Attachment 2
Structural Integrity Calculation Package, File No. PV-04Q-330

STRUCTURAL INTEGRITY Associates, Inc.	CALCULATION PACKAGE	FILE No.: PV-04Q-330 PROJECT No.: PV-04Q

PROJECT NAME: Pressurizer Heater Sleeve Repair Evaluations

CLIENT: Arizona Public Service

TITLE: Heater Sleeve/Sheath Weld Evaluation – Alloy 600 Sheaths

Document Revision	Affected Pages	Revision Description	Project Mgr. Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1-6	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 only, since all materials were the same. The materials of construction were Alloy 600 for the sleeve and sheath. For the replacement sleeve, Alloy 690 material is used. The sheath is the same Alloy 600 material [2].

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

Since thermal steady state stress analyses were not performed for the units with the same sleeve and sheath material, material's information will be taken from another unit's Stress Report that has Type 316 stainless steel sheaths [3].

2.0 MATERIAL PROPERTIES

The Type 316 material properties used in the original Stress Report [3] 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 [1]:

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 [4]:

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 stresses, which are calculated in Reference 3, can be estimated by solving the following equation:

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

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

200°F	300°F	400°F	500°F	600°F	700°F
-0.10	-0.01	0.00	0.09	0.07	0.06

Since the thermal stresses due to the Alloy 600/690 property differences are very small and are less than 10% of those for the stainless steel/Alloy 600 combination, the thermal stresses due to the differences between Alloy 600 and Alloy 690 materials will not be considered further.

3.0 EVALUATION

The original Stress Reports [1] evaluated the sleeve to sheath weld for general primary stress, primary membrane-plus-bending 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:

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

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:

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

For the primary stress evaluation, the original calculated stress is 6.48 ksi in the fillet weld, which is less than the allowable stress value of 13.98 ksi for the Alloy 600 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:

$$P_m = (6.48)(3.318/3.182)(0.1227/0.1131) = 7.33 \text{ ksi} < 13.98 \text{ ksi} = 0.6\, S_m$$

Therefore, primary stress criteria are maintained.

For the primary membrane-plus-bending stress evaluation, the reported maximum stress intensity is 18.31 ksi, with an allowable stress intensity of 34.9 ksi. This is very conservative in that the bending portion of the total stress is secondary. 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:

$$P_L + P_b = (18.31)(3.318/3.182)(0.1227/0.1131)^2 = 22.5 \text{ ksi} < 34.9 \text{ ksi} = 1.5\, S_m$$

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

The maximum calculated primary-plus-secondary-plus-peak stress intensity is 81.55 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:

$$P_L+P_b+Q+F = (81.55)(2.55/2.50)(3.318/3.182)(0.1227/0.1131)^2$$
$$= 102.1 \text{ ksi}$$

The allowable number of cycles for an alternating stress of 51.0 ksi is greater than 20,000 cycles. For 1,050 total cycles [1], considering a 60 year life, the cumulative usage factor is (1,050/(20,000), or 0.05, 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. It is understood that any effect of thermal stress has not been considered herein. However, the effect should be small as compared to that evaluated for the Alloy 600/stainless steel junction in Reference 3, and the margins relative to acceptance criteria are large. In addition, the tolerance on the heater sheath (maximum diametrical clearance between the components of 0.062") has been evaluated, with the following results:

$$P_m = 7.49 \text{ ksi} < 13.98 \text{ ksi} = 0.6\ S_m$$
$$P_L+P_b = 23.5 \text{ ksi} < 34.9 \text{ ksi} = 1.5\ S_m$$
$$U = 0.05 < 1.0$$

5.0 REFERENCES

1. Combustion Engineering, Inc., "Analytical Report for Arizona Unit No. 1 Pressurizer," Report Number CENC-1336, August 1978/ Combustion Engineering, Inc., "Analytical Report for Arizona Unit No. 2 Pressurizer," Report Number CENC-1395, August 1979.
2. General Electric, "1¼" Dia. Pressurizer Heater-50KW," Drawing Number 24D505199, Revision J.
3. Combustion Engineering, Inc., "Analytical Report for Arizona Unit No. 3 Pressurizer," Report Number CENC-1490, October 1981.
4. ASME Boiler and Pressure Vessel Code, 1995 Edition with 1997 Addenda.