WCAP-14182
Addendum 1

SUPPLEMENTAL LEAK AND TENSILE TEST RESULTS FOR DEGRADED HEJ SLEEVED TUBES IN MODEL 44/51 S/G's

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1.0 INTRODUCTION

A proposed criteria to address potential degradation within the parent tube region of tubes in the Point Beach Unit 2, D C. Cook Unit 1, Kewaunee and Zion Unit 1 plants which have hybrid expansion joint (HEJ) sleeves installed was presented in WCAP-14157. The basis and test program supporting the proposed criteria utilized very conservative approaches and methodology to establish the individual components of the criteria. A supplemental testing program was performed which further supplements the technical basis of the proposed criteria. This report outlines the additional program and presents its results.

2.0 PURPOSE

The purpose of this report is to describe in detail the supplemental test program for potentially degraded HEJ's in the parent tube region, to discuss the test results, and to relate these results to the originally presented criteria.

3.0 TEST SETUP and SPECIMEN PREPARATION

3.1 Leak Testing

Leak testing was performed at identical temperature and pressure conditions as the test results presented in WCAP-14157. Those conditions were:

- elevated specimen temperature of 600°F,
- differential pressure leakage measurements at primary-to-secondary pressure differences of 1600 psi and 2560 psi.

Additionally, leak test data was gathered at a primary-to-secondary pressure differential of 2100 psi, to use as a mid-range data point. The 1600 psi differential is used to assess the leakage potential of degraded HEJ's at normal operating conditions. However, in order to maintain a liquid environment on the primary side, the pressure had to be elevated above the saturation pressure at 600°F. The 2560 psi differential represents the maximum primary-to-secondary differential the plant could experience during recovery from a double-ended guillotine rupture of the main steam pipe outside of containment but upstream of the main steam line isolation valves, coupled with a loss of offsite power.

Heat tape wrapped around the joint area of the specimens provided the heat input. The test media passed through two preheaters prior to entering the specimen. Escaping primary side test media was condensed, collected and measured. A tube of larger diameter than the test specimen was placed around the specimen and sealed at the top. Cooling coils were wrapped around the outer tube to cool the tube, thereby condensing the escaping steam as it impinged upon the cooled tube. Leakage measurement was either done by counting individual droplets of condensate or by collecting the condensate in a graduated container if the leakage was large.

Temperature measurement devices used to indicate the fluid and tube temperatures were calibrated, and the calibration periods were valid at the time of testing.

3.2 Tensile Testing

Tensile testing was performed to establish the point at which a potentially degraded HEJ sleeved tube would experience plastic overload failure in the non-degraded ligament section of the tube. The proposed acceptance criteria defines a maximum beginning of cycle crack arc length such that a non-degraded ligament which provides for structural integrity pursuant with the recommendations of Regulatory Guide 1.121 is anticipated at the end of the operating cycle.

Tests were performed at room temperature and at 600°F in a SATEC™, 120,000 lb maximum capacity testing machine. A laboratory furnace with a heated zone of 4 inches was placed around the tube/sleeve assembly and provided the heat input. A thermocouple was attached to the outside diameter of the tube in the joint area. Temperature escalation was performed in 50°F increments and the temperature was held at 600° for 15 minutes prior to tensile loading.

The calibration of the thermocouples and the load cell of the testing machine were current.

3.3 Specimen Preparation

Test specimens using Alloy 690 sleeve material were prepared to simulate throughwall cracks over varying arc lengths. Tubes for tensile testing were slit over 120°, 180°, and 240° of the tube circumference while leak test specimens were slit over 240°. The slits in the tube were machined using a 0.020 inch wide slitting wheel. Sleeves were installed using a bladder expansion process and the current field approved hydraulic expansion computer program. The tube/sleeve combinations were then mechanically (roll) expanded. The height of the roller was adjusted so that the bottom of the roller flat length (top of the hardroll lower transition) was coincident with the slit in the tube. Several specimens were also prepared with the slit located approximately 0.08 inch above the edge of the flat, in the hardroll flat length area. These specimens used an electron discharge machining (EDM) process to produce the slits. The EDM slits were produced prior to sleeve installation.

Dimensional data was recorded after hydraulic expansion and also after roll expansion. Roll expansion data was taken to show that the roll was produced according to the objective of locating the top of the lower transition coincident with the slit in the tube. Specimen slit angles and material heats are furnished in Table 1. Data is also contained in Table 1 which indicates the flat roll dimension from the tangent point of the bottom of the hardroll upper transition and roll flat to the edge of the slit for some of the specimens. Both 1X and 10X optical comparitor data are provided in Table 1. Dimensional data regarding the hydraulic expansion and roll expansion processes are provided in Table 2. The data in Table 2 shows that for all specimens but numbers PBU2-011 and PBU2-014 the slits were located either immediately at or within 1/16 of an inch of the top of the hardroll lower transition. This is evidenced by the fact that the dimensional data of Table 2 shows that immediately above the slit the diameters (Dim. C) are equal to or 1 mil larger than the diameter at the mid-point of the roll expansion (Dim. B). This phenomena of the diameters being 1 mil larger at the ends of the roll expansion is normal and can be detected in field eddy current dimensional recordings. In Table 2, the diameters at 1/16 inch below the slit and 1/8 inch below the slit are furnished as Dim D, and Dim. E, respectively. In some cases the diameter at 1/4 inch below is recorded as Dim. F.

Several specimens were also prepared using Alloy 600 tube and Alloy 600 sleeve material. For these specimens two tube sections were butted together at the approximate location of the top of the hardroll lower transition. After hydraulic expansion the tube section below the

transition was displaced downwards, creating a gap between the tube sections. Specimens were then roll expanded with the top of the roll transition located at the edge of the tube.

4.0 TEST PROGRAM AND RESULTS

4.1 Leak Test Program

The leak testing program was designed to provide a conservative leakage assessment of potentially degraded parent tubes in the HEJ lower hardroll transition. All specimens were produced with the intent to locate the upper edge of the transition at the tube slits. At this location the leakage would be conservative for cracking lower in the transition. The throughwall slits would also provide conservative data with regard to leakage since the inherent tortuosity of stress corrosion cracking upon leakage capability was eliminated. A schematic of the slitted leak test specimens is given in Figure 2.

After elevated temperature leak rate testing, the degraded (slit) samples were attempted to be pressurized to failure. However, leakage through the slit prevented significant pressure accumulation to produce a joint failure. These tests ultimately were used to establish the maximum pressure capability of the joint as limited by leakage, and provided data on the hydraulic restriction afforded by the hardroll interaction. The maximum pressure obtained during the second pressurization were 6780 psi, 5400 psi and 4400 psi for samples PBU2-002, PBU2-003 and PBU2-004, respectively. No apparent motion of the sleeve was detected. Specimen PBU2-002 was evidenced to have opened the slit width to about 0.04 inch at the midpoint of the slit. The end cap loads applied to the specimens for these tests are approximately 4100 lb force, 3240 lb force, and 2640 lb force, respectively.

4.2 Leak Testing Results

4.2.1 Slit Tube Leak Test Results

Leak test results are furnished in Table 3. Of the five slit tube specimens, 3 exhibited essentially [ ]^{a,b,c} leakage at all test conditions. The remaining two specimens had SLB leak rates of [ ]^{a,b,c} drops per minute. Conversion to gallons per minute indicates these leak rates were [ ]^{a,b,c} gpm, respectively. Specimen PBU2-004 experienced leakage such that the test setup could not maintain a pressure

differential greater than approximately 2450 psi. During the testing of this specimen at the maximum pressure differential some steam was noticed to escape the test setup. While the level of steaming was not recorded or quantifiable in any reasonable manner, it was also not considered excessive. The data point for this specimen will be arbitrarily increased by 25% to account for escaping steam. Also, the data point is adjusted to provide leakage data for a pressure differential of 2560 psi. The adjusted final value for this specimen is approximately [ ]^{a,b,c}.

4.2.2 Alloy 600 Sleeve Material Leak Test Results

Two specimens were initially prepared using Alloy 600 sleeves. In these specimens the end of the tube was located at the top of the hardroll transition. Surprisingly the results of these tests inidcated essentially [ ]^{a,b,c} at a ΔP of 2560 psi and temperature of 600°F. After testing it was noticed that the end of the tube was slightly below the top of the transition. Specimen 009 was modified to locate the end of the tube at the top of the transition and retested. Results are furnished in Section 4.2.3.

4.2.3 Leak Test Retest Results

Several specimens were retested with slits remachined slightly higher into the tube hardroll at 600°F. Specimen 003 was retested with the slit approximately 0.03 inch higher and specimen 009 was retested with the end of the tube cut 0.10 inch higher. Also, while not a retest, specimen 023 was tested in the same batch. Specimen 023 had a 240° TW slit and was separated in the ligament region during the no friction test. Examination of the specimen indicated that no motion between the tube or sleeve occurred in the roll region. The ligament tore and the tube was pulled down onto the hydraulically expanded region of the sleeve. Leak test results for these specimens are furnished in Table 3a.

For specimen 003, the leakage at 2560 psi actually was [ ]^{b}. However the leakage at 1600 psi and 2100 psi was [ ]^{b}. Specimen 009 leakage was [ ]^{b,c} in the first test and scimen 023 had a leakage of [ ]^{a,b,c} at a pressue differential of 2560 psi. For the retests and small roll diameter leak tests the pressure supply to the test media was applied by bottled nitrogen. In the first set of leak tests the pressure was applied using a hand pump. The nitrogen allows steady control of the test media pressure for larger levels of leakage.

4.2.4 Small Roll Expansion Diameter Leak Test Results

A final set of test specimens was prepared using a roller diameter setting which represents the lower end of the acceptable range of roll expanded diameters and resulted in tube OD measurement in the roll region of[ ]^{a,c}. This OD translates to an approximate sleeve ID of [ ]^{a,c}. Two leak test specimens were prepared at this setting. The data is found in Table 3c. The leak rates of the two specimens at a ΔP of 2560 psi and temperature of 600°F were [ ]^{a,b,c}. These results are consistent with the results at the larger roller setting. Optical comparitor roll flat length measurements for these two specimens indicates the roll flat lengths were [ ]^{a,c}, respectively, for the two specimens. These two points are bounded by the SLB leakage allowance of [ ]^{a,c} per indication.

4.3 Tensile Testing Program

The tensile testing program was intended to establish a relationship between plastic overload failure of the non-degraded ligament and applied load. Two tube heats were used, heat 1253 and 2761. The material properties of each heat were not available. A section of tube heat 1253 was tensile tested at 600° F. Measured yield and ultimate strengths were 43.3 ksi and 100.8 ksi, respectively. Comparison of the hydraulic expansion curves for the various samples indicates a higher maximum expansion pressure for samples produced with heat 1253 which suggests that heat 2761 has lower material properties than heat 1253 since the expansion computer controller stops the expansion when yielding of the tube/sleeve assembly occurs.

Alloy 690 sleeves were taken from the same heat number. The listed material properties of this heat are an average of 105.0 ksi ultimate and 53.0 ksi yield at room temperature. Alloy 600 sleeve material properties are ultimate of 102 ksi and yield of 46 ksi.

The first set of tensile tests were conducted at room temperature. The tube and sleeve were prototypically coupled at the upper joint with the exception of the slits in the tube. A tubesheet collar simulant was used only to provide proximity restraint; the tube was not rolled into the collar. The tube and sleeve were not mechanically attached in the lower joint. This test was designed to establish how much lateral shift at the non-degraded ligament the tubes would experience upon loading.

The majority of the specimens were tested according to the schematic shown in Figure 1. Tubes were approximately 24 inches long, with the slit located approximately 8 inches from one end. About 4 inches of sleeve extended below the end of the tube. At either end, the tube and sleeve were secured to the testing machine. Two specimens were also tested by loading the tube at both ends. This test was performed to establish the relationship of non-degraded ligament and load capability for test specimens at more prototypic conditions than the previously performed testing. By including a non-degraded section of tube, the dynamic response of the specimen would more accurately represent postulated in-situ conditions. While the tube and sleeve were coupled at the HEJ, no other tube sleeve coupling was introduced.

Two tensile specimens were also prepared using Alloy 600 tube material. These tests were used to establish the "first slip" force values as were done previously for Alloy 690 sleeve material. These specimens had no remaining tube ligament.

4.4 Tensile Testing Program Results

4.4.1 Limited Bending Test Results

The first set of tensile tests conducted at room temperature used one specimen with a 120° throughwall slit and one specimen with a 180° throughwall slit. The specimen with the 180° throughwall slit failed in the ligament. The maximum force recorded was [ ][a,b,c]. Sharp ratcheting with increasing deflection for decreasing forces was evidenced at about [ ][a,b,c]. Ratcheting with fairly large displacements of about 0.03 to 0.04 inch and steadily increasing forces are seen until ultimate ligament failure at [ ][a,b,c]. The other specimen did not fail in the ligament. This test was stopped at 7,100 lb. Similar frictional ratcheting is evidenced but the indication of ligament yielding is not detected.

4.4.2 Tensile Test Results: 240° and 180° TW Slitted Tubes at Operating Temperature

A total of 9 specimens were tested; 7 with 240° TW slits and 2 with 180° TW slits. Three tensile specimens with 240° slits failed at the ligament. The force values for these specimens ranged from [ ][a,b,c]. All other specimens failed in the sleeve. For these

specimens the failure load was approximately [ ]a,b,c. The tests indicated that upon loading, a bending moment was introduced at the non-degraded ligament. This bending moment caused a slight (maximum of about 1/8 inch) deflection of the tube/sleeve at the slit. Upon bending the tube/sleeve joint essentially "locks up", resulting in such a stiff condition that the sleeve failed in tension outside of the joint in the majority of the specimens.

Due to the exceptionally high loads that some of the slit tube joints experienced, it was believed that the slits were possibly located slightly into the transition, and that a restraint component due to the lip of tube material below the top of the transition was adding to the tensile strength of the joint. A third set of tests were conducted with 240° slits located approximately 0.08 inches into the flat length of hardroll, above the top of the hardroll lower transition. Alloy 690 sleeves were used. In this case, the same condition was reported; the sleeve itself failed in tension prior to plastic overload of the non-degraded ligament. Examination of the samples indicated that plastic overload fa ilure was imminent. Small fracture cracks were evident at the tip of the EDM slits. Maximum force values for these specimens, PBU2-025 and PBU2-026, were [ ]a,b,c, respectively.

4.4.3 Alloy 600 Sleeve Material/Alloy 600 Tube Material Tensile Test Results

Alloy 600 sleeve material tensile tests indicated [

]a,b,c. Examination of the two Alloy 600 sleeve specimens indicated that the location of the edge of the tube could have been approximately 1/16 to 1/8 inch below the top of the transition. Some stretching of the tube could have occurred resulting in a necked down condition which could have influenced the post-test roll length measurement. A retest was performed. The retest specimen was prepared in the same manner as the first set of Alloy 600 sleeve tensile tests except that this time the end of the tube was located approximately 3/32 inch above the top of the lower transition. However, first slip and maximum force values again were [

]a,b,c. First slip and maximum force values for the retest were [
]a,b,c respectively. Alloy 600 sleeve test tensile results are furnished in Table 4a.

4.4.4 Zero Friction Tensile Test Results

Based on the galling evidenced, the elevated temperature appears to exhibit higher coefficients of friction than for room temperature conditions. Several tests were conducted with the tube hardrolled into a tubesheet collar simulant, prototypic upper joint, and no physical attachment between the tube and sleeve. The tube was loaded in tension at both ends, the sleeve experienced no axial load. This test was designed to establish the effect of the combination bending lockup and ligament plastic overload capability. Two samples were run in this manner. Specimen 022 had 180° throughwall slit while specimen 023 had a 240° throughwall slit. At approximately[ ]a,b,c, the tube of specimen 022 slipped within the tubesheet collar and the test stopped. The slit had opened to about 0.07 inch width from 0.02 inch width. No significant tearing or imminent tearing of the ligament was noticed. Specimen 023 failed in the ligament at approximately [ ]a,b,c. At 1/5 inch of total machine motion the test was momentarily halted. At this point it was determined that the tube had not slipped at all in the collar and the slit had opened to 0.10 inch width, the total force was [ ]a,b,c. The specimen had shifted in the direction of the slit about 0.06 inch. The test was continued and the specimen failed at about 0.23 inches of total machine motion. Based on the ligament area and material properties, specimen 023 should have failed at about 2,900 lb, using the structural model of WCAP-14157. These two additional tests show that the [ ]a,b,c.

4.4.5 Small Roll Diameter Tensile Test Results

As stated earlier, a final set of specimens was prepared with a roller diameter setting that represents the lower end of the acceptable range of sleeve ID roll expansion diameters. Three tensile test specimens were prepared in this manner using Alloy 690 sleeves. The slit profile for these specimens was a 224° TW crack with a 30% minimum to 40% maximum slitted depth on the tube at the same elevation as the TW crack. Tensile test data is found in Table 4b. For all specimens the failure point of the ligament exceeded the $3\Delta P_{N.O.}$ end cap load of 1879 lbf for a primary to secondary ΔP of 1500 psi. Ligament failure loads for these specimens was [ ]a,b,c. In all three of these cases, minimum first slip was evidenced at about [ ]a,b,c. This was evidenced by a tape mark on the sleeve located at the end of the tube. When relative motion between the tube and sleeve was detected, the location on the curve was noted. Sleeve slippage at ligament

failure was found to be [ ]^{a,b,c}, and corresponds with the above listed forces. Frictional forces after ligament failure ranged from [ ]^{a,b,c}. In the two specimens which failed at [ ]^{a,b,c}, slippage in a ratcheting motion was detected. The load in the sleeve would build until the limitations of the roll transition and friction could not support the applied load and a skipping motion would occur.

4.5 Structural Integrity Conclusions

4.5.1 Conclusions Regarding Specimens Which Failed in the Ligament

From the three specimens that failed in the ligament several conclusions can be developed. These are;

1. For a remaining ligament of approximately 120°, representing about 0.040 in^2, the ultimate tensile strength capacity of the joint ranged from [ ]^{a,b,c}. Specimen 015 (tube heat 1253) had a yield stress of 72.05 Ksi at 600°F. Using a cross sectional area of 0.040 in^2 and the current structural model, the ligament would be predicted to fail at about 2882 lb force. This suggests that of the [ ]^{a,b,c}. Since no ratcheting was evidenced, it is believed that no joint slippage occurred prior to ligament failure. The force vs. displacement record for sample 007 is shown in Figure 3. As seen from this figure a gradually upward sloping curve is evidenced until a sharp failure point is seen. The re-initiation of this curve suggests the amount of friction remaining after separation of the ligament. As seen from the curve, this is approximately [ ]^{a,b,c}, The other two samples had friction forces immediately after failure of [ ]^{a,b,c}, for specimens 007, 012 and 015, respectively. All of the pull test curves indicate a change in slope of greater displacement for a unit force at about 4,000 lb. This is believed to yielding of the sleeve. This suggests the breakaway friction for the degraded joint is greater than 4,000 lb since no relationship between slope of the force/displacement curve and slit angle can be determined.

2. Based on the structural model of WCAP-14157, the EOC cross-sectional area of the non-degraded ligament is approximately 0.027 inch^2. If the force values

at ligament failure are reduced by a factor of 0.027/0.040, the area ratio of the structural model to the test specimens, the expected failure loads would be [ ]^{a,b,c}. In all cases the maximum end cap load resistance recommended by RG 1.121 is exceeded, and structural integrity of the sleeve/tube joints would be maintained. The maximum frictional forces defined by the test results would not be affected by the EOC non-degraded ligament. Again, in all cases, the frictional force values exceeded the most stringent RG 1.121 loading criteria.

Shown in Figure 4 is a plot of the tensile test results for the tensile specimens, of both slitted and completely removed tubes. All of the data is adjusted for lower tolerance limit material properties. As can be seen from the curve, there is a rather large variance between the plastic overload curve and the data points. The plastic overload curve represents the relationship between the cross-sectional area of the non-degraded limit and expected instability for that area based on lower tolerance limit material properties. The difference between the curve and the three specimens which failed in the ligaments represents the benefit provided by the bending lockup. As can be seen, this benefit can be on the order of [ ]^{a,b,c}. Conservatively, no credit for the bending lockup is included in the acceptance criteria limits.

4.5.2 Conclusions Regarding Tensile Test Specimens Which Failed in the Sleeve

From the six specimens which failed in the sleeve itself and not in the joint, the following can be inferred;

1. Four specimens had slit angles of 240^0 and two had slit angles of 180^o, however, the maximum force values were equal (since the sleeve failed), but these force values (7,980 lb to 8050 lb) were much larger than the three specimens that failed in the ligament. Again these specimens appeared to experience some yielding at about 4,000 lb jsut like the specimens that failed in the ligament, but these samples experienced a greater benefit of bending lockup, creating an exceptionally strong couple. Most likely the common yield point of 4,000 lb is the onset of yielding of the sleeve. The cross sectional area of the sleeve is approximately [ ]^{a,c} inch^2 and reducing the listed

yield of 53 ksi by 15% for temperature effects would suggest a yield point of approximately 3.964 lb force. No ratcheting was indicated in the force vs. displacement plot, suggesting that limited joint slippage occurred. A plot of sample 013, which had a 240° slit, is included in Figure 5. Of the 2.8 inches of deflection at failure, about 1.8 inches of stretching of the sleeve was evidenced (based on the length of the failed section when reassembled and measured). The slit opened up to about 3/32 inch at its widest point. Striations can be seen on the sleeve through the slit suggesting some slippage occurred.

4.5.3 Conclusions Regardring Tensile Test Specimens With Slit Profiles Consistent With the EOC Structural Model and Small Hardroll Diameters

From the three specimens with slits which mirrored the EOC structural model, the following can be implied:

1. The amount of friction after ligament failure is independent of the roll expansion diameter. For the 240° TW slit specimens the minimum peak frictional force after ligament failure was [ ]^{a,b,c}, while the minimum peak frictional force for the structural model slitted specimens with small hardroll diameters was [ ]^{a,b,c}.

2. A combination of bending lockup and frictional effects adds to the strength of the joint such that a joint integrity margin of about [ ]^{a,b,c} above the most stringent RG 1.121 requirement is shown.

The following general information is also pertinent to all tensile testing performed:

1. The displacements recorded for each specimen included overall system elasticity. This includes elasticity of tube, sleeve, joint, fixturing devices and tensile machine itself.

2. Frictional forces between the tube/sleeve hardroll interface exceeds the most stringent RG 1.121 loading requirement.

5.0 Conclusions

5.1 Leakage Potential of Degraded HEJ Tubes

Based on the supplemental testing performed, the following conclusions can be drawn:

1. The non-degraded ligament material provides sufficient radial stiffness to prevent excessive leakage during normal operating or SLB conditions.

2. For throughwall cracks which are represented by the EOC conditions which limit tube operability, leakage is bounded by [ ]^{a,b,c} at SLB conditions for cracks within [ ]^{a,b,c} inch below the top of the hardroll transition.

3. For throughwall cracks which are represented by the EOC conditions which limit tube operability that are located greater than [ ]^{a,b,c} inch below the top of the transition, leakage is negligible and will not significantly contribute to total primary-to-secondary leakage and subsequently offsite dose in the event of a non-isolable SLB.

5.2 Plastic Overload Potential of Degraded HEJ Tubes

For tubes with a non-degraded ligament existing at EOC conditions which are located at a minimum of [ ]^{a,b,c} inch below the top of the upper hardroll lower transition, friction in the hardroll joint and bending introduced at the ligament results in a lock-up condition such that the weakest member of the system is the sleeve itself, and overload capacity is several times greater than the maximum load condition established by RG 1.121.

For tubes with non-degraded ligaments defined by WCAP-14157 existing at EOC conditions and located within [ ]^{a,b,c} inch of the top of the upper hardroll lower transition, structural integrity will be maintained pursuant to the recommendations of RG 1.121. Additional margin is provided inherently by the design of the joint, however, no credit is taken for this margin when establishing the BOC repair limit. This margin is roughly [ ]^{a,b,c} above the RG 1.121 loading requirement.

The results of this report indicate that sufficient conservatism is provided by the proposed criteria outlined in Revision 0 of WCAP-14157. For EOC SLB leakage projections, leakage will be bounded by [ ][a,b,c] per tube. Structural integrity will be maintained pursuant to RG 1.121 at EOC conditions.

Table 1
Tube/Sleeve Specimen Manufactuiring Data

a,c,e

Table 1 (cont'd)
Tube/Sleeve Specimen Manufacturing Data

a,c,e

Table 2
Tube/Sleeve Dimensional Data

a,c,e

Table 2 (cont'd)
Tube/Sleeve Dimensional Data

a,c,e

Table 3
Degraded tube/sleeve leak rate testing: 600 F
leak rate measured in drops per minute/gallons per minute

a,b,c

Table 3a
Degraded Tube/Sleeve Leakage Retest Results; 600 F
Leak Rate in dpm/gpm

a,b,c

[ ]

Table 3b
Degraded Tube/Sleeve Leak Test Results, 600°F, Small Roll Diameter
Leak Rate in dpm/gpm

a,b,c

[ ]

Table 4
Degraded HEJ Tensile Test Results
Slitted Tubes

a,b,c

Table 4a
Degraded HEJ Tensile Test Results
360° Separated Tubes -- Alloy 600 Sleeve Mat'l

a,b,c

Table 4b
Degraded HEJ Tensile Test Results, 600°F, Small Roll Diameter, Alloy 690 Sleeve Mat'l, EOC Structural Model Type Slits

a,b,c

Figure 1

Tensile Test Specimen Schematic

a,c,e

Figure 2

Leak Test Specimen Schematic

a,c,e

Figure 3

Typical Ligament Failure Force vs. Displacement Plot

a,b,c

Figure 4

Tensile Test Data vs. Non-Degraded Ligament Plastic Instability

a,b,c

Figure 5

Typical Sleeve Failure Force vs. Displacement Plot

a,b,c

Westinghouse Non-Proprietary Class 3

Westinghouse Energy Systems

Westinghouse Non-Proprietary Class 3

Westinghouse Energy Systems