Westinghouse Non-Proprietary Class 3

Attachment to
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Interim Report on
Laser Weld Repair of Hybrid Expansion Joint Sleeves
Non-Proprietary

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**LASER WELD REPAIR OF HYBRID EXPANSION JOINT SLEEVES
INTERIM REPORT**

1.0 INTRODUCTION

The hybrid expansion joint (HEJ) sleeve is a mechanically attached sleeve used to bridge regions of degradation that have occurred in Alloy 600 steam generator tubes in the tubesheet crevice and top of tubesheet region. The HEJ sleeve design, which is illustrated in Figure 1, consists of two mechanical joints. The lower joint is located within the tubesheet region and consists of a [

]a,c,e

The upper joint, which is located in the free span above the top of the tubesheet, also consists of a [

]a,c,e

In-service inspections of the HEJ sleeves installed in the Kewaunee, Point Beach Unit 2, and Zion steam generators have detected indications in the sleeved region of the parent tubing. The majority of the parent tube indications are in the region of the lower transition of the upper hard rolled section of the sleeved tube, and below. All sleeved tubes with indications within the pressure boundary portion of the parent tube in the joint region have so far been plugged.

Because of the location of the parent tube indications, illustrated in Figure 2 and tabulated in Table 1, it is possible to perform a repair operation which would form a new pressure boundary attachment point above the indications effectively removing the degraded tube region from the pressure boundary. The repair will allow the sleeved tube to remain in service with no additional penalty on the operational characteristics of the HEJ sleeved tube.

The repair technique being proposed is a laser weld within the upper hard rolled zone. The integrity of the weld will be verified by ultrasonic (UT) examination. The weld will then be stress relieved by heat treatment. This approach, which is based on the very successful proven technology of the laser welded sleeve, can be applied with no additional modification to the existing HEJ sleeve geometry. Therefore, there are no changes to the flow or heat transfer characteristics of the sleeved tube or the RCS.

This interim report presents the laser welded repair process to be employed, the weld process qualification testing plan, and the accelerated corrosion testing program that will be implemented to establish the acceptability of the repair. A detailed report addressing the licensing issues relating to the laser welding repair of the HEJ sleeves will be issued at a later date when all the testing has been completed.

2.0 DESCRIPTION OF THE LASER WELD HEJ REPAIR PROCESS

The laser welding process is employed to repair potentially degraded HEJ sleeved tubes by effectively isolating the degradation and establishment of a modified pressure boundary. As noted above, the installation of sleeves in steam generator tubes by laser welding is a proven technology with over 30,000 installations in service. The technique has been applied to the installation of Alloy 690 sleeves.

The proposed design of the laser welded HEJ repair is illustrated in Figure 2. The repair consists of a laser weld made in the approximate center of the pre-existing hard rolled region of the upper joint. No changes will be made to the lower HEJ sleeve joint. The weld geometry based on field experience is approximately [

]^{a,e} The weld establishes a new pressure boundary above the existing degradation as illustrated in Figure 2. The new pressure boundary is along the sleeve from the lower joint to the weld region. The pressure boundary connection between the sleeve and the tube is the weld, and above the weld the pressure boundary is the tube.

No additional expansion of the sleeve within the tube will be necessary as the sleeve is in tight contact with the tube in the HEJ hard roll region where the weld will be made. The only operation prior to laser welding is a cleaning operation on the sleeve ID similar to that currently done to the tubing before installing a sleeve.

The weld process to be used in HEJ repair was qualified in accordance with the rules of ASME Code Sections IX and XI, and to the additional Westinghouse requirements for weld geometry. The requirements for an acceptable weld process for a laser welded sleeve that were qualified in the laboratory testing portion of the program included:

a) Weld width at sleeve to tube interface of greater than [ ]a,e

b) No porosity that would reduce the weld throat to below that in a).

c) No cracks in the weld of base tube when examined at a magnification of at least 10X

d) No indications when the weld ID surface is subjected to a liquid penetrant testing.

The feasibility of the laser weld repair process has been verified through laboratory testing. In addition, mockups of the HEJ and the repaired HEJ have been prepared under conditions of tube lockup to evaluate the impact of the processes on the residual stress state of the repaired tube. The results of the residual stress measurements are reported in Section 4.1. Final verification of the repair processes will be done through accelerated corrosion testing of mockups fabricated with the processes used in the field repair of the HEJ sleeves, and testing under pre-stressed conditions equivalent to the fabrication residual stresses.

As currently envisioned, field implementation of the laser weld repair of HEJ sleeves will involve the following process steps:

a) Cleaning the inside surface of the sleeve will be accomplished using the wet hone process.

b) Laser welding of the HEJ sleeve will be performed. No special precautions other than the primary ventilation air flow will be required for drying the weld region as the weld is located in the hard rolled section where [ ]a,c

c) UT examination of the weld will be conducted. The examination will verify the presence of the weld over the full circumference and the adequacy of the weld width at the sleeve/tube interface. The inspection acceptance criteria will be the same as that used for newly installed laser welded sleeves.

d) Heat treatment of the weld. This stress relief operation will be performed with a [

]a,c,e

e) Baseline eddy current (EC) inspection will be performed using an approved probe. This inspection will verify that there are no cracks in the weld and provide the EC signature for future inspections.

The laser weld repair will not be performed on HEJ sleeves that are known to have indications in the upper hard roll region above proposed weld location and beyond. Such sleeved tubes will be removed from service.

3.0 HEJ REPAIR DEVELOPMENT AND TESTING

3.1 Weld Process Development

Some initial laser welds were made on sleeved tube geometries consistent with those of the HEJ in 7/8-inch tubes. The welds were made in the hard rolled region with the current 7/8 inch laser weld head and weld parameters within the currently qualified 7/8 inch tube sleeve laser weld process. After welding was completed the welds were metallographically sectioned and evaluated. The geometry of the welds were within the requirements of [

]a,e The welds were sound with no cracking, porosity, or indications on the weld ID when subject to liquid dye penetrant inspection.

3.2 Laser Welding With Contaminated Sleeve/Tube Interface

Evaluation of the HEJ samples removed from Kewaunee suggests that primary water had passed through the sleeve-to-tube interface at the HEJ region, and there is the possibility of oxides and contaminants being present in the hardroll region. One of the concerns that was examined in the preliminary evaluation of laser welding as a repair process was the effect of contaminants on the weld integrity.

The information on types of contaminants present in the joint region was obtained through analyses performed on HEJ sleeved tubes removed from the Kewaunee generators. These analyses revealed the contaminants to consist of those summarized in Table 2.

For the trial welds both the sleeve and the tube were [

]a,c,e

The HEJ joints were fabricated in the same manner as they were fabricated in the field. The laser welding was performed with weld parameters in the middle of the qualified ranges. The width of the weld was approximately [ ]a,e The weld was sound with no cracking.

The tests that were performed demonstrated that; a) the qualified process for laser welding of sleeves in 7/8-inch tubes produces acceptable welds in the HEJ sleeves, and b) the [

]c,e

4.0 HEJ REPAIR MOCKUP FABRICATION

Part of the process of verification of the HEJ repair is the fabrication of mockups of the HEJ, including the laser weld repair. The purpose of the fabrication of the mockups is twofold. The first is to determine the magnitude of the residual stress that may be imparted to the sleeve and parent tube during the installation of an HEJ sleeve under conditions of tube lockup, i.e., the condition where the tube is locked at the first support plate, and during the laser weld repair process. The latter includes both the welding cycle and the subsequent stress relief heat treatment of the laser weld region.

The second purpose in fabricating the mockups is to provide the samples that can be corrosion tested under accelerated condition to evaluate the resistance of the HEJ laser welded repairs to primary water stress corrosion cracking.

The test stand for the fabrication of the mockups is designed to simulate as much as reasonably possible the steam generator configuration assuming the tube is locked at the first support plate. The span between the top of the tubesheet and the support plate is consistent with that of the Model 51 steam generators as shown in Figure 3. The tubesheet in the case of the mockups is simulated by a [

]a,c,e

Some modifications to the mockup dimensions were necessary to provide a sample that could be accommodated in the high temperature, high pressure autoclaves in which the accelerated corrosion tests would be conducted. None of the dimensional differences affect the residual stresses obtained, or the corrosion test results. Where necessary, adjustments will be made based on geometrical considerations to make the residual stresses compatible with what would be expected for field installations assuming locked tube conditions.

The test program to verify the HEJ repair process includes the fabrication of a total of eight laser weld repair of HEJ sleeve mockups in the as-stress relieved condition as identified in Table 3. Four of these will be fabricated with no rolldown, i.e., the transition from the hard rolled expanded diameter to the hydraulically expanded diameter, will be very sharp. The remaining four will be fabricated with a 0.25 to 0.5 inch long rolldown of the lower transition. Eight additional samples will be fabricated in the as-welded condition. Four will be with the rolldown and four without.

The tubing used in the fabrication of the mockups and roll transition samples for reference measurement is from a reference heat of low temperature mill annealed Alloy 600 that has a known susceptibility to primary water stress corrosion cracking. The sleeves used in the mockup fabrication are production, thermally treated Alloy 690 sleeves.

4.1 Residual Stresses

The residual fabrication stresses were determined through strain gages attached to the tube at locations above and below the HEJ joint. Stresses were determined at each fabrication step from the fabrication of the HEJ through the laser weld repair processes.

All HEJ fabrication processes were consistent with the field process used to install HEJ sleeves in the generators. The laser welding process is the same as that intended for use in the field repairs. The stress relief process, which was also the same as that intended to be used in the field, employed a [

]a,e

The average residual stresses after the HEJ fabrication, the laser weld and the stress relief operations are summarized in Table 4. The data are provided for both the rolldown and no rolldown configurations. These data show that the residual stresses after the HEJ sleeve installation were [

]a,e

Minor adjustments to account for the differences in sleeve length between the mockups and the field sleeves may be necessary.

A typical time-stress history during the installation of the HEJ and the subsequent repair is shown in Figure 4. This figure shows the change in residual stress as each operation progresses and shows the final residual stress state for a laser weld repair in the stress relief heat treated condition.

4.2 Sleeved Tube Geometry and Weld Integrity

The laser weld repair, which includes the stress relief of the weld, does not result in any change in tube diameter nor the introduction of any significant bowing of the tube. The typical tube diameter of the repaired HEJ tube in the region of the upper joint is shown in Figure 5. The final tube diameter is established during the HEJ sleeve installation and there is no additional diametral change associated with the laser weld repair. The tube diameter of the mockups after the hydraulic expansion of the upper joint is approximately [ ]a,e The tube diameter after hard rolling of the upper joint of the mockups was typically [

]a,e

There was no evidence in the data shown in Figure 5 of local bulging during the suggested stress relief operation. This is also apparent in the time-stress history shown in Figure 4. Bulging would be evident in the time-stress history as a region of no change in stress at some point in the stress relief cycle. In the HEJ repair cycle the stress continues to become more compressive throughout the duration of the stress relief cycle.

Visual examination of the weld surface showed the weld to be sound with no evidence of cracking or blowholes. UT examination also showed the welds to be of good quality and within the desired range of weld width at the sleeve to tube interface.

5.0 CORROSION TESTING

The resistance of the laser weld repaired HEJ sleeved tube to primary water stress corrosion cracking (PWSCC) will be verified through accelerated corrosion testing of the mockups that were prepared under locked tube conditions. These mockups are considered a conservative representation of the field HEJ sleeved tubes in that the assumption is made that the tubes are "hard" locked at the first support plate and have not broken free during SG operation or during the HEJ sleeve repair.

The mockups will be sectioned and corrosion tested in high temperature, high pressure autoclaves. The tube region above the HEJ joint in the mockup will be pre-stressed to the level of the typical residual stress for the various mockup types shown in Table 3, i.e., rolldown with and without stress relief, and no rolldown with and without stress relief. In addition, a number of mechanical roll transition mockups will be included in the corrosion tests with the HEJ repair mockups. The roll transition corrosion test results will be used to relate the performance of the HEJ repairs in the corrosion tests to the expected field performance.

The accelerated corrosion tests will be conducted in a [ ]a,c,e in high pressure, high temperature autoclaves. The tests are conducted with a [ ]a,c,e on the ID of the sleeved tube. In this mockup design the [ ]a,c,e will be at a pressure of 3000 psi and will have access to the ID of the sleeve, the upper side of the laser weld, and the hard roll and hydraulic expansion transitions above the weld, and the tube ID above the weld. These are the same regions that will be exposed to the primary water environment in the steam generator. The OD of the mockup tube will be exposed to [ ]a,c,e The differential pressure between ID and OD environments will be maintained at [ ]a,c,e

Assessment of the performance of the HEJ repair mockups in the corrosion test will be through monitoring of the [

.][a,c,e] Additional characterization of any corrosion that may occur will be done through non-destructive examinations. Destructive examinations may also be employed to characterize corrosion performance, if necessary.

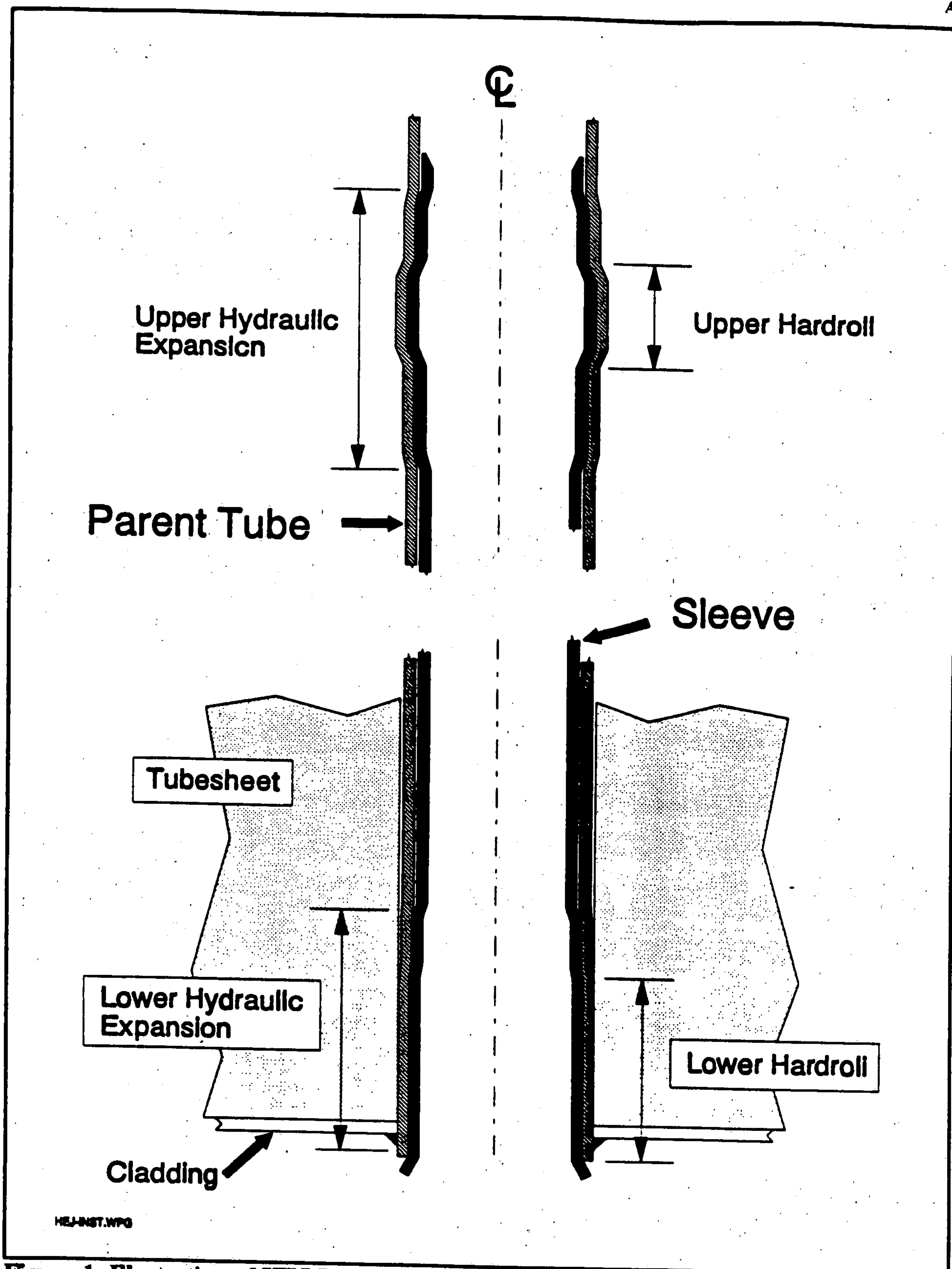

Figure 1. Illustration of HEJ Installation

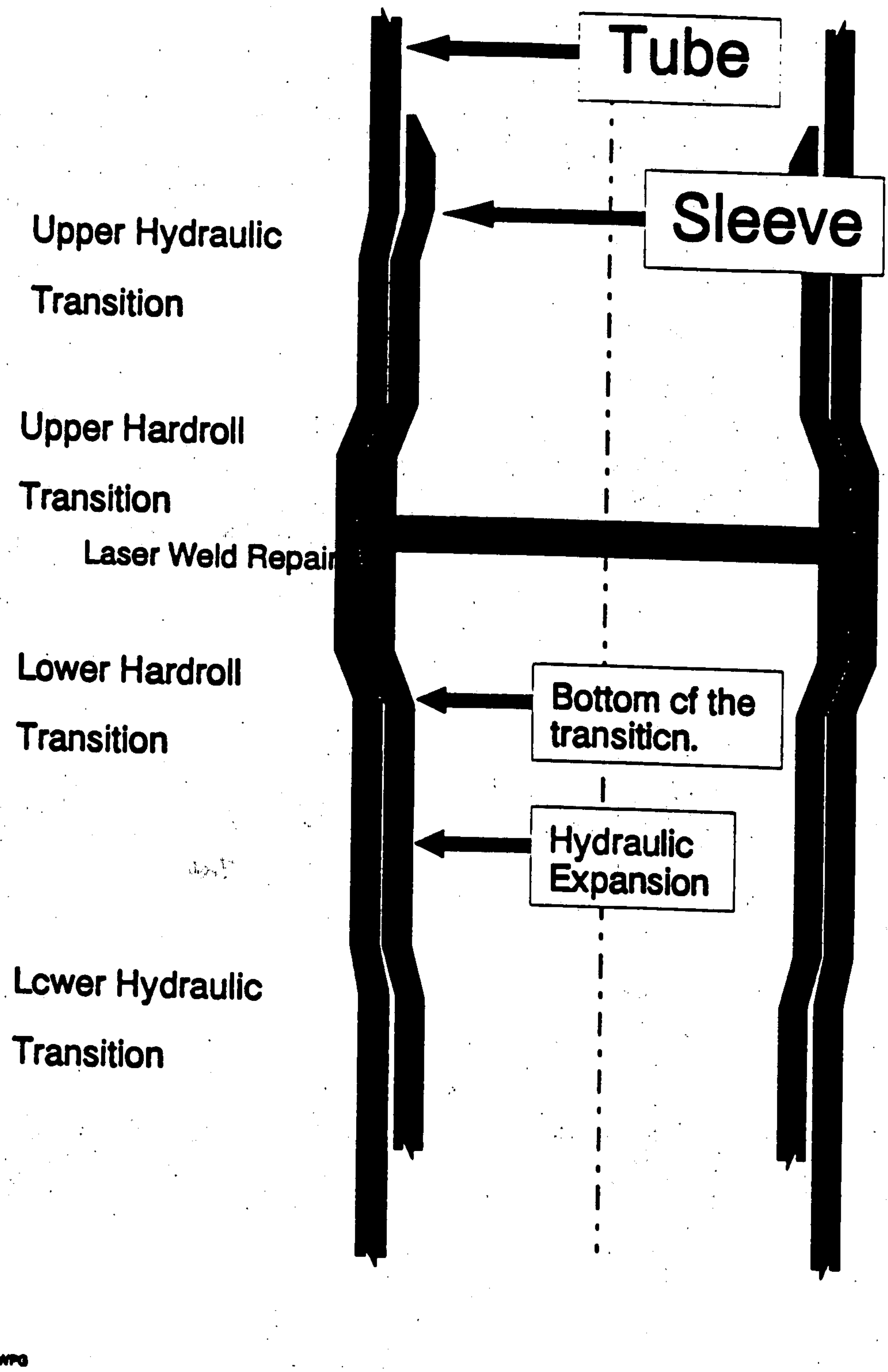

Figure 2. Illustration of Laser Weld Repair in Kewaunee HEJ Upper Joint

a,c,e

[ ]

Figure 3 Test Stand for Fabrication of the LWS Mockups Under Locked Tube Conditions

Figure 4 Tube Stress - HEJ and LWS Repair Fabrication

a,c,

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Figure 5 Tube OD Dimensions at HEJ

a,c,e

Table 1 Distribution of 7/8" Tube HEJ PTIs by Transition

HEJ Tran.	Kewaunee	Point Beach 2	Zion	Totals	%
HELT	212	134	3	349	28.4
HRLT	480	353	7	840	68.5
HRUT	0	7	0	7	0.6
HEUT	6	1	0	7	0.6
TOTALS	698	495	10	1,203	100.0
AXIAL	10	0	0	10	
VOL.	2	0	0	2	
TOTALS	12	0	0	12	
GRAND TOTAL	710	495	10	1,215	

HELT - Hydraulically Expanded Lower Transition
HELT - Hard Roll Lower Transition
HRUT - Hard Roll Upper Transition
HRUT - Hydraulically Expanded Upper Transition

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Table 2 Crevice Simulant for HEJ Sleeve Testing

Anions or Cations Compounds Used	Initial Cation Concentratione ug/ml	Initial Anion Concentration ug/ml	Anions Conc. (Note 1)	Cation Conc. (Note1)
K as K_2CO_3		a,c,e	21	
Ca as $CaCO_3$			21	
Na as Na_2CO_3			97	
Na and SO_3 as Na_2SO_3				10
Mg as $Mg(OH)_2$			25	
Li as LiOH			10	
Oxalate as Oxalic Acid			10	
Acetate as Acetic Acid			37	
Formate as Formic Acid			70	
Cl as KCl				20
SO_4 as K_2SO_4				171
B as H_3BO_3				
pH of solution				

Note 1: Examination of Crevice of Pulled Tubes. Reference 95-8TE2-KEWSG-M1 (9/95) And 95-5TE4-ROBIN-M1 (8/95)

Table 3 Corrosion Test Program for Kewaunee HEJ Repair

Specimen Configuration	Specimen Type	Corrosion Mockup Condition	Number of Corr.Mockups
Configuration "A" Samples (Rolldown)	HEJ/LWS Mockup	As-Welded	4
	HEJ/LWS Mockup	Weld Stress Relief	4
Configuration "B" Samples (No Rolldown)	HEJ/LWS Mockup	As-Welded	4
	HEJ/LWS Mockup	Weld Stress Relief	4
Hard Roll Transitions	Roll Transition Mockups	As-Expanded	6

a,c,e

Table 4 Comparison of Far Field Stresses After HEJ Fabrication and After HEJ Repair

a,c,e

Table 4 (Cont'd) Comparison of Far Field Stresses After HEJ Fabrication and After HEJ Repair

PROPRIETARY INFORMATION

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