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Repair of

Kewaunee

Steam Generator Tubes

Using A Resleeving Technique

FINAL REPORT

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ABSTRACT

A technique is presented for repairing steam generator tubes which have been previously sleeved in a pressurized water reactor Nuclear Steam Supply System (NSSS). The technique described alleviates the need for plugging previously sleeved steam generator tubes which require repair prior to returning the steam generators to service. This resleeving technique is a two step process. The first step consists of tube preparation. This is the removal of the Hybrid Expansion Joint (HEJ) lower sleeve section; expansion of the remaining HEJ sleeve section; and the severing of the tube (within the tubesheet) to reduce residual stresses. The second step of the process consists of installing a thermally treated Alloy 690 sleeve which spans the section, or sections, of the original steam generator tube which requires repair. The sleeve is welded at the upper end and hard rolled at the lower end.

This report details analyses and testing performed to verify the adequacy of repair by resleeving in a Kewuanee steam generator tube. These verifications show tube resleeving to be an acceptable repair technique.

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1. INTRODUCTION

1.1 PURPOSE

The purpose of this report is to provide sufficient information, in conjunction with References 1.3.1 and 1.3.2, to support a technical specification change allowing installation of [ ] full depth tubesheet (FDTS) sleeves in the Kewaunee steam generators. These sleeves will be installed using a resleeving process. This process involves the removal of a portion of the previously installed HEJ sleeve, preparation of the remaining sleeve section and tube, and installation of the FDTS sleeve to bridge the degraded portion of the tube. Figure 4-1 shows the sequence for the resleeve process.

1.2 BACKGROUND

As steam generators age, previously installed repair techniques may cause unexpected tube degradation. Using increased sleeve lengths, which are outside the bounds of the parameters covered in References 1.3.1 and 1.3.2, it may be possible to repair these tube locations. This report addresses this resleeving process, including the change in sleeve length and the resulting differences in sleeve loadings and stress levels associated with the new sleeve/tube assembly.

1.3 REFERENCES

1.3.1 CEN-629-P, Revision 02, Repair of Westinghouse Series 44 and 51 Steam Generator Tubes Using Leak Tight Sleeves, Combustion Engineering Inc., January 1997.

1.3.2 CEN-413-P, Kewaunee Steam Generator Tube Repair Using Leak Tight Sleeves, Combustion Engineering Inc., January 1992.

1.3.3 CEN-625-P, Revision 00, Verification Of The ABB CENO Steam Generator Tube Sleeve Installation Process And Operating Performance, Combustion Engineering Inc., September 1995.

2. SUMMARY AND CONCLUSIONS

The removal of the HEJ sleeve, the associated tube preparation, and the change in sleeve length described in this report have only a minimal effect on the loads, stresses and flow effects experienced by the full depth tubesheet sleeve described in References 1.3.1 and 1.3.2. As such, the safety factors described in the analysis and verified by the testing performed, still provide more than adequate margin against operating and faulted conditions.

3. ACCEPTANCE CRITERIA

The conditions evaluated in conjunction with the design criteria contained in References 1.3.1 and 1.3.2 are defined as follows:

Primary Side:	617° F (operating)	2235 psig (operating)
	650° F (design)	2500 psig (design)
Secondary Side	533° F (operating)	635 psig (operating)
	550° F (design)	1085 psig (design)

4. DESCRIPTION OF HEJ REMOVAL PROCESS, ABB SLEEVE DESIGN AND SLEEVE INSTALLATION EQUIPMENT

4.1 TUBE PREPARATION PROCESS

In order to accomplish the resleeve repair, the tubesheet section of the existing HEJ sleeve is removed, followed by the expansion of the remaining sleeve remnant out to or beyond the nominal tube ID. This expansion establishes a clear path for the ABB sleeve installation process. The following provides an overview of the process steps. Figure 4.1 provides visual representation of these steps in their proper sequence.

- TIG relax the HEJ sleeve lower roll expansion joint within the tubesheet region of the tube.
- Whip Cut the HEJ sleeve approximately 5" below the upper end of the sleeve.
- Grip the lower sleeve section and remove it from the parent tube.
- Expand the remaining HEJ remnant region which contains the hydraulic and hardroll expansions (location of the laser weld repair).
  - Kinetic expansion (primary approach)
  - Roll expand (contingency)
- Perform tube free path and gaging.
- Whip cut the parent tube.
- Perform sleeve installation steps.

4.1.1 TIG Relaxation Process

The TIG relaxation process involves using a rotating gas tungsten arc weld tool to release the hard rolled lower HEJ sleeve to tube joint. The weld tool is inserted into the lower end of the sleeve to a preset position. A predetermined set of welding parameters are called up from the weld power supply menu. The process is started and the arc is initiated. Once a weld puddle has been established, the weld head begins rotation and is moved axiallly downward to form a spiral weld bead on the inside surface of the sleeve until weld cycle completion.

By melting the sleeve only in the hard rolled region, the joint is relaxed, allowing removal of the sleeve during a later process step. This is accomplished by the melting and solidifying of the sleeve material. During the solidification process, the metal shrinks, leading to a contraction of the sleeve toward its ID. This contraction is what relaxes the mechanical joint.

4.1.2 Sleeve Whip Cutting And Sleeve Removal

Upon completion of the shrinking step, the sleeve is severed approximately five (5) inches below the upper sleeve end using a whip cutting process. The whip cutter consists of a high speed motor to rotate the cutter, a speedometer cable and a cutting blade. The cutting blade is assymmetric in order to maintain an outward force during rotation. The blade is positioned in the sleeve using a hardstop or clearly visible mark on the cable. The motor is actuated and the process is monitored until the sleeve has been severed.

Upon completion of the sleeve cutting, a removal tool is used to remove the HEJ sleeve section. The tool is placed in the sleeve to a predetermined position and expanded into the sleeve. The tool and severed sleeve are then removed from the tube by using a downward force off of the tubesheet face.

4.1.3 Tube/Sleeve Remnant Expansion

The primary expansion process utilizes a kinetic expansion device (KED) that is connected to a denator box through an extension sheath. The KED utilizes a polyethylene end effector/candle to house the denator and pentaerythlritol tetranitrate (PETN) detonator cord for hard stopping against the remnant, the point at which the candle initiates energy release at the HEJ remnant region. The wires necessary for detonation extend from the candle. These wires are housed in a poly sheath which is pinned and glued to the candle at the working end. At the firing end, the wires and poly sheath are neatly and securely merged to a connector which plugs into the extension cable. The entire assembly is inserted from outside the steam generator through a snorkel and manipulator toolhead. Accurate positioning is provided by the manipulator toolhead, hard stop, and reference markings. The detonator and non-volatile PETN cord are initiated through a high voltage (~3000 volts) and significant amperage signal from the detonator box.

The mechanical roll expansion process is avavilable as a contingency. The roll expansion process utilizes the same tooling and techniques as that used for installing mechanical plugs or sleeves. It also contains built-in diameter feedback for turning off the motor at the target expanded diameter.

4.1.4 Tube Severing And Gauging

The parent tube is severed in the tubesheet region upon completion of HEJ sleeve remnant expansion. The same whip cutting system is utilized with modified end affectors to accomplish the tube cutting. This process is performed in order to relieve stresses in the parent tubes induced during previous repair attempts. The tube and sleeve remnant region will be inspected to ensure passage of an ABB sleeve through the expanded joint region. Should it be required, additional rolling will be performed.

4.2 ABB-CE SLEEVE

The change in sleeve length, for the full depth tubesheet sleeve with either a welded lower joint or a rolled lower joint has no affect on the contents of Section 4.0 of Reference 1.3.1, except for Figure 4-2A and Figure 4-2B. The length of the sleeves has been increased from [ ]. The sleeve installation equipment, as described in Reference 1.3.1, is not affected by the new sleeve length.

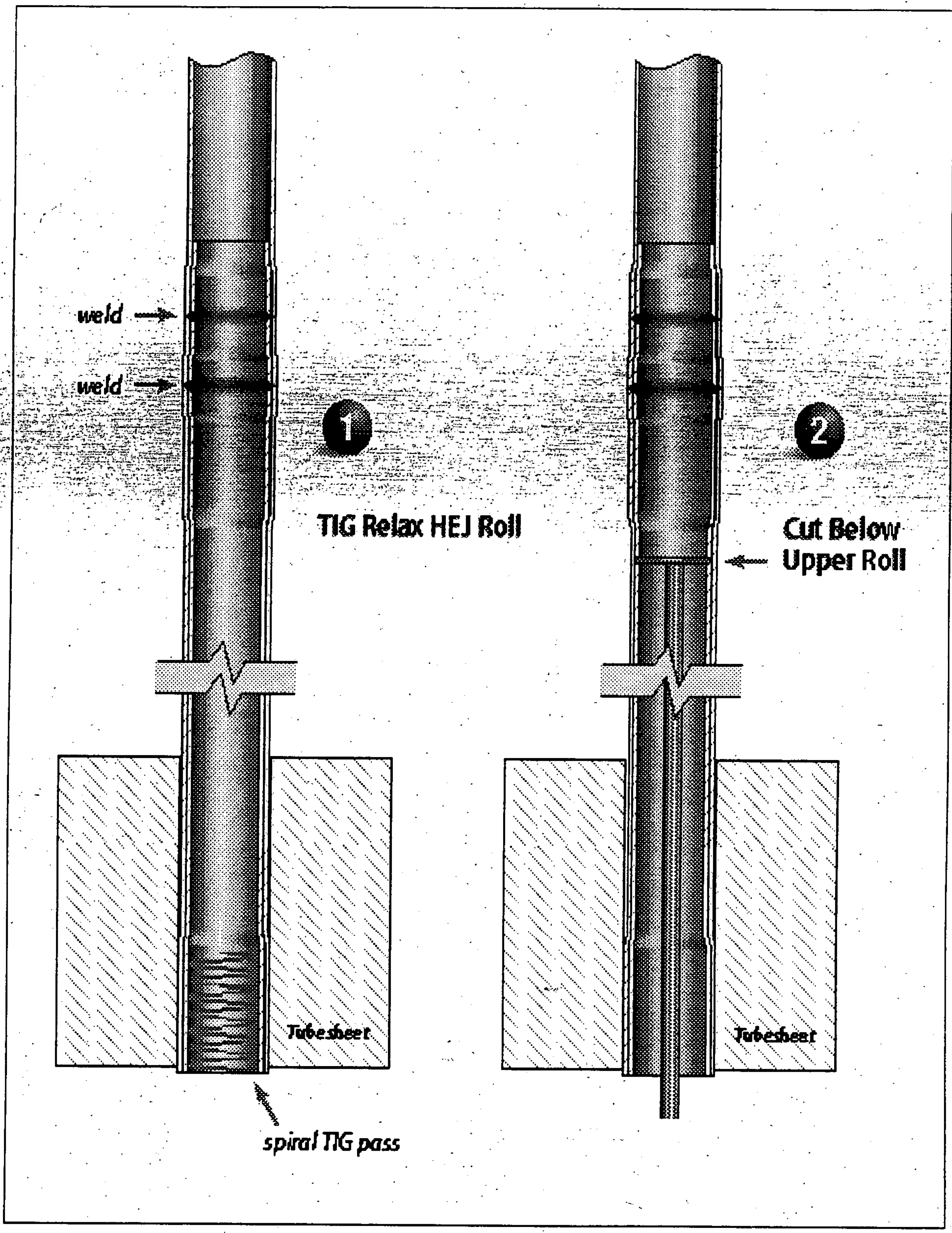

FIGURE 4-1A
SLEEVE REMOVAL/INSTALLATION ILLUSTRATION

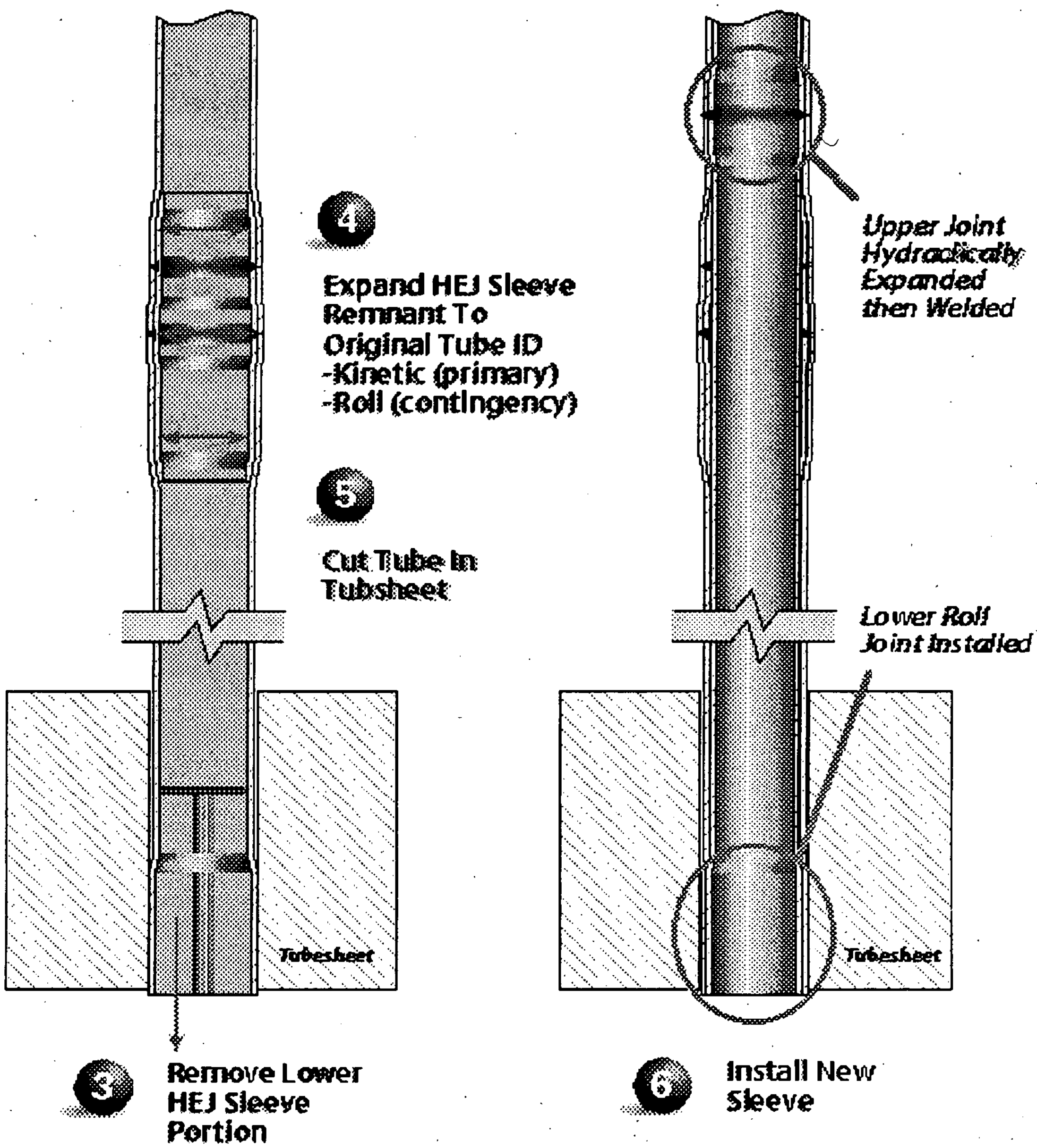

FIGURE 4-1B
SLEEVE REMOVAL/INSTALLATION ILLUSTRATION

FIGURE 4-2A
FULL DEPTH TUBESHEET SLEEVE WITH A WELDED LOWER JOINT

FIGURE 4-2B
FULL DEPTH TUBESHEET SLEEVE WITH A ROLLED LOWER JOINT

5. SLEEVE EXAMINATION PROGRAM

5.1 ULTRASONIC INSPECTION

The changes in sleeve length have no affect on the contents of this section of Reference 1.3.1.

5.2 EDDY CURRENT EXAMINATION

The changes in sleeve length and additional ECT testing have the following affects on the contents of this section of Refernece 1.3.1.

5.2.1 Background

Based on the revised calculations performed in Section 8 of this addendum for R.G. 1.121 analysis, the eddy current testing acceptance criteria given in Section 5.2 of Reference 1.3.1 provides an adequate margin of 13.5% (vs 12%) with respect to growth and ECT uncertainty. ABB-CE takes the approach to plug a sleeve upon detection.

5.2.2 Plus Point Probe Qualification Study

To support faster eddy current acquisition speeds for sleeve inspection, a set of tests were run on sleeves at various rotational and axial speeds and compared with data previously acquired (Reference 5.4.3, Appendix H Qualification). Based on the results of this test program (Reference 5.4.4), it is recommended that higher acquisition speeds that achieve a nominal data density of 40 samples per inch be used for future sleeve inspections.

5.3 VISUAL EXAMINATION

The changes in sleeve length have no affect on the contents of this section of Reference 1.3.1.

5.4 REFERENCES

The additional ECT testing program completed in 1997, has the following affects on the contents of this section of Refernece 1.3.1.

5.4.4 Sleeve Data Comparison for Motorized Rotating Plus-Point Coil At Various Rotational and Axial Samples Speeds in 0.875" Tubing, Report No. 97-TR-FSW-001.

6. SLEEVE TUBE CORROSION TEST PROGRAM

6.1 The addition of the tube preparation process and changes in sleeve length have no affect on the contents of this section of Reference 1.3.1. This is based on testing indicating that this process results in far field tube stresses no greater than those resulting from the standard sleeve installation process.

Using a mockup described in Section 9, strain gauge data were developed for the process steps involved in both the tube preparationprocess and the sleeve installation process. The strain gauges were positioned in the tube free span region above the new sleeve installation. Below is a summary of the stresses associated with the strain readings for the sleeve removal and tube preparation.

Sample Number	Tube Preparation Stresses
HY-01	-14,677 psi
HY-02	-2,826 psi
LY-01	-16,075 psi
LY-02*	+3,450 psi

* Tube preparation process steps intentionally performed out of order.

The tube preparation stress levels are all in the compressive mode, except for the one sample in which the tubesheet whip cut was performed prior to the kinetic expansion. The stress levels associated with the sleeve installation are all in the tensile mode, as shown below. It should be noted that these values were determined for the sleeve installation only by zeroing the strain gauges prior to the sleeve installation steps.

[

Sample Number	Sleeve Installation Stresses

]

The sleeve installation data compare favorably with strain gauge data generated in previous locked tube configurations. These earlier tests (Reference 1.3.3) showed stress levels in the [ ] psi range. Based upon this data, the resleeve installation process imparts net far field stresses no greater than, and most likely less than, those for the standard ABB CENO welded sleeve installation process.

7. MECHANICAL TESTS OF SLEEVED STEAM GENERATOR TUBES

The HEJ sleeve removal process and the changed sleeve length have no affect on the contents of this section of Reference 1.3.1.

Table 7-1 of Reference 1.3.1, summarizes the results of the mechanical testing performed on the sleeve-tube assemblies. The demonstrated load capacity of the assemblies (including the increased length sleeves) provides an adequate safety factor for normal operating and postulated accident conditions. The load capability of the upper and lower sleeve joints is sufficient to withstand thermally induced stresses in the weld resulting from the temperature differential between the sleeve and the tube and pressure induced stresses resulting from normal operating and postulated accident conditions. The burst and collapse pressures of the sleeve provide a large safety factor over limiting pressure differential. Mechanical testing revealed that the installed sleeve will withstand the cyclic loading resulting from power changes in the plant and other transients.

8. STRUCTURAL ANALYSIS OF SLEEVE-TUBE ASSEMBLY

This analysis establishes the structural adequacy of the sleeve-tube assembly. The methodology used is in accordance with the 1995 Edition of the ASME Boiler and Pressure Vessel Code, Section III. The work was performed in accordance with 10CFR50 Appendix B and other applicable U.S. Nuclear Regulatory Commission requirements.

8.1 SUMMARY AND CONCLUSIONS

Based on the analytical evaluation contained in this section and the mechanical test data contained in Section 7.0, it is concluded that the Full Depth Tubesheet (FDTS) sleeves described in this document, meet all the requirements stipulated in Section 8.0 with substantial additional margins. In performing the analytical evaluation on the tube sleeves, the operating and design conditions for Wisconsin Public Service Kewaunee Steam Generators with 7/8 inch Inconel 600 tubes are considered (Reference 8.4).

8.1.1 Design Sizing

In accordance with ASME Code practice, the design requirements for tubing are covered by the specifications for the steam generator "vessel". The appropriate formula for calculating the minimum required tube or sleeve thickness is found in Paragraph NB-3324.1, tentative pressure thickness for cylindrical shells (Reference 8.1). The following calculation uses this formula for the tube sleeve material which is Alloy 690 material with a specified minimum yield of 40.0 ksi (Reference 8.15).

$$t = \frac{PR}{S_m - 0.5\,P}$$

$$t = \frac{(1.600)\,(.333)}{26.6 - 0.5(1.600)}$$

$$t = 0.021\ in. < t_{min} = 0.037\ in.\ (minimum\ sleeve\ thickness,)\ \text{Reference 8.9}$$

Where t = Minimum required wall thickness, in.

P = Design Tubesheet differential pressure, ksi (max. value for plants, Ref. 8.2)

R = Inside Radius of sleeve, in. (maximum value for plants considered)

S_m = Design Stress Intensity, S.I. @ 650°F maximum design (per Reference 8.15)

8.1.2 Detailed Analysis Summary

When properly installed and welded within specified tolerances, the FDTS sleeve and its upper weld and lower rolled joint possess considerable margin against pull-out for all loading which can be postulated from operating, emergency, test, and faulted conditions.

The axial loads in the sleeve are a function of their location within the bundle and of the degree of tube/support lock-up. The most severe combination is near the bundle periphery region and is determined to be 1412 lb. for the sleeve design with upper weld joint and lower rolled joint at 100% steady state power for the Kewaunee plant in Reference 8.4.

In Section 8.2, a comparison is made between calculated failure modes and test data discussed in Section 7.0 of this report. The agreement between calculated and test data is good. Safety factors are determined for hypothetical pipe break accidents, and a minimum factor of safety of 3.1 is determined. The normal operations safety factor of 1.4 for the sleeve design with upper weld joint and lower rolled joint is based on the full power restrained thermal expansion loading. Push-out at the lower sleeve/tube joint is the critical consideration (see Section 8.4.6).

The axial sleeve loads calculated in Section 8.4 are used as boundary conditions and the basis for assumptions in the Section 8.6 fatigue evaluations.

TABLE 8-1

SUMMARY OF SLEEVE AND WELD ANALYSIS SIGNIFICANT RESULTS

CATEGORY	ALLOWABLE* (ksi)	ANALYSIS RESULTS (max.) (Stress in ksi)	LOCATION (worst)
Primary Stress	$S_m = 26.6$	General S.I. = 15.2	Sleeve (Normal Design)
	ATS Sleeve Weld (0.080 inch weld)		
Primary Local Stress	$1.5\ S_m = 40.0$	Stress Intensity = 14.2	Across Sleeve
Stress Range	$3\ S_m = 80.0$	Stress Intensity = 36.0	Outside Sleeve
Fatigue	U = 1.0	Usage Factor = 0.12	Outside Sleeve
Main Steam Line Break (MSLB)	$0.7\ S_u = 63.0$**	Stress Intensity = 24.3	Sleeve (Accident Cond.)
	ATS Sleeve Weld (0.020 inch weld)		
Stress Range	$3\ S_m = 80.0$	Stress Intensity = 46.5	Top of Weld
Fatigue	U = 1.0	Usage Factor = 0.42	Top of Weld
Main Steam Line Break (MSLB)	$.6(.7S_u) = 37.8$**	Shear Stress = 22.4	Weld (Accident Cond.)

* - The allowables listed in Table 8-1 are in accordance with the ASME Code (References 8.1 and 8.15).

** - While the minimum tensile strength and yield strength are listed in Reference 8.15 as 80.0 ksi and 40 ksi, respectively, the actual material properties were found to be higher based on Reference 8.18. Typically, $S_u > 100$ ksi and $S_y > 50$ ksi at room temperatures. Based on the trending curves in Reference 8.19 for the above room temperature allowables, it can be expected that S_u is greater than or equal to 90 ksi at 650°F. This value will be used to evaluate the accident conditions and the allowable sleeve wall degradation in Section 8.3.

FORMULAS FOR GENERAL MEMBRANE STRESSES SUMMARIZED IN TABLE 8-1

(Note: All SI equations below are a derivation of the formula in Par. NB-3324.1 of Ref. 8.1.)

1. GENERAL PRIMARY MEMBRANE STRESS (DESIGN TUBESHEET DELTA PRESSURE)

$$S.I._{memb} = \frac{PR}{t} + \frac{P}{2} \qquad P = \Delta P = 1600 \text{ psi}$$

$$S.I._{memb} = \frac{(1.600)(.333)}{.037} + \frac{1.600}{2}$$

$$S.I._{memb} = 15.2 \text{ ksi} < \text{Allowable of } S_m = 26.6 \text{ ksi}$$

2. MAIN STEAM LINE BREAK

$$S.I._{MSLB} = \frac{\Delta PR}{t} + \frac{\Delta P}{2}$$

Where, $\Delta P = 2.560$ ksi (Derived from NRC Generic Letter 95-05: "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking", (page 3 of Attachment 1 in Reference 8.17) as applied to their plants (Reference 8.20).

$$S.I._{MSLB} = \frac{(2.560)(.333)}{.037} + \frac{2.560}{2}$$

$$S.I._{MSLB} = 24.3 \text{ ksi} < \text{Allowable of } 0.7\, S_u = 63.0 \text{ ksi}$$

3. PRIMARY PIPE BREAK (LOCA)

$$S.I._{LOCA} = \frac{\Delta PR}{t} + \frac{\Delta P}{2}$$

Where ΔP is the maximum secondary side hot standby pressure (-1.085 ksi, external in Reference 8.2), which is less than approximately 7.7 ksi required for instability failure to occur with this type of external pressure application. Thus, the equation for internal pressure is applicable for this ΔP external pressure value.

$$S.I._{LOCA} = \frac{(-1.085)(.370)}{.037} + \frac{(-1.085)}{2}$$

$$S.I._{LOCA} = -11.4 \text{ ksi} < \text{Allowable of } 0.7\, S_u = 63.0 \text{ ksi}$$

TABLE 8-2

SUMMARY OF LOWER ROLLED JOINT DESIGN, ANALYSIS AND TEST RESULTS

8.2 LOADINGS CONSIDERED

In this section a number of potential failure modes are examined to determine the relative safety margins for selected events. Failure loads are calculated based on minimum dimensions and compared with mechanical testing results from Section 7.0. Both calculated and measured loads are compared with the maximum postulated loads.

8.2.1 Upper Sleeve Weld Pullout Load

Assuming the parent tube is totally severed, the minimum load required to shear the upper tube weld is calculated. The force required to pull the expanded sleeve through the unexpanded tube is conservatively neglected.

[ ]

In the event of a main steam line break (MSLB), the pressure differential would be 2560 psi per NRC Generic Letter 95-05: "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking", (page 3 of Attachment 1 in Reference 8.17) as applied to the Westinghouse plants (Reference 8.20). Postulating a main steam line break (MSLB) accident, the maximum pullout load would be:

$$F_{MSLB} = P_{MSLB} \times \pi R_{it}^2 = (2560)\,\pi\,(.3875)^2 = 1208 \text{ lbs.}$$

$$\text{Safety Factor } SF_{MSLB} = 4500/1208 = 3.7$$

8.2.2 Lower Sleeve Rolled Section Pushout Load

Assuming the parent tube is totally severed, the minimum load required to rupture the lower rolled section is calculated. The minimum measured test value for the pushout load is 2000 lb. for the rolled section. See Section 7 for details.

Postulating a loss of primary coolant accident (LOCA) during hot standby condition (0% Power), the maximum available load would be:

$$F_{LOCA} = P_{SEC} \times \pi R_{ot}^2 = 1085(\text{max. value per Ref. 8.2})\,\pi\,(.4375)^2 = 652 \text{ lbs.}$$

Safety factor SF = 2000 / 652 = 3.1 with rolled joint in welded/rolled design

Note that the LOCA pipe break accident is not controlling for this joint. See Section 8.4.6.

8.2.3 Weld Fatigue

Since the factors of safety are quite high for loadings due to primary stress, the failure mechanism of greatest interest is the fatigue failure mode considering the variable axial loading of the sleeve during normal operating transients.

In Section 8.6, fatigue evaluations of the upper weld which join the sleeve to the tube will be made. It is first necessary to determine the effects that tube lock-up within the tubesheet and tube supports have on the axial loads in the sleeve during normal operation. This subject is addressed in Section 8.4.

8.3 EVALUATION FOR ALLOWABLE SLEEVE WALL DEGRADATION USING REGULATORY GUIDE 1.121

NRC Regulatory Guide 1.121 (Reference 8.3) requires that a minimum acceptable tube (or sleeve) wall thickness be established to provide a basis for leaving a degraded tube in service. For partial thru-wall attack from any source, the requirements fall into two categories, (a) normal operation safety margins, and (b) considerations related to postulated pipe rupture accidents.

8.3.1 Normal Operation Safety Margins

It is the general intent of these requirements to maintain the same factors of safety in evaluating degraded tubes as those which were contained in the original construction code, ASME Boiler and Pressure Vessel Code, Section III (Reference 8.1).

For Inconel Alloy 600 and 690 tube or sleeve material the controlling safety margin is:

"Tubes with partial thru-wall cracks, wastage, or combinations of these should have a factor of safety against failure by bursting under normal operating conditions of not less than 3 at any tube location".

From Reference 8.2, the normal operating conditions for the "worst" case envelopment of steam generators (including the Kewaunee steam generators in Reference 8.4) are:

Primary Pressure P_{pri} = 2250 psia
Secondary Pressure P_{sec} = 720 psia
Differential Pressure DP = $P_{pri} - P_{sec}$ = 1530 psi

Average Pressure $P_{avg} = 0.5 (P_{pri} + P_{sec}) = 1485$ psia

Assuming the parent tube is totally severed, the sleeve is required to carry the pressure loading. The following terms are used in this evaluation.

R_{is} = sleeve nominal inside radius

Sy_{rm} = minimum required yield strength (per U.S. NRC Reg. Guide 1.121, Ref. 8.3)

Sy_{min} = minimum yield strength of sleeve (Sy = 35.2 ksi min. at 650 °F, Ref. 8.15)

Based on the information provided in Table 8-1, the sleeve material has an actual minimum spec tensile strength of 90.0 ksi at 650°F. The required thickness is shown below using a derivation of the formula in Paragraph NB-3324.1 of Reference 8.1 with 3 times ΔP as mentioned in Regulatory Guide 1.121 and S_u in place of S_m.

$$t = \frac{3\Delta P \; R_{is}}{S_u - P_{avg}} = \frac{3(1.530)(.3315)}{90.0 - 1.485} = \underline{0.0172} \; inch$$

Since the sleeve has a minimum wall thickness of 0.0370 inch (Reference 8.9), then

[ ]

As a confirmatory check, the required minimum yield is

$$Sy_{rm} = \frac{\Delta P \; R_{is}}{t} + P_{avg} = \frac{(1.530)(.3315)}{0.0172} + 1.485 = 31.0 \; ksi < Sy_{min} = 35.2 ksi$$

Therefore, the [ ] allowable degradation is controlling for the normal operating conditions.

8.3.2 Postulated Pipe Rupture Accidents

NRC Regulatory Guide 1.121 requires the following:

"The margin of safety against tube failure under postulated accidents, such as a LOCA, steam line break, or feedwater line break concurrent with the safe shutdown earthquake (SSE), should be consistent with the margin of safety determined by the stress limits specified in NB-3225 of Section III of the ASME Boiler and Pressure Vessel Code".

The above referenced ASME code paragraph deals with "faulted conditions", where for an elastic analysis of Inconel 690 sleeves, a general membrane stress of $0.7 \, S_u = 0.7(90.0) = \underline{63.0}$ ksi is allowed.

In conjunction with the NRC Regulatory Guide 1.121, the following accidents are postulated:

(a) For a downcomer feedring steam generator, a feedwater line break (FWLB) accident would have very little effect on tube spans just above the tubesheet.

(b) A LOCA accident causes large tube bending stresses in the upper tube bundle but produces only negligible compressive stresses in the region of interest.

(c) The only significant loading from a main steam line break (MSLB) accident on a sleeve is the differential pressure which is considered on page 8-5. If the sleeved tube is locked into the first tube support, there is a potential for a small amount of additional axial stress. However, this axial stress would have a small value and was therefore neglected due to the following considerations:

   a. Based on ABB/CE's past experience with the calculation of flow loads due to a steam line pipe break, it is not certain in which direction the flow would load the lowest tube support. Cases have been observed, in which the flow path of least resistance was downward through the first tube support and then upward through the downcomer annulus.

   b. Since any load on the tube support would be shared with other locked tubes, the load per tube would be small (less than 10 pounds), based on an EPRI study performed by ABB/CE. (See Reference 8.8).

The required thickness for a main steam line break (MSLB) accident is shown below using the derivation of the formula in Paragraph NB-3324.1 of Reference 8.1 with .7 S_u in place of S_m.

$$t = \Delta P\, R_{is}/(.7S_u - P_{avg}) = (2.56)(.3315)/(.7 \times 90.0 - 1.485) = 0.0138 \text{ inch}$$

Since the sleeve has a minimum wall thickness of [ ] (Reference 8.9), then

% allowable degradation = [ ]

Therefore, the [ ]allowable degradation in Section 8.3.1 is controlling for both the main steam line break (MSLB) accident and normal operating conditions.

8.3.3 Minimum Weld Height Requirement

[ ]

Design Condition:

$\Delta P = 1600$ psi	Tube differential pressure (page 8-1)	
$S_m = 26.6$ ksi	Design stress intensity (page 8-1)	
$\tau_{allow} = .6\ S_m$	$\tau_{allow} = 15.96$ ksi	Allowable shear stress
$R_{it} = .3875$ in	Tube inside radius	
$F_D = \pi \times R_{it}^2 \times \Delta P$	$F_D = .755$ kips	Design axial load on sleeve
$A_s = F_D / \tau_{allow}$	$A_s = .047\ in^2$	Required weld shear area
$t_{req} = A_s/(2 \times \pi \times R_{it})$	$\underline{t_{req} = .02\ in}$	Average minimum required height of weld (axial extent)

Faulted Condition - Main Steam Line Break:

$\Delta P = 2560$ psi	MSLB differential pressure (page 8-5)	
$S_u = 90$ ksi	Act. Min. Spec Tensile Strength per Table 8-1, page 8-4	
$\tau_{allow} = .6 \times (.7 \times S_u)$	$\tau_{allow} = 37.8$ ksi	Allowable shear stress (Reference 8.1, Appendix F)
$R_{it} = .3875$ in	Tube inside radius	
$F_D = \pi \times R_{it}^2 \times \Delta P$	$F_D = 1.208$ kips	Faulted axial load on sleeve
$A_s = F_D / \tau_{allow}$	$A_s = .032\ in^2$	Required weld shear area
$t_{req} = A_s/(2 \times \pi \times R_{it})$	$\underline{t_{req} = .013\ in}$	Average minimum required height of weld (axial extent)

8.4 EFFECTS OF TUBE LOCK-UP ON SLEEVE LOADING

Objective: Conservatively determine the maximum axial loads on the sleeve (tension and compression) during normal operation.

General Assumptions: (See Figures 8-2 through 8-4 for details).

1. The model is a system of axial members with properties and boundaries in Tables 8-3A and 8-3B.
2. Point B in Figure 8-2 is fixed (tube in tubesheet and secondary face of tubesheet).
3. Locations C and D in Figure 8-2 are rigid (sleeve to tube weld and sleeve to tube rolled joint).
4. All adjacent tubes are unplugged, unsleeved and locked between the tubesheet (point B) and the first tube support above the upper sleeve weld joint (point A).
5. Member 3 (tube inside the tubesheet) is locked into the tubesheet at both ends (points B and D) and is, therefore, forced to move as the tubesheet moves.

[ ]

8.4.1 Sleeved Tube in Central Bundle Region, Free at Support Plate

[ ]

$$\delta_1 = L_1 \alpha_1 (T_{pri} - 70)$$
$$\delta_2 = L_2 \alpha_2 (T_{sec} - 70)$$
$$\delta_3 = L_3 \alpha_3 (T_{pri} - 70)$$
$$\delta_{Forced} = \delta_2 + \delta_3 - \delta_1$$

$$K_{23} = \frac{1}{\frac{1}{K_2} + \frac{1}{K_3}} = \frac{1}{\frac{1}{K_2} + 0} = K_2 \text{ since member 3 is rigid}$$

The sleeve loads, F_1, are in Table 8-4A for the transient conditions shown in the same table.

8.4.2 Sleeved Tube Near Bundle Periphery, Free at Support Plate

[ ]

$$\text{Thus: } \quad \delta_{Forced} = \frac{F_1}{K_1} - \frac{F_2}{K_2}, \text{ but for equilibrium } F_2 = -F_1$$

$$\text{Therefore: } \quad \delta_{Forced} = (F_1/K_1) + (F_1/K_2)$$

$$\delta_{Forced} = F_1 \bullet (K_1 + K_2)/(K_1K_2)$$

$$\text{Transposing: } \quad F_1 = \delta_{Forced} \bullet \frac{K_1 K_2}{K_1 + K_2}$$

8.4.3 Sleeved Tube in Central Bundle Region, Lock-up at First Support Plate

[ ]

The composite member, CD or 6, is the assembly modeled in Figure 8-4.

$$K_6 = K_1 + K_2$$

$$\delta_6 = (\delta_1 + \Delta_1) \textit{ net elongation (Results in Table 8 - 4A)}$$

$$\delta_4 = L_4\, \alpha_4\, (T_i - 70)$$

$$\delta_5 = L_5\, \alpha_5\, (T_i - 70)$$

$$\delta_{Forced} = \delta_5 + \delta_3 - \delta_4 - \delta_6$$

The term δ_{Forced}, can be calculated from data in Tables 8-4A and 8-5A. The following relationship can be developed from the model depicted in Figure 8-4:

$$\delta_{Forced} = \frac{F_4}{K_4} + \frac{F_6}{K_6}, \textit{ but for equilibrium } F_4 = F_6$$

$$\textit{Therefore:}\quad \delta_{Forced} = \frac{F_6}{K_4} + \frac{F_6}{K_6} = \frac{K_6 F_6 + K_4 F_6}{K_4 K_6} = F_6 \frac{(K_4 + K_6)}{K_4 K_6}$$

$$\textit{Transposing:}\quad F_6 = \delta_{Forced} \bullet \frac{K_4 K_6}{K_4 + K_6}$$

Then, the deflection of member 6 is $\Delta_6 = F_6/K_6$ and, referring to Figure 8-3, the deflection of member 1, the sleeve, is $\Delta_1 = F_1/K_1$. The sleeve load is therefore:

$F_1 = K_1 \times (\Delta_1 + \Delta_6)$ where Δ_1 is from Table 8-4A.

The axial forces, F_1, are in Table 8-5A for the transient conditions given in this same table.

8.4.4 Sleeved Tube Near Bundle Periphery, Lock-up at First Support Plate

[ ]

TABLE 8-3A
39 INCH SLEEVE
AXIAL MEMBER PHYSICAL PROPERTIES IN CENTRAL BUNDLE REGION

NOTE:
[1] Nominal Dimensions for sleeve from Reference 8.9.
[2] α_m and E for Inconel 690 from Reference 8.11.
[3] Nominal Dimensions for tubes from Reference 8.13.
[4] α_m and E for Inconel 600 from Reference 8.14, Part D, Tables TM-4, TE-4
[5] α_m for Carbon Moly Steel from Reference 8.14, Part D, Table TE-1.

TABLE 8-3B
39 INCH SLEEVE
AXIAL MEMBER PHYSICAL PROPERTIES NEAR BUNDLE PERIPHERY

NOTE:

[1] Nominal Dimensions for sleeve from Reference 8.9.
[2] α_m and E for Inconel 690 from Reference 8.11.
[3] Nominal Dimensions for tubes from Reference 8.13.
[4] α_m and E for Inconel 600 from Reference 8.14, Part D, Tables TM-4, TE-4.
[5] α_m for Carbon Moly Steel from Reference 8.14, Part D, Table TE-1.

TABLE 8-4A
39 INCH SLEEVE
AXIAL LOADS IN SLEEVE WITH TUBE NOT LOCKED INTO TUBE SUPPORT FOR CENTRAL BUNDLE REGION

*NOTE: Due to small variation, E and α_m value for normal operation, 100% power, are used.

TABLE 8-4B
39 INCH SLEEVE
AXIAL LOADS IN SLEEVE WITH TUBE NOT LOCKED INTO TUBE SUPPORT NEAR BUNDLE PERIPHERY

[ ]

*NOTE: Due to small variation, E and α_m value for normal operation, 100% power, are used.

TABLE 8-5A

39 INCH SLEEVE

AXIAL LOADS IN SLEEVE WITH TUBE LOCKED INTO TUBE SUPPORT FOR CENTRAL BUNDLE REGION

* - NOTE: Due to small variation, E and a_m value for normal operation, 100% power are used.

TABLE 8-5B

39 INCH SLEEVE

AXIAL LOADS IN SLEEVE WITH TUBE LOCKED INTO TUBE SUPPORT NEAR BUNDLE PERIPHERY

[ ]

* - NOTE: Due to small variation, E and α_m value for normal operation, 100% power are used.

8.4.5 Effect of Tube Prestress Prior to Sleeving

8.4.6 Lower Sleeve Rolled or Weld Section Pushout Due to Restrained Thermal Expansion

8.5 SLEEVED TUBE VIBRATION CONSIDERATIONS

The vibration behavior is reviewed since the installation of a sleeve in a tube could affect the dynamic response characteristics of the tube.

8.5.1 Effects of Increased Stiffness

Stiffness and mass have opposing influences on tube vibration. While increased stiffness tends to raise the tube natural frequency, increased mass tends to lower it. ABB/CE's vibrational testing (Reference 8.6) demonstrated among other things, that a solid rod of the same O.D. as a tube will vibrate at nearly the same frequency. However, the displacements for the stiffer rod will be significantly less.

In addition, if any contact is made between the tube and sleeve along their length, the increased damping will absorb more energy. The damping would have a significant effect on amplitude of vibration. In light of this damping effect and the other above mentioned effects resulting from a sleeve inside a tube, the vibration performance of the tube/sleeve assembly is superior over the original tube.

8.5.2 Effect of Severed Tube

8.6 STRUCTURAL ANALYSIS FOR NORMAL OPERATION

A static elastic analysis of the sleeved tube assembly was performed according to the requirements stipulated in NB-3220 Section III of the ASME Code Section. This section describes the methods used to analyze the upper tube weld, lower stub weld, and sleeved tube plug weld.

8.6.1 Fatigue Evaluation of Upper Sleeve/Tube Weld

The Finite Element Method (FEM) was incorporated in this analysis, using the ANSYS Computer Code (Reference 8.5). Figure 8-5 depicts the FEM model of the upper tube weld for both sleeve designs.

The lower end of the tube was assumed to be locked near the secondary side surface of the tubesheet. From Section 8.4, it was found that the sleeve develops higher compressive loadings if the tube is free to slide through the first support . Therefore, sliding at the tube-to-support interface was conservatively assumed. The FEM model consists of 2-D isoparametric elements with an axisymmetric option.

The transient conditions listed in Reference 8.4 are shown in Table 8-6 and are grouped as follows for simplicity of analysis:

- The 410 cycles between ambient (room temperature) and hot standby represent the 400 heatups and cooldowns plus 10 turbine roll tests.

- The 20,500 cycles between hot standby and full power are the sum of 18,300 loading and unloading conditions and 2200 step load variations.

- The 600 cycles between full power and reactor trip are a combination of 400 trip, 80 loss of flow, 80 loss of load and 40 loss of power cycles. "Loss of Flow", which is assumed to represent the greatest variation from full power, is utilized to define the "Trip" condition.

The axial load for 100% power condition is determined from the thermal interaction in Section 8.4 and is found to be less than the axial load calculated in Reference 8.7 (i.e. 1412 lb. vs. 1420 lb.). Therefore, the larger axial load results from Reference 8.7 are applied to the bottom of the sleeve FEM model such as was done in Reference 8.7. The pressure stresses and stresses due to radial thermal expansion are conservatively excluded since they result in tensile stresses which relieve the compressive stresses resulting from the axial loads. The above described transients are combined in the worst case combinations in the fatigue evaluation, using the higher axial load results from Reference 8.7.

Leak test and hydro test are isothermal and produce negligibly small sleeve loads. The upper weld edges are insensitive to pressure cycling, hence, test conditions are not considered in the upper weld fatigue evaluation.

At the weld tip region, a stress concentration factor of four (4) is applied to the total stresses from the computer code output for the purpose of calculating peak stresses. The results of the analysis, which consist of the nodal stress tabulations at the critical sections and fatigue usage factors, are contained in Appendix 8A.

The minimum required axial length of weld of .02 inches was determined in Section 8.3.3. A fatigue analysis was performed for this configuration. The finite element model used for the .08 inch weld design was modified by refining the element mesh as shown in Appendix 8A. The stress concentration factor of four (4) is applied to the linearized stresses from the computer output. The results of the analysis are also contained on Appendix 8A. All stresses and usage factors for both configurations are satisfactory when compared to allowables.

8.6.2 Evaluation of Lower Sleeve Rolled Section

The lower section of the sleeve will be rolled into the tube for the sleeve design with welded upper joint and rolled lower joint. Normal operating and transient conditions used in the cyclic loading tests on the steam generator tube sleeves are based on the tubesheet flexure (internal pressure differential) and differential thermal expansion of the tube and sleeve.

The transient conditions listed in Reference 8.4 are shown in Table 8-7. The logic for this grouping is as follows:

- The 450 cycles between ambient and hot standby represent the 400 heatup and cooldown conditions combined with 50 primary side leak tests.
- The 20,500 cycles between hot standby and full power are the sum of 18,300 loading and unloading conditions and 2200 step load events.
- The 600 cycles between full power and reactor trip are a combination of 400 trip, 80 loss of flow, 80 loss of load and 40 loss of power cycles.
- The 850 cycles between ambient and secondary leak test are composed of 800 tube leakage test conditions and 50 secondary side leakage tests. A pressure of 840 psi was conservatively selected to represent the secondary leak test condition.

The tubesheet ligament stress in the load cycling tests is based upon the maximum allowable primary membrane stress intensity of 1.5 S_m or 40 ksi for the tubesheet material for the maximum design tubesheet differential pressure, (i.e. $\Delta P = P_1 - P_2$), of 1600 psi. For a rolled joint at 0.625" from the tubesheet surface, the ligament stress is 37.64 ksi. This ligament stress value is used in the load cycling tests. This test value is conservative when compared to the tubesheet ligament stresses in Figure 8-6 which are from Reference 8-12.

TABLE 8-6

UPPER SLEEVE WELD - TRANSIENTS CONSIDERED

<u>CONDITIONS</u>:

(a) Worst case: (a) Tube is not locked-in to first tube support (b) Tube is near periphery.
(b) Tube is Intact: Tube/Sleeve restrained thermal expansion.
(c) Pressure stress is not significant in fatigue.

* - Maximum Axial Loads and Primary/Secondary Temperature differences for tube sleeve designs in Reference 8.7.

TABLE 8-7

LOWER SLEEVE SECTION - TRANSIENTS CONSIDERED

CONDITIONS:

(a) Worst Case: Tube is not locked-in to first tube support.
(b) Tube is Intact: Tube/sleeve restrained thermal expansion.
(c) Differential pressure causes tubesheet flexure.
(d) Axial loads are from Tables 8-4A and 8-4B.

* - Maximum Axial Loads from Section 8.4
** - Primary and Secondary Pressures from Reference 8-4.

8.7 REFERENCES FOR SECTION 8.0

8.1 ASME Boiler and Pressure Vessel Code, Section III for Nuclear Power Plant Components, 1995 edition.

8.2 ABB/CE Letter Report No. CSE-96-115, "Tube Sleeve History Data for 7/8 inch Steam Generator Tubes", May 03, 1996.

8.3 U.S. NRC Regulatory Guide 1.121, "Bases for Plugging Degraded PWR Steam Generator Tubes".

8.4 ABB/CE License Report CEN-413-P, Rev. 0-P, "Kewaunee Steam Generator Tube Repair Using Leak Tight Sleeves", January 1992.

8.5 "ANSYS" Finite Element Computer Code, Rev. 5.1, 1994 by Swanson Analysis Systems, Inc.

8.6 "Vibration in Nuclear Heat Exchangers Due to Liquid and Two-Phase Flow," By W.J. Heilker and R.Q. Vincent, Journal of Engineering for Power, Volume 103, Pages 358-366, April 1981.

8.7 ABB/CE License Report CEN-629-P, Rev. 02, "Repair of Westinghouse Series 44 and 51 Steam Generator Tubes Using Leak Tight Sleeves", January 1997.

8.8 EPRI NP-1479, "Effect of Out-of-Plane Denting Loads on the Structural Integrity of Steam Generator Internals," Contractor: Combustion Engineering, August 1980.

8.9 ABB/CE Drawing No. C-SGN-218-058-01, "Welded Sleeve for 7/8" Diameter Westinghouse Steam Generator", January 1986.

8.10 ABB/CE Drawing No. C-SGN-218-059-04, "Welded Sleeve Installation - Westinghouse 7/8" Diameter Tubes", February 1989.

8.11 <u>Inconel 690</u>, Huntington Alloys, Inc., Huntington, W. Virginia.

8.12 "Primary/Secondary Boundary Components Steady State Stress Evaluation", Prepared by Raymond Paul Wedler, Westinghouse Electric Corp., April 1965 (REF-96-001).

8.13 Westinghouse Steam Generator Standard Information Package, January 04, 1982 (REF-96-002).

8.14 ASME Boiler and Pressure Vessel Code, Section II, Materials, 1995 edition.

8.15 ASME Boiler and Pressure Vessel Code Case N-20-3, "SB-163 Nickel-Chromium-Iron Tubing (Alloys 600 and 690) ... at Specified Minimum Yield Strength of 40.0 ksi ..., Section III, Division 1, Class 1", November 30, 1988.

8.16 ABB/CE Report No. TR-ESE-178, Rev. 1, "Palisades Steam Generator Tube/Sleeve Vibration Tests", October 05,1977 (REF-96-003).

8.17 NRC Generic Letter 95-05, "Voltage Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking", August 03, 1995 (REF-97-030).

8.18 ABB/CE Letter Memo, E.P. Kurdziel to D.P. Siska, "Mill Test Reports for I-690 Sleeve Material", dated August 8, 1996 (REF-96-006).

8.19 Nuclear Systems Materials Handbook, Volume 1, "Design Data", TID 26666, Group 4, Section 3 - Inconel alloy 600 (REF-96-004).

8.20 Fax on Main Steam Line Break Pressure Information, dated January 14, 1997.

FIGURE 8-1

SLEEVE/TUBE ASSEMBLY

8.17 NRC Generic Letter 95-05, "Voltage Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking", August 03, 1995 (REF-97-030).

8.18 ABB/CE Letter Memo, E.P. Kurdziel to D.P. Siska, "Mill Test Reports for I-690 Sleeve Material", dated August 8, 1996 (REF-96-006).

8.19 Nuclear Systems Materials Handbook, Volume 1, "Design Data", TID 26666, Group 4, Section 3 - Inconel alloy 600 (REF-96-004).

8.20 Fax on Main Steam Line Break Pressure Information, dated January 14, 1997.

FIGURE 8-2

SYSTEM SCHEMATIC FOR KEWAUNEE STEAM GENERATOR

FIGURE 8-3

STIFFNESS MODEL OF SLEEVE AND LOWER TUBE

FIGURE 8-4

STIFFNESS MODEL OF UPPER TUBE AND SURROUNDING TUBES

FIGURE 8-5

FINITE ELEMENT MODEL OF UPPER TUBE WELD

FIGURE 8-6

TUBESHEET PERFORATED PLATE LIGAMENT STRESSES (REFERENCE 8.12)

APPENDIX 8A

FATIGUE EVALUATION OF UPPER SLEEVE/TUBE WELD

INTRODUCTION

The analysis presented in this appendix is discussed in detail in Section 8.6.1 of this Report. The results from the two (2) finite element models considered are presented in this Appendix. The model geometry is shown in Figure 8-5. The only difference in the two models is the weld height and the number of elements. The 80 mil weld height model is based on the design geometry minimum dimension. The 20 mil model is based on the minimum required axial weld length for operating and accident conditions. All stresses and usage factors for both configurations are satisfactory when compared to allowables.

GENERAL DISCUSSION

The lower end of the tube was assumed to be locked near the secondary side surface of the tubesheet. From Section 8.4, it was found that the sleeve develops higher compressive loadings if the tube is free to slide through the first support. Therefore, sliding at the tube-to-support interface was conservatively assumed. The FEM model consists of 2-D isoparametric elements with an axisymmetric option. Since the axial load at 100% power condition in Section 8.4 is less than the axial load from Reference 8.7 (i.e. 1412 lb. vs. 1420 lb.), the greater axial load results from Reference 8.7 are used in this Appendix with the transient conditions from Reference 8.4. The ANSYS input and output data are included in Attachment I of Reference 8.7.

The transient conditions listed in Reference 8.4 are shown in Table 8-6 and are grouped as follows for simplicity of analysis:

The 410 cycles between ambient (room temperature) and hot standby represent the 400 heatups and cooldowns plus 10 turbine roll tests.

The 20,500 cycles between hot standby and full power are the sum of 18,300 loading and unloading conditions and 2200 step load variations.

The 600 cycles between full power and reactor trip are a combination of 400 trip, 80 loss of flow, 80 loss of load and 40 loss of power cycles. "Loss of Flow", which is assumed to represent the greatest variation from full power, is utilized to define the "Trip" condition.

The axial load results determined from the thermal interaction in Section 8.4 of Reference 8.7 are applied to the bottom of the sleeve FEM model. The pressure stresses and stresses due to radial thermal expansion are conservatively excluded since they result in tensile stresses which relieve the compressive stresses resulting from the axial loads. The above described transients are combined in the worst case combinations in the fatigue evaluation, using the larger axial load results from Reference 8.7.

For the 80 mil weld model, a stress concentration factor of four (4) is applied to the total stresses from the computer code output for the purpose of calculating peak stresses. The concentration factor is only applied to the axial and radial stresses since the shear stresses are relatively negligible. The concentration factor is applied at the sleeve outside surface located below the weld, the top and bottom of the weld, and to the inside surface of the tube at the location above the weld.

For the 20 mil weld tip region the stress concentration factor of four (4) is applied to the linearized stresses from the computer output. The factor is conservatively applied to the linearized membrane plus bending stresses for the axial, radial and shear stress components.

FIGURE 8A-1

NODE AND STRESS CUT IDENTIFICATION

TABLE 8A-1A

STRESS RESULTS 100% STEADY STATE

TABLE 8A-1B

STRESS RESULTS 0% STEADY STATE

TABLE 8A-1C

STRESS RESULTS REACTOR TRIP

TABLE 8A-2

FATIGUE EVALUATION AT WORST LOCATION

By inspection of Tables 8A-1A, 1B and 1C it can be seen that the usage factor for the other locations will be less than .124.

FIGURE 8A-2

NODE AND STRESS CUT IDENTIFICATION FOR 20 MIL WELD

TABLE 8A-3A

STRESS RESULTS 100% STEADY STATE (.02" Weld)

[ ]

TABLE 8A-3B

STRESS RESULTS 0% STEADY STATE (.02" Weld)

TABLE 8A-3C

STRESS RESULTS REACTOR TRIP (.02" Weld)

TABLE 8A-4A

RANGE OF STRESS AT WORST LOCATIONS (.02" Weld)

Max. SI Range = 38.26 < 3 S_m = 80 ksi

Max. SI Range = 46.5 < 3 S_m = 80 ksi

TABLE 8A-4B

FATIGUE EVALUATION AT WORST LOCATIONS (.02" Weld)

A stress concentration factor of 4 is applied to the axial, radial and shear stress.

TABLE 8A-4B (Cont'd)

FATIGUE EVALUATION AT WORST LOCATIONS (.02" Weld)

A stress concentration factor of 4 is applied to the axial, radial and shear stress.

By inspection of Tables 8A-3A, 3B and 3C it can be seen that the usage factors for the other locations will be less than .42.

9. RESLEEVE PROCESS VERIFICATION

9.1 HEJ REMOVAL AND TUBE PREPARATION

The methodology for HEJ sleeve removal and expansion of the remaining remnant was described in Section 4.1. The removal of the lower HEJ sleeve region was previously proven as a viable technique (used during tube pull of 6 tube locations to evaluate laser repaired HEJ expansions). The expansion approach however, required development and testing. Several different concepts were designed, fabricated, and tested to determine the most effective approach to achieve the desired expansion characteristics. These expansion methods included hydraulic with an elastomer bladder, hydraulic with tube-in-tubesheet style expanders, hydraulic using insitu pressure testing probes, mechanical roll , mechanical mandrel, and kinetic energy. Based on these preliminary tests the kinetic expansion process was chosen since it provided the most consistent expansion over the other methods and also was able to expand the remnant ends. Roll expansion was chosen as a backup approach to open up a restriction in the event there was incomplete expansion over the entire length.

In order to ensure the tube preparation process would perform acceptably in the steam generators at Kewaunee, parameters for achieving acceptable expansions were developed. Six to eight simulated HEJ specimens were kinetically expanded in order to demonstrate acceptable characteristics. Upon completion of these specimens, twelve free tube samples of the installed HEJ sleeves with laser repairs were expanded. These specimens were provided by the OEM and included the heating, welding, and stress relief of HEJ expansions. The testing using the OEM supplied specimens were expanded in a full U-bend tube mockup. Five of these specimens were forwarded to ABB-CE for testing of tube cleaning and sleeve welding.

Tests were also performed in a mockup on a manipulator tool head to verify acceptable positioning and performance. Four additional specimens were tested in this manner using the final design configuration and prescribed design parameters. A total of approximately 25 tube specimens with HEJ sleeves were tested with the final design configuration and parameters.

Based upon the above tests, an acceptable tube preparation process was established. The sleeve shrinking, whip cutting, sleeve removal and kinetic expansion were performed on the variety of specimens described above in a successful manner.

9.2 SLEEVE INSTALLATION

Five of the specimens supplied by the OEM were forwarded to ABB for sleeve installation. The specimen inside surfaces were inspected using ABB's field equipment prior to the sleeving process. Residue from the kinetic expansion were evident throughout the tube/sleeve specimen.

Cleaning of the inside surface was performed using the field procedures. Each specimen was cleaned with a reciprocating centrifugal brush for two minutes, followed by two passes with a rotating cotton swab. Visual inspection of these specimens after the cleaning process revealed a bright, shiny surface with no evidence of the residue left by the kinetic expansion. A sleeve sample was then expanded into each specimen. Using the standard weld procedure specification, sleeve to tube welds were produced in each specimen.

The welds were inspected and passed visual and ultrasonic examination. Finally, the welds were sectioned longitudinally and viewed under 10x magnification. All of the welds were acceptable. Based upon these test results, the sleeve installation process as currently performed by ABB-CE is acceptable for use as part of the resleeving program.

9.3 MOCKUP TESTING

9.3.1 Locked Tube Mockup Fabrication

Four (4) mockups were fabricated in order to determine the far field stresses imposed on the tube free span by the tube preparation process and the sleeve installation process. A sketch of these mockups is shown in Figure 9-1. A length of steam generator tube was welded to two steel plates which had four threaded rods used to apply preloads on the tubes. Strain gauges were used to measure the loads imparted by the various resleeving process steps.

The mockups were welded to match the configuration shown in the figure. A 48" span between the two faces of the plates was used to simulate the distance from the secondary face of the tubesheet to the bottom of the first support plate. This is representative of the span length found in Westinghouse Series 51 steam generators. The 48" span is a conservative value. While it is possible for the tube to be locked at the secondary face of the tubesheet, it is more likely that the tube will be locked low in the tubesheet where the lower tube joint is located. If the tube was locked at the lower tube roll joint, the actual locked span would be 67.4" (a larger span results in lower expansion loads).

Four strain gauges were installed on the outside surface of the freespan portion of the tube. The gauges were mounted parallel to the tube axis every 90 degrees and were located at the same elevation. The gauges were mounted approximately 12" below the bottom of the tube support plate.

Threaded rods were installed into the corners of the carbon steel plates. The nuts were engaged until they contacted the steel plates. The strain gauge values for this condition were measured and recorded. These values are used for the unstrained gauge values when calculating the load induced on the tube by the tube preparation process.

After the threaded rods were locked into place and the strain gauge zero readings recorded, the four locked tube mockups were sent to the steam generator OEM. The OEM installed HEJ sleeves in the four mockups using field representative processes and eqmipment. Two of the mockups had a 360 degree through wall circumferential crack cut in the tube at the HEJ sleeve lower hard roll transition. These cuts were made after the HEJ sleeves had been installed, but prior to performing the laser weld repairs

After machining circumferential cracks in two of the mockups, the OEM performed the laser weld repair process in each of the four mockups. These repairs were representative of repairs performed at Kewaunee Nuclear Station.

The mockups were then sent to FTI for tube preparation. The HEJ lower sleeve section hard roll was TIG relaxed, cut below the HEJ expansion, then removed. The strain gauge readings for these steps were monitored and recorded. Next, the kinetic expansion was performed and the tubes were whip cut within the simulated tubesheet section. One specimen was cut before the expansion process to determine the effects of a different process sequence.

Upon completion of the tube preparation, the mockups were sent to ABB for sleeve installation. The strain gauges were zeroed at this time, prior to the beginning of the sleeving process. Strain gauge readings were taken after each of the sleeve process steps. These include sleeve expansion into the tube, sleeve to tube welding and sleeve to tube hard rolling.

9.3.2 Strain Gauge Results

On the average, the HEJ sleeve installation and repair process by Westinghouse on the four specimens introduced approximately 9,723 psi tensile stress into the locked tube span above the sleeve region. The TIG and cutting operations for lower sleeve removal tended to significantly decrease the tensile stress remaining in the tube. The tensile stress imparted on the tubes as a result of the kinetic expansion is estimated to be within the range of 1,281-11,575 psi tensile stress. The large range is attributed primarily to the full circumferential parent tube defect on one of the specimens which slightly separated during the expansion process and therefore significantly reduced the observed tensile load in the tube above the expansion. The final tubesheet whip cut eliminated the tensile load and actually put compression into 3 specimens while the specimen cut prior to expansion exhibited a slight tensile load after the kinetic expansion and roll expansion end opening. This specimen was reported to have lower sleeve joint slippage during HEJ installation and subsequent repairs by the OEM which may have had some effect on the final results.

In the actual steam generator, the tubesheet whip cut would be made higher within the tubesheet away from the roll expansion effects of the installed HEJ near the primary face. Thus, the compressive load condition observed may not be present to the magnitudes noted unless crevice sludge is packed sufficiently to provide similar frictional resistance.

The expansion process may introduce a relatively small amount of additional load/stress over that existing as a result of the OEM repairs. Two specimens noted more loading after expansion and two noted less.

The sleeve installation process imparted a tensile stress on the tube free span for all the specimens. The range of the stress was from [ ]. These values are consistent with previous work performed by ABB in this area. The summarized results are included as Table 9-1.

9.4 FIELD DEMONSTRATION

Twenty-five tubes were chosen for full tube preparation and subsequent ABB sleeve installation. All of the tubes were prepared for resleeving in an acceptable manner. The acceptance of these expansions was verified through ECT profilometry to check for excessive ID expansion, ECT RPC to verify that no defects had propagated into the region of the sleeve weld, physical gaging to determine the ability to insert sleeves and video probe examination to verify the integrity of the expanded components. The results of these activities indicated that all 25 locations were suitable for further sleeve installation steps. There was no indication of damage to the expanded components or potential for disturbance of adjacent tube locations.

Upon successful completion of the tube preparation, twnty-five sleeves were installed in these locations. There were difficulties encountered in the tube cleaning process which required additional process steps to be employed. Based upon this, further testing is being performed on the cleaning process in order to finalize the tube cleaning steps. The installation of the sleeves was accomplished without any difficulty. The welding process was acceptable, though some weld defects did occur. [

].

One of the sleeved tubes was removed from the steam generator and is currently being evaluated in the ABB labs using non-destructive and destructive examination techniques.

Though the demonstration program did not result in 100% tube recovery, the application of the lessons learned from the program should ensure an increased tube recovery percentage during the resleeving production phase of the program.

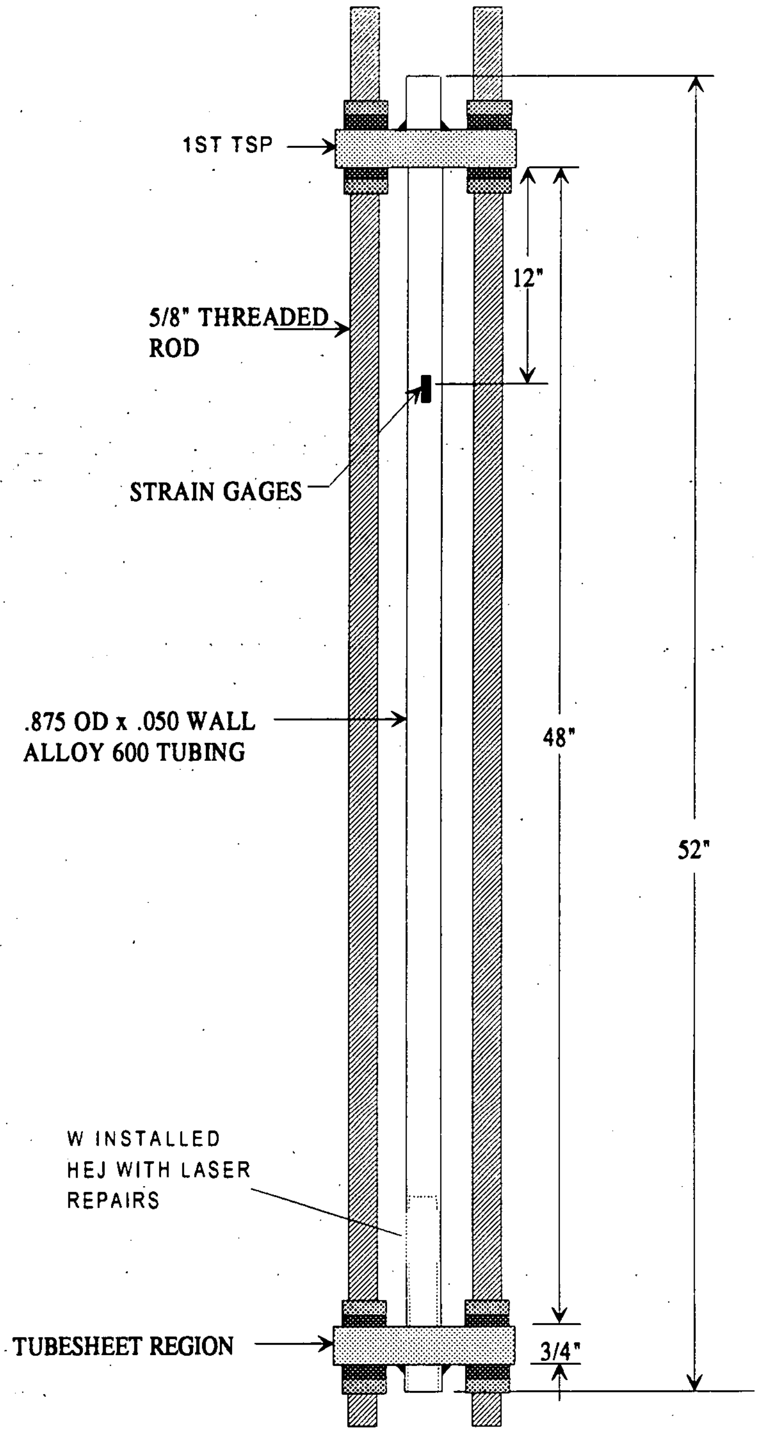

FIGURE 9-1

MOCKUP CONFIGURATION

TABLE 9-1

MOCKUP STRAIN GAUGE RESULTS

Sample Number	Tube Preparation Stresses
HY-01	-14,677 psi
HY-02	-2,826 psi
LY-01	-16,075 psi
LY-02*	+3,450 psi

* Tube preparation process steps performed out of order.

Sample Number	Sleeve Installation Stresses

* Tube preparation process steps performed out of order.

10. EFFECT OF SLEEVING ON OPERATION

[ ]

FDTS SLEEVE LENGTH	EQUIVALENCY RATIO, SLEEVES/PLUG

[ ]

AFFIDAVIT PURSUANT

TO 10 CFR 2.790

I, Ian C. Rickard depose and say that I am the Director, Operations Licensing, of Combustion Engineering, Inc., duly authorized to make this affidavit, and have reviewed or caused to have reviewed the information which is identified as proprietary and referenced in the paragraph immediately below. I am submitting this affidavit in conjunction with the application of Wisconsin Public Service, and in conformance with the provisions of 10 CFR 2.790 of the Commission's regulations.

The information for which proprietary treatment is sought is contained in the following documents:

1. CEN-629-P, Rev. 02, "Repair of Westinghouse Series 44 and 51 Steam Generator Tubes Using Leak Tight Sleeves," January 1997.
2. Report Number 96-OSW-033, Rev. 00, "EPRI Steam Generator Examination of ABB-CE Welded Sleeves," April 2, 1996

These documents have been appropriately designated as proprietary.

I have personal knowledge of the criteria and procedures utilized by Combustion Engineering in designating information as a trade secret, privileged or as confidential commercial or financial information.

Pursuant to the provisions of paragraph (b) (4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure, included in the above referenced document, should be withheld.

1. The information sought to be withheld from public disclosure, is owned and has been held in confidence by Combustion Engineering. It consists of information concerning the steam generator tube repair process of sleeving, including qualification program results and analyses.
2. The information consists of test data or other similar data concerning a process, method or component, the application of which results in substantial competitive advantage to Combustion Engineering.
3. The information is of a type customarily held in confidence by Combustion Engineering and not customarily disclosed to the public. Combustion Engineering has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The details of the aforementioned system were provided to the Nuclear Regulatory Commission via letter DP-537 from F. M. Stern to Frank Schroeder dated December 2, 1974. This system was applied in determining that the subject document herein is proprietary.
4. The information is being transmitted to the Commission in confidence under the provisions of 10 CFR 2.790 with the understanding that it is to be received in confidence by the Commission.
5. The information, to the best of my knowledge and belief, is not available in public sources, and any disclosure to third parties has been made pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence.
6. Public disclosure of the information is likely to cause substantial harm to the competitive position of Combustion Engineering because:

    a. A similar product is manufactured and sold by major pressurized water reactor competitors of Combustion Engineering.

b. Development of this information by Combustion Engineering required millions of dollars and thousands of manhours of effort. A competitor would have to undergo similar expense in generating equivalent information.

c. In order to acquire such information, a competitor would also require considerable time and inconvenience to develop an understanding of welded steam generator tube sleeve installation problems and evaluate specific examples based on test or pulled steam generator tube data and develop and qualify a steam generator tube sleeving program.

d. The information consists of a description of the steam generator tube repair process of sleeving, including qualification program results and analyses, the application of which provides a competitive economic advantage. The availability of such information to competitors would enable them to modify their product to better compete with Combustion Engineering, take marketing or other actions to improve their product's position or impair the position of Combustion Engineering's product, and avoid developing similar data and analyses in support of their processes, methods or apparatus.

e. In pricing Combustion Engineering's products and services, significant research, development, engineering, analytical, manufacturing, licensing, quality assurance and other costs and expenses must be included. The ability of Combustion Engineering's competitors to utilize such information without similar expenditure of resources may enable them to sell at prices reflecting significantly lower costs.

f. Use of the information by competitors in the international marketplace would increase their ability to market nuclear steam supply systems by reducing the costs associated with their technology development. In addition, disclosure would have an adverse economic impact on Combustion Engineering's potential for obtaining or maintaining foreign licensees.

Further the deponent sayeth not.

I. C. Rickard

Ian C. Rickard, Director
Operations Licensing

Sworn to before me
this 20th day of March, 1997

Laurie J. White

Notary Public
My commission expires: 8/31/99

AFFIDAVIT PURSUANT

TO 10 CFR 2.790

I, I.C. Rickard, depose and say that I am the Director, Operations Licensing, of Combustion Engineering, Inc., duly authorized to make this affidavit, and have reviewed or caused to have reviewed the information which is identified as proprietary and referenced in the paragraph immediately below. I am submitting this affidavit in conjunction with the application of Wisconsin Public Service, and in conformance with the provisions of 10 CFR 2.790 of the Commission's regulations.

The information for which proprietary treatment is sought is contained in the following document:

CEN-632-P, Rev. 00-P - "Repair of Kewaunee Steam Generator Tubes Using a Resleeving Technique, Final Report," April, 1997

This document has been appropriately designated as proprietary.

I have personal knowledge of the criteria and procedures utilized by Combustion Engineering in designating information as a trade secret, privileged or as confidential commercial or financial information.

Pursuant to the provisions of paragraph (b) (4) of Section 2.790 of the Commission's regulations, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure, included in the above referenced document, should be withheld.

1. The information sought to be withheld from public disclosure, is owned and has been held in confidence by Combustion Engineering. It consists of

information concerning the steam generator tube repair process of sleeving, including qualification program results and analyses.

2. The information consists of test data or other similar data concerning a process, method or component, the application of which results in substantial competitive advantage to Combustion Engineering.

3. The information is of a type customarily held in confidence by Combustion Engineering and not customarily disclosed to the public. Combustion Engineering has a rational basis for determining the types of information customarily held in confidence by it and, in that connection, utilizes a system to determine when and whether to hold certain types of information in confidence. The details of the aforementioned system were provided to the Nuclear Regulatory Commission via letter DP-537 from F. M. Stern to Frank Schroeder dated December 2, 1974. This system was applied in determining that the subject document herein is proprietary.

4. The information is being transmitted to the Commission in confidence under the provisions of 10 CFR 2.790 with the understanding that it is to be received in confidence by the Commission.

5. The information, to the best of my knowledge and belief, is not available in public sources, and any disclosure to third parties has been made pursuant to regulatory provisions or proprietary agreements which provide for maintenanco of the information in confidence.

6. Public disclosure of the information is likely to cause substantial harm to the competitive position of Combustion Engineering because:

    a. A similar product is manufactured and sold by major pressurized water reactor competitors of Combustion Engineering.

    b. Development of this information by Combustion Engineering required millions of dollars and thousands of manhours of effort. A competitor would have to undergo similar expense in generating equivalent information.

c. In order to acquire such information, a competitor would also require considerable time and inconvenience to develop an understanding of welded steam generator tube sleeve installation problems, evaluate specific examples based on test or pulled steam generator tube data, and develop and qualify a steam generator tube sleeving program.

d. The information consists of a description of the steam generator tube repair process of sleeving, including qualification program results and analyses, the application of which provides a competitive economic advantage. The availability of such information to competitors would enable them to modify their product to better compete with Combustion Engineering, take marketing or other actions to improve their product's position or impair the position of Combustion Engineering's product, and avoid developing similar data and analyses in support of their processes, methods or apparatus.

e. In pricing Combustion Engineering's products and services, significant research, development, engineering, analytical, manufacturing, licensing, quality assurance and other costs and expenses must be included. The ability of Combustion Engineering's competitors to utilize such information without similar expenditure of resources may enable them to sell at prices reflecting significantly lower costs.

f. Use of the information by competitors in the international marketplace would increase their ability to market nuclear steam supply systems by reducing the costs associated with their technology development. In addition, disclosure would have an adverse economic impact on Combustion Engineering's potential for obtaining or maintaining foreign licensees.

Further the deponent sayeth not.

I.C. Rickard, Director
Operations Licensing

Sworn to before me
this 23rd day of April, 19967

Catherine P. McCarthy
Notary Public
My commission expires: 1/31/98