Attachment 1
Structural Integrity Calculation Package, File No. PV-04Q-329

STRUCTURAL INTEGRITY Associates, Inc.	# CALCULATION PACKAGE	FILE No.: PV-04Q-329 PROJECT No.: PV-04Q

PROJECT NAME: Pressurizer Heater Sleeve Repair Evaluations

CLIENT: Arizona Public Service

TITLE: Heater Sleeve/Sheath Weld Evaluation – Stainless Steel Sheaths

Document Revision	Affected Pages	Revision Description	Project Mgr. Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1-7	Original Issue	11/11/04 R.A. Mattson	11/11/04 R.A. Mattson 11/11/04 A.F. Deardorff

Table of Contents

1.0 INTRODUCTION

The original configuration for the connection between the pressurizer heater sleeves and heater sheaths consisted of a nominal 1.66″ outside diameter (OD) sleeve, with an inside diameter (ID) of 1.273″, connected to a nominal 1.245″ OD sheath. The connection was made using a 3/16" fillet weld. The preemptive repair being implemented at Palo Verde consists of a sleeve with the same OD, but with a 1.30" ID, and the same heater sheath OD. The connection weld is assumed to be a 3/16″ fillet.

The original Stress Report [1] evaluated the integrity of this fillet weld for internal pressure and the effects of steady state temperature. The materials of construction were Alloy 600 for the sleeve and SA-213, Type 316 for the sheath. For the replacement sleeve, Alloy 690 material is used. The sheath is the same Type 316 stainless steel [2].

The purpose of this calculation is to determine acceptability of the current condition.

2.0 MATERIAL PROPERTIES

The Type 316 material properties used in the original Stress Report will remain unchanged, and are:

Property/Temperature	100°F	200°F	300°F	400°F	500°F	600°F	700°F
$E^{(1)}$	28.2	27.7	27.1	26.6	26.1	25.4	24.8
$\alpha^{(2)}$	9.16	9.34	9.47	9.59	9.70	9.82	9.93
$S_m^{(3)}$	20.0	20.0	20.0	19.2	17.9	17.0	16.3

Notes:
(1) The units for the modulus of elasticity are times 10^6 psi.
(2) The units for the coefficient of thermal expansion are times 10^{-6} inch/inch/°F.
(3) The units for the allowable stress intensity are ksi.

For the original Alloy 600 sleeve material, the following properties were used:

Property/Temperature	100°F	200°F	300°F	400°F	500°F	600°F	700°F
$E^{(1)}$	31.5	30.9	30.5	30.0	29.6	29.2	28.6
$\alpha^{(2)}$	7.20	7.40	7.56	7.70	7.80	7.90	8.00
$S_m^{(3)}$	23.3	23.3	23.3	23.3	23.3	23.3	23.3

Notes:
(1) The units for the modulus of elasticity are times 10^6 psi.
(2) The units for the coefficient of thermal expansion are times 10^{-6} inch/inch/°F.
(3) The units for the allowable stress intensity are ksi.

For the Alloy 690 replacement sleeve material, the following properties were obtained from the ASME Code [3]:

Property/Temperature	100°F	200°F	300°F	400°F	500°F	600°F	700°F
$E^{(1)}$	-	29.5	29.1	28.8	28.3	28.1	27.6
$\alpha^{(2)}$	7.76	7.85	7.93	8.02	8.09	8.16	8.25
$S_m^{(3)}$	23.3	23.3	23.3	23.3	23.3	23.3	23.3

Notes: (1) The units for the modulus of elasticity are times 10^6 psi.
(2) The units for the coefficient of thermal expansion are times 10^{-6} inch/inch/°F.
(3) The units for the allowable stress intensity are ksi.

Thermal stresses are directly related to the modulus of elasticity times the coefficient of thermal expansion for the materials being welded. Below is a comparison of E times α for the materials of interest:

Property/Temperature	100°F	200°F	300°F	400°F	500°F	600°F	700°F
$E\alpha$ (Alloy 600)	226.8	228.7	230.6	231.0	230.9	230.7	228.8
$E\alpha$ (Alloy 690)	-	231.6	230.8	231.0	228.9	229.3	227.7
$E\alpha$ (Type 316)	258.3	258.7	256.6	255.1	253.2	249.4	246.3

The increase in thermal stress can be estimated by solving the following equation, assuming that the weld stress is proportional to the differential expansion between the heater sleeve and the heater sheath:

$$\sigma = \sigma_0 \frac{(E_{ss}\alpha_{ss} - E_{690}\alpha_{690})}{(E_{ss}\alpha_{ss} - E_{600}\alpha_{600})}$$

Solving the above equation for the values presented above yields stress ratios $[(E_{ss}\alpha_{ss} - E_{690}\alpha_{690})/(E_{ss}\alpha_{ss} - E_{600}\alpha_{600})]$ as follows:

200°F	300°F	400°F	500°F	600°F	700°F
0.90	0.99	1.0	1.09	1.07	1.06

Therefore, the increase in thermal stress when using Alloy 690 material in lieu of Alloy 600 material is bounded by 10%. This will conservatively be used as a multiplication factor on total pressure plus thermal stress.

3.0 EVALUATION

The original Stress Report evaluated the sleeve to sheath weld for general primary stress, primary membrane-plus-bending stress, primary-plus-secondary stress, and primary-plus-secondary-plus-peak stress, which is used in the fatigue evaluation. The new 3/16″ fillet weld has a throat which is reduced from that originally evaluated due to the increase in gap between the heater sleeve and sheath. This increase in gap also results in an increase in stress due to internal pressure.

The throat of the fillet weld evaluated in the original Stress Report was 0.1227″. For the new configuration, the throat can be calculated as follows:

$$\begin{aligned} \text{throat} &= (0.6225 + 0.1875 - 0.65) \cos 45^\circ \\ &= 0.1131'' \end{aligned}$$

The applied axial pressure force used in the original analysis was 3.182 kips, whereas the revised applied axial pressure force for the new configuration is:

$$\begin{aligned} F &= (\pi)(2{,}500)(0.65)^2 \\ &= 3.318 \text{ kips} \end{aligned}$$

For the primary stress evaluation, the original calculated stress is 6.48 ksi, which is less than the allowable stress value of 9.78 ksi for the Type 316 material. For the new configuration, the stress is increased by the increase in force (3.318/3.182) and by the decrease in the throat of the fillet weld (0.1227/0.1131). The calculated primary stress is, therefore:

$$\begin{aligned} P_m &= (6.48)(3.318/3.182)(0.1227/0.1131) \\ &= 7.33 \text{ ksi} < 9.78 \text{ ksi} = 0.6\ S_m \end{aligned}$$

Therefore, primary stress criteria are maintained.

Primary membrane-plus-bending stresses were not explicitly calculated in the original Stress Report since there are no primary bending loads on the fillet weld. However, the conservative methodology used in the Stress Report [4] for the other unit will be included herein, in which the bending component of stress was conservatively assumed to be primary.

The reported maximum stress intensity [4] is 18.31 ksi, with an allowable stress intensity of 34.9 ksi for Alloy 600 material. This calculated value will be increased due to the factors cited above. However, the throat factor will be squared in order to account for bending across the throat as opposed to pure shear.

The calculated primary membrane-plus-bending stress intensity is, therefore:

$$P_L + P_b = (18.31)(3.318/3.182)(0.1227/0.1131)^2$$
$$= 22.5 \text{ ksi} < 24.4 \text{ ksi} = 1.5\ S_m \text{ for Type 316 material}$$

Therefore, primary membrane-plus-bending stress criteria are maintained.

For the primary-plus-secondary stress evaluation, the reported maximum stress intensity is 30.35 ksi, with an allowable stress intensity of 48.9 ksi. This calculated value will be increased due to the factors cited above. However, the throat factor will be squared in order to account for bending across the throat as opposed to pure shear.

The calculated primary-plus-secondary stress intensity is, therefore:

$$P_L + P_b + Q = (30.35)(1.10)(3.318/3.182)(0.1227/0.1131)^2$$
$$= 41.0 \text{ ksi} < 48.9 \text{ ksi} = 3.0\ S_m$$

Therefore, primary-plus-secondary stress criteria are maintained.

The maximum calculated primary-plus-secondary-plus-peak stress intensity is 141.75 ksi, based upon the use of a stress concentration factor of 5.0. Again using the above ratio with a pressure increase factor for the trip transient of (2.55/2.50), the calculated primary-plus-secondary-plus-peak stress intensity is:

$$P_L + P_b + Q + F = (141.75)(2.55/2.50)(1.10)(3.318/3.182)(0.1227/0.1131)^2$$
$$= 195.2 \text{ ksi}$$

The allowable number of cycles for an alternating stress of 97.6 ksi is about 1,950 cycles. For 1,050 total cycles [1], considering a 60 year life, the cumulative usage factor may be bounded by (1,050/1,950), or 0.54, which is less than the allowable value of 1.0.

4.0 CONCLUSIONS

Based upon the above evaluations, the use of a 1.30″ ID heater sleeve is acceptable relative to the criteria contained within the ASME Code. In addition, the tolerance on the heater sheath (maximum diametrical clearance between the components of 0.062") has been evaluated, with the following results:

$$P_m = 7.49 \text{ ksi} < 9.78 \text{ ksi} = 0.6\ S_m$$
$$P_L + P_b = 23.5 \text{ ksi} < 24.4 \text{ ksi} = 1.5\ S_m$$
$$P_L + P_b + Q = 42.8 \text{ ksi} < 48.9 \text{ ksi} = 3.0\ S_m$$
$$U = 0.62 < 1.0$$

5.0 REFERENCES

1. Combustion Engineering, Inc., "Analytical Report for Arizona Unit No. 3 Pressurizer," Report Number CENC-1490, October 1981.
2. Framatome ANP, Inc. "Heater Element Assembly," Drawing Number 5042376, Revision 1/ Watlow Electric Mfg. Co., "Pressurizer Heater," Drawing Number WDG-3580, 8/15/80.
3. ASME Boiler and Pressure Vessel Code, 1995 Edition with 1997 Addenda.
4. Combustion Engineering, Inc., "Analytical Report for Arizona Unit No. 1 Pressurizer," Report Number CENC-1336, August 1978.