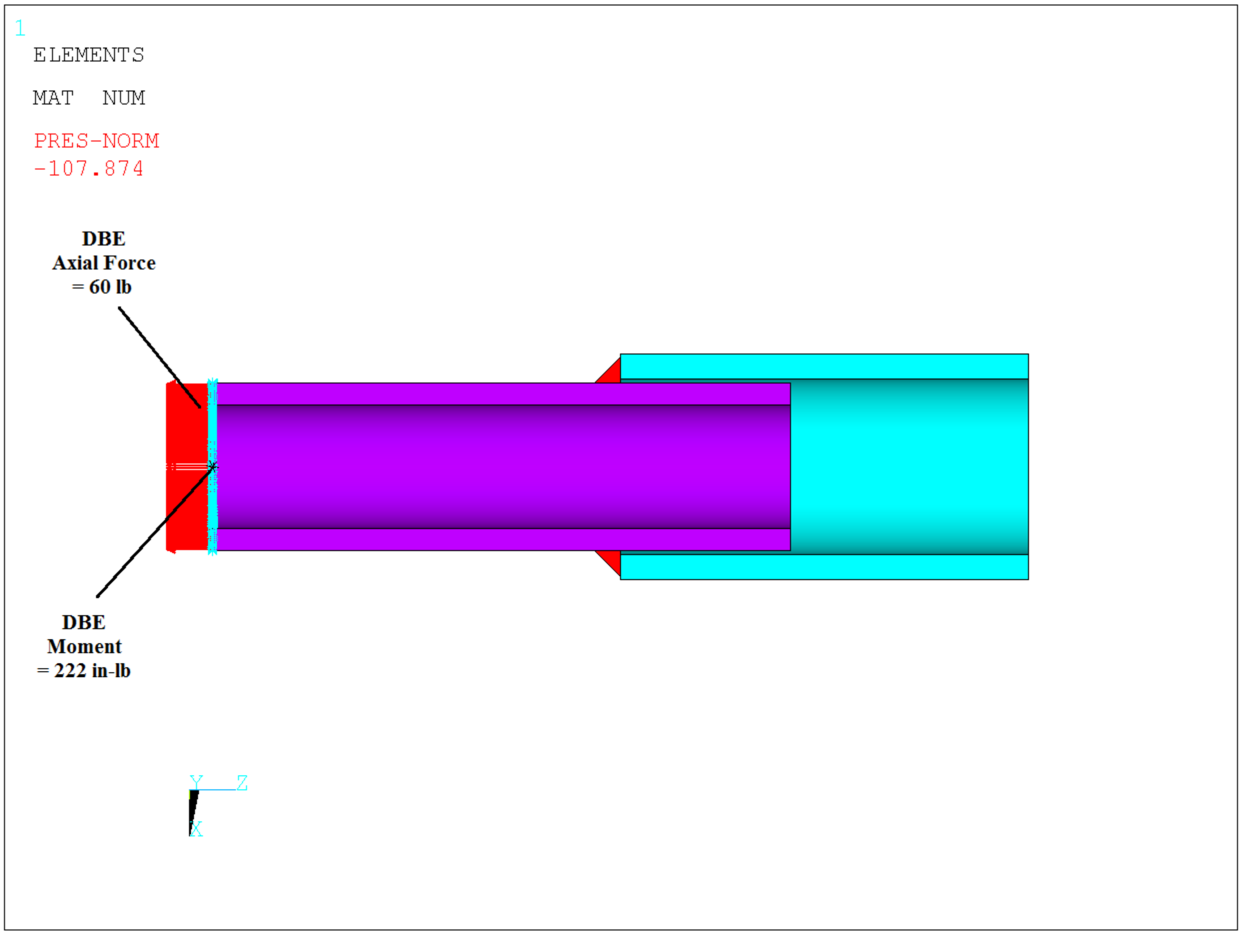

Figure 7. DBE Application

(Units in figure are psi)

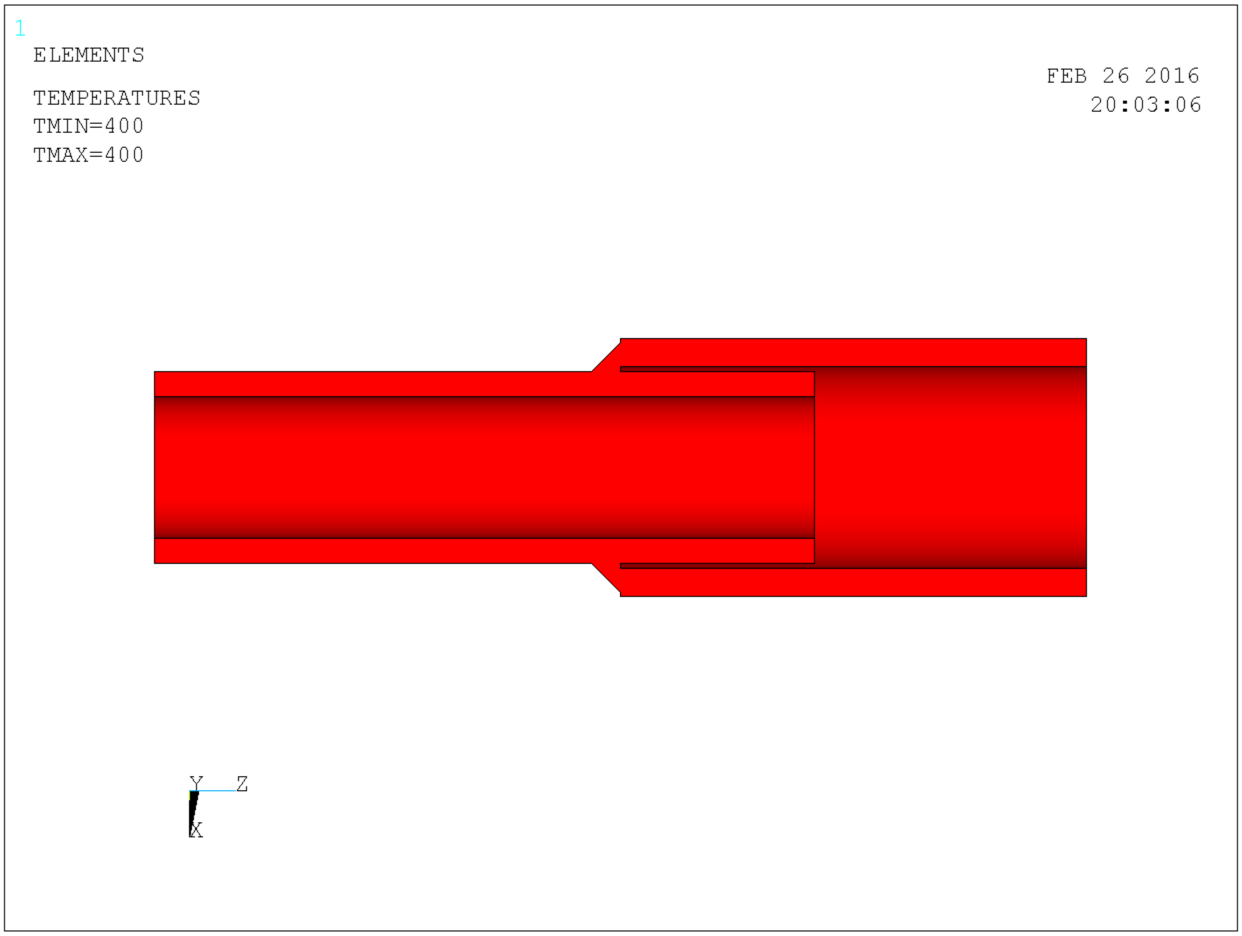

Figure 8. Thermal Application

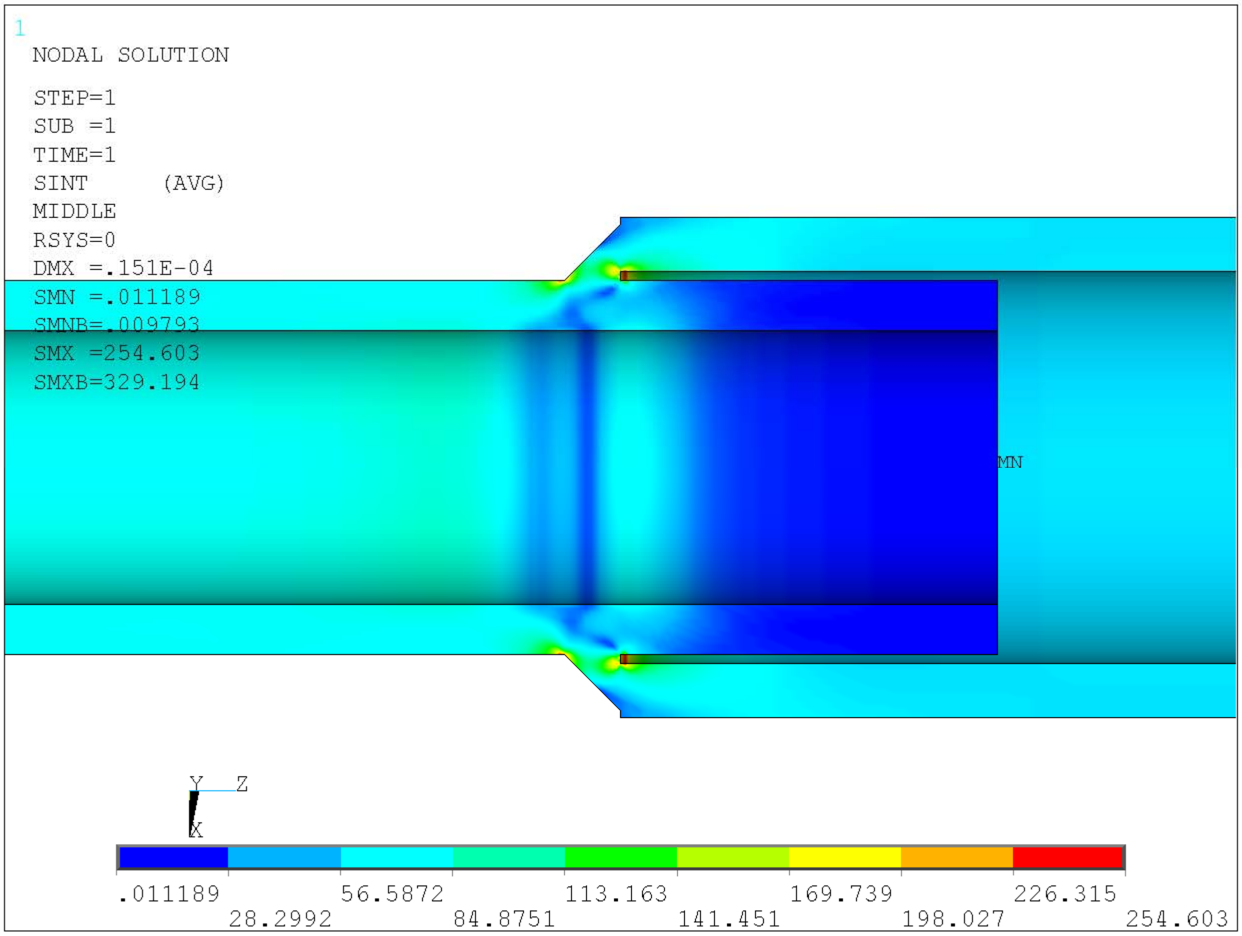

Figure 9. Dead Weight Stress Intensity Results

(Units in figure are psi)

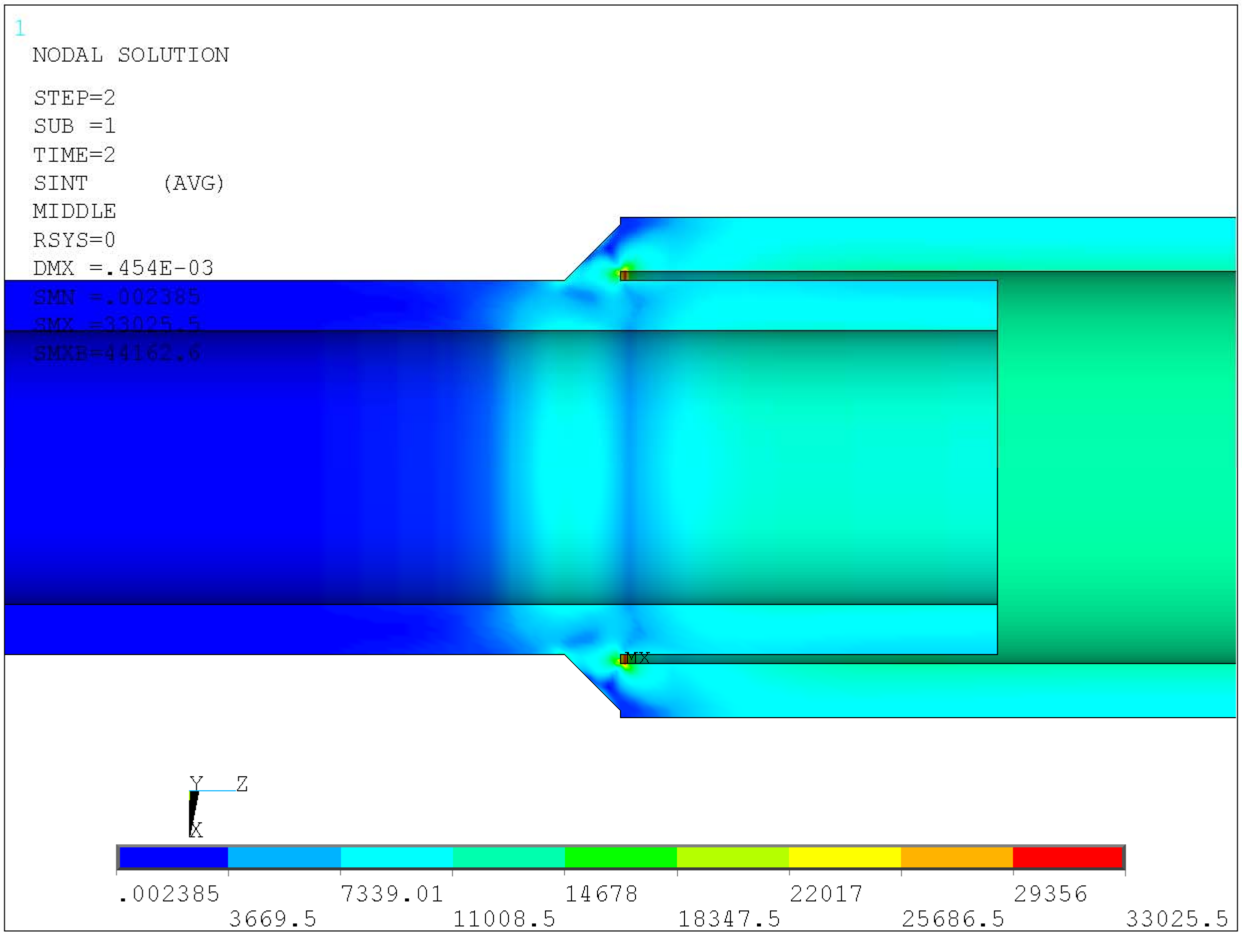

Figure 10. Design Pressure Stress Intensity Results

(Units in figure are psi)

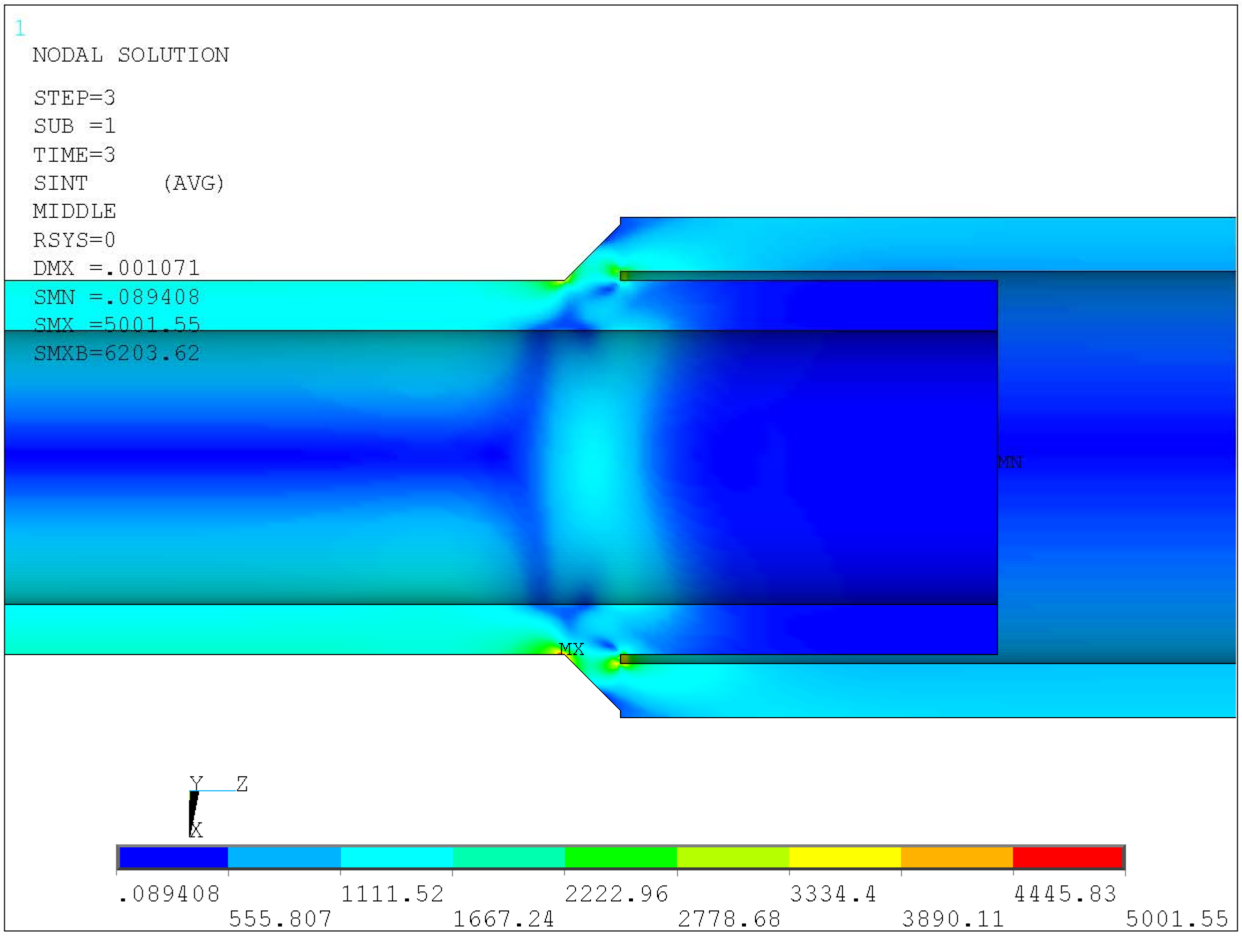

Figure 11. DBE Stress Intensity Results

(Units in figure are psi)

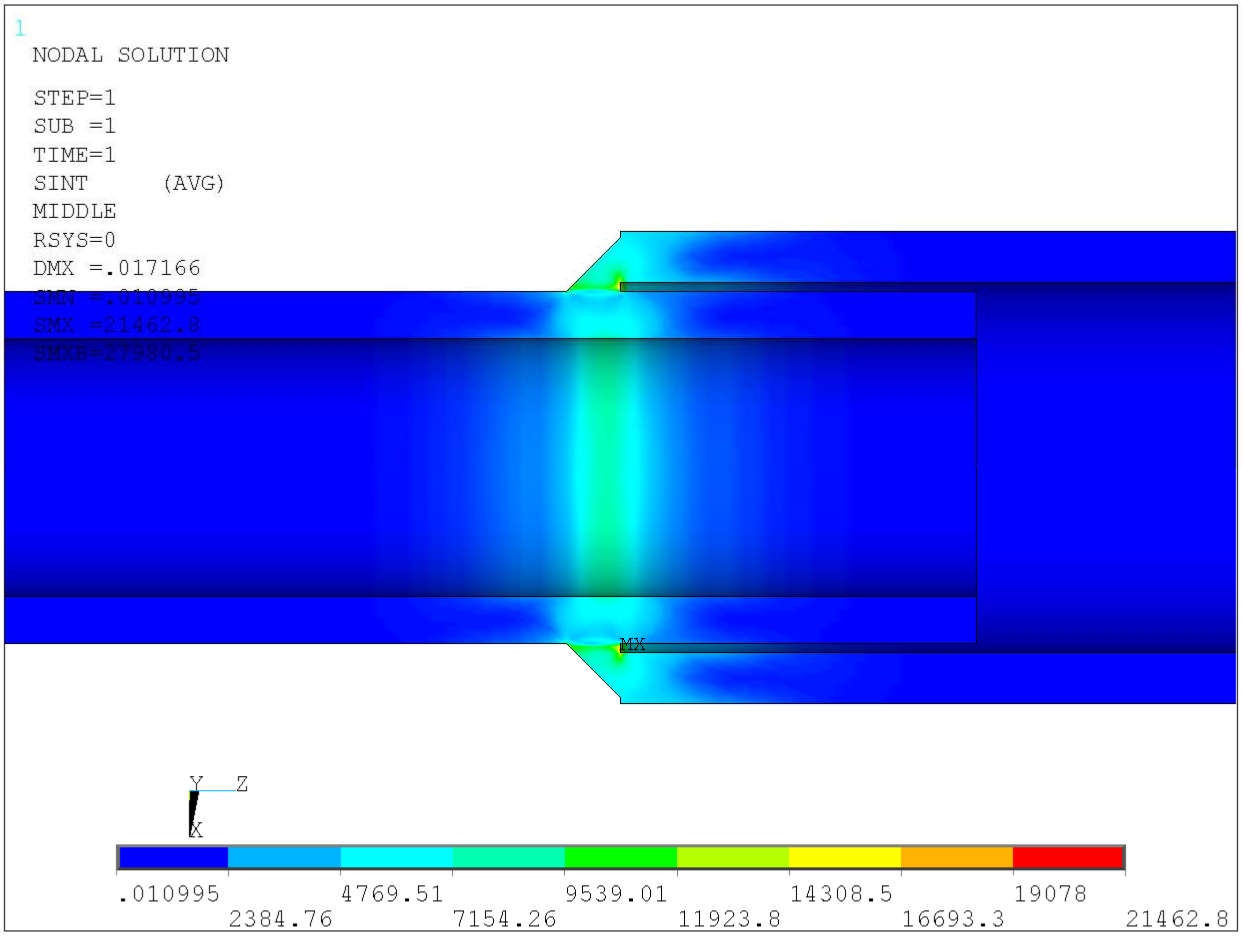

Figure 12. Thermal Stress Intensity Results

(Units in figure are psi)