Westinghouse Electric Corporation
Energy Systems

Nuclear Services Division
Box 355
Pittsburgh Pennsylvania 15230-0355

May 17, 1996
CAW-96-967

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Attention: Mr. William T. Russell, Director

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: WCAP-13698, Revision 2, "Laser Welded Sleeves for 3/4 inch Diameter Tube, Feedring-type and Westinghouse Preheater Steam Generators", Revision 2, April 1995 (Proprietary).

Dear Mr. Russell:

The proprietary information for which withholding is being requested in the above-referenced reports is further identified in Affidavit CAW-96-967 signed by the owner of the proprietary information, Westinghouse Electric Corporation. The affidavit, which accompanies this letter, sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of 10 CFR Section 2.790 of the Commission's regulations.

Accordingly, this letter authorizes the utilization of the accompanying Affidavit by Houston Lighting and Power Company.

Correspondence with respect to the proprietary aspects of the application for withholding or the Westinghouse affidavit should reference this letter, CAW-96-967, and should be addressed to the undersigned.

Very truly yours,

WRRice for
N. J. Liparulo, Manager
Nuclear Safety Regulatory & Licensing Activities

SRG/bbp

Attachment

cc: Kevin Bohrer/NRC(12H5)

NSD227L/CAW-96-967

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared William R. Rice, who, being by me duly sworn according to law, deposes and says that he is authorized to execute this Affidavit on behalf of Westinghouse Electric Corporation ("Westinghouse") and that the averments of fact set forth in this Affidavit are true and correct to the best of his knowledge, information, and belief:

William R. Rice

William R. Rice, Interim Manager
Regulatory and Licensing Initiatives

Sworn to and subscribed
before me this 17th day
of May, 1996

Denise K Henderson
Notary Public

Notarial Seal
Denise K. Henderson, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Oct. 28, 1996
Member, Pennsylvania Association of Notaries

(1) I am Interim Manager, Regulatory and Licensing Initiatives, in the Nuclear Services Division, of the Westinghouse Electric Corporation and as such, I have been specifically delegated the function of reviewing the proprietary information sought to be withheld from public disclosure in connection with nuclear power plant licensing and rulemaking proceedings, and am authorized to apply for its withholding on behalf of the Westinghouse Energy Systems Business Unit.

(2) I am making this Affidavit in conformance with the provisions of 10CFR Section 2.790 of the Commission's regulations and in conjunction with the Westinghouse application for withholding accompanying this Affidavit.

(3) I have personal knowledge of the criteria and procedures utilized by the Westinghouse Energy Systems Business Unit in designating information as a trade secret, privileged or as confidential commercial or financial information.

(4) 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 should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse.

(ii) The information is of a type customarily held in confidence by Westinghouse and not customarily disclosed to the public. Westinghouse 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 application of that system and the substance of that system constitutes Westinghouse policy and provides the rational basis required.

Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage, e.g., by optimization or improved marketability.

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

There are sound policy reasons behind the Westinghouse system which include the following:

(a) The use of such information by Westinghouse gives Westinghouse a competitive advantage over its competitors. It is, therefore, withheld from disclosure to protect the Westinghouse competitive position.

(b) It is information which is marketable in many ways. The extent to which such information is available to competitors diminishes the Westinghouse ability to sell products and services involving the use of the information.

(c) Use by our competitor would put Westinghouse at a competitive disadvantage by reducing his expenditure of resources at our expense.

(d) Each component of proprietary information pertinent to a particular competitive advantage is potentially as valuable as the total competitive advantage. If competitors acquire components of proprietary information, any one component may be the key to the entire puzzle, thereby depriving Westinghouse of a competitive advantage.

(e) Unrestricted disclosure would jeopardize the position of prominence of Westinghouse in the world market, and thereby give a market advantage to the competition of those countries.

(f) The Westinghouse capacity to invest corporate assets in research and development depends upon the success in obtaining and maintaining a competitive advantage.

(iii) The information is being transmitted to the Commission in confidence and, under the provisions of 10CFR Section 2.790, it is to be received in confidence by the Commission.

(iv) The information sought to be protected is not available in public sources or available information has not been previously employed in the same original manner or method to the best of our knowledge and belief.

(v) The proprietary information sought to be withheld in this submittal is that which is appropriately marked in "Laser Welded Sleeves for 3/4 Inch Diameter Tube, Feedring-Type and Westinghouse Preheater Steam Generators," WCAP-13698 Rev. 2 (Proprietary), April 1995, being transmitted by Houston Lighting and Power Company letter and Application for Withholding Proprietary Information from Public Disclosure, to the Document Control Desk, Attention Mr. William T. Russell. The proprietary information as submitted for use by Houston Lighting and Power Company for the South Texas Nuclear Power Plants is expected to be applicable in

other licensee submittals in response to certain NRC requirements for justification of the use of laser welded sleeving in steam generator tubes.

This information is part of that which will enable Westinghouse to:

(a) Provide documentation of the methods for laser welded sleeving of steam generator tubes.

(b) Establish applicable testing methods.

(c) Establish the use of fiber optics in laser welded sleeving applications.

(d) Establish applicable codes and standards which are to be applied to the process.

(e) Assist the customer to obtain NRC approval.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for purposes of meeting NRC requirements for licensing documentation.

(b) Westinghouse can sell support and defense of the technology to its customers in the licensing process.

Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar sleeving services and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

The development of the technology described in part by the information is the result of applying the results of many years of experience in an intensive Westinghouse effort and the expenditure of a considerable sum of money.

In order for competitors of Westinghouse to duplicate this information, similar technical programs would have to be performed and a significant manpower effort, having the requisite talent and experience, would have to be expended for developing testing and analytical methods and performing tests.

Further the deponent sayeth not.

Houston Lighting and Power Company

Information to be Included in the Submittal Letter to the NRC

The following paragraphs should be included in your letter to the NRC:

Enclosed are:

1. xxx copies of WCAP-13698, "Laser Welded Sleeves for 3/4 inch Diameter Tube, Feedring-type and Westinghouse Preheater Steam Generators", Revision 2, April 1995" (Proprietary).

2. xxx copies of WCAP 13699, "Laser Welded Sleeves for 3/4 inch Diameter Tube, Feedring-type and Westinghouse Preheater Steam Generators", Revision 2, April 1995" (Non-Proprietary).

Also enclosed are a Westinghouse authorization letter, CAW-96-967, accompanying affidavit, Proprietary Information Notice, and Copyright Notice.

As Items 1 contains information proprietary to Westinghouse Electric Corporation, it is accompanied by an affidavit signed by Westinghouse, the owner of the information. The affidavit sets forth the basis on which the information may be withheld from public disclosure by the Commission and addresses with specificity the considerations listed in paragraph (b)(4) of Section 2.790 of the Commission's regulations.

Accordingly, it is respectfully requested that the information which is proprietary to Westinghouse be withheld from public disclosure in accordance with 10 CFR Section 2.790 of the Commission's regulations.

Correspondence with respect to the copyright or proprietary aspects of the items listed above or the supporting Westinghouse Affidavit should reference CAW-96-967 and should be addressed to N. J. Liparulo, Manager of Nuclear Safety Regulatory & Licensing Activities, Westinghouse Electric Corporation, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Proprietary Information Notice

Transmitted herewith are proprietary and/or non-proprietary versions of documents furnished to the NRC in connection with requests for generic and/or plant-specific review and approval.

In order to conform to the requirements of 10 CFR 2.790 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) contained within parentheses located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (4)(ii)(a) through (4)(ii)(f) of the affidavit accompanying this transmittal pursuant to 10 CFR 2.790(b)(1).

ATTACHMENT 5

Proprietary Westinghouse Report
WCAP-13698 Revision 2;
"Laser Welded Sleeves for 3/4 Inch Diameter Tube Feedring-Type and Westinghouse Preheater Steam Generators, Generic Sleeving Report," April 1995

ATTACHMENT 6

Non-proprietary Westinghouse Report
WCAP-13699 Revision 2;
"Laser Welded Sleeves for 3/4 Inch Diameter Tube Feedring-Type and Westinghouse Preheater Steam Generators, Generic Sleeving Report," April 1995

Westinghouse Class 3

Westinghouse Energy Systems

-9604260208 193pp

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WESTINGHOUSE CLASS 3

WCAP-13699
Rev. 2

SG-95-04-005

LASER WELDED SLEEVES
FOR
3/4 INCH DIAMETER TUBE FEEDRING-TYPE AND
WESTINGHOUSE PREHEATER STEAM GENERATORS

Generic Sleeving Report

April 1995

WESTINGHOUSE ELECTRIC CORPORATION
NUCLEAR SERVICES DIVISION
P.O. BOX 355
PITTSBURGH, PA 15230

WPF1738:49/040695

ABSTRACT

This report provides the technical basis for licensing the use of the Westinghouse Laser Welded Sleeve (LWS) technique to return a 3/4 inch diameter tube with indications of degradation to an operable condition. This report summarizes the generic design, structural, thermal-hydraulic, materials and inspection analyses and corrosion and mechanical tests, as well as installation processes of two distinct types of sleeves. It addresses a tubesheet sleeve and a tube support sleeve for Combustion Engineering feedring-type steam generators and for Westinghouse Models D3, D4, D5, E1 and E2 preheater-type steam generators, all of which utilize 3/4 inch outside diameter tubes.

The Westinghouse LWS technique has been licensed previously for use within 7/8 inch diameter steam * generator tubing, has been installed and is in operation. It has also been licensed for use in a domestic plant with 3/4 inch tubing. It is in use in this configuration in a non-domestic plant with 3/4 inch tubing. This revision adds installation in 3/4 inch tubes which were installed in the tubesheet by explosive and hydraulic expansion processes. That technology base and the technology base for the hybrid expansion joint (HEJ) technique for sleeving are utilized herein with the described evaluations to form the technical basis for the LWS technique for 3/4 inch diameter tubing.

*Denotes change

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1.0 INTRODUCTION

Under Plant Technical Specification requirements steam generator (SG) tubes are periodically inspected for degradation using non-destructive examination techniques. If established inspection criteria are exceeded, the tube must be removed from service by plugging or the tube must be brought back into compliance with the Technical Specification Criteria. Tube sleeving is one technique used to return the tube to an operable condition. Tube sleeving is a process in which a smaller diameter tube or sleeve is positioned to span the area of degradation. It is subsequently secured to the tube, forming a new pressure boundary and structural element in the area between the attachment points.

This report presents the technical bases developed to support licensing of the laser welded sleeve installation process for use in 3/4" diameter tubing. Two distinct types of sleeves are addressed, a tubesheet sleeve and a tube support sleeve. Each of these sleeve types has several installation options which can be applied. There are two types of tubesheet sleeves. The first one extends the full length of the tube within the tubesheet, is joined to the tube in the vicinity of the tubesheet bottom and is referred to as the full length tubesheet sleeve (FLTS). The other type extends over approximately one-third of the tube length within the tubesheet, is joined to the tube approximately 14 inches above the tubesheet bottom and is referred to as the elevated tubesheet sleeve (ETS). The latter type of sleeve allows much greater radial coverage of the bundle, i.e., installation closer to the bundle periphery, than the FLTS. The FLTS is appropriate for all plants which have degradation at the top of the tubesheet, and/or within the tubesheet above the lower joint since the lower joint is formed at the bottom of the tubesheet. Depending on the length of the FLTS and elevation of the lowest baffle/support in the bundle, this sleeve may also address degradation above the tubesheet top. The ETS is appropriate for all plants with SG tubes which have degradation at the top of the tubesheet, and/or within a distance of several inches below the top of the tubesheet. Depending on the length of the ETS and elevation of the lowest baffle/support in the bundle, this sleeve may also address degradation above the tubesheet top. The tube support sleeve (TSS) may be installed to bridge degradation located at tube support locations or in the free span section of the tube. The types of tube supports include flow distribution baffles, drilled plates and grids (a.k.a., "eggcrates").

This technical basis for laser welded sleeves is applicable to Combustion Engineering feedring-type steam generators, (FSGs) and Westinghouse Model D3, D4, D5, E1 and E2 steam generators of the preheater-type design (PSGs), all of which utilize 3/4 inch OD tubing.

1.1 Report Applicability

Each FSG tube bundle contains both U-tubes and modified U-tubes. The modified U-tubes are designed such that the bends at the bundle top have horizontal extent. All of the FSG heat transfer tubes are Alloy 600 and have a nominal OD of 3/4 inch and a nominal wall thickness of 0.048 inch. The PSGs are U-tube heat exchangers with Alloy 600 heat transfer tubes which have a 3/4 inch nominal outside diameter (OD) and 0.043 inch nominal wall thickness. The Model D3/4, E1 and initial E2 steam

generators have mill annealed tubes; the Model D5 and later E2 steam generators have thermally treated tubes.

Data are presented to support the application of two sleeve designs; tubesheet and tube support. Moreover, with each design, several utility selectable application options are provided. The sleeve length and options are:

Tube support sleeve

- 6 to 12 inches long (15 inches long for the grid supports of the FSGs)
- welding with post weld heat treatment (without post weld heat treatment is an option for shorter term operation).

Tubesheet sleeve

- 27 inches to 36 inches long FLTS [ ][b] (Variations apply for some models)
- 12 to 30 inches long ETS
- upper weld joint with post weld heat treatment (without post weld heat treatment is an option for shorter term operation).
- lower joint with seal weld (without seal weld is an option)

The sleeves described herein have been designed and analyzed to meet the service requirements of the FSGs and the PSGs through the use of conservative and enveloping thermal boundary conditions and structural loadings. Previous testing of sleeve lower mechanical joints of sleeves for 3/4 inch OD and 7/8 inch OD tubes has been utilized. It has been determined that the results of these tests are applicable to the lower mechanical joints of sleeves for the 3/4 inch OD tubes in this report, provided that confirmatory leak tightness tests at room temperature are performed. (The mechanical lower joint is discussed because the laser weld for this location is optional; the mechanical joint is required.)

Similarly, previous testing of upper and lower laser welds of sleeves for 7/8 inch OD tubes has been performed. The results of that program are also applicable to the corresponding joints of the sleeves for 3/4 inch OD tubes in this report. The test data for the laser welded sleeves for 7/8 inch OD tubes are provided here as bases in addition to the analytical bases for the upper and lower laser welds of this sleeve.

The structural analysis and mechanical performance of the sleeves are based on installation in the hot leg of the steam generator. [

][c]

1.2 Sleeving Boundary

Tubes to be sleeved will be selected by radial location, tooling access (due to channelhead geometric constraints), sleeve length, and eddy current analysis of the extent and location of the degradation.

The boundary is determined by the amount of clearance below a given tube, as well as tooling and robot delivery system constraints. At the time of application, the exact sleeving boundary will be developed. Owing to the constant development of tooling, designs and processes, essentially 100 per cent coverage of the tubesheet map, for tubesheet and tube support sleeves, is expected.

2.0 SLEEVE DESCRIPTION AND DESIGN

2.1 Sleeve Design Description

Tube sleeves can effectively restore a degraded tube to a condition consistent with the design requirements, i.e., the strength and pressure retaining capabilities of the tube. The design of the sleeve and sleeve weld is predicated on the design rules of Section III, Subsection NB, of the American Society of Mechanical Engineers Boiler & Pressure Vessel Code (ASME Code). Also, the sleeve design addresses dimensional constraints imposed by the tube inside diameter and installation tooling. These constraints include variations in tube wall thickness, tube ovality, tube inside diameter, tube to tubesheet joint variations and runout/concentricity variations.

2.1.1 Tubesheet Sleeve

2.1.1.1 Full-Length Tubesheet Sleeve

The reference design of the full-length tubesheet sleeve, as installed, is illustrated in Figure 2-1. At the upper end, the sleeve configuration consists of a section which is hydraulically expanded. The hydraulic expansion of the upper joint brings the sleeve into contact with the parent tube to achieve the proper fitup geometry for welding. Following the hydraulic expansion, an autogenous weld is made between the sleeve and the tube using the laser welding process. This joint configuration is known as a laser welded joint (LWJ) and in this case, it occurs in the free span, i.e., above the tubesheet.

The FLTS extends from the tubesheet primary face to the free span, i.e., above the tubesheet top. The tube degradation may be anywhere between the upper and lower joints. In the process of sleeve length optimization and allowing for axial tolerance in locating degradation by eddy current inspection, the guideline is that the welds and rewelds are to be positioned a [

]a,c,e.

The upper joint is designed to provide [

]a,c,e.

At the lower end, the sleeve configuration consists of a section which is [

]a,c,e

[

]^{a,c,e}

2.1.1.2 Elevated Tubesheet Sleeve

The ETS is illustrated in Figure 2-2. It is applicable to the steam generators in which the tubes were installed in the tubesheet by the roll expansion process. These include the [

]^{a,c,e}. The ETS design is also applicable to steam generators in which the tubes were installed in the tubesheet by explosive or hydraulic expansion, based on confirmatory qualification of the ETS lower joint process for the respective tube joint design. The ETS upper joint is identical to other free span joints, i.e., the upper joint of the FLTS and the tube support sleeve. The ETS lower joint is fabricated by the same types of processes which are used to fabricate the FLTS lower joints, i.e., hydraulic expansion and roll expansion. The preferred approach to design of the lower joint is direct fabrication on the tube with no preparatory roll expansion. However, in case the tube in the location of the ETS lower joint requires preparation before sleeving such as "truing" or making an interference fit with the tubesheet hole surface, it may be locally roll expanded. It is expected that, although essentially no crevice exists between the tube outside surface and the tubesheet hole surface, the tube may not have had an interference fit with the hole when it was expanded in the factory. Preparatory roll expansion of the tube over at least the two inch axial length of the roll expansion of the sleeve joint is expected to provide adequate axial anchorage of the tube and sleeve at the lower joint. The ETS is similar to the FLTS in that it is designed to address tube degradation in the tube free span and in the vicinity of the tubesheet top. However, unlike the FLTS, it is limited to these applications and is not designed to address degradation in the remainder of the tube within the tubesheet.

[

]^{a,c,e}

[

]a,c,e.

[

]a,c,e

The sleeve material, thermally treated Alloy 690, was selected to provide additional resistance to stress corrosion cracking.

2.1.3 Sleeving of Previously Plugged Tubes

Previously plugged tubes must meet the same requirements as sleeving candidates as never-plugged, active tubes. An example of this requirement is that the minimum distance, as measured along the tube axis between degradation and the location of the sleeve welds, is the same in both cases. Another example is that the tube deplugging process performed by Westinghouse as part of the sleeving process is designed to leave the tube in a condition to be returned to service unsleeved, excluding the degradation which caused the tube to be plugged in the first place. The deplugging process is designed to leave the tube-to-tubesheet weld and tube portion adjacent to the weld in a condition to perform the pressure boundary function without any added integrity from the sleeve-to-tube lower joint.

2.2 Sleeve Design Documentation

The sleeves are designed and analyzed according to the 1989 edition of Section III of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, as well as applicable United States Nuclear Regulatory Commission (USNRC) Regulatory Guides. (As of the date of this report, the 1989 edition is the latest edition approved by the NRC.) The associated materials and processes also meet the rules of the ASME Boiler and Pressure Vessel Code. Specific documents applicable to this program are listed in Table 2-1. The sleeving codes, i.e., IWB-4300, first approved in the Section XI Div. 1, 1989 Addenda, dated March 1990 are used in this evaluation as guidelines.

2.2.1 Weld Qualification Program

All of the laser welding processes have been qualified, used in the field and have produced structures which are now operating, for [ ]a,c,e sleeves for 7/8 inch OD tubes and for [ ]a,c,e inch sleeves

for FSGs. The laser welding processes used to install [ ]^{a,c,e} nominal OD sleeves in 7/8 inch nominal OD tubes, (a.k.a., the "7/8 inch sleeves") and the PSG sleeves were qualified per the guidelines of the ASME Code. The laser welding processes to be used to install [ ]^{a,c,e} nominal OD sleeves in the 3/4 inch nominal OD tubes of the FSGs are being qualified per the guidelines of the ASME Code. These requirements specify the generation of a procedure qualification record and welding procedure specification. The processes for the larger-diameter sleeve/tube joints required requalification for the smaller-diameter sleeve/tube joints. This is due to a change in two of the essential variables, in excess of limits as defined in ASME Code Section XI, IWB-4313.1. Therefore, the welding processes for PSGs were qualified separately and the welding processes for FSGs are being qualified separately.

Specific welding processes are generated for:

- Sleeve weld joints made outside of the tubesheet
- Sleeve weld joints made outside of the tubesheet with thermal treatment
- Repair or rewelding of sleeve joints
- Sleeve weld joints made within the tubesheet

Representative field processes are used to assemble the specimens to provide similitude between the specimens and the actual installed welds. The laser welded joints are representative in length and diametral expansion of the hydraulic-and-roll-expansion zones. The sleeve and tube materials are 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 are used to develop the weld process. [

]^{a,c,e}

The documentation specified by ASME Section XI (sleeving codes - '89 Addenda) may be provided at any reasonable time before the actual sleeving job. This weld qualification documentation is typically submitted to the customer no later than the date of submission of the field procedures.

2.2.2 Weld Qualification Acceptance Criteria

For the qualification of the process, the acceptance criteria specify that the welds shall be free of cracks and lack of fusion and meet design requirements for weld throat and minimum leakage path. The welds shall meet the liquid penetrant test requirements of NB-3530.

Table 2-1

ASME CODE RULES AND REGULATORY REQUIREMENTS

Item	Applicable Criteria	Requirement
Sleeve design	Section III	NB-3000 Design
	Operating Requirements	Analysis Conditions
	Reg. Guide 1.83	SG Tubing Inspectability
	Reg. Guide 1.121	Plugging Limit
Sleeve Material	Section II	Material Composition
	Section III	NB-2000, Identification, Tests and Examinations
	Code Case N-20-3	Mechanical Properties
Sleeve Joint	10CFR100	Predicted Steam Line Break Leak Rate
	Technical Specifications	Operating Primary-to-Secondary Leak Rate
	Section IX	Weld Qualification
	Code Case N-395/Section IX/ Section XI	Laser Welding Essential Variables, procedure qualification record, sleeving procedure specification, certified design report, etc.

a,c,e

Figure 2-1

Tubesheet Full-Length Laser Welded Sleeve Installed Configuration

a,c,e

Figure 2-2

Tubesheet Elevated Laser Welded Sleeve Installed Configuration

a,c,e

Figure 2-3

Tube Support Laser Welded Sleeve Installed Configuration

3.0 ANALYTICAL VERIFICATION

This section of the report provides the analytical justification for the laser welded sleeves. Section 3.1 deals with the structural justification, Section 3.2 provides the thermal/hydraulic justification, and Section 3.3 addresses flow induced vibration concerns for laser welded sleeving.

3.1 Structural Analysis

Section 3.1 summarizes the structural analysis of laser welded sleeves for feedring and preheater steam generators with 3/4 inch tubes in Combustion Engineering (CE) and Westinghouse plants, respectively. The analysis has been performed by modifying the results of the previously completed laser welded sleeving evaluation for Westinghouse steam generators with 7/8 inch tubes (Reference 1), accounting for any necessary changes in geometry and loads. It should be noted that the loading conditions considered in the analysis represent an umbrella set of conditions based on the applicable design specifications, and are defined in Reference 2. The analysis includes development of the finite element models, a heat transfer and thermal stress evaluation, a primary stress intensity evaluation, a primary plus secondary stress range evaluation, and a fatigue evaluation for mechanical and thermal conditions. Calculations are also performed to establish minimum wall requirements for the sleeve. Finally, the analysis addresses a number of special considerations as they affect the adequacy of the sleeve designs.

3.1.1 Component Description

3.1.1.1 Tubesheet Sleeve

The design of the full length tubesheet sleeve, as installed, is illustrated in Figure 2-1. [

]^{a,c,e}

At the lower tube/sleeve interface, the sleeve configuration consists of a section [

]^{a,c}

At the upper end of the sleeve, the sleeve consists of a section that [

]^{a,c} A schematic of the tube / sleeve interfaces and the various [ ]^{a,c} is provided in Figure 3-1.

3.1.1.2 Elevated Tubesheet Sleeve

The installed elevated tubesheet sleeve is illustrated in Figure 2-2. [

]a,c,e

At the lower tube/sleeve interface of roll expanded tube joints, the sleeve configuration consists of a section [

]a,c The sleeve configuration for explosively expanded or hydraulically expanded tube joints, based on confirmatory qualifications, is the same as that of the configuration for roll expanded tubes.

At the upper end of the sleeve, the sleeve consists of a section that [

]a,c A schematic of the tube / sleeve interfaces and the various [ ]a,c is provided in Figure 3-1.

3.1.1.3 Tube Support Sleeve

The installed configuration of the tube support sleeve is shown in Figure 2-3. The sleeve is nominally 6 to 12 inches (15 inches for the grid support) long, and is [

]a,c

3.1.2 Summary of Material Properties

The material of construction for the tubing in Westinghouse and CE steam generators with 3/4 inch tubes is a nickel base alloy, Alloy 600 in either a mill annealed (MA) or thermally treated (TT) condition. The sleeve material is also a nickel base alloy, thermally treated Alloy 690. Summaries of the applicable mechanical, thermal, and strength properties for the tube and sleeve materials are provided in Tables 3-1 and 3-2, respectively. The sleeve evaluation also includes the response of the tubesheet, which is constructed of SA-508, Class 2 Carbon steel for both Westinghouse and CE units. A summary of the applicable properties for the tubesheet material is provided in Table 3-3. Thermal properties for air and water, used in performing the heat transfer analysis, are provided in Tables 3-4 and 3-5, respectively. The fatigue curve used in the analysis of the laser welds corresponds to the code curve for austenitic and nickel-chromium-iron (Inconel).

3.1.3 Applicable Criteria

The applicable criteria for evaluating the sleeves is defined in the ASME Code, Section III, Subsection NB, 1989 Edition, Reference 3. The lower joint in the tubesheet sleeve may contain a seal weld. The seal weld is included and evaluated to the ASME Code criteria as a structural weld. (This is the conservative configuration). In establishing minimum wall requirements for plugging limits, ASME Code minimum values for the material properties are used. A summary of the applicable stress and fatigue limits for the sleeve and tube is given in Tables 3-6 through 3-9.

3.1.4 Loading Conditions Considered

The loadings considered in the analysis represent an umbrella set of conditions and are defined in Reference 1. The analysis considers a full duty cycle of events that includes design, normal, upset, faulted, emergency and test conditions. A summary of the applicable transient conditions is provided in Table 3-10. This duty cycle considers all relevant transients for both FSGs and PSGs with 3/4 inch tubes. The applicable temperatures and pressures are based on the design specifications for the steam generators. Umbrella pressure loads for Design, Faulted, Emergency and Test conditions are summarized in Table 3-11.

3.1.5 Analysis Methodology

A detailed evaluation of [

]a,c,e

[

]a,c,e

[

][a,c,e]

The analysis has also investigated the potential effects of the various [

][a,c,e]

Since the size of the tubes and sleeves [

][a,c,e]

The analysis of the laser welded sleeve designs utilizes both conventional and finite element analysis techniques. Several finite element models are used for the analysis (Reference 1). For the tubesheet sleeve analysis, [

][a,c] Typically, the tubesheet sleeve model incorporates a [ ][a,c] in the tubesheet. The analysis considers both [

][a,c]

All PSGs and FSGs are full-depth expanded in the tubesheet. However in spite of the actual configuration, the limiting geometry, judged to be a partial (tubesheet) depth expansion at the bottom of the tubesheet,][a,c] is considered in this analysis. The tolerances used in developing the sleeve models are such that [

][a,c] The results for the upper joint for the tubesheet sleeve are concluded to conservatively apply to the tube support plate sleeve. This is based on the temperature and pressure loads for the tubesheet sleeve for all transient conditions being greater than or equal to those for the tube support sleeve.

The nominal width (interfacial axial extent) of the laser weld joining the tube and sleeve for all joints is [ ][a,c] However, qualification tests for the weld process are expected to show that the welds may be as small as [ ][a,c] Thus, in performing this analysis, a weld width of [ ][a,c] was considered. Therefore, the stress and fatigue results reported later in the report are for the limiting weld geometry, or the [ ][a,c] width.

3.1.5.1 Sleeve/Tube Size Considerations

As indicated earlier, results from the previously completed evaluation of sleeving for 7/8 inch tubes (Reference 1) are to be used to form a basis to demonstrate acceptability of sleeving for 3/4 inch steam generator tubes. [

]a,c,e

Since the designs of the [

]a,c,e

These factors were developed by [

]a,c

These modified stresses were then used in the subsequent ASME code evaluation to demonstrate acceptability of the sleeve design for both Westinghouse and CE model steam generators with 3/4 inch tubes.

3.1.5.2 Tubesheet Rotation Effects

Loads are imposed on the sleeve as a result of tubesheet rotations under pressure and temperature conditions. Reference 1 established the tubesheet rotations for five reference loading conditions for Westinghouse Series 44 and 51 steam generators. The five reference loading conditions consisted of [ ]a,c. The [ ]a,c loadings. The [ ]a,c. This section establishes the applicability of the tubesheet rotation loadings determined in Reference 2 to the laser welded sleeves for the PSGs as well as for the FSGs.

Differences among the geometries of the Westinghouse steam generators are given in the top part of Table 3-13. Plate bending equations may be used to compare the stresses in the perforated part of the tubesheet for the different geometries. As is shown in the bottom part of Table 3-13, the bending stresses produced by pressure are [ ]a,c,e

The geometry of the FSGs is markedly different from the Westinghouse steam generators, since the diameter of FSG tubesheets are larger with a central stay between the channelhead and tubesheet. Accordingly, a finite element analysis was performed for the FSG to determine the tubesheet rotations produced by the five reference pressure and temperature conditions. Figure 3-5 shows the finite element model of the channel head, stay, tubesheet, and lower shell. The boundary conditions and deformed geometry for the [ ]a,c,e. Thus the results obtained for the Series 51 steam generator sleeves in Reference 1 are conservative when applied to the FSGs.

As was described in Reference 1, [

]a,c

3.1.5.3 Thermal Transient Comparisons

Since the size of the tubes and sleeves are not identical for the Series 51 SG (7/8 inch) and the PSGs and FSGs (3/4 inch), a potential exists that the [

]a,c,e

The [ ]a,c transients used in the Reference 1 evaluation were applied to the Series 51 SG, and stresses were calculated for the times selected in the Reference 1 analysis. Axial stresses and stress intensities were tabulated at the weld and the inside and outside surfaces adjacent to the weld. These stresses are given in Table 3-15 for each of the transients. The WECEVAL LC# in the last column of Table 3-15 refers to the load condition number of the thermal transient stresses used in the Reference 1 fatigue analysis.

Thermal boundary conditions [

]a,c. These transients were applied to the appropriate finite element model (PSG or FSG sleeve/tube geometry), and stresses calculated at selected times comparable to those selected in the Reference 1 evaluation.

As for the Series 51 model, [

]a,c,e

3.1.6 Heat Transfer Analysis

A detailed heat transfer analysis [

]a,c,e

The first step in calculating the stresses induced in the sleeves as a result of the thermal transients is to perform a heat transfer analysis to establish the temperature distribution for the sleeve, tube, and tubesheet. Based on a review of the transient descriptions, [ ]a,c enveloping transients were selected for evaluation in the previous 7/8 inch tube sleeve analysis (Reference 1). They include the following events:

[ ]a,c

The [

]a,c

In performing the heat transfer analysis for the enveloping transients, [

]a,c A sketch of the model boundary conditions for the heat transfer analysis are shown in Figure 3-9.

In order to determine the appropriate boundary conditions for the heat transfer analysis, [ ]a,c

[

]a,c

3.1.7 Tubesheet/Channelhead/Shell Evaluation

A detailed tubesheet/channelhead/shell evaluation for 7/8 inch tube sleeves was performed in Reference 1. This previously completed analysis has determined that [

]^{a,c}

3.1.8 Stress Analysis

In performing the stress evaluation for the sleeve models, [

]^{a,c} Sketches of the model boundary conditions for the primary side pressure cases are shown in Figures 3-10 through 3-13. Sketches of the model boundary conditions for the secondary side pressure cases are shown in Figures 3-14 through 3-17. It should be noted for both sets of loads that the end cap load on the tube is not included, but is considered in a separate load case.

The analysis considers [

]^{a,c}

The effects of [

]^{a,c}

Finally, [

]^{a,c}

The total stress distribution in the sleeve-to-tube assembly is determined by combining the calculated stresses as follows:

$$\sigma_{total} = P_{PR}\,(\sigma)\text{ unit primary pressure / 1000}$$
$$+\ P_{SEC}\,(\sigma)\text{ unit secondary pressure / 1000}$$
$$+\ (\sigma)\text{ thermal transient stress}$$
$$+\ P_{Axial}\,(\sigma)\text{ unit axial load / 1000}$$

Note that the 7/8 inch tube sleeve evaluation has determined that [

]^{a,c}

3.1.9 ASME Code Evaluation

The ASME Code evaluation was performed using a Westinghouse proprietary computer code. The evaluation was performed for specific analysis sections (ASN's) through the finite element model. The ASN's evaluated to determine the acceptability of the sleeve design are shown in Figure 3-4 for the upper LWJ. [

]^{a,c}

The umbrella loads for the primary stress intensity evaluation have been given previously in Table 3-11. The largest magnitudes of the [

]^{a,c}

The results for maximum range of stress intensity and fatigue are summarized in Table 3-18 for the tube being [

]^{a,c}

The analysis results show the ASME Code limits to be satisfied.

In evaluating seismic stresses, [

]^{a,c,e}

[

]^{a,c,e}

3.1.10 Minimum Required Sleeve Wall Thickness

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 in terms of allowables for the primary membrane and membrane-plus-bending stress intensities. Hence, only the primary loads (loads necessary for equilibrium) need be considered.

For computing t_{min}, the pressure stress equation NB-3324.1 of the Code is used. That is,

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

Separate calculations are performed for the Model D, Model E, and Feedring steam generators.

Normal/Upset Operation Loads

The limiting stresses during normal and upset operating conditions are the primary membrane stresses due to the primary-to-secondary pressure differential ΔP_i across the tube wall. The limits on primary stress, P_m, for a primary-to-secondary pressure differential ΔP_i, are as follows:

Normal: $P_m < S_u/3$
Upset: $P_m < S_y$

Accident Condition Loadings

LOCA + SSE
The dominant loading for LOCA and SSE loads occurs [

]^{a,c}

FLB/SLB + SSE:
The maximum primary-to-secondary pressure differential occurs during a postulated feedline break (FLB) accident. Again, [ ]^{a,c} the SSE bending stresses are small. Thus, the governing stresses for the minimum wall thickness requirement are the pressure membrane stresses. For

the FLB + SSE transient, the applicable pressure loads are [ ]^{a,c} The applicable criteria for faulted loads is:

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

A summary of the resulting minimum required wall thicknesses are given in Table 3-19. Also provided in Table 3-19 is a summary of the limiting minimum wall requirement for each model steam generator considering all of the loading conditions.

3.1.11 Determination of Plugging Limits

The minimum acceptable wall thickness and other recommended practices in Regulatory Guide 1.121 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.

As 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 is applied for use in the determination of the operational sleeve thickness acceptable for continued service and thus 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, no degradation has been detected on Westinghouse designed mechanical joint sleeves and no sleeved tube has been removed from service due to degradation of any portion of the sleeve. This result can be attributed to the changes in the sleeve material relative to the tube and the lower heat flux due to the double wall in the sleeved region. Sleeves installed with the laser weld joint are expected to experience the same performance. As a conservative measure, the conventional practice of applying a value of [ ]^{a,c} of the sleeve wall, applied as an allowance for continued degradation, is used in this evaluation.

In summary, the operational sleeve thickness acceptable for continued service includes the minimum acceptable sleeve wall thickness, and the combined allowance for NDE uncertainty and operational degradation [ ]^{a,c}. A summary of the resulting plugging limits as determined by Regulatory Guide 1.121 recommendations are given in Table 3-20.

3.1.12 Application of Plugging Limits

Sleeves which have eddy current indications of degradation in excess of the plugging limits must be repaired or plugged. Those portions of the sleeve for which indications of wall degradation must be evaluated are summarized as follows:

1) [ ]^{a,c}

2) [ ]^{a,c}

3) [ ]^{a,c}

4) [ ]^{a,c}

5) [ ]^{a,c}

3.1.13 Analysis Conclusions

Based on the results of this analysis, the design of the laser welded tubesheet sleeve and the tube support plate sleeve are concluded to meet the requirements of the ASME Code. The applicable plugging limit for the sleeves is 38 per cent of the nominal wall thickness.

Table 3-1
Summary of Material Properties
Alloy 600 Tube Material

PROPERTY	TEMPERATURE (°F)						
	70	200	300	400	500	600	700
Young's Modulus psi x 1.0E06	31.00	30.20	29.90	29.50	29.00	28.70	28.20
Coefficient of Thermal Expansion in/in/°F x 1.0E-06	6.90	7.20	7.40	7.57	7.70	7.82	7.94
Density lb-sec^2/in^4 x 1.0E-04	7.94	7.92	7.90	7.89	7.87	7.85	7.83
Thermal Conductivity Btu/sec-in-°F x 1.0E-04	2.01	2.11	2.22	2.34	2.45	2.57	2.68
Specific Heat Btu-in/lb-sec^2-°F	41.2	42.6	43.9	44.9	45.6	47.0	47.9

STRENGTH PROPERTIES (ksi)							
Sm	23.30	23.30	23.30	23.30	23.30	23.30	23.30
Sy	35.00	32.70	31.00	29.80	28.80	27.90	27.00
Su	80.00	80.00	80.00	80.00	80.00	80.00	80.00

Table 3-2
Summary of Material Properties
Sleeve Material
Thermally Treated Alloy 690

PROPERTY	TEMPERATURE (°F)						
	70	200	300	400	500	600	700
Young's Modulus psi x 1.0E06	30.30	29.70	29.20	28.80	28.30	27.80	27.30
Coefficient of Thermal Expansion in/in/°F x 1.0E-06	7.76	7.85	7.93	8.02	8.09	8.16	8.25
Density $lb\text{-}sec^2/in^4$ x 1.0E-04	7.62	7.59	7.56	7.56	7.54	7.51	7.51
Thermal Conductivity Btu/sec-in-°F x 1.0E-04	1.62	1.76	1.9	2.04	2.18	2.31	2.45
Specific Heat $Btu\text{-}in/lb\text{-}sec^2\text{-}°F$	41.7	43.2	44.8	45.9	47.1	47.9	49.0

STRENGTH PROPERTIES (ksi)							
Sm	26.60	26.60	26.60	26.60	26.60	26.60	26.60
Sy	40.00	36.80	34.60	33.00	31.80	31.10	30.60
Su	80.00	80.00	80.00	80.00	80.00	80.00	80.00

Table 3-3
Summary of Material Properties
Tubesheet Material
SA-508 Class 2

PROPERTY	TEMPERATURE (°F)						
	70	200	300	400	500	600	700
Young's Modulus psi x 1.0E06	29.20	28.50	28.00	27.40	27.00	26.40	25.30
Coefficient of Thermal Expansion in/in/°F x 1.0E-06	6.50	6.67	6.87	7.07	7.25	7.42	7.59
Density lb-sec^2/in^4 x 1.0E-04	7.32	7.3	7.29	7.27	7.26	7.24	7.22
Thermal Conductivity Btu/sec-in-°F x 1.0E-04	5.49	5.56	5.53	5.46	5.35	5.19	5.02
Specific Heat Btu-in/lb-sec^2-°F	41.9	44.5	46.8	48.8	50.8	52.8	55.1

STRENGTH PROPERTIES (ksi)							
Sm	26.70	26.70	26.70	26.70	26.70	26.70	26.70
Sy	50.00	47.50	46.10	45.10	44.50	43.80	43.10
Su	80.00	80.00	80.00	80.00	80.00	80.00	80.00

Table 3-4
Summary of Material Properties
Air

PROPERTY	TEMPERATURE (°F)						
	70	200	300	400	500	600	700
Density $lb\text{-}sec^2/in^4$ x 1.0E-08	10.63	8.99	7.79	6.89	6.17	5.59	5.11
Thermal Conductivity Btu/sec-in-°F x 1.0E-07	3.56	4.03	4.47	4.91	5.35	5.78	6.20
Specific Heat $Btu\text{-}in/lb\text{-}sec^2$-°F x 1.0E+01	9.27	9.31	9.38	9.46	9.55	9.66	9.78

Table 3-5
Summary of Material Properties
Water

PROPERTY	TEMPERATURE (°F)						
	70	200	300	400	500	600	700
Density $lb\text{-}sec^2/in^4$ x 1.0E-05	9.28	9.01	8.58	8.04	7.34	6.35	4.65
Thermal Conductivity Btu/sec-in-°F x 1.0E-06	8.46	9.07	9.14	8.89	8.24	6.9	4.42
Specific Heat $Btu\text{-}in/lb\text{-}sec^2$-°F x 1.0E+02	3.82	3.88	3.96	4.12	4.37	5.26	8.51

Table 3-6
Criteria for Primary Stress Intensity Evaluation
Sleeve - Alloy 690

CONDITION	CRITERIA	LIMIT (KSI)
DESIGN	$P_m \leq S_m$ $P_1 + P_b \leq 1.5\ S_m$	$P_m \leq 26.60$ $P_1 + P_b \leq 39.90$
FAULTED	$P_m \leq .7\ S_u$ $P_1 + P_b \leq 1.05\ S_u$	$P_m \leq 56.00$ $P_1 + P_b \leq 84.00$
TEST	$P_m \leq 0.9\ S_y$ $P_1 + P_b \leq 1.35\ S_y$	$P_m \leq 36.00$ $P_1 + P_b \leq 54.00$
EMERGENCY	$P_m \leq S_y$ $P_1 + P_b \leq 1.5\ S_y$	$P_m \leq 40.00$ $P_1 + P_b \leq 60.00$
ALL CONDITIONS	$P_1 + P_2 + P_3 \leq 4.0\ S_m$	$P_1 + P_2 + P_3 \leq 106.4$

Note: P_i (i=1,2,3) = Principal stresses

Table 3-7
Criteria for Primary Stress Intensity Evaluation
Tube - Alloy 600

CONDITION	CRITERIA	LIMIT (KSI)
DESIGN	$P_m \leq S_m$ $P_1 + P_b \leq 1.5\ S_m$	$P_m \leq 23.30$ $P_1 + P_b \leq 34.95$
FAULTED	$P_m \leq .7\ S_u$ $P_1 + P_b \leq 1.05\ S_u$	$P_m \leq 56.0$ $P_1 + P_b \leq 83.88$
TEST	$P_m \leq 0.9\ S_y$ $P_1 + P_b \leq 1.35\ S_y$	$P_m \leq 31.50$ $P_1 + P_b \leq 47.25$
EMERGENCY	$P_m \leq S_y$ $P_1 + P_b \leq 1.5\ S_y$	$P_m \leq 35.00$ $P_1 + P_3 \leq 52.5$
ALL CONDITIONS	$P_1 + P_2 + P_3 \leq 4.0\ S_m$	$P_1 + P_2 + P_3 \leq 93.20$

Note: P_i (i=1,2,3) = Principal stresses

Table 3-8
Criteria for Primary Plus Secondary Stress
Intensity Evaluation
Sleeve - Alloy 690

CONDITION	CRITERIA	LIMIT (KSI)
NORMAL, UPSET, and TEST	$P_1 + P_b + Q \leq 3\ S_m$*	$P_1 + P_b + Q \leq 79.8$
NORMAL, UPSET, and TEST	Cumulative Fatigue Usage	1.0

* - Range of Primary + Secondary Stress Intensity

Table 3-9
Criteria for Primary Plus Secondary Stress
Intensity Evaluation
Tube - Alloy 600

CONDITION	CRITERIA	LIMIT (KSI)
NORMAL, UPSET, and TEST	$P_1 + P_b + Q \leq 3\ S_m$*	$P_1 + P_b + Q \leq 69.9$
NORMAL, UPSET, and TEST	Cumulative Fatigue Usage	1.0

* - Range of Primary + Secondary Stress Intensity

Table 3-10
Summary of Transient Events

CLASSIFICATION	CONDITION	CYCLES
Normal		
Upset		

a,c,e

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Table 3-10 (continued)
Summary of Transient Events

CLASSIFICATION	CONDITION	CYCLES
Faulted		
Emergency		
Test		

a,c,e

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Table 3-11
Umbrella Pressure Loads for
Design, Faulted, and Test Conditions

CONDITIONS	PRESSURE LOAD, PSIG PRIMARY	SECONDARY	
Design	[	]	b,c
Design Primary			
Design Secondary			
Primary to Secondary Boundary(1)			
Secondary to Primary Boundary(1)			
Faulted			
Reactor Coolant Pipe Break(2)			
Feedline Break			
Steam line Break			
RC Pump Locked Rotor(3)			
Control Rod Ejection(4)			
Test			
Primary Side Hydrostatic Test			
Secondary Side Hydrostatic Test			
Tube Leak Test A			
Tube Leak Test B			
Tube Leak Test C			
Tube Leak Test D			
Primary Side Leak Test			
Secondary Side Leak Test			
Emergency			
Small LOCA(5)			
Small SLB(6)			
Complete Loss of Flow(7)			
CE Loss of FW Flow - Cold FW Hot Dry SG			
CE Complete Loss of Secondary Side Pressure			

]b,c
3) [ ]b,c
4) [ ]b,c
5) [ ]b,c
6) [ ]b,c
7) [ ]b,c

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Table 3-12
Stress Modification Factors
7/8 Inch to 3/4 Inch Tube Sleeves

a,c,e

Table 3-13
Tubesheet Comparisons for
Westinghouse Steam Generators

a,c,e

Table 3-14
Comparisons of Tubesheet Stresses for FSGs and Series 51 Steam Generators

a,c,e

Table 3-15
Transient Stresses at Sleeve/Tube Weld - Series 51 SG

a,c,e

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Table 3-16
Ratio of Models D, E, and FSGs to Series 51 SG Transient Stresses

a,c,e

[ ]

Table 3-17
Summary of Maximum Primary Stress Intensity
Full Length Tubesheet Laser Welded Sleeve

Sleeve/Tube Weld Width of [ ]a,c
[ ]a,c

a,c,e

[ ]

Table 3-18
Maximum Range of Stress Intensity and Fatigue
Full Length Tubesheet Laser Welded Sleeve

Sleeve/Tube Weld Width of [ ]a,c

[ ]a,e

Component	Calculated S.I. (KSI)	Allowable S.I. (KSI)	Calculated / Allowable
	[ ]a,c		[ ]a,c
Sleeve		79.80	
Tube		69.90	
Weld		69.90	

Cumulative Fatigue Usage Factor(2)
[ ]a,c ≤ 1.0

(1) With thermal bending stress removed per NB-3228.5(a).
(2) Including K_e factors for simplified Elastic-plastic analysis.

Table 3-19
Summary of Minimum Wall Thickness Calculations
Laser Welded Sleeve

a,c,e

Table 3-20
Summary of Recommended Plugging Margins
Laser Welded Sleeves

a,c,e

[ ]

a,c

Figure 3-1

Schematic of Tubesheet Sleeve Configuration

a,c

[ ]

Figure 3-2

Upper LWJ Comparison Model - Full Model

a,c

Figure 3-3

Upper LWJ Comparison Model - Weld Zone

a,c

Figure 3-4

ASN Location - Upper LWJ

a,c,e

Figure 3-5

Finite Element Model of
FSG Channel Head/Tubesheet/Shell

a,c,e

Figure 3-6

**FSG Channel Head/Tubesheet/Shell Model
Primary Pressure Boundary Conditions
and Deformed Geometry**

a,c,e

[ ]

Figure 3-7

FSG Channel Head/Tubesheet/Shell Model Tubesheet Expansion Boundary Conditions and Deformed Geometry

a,c,e

Figure 3-8

Finite Element Model of Sleeve/Tube Weld for Thermal Transient Stresses

a,c

Figure 3-9

Thermal/Hydraulic Boundary Conditions
Tubesheet Sleeve Analysis

a,c,e

[ ]

Figure 3-10

Boundary Condition for Unit Primary Pressure
[ ]^{a,c,e} $P_{PRI} > P_{SEC}$

a,c,e

Figure 3-11

Boundary Condition for Unit Primary Pressure

[ ]^{a,c,e} $P_{PRI} < P_{SEC}$

a,c,e

[ ]

Figure 3-12

Boundary Condition for Unit Primary Pressure

[ ]^{a,c,e} $P_{PRI} > P_{SEC}$

a,c,e

Figure 3-13

Boundary Condition for Unit Primary Pressure

[ ]^{a,c,e} $P_{PRI} < P_{SEC}$

a,c e

Figure 3-14

Boundary Condition for Unit Secondary Pressure

[ ]^{a,c,e} $P_{PRI} > P_{SEC}$

a,c,e

Figure 3-15

Boundary Condition for Unit Secondary Pressure
[ ]^{a,c,e} $P_{PRI} < P_{SEC}$

a,c,e

[ ]

Figure 3-16

Boundary Condition for Unit Secondary Pressure
[ ]^{a,c,e} $P_{PRI} > P_{SEC}$

a,c,e

[ ]

Figure 3-17

Boundary Condition for Unit Secondary Pressure
[ ]^{a,c,e} $P_{PRI} < P_{SEC}$

3.2 Thermal Hydraulic Analysis

3.2.1 Safety Analyses and Design Transients

From the standpoint of system effects, safety analyses and system transients, steam generator tube sleeving has the same effect as tube plugging. Sleeves, like plugs, increase both the flow resistance and the thermal resistance of the steam generator.

Each NSSS is analyzed to demonstrate acceptable operation to a level of plugging denoted as the plugging limit. When the steam generators include both plugs and sleeves, the total effect must be shown to be within the plugging limit. To do this, an equivalency relationship between plugged and sleeved tubes needs to be established. The following section derives a hydraulic equivalency number. This number represents the number of sleeved tubes which are hydraulically equivalent to a single plugged tube. It is a function of various parameters including 1) the number and location of sleeves in a tube, 2) the steam generator model, and 3) the operating conditions. Conservative bounding values are determined so that a single number applies to a given steam generator model and tube sleeve configuration.

Once the hydraulic equivalency number is established, the equivalent plugging level of a steam generator and NSSS can be determined. This equivalent plugging level must remain within the plugging level established for the plant.

3.2.2 Equivalent Plugging Level

The insertion of a sleeve into a steam generator tube results in an increase in flow resistance and a reduction in primary coolant flow in that tube. Furthermore, the insertion of multiple sleeves (tubesheet and/or tube support sleeves) will lead to a larger flow reduction in the sleeved tube compared to a nominal unsleeved tube. The flow reduction through a tube due to the installation of one or more sleeves can be considered equivalent to a portion of the flow loss due to a plugged tube. A parameter termed the "hydraulic equivalency number" has been developed which indicates the number of sleeved tubes required to result in the same flow loss as that due to a single plugged tube.

The calculation of the flow reduction and equivalency number for a sleeved tube is dependent upon: 1) the tube geometry, 2) the sleeve geometry, and 3) the steam generator primary flow rate and temperature. These parameters are used to compute the relative difference in flow resistance of sleeved and unsleeved tubes operating in parallel. This difference in resistance is then used to compute the relative difference in flow between sleeved (W_{slv}) and unsleeved (W_{unslv}) tubes. The hydraulic equivalency number is then simply:

[ ]a.c.e

The hydraulic equivalency number can be computed for both normal operating conditions and off-normal conditions such as a LOCA. For LOCA conditions, the equivalency number is established using flow rates consistent with the reflood phase of a post-LOCA accident when peak clad temperatures exist. The equivalency number for normal operation is independent of the fuel in the reactor. In all cases, the hydraulic equivalency number for normal operation is more limiting than for postulated LOCA conditions.

As a result of the flow reduction in a sleeved tube and the insulating effect of the double wall at the sleeve location, the heat transfer capability of a sleeved tube is less than that of an unsleeved tube. An evaluation of the loss of heat transfer at normal operating conditions indicated that the percentage loss of heat transfer capability due to sleeving is less than the percentage loss associated with the reduction in fluid flow. In other words, the heat transfer equivalency number is larger than the hydraulic equivalency number. Thus, the hydraulic equivalency number is limiting.

The specific LOCA conditions used to evaluate the effect of sleeving on the ECCS analysis occur during a portion of the postulated accident when the analysis predicts that the fluid in the secondary side of the steam generator is warmer than the primary side fluid. For this situation, the reduction in heat transfer capability of sleeved tubes would have a beneficial reduction on the heat transferred from secondary to primary fluids.

Hydraulic Equivalency Calculation

The goal of the calculations described below is to develop conservative values of hydraulic equivalency to bound all possible sleeve configurations that might be considered for steam generators with 3/4 inch tubes. The steam generators included FSG configurations with heat transfer areas of 88,500 ft^2 and 103,600 ft^2. Hydraulic equivalency numbers are generated for a tube with each of the following tubesheet sleeve configurations and up to 12 tube support sleeves.

1) No tubesheet sleeve

2) One tubesheet sleeve (hot or cold leg)

3) Two tubesheet sleeves (hot and cold leg)

Based on previous evaluations (Reference 1), the most conservative sleeve configurations and operating conditions were selected for determining hydraulic equivalency. A sensitivity study was then performed with the least conservative limit of the same configurations and operating conditions to verify that the parameters selected were conservative.

Previous evaluations have shown that for any given sleeve, location of the sleeve in the cold leg at the highest tube support elevation gave the lowest (most conservative) value of equivalency number. Therefore, for each sleeve configuration examined, the maximum possible number of sleeves were located

in the cold leg at the higher tube support elevations. Additional dynamic structural evaluations would be required to verify sleeves in the cold legs of PSGs because of the additional effects of the preheater crossflow). Also, the longest tubesheet sleeve (36 inches) was used for all calculations. This sleeve gives a lower equivalency value than shorter sleeves. Only one tube support sleeve length (12 inches) is under consideration for the Westinghouse Models. The longest TSS (15 inches for the "grid" (eggcrate)) was used for the FSGs.

Operating conditions affect equivalency to a smaller degree, with high values of primary flow or T_{hot} and low values of T_{cold} giving the most conservative values of equivalency. The following values of these parameters were selected for each of the steam generator models. These operating conditions are at the conservative end of the typical range for the particular model. For the FSG models, the 88,500 ft^2 generator was chosen because it gave the lowest hydraulic equivalency numbers.

Operating Conditions Used for Hydraulic Equivalency Calculations

Parameter	Conservative Parameter Value		
	FSG	Model D	Model E
Primary Flow - GPM	170000	100000	100000
Primary T_{hot} - °F	615	620	626
Primary T_{cold} - °F	540	543	555

Calculated values of hydraulic equivalency are presented for these three steam generator models as a function of sleeve configuration in Figures 3-18 through 3-20. The table at the bottom of each figure displays the values of hydraulic equivalency plotted along with the configuration of tube support plate sleeves for each case. Notice that the tube support plate sleeves fill up the cold leg, top tube support plate locations first and then spill over to the hot leg. This procedure conservatively minimizes the hydraulic equivalency for each tube support plate sleeve configuration.

Hydraulic Equivalency Sensitivity Study

In order to confirm previous evaluations with respect to the most conservative values for sleeve configuration and operating conditions, a sensitivity study was performed with the Model D. Sleeve configurations with one tubesheet sleeve and up to 12 tube support sleeves, presented in Figure 3-18, were used as the reference configurations. The following four cases made up the sensitivity study.

- Reference case, tube support plates in the cold leg, conservative operating conditions (high primary flow and T_{hot}, low T_{cold})

- Sleeves shifted to the hot leg

- Least conservative operating conditions (low primary flow and T_{hot}, high T_{cold})

- LOCA operating conditions

The operating conditions for the various cases are as follows:

Parameter	Model D Operating Condition		
	Reference	Least Conservative	LOCA*
Primary Flow	100000 gpm	89000 gpm	20000 lbm/hr
Primary T_{hot} - °F	620	612	522
Primary T_{cold} - °F	534	558	522
Primary Pressure-psia	2250	2250	37

*LOCA conditions are superheated vapor during the reflood phase

Table 3-21 presents the hydraulic equivalency values for the sensitivity study cases. For each variant from the reference case, the ratio to the reference case hydraulic equivalence value is also tabulated. The table shows that in every case, the reference equivalency ratio is equal to or smaller than the variants. The equivalency numbers of Figures 3-18 through 3-20, therefore, can be used as bounding values for each model, all sleeve configurations and at all operating conditions.

The total equivalent number of plugged tubes is the sum of the number of plugs associated with sleeving (number of sleeves divided by the hydraulic equivalency number) and the actual number of plugged tubes. In the event that the total plugging equivalency derived from this information is near the tube plugging limit for a particular plant application, then less conservative, plant-specific equivalency calculations may be completed to justify increased sleeving. Rather than using the preceding conservative, enveloping conditions, these calculations could make use of: 1) actual plant primary side operating conditions, 2) actual tube and sleeve geometries, and 3) actual locations of the tubesheet and support plate sleeves.

The method and values of hydraulic equivalency and flow loss per sleeved tube outlined above can be used to represent the equivalent number of sleeves by the following formula:

$$P_e = P_a + \sum_i \left(\frac{S_i}{N_{hyd,i}}\right) + P_c$$

where:

P_e = Equivalent number of plugged tubes
P_a = Number of tubes actually plugged
S_i = Number of active tubes with a sleeve combination "i"
$N_{hyd,i}$ = Hydraulic equivalency number for a sleeve configuration "i"
P_c = Equivalent number of plugged tubes due to other sleeve designs

Table 3-21
Hydraulic Equivalency Sensitivity Study

TSP Sleeves	Ref. Case	Hot Leg Sleeves Value	Hot Leg Sleeves Ratio	Least Conservative Operating Cond. Value	Least Conservative Operating Cond. Ratio	LOCA Operating Conditions Value	LOCA Operating Conditions Ratio
0							
1							
3							
5							
7							
9							
12							

a,c,e

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3.2.3 Fluid Velocity

As a result of tube plugging and sleeving, primary side fluid velocities in the steam generator tubes will increase. The effect of this velocity increase on the sleeve and tube has been evaluated assuming a limiting condition in which 20 per cent of the tubes in a steam generator are plugged.

Using the conservatively high primary flow rates defined previously for the various models with 20 per cent of the tubes plugged, the fluid velocities through an unplugged and unsleeved tube are in the range [ ]^{a,c,e}. For a tube with a single tube support plate sleeve, the local velocity in the sleeve region is computed to be [ ]^{a,c,e}. These velocities are smaller than the inception velocities for fluid impacting, cavitation, or erosion-corrosion for ~~Inconel~~ Alloy 600 and 690 tubing. As a result, the potential for tube degradation due to these mechanisms is low.

a,c,e

[ ]

Figure 3-18

Hydraulic Equivalency Number 3/4 In. OD Tube, Model D SG

a,c,e

Figure 3-19

Hydraulic Equivalency Number 3/4 In. OD Tube, Model E SG

a,c,e

Figure 3-20

Hydraulic Equivalency Number 3/4 In. OD Tube, FSG

3.3 Sleeved Tube Relative Flow Induced Vibration Assessments

The purpose of this Section is to provide the bases, methodology overview, salient parameters and results which together show acceptability of tube modifications implicit with installation of laser welded sleeves in terms of tube flow induced vibration (FIV) and wear potential. The two viable vibration mechanisms for tubes in steam generator tube bundles are due to cross flow turbulence and fluidelastic excitations. It is noted that the mechanisms of axial flow turbulence and vortex shedding are not considered viable as major causative mechanisms based on field experiences and, hence, are not addressed further.

Results from these assessments are intended to show that the limiting cases of a tube modification caused by laser welded sleeves do not cause significant potential field issues with respect to FIV responses. These results, along with the experience that FIV problems have not occurred in field SG straight-legs, either of FSG or PSG design, are intended to provide adequate assurance that laser welded sleeves are acceptable in each of the designs considered.

3.3.1 Flow Induced Vibration Evaluation Methodologies

Westinghouse capabilities and methodologies for the evaluations of flow induced vibrations are under continuous development (see References 7 through 15). To perform the subject evaluations a relative analysis method was developed and used. This relative method is described below.

The first case considered for each laser welded sleeve configuration was that a laser welded sleeve has been installed in a tube and, at the same time, the tube is conservatively assumed to be severed through 360 degrees of arc at some location within bounds of the length of the sleeve. The second, and reference case, is that of the unmodified (nominal) tube. Ratios of the vibration responses for these cases provide the desired relative results, which are then put into perspective relative to actual field and test operating experiences to provide the required demonstration of acceptability. These evaluations address three specific laser welded sleeve (off nominal) configurations. They are characterized as: [ ],^{a,c} [ ]^{a,c} and [ ]^{a,c} These configurations are defined in Table 3-23 and in Figures 2-1, 2-2, and 2-3, respectively.

In these relative evaluations, it is necessary to establish all vibration response related parameters which vary between the two cases being compared. A sleeved and separated tube produces physical changes in the structural tube system, relative to the nominal case, such that the length of that system may be increased and / or its cross-sectional properties decreased. Each of these effects results in both reduced natural frequencies and changed mode shapes. Because damping is known to be a strong function of frequency, it too must be considered explicitly.

Linear system vibration responses for both the turbulence and fluidelastic mechanisms are obtained with the Westinghouse proprietary computer code FASTVIB. Initial separate evaluations are typically performed, as in this case.

Another Westinghouse computer program, WECAN, provides for the generation of a finite element model of the tube and tube support system in the form of a linear superelement. The finite element model provides the vehicle to define the mass and stiffness matrices for the tube system as well as the geometry of the tube and tube support plate. This information is used to determine the modes (eigenvalues) and mode shapes (eigenvectors) for the linearly supported tube being considered. Table 3-22 provides the tube and sleeve cross sectional properties used in the creation of the 20 developed superelements. Schematics of the superelements showing the tube, tube support, and salient structures geometry and node designations are provided in Tables 3-25 through 3-27. Table 3-25 gives this information for the Models D, Table 3-26 is for the Model E1/2, and Table 3-27 addresses the FSGs.

Inputs to the FASTVIB code are, typically, the mass and stiffness matrices, the secondary fluid flow velocity and density distributions, a set of pre-determined permissible boundary conditions for each tube (or tube span) in the bundle to be evaluated, the fluidelastic constant, beta, and damping appropriate to the flow, boundary conditions, and the lower limit value to the reduced velocity parameter. Because the present evaluations are relative, however, several of these inputs are not required. Notable among these are the velocity distributions and the beta values.

The secondary side fluid density distributions used for the present evaluations were developed from three-dimensional flow studies for each of the SG models being considered. For the Models D and E, ATHOS computer code results were used. The FSG distributions were based on the THIRST code as reported in Reference 16. Density as a function of elevation was extracted from these code results in a region of the cold leg near the periphery of the bundle. These density distributions were intentionally chosen to provide conservative evaluation results as they have nearly the highest values in the bundle at the selected full power operating conditions. They are given in Table 3-24 for each of the relevant SGs along with the associated equivalent tube density profiles. It is these latter profiles which are input to the WECAN superelement models to form the tube mass matrices.

These evaluations are intentionally and conservatively limited to hot leg geometries for each SG model. (Additional dynamic structural evaluations would be required to verify in the cold legs of PSGs because of the additional effects of the preheater crossflow.) Specific boundary conditions considered for each tube location are typically obtained on the basis of results from the application of Monte Carlo methods. However, in this present evaluation, the boundary conditions considered are conservatively chosen as up to two missing tube supports at the four lowest (true) tube supports a.k.a., TSPs on the hot leg side. Included in these conditions are: 1) all supports active, 2) any one support inactive, 3) any two supports inactive, including the conservative case of two consecutive supports inactive. In all cases the fifth and higher supports are assumed to provide pinned tube support.

Output from a FASTVIB evaluation is usually comprised of the fluidelastic stability ratio and the root-mean-square turbulence vibration amplitude. Because these are relative evaluations, the output (results) here becomes ratios of appropriate stability ratios and root-mean-square turbulence vibration amplitudes. These results can be presented in many different forms. Generally, it is instructive to produce maps showing the worst case boundary condition result at each tube location considered in the tube bundle. Since these relative evaluations are being performed on a conservative "worst expected case tube condition" basis, there is only one evaluation result for each of two mechanisms and ten boundary conditions for the three sleeve configurations in each of five SG models. Thus, the presentation format chosen for these evaluations is a table. This table is presented and discussed below.

3.3.2 Effects of Damping on Relative Evaluations

Tube damping plays the very important role of establishing tube vibration and stress magnitudes for both the fluidelastic and turbulence mechanisms once all other system and forcing function parameters are established. For these relative evaluations, damping is important because of the change in frequencies brought about by the introduction of the sleeve, and the conservative assumption of a severed tube, with their associated, but independent, changes in effective tube system geometry.

In order to establish the magnitude of the effects of damping on the FIV evaluation results and the difference in these damping effects given different damping relations associated with different SG straight-leg conditions, a parametric evaluation was completed. This evaluation was accomplished before the final relative evaluations and was intentionally made independent of the mode shape integral effects. Results from these parametric evaluations are provided in Figures 3-21 through 3-24. These four figures illustrate the basis for our developed damping position for these laser welded sleeve FIV evaluations. They demonstrate that; 1) it is beneficial to consider damping for these relative evaluations of FIV responses at all frequencies and frequency changes due to the introduction of a laser welded sleeve and an assumed severed tube, and, 2) the results are insensitive to the choice of absolute damping relation of which SG model is used. Given this latter result, damping originally developed for a specific SG straight-leg evaluations was chosen for use in all the present laser welded sleeve and nominal tube configuration evaluations. Based on physical considerations associated with the various tube / sleeve configurations, it is expected that this chosen damping relation is relevant and conservative for laser welded sleeve configurations and relevant for the nominal configurations.

3.3.3 Flow Induced Vibration Results and Conclusions

The subject laser welded sleeve FIV evaluation results are provided on Table 3-28. As can be seen from this Table, each of the five SG configurations forms a sub-table. On each of these sub-tables both fluidelastic and turbulence results are presented for all the boundary conditions considered and for each of the three sleeve configurations considered. The boundary conditions are varied between pinned and open at the four lowest true tube support plates. Again, each individual result is the ratio of the FASTVIB predicted response for the vibration mechanism and sleeve configuration indicated at the top of the

columns to the FASTVIB predicted response for the nominal sleeve configuration subjected to the same mechanism and conditions.

Fluidelastic Stability

The Model D3 results, given in columns 6, 7 and 8 of Table 3-28, show that there are only three configurations with a ratio exceeding 1.10, which implies a 10 per cent increase for the sleeved configuration over nominal. The first of these is for the ELEV sleeve, a.k.a., ETS, configuration and shows about 21 per cent increase for the case of open boundary conditions at the lowest two (consecutive) plates. The last two are for the FLTS configuration and show about 29 per cent increase for the lowest TSP open condition, and about 53 per cent for open boundary conditions at the lowest two (consecutive) plates.

The Model D4 results show that there are only five configurations with a ratio exceeding 1.10. The first two of these are for the ELEV sleeve configuration and show about 12 per cent increase for the lowest TSP open condition, and about 19 per cent for open boundary conditions at the lowest two plates. The last three are for the FLTS configuration and show about 45 per cent increase for the lowest TSP open condition, about 48 per cent for open boundary conditions at the lowest two (consecutive) plates, and about 28 per cent for open boundary conditions at the first (lowest) and third plates.

The Model D5 results are very nearly identical to those for the Model D4.

The Model E results are also very nearly identical to those for the Model D4 with only minor variations in the percentages for each of the (same) configurations (see the table).

The FSG results also show that the same five configurations have a ratio exceeding 1.10. In this case the results for the ELEV sleeve configuration show about 14 per cent increase for the lowest TSP open condition, and about 21 per cent for open boundary conditions at the lowest two plates. The last three are again for the FLTS configuration and show about 38 per cent increase for the lowest TSP open condition, about 53 per cent for open boundary conditions at the lowest two (consecutive) plates, and about 16 per cent for open boundary conditions at the first and third plates.

Because there are no known unacceptable cases of straight-leg fluidelastic vibration and wear conditions in SGs where design conditions are prevalent at any of the field units where the subject SG models are employed, the fluidelastic stability ratio increases implied by the results discussed above and presented in Table 3-28, are expected to be acceptable.

Turbulence Response

The turbulence response results, given in columns 9, 10 and 11 of Table 3-28, show that there are more cases where the turbulence ratios exceed 1.10 than there are fluidelastic cases for the same SG model. However, it is well known on the bases of both tests and field results that the absolute turbulence response for the nominal condition case for the hot leg in any of the SG models considered is quite small, on the order of tenths of mils. Thus, it is fully expected that there would be no real vibration and wear issues introduced into any of these SG models if the turbulence amplitudes were increased by the largest ratio in the table, which is about 3.5. It is also expected that, at these higher amplitudes, the turbulence response would remain below the endurance limit and, therefore, would not change the tube / sleeve system fatigue evaluation outcome relative to the nominal case.

Table 3-22
3/4 Inch Tube Laser Welded Sleeve Evaluations
Tube and Sleeve Cross Sectional Properties

a,c,e

Table 3-23
3/4 Inch Tube Laser Welded Sleeve Evaluations
Sleeve Position Definitions and Lengths

a,c,e

Table 3-24
Laser Welded Sleeve Relative Evaluations
Tube Density Distribution Estimates

a,c,e

Table 3-25
Laser Welded Sleeve Superelement Geometry and Nodes for Models D3, D4 and D5 SGs

a,c,e

Table 3-26
Model E2 LWS Superelement Geometry and Nodes

a,c,e

Table 3-27
FSG (Specific Case) LWS Superelement Geometry and Nodes

a,c,e

[ ]

Table 3-28
Relative Flow Induced Vibration Evaluation
Results for Laser Welded Sleeve Configuration
with Various Tube Support Plate Boundary Conditions

a,c,e

Figure 3-21

LWS Effects on Stability Ratio

[ ]a,c,e

a,c,e

Figure 3-22

LWS Effects on Stability Ratio

[ ]a,c,e

[ ]a,c,e

Figure 3-23

LWS Effects on Turb. Response

[ ]a,c,e

a,c,e

Figure 3-24

LWS Effects on Turb. Response

[ ]a,c,e

a,c,e

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3.4 References

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16. "Thermal Hydraulic Analysis of a Combustion Engineering Series 67 Steam Generator," EPRI Report NP-1678, January 1981.

4.0 MECHANICAL TESTS

Mechanical tests are used to provide [

]a,c,e

Mechanical testing was previously applied to both Hybrid Expansion Joint (HEJ) (lower joint) and laser welded (free span and lower joint) sleeving to confirm analyses that evaluated the interaction between the sleeve and tube. Mechanical testing is primarily concerned with leak resistance and joint strength, including fatigue resistance. A consistent characteristic observed in the testing of HEJ lower joints for sleeves is that leakage, when observed, is generally higher at room temperature (RT) and normal operation, steamline break (SLB) and greater-than-SLB pressure differential conditions than at elevated temperatures and other applied-load conditions. This result obviates all of the combined or separate elevated temperature leak tightness and applied-load types of tests and permits qualification of these 3/4 inch HEJ lower joints on the basis of the RT leak tightness test and the previous testing. During testing, some of the specimens were subjected to cyclic thermal and mechanical loads, simulating plant transients. [

]a,c,e Other specimens were subjected to tensile and compressive loads to the point of mechanical failure. These tests demonstrate that the required joint strength exceeded the loading the sleeve joint would receive during normal plant operations or accident conditions.

Section 4.1 summarizes previous mechanical tests and results for HEJ 3/4 inch tube sleeves which are applicable to the installation of the lower HEJ of this tubesheet sleeve in 3/4 inch tubing, based on confirmatory room temperature leak tightness pressure tests. (The mechanical lower joint is discussed because the laser weld for this location is optional; the mechanical joint is required.) Section 4.2 summarizes previous mechanical tests and results for the lower joint of the 7/8 inch HEJ sleeve. The 7/8 inch sleeve results show the adequacy of obtaining the required strength of the roll expanded portion of the HEJ, based on optimal roll thinning of the sleeve. This same method is used to achieve the required strength of the roll expanded portion of the HEJ for the 3/4 inch sleeves. Section 4.2 also summarizes previous mechanical tests and results for 7/8 inch laser welded joints. These data were provided to show that tests corroborated the analyses for those joints. Therefore, verification by analysis is sufficient for the 3/4 inch laser welded sleeve joints.

4.1 Tubesheet HEJ Tests – 3/4 Inch Tube Sleeves

4.1.1 Case No. 1 - Westinghouse Steam Generator (WSG)

The mechanical tests of the tubesheet lower joint (HEJ), provided for another Westinghouse 3/4 inch OD (nominal) tube steam generator are applicable to the 3/4 inch OD (nominal) tubes of the FSGs and PSGs. The test conditions are listed in Table 4-1 and the generic, allowable, primary-to-secondary leak rates are listed in Table 4-2. The test results are provided in Table 4-3. As discussed earlier, the HEJs are formed in tube-to-tubesheet joint unit cells. End caps are installed on the collar and sleeve top, per Figure 4-1, to permit the samples to be pressurized. The end caps are threaded to permit tensile and compressive loading.

Table 4-1
Case No. 1 - Westinghouse Steam Generator
Mechanical Test Program Summary
Tubesheet HEJ Tests - 3/4 Inch Tube Sleeves

a,c,e

[ ]

WPF1147A-4:1b/052793

a,c,e

[ ]

Figure 4-1
Tubesheet Sleeve Lower Joint Test Specimen

4.1.1.1 Acceptance Criteria - 3/4 Inch Tube HEJ Sleeve (FSG)

For push-out and pull-out tests, all joints shall exhibit loads for initial slip, where observable, or loads for start of non-linear load-deflection, above the 0 to 2200 lb. push/release effective axial loads that were applied during the fatigue tests. The leak rate criteria are based on typical Technical Specifications and Regulatory requirements. Table 4-2 shows the leak rate criteria for the FSGs and PSGs.

4.1.1.2 Results of Verification Tests - 3/4 Inch Tube HEJ Sleeves (FSG)

The test results for the HEJ (lower joint) specimens are presented in Table 4-3. For normal operating conditions, i.e., 1485 to 1600 psi at RT and 600°F, [

]^{a,c,e}

In the case of the fatigue testing, this number of cycles (30,000) represents the number of expected yearly cycles multiplied by a suitable factor to achieve an accelerated test condition. On that basis the test results provide data which are conservative in nature and exceed the actual operating conditions. The other parameters associated with the thermal cycle test, for example, such as temperature ramp, hold time and temperature gradient, are accelerated to achieve meaningful test results within an acceptable time frame. Consequently, the test results obtained and discussed are those of accelerated conditions designed to test the sleeve at the endurance limit. The results do not imply that after a specific length of operating time the sleeves will begin to leak. Rather they demonstrate that under extreme accelerated test conditions leakage is small or zero, providing assurance that in the actual operating case the sleeves will perform at a zero leakage base. Additionally, by using that same test series for all sleeve designs it is possible to measure consistency in process modification and/or small changes in the overall design to facilitate an assessment of the effect on total sleeve performance.

[

]^{a,c,e}

General Note: In the test portions of this report, the units of primary-to-secondary side differential pressures are listed simply as "psi," rather than "psid." The secondary side pressures were zero psig.

Table 4-2
Typical Bounding Maximum Allowable Leak Rates for Feedring - Type and Preheater Steam Generators

Condition	Plant	Allowable Leak Rate: Most Limiting Sleeved SG, gpm (gpd)			Allowable Leak Rate per Sleeve**
		Model D	Model E	FSG	

[ ] d,e

[ ] d,e

** Based on installation of 2000 tubesheet sleeves with non-welded lower joints - for plant.

The conclusions reached as a result of the test program are:

A consistent characteristic observed in the testing of mechanical joints is that the leakage, when observed, is generally higher at room temperature (RT) conditions. This characteristic has lead to the increased use of the room temperature hydrostatic test in process, tooling, personnel, procedure and demonstration phases.

For the lower joint, initial leak rates, both at room temperature and at 600°F, [

]^{a,c,e} As stated earlier in this report, if the FSGs or PSGs of individual plants require minor modifications to the qualified HEJ processes, due to environmental or other conditions, these needs will be addressed in the specific preparations for the repair project. Any additional qualifications will be documented separately. Note: Leak rate measurement is based on counting the number of drops leaking during a 10-20 minute period. Conversion to volumetric measure is based on assuming 19.8 drops per milliliter.

Thermal cycling between 120°F and 600°F, for the lower joint, had no detectable adverse influence on joint leak rate. The leak rate after testing remained at [ ]^{a,c,e}

Fatigue tests of the HEJ had no discernable adverse effect on joint leak resistance or structural integrity. [ ]^{a,c,e}

For push-out and pull-out tests, all joints tested exhibited loads for initial slip, where observable, or loads for start of non-linear load-deflection, above the effective axial loads that were applied during the fatigue tests.

The leak rates observed during a simulated steam line break test were well below the acceptance criteria.

The leak rates observed during a simulated LOCA remained at [
],^{a,c,e} which is far below the acceptance limit.

a,c,e

a,c,e

a,c,e

a,c,e

a,c,e

4.1.2 Case No. 2 - Feedring Steam Generator

The verification based on mechanical tests of the tubesheet lower joint (HEJ) previously performed for an FSG [also applies to the installation of these sleeves in these FSGs. The previous case involved a 0.631 inch OD (nominal) sleeve, of a bimetallic configuration, consisting of Alloy 690 as the base metal, of 0.034 inch nominal wall thickness, metallurgically joined to a thin outer layer of, approximately 0.0075 inch thickness, Alloy 625. Therefore, the composite wall thickness was nominally 0.0435 inch.][a,c,e] The test conditions are listed in Table 4-4.

4.1.2.1 Acceptance Criteria - 3/4 Inch HEJ Sleeve (FSG)

The acceptance criteria for these strength tests were the same as for those listed for Case No. 1. The leak rate criteria for these tests are also listed in Table 4-2.

4.1.1.2 Results of Verification Tests - 3/4 Inch Tube HEJ Sleeves (FSG)

From the test results obtained (Table 4-5), the following conclusions were reached:

a,c,e

a. [

b.

c.

d.]

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Table 4-4
Case No. 2 - FSG
Mechanical Test Program Summary
Tubesheet HEJ Tests - 3/4 Inch Tube Sleeves

a,c,e

Specimen No.	
VBL-1	
-2	
-3	
-4	
-5	
-6	
-7	
-8	
-9	
-10	
-11	
-12	
-13	
-14	
-15	
-16	
-17	
-18	
-19	
-20	

b,c,e

b,c,e

Specimen No.	
VBL-1	
-2	
-3	
-4	
-5	
-6	
-7	
-8	
-9	
-10	
-11	
-12	
-13	
-14	
-15	
-16	
-17	
-18	
-19	
-20	

Table 4-5 (Page 3 of 5)
Verification Test Results - Lower Joint (HEJ)
Alloy 690/625 Bimetallic Sleeve for 3/4 Inch Tube (FSG)

b,c,e

Specimen No.
VBL-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-20

Table 4-5 (Page 4 of 5)
Verification Test Results - Lower Joint (HEJ)
Alloy 690/625 Bimetallic Sleeve for 3/4 Inch Tube (FSG)

b,c,e

Specimen No.
VBL -1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-20

Table 4-5 (Page 5 of 5)
Verification Test Results - Lower Joint (HEJ)
Alloy 690/625 Bimetallic Sleeve for 3/4 Inch Tube (FSG)
(Notes to Table 4-5)

a,b,c,e

1. [
2.
3.
4.
5.
6.
7.
8.]

4.2 Tubesheet HEJ, Free Span and Tubesheet LWS Tests – 7/8 Inch Tube Sleeves

The same type of testing as shown for the 3/4 inch sleeve HEJs was performed for 7/8 inch nominal OD tube sleeves (Reference 1) and are applicable. The 7/8 inch sleeves were installed previously and are in successful operation. The 7/8 inch tube Westinghouse steam generators are very similar in design and manufacture to the FSGs and PSGs. Therefore, all of the 7/8 inch free span and tubesheet LWS testing, as well as the tubesheet HEJ testing, applies to the respective areas of the 3/4 inch sleeves of the FSGs and PSGs. All of the applicable results of the 7/8 inch sleeve testing are included here.

It has been pointed out earlier in this report that sleeve-to-tube welds are verified by analysis and that no laboratory testing is required. However, considerable weld testing was also performed for the previous, 7/8 inch sleeve program. The applicable results of that program are provided here as additional bases for the 3/4 inch sleeve weld. [

]^{a,c,e}

Because of the [

][a,c,e] As pointed out earlier in this report, if the sleeving of FSGs or PSGs requires minor modifications to the qualified HEJ processes due to environmental or other unique conditions and this entails testing, these needs and potential tests at RT conditions will be addressed and documented separately.

The test conditions summarized in Table 4-6 (specific test conditions displayed in data tables) may vary due to evolution of the testing process. Test parameters have also been modified slightly over time as more refined analysis of plant loading conditions are applied.

The generic, allowable, primary-to-secondary leak rates are listed in Table 4-2 and the results are provided in Tables 4-7 through 4-12. The test samples were fabricated per Figure 4-1.

Table 4-6
Mechanical Test Program Summary
Tubesheet HEJ Tests - 7/8 Inch Tube Sleeves

a,c,e

4.3 Acceptance Criteria - 7/8 Inch Tubesheet HEJ Sleeves

The leak rate criteria that have been established are based on typical Technical Specifications and Regulatory requirements. Table 4-2 shows the generic leak rate criteria for the Series 44 and 51 steam generators.

While the laser weld joint is hermetic and exhibits no leakage, in practice the lower joint of a tubesheet sleeve may be installed with or without a seal weld. In the case where a seal weld is not applied, the leakage characteristics must be evaluated. The values of the fabrication parameters of the HEJ are independent of the plan to weld or not to weld the sleeve.

[ ]^{a,c,e} indicate acceptable joint performance.

4.4 Results of Testing - 7/8 Inch Sleeves

4.4.1 HEJ Lower Joint

As discussed earlier, the joints are formed in unit cell collars. End caps are then installed on the collar and sleeve (Figure 4-1) to permit the samples to be pressurized. The end caps are threaded to permit tensile and compressive loading.

4.4.1.1 No Seal Weld

The test results for the Series 44 and 51 lower joint specimens are presented in Table 4-7. The specimens [

]^{a,c,e}

a,c,e

Table 4-7
Verification Test Results for HEJ Lower Joints - 7/8 Inch Sleeves

For the tests the following joint performance was noted:

Specimen MS-2: Initial leak rates at all pressures and at normal operating pressure following thermal cycling were [

]^{a,b,c,e}

Specimen MS-3: [

]^{a,b,c,e}

Specimen MS-7: [

]^{a,b,c,e}

4.4.1.2 Description of Additional Test Programs - HEJ Lower Joint With Exceptional Conditions and No Seal Weld

Additional test programs were performed to verify acceptable performance of the sleeve lower mechanical joint to accommodate exceptional conditions which may exist in the steam generator tubes and conditions which may be encountered during installation of sleeves.

These exceptional conditions in steam generator tube characteristics and sleeving operation process parameters included:

- shorter lengths of roller expanded lower tube joints
- shorter lengths of roller expanded lower sleeve joints

The specific exceptional tube conditions and changes to the sleeving process parameters tested in the first program, are shown in Table 4-8.

Each process operation and sequence of operations employed in fabricating each test sample was consistent with those specified for sleeves to be installed by field procedures. In addition, the exceptional tube conditions and changes to the sleeving process parameters described in Table 4-9 were included in the assembly of tube and collar subassemblies.

Table 4-8
Verification Test Results for HEJ Lower Joints with Exceptional Conditions for Tube and Sleeve - 7/8 Inch Sleeves

a,c,e

NOTES

1. The long sleeve end of RT 3 buckled prematurely during the room temperature compression test. Sleeve lengths for all subsequent sleeves were shortened.
2. The weld between the sleeve and the test end cap of RT 2 failed prematurely.

Table 4-9
Additional Verification Test Results for HEJ Lower Joints with Exceptional Conditions for Tube and Sleeve - 7/8 Inch Sleeves

a,c,e

4.4.1.3 Lower Joint Testing with Seal Weld

Nine specimens were fabricated in collars with laser seal welds added to the sleeve end at the elevation of the tubesheet clad. They were then subjected to the fatigue, thermal cycling, compressive, and tensile test as defined in Table 4-6. The results of this testing are summarized in Table 4-10. [

]a,c,e

4.4.2 Free Span Joint Mechanical Testing

Free span joints are representative of the tubesheet sleeve upper joint and both joints of the tube support sleeves. This joint configuration, where there is no tubesheet backing the tube, is simulated using a test specimen as shown in Figure 4-2.

Eleven free span weld specimens were fabricated using representative field parameters. All specimens were then stress relieved to account for the mechanical property effects resulting from thermal treatment. All free span test specimens were given a stress relief heat treatment in the range of [

]a,c,e The temperature source was a radiant heater installed inside the sleeve which was centered on the weld. The maximum temperature attained by the tube was measured by thermocouple attached to the tube outer surface and summarized in Table 4-11. The temperature was ramped up [

]a,c,e Following stress relief the thermocouple attachments were filed off.

4.4.2.1 Free Span Joint Test Results

The welds were subjected to leak testing [

]a,c,e

Two welds were metallurgically examined following fatigue testing (L-552 and L-555). Based on this examination [

]a,c,e

Compressive test specimens L-540 and L-543 were examined following testing and [

]a,c,e under design loading conditions.

4.4.2.2 Impact of Tube Fixity on Free Span Weld Performance

Under certain conditions tubes may become locked to the support plate structure of the steam generator, normally during operation at full temperature (approximately 600°F). Upon cool down, differential

thermal expansion rates between the sleeve and steam generator structure can impact tensile loads on the tube. [ ]a,c,e

[ ]a,c,e

4.4.2.3 Results of Fixed Tube Free Span Welding

[ ]a,c,e

[ ]a,c,e

a,c,e

[ ]

Figure 4-2
Free Span Laser Weld Joint Test Specimen

Table 4-10
HEJ Lower Joint Test Results (with Seal Weld) - 7/8 Inch Sleeves

a,c,e

Specimen Number	
M1	
M2	
M3	
M4	
M5	
M6	
M7	
M8	
M9	

(Leak rate in drops per minute)

a,c,e

SPECIMEN NUMBER	COMPRESSIVE LOAD (lbs.)	TENSILE LOAD (lbs.)
M1		
M2		
M4		
M6		
M7		
M9		

Table 4-11
Free Span Joint Maximum Stress Relief Temperature - 7/8 Inch Sleeves

Specimen Number	Maximum Temperature (°F) a,c,e
L-536	
L-540	
L-543	
L-544	
L-546	
L-548	
L-550	
L-551	
L-552	
L-555	

Table 4-12
Free Span Joint Leak Rate and Loading Data - 7/8 Inch Sleeves

a,c,e

Specimen Number
L-536
L-540
L-543
L-544
L-546
L-548
L-550
L-551
L-552
L-55

Leak rate is in drops per minute.

4.5 References

1. WCAP-13088, Rev. 1, "Westinghouse Series 44 and 51 Steam Generator Sleeving Report (Laser Welded Sleeves)," 1/93 (Westinghouse Proprietary Class 2)

5.0 STRESS CORROSION TESTING OF LASER WELDED SLEEVE JOINTS

The material used for sleeving, Alloy 690 TT (thermally treated), has been demonstrated to be highly resistant to intergranular stress corrosion cracking (IGSCC) under steam generator conditions (Reference 1). The resistance of the laser welded sleeve joint to in-service corrosion is directly related to the resistance of the Alloy 600 tubing to intergranular corrosion cracking. Stresses in the tubing, either service operating stresses or residual stresses, are a major factor in determining the response of the material in terms of IGSCC. Two potential sources of residual stresses in the laser welded sleeving process include a) minor stresses related to hydraulic expansion during sleeve placement and b) residual stresses that may be introduced as a result of welding.

This section summarizes the results of a testing program to evaluate the resistance of laser sleeve weldments in steam generator tubing to primary water stress corrosion (PWSCC). The testing was conducted under conditions which accelerate corrosion in steam generator materials that may be susceptible to stress corrosion cracking during long term steam generator service. The laser welding processes used to fabricate the samples for these tests are representative of the neodymium pulsed YAG (Nd:YAG) laser currently used for sleeve welding and the CO_2 laser previously used in a field sleeve welding application.

5.1 Corrosion Test Description

An accelerated corrosion test developed by Westinghouse is used as a means to evaluate the resistance of steam generator materials to degradation in steam generator primary water environments. The test produces the intergranular stress corrosion cracking type degradation that has been observed in some mill annealed Alloy 600 steam generator tubing, but in a reduced time period. The test has also been found to provide the same relative ranking of heats of tubing material in terms of resistance to IGSCC that has been observed in service.

The accelerated test is conducted in an autoclave operating at 750°F (400°C) with steam at 3000 psig. The steam contains [ ]a,c,e with each ion at 30 ppm as a sodium salt. The ID of the specimen is exposed to the 3000 psi doped steam while the OD sees undoped steam at 1500 psi.

The configuration of the laser welded specimens used in the corrosion testing of a free-span upper joint as illustrated in Figure 5-1. The sleeve joints were fabricated using equipment and practices representative of field sleeving operations. The doped steam test environment is introduced to the inside of the sleeve and has access to the ID of the sleeve, one side of the weld joint, and to the OD of the sleeve and the ID of the tube on the same side of the weld joint. The other side of the weld joint and the OD of the tube are exposed to the 1500 psi, undoped steam environment. The 1500 psi differential across the tube wall simulates the active loading that is present in operating steam generators. In this way it is possible to test the weld under stress conditions representative of those in the generator.

The configuration of the lower tubesheet sleeve weld joint is illustrated in Figure 5-2. As in the case of the free span weld corrosion test, the doped steam environment is introduced to the ID of the sleeve and has access to the one side of the weld. The OD of the tube is exposed to the undoped steam.

The corrosion performance of the sleeve weld joint is compared with that of tube roll transitions exposed to the same test environment. The roll transition control samples illustrated in Figure 5-3 are representative of the transitions found at the top of the tubesheet in full depth, hard rolled steam generator tubes. The inclusion of the potentially PWSCC susceptible configuration (the roll transition) in the test provides verification of the aggressiveness of the corrosion test environment. Any variability in the aggressiveness of the environment from one autoclave run to another is accounted for by having roll transition controls in each run.

The time for a corrosion crack to progress through the tube wall of the test sample is measured in the accelerated corrosion test. For both roll transitions and sleeve welds, a through wall crack will result in a decrease in the 1500 psi differential (3000 psi ID, 1500 psi OD). The time at which the differential pressure changes is recorded as the time to sample failure.

5.2 Corrosion Resistance of Free-Span Laser Welded Joints - As Welded Condition

Corrosion tests have been performed on laser welded sleeve joints fabricated by the CO_2 laser process and by the pulsed Nd:YAG laser process. They are both included in this discussion because there are similarities in the corrosion resistance of the joints fabricated by these laser welding methods.

Most of the welded joint corrosion samples and roll transition sections were fabricated from mill annealed Alloy 600 tubing from Heats NX-1019 and NX-7368. These are high carbon heats (0.04 per cent C) which previous testing has shown to be sensitive to PWSCC, and which have been used in a variety of corrosion test programs over the past several years. A set of CO_2 laser welded samples was also fabricated from a lower carbon (0.02 per cent C) mill annealed Alloy 600 tubing, Heat NX-9621, which has exhibited susceptibility to PWSCC. The lower carbon heat was included to determine if the carbon difference produced adverse metallurgical changes during welding. [

]a,c,e

[

]a,c,e

[

]a,c,e

The response of laser welded joints to the accelerated corrosion conditions is shown in Figures 5-5 and 5-6 for CO_2 welds and in Table 5-1 and Figure 5-7 for Nd:YAG laser welds. These figures are log-normal distribution plots of the cumulative percentage of samples exhibiting cracking as a function of time. The as-welded joints generally exhibited times for through wall IGSCC in [

]a,c than that of the roll transitions. One tubing heat, NX-2721, exhibited about [ ]a,c for cracking for the roll transition and the as-welded joints. [

]a,c,e

[

]a,c,e

5.3 Corrosion Resistance of Free-Span Laser Welded Joints - With Post Weld Stress Relief

Because stress corrosion cracking is dependent to a large extent on residual stresses, a reduction in the residual stress level in the laser sleeve weldments will enhance the corrosion resistance of the welded joint. During the CO_2 laser weld program, extensive development of a post weld stress relief heat treatment was conducted. A local stress relief treatment [ ]a,c,e was developed. The stress relief parameters developed, [ ]a,c,e, reduce the residual stresses significantly without significant microstructural changes.

The effectiveness of a stress relief treatment is evident in Figure 5-5 where a minimum [ ]a,c,e in the time to cracking in heat treated welds over as-fabricated welds can be seen. The beneficial effect of stress relief is also evident in the Nd:YAG laser welds (see Figure 5-7) made with both CLW and CMP parameters. The test of stress relieved CLW and CMP parameter weld joints [

]a,c This indicates more than a ten fold increase in time to cracking compared to that of an as-welded joint. The effect of the stress relief can also be seen in the cross section of the heat treated CLW weldment shown in Figure 5-8. Only minor IGSCC [

]a,c corrosion test. This suggests a decrease in the cracking rate of stress relieved joints to [

]a,c as-welded joints. In addition, there was no evidence of the minor corrosion at the weld surface that was noted previously for an as-welded corrosion test sample.

5.4 Corrosion Resistance Evaluation of Lower Tubesheet Sleeve Laser Welded Joints

Post weld stress relief heat treatment is [

]^{a,c} Accelerated corrosion testing was performed on specimens representative of the as-fabricated lower tubesheet sleeve joint for 0.875 inch diameter tubing, with the sample configuration shown in Figure 5-2. For control purposes, tube roll transition specimens were included in the corrosion tests as reference standards.

The specimens were subjected to the steam test conditions described in Section 5.1 for a [

]^{a,c} The corrosion test results, tabulated in Table 5-2, show that the roll transition samples [ ]^{a,c} with previous tests of roll transition samples. One of the welded sleeve samples, sample CTLSR-01, [

]^{a,c}

[

]^{a,c}

5.5 Effects of Sleeving on Tube-to-Tubesheet Weld

5.5.1 Lower HEJ Joint

The effect of hard rolling the sleeve over the tube-to-tubesheet weld was examined in the sleeving of 0.750 inch OD tubes. Evaluation of the 0.750 inch tubes showed no tearing or other degrading effects on the weld after hard rolling.

5.5.2 Lower Seal Weld

[

]^{a,c,e}

5.6 Outside Diameter Surface Condition

Because the sleeving operation is conducted from the primary side, no operations are conducted on the tubing OD surface. In operational steam generators, the outside surfaces of the tubes can collect boiler water deposits and scales. These are typically oxides or minerals in the thermodynamically stable form of the constituent elements, magnetite being the most prominent deposit. At the temperatures of the tubing OD during the sleeve weldings and thermal treatment, these compounds are typically stable and do not thermally decompose. All such compounds have molecular structures that are too large for diffusion into the lattice of the Alloy 600 tubing. Reactions between these stable oxides and minerals and the alloying elements of the Alloy 600 tubing are thermodynamically unfavorable. Consequently the presence of boiler sludge/scale species on the OD surfaces of tubes that receive the temperatures associated with LWS is not expected to produce deleterious tube-sludge/scale interactions.

Three tests performed as a part of the development of a sleeve brazing technique, also support the preceding discussions. The first test involved a laboratory evaluation in which a braze cycle was applied to tubing in contact with simulated plant sludge. The braze cycle involved [

][a,c]. Bend tests of longitudinal sections removed from the brazed area showed no embrittlement as a result of the thermal cycle or exposure to the sludge stimulant. A second test involved microprobe analyses of polished metallographic cross sections. Results indicated the presence of Fe, Ni, Cr, Cu and Zn on the tube OD surface, but no evidence was found of diffusion into the tubing. A third test involved removal of a tube from an operating plant which was brazed in the region of sludge. The pulled tube was analyzed for the presence of contaminants on the OD surface and beneath the OD surface. The microprobe analysis detected Fe, P, Si, Cu, Ca and Na on the tube OD, but there was no indication of diffusion into the tube.

In addition to the above tests, archive tubes from two plants were welded and a microanalytical examination was made for contaminant ingress before and after welding. Before welding, [

][a,c].

A final test involved metallographic observations of three areas on a U-bend of Alloy 600 tubing which was coated with sludge and heat treated in air [

][a,b]

To summarize, several observations have been made for a variety of Alloy 600 samples heated to temperatures from [ ][a,c] in the presence of typical secondary side chemical species. No significant diffusion, corrosion, or embrittlement of the tubing has been found.

a,c,e

[ ]

Figure 5-1

Accelerated Corrosion Test Specimen for Welded Joint Configuration

a,c,e

Figure 5-2

Accelerated Corrosion Test Specimen for Lower Tubesheet Sleeve Welded Joint Configuration

a,c,e

Figure 5-3

Accelerated Corrosion Test Specimen for Roll Transition Configuration

a,c,e

Figure 5-4

IGSCC in Alloy 600 Tube of YAG Laser Welded Sleeve Joint After 109 Hours in 750°F Steam Accelerated Corrosion Test

a,c,e

Figure 5-5

Cumulative Per Cent Cracking for CO_2 Laser Welded Sleeves in 750°F Accelerated Steam Corrosion Test

a,c,e

Figure 5-6

Cumulative Per Cent Cracking for CO_2 Laser Welded Sleeves in 750°F Accelerated Steam Corrosion Test

Table 5-1
Summary of Accelerated 750°F Steam Corrosion Test Results for YAG Laser Sleeve Welds

a,c,e

a,c,e

Figure 5-7

Cumulative Per Cent Cracking for YAG Laser Welded Sleeves in 750°F Accelerated Steam Corrosion Test

a,c,e

Figure 5-8
Minor IGSCC in Alloy 600 Tube of Stress Relieved YAG Laser Welded Sleeve Joint after 1000 Hours in 750°F Steam Accelerated Corrosion Test

Table 5-2

Corrosion Resistance Evaluation of Lower Tubesheet Laser Welded Sleeve Joints

Mockup: Alloy 600 MA (Heat 7368, 0.875 in. OD) tube, mechanically expanded into steel collar

Sleeve: Alloy 690TT

a,c,e

[ ]

a,b,c

Figure 5-9

Illustration of Path of IGSCC in the Alloy 600 Tube of Lower Tubesheet Sleeve Welded Joint. Crack Initiated at Point A and Progressed to Point B

5.7 References

1. "Alloy 690 for Steam Generator Tubing Applications," EPRI Report NP-6997-SD, Final Report for Program S408-6, October 1990.

6.0 INSTALLATION PROCESS DESCRIPTION

The following description of the sleeving process pertains to current processes used. Westinghouse continues to enhance the tooling and processes through development programs. As enhanced techniques are developed and verified they will be utilized. Use of enhanced techniques which do not materially affect the technical justification presented in this report are considered to be acceptable for application. Section XI, Article IWB-4330 (Reference 1), of the ASME Code is used as a guideline to determine which variables require requalification.

The installation processes described in this section were developed and used for the installation of 7/8 inch sleeves. In the cases where sleeve/tube configuration diameters would require it, the corresponding processes will be requalified for the 3/4 inch sleeves.

The sleeves are fabricated under controlled conditions, serialized, cleaned, and inspected. They are typically placed in polyethylene sleeves, and packaged in protective styrofoam trays inside wood boxes. Upon receipt at the site, the boxed sleeves are stored in a controlled area outside containment and as required moved to a low radiation, controlled region inside containment. Here the sealed sleeve box is opened and the sleeve removed, inspected and placed in a protective sleeve carrying case for transport to the steam generator platform. The sleeve packaging specification is extremely stringent and, if unopened, the sleeve package is suitable for long term storage.

Sleeve installation consists of a series of steps starting with tube end preparation (if necessary) and progressing through tube cleaning, sleeve insertion, hydraulic expansion at both the lower and upper joint, hard rolling the lower tubesheet joint locations, welding the upper joint [ ]^{a,c,e}, visual inspection and eddy current inspection. The sleeving sequence and process are outlined in Table 6-1. These steps are described in the following sections. More information on the currently used equipment can be obtained from References 2, 3, and 4.

6.1 Tube Preparation

There are two steps involved in preparing the steam generator tubes for the sleeving operation. These consist of rolling at the tube mouth and tube cleaning. Tube end rolling is performed only if necessary to insert a sleeve.

6.1.1 Tube End Rolling (Contingency)

If gaging or inspection of tube inside diameter measurements indicate a need for tube end rolling to provide a uniform tube opening for sleeve insertion, a light mechanical rolling operation will be performed. This is sufficient to prepare the mouth of the tube for sleeve insertion without adversely affecting the original expanded tube or the tube-to-tubesheet weld. Tube end rolling will be performed only as a contingency.

Testing of the rolling of all three of the types of tube welds, i.e., tube OD weld (for the protruding tube joint), recessed and flush, has been performed and has been confirmed to be acceptable based on mechanical considerations. Westinghouse has performed tube end rolling of all of these types of tube welds in the field.

6.1.2 Tube Cleaning

The sleeving process includes cleaning the inside diameter area of tubes to be sleeved to prepare the tube surface for the upper and lower joint formation by removing boric acid, frangible oxides and foreign material. Evaluation has demonstrated that this process does not remove any significant fraction of the tube wall base material. Cleaning also reduces the radiation shine from the tube inside diameter, thus contributing to reducing man-rem exposure.

The interior surface of each candidate tube will be cleaned by a [

]^{a,c,e} The hone brush is mounted on a flexible drive shaft that is driven by an pneumatic motor and carries reactor grade deionized flushing water to the hone brush. The hone brush is driven to a predetermined height in the tube that is greater than the sleeve length in order to adequately clean the joint area. [

]^{a,c,e} The Tube 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 end and contain the spent flushing water. A flexible conduit is attached to the guide tube and connects to the tube cleaning unit on the steam generator platform. The conduit acts as a closed loop 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 which routes the water to the radioactive waste drain.

Currently tube cleaning is required as part of the sleeve installation process. However, test programs are planned to evaluate the necessity of this process step. Should subsequent testing indicate acceptable weld results without it, as judged by weld performance meeting the mechanical, leakage inspection criteria defined in this document, honing may be dropped from the installation sequence. To implement welding without honing, the weld would be requalified and a "no-hone" weld process specification prepared.

6.2 Sleeve Insertion and Expansion

When all the candidate tubes have been cleaned, the tube cleaning end effector will be removed from the tool delivery robot and the Select and Locate End Effector (SALEE) will be installed. The SALEE consists of two pneumatic camlocks, dual pneumatic gripper assemblies, a pneumatic translation cylinder, a motorized drive assembly, and a sleeve delivery conduit.

Table 6-1

Sleeve Process Sequence Summary

TUBE PREPARATION	1)	Light Mechanical Roll Tube Ends (if necessary)
	2)	Clean Tube Inside Surface
SLEEVE INSERTION	3)	Insert Sleeve/Expansion Mandrel Assembly
	4)	Hydraulically Expand Sleeve Top and Bottom Joints
TUBESHEET LOWER JOINT FORMATION	5)	Roll Expand Tubesheet Lower Sleeve End
WELD OPERATION	6)	Weld Upper and Lower Support Sleeve Joints
	7)	Weld Upper Tubesheet Sleeve Joints [ ]a,c
INSPECTION	8)	Visually Inspect Lower Tubesheet Sleeve Weld (if performed)
	9)	Ultrasonically Inspect Sleeve Welds (Free span welds only on a sample plan)
STRESS RELIEF	10)	Post Weld Stress Relief Sleeve Welds [ ]a,c
INSPECTION	11)	Baseline Eddy Current Sleeves

The tool delivery robot draws the SALEE through the manway into the channel head. It then positions the SALEE to receive a sleeve, tilting the tool such that the bottom of the tool points toward the manway and the sleeve delivery conduit provides linear access. At this point, the platform worker pushes a sleeve/mandrel assembly through the conduit until it is able to be gripped by the translating upper gripper.

The tool delivery robot then moves the SALEE to the candidate tube. Camlocks are then inserted into nearby tubes and pressurized to secure the SALEE to the tubesheet.

Insertion of the sleeve/mandrel assembly into the candidate tube is accomplished by a combination of SALEE's translating gripper assembly and the motorized drive assembly which pushes the sleeve to the desired axial elevation. For tube support sleeves, the support is found by using an eddy current coil which is an integral part of the expansion mandrel. The sleeve is positioned by using the grippers and translating cylinder to pull the sleeve into position to bridge the tube support. For tubesheet sleeves, the sleeve is positioned by use of a positive stop on the delivery system.

At this point, the sleeve is hydraulically expanded. The bladder style hydraulic expansion mandrel is connected to the high pressure fluid source, the Lightweight Expansion Unit (LEU), via high pressure flexible stainless tubing. The Lightweight Expansion Unit is controlled by the Sleeve/Tube Expansion Controller (S/TEC), a microprocessor controlled expansion box which is an expansion control system previously proven in various sleeving programs. The S/TEC activates, monitors, and terminates the tube expansion process when proper expansion has been achieved.

The one step process hydraulically expands both the lower and upper expansion zones simultaneously. The computer controlled expansion system automatically applies the proper controlled pressure depending upon the respective yield strengths and diametrical clearance between the tube and sleeve. The contact forces between the sleeve and tube due to the initial hydraulic expansion are sufficient to keep the sleeve from moving during subsequent operations. At the end of the cycle, the control computer provides an indication to the operator that the expansion cycle has been properly completed.

When the expansion is complete, the mandrel is removed from the expanded sleeve by reversing the above insertion sequence. The SALEE is then repositioned to receive another sleeve/mandrel assembly.

6.3 HEJ Lower Joint (Tubesheet Sleeves)

In the tubesheet, the sleeve is joined to the tube by a hard roll (following the hydraulic expansion) performed with a roll expander [

]^{a,c,e} Control of the mechanical expansion is maintained through [

]^{a,c,e}

6.4 General Description of Laser Weld Operation

Welding of the upper tubesheet sleeve joint and the upper and lower tube support sleeve joints will be 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 SALEE (described earlier) and an eddy current coil located on the weld head. At the initiation of welding operations, the shielding gas and laser beam are delivered to the welding head. During the welding process the head is rotated around the inside of the tube to produce the weld. A motor, gear train, and encoder provide the controlled rotary motion to deliver a 360 degree weld around the sleeve circumference.

The welding parameters, qualified to the rules of the ASME code, are computer controlled at the weld operators station. The essential variables per Code Case N-395 are monitored and documented for field weld acceptance.

6.5 Rewelding

Under some conditions, the initial attempt at making a laser weld may be interrupted before completion. Also, the ultrasonic test (UT) examination of a completed initial weld may be indeterminate resulting in the weld being rejected. In these cases, an additional weld, having the same nominal characteristics as the initial weld, will be made close to and either inboard or outboard of the initial weld. If the sleeve/tube has not been perforated by the interrupted weld, an additional weld, having the same nominal characteristics as the original weld, will be made in the expansion zone near the original weld either inboard or outboard of this initial wall. If a perforation of the sleeve is suspected in the initial weld area, the repair weld will be located inboard of the initial weld. Otherwise, the repair weld will be located outboard of the initial weld. If the sleeve/tube were perforated during interruption of the initial weld, the tube would be removed from service.

6.6 Post-Weld Heat Treatment [ ]a,c

6.6.1 Post-Weld Heat Treatment Tooling

The tooling required to perform the stress relief process consists of four basic items:

a. A fiber optic probe
b. A heater (production) probe
c. A pop-up end effector
d. A production and effector

The fiber optic probe is used in conjunction with the pop-up end effector. The end effector places a probe within the proper zone to perform the stress relief operation. [

]a,d This is done by using the ROSA robotic arm and the SALEE to sequentially place production probes at the proper welded sleeve/tube interfaces, including reweld locations, followed by application of the stress relief process.

6.6.2 Post Weld Heat Treat Process

The laser welded joints (LWJ) exhibit [

]b,c

Westinghouse has extensive experience in stress relief processes from prior work on U-Bend and support plate heat treat programs. The objective of the laser weld post-weld heat treatment is to relieve residual stresses in the sleeve/tube that may be introduced by application of the welding process. The length of sleeve/tube heat treatment spans the weld and the adjacent heat affected zone.

To satisfactorily relieve the residual stresses, it was necessary to develop the optimal heat up, soak, and ramp down power cycles. Several physical factors affect the control of tube temperature within the required temperature band:

1. The tube is predominantly cooled by radiation, with minor effects of conduction and convection.

2. The physical configuration (power density) of the heat source affects heat distribution within the tube.

3. The heat source and the heated portion of the tube cannot be excessively long. Under certain boundary conditions of tube fixity, excessive compressive stresses can occur within the tube during heat treatment. This could result in bowing or barreling of the tube.

4. The process has to account for weld axial positional tolerances as well as heater axial positional tolerances.

To address these factors, the heat source was sized such that it heated the weld and heat affected zone with sufficient margin to allow for axial position variations.

Given the heat source, laboratory tests were performed which addressed the following issues:

a. Nominal heat source power.

b. Initial heat source power profile to expedite the time required to achieve acceptable tube temperatures.

c. Acceptable soak powers and temperatures.

d. Effect of varying tube emissivities.

e. Effect of a misplaced heater.

f. Circumferential tube temperature profile.

g. Axial tube temperature profile.

h. Sleeve to tube temperature gradient.

The stress relief process was verified through extensive mockup testing. The test mockup shown in Figure 6-2 was used for stress relief process testing. The initial sleeve/tube samples are shown in Figure 6-3. [

]a,c

The sleeve/tube samples used for final process development were prototypic of the field sleeve/tube joint configuration, shown in Figure 6-4. The weld centerline was positioned [

]a,c,e

[

]a,c

The results of the above laboratory testing led to a typical power profile as shown in Figure 6-5. This figure represents a typical profile, for a tube with a particular emissivity. [

]a,c,e

a,c,e

Figure 6-1

Laser Welded Sleeve with Reweld

a,c,e

Figure 6-2

Vertical Test Stand Mock-Up

a,c,e

Figure 6-3

Initial Stress Relief Test Samples Detailed

a,c,e

Figure 6-4

Field Prototypic Stress Relief Test Samples Detailed

a,c,e

Figure 6-5

Typical Stress Relief Power Profile

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.

If it is necessary to remove a sleeved tube from service as judged by an evaluation of a specific sleeve/tube configuration, tooling and processes are available to plug the tube.

6.8 References

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

2. Boone, P. J., "ROSA III, A Third Generation Steam Generator Service Robot Targeted at Reducing Steam Generator Maintenance Exposure," CSNI/UNIPEDE Specialists Meeting on Operating Experience with Steam Generator, paper 6.7, Brussels, Belgium, September 1991.

3. Wagner, T. R., VanHulle, L., "Development of a Steam Generator Sleeving System Using Fiber Optic Transmission of Laser Light," CSNI/UNIPEDE Specialists Meeting on Operating Experience with Steam Generators, paper 8.6, Brussels, Belgium, September 1991.

4. Wagner, T. R., "Laser Welded Sleeving in Steam Generators," AWS/EPRI Seminar, Paper IID, Orlando, Florida, December 1991.

7.0 NDE INSPECTABILITY

The welding parameters are computer controlled at the weld operator's station. The essential variables, per ASME Code Case N-395, are monitored and documented to produce repeatability of the weld process. In addition, two non-destructive examination (NDE) capabilities have been developed to evaluate the success of the sleeving process. One method is used to confirm that the laser welds meet critical process dimensions and acceptable weld quality. The second method is then applied to establish the necessary baseline data to facilitate subsequent routine in-service inspection capability.

The installation processes described in this section were developed and used for the installation of 7/8 inch sleeves. In the cases where sleeve/tube configuration diameters require it, the corresponding processes will be requalified for the 3/4 inch sleeves.

7.1 Inspection Plan Logic

The basic tubesheet sleeve inspection plan shall consist of:

A. Eddy Current Examination (Section 7.3) [ ]d

1. Demonstrate presence of upper and lower hydraulic expansions
2. Demonstrate lower roll joint presence
3. Determine location of upper weld
4. Record baseline of entire sleeved tube for future inspections

B. Ultrasonic Inspection (Section 7.2) [ ]d or alternate methods (Section 7.4).

1. Demonstrate quality of upper weld
2. Determine width of the upper weld

C. Visual Inspection [ ]d

1. Exhibit presence and full circumference continuity of lower weld, if seal weld option selected

D. Weld Process Control [ ]d

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

The basic tube support sleeve inspection of the sleeved tubes shall consist of:

A. Eddy Current Examination (Section 7.3) [ ]a

1. Demonstrate presence of upper and lower hydraulic expansions
2. Determine location of upper weld and lower welds
3. Record baseline of entire sleeved tube for future inspections

B. Ultrasonic Inspection (Section 7.2) [ ]d or alternate methods (Section 7.4)

1. Determine quality of the upper and lower welds
2. Determine if minimum width requirement of the upper and lower welds is met.

C. Weld Process Control [ ]d

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

7.2 General Process Overview of Ultrasonic Examination

The ultrasonic inspection process is based on further refinements of past well-known and field-proven techniques used on brazed and CO_2 laser welded sleeves installed by Westinghouse.

The inspection process developed for application to the laser welds uses the transmission of ultrasound to the interface region (i.e., the sleeve OD/tube ID boundary) and analyzing the amount of reflected energy from that region. An acceptable weld joint should present no acoustic reflections above a calibrated limit at the weld interface, but produce reflection from the tube OD that is above a calibrated limit.

Appropriate transducer, instrumentation and delivery systems have been designed and techniques established to demonstrate detectability and resolution of relevant defects at the interface. [

]a,c,e

7.2.1 Principle of Operation and Data Processing of Ultrasonic Examination

The ultrasonic inspection of a laser weld is schematically outlined in Figure 7-1. An ultrasonic wave is launched by the application of a pulse to a piezoelectric transducer. The wave propagates in the couplant

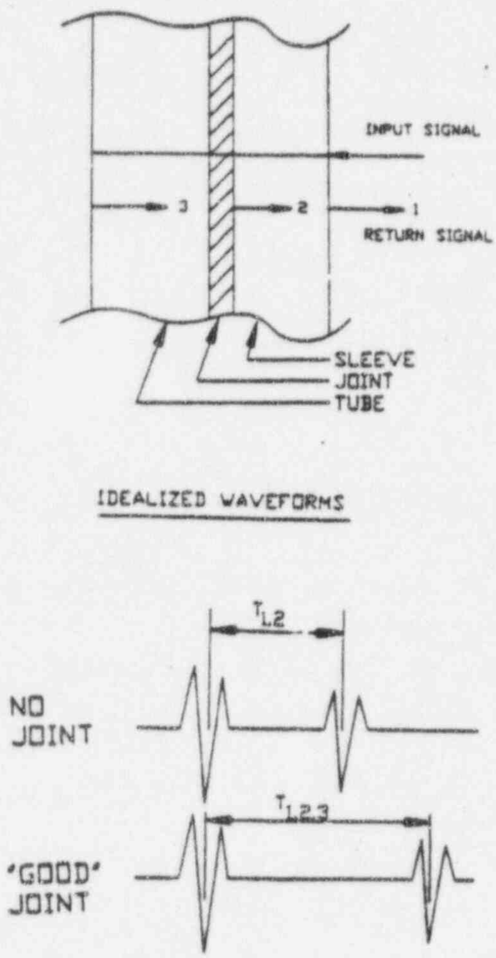

Figure 7-1

Ultrasonic Inspection of Welded Sleeve Joint

medium (water) until it strikes the sleeve. Ultrasonic energy is both transmitted and reflected at the boundary. The reflected wave returns to the transducer where it is converted back to an electrical signal, which is amplified and displayed on a UT instrument oscilloscope.

The transmitted [

]^{a,c,e}

The condition of [

]^{a,c,e}

An automated system is used for digitizing and storing the UT wave forms [

]^{a,c,e}

7.2.2 Ultrasonic Inspection Equipment and Tooling

The probe system is delivered by the Westinghouse ROSA zero entry system. The various subsystems include the water couplant, UT, motor drives, electrical systems and data display/storage.

The probe motion is accomplished via rotary and axial drive modules which allow a range of speeds and axial advance per 360° scan of the transducer head. The axial advance allows for overlap providing a high degree of overlapping coverage without sacrificing resolution or sensitivity.

The controls and displays are designed for trailer mounting outside containment. The system also provides for easy periodic calibration of the UT subsystem on the steam generator platform.

a,c

Figure 7-2

Typical Digitized UT Waveform

The permanent record of the inspection is a color plot C-scan derived from the digitized and stored A-Scan waveforms. Figure 7-3 is an example of an acceptable laser weld C-scan. The UT instrument is used with the gate modules synchronized to the front wall (sleeve I.D.) signal. [

]a,c,e

7.2.3 Laser Weld Test Sample Results

Ultrasonic test process criteria are developed by UT examination and subsequent destructive analysis of sleeve weld samples. Process criteria are qualified by generating a variety of weld samples, some of which are modified to assure marginal and rejectable structural conditions. The samples are ultrasonically examined, and the UT acceptance criteria are applied. No structurally unacceptable welds may be accepted for the process/criteria to be qualified.

Once qualified, the process requires a setup standard for calibration prior to weld examination.

The standard consists of a machined Alloy 690 thick-walled tube with the following reference reflectors (Figure 7-4):

- Tube ID machined to expaneded sleeve ID dimension.

- Tube OD machined to expanded sleeve OD dimension.

- Tube OD machined to parent tube OD.

- Simulated weld with minimum weld width allowable per structural criteria.

- OD Flat bottomed hole with bottom at sleeve/tube interface dimension.

A plot of the setup standard scan is shown in Figure 7-5. (This figure depicts the UT setup standard for the 7/8 inch sleeve; a corresponding standard will be made for the 3/4 inch sleeve.) The plot shows the sleeve backwall reflection (gate 1) C-scan, the tube backwall reflection (gate 2) C-scan, and axial and circumferential section B-scans. A combined scan showing a logical combination of the gate 1 and gate 2 conditions as they relate to pre-determined thresholds is also available. A signal above the threshold in gate 2 while gate 1 is below threshold indicates a region of weld.

7.2.4 Ultrasonic Inspection Summary

The UT laser weld inspection system can confirm that there is a metallurgical bond between the sleeve and the tube. The system is used to determine any existence of leak path across the weld and a minimum acceptable weld width for 360 degrees around the circumference.

a,c

[ ]

Figure 7-3

C-Scan from UT Examination of an Acceptable Laser Weld

a,c,e

Figure 7-4

UT Setup Standard

a,c

[ ]

Figure 7-5

C-Scan from UT Examination of Equipment Setup Standard

a,c

Figure 7-6

C-Scan from UT Examination of Workmanship Sample of a Laser Welded Sleeve with Two EDM Notches

7.3 Eddy Current Inspection

Upon conclusion of the sleeve installation process, a final eddy current inspection is performed on every installed sleeve to provide interpretable baseline data on the sleeve and tube. This information is gathered by an eddy current process which utilizes a double cross wound coil. The double crosswound coil is designed to minimize the effects of geometry and weld zone changes that are 360° in nature, i.e.: upper and lower hydraulic expansion transition areas, roll expansion transition areas, top of sleeve, the band of good weld material, etc.

7.3.1 Eddy Current Inspection Principle of Operation

The eddy current inspection equipment, techniques, and results presented herein apply to the proposed Westinghouse sleeving process. Eddy current inspections are routinely carried out on the steam generators in accordance with the Plant Technical Specifications. The purpose of these inspections is to detect at an early state tube degradation that may have occurred during plant operation so that corrective action can be taken to minimize further degradation and reduce the potential for significant primary-to-secondary leakage.

The standard inspection procedure involves the use of a bobbin eddy current probe, with two circumferentially wound coils which are displaced axially along the probe body. The coils are connected in the so-called differential mode; that is, the system responds only when there is a difference in the properties of the material surrounding the two coils. The coils are excited by using an eddy current instrument that displays changes in the material surrounding the coils by measuring the electrical impedance of the coils. Presently, this involves simultaneous excitations of the coils with several different test frequencies.

The outputs of the various frequencies are combined and recorded. The combined data yield an output in which signals resulting from conditions that do not affect the integrity of the tube are reduced. By reducing unwanted signals, improved inspectability of the tubing results (i.e., a higher signal-to-noise ratio). Regions in the steam generator such as the tube support plate, tubesheet laser weld area and sleeve transition zones are examples of areas where multifrequency processing has proven valuable in providing improved inspectability.

After sleeve installation all sleeved tubes are subjected to an eddy current inspection which includes a verification of correct sleeve installation for process control, degradation inspection and establishing a baseline for all subsequent inspection comparison.

There are a number of probe configurations that lend themselves to enhancing the inspection of the sleeve/tube assembly in the regions of laser weld as well as configuration transitions. The crosswound coil probe has been selected since it provides an advancement in the state-of-the-art over the conventional bobbin coil probe, yet retains the simplicity of the inspection procedure.

The inspection for degradation of the sleeve/tube assembly has typically been performed using crosswound coil probes operated with multifrequency excitation. For the weld free straight length regions of the sleeve/tube assembly, the inspection of the sleeve and tube is consistent with normal tubing inspections. In sleeve/tube assembly joint regions, data evaluation becomes more complex. The results discussed below suggest the limits on the volume of degradation that can be detected in the vicinity of the laser weld and geometry changes.

7.3.2 Transition Region Eddy Current Inspection

The detection and quantification of degradation at the transition regions of the sleeve/tube assembly depend upon the signal-to-noise ratio between the degradation response and the transition response. As a general rule, lower frequencies tend to suppress the transition signal relative to the degradation signal at the expense of the ability to quantify the degradation. Similarly, the inspection of the tube through the sleeve requires the use of low frequencies to achieve detection with an associated loss in quantification. Thus, the search for an optimum eddy current inspection represents a trade-off between detection and quantification. With the crosswound coil type inspection, this optimization leads to a primary inspection frequency for the sleeve on the order of [ ]^{a,c,e} and for the tube and transition regions on the order of [ ]^{a,c,e}.

Figure 7-7 shows a typical [ ]^{a,c,e} calibration curve for the sleeve from which OD sleeve indications can be assessed.

For the tube/sleeve combination, the use of the crosswound probe, coupled with a multifrequency mixing technique for further reduction of the remaining noise signals significantly reduces the interference from all discontinuities (e.g., a diameter transition) which have 360-degree symmetry, providing improved visibility for discrete discontinuities. As is shown in the accompanying figures, in the laboratory this technique can detect OD tube wall penetrations with acceptable signal-to-noise ratios at the transitions when the volume of metal removed is equivalent to the ASME calibration standard.

The response from the sleeve/tube assembly transitions with the crosswound coil is shown in Figures 7-8, 7-9 and 7-10 for the sleeve standards, tube standards and transitions, respectively. Detectability in transitions is enhanced by the combination of the various frequencies. For the crosswound probe, two frequency combinations are shown; the [ ]^{a,c,e} combination provides the overall detection capability while the [ ]^{a,c,e} combination provides improved sensitivity for the sleeve and some quantification capability for the tube. Figure 7-11 shows the phase/depth curve for the tube using this combination. As examples of the detection capability at the transitions, Figures 7-12 and 7-13 show the responses of a 20 per cent OD penetration in the sleeve and 40 per cent OD penetration in the tube, respectively.

For the inspection of the region at the top end of the sleeve, the transition response signal-to-noise ratio is about a factor of four less sensitive than that of the expansions. Some additional inspectability has been

a,c,e

Figure 7-7

[ ]^{a,c,e} Calibration Curve

a,c

Figure 7-8

Eddy Current Signals from the ASTM Standard, Machined on the Sleeve O.D. of the Sleeve/Tube Assembly Without Expansion (Cross Wound Coil Probe)

a,c,e

Figure 7-9

Eddy Current Signals from the ASTM Standard Machined on the Tube O.D. of the Sleeve/Tube Assembly Without Expansion (Cross Wound Coil Probe)

a,c,e

Figure 7-10

Eddy Current Signals from the Expansion Transition Region of the Sleeve/Tube Assembly (Cross Wound Coil Probe)

a,c,e

[ ]

Figure 7-11

Eddy Current Calibration Curve for ASTM Tube Standard at [ ]a,c,e and a Mix Using the Cross Wound Coil Probe

a,c,e

Figure 7-12

Eddy Current Signal from a 20 Per Cent Deep Hole, Half the Volume of ASTM Standard, Machined on the Sleeve O.D. in the Expansion Transition Region of the Sleeve/Tube Assembly (Cross Wound Coil Probe)

a,c,e

Figure 7-13

Eddy Current Signal from a 40 Per Cent ASTM Standard, Machined on the Tube O.D. in the Expansion Transition Region of the Sleeve/Tube Assembly (Cross Wound Coil Probe)

gained by tapering the wall thickness at the top end of the sleeve. This reduces the end-of-sleeve signal by a factor of approximately two. The crosswound coil, however, again significantly reduces the response of the sleeve end. Figure 7-14 shows the response of various ASME tube calibration standards placed at the end of the sleeve using the cross-wound coil and the [ ]^{a,c,e} frequency combination. Note that under these conditions, degradation at the top end of the sleeve/tube assembly can be detected.

The cases considered above cover the inspection of laser-welded and HEJ pressure boundaries in these areas:

(i) The entire length of the tube support sleeve between the upper and lower welds.

(ii) The entire length of the tubesheet sleeve extending from the upper weld down to the end of the sleeve.

(iii) The entire length of the tube from the hot leg tube entry to the top support of the cold leg, with the exception of the following areas:

iiia) The length of tubing between the upper and lower welds of each TSS.

iiib) The length of tubing between the upper weld of a tubesheet sleeve, down to the tube length behind the hardroll area of the tubesheet sleeve.

Note that indication of tube degradation of any type including a complete break between the upper weld joint and the lower weld joint does not require that the tube be removed from service.

Also, in a free span joint with more than one weld, the weld closest to the end of the sleeve represents the joint to be inspected and the limit of sleeve inspection.

7.3.3 Laser Weld Region Eddy Current Inspection

The only zone not addressed in Section 7.3.2 is the zone where the laser weld exists.

The basis for the ECT of this structure was developed by test, using a prototype laser weld. The test sample used for this study was a prototypical laser weld in an expanded sleeve zone of a sleeve/tube assembly. The weld was inspected before and after the introduction of a 40 per cent thru-wall 3/16 inch diameter flat bottom hole placed on the outside surface of the tube at the centerline of the weld. This weld presents an axisymmetric condition similar to the transition geometry which is demonstrated by the low phase angle signal similar to transition signals. The weld also displays a material disturbance by its distinct lobes which can be successfully mixed out.

Figure 7-15 shows the [ ]^{a,c,e} response from the weld zone and Figure 7-16 shows the successful [ ]^{a,c,e} mix response using cross-wound coils.

a,c,e

Figure 7-14

Eddy Current Response of the ASTM Tube Standard at the End of the Sleeve Using the Cross Wound Coil Probe and Multifrequency Combination

a,c,e

Figure 7-15

Crosswound [ ]^{a,c,e} Eddy Current Baseline of Laser Weld

a,c,e

Figure 7-16

Crosswound Mix Eddy Current Response
Baseline of Laser Weld

The [ ]^{a,c,e} combination has proven to be optimum for detection in the weld zone, particularly at the tube I.D./sleeve O.D. interface. Figures 7-17 and Figure 7-18 show the response of the 40 per cent FBH using [ ]^{a,c,e} and mix, respectively.

7.3.4 Eddy Current Inspection Summary

Conventional eddy current techniques have been modified to incorporate the most recent technology in the inspection of the sleeve/tube assembly. The resultant inspection of the sleeve/tube assembly involves the use of a cross-wound coil for the straight regions of the sleeve/tube assembly and for the transition regions. The advent of digital E/C instrumentation and its attendant increased dynamic range and the availability of eight channels for four frequencies has expanded the use of the crosswound coil for sleeve inspection. While there is a significant advancement in the inspection of portions of the assembly using the cross-wound coil over conventional bobbin coils, efforts continue to advance the state-of-the-art in eddy current inspection techniques. As enhanced techniques are developed, they will be utilized after they are verified. For the present, the cross-wound coil probe represents an inspection technique that provides additional sensitivity and support for eddy current techniques as a viable means of assessing the sleeve/tube assembly.

7.4 Alternate Post Installation Acceptance Methods

Ultrasonic or volumetric inspection is the prime method for post-installation weld quality evaluation, with eddy current examination being used as the prime in-service examination technique. However, there are cases, due [

]^{a,c,e}

[

]^{a,c,e}

In support of accepting UT indeterminate welds, several alternate strategies will be applied, as agreed to by the implementing utility and Westinghouse. While this summary is not meant to preclude other methods, it is included to provide an indication of the rigor of the alternate methods.

7.4.1 Bounding Inspections

[ ]^{a,c,e}

a,c,e

Figure 7-17
Crosswound [ ]a,c,e Eddy Current Response After 40 Per Cent Flat Bottomed Hole was Placed in O.D. of Tube at Center of Weld

a,c

Figure 7-18

Crosswound Mix Eddy Current Response After 40 Per Cent Flat Bottomed Hole was Placed in O.D. of Tube at Center of Weld

[

]a,c,e

7.4.2 Workmanship Samples

[

]a,c,e

7.4.3 Other Advanced Examination Techniques

As other advanced techniques become available and are proven suitable, Westinghouse may elect, with utility concurrence, to alter its post-installation inspection program. [
]b

[

]b

In summary, Westinghouse proposes to apply alternate inspection techniques with utility concurrence as they become available. It is intending that this licensing report not preclude the use of these inspections as long as they can be demonstrated to provide the same degree or greater of inspection rigor as the initial use methods identified in this report.

7.5 Inservice Inspection Plan for Sleeved Tubes

The need exists to perform periodic inspections of the supplemented pressure boundary. The inservice inspection program will consist of the following:

a. The sleeve 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. 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 removed from service by plugging. Any change in the eddy current signature of the sleeve and sleeve/tube joint region will require further inspection by alternate techniques prior to acceptance. Otherwise the tube containing the sleeve in question shall be removed from service by plugging.

7.6 References

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.