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Laser Welded Repair of Hybrid Expansion Joint Sleeves For Kewaunee Nuclear Power Plant

Westinghouse Energy Systems

Westinghouse Non-Proprietary Class 3

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LASER WELDED REPAIR OF HYBRID EXPANSION JOINT SLEEVES FOR KEWAUNEE NUCLEAR POWER PLANT

July, 1998

WESTINGHOUSE ELECTRIC COMPANY
ENERGY SYSTEM BUSINESS UNIT
NUCLEAR SERVICE DIVISION
P.0. BOX 355
PITTSBURGH, PENNSYLVANIA 15230

ABSTRACT

This report provides the technical basis for the use of the Westinghouse Laser Welded Sleeve (LWS) technique to repair hybrid expansion joint (HEJ) sleeved tubes at the Kewaunee Nuclear Power Plant. This report summarizes and/or references the results of design and materials evaluations, structural and thermal/hydraulic analyses, as well as corrosion, inspection and mechanical testing, and reviews the Laser Weld Repair (LWR) process for HEJ sleeves.

In-service inspections of the HEJ sleeves installed in Kewaunee have detected indications in the sleeved region of the parent tubing. The majority of the parent tube indications are in, or below the region of the lower transition of the HEJ upper hardroll. To date, all sleeved tubes with indications within the lower transition of the upper hardroll region have been plugged.

Because of the location of the parent tube indications, it is possible to use the LWS technique to perform a Laser Welded Repair (LWR). The LWR would form a new pressure boundary ttachment point above the indications, thus effectively removing the degraded tube region from he pressure boundary. The repair would allow the sleeved tube to remain in service with no additional penalty on the operational characteristics of the HEJ sleeved tube.

This report concludes that LWR can be an acceptable means for repair of HEJ sleeves at the Kewaunee Nuclear Power Plant.

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1.0 INTRODUCTION AND SUMMARY

1.1 Scope and Definition

This report provides the technical basis for use of the Westinghouse Laser Welded Sleeve (LWS) method to perform a Laser Welded Repair (LWR) of hybrid expansion joint (HEJ) sleeves at the Kewaunee Nuclear Power Plant. This report, WCAP-14685 Revision 4, replaces Rev. 0, Rev. 1, Rev. 2 and Rev. 3 of WCAP-14685 (References 1-1, 1-2, 1-3 and 1-8, respectively). In this current Revision 4, the analytical verification in Section 3 has been extensively modified to document the evaluation of an increased Kewaunee full power pressure differential loading. In addition, it was determined recently that the finite element model used to initially qualify the 0.015 inch minimum acceptable weld width under-predicted the shear stress in the welds. This WCAP revision also documents the updated analysis and test program that qualifies the 0.015 inch minimum weld width for both pressure and fatigue loadings.

All other sections (other than Section 3) remain unchanged from Revision 3, Reference 1-8. Relevant design and materials evaluations, and thermal/hydraulic analyses, as well as corrosion, inspection and mechanical tests are also referenced in these unchanged sections.

Unless otherwise specified, use of the term *HEJ* will be meant to include only the upper, hydraulically expanded plus roll expanded joint in an HEJ sleeved tube. The lower joint in the HEJ sleeve is unaffected by the LWR. The term *LWR* implies the weld plus subsequent stress relief. Where a more specific definition of the location is required, *HE LWR* will be used to identify a laser weld repair in the hydraulically expanded-only region above the hardroll, and *HR LWR* will be used to identify a laser weld repair in the hardroll region.

1.2 Degradation Locations

Inspection information is useful in illustrating the potential benefit of LWR in addressing HEJ degradation patterns, and in reviewing the condition of the potential LWR locations prior to welding. In-service inspections (Reference 1-4) of the HEJ sleeved tubes at Kewaunee have detected indications in the upper HEJ region of the parent tubing. The first parent tube indications at Kewaunee were detected in the Spring of 1994. The majority of the parent tube indications (PTIs) are in or below the region of the lower transition of the HEJ upper hardroll. Figure 1-1 provides a definition of the HEJ expansion transitions. Figure 1-2 illustrates the combined degradation location results for the 1994 and 1995 Kewaunee inspections.

Three HEJ-sleeved tube samples were removed from Kewaunee in 1995 for laboratory inspection and testing. During NDE and visual inspection, no cracks were found at the upper transitions of the two destructively examined Kewaunee HEJ samples. In addition, no cracking was detected in either the straight portion of the HEJ hardroll or the portion of the upper hydraulic expansion above the hardroll.

Seven HEJ-sleeved tubes samples with circumferential indications at the hard roll lower transition (HRLT) were removed from Kewaunee in 1996, and four of these were destructively examined. The HRLT indications varied from 200° to 360° in circumferential extent. One of the specimens, SG-A tube R2C21, had a throughwall indication completely around the circumference, leaving a 0.005 to 0.010 inch gap visible in the as-received condition. Since this tube was removed from the secondary side of the steam generator, rather than by a primary side tube pull, the gap presumably was unaffected by the removal and present prior to removal. Despite the crack in the HRLT, destructive examination of this tube showed no parent tube or sleeve cracking in either the straight portion of the HEJ hardroll or the portion of the upper hydraulic expansion above the hardroll.

1.3 HEJ Sleeved Tube Structural Integrity Criteria

The LWR technique is intended to repair HEJ sleeved tubes. Laser weld repair will not be performed in HEJ sleeves which are known to have indications in the region above the proposed weld location; such sleeved tubes will be removed from service.

1.4 Pressure Boundary Considerations

Laser welding repair of the HEJs will form a new pressure boundary from that of the HEJ sleeve (Reference 1-5). By welding the tube and sleeve with the autogenous laser welding process at either the HE LWR or HR LWR location illustrated in Figure 1-3, the additional parent tube length between the uppermost acceptable laser weld and the lower hydraulic expansion transition of the (upper) HEJ is excluded as pressure boundary. The revised pressure boundary definition is consistent with that of a laser welded sleeve (Reference 1-6).

1.5 Laser Welding With Contaminated Sleeve/Tube Interface

The repair technique being proposed is a laser weld within the upper hardrolled zone of a HEJ and/or the hydraulically expanded region above the upper hardroll of a HEJ. Inboard (lower elevation) rewelds are permitted at each location. The weld will be stress relieved by heat treatment, and the integrity of the weld between the tube and sleeve will then be verified by ultrasonic (UT) examination and by eddy current testing (ECT). The LWR approach, 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.

Evaluation of two HEJ samples removed in 1995 from Kewaunee (neither of which had throughwall parent tube cracks), as described in Reference 1-7, and of the four HEJ samples removed from Kewaunee in 1996 indicates that primary water had passed through the sleeve-to-tube interface at the HEJ region, and the potential exists for water, oxides and primary and secondary side contaminants to be present in the hardroll region. Cracking at the hard roll lower transitions was found to be of primary water stress corrosion cracking origin, also demonstrating the presence of water in the tube/sleeve crevice region.

To address the presence of these, an optional drying step is developed for LWR. Sections 2.3 through 2.5 details both the initial weld process development in the HR LWR location and subsequent weld process work to address moisture and weld quality issues. Corrosion testing of LWR samples (Section 5.5) indicates acceptable performance.

1.6 Summary of Report Sections

A summary of each of the following sections is provided below:

Section 2 - The LWR for Kewaunee uses weld process parameters similar to those of 7/8" laser welded sleeves. A revised LWR procedure qualification for welding was performed with assumed contaminant simulants in the hydraulic expansion region. The weld procedure qualification conformed to the requirements of ASME Section IX and XI.

Section 3 - LWR of HEJ sleeves at either the upper HE or upper HR, meets all primary stress limits, maximum range of stress intensity limits, and satisfies all ASME Code fatigue limits. The plugging limit for the sleeve, in percent of undegraded minimum wall thickness, is [ ]^{b,c,e}.

Section 4 - It is found in the tests that a) the laser weld is leak tight to pressures greater than 3100 psi at 600°F, b) the load carrying capability of the laser weld exceeds the end cap loadings associated with a safety factor of 3 applied to the normal operating primary-to-secondary pressure differential, and c) the LWS test results are directly applicable to the LWR.

Section 5 - Contaminant solutions from removed HEJ specimens are described. Corrosion testing has indicated that the [ ]^{c,e}

Section 6 - The LWR welding and stress relief steps are essentially identical to those for LWS. An optional drying step is included to address potential crevice moisture.

Section 7 - Inspection techniques and criteria are similar to those used for LWS. Administrative controls are added to verify that post-weld heat treatment has been performed on HE and HR LWR locations which have been preheated. Ultrasonic (UT) inspection is performed immediately after welding and subsequent to post-weld stress relief heat treatment.

It is concluded that the evaluation and qualification testing programs demonstrate that LWR can be an acceptable means to repair HEJ sleeved tubes.

1.7 References for Section 1

1-1 WCAP-14685, "Laser Welded Repair of Hybrid Joint Sleeves for Kewaunee Nuclear Power Plant", W Nuclear Services Division, August 1996. (Westinghouse Proprietary Class 2C).

1-2 WCAP-14685 Rev. 1, "Laser Welded Repair of Hybrid Joint Sleeves for Kewaunee Nuclear Power Plant", W Nuclear Services Division, January 1997. (Westinghouse Proprietary Class 2C).

1-3 WCAP-14685 Rev. 2, "Laser Welded Repair of Hybrid Joint Sleeves for Kewaunee Nuclear Power Plant", W Nuclear Services Division, April 1997. (Westinghouse Proprietary Class 2C).

1-4 Letter Dated 12/13/95, R. J. Laufer (Project Manager, NRC NRR), "Summary of December 8, 1995, Meeting on WPSC's Proposed License Amendment on Steam Generator Tube Repair Criteria", Docket No. 50-305.

1-5 WCAP-11643 Rev. 1, "Kewaunee Steam Generator Sleeving Report (Mechanical Sleeves)", W Nuclear Service Division, November 1988. (Westinghouse Proprietary Class 2).

1-6 WCAP-13088 Rev. 3, "Westinghouse Series 44 and 51 Steam Generator Generic Sleeving Report, Laser Welded Sleeves", W Nuclear Services Division, January 1994. (Westinghouse Proprietary Class 2).

1-7 WCAP-14513, "Presentation Materials for the August 10th, 1995, Meeting with American Electric Power Service Corporation, USNRC, and Westinghouse Concerning Application of the Revised Pressure Boundary Limit for HEJ Sleeved Tubes", November 1995. (Westinghouse Proprietary Class 2C).

1-8 WCAP-14685 Rev. 3, "Laser Welded Repair of Hybrid Joint Sleeves for Kewaunee Nuclear Power Plant", W Nuclear Services Division, May 1997. (Westinghouse Proprietary Class 2C).

a,c

Figure 1-1
Definitions of HEJ Upper Expansion Transitions

a,c

Figure 1-2

Cumulative Degradation Location Results for Kewaunee Upper Expansions

a,c

[illegible]\hej\report\fig_1_3.wpd

Figure 1-3
Illustration of Laser Weld Repair in Kewaunee HEJ Upper Joint

2.0 REPAIR DESIGN DESCRIPTION AND WELD QUALIFICATION

This section describes the laser weld repair geometry and the laboratory weld qualification program. Related sections are Section 6.0, which describes the LWR process, and Section 5.0, which describes the corrosion test program.

2.1 Hybrid Expansion Joint Configuration

The HEJ sleeve is used to bridge regions of degradation observed in Alloy 600 steam generator tubes in the tubesheet crevice and top of tubesheet region. The HEJ sleeve design, illustrated in Figure 2-1, consists of two mechanical joints. The lower joint is located within the tubesheet region and consists of a [ ]^{a,c,e} The upper joint, located in the free span above the top of the tubesheet, also consists of a [ ]^{a,c,e} Complete information on the design, qualification, and testing of the HEJ sleeve for Kewaunee is included in Reference 1-5.

2.2 LWR Design Configuration

The repair technique is a laser weld repair [ ]^{a,c,e} in the hydraulically expanded-only region above the hardroll, designated an HE LWR, or a laser weld repair within the hardroll region of the HEJ, designated an HR LWR. At both the HE LWR and HR LWR locations, rewelds are permitted at the original weld locations and at the reweld locations [ ]^{a,c,e} the original locations. In any one sleeve, a weld and the associated optional reweld are permitted at either the HE or the HR locations, but not at both the HE and HR locations. At the time of this report, no inboard rewelds have been performed at either the HE LWR or HR LWR positions. The original and reweld positions are illustrated in Figure 1-3.

The production of a laser weld in either or both of the above regions [ ]^{a,c}.

A discussion of fabrication stresses is included in the discussion of the corrosion test specimen preparation in Section 5.0.

2.3 Weld Process Development

The weld process development described in Reference 1-1 consisted of making laser welds in the hardroll region of 7/8-inch HEJ sleeved tube geometries. The welds were [

]^{b,c,e}

The Reference 1-1 weld process allowed either a [

]^{b,c,e}

The initial LWR welds made at Kewaunee during the 1996 outage started with the weld in the hardroll region and the [

]^{a,c,e}

A laboratory program was undertaken to address the welding issues at the HEJ hardroll. HEJ test samples were fabricated [

]^{a,c,e}

To provide a condition more similar to the standard laser welded sleeve geometry, welding was performed in the upper hydraulic expansion region of the HEJ. This resulted in a significantly enhanced weld quality. A test matrix was developed to optimize parameters which affect the weld quality. The tests indicated that [

]^{a,c,e} This gave a marked overall improvement in weld quality.

Two refinements were made to the weld process: [

]^{a,c,e} The changes were incorporated into a weld process specification, and weld qualification program was performed as described in Section 2.5.

The repair process initially specified ultrasonic inspection (UT) immediately after welding and prior to post-weld heat treatment and to plugging-related reroll operations. In some cases, however, these operations appear to have resulted in weld tearing, therefore, the process has been revised to require that all process steps be performed prior to a final UT inspection.

2.4 Interim Operational Effects and Testing

HEJ sleeves were installed in Kewaunee in 1988, 1989, and 1991. As noted in section 1.5, examination of the HEJ samples removed from Kewaunee indicated that primary water had passed through the sleeve-to-tube interface at the HEJ region, and the potential exists for water, oxides, and primary and secondary side contaminants to be present in the hardroll region. Contaminants present in the joint based on 1995 HEJs removed from Kewaunee are summarized in Table 2-1.

For the revised LWR weld process, testing performed in December 1996 and January 1997 utilized three types of samples: [

]^{a,c,e} A comparison of Table 2-1 and 2-2 indicates that the tubes removed in 1996 had higher levels of contaminants than the tubes examined in 1995 and that secondary water had entered the crevice via a throughwall crack; the significant levels of copper in the 1996 samples indicates the presence of secondary side contaminants.

Laser welding was performed in the upper hydraulic expansion region (HE LWRs) of a number of HEJ specimens. Four HE LWR specimens were made using the contaminant solution of Table 2-2. Metallurgical sectioning and examination of these specimens showed that the welds were sound, with no cracking.

2.5 Weld Qualification Program

The revised LWR weld process specification is similar to that used for the initial LWR program (and therefore similar to the LWS weld process specification), however, it employs a number of enhancements and essential variable changes to address factors encountered in the Kewaunee field implementation.

The revised LWR procedure qualification was performed [

]^{a,c,e}

The laser welded joints were representative in length and diametral expansion of the expansion zones. The sleeve and tube materials were consistent with the materials and dimensional conditions representative of the field application. Essential welding variables, defined in ASME Code Section IX, Code Case N-395 and Section XI, IWB-4300 were recorded and conformed to the applicable portion of the weld process specification. [

]^{a,c,e}

Table 2-1
Crevice Simulant Based on 1995 Kewaunee Removed HEJ

Anions or Cations Compounds Used	Test Simulant Initial Cation Concentration (μg/ml)	Test Simulant Initial Anion Concentration (μg/ml)	Pulled HEJ Cation Conc. (Note 1) (μg/ml)	Pulled HEJ Anion Conc. (Note 1) (μg/ml)
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 HCl				28
SO_4 as H_2SO_4				171
B as H_3BO_3				
pH of Solution				

Note 1: Concentration estimated from leachate of pulled Kewaunee HEJs, per Reference 1-7.

Table 2-2

Crevice Simulant Used for HEJ Sleeve Repair Welding on Hydraulic Expansion Region (Based on 1996 Kewaunee Removed HEJ)

a,c

a,c

Figure 2-1
Illustration of HEJ Sleeve

3.0 ANALYTICAL VERIFICATION

3.1 Structural Analysis

This section provides the structural basis for the laser welded repair of the HEJ mechanical sleeves in the Series 51 steam generators used in Kewaunee. Reference 3-1 documents the initial structural evaluation of the HEJ sleeve and tube assembly with sleeve material TT Alloy 690, tube material MA Alloy 600, and a [$]^{a,c}$ in accordance with the criteria of the 1983 Edition of the ASME Code, Reference 3-6. Subsequent evaluations were performed for [

$]^{a,c}$

sleeve length is the limiting analysis case. The initial evaluation showed that the HEJ mechanical sleeve configuration satisfied the Code limits for primary stress intensity, maximum range of stress intensity, and cumulative fatigue usage for the Kewaunee loading conditions specified in Reference 3-2. The initial HEJ structural evaluation of Reference 3-1 also gives minimum wall thicknesses for the HEJ sleeve that are based on lower bound tolerance limit strength data.

Eddy-current (EC) inspections of the Kewaunee HEJ sleeves have detected indications in the sleeved region of the parent tube, Reference 1-4. Most of these indications are within the currently defined pressure boundary for an HEJ sleeve (see paragraph 1.2), but would not be included in the pressure boundary subsequent to laser weld repair (see Figure 1-3); the HEJ LWR pressure boundary is consistent with the pressure boundary defined for a laser welded sleeve (Reference 1-6).

The structural evaluation of the repaired HEJ joint is based on finite element calculations that extend the existing generic LWS evaluation to the similar laser weld repair of the HEJ sleeves in Kewaunee, thereby structurally qualifying the laser weld repair for use in Kewaunee. The existing generic structural analyses, qualifying the LWS sleeves for 7/8 inch tubes in Series 44 and 51 steam generators, are documented in References 3-4 and 3-11. These existing generic LWS analyses were performed for a generic set of loading conditions given in Reference 3-5, which umbrella most of the Kewaunee loads specified in Reference 3-2. Throughout the discussions of this section, it is assumed that the LWR has been stress relieved. Stress relief parameters are discussed in Section 6.6.

The sleeve, tube, and 0.015 inch minimum laser weld engagement length have been re-evaluated for the increased Kewaunee pressure differential loading discussed in Reference 3-8. Also, it has been determined that the finite element model, used in Reference 3-4 to initially qualify the minimum acceptable weld engagement length, under-predicted the shear stresses in the weld. This section updates the structural qualification of the 0.015 inch minimum weld using the methods and results documented in Reference 3-11 for pressure and fatigue loads. In addition, the minimum sleeve wall thicknesses for normal, maximum upset, and maximum faulted conditions have been re-calculated for the increased Kewaunee pressure differential loading using the more conservative minimum strength data from the ASME Code rather than the lower tolerance limit strength data used in Reference 3-1. The limiting wall thickness for the Kewaunee sleeve is used to define the sleeve plugging limit based on the tube plugging criteria of Reg. Guide 1.121, Reference 3-7.

3.1.1 Geometry

In the Kewaunee HEJ LWR, laser welds may be located at either the upper hard roll (HR) zone, or the upper hydraulic expansion (HE) zone, as shown in Figure 1-3. There are no tubes in service at Kewaunee with laser welds at both the HR and HE zones. For purposes of analysis, at either the HR or HE zone, the welds may be at either the initial "first weld" location or at the "reweld" location. If there is a [

]^{a,c} Therefore, as shown schematically in Figure 3-1, the [

]^{a,c}

3.1.2 Materials

The tubes are mill annealed (MA) Alloy 600 (35 ksi minimum yield), and the sleeves are thermally treated (TT) Alloy 690 (40 ksi minimum yield). It is assumed that [

]^{a,c} The tubesheet material is SA-508 Class 2 carbon steel. Structural and thermal-mechanical properties are taken from the appropriate tables of Appendix I of the 1989 Edition of the ASME Code, Reference 3-6. Likewise, the cumulative fatigue calculations are based on the design fatigue curves for nickel-chromium-iron alloys (600 and 690) in Figures I-9.2.1 and I-9.2.2 of Appendix I of Reference 3-6.

The following material properties, taken from References 3-6 and 3-9, are used in this evaluation:

Alloy 600 Tubes at 550°F

E = elastic modulus = $28.85\text{x}10^6$ psi
μ = Poisson's ratio = 0.3
α = mean coefficient of thermal expansion from 70°F = $7.77\text{x}10^{-6}$ $(°\text{F})^{-1}$
S_m = 23.3 ksi (70 to 800°F)
S_u = ultimate tensile strength = 80 ksi (70 to 800°F)
S_y = yield strength = 35 ksi (70°F), 28.35 ksi (550°F)

Alloy 690 Sleeve at 600°F

E = elastic modulus = $27.8\text{x}10^6$ psi
μ = Poisson's ratio = 0.3
α = mean coefficient of thermal expansion from 70°F = $8.16\text{x}10^{-6}$ $(°\text{F})^{-1}$
S_m = 26.6 ksi (70 to 800°F)
S_u = ultimate tensile strength = 80 ksi (70 to 800°F)
S_y = yield strength = 40 ksi (70°F), 35.3 ksi (600°F)

SA-508 Class 2 or 2a Tubesheet at 600°F

E = elastic modulus = $26.4\mathrm{x}10^{6}$ psi
μ = Poisson's ratio = 0.3
α = mean coefficient of thermal expansion from 70°F = $7.42\mathrm{x}10^{-6}$ $(°\mathrm{F})^{-1}$

3.1.3 Loading Conditions

The structural evaluation of the generic laser welded sleeves (LWS) for Series 44 and 51 Steam Generators, documented in Reference 3-4, is based on the normal operating load parameters in Table 3-1 for the maximum generic primary to secondary (steam) pressure and temperature differentials of [ ]^{a,c}, respectively. Based on the Keawunee plant specific data in Reference 3-8, the current maximum operating pressure differential for Kewaunee is [ ]^{a,c} differential considered in the evaluation of Reference 3-4. Therefore, it is necessary to re-evaluate the structural integrity of the HEJ LWR for a higher primary to secondary pressure differential. Based on the RETRAN results calculated by WPS in Reference 3-8, [ ]^{a,c}

Therefore, for the re-evaluation of the HEJ LWR reported herein, the design [ ]^{a,c} is conservatively selected as an upper bound on the operating pressure differential, consistent with the definitions of design and normal operation pressure differentials in NB-3112.1 and NCA-2142.1(a) of the ASME Code, Reference 3-6. As shown in last column of Table 3-1, the [ ]^{a,c} Table 3-2 lists the maximum pressures considered in this re-evaluation for design, upset, test and faulted conditions. Also shown in Table 3-2 are the corresponding design, upset, test and faulted pressure differentials, specified in Reference 3-5, that were used in the generic evaluation of LWS for 7/8 inch OD host tubes, Reference 3-4.

Table 3-3 lists the generic normal, upset, and test transients, from Reference 3-5, used in the generic fatigue evaluation of References 3-4 and 3-11. The normal and upset data in Table 3-3 correspond to the generic 100% power normal operating parameters listed in Table 3-1. The normal, upset, and test transients, assumed for the Kewaunee fatigue analysis, are given in Tables 3-4 and 3-5. The 100% full power normal operating primary pressure (P_p) is 2235 psig for both Kewaunee and the generic LWS. Therefore, it is assumed that the primary pressure (P_p) is same for the transients in Tables 3-3, 3-4, and 3-5.

The primary side hot leg temperature, T_h, is normalized for Kewaunee, using the generic T_h data in Table 3-3, assuming the following for any of the normal or upset transients:

[

$]^{a,c}$

The resulting normalized hot leg (T_h) temperatures assumed for Kewaunee are listed in Tables -4 and 3-5.

In a like manner, the Kewaunee normal and upset steam pressures and temperatures may be found by either [

$]^{a,c}$

Since it is not known which normalization gives the highest fatigue usage, both procedures are employed in the Kewaunee HEJ LWR fatigue re-evaluation.

In Table 3-4, the Kewaunee [$]^{a,c}$ data in Table 3-3, by assuming the following:

[

$]^{a,c}$

In Table 3-4, the Kewaunee [$]^{a,c}$ from the above equation.

In Table 3-5, [ ]^{a,c} data in Table 3-3 by assuming the following:

[ ]^{a,c}

In Table 3-5, the Kewaunee [ ]^{a,c} from the above equation.

The Kewaunee cumulative fatigue evaluation is performed for both the transients in Table 3-4 and the transients in Table 3-5. The parameter NOC in Tables 3-3, 3-4, and 3-5 gives the number of cycles (occurrences) for each load transient in a 40 year hypothetical fatigue design life, from Reference 3-5, used in the generic fatigue evaluation of Reference 3-4. The generic specified number of cycles are conservative, especially the [ ]^{a,c} are very conservatively retained in this evaluation.

3.1.4 Pressure Stress Evaluation

Figure 3-1 shows the analysis sections (ASNs) of the Kewaunee HEJ LWR considered in this re-evaluation. Recall that the laser weld repair occurs either at the upper HEJ hard roll (HR) zone or at the upper hydraulic expansion (HE) zone, but not both in the same HEJ sleeve. Therefore, in Figure 3-1, the primed ASNs, 2', 3', 5' at the HE, do not occur in the same sleeve and host tube as ASNs 2, 3, 5 at the HR. From previous analysis in Reference 3-4, the limiting pressure stresses [ ]^{a,c} Thus, for the tube and sleeve it is only necessary to re-evaluate the pressure stresses at the [ ]^{a,c} in Figure 3-1, are re-evaluated for the increased Kewaunee ΔP loads and HEJ geometry using the results from the generic experimental stress analysis of LWS discussed in Reference 3-4.

3.1.5 Far Field Pressure Stresses in Tube and Sleeve

Since external seismic and pipe accident loads are negligible near the top of the tubesheet (TTS), then from Appendix A-2222 of the ASME Code, Reference 3-6, the maximum far field stress intensity (P_m), in either the tube or sleeve due to pressure loading only, is given by:

$$P_m = \left(P_p - P_{stm}\right)\left(\frac{R}{t}\right)_{\max} + \frac{1}{2}\left(P_p + P_{stm}\right),$$

where: P_p = primary side pressure (psig),
P_{stm} = secondary side steam pressure (psig),
R = tube or sleeve inner radius (inch),
t = tube or sleeve wall thickness (inch).

For the limiting Series 51 tube geometry, the maximum R / t ratio occurs for the combination of the maximum [

$]^{a,c}$

For the Series 51 limiting sleeve geometry, the maximum R / t ratio occurs for the combination of the maximum [

$]^{a,c}$

The following loads (from Table 3-2) and the ASME Code allowable P_m stress intensities (from Referen3-6) apply:

For design conditions, [$]^{a,c}$
Allowable: $P_m \leq$ [$S_m = 23.3$ ksi for Alloy 600 Tube, 26.6 ksi for Alloy 690 sleeve].

For the [$]^{a,c}$
$P_m \leq$ [1.1 $S_m = 25.63$ ksi for Alloy 600 Tube, 29.26 ksi for Alloy 690 sleeve].

For test condition at [$]^{a,c}$
$P_m \leq$ [0.9 $S_y = 25.51$ ksi for Alloy 600 Tube, 31.77 ksi for Alloy 690 sleeve].

For test condition at [$]^{a,c}$
$P_m \leq$ [0.9 $S_y = 31.5$ ksi for Alloy 600 Tube, 36.0 ksi for Alloy 690 sleeve].

For [$]^{a,c}$
$P_m \leq$ [2.4 $S_m = 55.92$ ksi for Alloy 600 Tube, 0.7 $S_u = 56.0$ ksi for Alloy 690 sleeve].

The resulting far field membrane stress intensities in the tubes and sleeves are evaluated in Table 3-6 which lists the ratio of P_m to the allowable for design, upset, test and faulted conditions. It is seen that the ratio is less than one (P_m is less than the allowable) for all load conditions, and it is concluded that the tube and sleeve satisfy the ASME Code pressure stress limits for the increased ΔP loads for Kewaunee.

3.1.6 Pressure Stresses in Laser Welds

From Reference 3-4, the [$]^{a,c}$ where the HEJ sleeves are installed. Also, it is conservatively assumed that the [$]^{a,c}$ as shown schematically in Figure 3-2. Under this assumption, the [$]^{a,c}$ The pressure stresses, in the assumed 0.015 inch minimum thickness welds at ASN 5 and ASN 5' in Figure 3-1, are re-evaluated for the increased Kewaunee ΔP loads and the HEJ geometry using the test results from the experimental stress analysis of the generic Series 44 and 51 LWS discussed in Reference 3-11.

Appendix II and paragraph NB-3649 of the ASME Code, Reference 3-6, provide for experimental stress analysis and burst testing to demonstrate compliance with the structural limits of Subsection NB. From Reference 3-11, the limiting case for pressure loading occurs for the [ ]^{a,c} Compliance with elastic ASME Code limits for design conditions requires a factor of safety of three between the maximum test pressure and the maximum design pressure, consistent with the allowable membrane stress for design conditions of $S_u / 3$. For a [ ]^{a,c} In evaluating the pressure test results in Reference 11, the measured failure pressure is adjusted to account for [ ]^{a,c}

The limiting generic sleeve-tube interface geometry is obtained by assuming [

]^{a,c}

The R_{max} for the Kewaunee HEJ upper hydraulic expansion (HE) interface is equivalent to the above generic sleeve-tube interface (and R_{max}). Therefore, all of the above parameters also apply to the Kewaunee HEJ LWR, except that the [

]^{a,c} The limiting HEJ LWR sleeve-tube interface geometry at the upper hard roll (HR) zone is [

]^{a,c}

Table 3-4 of Reference 3-11 lists the safety factors determined by the burst tests of the generic Series 44 and 51 LWSs in 7/8 inch OD host tubes. The minimum measured safety factor of the [ ]^{a,c} These results apply both to the 0.015 inch generic LWS and the 0.015 inch minimum weld at the Kewaunee HEJ upper hydraulic expansion (HE) zone, both of which have a [ ]^{a,c} The minimum safety factor for the 0.015 inch minimum weld at the Kewaunee HEJ upper hard roll (HR) zone [

]^{a,c} Since the adjusted minimum safety factor is greater than three, the ASME Code pressure stress limits are met at both the upper HR and upper HE 0.015 inch minimum welds for the LWR of the Kewaunee HEJ sleeves.

3.1.7 Primary Plus Secondary Stress Intensity Range Evaluation

The maximum range of primary plus secondary stresses in the sleeve and tube must be less than $3S_m$ (69.9 ksi in the Alloy 600 tube and 79.8 ksi in the Alloy 690 sleeve). The generic LWS primary plus secondary stress range evaluation of the sleeve and tube in Reference 3-4 is based on the load transients in Table 3-3, which bound the Kewaunee transients in Tables 3-4 and 3-5 with respect to the [

]^{a,c} the maximum $3S_m$ range, the generic results in Table 3-14 of Reference 3-4, which show that the sleeve and tube meet the $3S_m$ limit with substantial margin, also apply to and bound the Kewaunee sleeve and tube evaluation. Therefore, since the

Kewaunee [ ]^{a,c} it is concluded that the Kewaunee sleeve and tube, in the vicinity of the HEJ LWR, also meet the $3S_m$ limit of the ASME Code with substantial margin.

As cited above, the [

]^{a,c} Thus, the combined pressure and thermal cyclic stresses in the Kewaunee laser welds at the upper HR and HE zones, due to the normal, upset, and test transient loads in Tables 3-4 and 3-5, need only be considered from a fatigue standpoint in order to show compliance with the ASME Code for cyclic operation.

3.1.8 Fatigue Evaluation

Based on the generic fatigue calculations in Reference 3-4, the [

]^{a,c} The finite element methods used in the generic fatigue evaluation of the 0.015 inch minimum weld thickness, given in Reference 3-11, are also employed in the fatigue re-evaluation of the 0.015 inch minimum thickness Kewaunee HEJ laser welds.

Finite Element Model of Kewaunee HEJ LWR

The combinations of thermal and pressure loads produce shear forces on the laser welds due to relative axial motions between the sleeve and tube that are resisted (constrained) by the welds. While it is likely that the HEJ hard roll also carries some of this shear load, it is conservatively assumed, as discussed previously, that all of the shear force at the sleeve-tube interface is carried by the 0.015 inch minimum thickness laser weld, either at the HEJ upper hydraulic expansion (HE) zone or at the HEJ upper hard roll (HR) zone. Since these welds are at different elevations relative to the tubesheet, two finite element models are required, one to simulate the weld at the upper HR zone, and one to simulate the weld at the upper HE zone.

The [

]^{a,c} as discussed in Reference 3-11. The [

]^{a,c} The HEJ sleeves in Kewaunee are similar to the generic full length tubesheet sleeves (FLTS), which were evaluated for fatigue in Reference 3-11, assuming a length of [ ]^{a,c} for the FLTS. The Kewaunee HEJ sleeves were installed in three lengths, [ ]^{a,c} Figure 3-3 shows schematic of the resulting spring and spar model for the Kewaunee HEJ LWR. The [ ]^{a,c} long HEJ sleeve is simulated since it gives a somewhat larger length of sleeve and tube that are thermally mismatched.

The average shear stress, τ, acting on the weld thickness, is:

$$\tau = \frac{F}{A_w} = \frac{F}{\pi \, ID \, w} ,$$

where F is the external shear force on the weld (due to the sleeve-tube interaction), A_w is the weld average shear area, ID is the host tube's nominal inner diameter [

]^{a,c} and w is the weld average engagement width (assumed to be the 0.015 inch minimum for all cases in this evaluation).

As discussed in Reference 3-11, [

]^{a,c}

The effect of the relatively "rigid" tubesheet on the tube thermal expansion is simulated using a [ ]^{a,c} that has the material properties of the tubesheet (SA-508 Class 2) and spans the distance from the [

]^{a,c}

The host (sleeved) tube is assumed to be at the center of a [

]^{a,c}

The Kewaunee HEJ LWR fatigue analysis considers both [

]^{a,c}

The end cap loading due to pressure is [

]^{a,c} are not shown in Figure 3-3 to preserve clarity).

Thermal loads are simulated by assigning temperatures to the [ ]^{a,c} based on the results of the thermal analysis in Reference 3-11. All of the sleeve and tubesheet nodes are [ ]^{a,c}. Most of the host tube, and all of the adjacent tube bundle nodes, are [ ]^{a,c} The host tube length, [ ]^{a,c}

Shear Forces on Weld Due to Unit Loads

Since the tube can be [ ]^{a,c}

The following four unit load cases were run for each of the four above model combinations:

[ ]^{a,c}

All thermal expansion cases are [ ]^{a,c} Table 3-7 lists the resulting finite element calculated shear forces due to the above unit loads for the welds at the upper hard roll (HR) zone and at the upper expansion (HE) zone for [ ]^{a,c}

Cumulative Usage Calculations For Kewaunee HEJ LWR Welds

The cumulative fatigue usage factors for the Kewaunee HEJ LWR were calculated, using the methods discussed in Reference 3-11, considering the Kewaunee transient loads in Tables 3-4 and 3-5 and the finite element calculated shear forces acting on the laser welds, due to the unit loads in Table 3-7. The resulting calculated cumulative usage factors for the Kewaunee HEJ welds are summarized in Table 3-8. Also shown in Table 3-8, for comparison, are the calculated generic cumulative usage factors for the Series 44 and 51 7/8 inch OD full length tubesheet sleeve (FLTS) from Reference 3-11. The results in Table 3-8 are calculated using a conservative upper bound fatigue strength reduction factor of [ ]^{a,c} as discussed in Reference 3-11.

In all cases, the 0.015 inch minimum weld engagement length was used to calculate the weld's shear area, and all transient loads were conservatively assumed to [ ]^{a,c} in rming the cyclic stress ranges. In reality, the various transient loads would [ ]^{a,c} resulting in even smaller cumulative usage factors, as discussed in Reference 11. Also, the generic number of load-unload cycles assumed in the usage calculations[ ]^{a,c} is very conservative. As discussed previously, the Kewaunee design specification, Reference 3-2, calls for [ ]^{a,c} load-unload cycles. Both of these large numbers of load-unload cycles assume the plant is operated using load follow. In reality, Kewaunee baseloads (remains at or near 100% power), and a more realistic, yet conservative, number of load-unload cycles is [ ]^{a,c}. However, since the usage factors in Table 3-8 are small and well within the ASME Code allowable of one, there is no need to regroup or reduce the number of transients. Based on the results in Table 3-8, it is concluded that the 0.015 inch minimum weld size in the laser weld repair of the Kewaunee HEJ sleeves meets the ASME Code limit for a forty year fatigue design life using very conservative loads and models.

3.1.9 Minimum Sleeve Wall Calculations

The minimum wall calculations and resulting plugging margins are given in Reference 3-1 for the Kewaunee HEJ sleeve and in Reference 3-4 for the generic laser welded sleeves. [

]^{a,c}

In establishing the safe limiting condition of a sleeve in terms of its remaining wall thickness, the effects of loadings during both the normal operation and the postulated accident conditions must be evaluated. The applicable stress criteria are given in terms of allowables for the primary membrane and membrane-plus-bending stress intensities. Hence, only the primary loads (those necessary for equilibrium) need be considered. For sleeves near the tubesheet, there are essentially no external primary bending loads and only the membrane P_m stress intensity is significant. Therefore, for computing t_{min}, the pressure stress equation NB-3324.1 of the Code, Reference 3-6, is used. That is,

$$t_{min} = \frac{\Delta P_i \ R_i}{P_m - 0.5 \ (P_i + P_o)},$$

where: R_i = maximum inner radius of unexpanded sleeve = [$]^{a,c}$,
P_i = internal pressure = P_P = primary pressure (psig),
P_o = external pressure = P_S = secondary pressure (psig),
$DP_i = P_i - P_o$,
P_m = allowable maximum value of primary membrane stress intensity (psi).

Normal Operation

From Table 3-1, the load parameters for normal steady state operation are:

$P_i = P_P =$ [$]^{a,c}$ psig, $P_o = P_S =$ [$]^{a,c}$ psig, $DP_i = P_i - P_o =$ [$]^{a,c}$ psi, sleeve @ 593°F,

and the allowable $P_m = S_u / 3 = 80 / 3 = 26.6$ ksi for TT Alloy 690. The resulting minimum thickness is:

[$]^{a,c}$

Maximum Upset Condition

From Table 3-2, the maximum upset conditions occur during the loss of load transient at the time when the primary pressure is [

$]^{a,c}$ These upset parameters are conservatively based on the data assumed in Table 3-4 that bound the Kewaunee evaluation. The load parameters for the maximum upset condition are:

$P_i = P_P =$ [$]^{a,c}$ psig, $P_o = P_S =$ [$]^{a,c}$ psig, $DP_i = P_i - P_o =$ [$]^{a,c}$ psi, sleeve @ 641°F,

and the allowable $P_m = S_y = 35.2$ ksi for TT Alloy 690 at 641°F, Reference 3-9. The resulting minimum thickness is:

[$]^{a,c}$

Accident Condition: LOCA + SSE

The dominant loading for LOCA and SSE loads occurs at the top tube support in the form of bending stresses in the tubes. At tube support intersections below the top support, LOCA loads drop off dramatically. Because the sleeve is located [$]^{a,c}$, the LOCA + SSE bending stresses in the sleeve are quite small. Therefore, the governing accident condition for the sleeve is a postulated secondary side blowdown, either a feedline break (FLB) or a steamline break (SLB) as discussed below.

Accident Condition: FLB / SLB + SSE

From Table 3-2, the maximum primary-to-secondary pressure differential occurs during a postulated feedline break (FLB) accident[1]. Again, because of the sleeve location, the SSE bending stresses are small. Thus, the governing stress for the minimum wall thickness requirement is the pressure membrane stress. The applicable criterion for faulted loads is:

$$P_m < \text{lesser of } 0.7\ S_u \text{ or } 2.4\ S_m$$

From Table 3-2, the load parameters for the feedline break are:

$P_i = P_P = [\quad]^{a,c}$ psig, $P_o = P_S = [\ ]^{a,c}$, $DP_i = P_i - P_o = [\quad]^{a,c}$ psi, sleeve @ 568°F,

and the allowable $P_m =$ lesser of $0.7\ S_u$ or $2.4\ S_m$. For Alloy 690 at 568°F,

$$0.7\ S_u = 0.7\ (80) = 56 \text{ ksi, and } 2.4\ S_m = 2.4\ (26.6) = 63.84 \text{ ksi.}$$

Thus, $P_m = 56$ ksi and the resulting minimum thickness is:

---

[1] The use of 2650 psig for FLB is conservative; 2560 psig is more credible.

[ ]^{a,c}

A summary of the normal, upset and accident minimum required wall thicknesses is given in Table 3-9.

3.1.10 Determination of Plugging Limits

The minimum acceptable wall thickness and other recommended practices in Regulatory Guide 1.121, Reference 3-7, are used to determine a plugging limit for the sleeve. The Regulatory Guide was written to provide guidance for the determination of a plugging limit for steam generator tubes undergoing localized tube wall loss and can be conservatively applied to sleeves. Tubes with sleeves which are determined to have indications of degradation of the sleeve in excess of the plugging limit, would have to be repaired or removed from service.

[illegible]s recommended in paragraph C.2.b of the Regulatory Guide, an additional thickness degradation allowance must be added to the minimum acceptable tube wall thickness to establish the operational sleeve thickness acceptable for continued service. Paragraph C.3.f of the Regulatory Guide specifies that the basis used in setting the operational degradation allowance include the method and data used in predicting the continuing degradation and consideration of NDE measurement errors and other significant eddy current testing parameters. An NDE measurement uncertainty value of [ ]^{a,c} of the sleeve wall thickness, Reference 3-4, is applied for use in the determination of the operational sleeve thickness acceptable for continued service in the determination of the plugging limit.

Paragraph C.3.f of the Regulatory Guide specifies that the bases used in setting the operational degradation analysis include the method and data used in predicting the continuing degradation. To develop a value for continuing degradation, sleeve experience must be reviewed. To date, [

]^{a,c}. As a conservative measure, the conventional practice of applying a value of [ ]^{a,c} of the sleeve wall, Reference 3-4, applied as an allowance for continued degradation, is used in this evaluation.

From Table 3-9, the structural limiting minimum sleeve wall thickness is [ ]^{a,c} undegraded minimum wall thickness of the sleeve. Therefore, as shown in Table 3-10, the plugging limit for the Kewaunee sleeve, in percent of undegraded minimum wall thickness, is:

[ ]^{a,c}

3.2 Thermal/Hydraulic Analysis

The thermal/hydraulic analysis results presented in the original Kewaunee sleeving report, Reference 1-5, are unaffected by LWR.

3.3 Conclusions of Analytical Verification

Conclusions of the analytical verification are:

- The laser weld repair at either the initial or reweld locations at either the hydraulic expansion or hard roll of the Kewaunee HEJ sleeve upper joint satisfies all primary stress limits with positive structural margin at all analysis sections.

- The laser weld repair at either the initial or reweld locations at either the hydraulic expansion or hard roll of the Kewaunee HEJ sleeve upper joint meets the maximum range of stress intensity limit with positive structural margin at all analysis sections for all specified normal, upset, and test loads.

- The laser weld repair at either the initial or reweld locations at either the hydraulic expansion or hard roll of the Kewaunee HEJ sleeve upper joint satisfies the ASME Code fatigue limit with positive structural margin for all specified normal, upset, and test load combinations for a forty year fatigue design life at all analysis sections.

- The plugging limit for the Kewaunee sleeve, in percent of undegraded minimum wall thickness, is [ ]^{a,c}.

3.4 References for Section 3

3-1 WCAP-11643, Revision 1, "Kewaunee Steam Generator Sleeving Report (Mechanical Sleeves)," November 1988. (Westinghouse Proprietary Class 2)

3-2 Design Specification 677031, Revision 4, "Reactor Coolant Systems 51 Series Steam Generator for Wisconsin Public Service Kewaunee Project," March 20, 1975. (Westinghouse Proprietary)

3-3 WCAP-14157, Revision 0, "Technical Evaluation of Hybrid Expansion Joint (HEJ) Sleeved Tubes With Indications Within the Upper Joint Zone," August 1994. (Westinghouse Proprietary Class 2C)

3-4 WCAP-13088, Revision 3, "Westinghouse Series 44 and 51 Steam Generator Generic Sleeving Report (Laser Welded Sleeves)," January 1994. (Westinghouse Proprietary Class 2)

3-5 Design Specification 412A19, "Laser Welded Sleeves for Plants With Series 44 and 51 Steam Generators," Rev. 0, December 17, 1992. (Westinghouse Proprietary Class 2C)

3-6 ASME Boiler and Pressure Vessel Code, Section III, "Rules, For Construction of Nuclear Power Plant Components," The American Society of Mechanical Engineers, New York, NY, 1989 Edition.

3-7 USNRC Regulatory Guide 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes (For Comment)," August 1976.

3-8 WPS Letter KS-W-1380, Lynne M. Gunderson (Wisconsin Public Services Corporation) to Stephen P. Swigart (Westinghouse Nuclear Services Division), "Results of the Ten Percent Step Load Transient as Performed by WPS," July 14, 1998.

3-9 Code Case N-20-3 to Reference 3-6, ASME Boiler and Pressure Vessel Code, Section III, "Rules, For Construction of Nuclear Power Plant Components," The American Society of Mechanical Engineers, New York, NY, 1989 Edition.

3-10 ASME Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," The American Society of Mechanical Engineers, New York, NY, 1989 Edition.

3-11 WCAP-13088, Revision 4, Addendum 1, "Westinghouse Series 44 and 51 Steam Generator Generic Sleeving Report (Laser Welded Sleeves)," June 1998. (Westinghouse Proprietary Class 2C)

Table 3-1
Comparison of Normal Operating Parameters Generic LWS Evaluation (References 3-4 & 3-5), Kewaunee WPS RETRAN at 96% Power (Reference 3-8), and Assumed for Re-Evaluation of Kewaunee HEJ LWR

a,c

Table 3-2
Maximum ΔP Loads Used In Kewaunee HEJ LWR and Generic LWS Structural Evaluations

a,c

Notes:

[1] Maximum upset ΔP occurs for "loss of load" transient (at time 10 seconds), Table 3-4.

[2] Per NB-3223 of Reference 3-6, the maximum allowable upset ΔP is 110% of the design ΔP.

[3] After a unit is in service, per IWB-5000 of Section XI of the ASME Code, Reference 3-10, the maximum hydrostatic ΔP is limited to 1.1 x operating ΔP (1760 psi) at 70°F and 1.02 times the operating ΔP (1632) at elevated temperature. The generic case conservatively assumes 1600 psi at elevated temperature, which is > 1.02 x generic operating ΔP (1.02 x 1530 = 1561 psi). The elevated temperature ΔP bounds due to the lower yield strength.

[4] Feedline break (FLB) at 668°F, Reference 3-5.

Table 3-3
Loads Used in Generic Fatigue Evaluation of Series 44 and 51 7/8 LWS (Ref. 3-4) from Ref. 3-5
(NOC cycles are for 40 years.)

a,c

Table 3-4
Loads Used in Fatigue Evaluation of 0.015 inch Minimum Weld in LWR of Kewaunee HEJ Sleeves

Generic Loads From Table 3-3 are normalized using T_h and T_{stm}

P_{stm} obtained from steam saturation tables.

(NOC cycles are for 40 years.)

a,c

Table 3-5

Loads Used in Fatigue Evaluation of

0.015 inch Minimum Weld in

LWR of Kewaunee HEJ Sleeves

Generic Loads From Table 3-3 are normalized using T_h and P_{stm}

T_{stm} obtained from steam saturation tables.

(NOC cycles are for 40 years.)

a,c

Table 3-6
Far Field Membrane Pressure Stress Intensities In Tube And Sleeve For Assumed Kewaunee Maximum ΔPs

a,c

Table 3-7
Calculated Shear Forces on Sleeve/Tube Laser Welds Due Indicated Unit Load Case

a,c

Table 3-8
Calculated Cumulative Fatigue Usage Factors For Kewaunee HEJ LWR Welds Minimum Engagement Length of 0.015 inch K_f = [ ]^{a,c} and 40 year Fatigue Design Life

a,c

Table 3-9
Summary of Minimum Wall Thickness Calculations
Laser Weld Repair of Kewaunee HEJ Sleeves

a,c

Table 3-10
Summary of Recommended Plugging Margins
Laser Weld Repair of Kewaunee HEJ Sleeves

a,c

a,c

Figure 3-1
Analysis Sections (ASNs) for
Laser Welded Repair of HEJ Sleeve

a,c

Figure 3-2
Location of Assumed Tube
Severance For Analysis

a,c

Figure 3-3
Schematic of Structural Finite Element
Model of Kewaunee HEJ LWR

.0 MECHANICAL TESTS

Mechanical tests were described in the generic laser welded sleeving (LWS) report for application in 7/8-inch tubes, Reference 1-6, as well as the HEJ sleeving report for Kewaunee, Reference 1-5.

Reference 1-6 shows that:

a.) The laser weld is leak tight to pressures greater than 3100 psi at 600°F,

b.) The load carrying capability of the laser weld exceeds the end cap loadings associated with a safety factor of 3 applied to the Kewaunee normal operating primary-to-secondary pressure differential (most limiting Regulatory Guide 1.121 case).

It was concluded that the LWS test results are directly applicable to the LWR HEJ, and that the upper joint is acceptable based on Reference 1-6 leakage and load carrying criteria and test results.

The leak rate criteria for LWR HEJ sleeves are the same as those for the HEJ sleeves described in the Kewaunee HEJ sleeve report, Reference 1-5. Allowable leak rates for normal and postulated accident conditions were defined in Table 3.3.4.3-1 of Reference 1-5. Since the upper joint in an LWR HEJ sleeve is hermetically sealed by the laser weld, leakage from only the lower joint is considered in evaluating the LWR HEJ sleeve against the acceptance criteria. The HEJ lower joint is unaffected by LWR, and the LWR HEJ leak rates remain well within the allowable limits. Similarly, Reference 1-5 shows that the LWR HEJ lower joint, which has a load carrying capability greater than an end cap loading equal to three times the normal Kewaunee operating primary-to-secondary pressure, continues to meet the limiting Regulatory Guide 1.121 criterion.

The results do not change when considering the LWR HEJ as an assembly (both upper and lower joints), and the mechanical testing confirms LWR HEJ acceptability with regard to leakage and load carrying capability.

5.0 CORROSION TESTING

The following section provides the results of corrosion tests performed in support of HEJ LWR. The mockups described in this section were prepared using [ ]^{a,c,e} At the start of the 1996 outage repair efforts, the weld acceptance rates for the HR LWR position at Kewaunee were lower than desired. This was [ ]^{a,c,e} position was qualified in the Westinghouse development laboratory and the basis for its acceptance is provided in this report.

The HE LWR far-field stresses are expected to differ negligibly from those determined for the HR LWR. The difference in elevation between the two repair locations is about [ ]^{a,c,e}, and for a weld-to-TSP span greater than 40 inches, this change is negligible. The HE LWR position is expected to offer a potential benefit in that the distance from the weld to the hydraulic expansion transition is reduced from [ ]^{a,c,e}, which may enhance the potential for thermal stress relief of the hydraulic expansion during post-weld stress relief. As noted in Section 5.4, the discussion of HR LWR corrosion tests, the HR LWR mockups failed at the UHE location.

For the reasons discussed here, it is judged that the results of the corrosion tests for the HR LWR specimens, including estimates of the service performance of the repaired sleeves, remain valid and may be conservative.

Laser welding was performed in the upper hydraulic expansion region (HE LWRs) of a number of HEJ specimens. Four HE LWR specimens were made using the contaminant solution of Table 2-2. Metallurgical sectioning and examination of these specimens showed that the welds were sound, with no cracking. However, if field conditions are different from those stated in Table 2-2, acceptance rates for welds may vary.

5.1 Test Matrix Basis

The corrosion test specimen matrix is presented in Table 5-1. Examination of field HEJs has shown that "roll-down" can occur at the lower end of the upper mechanical roll, so half of the specimens were prepared with the roll-down effect, and half without. To evaluate the effects of post-LWR thermal stress relief on corrosion performance, HEJ LWR specimens were made with and without thermal stress relief of the LWR region.

For corrosion testing in doped steam, it is standard practice to include roll-expansion specimens prepared with tubing of known low resistance to PWSCC, in order to obtain "baseline" data for comparison to the test specimens; this approach was employed in LWR HEJ testing. Six such roll-expansion specimens were prepared, and these were exposed on a distributed basis among the various autoclaves used for the HEJ LWR tests.

5.2 Specimen Preparation

The matrix illustrating the specimens types is shown in Table 5-1. The tubing used in the fabrication of both the HEJ LWR specimens and roll transition specimens is from a reference heat of mill annealed Alloy 600 that was processed to have low resistance to primary water stress corrosion cracking. The corrosion resistance of this material in doped steam has been well-characterized in the doped steam test environment. Sleeves used for fabrication of the specimens were from production lots of thermally treated Alloy 690 sleeving.

Prior to assembly as HEJs, the sixteen sleeve and tube sections were [

]^{a,c,e} The HEJ test assemblies were then fabricated using the same process as the field HEJs.

All of the specimens were fabricated under conditions believed to conservatively represent those in the field, viz, with the tubes "locked" against axial motion at the tube support plates (TSPs). During specimen fabrication, the far-field stresses from the HEJ sleeving process, and those arising from LWR (including stress relief), were measured and recorded.

The test stand for the fabrication of the specimens is designed to simulate the steam generator structure, assuming the tube is locked at the first support plate. The span between the top of the tubesheet and the support plate, as shown in Figure 5-1, is consistent with that of the Model 51 steam generators. In each specimen, the tubesheet is simulated by a [

]^{a,c,e}

5.2.1 Far-Field Stresses

The far-field fabrication stresses were measured by [

]^{a,c}. Axial stresses were determined at each fabrication step, from the fabrication of the HEJ through the laser weld repair process and thermal stress relief.

All HEJ fabrication processes were consistent with the field process used to install HEJ sleeves in the steam generators. The laser welding process and stress relief process are the same as those which are to be used to effect the field repairs. The stress relief process employed a [

]^{a,c}

The average far-field stresses after HEJ fabrication, laser welding and stress relief operations are summarized in Table 5-2. The data are provided for both the roll-down and no roll-down configurations. Installation and fabrication of the HEJ sleeve joint led to average far-field [

]^{a,c}

A typical time-stress history during the installation of the HEJ and the subsequent repair is shown in Figure 5-2. This figure shows the change in far-field stress as each operation progresses and shows the final far-field stress state for a laser weld repair in the stress relieved condition.

5.2.2 Sleeved Tube Geometry and Weld Integrity

The laser weld repair, which includes the stress relief of the weld, did not result in any change in tube diameter or the introduction of any significant bowing or buckling of the tube. The typical tube diameter of the repaired HEJ tube in the region of the upper joint is shown in Figure 5-3. The final tube diameter is established during the HEJ sleeve installation and there is no additional diametral change associated with the laser weld repair.

There was no evidence in the data shown in Figure 5-3 of local bulging during the stress relief operation. [

]^{a,c}.

Visual examination of the weld surface showed the welds to be sound with no evidence of cracking or blowholes. UT examination also showed the welds to be of good quality and as meeting the acceptance criteria defined in Section 7.0. Metallographic sectioning was performed on a number of weld-repaired sections to verify the weld parameters were consistently producing weld axial extents (the structural boundary between the Alloy 690 sleeve and the Alloy 600 parent tube) greater than the analyzed minimum value defined in Section 3.1.1.

5.3 Corrosion Test Method

The resistance of the laser weld repaired HEJ sleeved tube to primary water stress corrosion cracking (PWSCC) was evaluated in accelerated corrosion tests of the specimens prepared under locked tube conditions. The accelerated corrosion tests were conducted in dense steam in a high pressure autoclave operating at [

]^{a,c}. This test provides an extreme acceleration of the corrosion process relative to that which occurs in an operating steam generator. In some respects, the doped steam test can be viewed as a stress-indexing test; failure times in the doped steam test can generally be analyzed in terms of the stresses (residual and pressure) present in the test articles. In view of the dominant role of stress in PWSCC of Alloy 600, this is a particularly valuable feature of the test.

To facilitate interpretation of the corrosion test results and to provide verification of the aggressiveness of the test environment, roll expansion transition specimens, prepared of a reference laboratory heat of Alloy 600 with known low resistance to PWSCC, were included in the autoclaves.

For the current test program, the configuration of the test assembly is shown in Figure 5-4. The specimen is loaded axially [

]^{a,c}. For the LWR HEJ specimens, all specimens were tested with a load which produced an [ ]^{a,c,e} as measured in the straight portion of tube above the HEJ. This is a conservative (high) value and includes, in addition to the largest above-the-HEJ far field stress measured for the sixteen specimens from Table 5-2 (average of A and B strain gages for specimen KR-02), an adjusted stress contribution for the "end cap load" which conservatively assumes that the tube is *not* locked in the tube support plate, and an adjustment for modulus effects (relative to actual SG operating conditions) that occur in heating the test specimens to 750°F. Note that the addition of the end cap loading is conservative for the majority of Kewaunee tubes, since most of the tubes are believed to be "locked" at the first hot leg TSP.

The corrosion tests were to be run for a period of [

]^{a,c}. Post-test examinations are done by non-destructive (eddy current) and destructive examinations as necessary, to locate and characterize the degradation.

5.4 Corrosion Test Results

The results of the corrosion tests are presented in Table 5-3. Included in the data are the results for the roll expansion specimens. Autoclave facilities capable of testing specimens of the size and complexity of the LWR HEJ test articles are limited; hence, initial emphasis was placed on the specimens representative of the laser weld repair process proposed for Kewaunee. Tests of several of the non-stress relieved specimens were also performed for reference information.

Nondestructive and destructive tests were performed on all of the stress relieved specimens (KR-1 to KR-8) and the results are presented in Table 5-4. [

]^{a,c}.

Two of the tube sections (KR-7 and KR-8) showing [

]^{a,c}. In general, Table 5-4 shows a good agreement between the crack dimensions determined by destructive and nondestructive methods. In some cases, the destructive examination showed greater crack lengths or additional cracks.

The testing of the stress relieved specimens indicated that [

]^{a,c}.

[

]^{a,c}.

A review of the time to develop stress corrosion cracking in Table 5-3 indicates that the stress relieved specimens take much longer [ ]^{a,c} to crack as compared to the specimens without stress relief [ ]^{a,c}. There was [

]^{a,c} specimens.

Of [

]^{a,c}.

Estimate of LWR Service Performance

The mean time-to-failure of the roll expansion specimens was [ ]^{a,c}. Using the data shown in Table 5-3 for total times in test [

]^{a,c}. Hence,

[ ]^{a,c}

However, the stress dependency of cracking in doped steam and in primary water are not the same. In data (Reference 5-1) established from tests on dead-weight loaded specimens that the stress exponent, n, for Alloy 600 in doped steam is [ ]^{a,c}.

Hence, in primary water,

[ ]^{a,c}

r, times-to-crack in primary water are related to times-to-crack in doped steam by,

[ ]^{a,c}

For this set of data, using the average values cited above,

[ ]^{a,c}

This implies that the failure of LWR HEJ tubes will not occur before greater than [ ]^{a,c} the operating period required to crack roll-expanded tubing. For SGs operating with an inlet temperature (T_{hot}) on the order of 600°F, the operating time required to crack a roll expansion would be well over [ ]^{a,c}. Hence, the projected performance of LWR HEJ sleeves is greater than [ ]^{a,c}.

For the worst case, using only the data for the earliest failure in the doped steam tests, [ ]^{a,c} for the repaired joint on a worst-case basis.

Estimate of Performance of Non-Stress Relieved Specimens

The mean time-to-failure of the roll expansion specimens was [ ]^{a,c}. Using the data shown in Table 5-3 for total times in test, the mean time-to-failure for the [ ]^{a,c}. Hence,

[ ]^{a,c}

As noted above, the stress dependency of cracking in doped steam and in primary water are not the same. Applying the same relationships as described above,

[ ]^{a,c}

This implies that the failure of non-stress relieved LWR HEJ tubes will not occur before greater [ ]^{a,c} the operating period required to crack roll-expanded tubing. This is a [ ]^{a,c} than the operating period indicated for stress relieved LWR HEJs.

5.5 References for Section 5

5-1 "Strain-Rate Damage Model for Alloy 600 in Primary Water", Final Report on Research Project S303-8, EPRI Report NP-7008, October 1990.

Table 5-1
Corrosion Test Matrix for Kewauuee HEJ Repair

a,c

Table 5-2 (Cont'd.) Str[illegible] Measured in Mockup Fabrication

a,c

Table 5-3 Results of Corrosion Tests in Doped Steam

a,c

Table 5-4 Test Results of Stress Relieved Corrosion Samples

a,c

a,

Figure 5-1

Test Stand for Fabrication of LWS Mockups Under Locked Tube Conditions

Figure 5-2
Stress Time History for HEJ LWS Repair and Stress Relief

a,c,e

Figure 5-3
HEJ Tube OD Dimensions Post-LWS Repair

a,c,

a,c,e

Figure 5-4

Corrosion Test Sample Configuration

6.0 REPAIR PROCESS DESCRIPTION

The repair of steam generator tubes by laser welded sleeving has been performed for over 30,500 installations to date. All of the sleeves installed by the laser welding technique have been Alloy 690TT, which is the material employed for the HEJ sleeves utilized at Kewaunee.

6.1 HEJ Sleeve Installation

The HEJ sleeve design configuration was briefly described in Section 2. Complete information on the HEJ sleeve installation is available in Reference 1-5, the Kewaunee sleeving report.

6.2 Sleeve ID Cleaning

To address the inside surface of the HEJ sleeve at the intended weld location, the HEJ LWR repair process includes a cleaning step to remove potential deposit of boric acid, frangible oxides or other material. Tests show that this process does not remove any significant fraction of the sleeve base material. Cleaning also removes radioactive deposits from the sleeve inside diameter, thereby reducing exposure rates in the channel head.

The interior surface of each candidate sleeve is cleaned by a [ ]^{a,c,e} The hone brush is mounted on a flexible drive shaft and driven by a pneumatic motor. The hone brush is driven only in the vicinity of the upper hard roll. [ ]^{a,c,e} The Cleaning End Effector mounts to a tool delivery robot and consists of a guide tube sight glass and a flexible seal designed to surround the tube/sleeve end and contain the spent flushing water. A flexible conduit is attached to the guide tube and connects to the cleaning unit on the steam generator platform. The conduit acts as a closed system which serves to guide the drive shaft/hone brush assembly through the guide tube to the candidate tube and also to carry the spent flushing water to an air driven diaphragm pump. The pump routes the water to the radioactive waste drain.

6.3 Drying of Sleeve/Tube at Weld Location

Examinations of test and field welds have shown that the presence of moisture in the crevice between the tube and sleeve can have an adverse effect on weld quality. Therefore, the LWR process includes an optional drying step prior to welding in order to vaporize residual moisture and volatile contaminants that may be present in the sleeve/tube crevice. Drying of the upper HEJ hardroll or expansion region is performed using the same probe as that used for post-weld heat treatment.

6.4 General Description of Laser Weld Operation

The design of the laser welded HEJ repair was illustrated in Figure 1-3. The repair technique is a laser weld within the upper hardrolled zone of a HEJ or the hydraulically expanded region above the upper hardroll of a HEJ.

The integrity of the weld between the tube and sleeve will be verified by ultrasonic (UT) examination and by eddy current testing (ECT). The weld will then be stress relieved by heat treatment. The weld geometry based on field experience is approximately [

]^{a,e} No changes are made to the HEJ sleeve lower joint.

Welding of the HEJ sleeve is accomplished by a specially developed laser beam transmission system and rotating weld head. This system employs a Nd:YAG laser energy source located in a trailer outside of containment. The energy of the laser is delivered to the steam generator platform junction box through a fiber optic cable. The fiber optic contains an intrinsic safety wire which protects personnel in the case of damage to the fiber. The weld head is connected to the platform junction box by a prealigned fiber optic coupler. Each weld head contains the necessary optics, fiber termination and tracking device to correctly focus the laser beam on the interior of the sleeve.

The weld head/fiber optic assembly is precisely positioned within the hydraulic expansion region using the Select and Locate End Effector (SALEE). The SALEE consists of [

]^{a,c}.

The LWR process is similar to that employed for laser welded sleeves in 7/8" tubes, as discussed in Section 2.0. The weld process was qualified in accordance with the rules of ASME Code Sections IX and XI (Reference 6-1), and to the additional Westinghouse requirements for weld geometry. The welding parameters are computer controlled at the weld operator's station. The essential variables per Code Case N-395 are monitored and documented for field weld acceptance. 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 the analyzed minimum width (see Section 3.1.1).

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 detailed installation process verification steps will be specified in the Kewaunee HEJ LWR field service procedure.

6.5 Rewelding

Under some conditions, the initial attempt at making a laser weld may be interrupted before completion or determined to be unsatisfactory, [ ]^{a,c}. As indicated on Figure 1-3, inboard (lower elevation) rewelds are permitted at both the HE LWR and HR LWR reweld locations, [ ]^{a,c,e} below the initial weld. In addition, [

]^{a,c,e}

6.6 Post-Weld Heat Treatment

Corrosion testing of LWR HEJ mockups, as discussed in Section 5, demonstrated the relative corrosion performance of post-weld thermal stress relieved specimens versus non-stress relieved specimens. The data support the efficacy of post-weld thermal stress relief. This stress relief [illegible]ration will be performed with a [

]^{a,c,e}

The field tooling used by Westinghouse for stress relief consists of the heater probes and an en[illegible] effector. The heater probe is a [$]^{a,d}$ The end effector places a probe within the proper zone to perform the stress relief operation. This is done by using the ROSA robotic arm and the SALEE to sequentially place the heater probes at the proper welded sleeve/tube interfaces, including reweld locations, followed by application of the stress relief process. This equipment has been used routinely and consistently for field sleeving efforts.

6.7 Inspection Plan

In order to verify the final sleeve installation, inspections will be performed on sleeved tubes to verify installation and to establish a baseline for future eddy current examination of the sleeved tubes. Specific NDE processes are discussed in Section 7.0. The inspection acceptance criteria include which are similar to those of laser welded sleeves, and which address issues specific to LWR. Tubes with laser weld repaired HEJ sleeves which do not meet the inspection acceptance criteria will be removed from service.

6.8 References for Section 6

6-1 ASME Boiler and Pressure Vessel Code, Section XI, Article IWB-4300, 1989 Edition, 1989 Addenda.

Table 6-1

HEJ Laser Weld Repair Process Sequence Summary

SLEEVE ID CLEANING	1)	Hone ID of HEJ Sleeves at Weld Location
DRYING (Optional)	2)	Heat Sleeve/Tube at Weld Location
WELD OPERATION	3)	Weld Upper HEJ Sleeve Joint
UT INSPECTION	4)	Ultrasonically Inspect Sleeve Weld
STRESS RELIEF	5)	Post Weld Stress Relief of Weld
REROLL (if required)	6)	Reroll TIG-Relaxed Region from Plug Removal
UT INSPECTION	7)	Ultrasonically Inspect Sleeve Weld
EC INSPECTION *	8)	Eddy Current Inspect Sleeve/Weld

* Note: EC Inspection may be optionally performed prior to post-weld stress relief of the weld.

7.0 NDE INSPECTABILITY

Laser welding parameters are computer controlled at the weld operator's station. The essential variables of ASME Code Case N-395 are monitored and documented for each weld. In addition, two non-destructive examination (NDE) techniques are used to evaluate the acceptability of the weld. Both ultrasonic examination and eddy current testing are used to confirm that the laser weld meets critical dimensional and integrity requirements.

7.1 Inspection Plan Logic

The basic LWR sleeve inspection plan consists of:

A. Ultrasonic Inspection (Section 7.2) [ ]^{a,c,e} to:

1. Verify minimum required weld width.
2. Determine the continuity of the weld.
3. Detect significant tube ID surface discontinuities.

B. If eddy current inspection of a sleeve is performed prior to, but during the same outage as LWR, inspection of only the weld region of the HEJ LWR (as described in Section 7.3) would be required. If no such prior inspection has been performed, eddy current inspection of the full length of the sleeve would be required. In both cases, ECT is to:

1. Verify that the weld is located at the proper axial position for an HE LWR, HE LWR reweld, HR LWR, or an HR LWR reweld, in accordance with the field procedure requirements.

2. Verify the presence of post-weld heat treatment for LWR locations. If ECT is performed prior to stress relief, then administrative controls (discussed below) are employed for ensuring stress relief was performed at the proper location.

3. Perform a volumetric inspection of the sleeve, the sleeve/tube joint, and the parent tube in the vicinity of the welded sleeve joint. This inspection is also to determine if hot weld hot cracking has occured.

4. Verify that the minimum distance between the centerline of the weld and potential degradation in the non-pressure boundary portion of the parent tube (i.e., in the parent tube portion immediately below the weld) is [

   ]^{a,c,e}

EC detection of changes in tube permeability can be used, as indicated in (2) above, to confirm that LWR stress relief has been performed, provided that the location has not been previously exposed to heat treatment temperatures above [

]^{a,c,e} then process controls must be used to ensure correct positioning of the heat treat probe and application of the qualified post weld stress relief in lieu of eddy current inspection.

The process controls include a series of independent position verifications to ensure that the heat treatment is implemented at the proper tube and elevation. These include:

1.) [

]^{a,c,e}

2.) [

]^{a,c,e}

3.) [

]^{a,c,e}

4.) [

]^{a,c,e}

5.) [

]^{a,c,e}

6.) [

]^{a,c,e}

As indicated in Table 6-1, eddy current inspection may be optionally performed prior to post-weld stress relief of the weld. In this case, process controls rather than eddy current inspection are used to verify the presence of post-weld heat treatment. The weld location information and the volumetric inspection data will provide a credible benchmark for future inspections.

C. Weld Process Control [ ]^{a,c,e} to:

1. Demonstrate that the weld process parameters comply with the qualified weld process specification.

7.2 Overview of Ultrasonic Examination Process

The ultrasonic (UT) inspection process for LWR HEJ sleeves is based upon techniques which have been successfully used on Westinghouse laser welded sleeves for 3/4-inch and 7/8-inch OD tubes.

The UT inspection technique has been adapted to examine laser welds. UT transmits ultrasound to the interface region (the sleeve OD /tube ID boundary) and analyzes the amount of reflected energy from that region. An acceptable weld joint should present no acoustic reflectors from this interface above a predetermined threshold.

Appropriate transducer, instrumentation and delivery systems have been designed and techniques established to demonstrate the ability to identify welds with widths below the structural requirements. The entire weld interface (100 per cent of the axial and circumferential extent) will be examined. Acceptance of welds is based upon application of criteria which are qualified by destructive examination of marginal welds. The development of criteria based upon direct evaluation of destructively examined welds provides a high degree of confidence in the weld acceptance criteria. The acceptance criteria are detailed in the appropriate field procedure.

7.2.1 Principle of Operation and Data Processing of Ultrasonic Examination

The ultrasonic examination of a laser weld is schematically outlined in Figure 7-1. An ultrasonic wave is launched by application of an electrical pulse to a piezoelectric transducer. The wave propagates in the couplant medium (water) until it strikes the ID of the sleeve. Ultrasonic energy is both transmitted and reflected at the boundary. The reflected wave returns to the transducer where it is converted back into an electrical signal which is amplified and displayed on the UT display.

The transmitted wave propagates in the sleeve until it reaches the sleeve OD. If fusion between the sleeve and tube exists, the wave continues to propagate through the weld joint into the tube. This wave then reaches the outer wall (backwall) of the tube and is reflected back to the transducer. The resulting UT display from a sound weld joint is a large signal from the sleeve ID, followed by a tube backwall "echo" spaced by the time of travel in the sleeve-tube-weld assembly ($T_{1,2,3}$). If no fusion between the sleeve and the tube exists, another pattern is observed with a large signal from the sleeve ID followed by a reflection from the sleeve OD. The spacing of these echoes depends on the time of travel in the sleeve alone ($T_{1,2}$). Additional reflections after the sleeve OD reflections are considered "multiples" of the sleeve OD reflection. These are caused as the sound energy reflected off the sleeve OD bounces back and forth between the sleeve ID and OD, and decays over time.

[

]^{a,c,e}

Criteria for the acceptance of a laser weld is based upon combination of the observed ultrasonic response at the at the weld surface, the sleeve/tube interface, and the tube OD.

An automated system is used for digitizing and storing the UT wave forms (A-Scans). [

]^{a,c,e} The ultrasonic response from the weld is then digitized for each pulse. A typical digitized A-scan is shown in Figure 7-2. Time intervals known as "gates" are set up over the signals of interest in the A-Scan so that an output known as a "C-Scan" can be generated. The C-Scan is a developed view of the inspection area which maps the amplitude of the signals of interest as a function of position in the tube. A combined C-scan which shows the logical combinations conditions of signals in two gates with respect to predetermined threshold values can also be displayed. Figure 7-3 shows the A, B, C, and combined C-scan display for a weld in a calibration standard.

7.2.2 Laser Weld Test Sample Results

Ultrasonic test process criteria are developed by [

]^{a,c,e}

Field application requires calibration to establish that the system essential variables are set per the same process which was qualified. Elements of the calibration are to:

- Set system sensitivity (gain)
- Provide time of flight reference for sleeve ID, OD and tube OD signals
- Verify proper system function by examination of a workmanship sample

Figure 7-4 depicts a calibration standard for the sleeve weld UT exam. (This figure shows the standard for a 3/4 inch sleeve; a corresponding standard exists for a 7/8 inch sleeve.)

7.2.3 Ultrasonic Inspection Equipment and Tooling

The probe is delivered with a robotic tooling system. The various subsystems include the water couplant, UT, motor control, and data display/storage.

The probe motion is accomplished via rotary and axial drives which allow a range of speeds and axial advances per 360° scan of the transducer head (pitch). The pitch provides a high degree of overlapping coverage without sacrificing resolution or sensitivity.

The controls and displays are configured for remote location in a trailer outside of containment. The system also provides for periodic calibration of the UT system on the steam generator platform.

7.3 Eddy Current Inspection

Eddy current inspection is performed on each repair to meet the process verification and inspection requirements outlined in Section 7.1 B. Probes of either the array- or rotating-type which are qualified to meet ASME XI and EPRI Guideline NP-6201 Appendix H requirements are to be used in the inspection.

As other advanced techniques become available and are qualified for use, they may be implemented in LWR inspection programs.

7.4 Inservice Iuspection Plan for LWR HEJs

The need exists to perform periodic inspections of the tube and sleeve pressure boundary. The inservice inspection program of LWR HEJs will consist of the following:

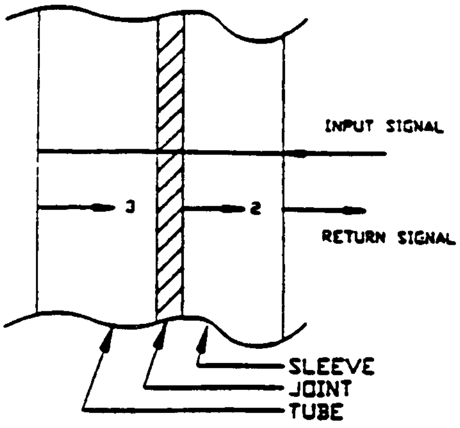
a) The LWR region will be eddy current inspected upon completion of installation to obtain a baseline signature to which all subsequent inspections will be compared.

b) Periodic inspections will be performed to monitor sleeve and tube wall conditions in accordance with the inspection section of the individual plant Technical Specifications.

The inspection of sleeves will necessitate the use of an eddy current probe that can pass through the sleeve ID. For the tube span between sleeves, this will result in a reduced fill factor for bobbin inspections. The possibility for tube degradation in free span lengths is extremely small. Plant data have shown that this area is less susceptible to degradation than other locations. Any tube indication in this region will require further inspection by alternate techniques (i.e., surface riding probes) prior to acceptance of that indication. Otherwise the tube shall be repaired or plugged. Any eddy current indication in the free span, sleeve or sleeve/tube joint region which cannot be dispositioned by standard dual-analyst review will require further inspection by alternate techniques, i.e., surface riding probes, prior to acceptance of that indication. Otherwise the tube containing the sleeve shall be repaired or plugged.

7.5 References for Section 7

7-1 Stubbe, J., Birthe, J. Verbeek, K., "Qualification and Field Experience of Sleeving Repair Techniques: CSNI/UNIPEDE Specialist Meeting on Operating Experience with Steam Generators, paper 8.7, Brussels, Belgium, September 1991.



IDEALIZED WAVEFORMS

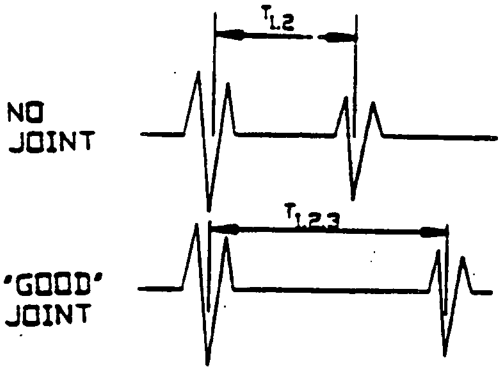


Figure 7-1

Ultrasonic Inspection of Welded Sleeve Joint

a,c

Figure 7-2

Typical Digitized UT Waveform

a,c,e

Figure 7-3
A, B, C, and Combined C-Scan Display for Weld in UT Calibration Standard

a,c,e

Figure 7-4

UT Calibration Standard