Attachment 3
To
W3F1-2007-0010

Non-Proprietary Copies of Westinghouse Documents Associated with the SG Batwing Issue

CDC#51382

DESIGN CRITERIA

FOR

SUPPORT BAR

STABILIZER

FOR

STANDARD PLANTS

DOCUMENT NO. 00000-DC-STD-702, REVISION 00

Nuclear Power Systems
COMBUSTION ENGINEERING, INC.
Windsor, Connecticut

Prepared by: ________ Date: ________
D. M. Matteson, Cognizant Engineer

Approved by: ________ Date: 3/26/85
A. J. Anthony

Approved by: ________ Date: 4/9/85
W. J. FitzPatrick

Approved by: for W. J. FitzPatrick Date: 4/9/85
T. E. Natan

This document is not for distribution outside of Combustion Engineering, Inc.

Issue Date: 4/15/85

QA Status: Verified

The safety related design information contained in this document has been reviewed and satisfied (where applicable) ... check list(s) ___, ___, and ___ of the Quality Assurance of Design Manual. This review is so certified.

Independent Reviewer ________

Date ________

RECORD OF REVISIONS

NO.	DATE	PAGES INVOLVED	PREPARED BY	APPROVALS
00	3/85	All Pages	D. M. Matteson	A. J. Anthony W. J. FitzPatrick T. E. Natan

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1.0 PURPOSE

1.1 The purpose of this document is to provide the criteria required to design support bar stabilizers for steam generators.

2.0 SCOPE

2.1 This document provides criteria for the detailed design of the support bar stabilizers for steam generators.

2.2 This document provides criteria for installation of the support bar stabilizers.

2.3 Design requirements of the support bar stabilizer servicing and inspection equipment are not included.

2.4 Specific contract related support bar stabilizer criteria are not included.

3.0 REFERENCES

3.1 DESIGN BASIS

3.1.1 ASME Boiler and Pressure Vessel Code.

3.1.2 General Specification for Steam Generator Assemblies, Specification No. 00000-PE-120.

3.1.3 ANSI-N18.2, Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plant.

3.1.4 Regulatory Guide 1.29, Seismic Design Classification.

3.1.5 CEND-353, Field Handling, Maintenance and Storage Requirements.

3.2 CHEMISTRY DESIGN GUIDE

3.2.1 General Chemistry Design Guide, 00000-PE-CG.

3.3 DRAWINGS

3.3.1 Tube Support Details Drawing No. E-234-614 (34XX Class Plants).

3.3.2 Tube Support Details Drawing No. E-78273-289-001 (System 80 Plants)

4.0 COMPONENT FUNCTIONAL REQUIREMENTS

4.1 FUNCTIONS

4.1.1 The support bar stabilizers shall be restrained from significant movement.

4.1.2 The support bar stabilizers shall be designed to minimize relative motion between the stabilizers and the support bars joined by the stabilizers.

4.1.3 The support bar stabilizers are not pressure retaining components.

5.0 PERFORMANCE REQUIREMENTS

5.1 DESIGN BASIS EVENTS

5.1.1 The support bar stabilizers shall be designed to function in the steam generator secondary coolant system and withstand the loads from Transient Operations, Normal Operating plus Operating Basis Earthquake, and Safe Shutdown Earthquake.

5.1.2 The support bar stabilizers shall be designed to satisfy the requirements of Reference 3.1.1, Section XI, and Section III, Subsection NB.

5.2 LIFETIME

5.2.1 The support bar stabilizers shall be designed to remain installed for life of the steam generator without loss of function.

5.3 ENVIRONMENT

5.3.1 The support bar stabilizers shall be designed to function in the steam generator secondary coolant system under water chemistry limits defined in Reference 3.2.1.

5.4 CORROSION RESISTANCE

5.4.1 The support bar stabilizers shall be designed to exhibit corrosion resistance greater than or equal to the support bars under typical faulted chemistry conditions. The support bars are fabricated from C-1008-1010 carbon steel for 34XX Mwt Class Plants and 410 stainless steel for System 80 Class Plants.

5.5 PRESSURE LOSS

5.5.1 The support bar stabilizers shall be designed to minimize the increased pressure loss and obstruction to the flow.

6.0 MECHANICAL DESIGN

6.1 SAFETY CLASSIFICATION

The criteria for establishing the safety class of a part of the NSSS is given in ANSI-N18.2, Nuclear Safety criteria for the Design of Stationary Pressured Water Reactor Plant, (Reference 3.1.3). The support bar stabilizers are Safety Class 1 components.

6.2 SEISMIC CLASSIFICATION

Guidance to the selection of seismic category is given in Regulatory Guide 1.29, Seismic Design Classification (Reference 3.1.4). The support bar stabilizes are Seismic Category 1 components.

6.3 CONDITION OCCURRENCES

The categories of conditions of design are defined and design requirements are specified in ANSI-N18.2, Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants (Reference 3.1.3). The conditions of design for which the support bar stabilizers shall be required to function are Normal Operation, Faulted, and Upset Conditions.

6.4 MECHANICAL LOADS

The mechanical loadings to be considered shall be determined as required by the safety classification of the support bar stabilizers specified in Paragraph 6.1 and shall include, but not be limited to weight, installation and mechanical expansion loads.

6.5 SEISMIC LOADS

The seismic loads to be considered shall be determined as required by the seismic classification specified in Paragraph 6.2 and the conditions of design for which it must function as specified in Paragraph 6.3.

6.6 LOCA LOADS

6.6.1 The LOCA loads to be considered shall be determined as required by the safety classification specified in Paragraph 6.1.

6.7 DESIGN FEATURES

6.7.1 The support bar stabilizers shall be located near the intersection of the horizontal and inclined sections of the support bars. Typical support bars are shown on References 3.3.1 and 3.3.2.

6.7.2 The support bar stabilizers shall be designed to accomodate any known phenomena including the following:

6.7.2.1 Differential thermal expansion

6.7.2.2 Flow induced forces

6.7.2.3 Mechanical Vibration

6.7.2.4 Seismic Loads

6.7.2.5 Stress or creep relaxation

6.7.2.6 Chemically induced erosion or corrosion.

6.7.3 Corrosion products or crud deposition shall not limit the serviceability of the support bar stabilizers.

6.7.4 The support bar stabilizers shall not create unacceptable loads on the support bars.

6.7.5 The support bar stabilizers shall maintain the nominal support bar spacing at the intersection of the horizontal and inclined sections of the support bars. The nominal center to center spacing is 0.866 ± .050 inches.

6.7.6 The support bar stabilizer shall not have any components that are not retained or captured by redundant means.

6.8 ENVIRONMENTAL CONDITIONS

6.8.1 Storage

Considerations for storage of components are given in CEND-353, Field Handling, Maintenance and Storage Requirements (Reference 3.1.5). Specific site related requirements are specified in the project requirements.

6.8.2 Construction

Recommended practices for care of components during construction are given in CEND-353, Field Handling, Maintenance and Storage Requirements.

6.8.3 Operation

See Paragraph 5.3 for operating environment considerations.

6.9 CHEMISTRY, METALLURGY

6.9.1 All materials must be compatible with the system and fluid conditions given in Reference 3.2.1.

6.10 INSTALLATION

6.10.1 The support bar stabilizers shall be designed to be installed on the support bars in the center of the steam generator.

6.10.2 The support bar stabilizers shall be designed to be installed through either of two means of access.

6.10.2.1 Through a 5 11/16 inch hand hole and up through the center of the eggcrate tube support assemblies.

6.10.2.2 Through the secondary side manway and down through a vacant tube lane.

6.10.2.3 The support bar stabilizers shall be designed to be removable.

6.11 EXAMINATION AND INSPECTION

6.11.1 The support bar stabilizers shall be designed to be inspected after installation by electronic, mechanical or visual methods.

7.0 DESIGN INTERFACES

The following information is required to perform the design and analysis of the support bar stabilizers.

7.1 MATERIAL PROPERTIES INFORMATION

7.1.1 Material Corrosion Resistance Information

7.1.2 Test Report

7.2 THERMAL HYDRAULIC INFORMATION

7.2.1 Normal Operating Temperatures and Hydraulic Pressures (loads) on support bar stabilizers.

7.2.2 Limiting conditions Transient Event (Reference 3.1.2) on support bar stabilizers.

7.3 SEISMIC INFORMATION

7.3.1 Operating Basis Earthquake Loads on support bar stabilizers.

7.3.2 Safe Shutdown Earthquake Loads on support bar stabilizers.

7.4 LOCA INFORMATION

7.4.1 Limiting condition LOCA Loads on Support Bar Stabilizers.

8.0 MECHANICAL INTERFACES

8.1 The following components interface with the support bar stabilizers.

8.1.1 Installation Equipment

8.1.2 Inspection Equipment

8.1.3 Support bar assemblies

8.1.4 Steam Generator Tubes

Entergy	CONDITION REPORT	CR-WF3-2007-00300

Originator: Hempel,Thomas R
Originator Group: Eng Design Mechanical Staff
Supervisor Name: Russo,John W
Discovered Date: 01/24/2007 14:31

Originator Phone: 6393
Operability Required: N
Reportability Required: Y
Initiated Date: 01/24/2007 15:08

Condition Description:

During the NRC Batwing Inspection on 1-22-06, the following discrepancies associated with ER-W3-2006-0339-000 and ER-W3-2006-0362-000 were discovered:

ER-W3-2006-0339-000 "Steam Generator Batwing Failure Use-As-Is Evaluation" contains erroneous information regarding the safety and seismic classification of the subject Steam Generator tube supports referred to as "batwings". The ER describes the batwings as Safety Class 1 / Seismic Category 1 components per CE Specification 00000-DC-STD-702 (CDCC #51382) "Design Criteria for Support Bar Stabilizer for Standard Plants". The support bar stabilizers in this specification were mistakenly interpreted to be tube supports or spacers referred to as batwings, which resulted in the incorrect safety / seismic classification depicted in ER-W3-2006-0339-000. The OEM - Westinghouse has stated this document (CDCC #51382) was intended as a stabilization device or tool that was never fabricated, utilized or installed and should be removed from the Waterford-3 records system to eliminate any further confusion. Westinghouse also provided the following statement as clarification in classifying batwings in the ER. "The batwings are designed to provide tube support during normal operation to prevent fluid-elastic instability. They are not required to mitigate accident conditions (e.g., LOCA or Steam Line Break) nor are they required to mitigate seismic events."

ER-W3-2006-0362-000 "Enhance the Steam Generator Batwing Support / Wrap Around Bar Welds" contains an erroneous statement in ER Section 1.3 that reads: "The existing weld designs per CE 74270-271-13 are still applicable to all other welds that are not in the presence of the stay cylinder region per PDD-5817-13616." Since batwing welds verified by inspection in areas both inside and outside the stay cylinder area were found deficient (weld one side rather than two) for Steam Generator 2, the reference to welds conforming to existing weld designs outside the stay cavity is inaccurate. Westinghouse Calculation CN-SGDA-05-36 has evaluated one sided batwing welds as acceptable and is included in the ER as a reference document.

None of the ERs conclusions or repairs are impacted by the identified conditions.

Immediate Action Description:

Suggested Action Description:

REFERENCE ITEMS:

Type Code	Description
CONDITION REPORT	CR-WF3-2007-00304

TRENDING (For Reference Purposes Only):

Trend Type	Trend Code
KEYWORDS	KW-ER
REPORT WEIGHT	1
KEYWORDS	KW-ENGINEERING REVIEW
IDENTIFIED BY	W3I
KEYWORDS	KW-STEAM GENERATOR
HEP FACTOR	H
SEVERITY WEIGHT	1
CU	ESDE
EI	ESDE

Entergy	ADMIN	CR-WF3-2007-00300

Initiated Date: 1/24/2007 15:08 **Owner Group :** Eng Design Mechanical Mgmt

Current Contact:

Current Significance: C

Closed by:

Summary Description:

During the NRC Batwing Inspection on 1-22-06, the following discrepancies associated with ER-W3-2006-0339-000 and ER-W3-2006-0362-000 were discovered:

ER-W3-2006-0339-000 "Steam Generator Batwing Failure Use-As-Is Evaluation" contains erroneous information regarding the safety and seismic classification of the subject Steam Generator tube supports referred to as "batwings". The ER describes the batwings as Safety Class 1 / Seismic Category 1 components per CE Specification 00000-DC-STD-702 (CDCC #51382) "Design Criteria for Support Bar Stabilizer for Standard Plants". The support bar stabilizers in this specification were mistakenly interpreted to be tube supports or spacers referred to as batwings, which resulted in the incorrect safety / seismic classification depicted in ER-W3-2006-0339-000. The OEM - Westinghouse has stated this document (CDCC #51382) was intended as a stabilization device or tool that was never fabricated, utilized or installed and should be removed from the Waterford-3 records system to eliminate any further confusion. Westinghouse also provided the following statement as clarification in classifying batwings in the ER. "The batwings are designed to provide tube support during normal operation to prevent fluid-elastic instability. They are not required to mitigate accident conditions (e.g., LOCA or Steam Line Break) nor are they required to mitigate seismic events."

ER-W3-2006-0362-000 "Enhance the Steam Generator Batwing Support / Wrap Around Bar Welds" contains an erroneous statement in ER Section 1.3 that reads: "The existing weld designs per CE 74270-271-13 are still applicable to all other welds that are not in the presence of the stay cylinder region per PDD-5817-13616." Since batwing welds verified by inspection in areas both inside and outside the stay cylinder area were found deficient (weld one side rather than two) for Steam Generator 2, the reference to welds conforming to existing weld designs outside the stay cavity is inaccurate. Westinghouse Calculation CN-SGDA-05-36 has evaluated one sided batwing welds as acceptable and is included in the ER as a reference document.

None of the ERs conclusions or repairs are impacted by the identified conditions.

Remarks Description:

Closure Description:

Entergy	CORRECTIVE ACTION	CR-WF3-2007-00300

CA Number: 1

	Group	Name
Assigned By:	Eng Design Mgmt	Lanka,Brian
Assigned To:	Eng Design Mechanical Mgmt	Russo,John W
Subassigned To :	Eng Design Mechanical Staff	Buford IV,Albert C

Originated By:	Greer,Hiram P	1/25/2007 15:30:41
Performed By:	Russo,John W	2/5/2007 15:46:01
Subperformed By:	Buford IV,Albert C	2/5/2007 15:39:41
Approved By:		
Closed By:	Lanka,Brian	2/5/2007 15:57:45

Current Due Date: 02/08/2007 **Initial Due Date:** 02/08/2007

CA Type: DISP - CA

Plant Constraint: NONE

CA Description:

Per the CRG, evaluate the condition and initiate appropriate corrective action(s).

Response:

Document discrepancies will be corrected by CA#4.

Subresponse :

Corrective Action 4 of this CR was issued and contains the appropriate actions to resolve the identified conditions. This action can be closed.

Closure Comments:

Entergy	CORRECTIVE ACTION	CR-WF3-2007-00300

CA Number: 3

	Group	Name
Assigned By:	WF3 CRG	Lam,Kien C
Assigned To:	Eng Design Mgmt	Lanka,Brian
Subassigned To :	Eng Design Mechanical Mgmt	Russo,John W

Originated By:	Lam,Kien C	1/25/2007 15:47:28
Performed By:	Lanka,Brian	2/5/2007 15:59:28
Subperformed By:	Russo,John W	2/5/2007 15:54:20
Approved By:		
Closed By:	Lanka,Brian	2/5/2007 15:59:28

Current Due Date: 02/08/2007 **Initial Due Date:** 02/08/2007

CA Type: ACTION

Plant Constraint: NONE

CA Description:

The CRG has evaluated CR-WF3-2007-00304 as a Category D and closed it administratively to this CR. Please ensure that the response and corrective actions, address the condition identified in CR-WF3-2007-00304. See CR description below.

CR Description: On January 24, 2007, an NRC Inspector conducting an ongoing inspection of SG Batwings communicated to a Waterford 3 licensing engineer concerns regarding the seismic qualification of SG#2 batwing to wrapper bar welds. The NRC Inspector specific concerns relate to (1) conformance with RG 1.29, (2) discussion of seismic qualification in design weld repair package, and (3) demonstrating seismic qualification for welds outside the stay cavity region that had not been repaired but were likely single sided, nonconforming welds. The NRC Inspector requested that Waterford 3 provide an explanation of SG operability given the specific concerns he communicated.

The Licensing Manager communicated to the NRC, in a return call, that the NRC concerns would be documented and evaluated within the Corrective Action Program.

Response:

I concur. This action is complete.

Subresponse :

Corrective Action #4 has been generated to correct the conditions identified by both CR-WF3-2007-00300 and CR-WF3-2007-00304. Therefore, corrective actions have been generated to resolve both conditions and this action may be closed.

Closure Comments:

Entergy	CORRECTIVE ACTION	CR-WF3-2007-00300

CA Number: 4

	Group	Name
Assigned By:	Eng Design Mechanical Staff	Buford IV,Albert C
Assigned To:	Eng Design Mechanical Mgmt	Lanka,Brian
Subassigned To :	Eng Design Mechanical Staff	Buford IV,Albert C

Originated By:	Buford IV,Albert C	2/5/2007 15:38:26
Performed By:		
Subperformed By:		
Approved By:		
Closed By:		

Current Due Date: 04/26/2007 **Initial Due Date:** 04/28/2007

CA Type: ACTION

Plant Constraint: NONE

CA Description:

Correct or clarify the following discrepancies contained in the referenced documents identified during the NRC Batwing Inspection as necessary utilizing an appropriate process (i.e. ER supplement, Linked ER):

1) The support bar stabilizers in this specification were mistakenly interpreted to be tube supports or spacers referred to as batwings, which resulted in the incorrect safety / seismic classification depicted in ER-W3-2006-0339-000.

2) ER-W3-2006-0362-000 "Enhance the Steam Generator Batwing Support / Wrap Around Bar Welds" contains an erroneous statement in ER Section 1.3 that reads: "The existing weld designs per CE 74270-271-13 are still applicable to all other welds that are not in the presence of the stay cylinder region per PDD-5817-13616." Batwing welds verified by inspection in areas both inside and outside the stay cylinder area were found deficient (weld one side rather than two) for Steam Generator 2.

3) Address NRC inspector operability concerns with compliance with Reg Guide 1.29.

4) Address NRC inspector operability concerns for discussion of seismic qualification in design weld repair package.

5) Address NRC inspector operability concerns for demonstrating seismic qualification for welds outside the stay cavity region that had not been repaired but were likely single sided, nonconforming welds.

Response:

Subresponse :

Closure Comments:

This Design Specification is Certified to be in Compliance with the requirements of the ASME Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, 1971 Edition through the Summer 1971 Addenda.

Certified by [signature] PE
Registration No. 12186
State of Connecticut
Date 4/15/85

CDCC# 51036

PROJECT SPECIFICATION

FOR

STEAM GENERATOR ASSEMBLIES

FOR

WATERFORD UNIT NO. 3

QA Review Verified

The safety related design information contained in this document has been reviewed and satisfies (where applicable) the items contained on check list(s) ___, ___, and ___ of the Quality Assurance of Design Manual. This review is so certified.

Independent Reviewer [signature]
Date [illegible]
Document Rev. No. 07

SPECIFICATION NO. 09270-PE-120
REVISION 07

Nuclear Power Systems
COMBUSTION ENGINEERING, INC.
Windsor, Connecticut

PREPARED BY [signature] DATE 4/11/85
E. M. WEISEL, COGNIZANT ENGINEER

APPROVED BY W J FitzPatrick DATE 4/12/85
W. J. FITZPATRICK, SUPERVISOR

APPROVED BY A Y Overman DATE 4/15/85
A. Y. OVERMAN, APPLICATION ENGINEER

APPROVED BY T F Turisco DATE 4/15/85
for J. W. VEIRS, PROJECT MANAGER

ISSUE DATE 4/15/85

RECORD OF REVISIONS

REVISION NO.	DATE	PAGES INVOLVED	PREPARED BY	APPROVALS
1	1-72 PS000434	Cover, i, 1,2,3, Figure 15, Figure 17 Sheet 1 and Figure 17 Sheet 2 Added Figure 18		
2	11/72 PS000435	Cover, i, 2,3, and 4. Transferred "Quantities of Documents" to new page 5,		
3	3/73 PS000436	Cover, i and 4		
4	5/74 PS000437	Cover, i, 2, 3, 4, 5, Appendix 1 and Figure 15		
5	4/75 PS000438	Cover, i, 1, 2, 3, 4, 5, Figure 16 Sheet 1, Figure 16 Sheet 3, Figure 16 Sheet 4, Figure 17 Sheet 1 and Figure 17 Sheet 2.		
6	9/75 PS000439	Cover, i and 4		
7	4/15/85 PS003289	Renumbered all pages, added Table of Contents, revised Figure 16 Sheet 3.	E.M. Weisel 20 pages	W.FitzPatrick A.Y. Overman J.W. Veirs

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APPENDICIES

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Calculation Note Number	Revision	Shop Order Number	Charge Number	Page
CN-SGDA-05-36-NP	1	120	114996/0050	1
Project	Releasable (Y/N)	Open Items (Y/N)	Files Attached (Y/N)	Total No. Pages
Waterford 3 Outage	Y	N	N	45

Title: Evaluation of Degraded Batwing Tube Supports in the Waterford 3 Steam Generators at 3716 MWt Power Uprate Conditions

Author(s) Name(s)	Signature / Date	For Pages
B. A. Bell	***Electronically Approved****	All

Verifier(s) Name(s)	Signature / Date	For Pages
D. P. Siska	***Electronically Approved****	All

Manager Name	Signature / Date
D. Merkovsky	***Electronically Approved****

***Electronically approved records are authenticated in the Electronic Document Management System.**

Westinghouse

Record of Revisions

Rev	Date	Revision Description
0	05/27/06	Original Issue
1	See EDMS	Sections 1.1, 2.0, 3.1, 6.2, 6.3.4, and 7.0 are revised. Section 6.3.6 is added to this revision.

Table Of Contents

1.0 Introduction

1.1 BACKGROUND / PURPOSE

During the Waterford 3 Spring 2005 outage, it was noted that two batwing bars of the approximate 350 bars for both steam generators had separated at the lower end and were two inches below their normal elevation (currently the ECT data only provides evidence of this condition without visual confirmation). Both batwing bars are in the same steam generator, SG32, and are immediately adjacent to one another. The Reference 2 e-mail (copy in Appendix B) describes two hypotheses for the failure modes. The first hypothesis stated that chemical cleaning in the steam generators weakened the weld joining the diagonal and horizontal bars, which comprise the lower batwing assembly (The weld filler material is nickel base alloy. Therefore, the aggressive chemical cleaning would primarily attack the heat affected zones (HAZ) at the weld/base metal interface.). However, the picture in the Reference 9 e-mail (copy in Appendix B) showed that the batwing bar failed at the mid-point of the horizontal portion instead of the weld joining the diagonal and horizontal bars. This situation required that the upper weld region between the batwing bar and "wrap-around bar" support the entire weight of the diagonal and half of the horizontal portions of the batwing bar. Since the batwing bar thickness could be as low as 0.069 inches in thickness (Reference 2), both the original batwing bar thickness and the reduced thickness of 0.069 inches are considered in the structural analysis of the upper weld region.

The second hypothesis in Reference 2 stated that the batwing did not fail at the lower weld, but was separated (a break in the 0.090 inch thickness) by wear from the tube itself. This tube location is tube row 38. It was assumed that the lower portion of the diagonal batwing bar was separated from the rest of the diagonal batwing bar at the tube row 38 location and is supported by the lower weld region between the diagonal and horizontal bars of the batwing assembly. Since the batwing bar thickness could be as low as 0.069 inches (Reference 2), both the original batwing bar thickness and the reduced thickness of 0.069 inches are considered in the structural analysis of the lower weld region.

This calculation note also addresses a potential overpressure condition in a sentinel-plugged tube during a loss of condenser vacuum transient to determine if the hole in the sentinel plug provides sufficient venting capacity. The resulting external pressure on the plug must not exceed the pressure used in the tube plug qualification program. In addition, the internal pressure in the tube should not result in tube failure for a batwing wear defect.

The purpose of this report revision is to address the quasi-static pressure loads discussed in Reference 15 and their effect on the original evaluation of the degraded batwing tube supports.

This calculation note was prepared according to Westinghouse Procedure WP-4.5 (Reference 1).

1.2 LIMITS OF APPLICABILITY

The calculations detailed herein are applicable only to the Waterford Unit 3 steam generators.

2.0 Summary of Results and Conclusions

The structural results for the two failure mode possibilities are shown in Table 2-1. In the first failure mode where the lower weld region is not considered, the upper weld region supports the full length of the diagonal batwing bar and half of the length of the horizontal batwing bar. Both the original and reduced batwing thicknesses (per Reference 2) are considered. In the second failure mode, the batwing bar is assumed to be severed at the tube row 38 location, and the remnant weight of the lower batwing bar is supported by the lower weld region. Both the original and reduced batwing thicknesses (per Reference 2) are also considered.

Table 2-1

Location	Calculated Stress (psi)	Allowable Stress (psi)
Upper Weld Region		
Original Batwing Bar Thickness	263.7 (Shear)	0.6 Sm = 11,040
	9,870.9 (Bending)	1.5 Sm = 27,600
	12,073.3 (Alternating)	Salt = 12,500 for an infinite number of allowable cycles per Reference 4
Reduced Batwing Bar Thickness	202.2 (Shear)	0.6 Sm = 11,040
	9,794.7(Bending)	1.5 Sm = 27,600
	11,980.2 (Alternating)	Salt = 12,500 for an infinite number of allowable cycles per Reference 4
Lower Weld Region*		
Original Batwing Bar Thickness	12.2 (Shear)	0.6 Sm = 11,040
	1,923.3(Bending)	1.5 Sm = 27,600
Reduced Batwing Bar Thickness	12.2 (Shear)	0.6 Sm = 11,040
	2,511.0 (Bending)	1.5 Sm = 27,600

* - Since the stresses in the lower weld region are less than those stresses in the upper weld region, the endurance limit in the lower weld region will also be infinite.

Based on the results in Table 2-1, it is concluded that the stresses in the upper and lower weld regions are below their respective allowables and will not fail during operation of the Waterford 3 steam generator. The endurance limit for both the original and reduced batwing bar thicknesses in the upper and lower weld regions is infinite per the ASME Code of Record (Reference 4) that was used in the original stress report (Reference 5).

The effects of the quasi-static pressure loads on the Batwing Bar (Reference 15) both with the original and reduced bar thickness are calculated in Section 6.3.6. The maximum quasi-static pressure load is less than 10% of the respective component of the Batwing Bar weight with either the original or reduced bar thickness. Therefore, the failed Batwing Bar with either bar thickness will not move during normal operation as a result of the maximum quasi-static pressure load application for either the 3390 MWt (Cycle 12) or 3716 MWt (20% SGTP) conditions. As a result, the stress calculation and its method of analysis for the upper weld region in Section 6.3.2 and summarized in Table 2-1 remains the same.

The external pressure on a sentinel plug during a loss of condenser vacuum transient is approximately 5400 psi. This value is well below the qualified pressure for this type of plug and will not cause the plug to collapse or eject. In addition, based on a conservative evaluation of growth rates, only one tube could have a flaw deep enough to burst with an internal pressure of 5400 psi. However, the primary-to-secondary leak rate would be limited to less than 0.1 GPM and would result in no safety concerns. Also, the quasi-static pressure loads discussed in Reference 15 do not have an effect on sentinel plug analyzed in Section 6.3.5

3.0 Assumptions and Open Items

3.1 DISCUSSION OF MAJOR ASSUMPTIONS

a,c

3.2 OPEN ITEMS

There are no open items associated with this calculation note.

4.0 Acceptance Criteria

The following acceptance criteria are used in this analysis.

1. The allowable shear stress is 0.6 Sm per Paragraph NB-3227.2 (a) of Reference 4.
2. The allowable primary membrane plus primary bending stress intensity is 1.5 Sm per Paragraph NB-3221.3 of Reference 4.
3. The allowable alternating stress for an infinite number of allowable cycles is 12,500 psi for the batwing bar carbon steel A-36 material per the ASME Code of Record (Reference 4) that was used in the original stress report (Reference 5).
4. The sentinel plug must be able to vent water at a sufficient rate to prevent an overpressure condition that could collapse or eject the plug (approximately 9500 psi). In addition, the calculated overpressure condition must not cause multiple tube bursts from batwing defects that would result in a primary to secondary leak rate that would exceed the make-up capacity of the charging pumps.

5.0 Computer Codes Used In Calculation

No configuration controlled computer codes are used in this analysis.

6.0 Calculations

The discussion of the analysis methodology is provided in Section 6.1. The design inputs used in the analysis are defined in Section 6.2. Section 6.3 presents the detailed results and conclusions from the evaluations.

6.1 METHOD DISCUSSION

Two hypotheses for the failure modes in the batwing bar assembly are considered. The first hypothesis considers the stresses in the upper weld region due to the dead weight loading of the diagonal and half the horizontal portion of the batwing bar (References 2 and 9). The dead weight loading is conservatively used instead of the normal operation loads. See Assumption 7) in Section 3.1 for details. Since the batwing bar thickness could be as low as 0.069 inches in thickness (Reference 2), both the original batwing bar thickness and the reduced thickness of 0.069 inches are considered in the structural analysis of the upper weld region. The structural analysis examines both the shear stress for the minimum weld shear area and the bending stress in the upper support region, as well as the endurance limit in this region per the ASME Code of Record (Reference 4) that was used in the original stress report (Reference 5).

In the second hypothesis, it is assumed that the batwing did not fail at the lower weld, but was separated by wear from the tube itself. This tube location is tube row 38. It was assumed that the lower portion of the diagonal batwing bar was separated from the rest of the diagonal batwing bar at the tube row 38 location and is supported by the lower weld region between the diagonal and horizontal bars of the batwing assembly. The dead weight loading is conservatively used instead of the normal operation loads. See Assumption 7) in Section 3.1 for details. Since the batwing bar thickness could be as low as 0.069 inches in thickness (Reference 2), both the original batwing bar thickness and the reduced thickness of 0.069 inches are considered in the structural analysis of the lower weld region. The structural analysis examines both the shear stress for the minimum weld shear area and the bending stress in the lower support region, as well as the endurance limit in this region per the ASME Code of Record (Reference 4) that was used in the original stress report (Reference 5).

The overpressure condition in a sentinel-plugged tube is calculated by developing a spreadsheet to calculate fluid conditions in the tube based on the Loss of Condenser Vacuum (LOCV) transient conditions specified in the Waterford FSAR (see Appendix B). The leak rate through the hole in the sentinel plug is based on the equation provided in Reference 10.

6.2 INPUT

The input parameters for the upper and lower batwing weld region calculations are from the design parameters in Reference 5 which are also applicable to the 3716 Mwt Power Uprate Condition.

Secondary Side Design Temperature = 560 °F

Secondary Side Design Pressure = 1100 psia

The input parameters for the calculation of the sentinel-plugged tube internal pressure from a LOCV transient are taken from the Waterford FSAR [Figure 15.2-4 (page 29) and Figure 15.2-7 (page 31) in Appendix B]. These values are as follows:

Initial Steam Generator Pressure = 750 psia
Initial Primary (RCS) Pressure = 2150 psia

The variation in the above two parameters during the LOCV is shown in Figures 15.2-4 and 15.2-7 in Appendix B. Note that the initial value for primary pressure is chosen in the FSAR Chapter 15 safety analysis to maximize the peak RCS pressure during the event. Starting at the low end of the pressure range allows a longer time for the reactor to operate following a LOCV before the plant is tripped from a high pressurizer pressure signal. It should also be noted that resulting values for primary and secondary pressure are based on licensing conditions and are considered conservative when compared to the likely plant response to this transient.

The quasi-static pressure loads on the batwing strips within the central cavity region for the 3390 MWt (Cycle 12) and uprated 3716 MWt with 20% SGTP are calculated in Reference 15. The summary of results from Reference 15 is in Table 6-1 for the Hot Leg side batwing strip and Table 6-2 for the Cold Leg side batwing strip. From Tables 6-1 and 6-2, the maximum quasi-static pressure load for the failed batwing strip is 0.161 lb_f/in^2 for the 3390 MWt (Cycle 12) condition and 0.187 lb_f/in^2 for the uprated 3716 MWt with 20% SGTP condition.

Table 6-1
(Reference 15)
Waterford Unit 3 Steam Generators

a,c

Table 6-2
(Reference 15)
Waterford Unit 3 Steam Generators

a,c

6.3 EVALUATIONS, ANALYSIS, DETAILED CALCULATIONS AND RESULTS

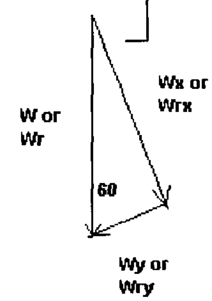
6.3.1 Batwing Bar Weights, W and WL

Weights of Full Bat Wing Bar, W, and Lower Bat Wing Bar Remnant, WL, with Original Bar Thickness of t = 0.090 inch & Wr and WLr with reduced Bar Thickness of tr = 0.069 inch (Reference 2):

[ ] a,c

W-Weight of Full Bat Wing Bar w/ Original Bar Thickness:

[ ] a,c



Wx and Wy – X and Y Components of Full Bat Wing Bar w/ Original Bar Thickness:

[ ] a,c

Wr – Weight of Full Bat Wing Bar w/ Reduced Bar Thickness:

[ ] a,c

Wrx and Wry – X and Y Components of Full Bat Wing Bar w/ Reduced Bar Thickness:

[ ] a,c

If the Bar is broken at tube row 38 location, the remnant weight of the lower Bar, WL, with Original Bar Thickness is:

[ ] a,c

WLx and WLy – X and Y Components of the lower Bat Wing Bar w/ Original Bar Thickness:

[ ] a,c

If the Bar is broken at tube row 38 location, the remnant weight of the lower Bar, WLr, with Reduced Bar Thickness is:

[ ] a,c

WLrx and WLry – X and Y Components of the lower Bat Wing Bar w/ Reduced Bar Thickness:

[ ] a,c

6.3.2 Stresses in the Upper Weld Region

Stresses in the Upper Weld Area with Original Bar Thickness of t = 0.090 inch:

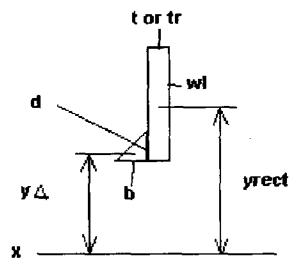
a,c

σushear – Max. Shear Stress:

$Sm := 18400psi$ General Membrane Stress for Carbon Steel A-36 at 560 °F

$Sy := 27600psi$ Yield Stress for Carbon Steel A-36 at 560 °F

$$\sigma ushear := \frac{Wx}{Auw} \qquad \sigma ushear = 263.7psi < 0.6 \cdot Sm = 11040psi$$



σubend – Max. Bending Stress:

a,c

$$\sigma ubend := \frac{M \cdot cu}{Ix} \qquad \sigma ubend = 9870.9psi < 1.5Sm = 27600psi$$

Therefore, the stresses in the upper weld region are still below the allowable and no yielding occurs in this region.

Maximum Stresses and Endurance Limit in the Upper Weld Area with Original Bar Thickness of t = 0.090 inch:

The maximum stresses occur in the y-z plane where:

$\sigma yz := \sigma ubend \qquad \sigma yz = 9870.9 psi$

$\sigma yzshear := \dfrac{Wy}{(A\Delta + Arect)} \qquad \sigma yzshear = 67.06 psi$ (negligible)

Therefore, the maximum and mininum stresses, σumax and σumin, for the original bar thickness are:

$\sigma umax := \sigma yz \qquad \sigma umax = 9870.9 psi$

$\sigma umin := 0 \cdot psi$ (Assumption 6) in Section 3.1)

Therefore, the stress intensity, SIu, is:

$SIu := \sigma umax - \sigma umin \qquad SIu = 9870.9 psi$

The peak stresses, Spumax and Spumin, are calculated as follows. In Reference 14, theoretical studies are used for determining the stress concentration factors in structural members containing cracks. From Figure 10 of Reference 14, for a thin cross section of 3/32 in., the stress concentration factors are Kt = 1.7 (tension) and Kb = 2.2 (bending). In this analysis, a stress concentration factor of K = 2.2 will be applied directly to the stress intensities.

$K := 2.2$

$Spumax := K \cdot \sigma umax \qquad Spumax = 21715.9 psi$

$Spumin := K \cdot \sigma umin \qquad Spumin = 0 psi$

$Sn := Spumax - Spumin \qquad Sn = 21715.9 psi$

The allowable number of cycles for the range of alternating stress intensity (Salt) modified by the ratio of modulus of elasticities for the fatigue curve, Efat, and the carbon steel bar, E, are calculated below:

$Efat := 30.0 \cdot 10^6 \cdot psi \qquad E := 26.98 \cdot 10^6 \cdot psi$

$Eratio := \dfrac{Efat}{E} \qquad Eratio = 1.112$

Therefore, the alternating stress intensity, Salt, and the number of allowable cycles, Na, are:

$Salt := \dfrac{Sn \cdot Eratio}{2} \qquad Salt = 12073.3 psi$

From Figure I-9.1, Reference 4, for the ultimate strength of less than 80 ksi, the number of allowable cycles, Na, at Salt of 12,073.3 psi is infinity (∞). Therefore, the endurance limit is infinite per the ASME Code of Record (Reference 4) that was used in the original stress report (Reference 5).

Stresses in the Upper Weld Area with Reduced Bar Thickness of tr = 0.069 inch:

a,c

[ ]

σurshear – Max. Shear Stress:

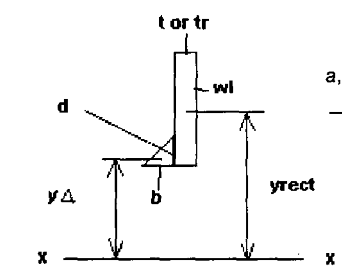
$Sm := 18400\,psi$ General Membrane Stress for Carbon Steel A-36 at 560 °F

$Sy := 27600\,psi$ Yield Stress for Carbon Steel A-36 at 560 °F

$\sigma urshear := \frac{Wrx}{Auw}$ $\sigma urshear = 202.2psi$ < $0.6 \cdot Sm = 11040psi$

σurbend – Max. Bending Stress:

a,c



[ ]

$\sigma urbend := \frac{Mr \cdot cu}{Ix}$ $\sigma urbend = 9794.7psi$ < $1.5Sm = 27600psi$

Therefore, the stresses in the upper weld region with a degraded bar thickness are still below the allowable and no yielding occurs in this region.

Maximum Stresses and Endurance Limit in the Upper Weld Area with Reduced Bar Thickness of tr = 0.069 inch:

The maximum stresses occur in the y-z plane where:

$\sigma ryz := \sigma urbend \qquad \sigma ryz = 9794.7psi$

$\sigma ryzshear := \frac{Wry}{(A\Delta + Arectr)} \qquad \sigma ryzshear = 65.507psi$ (negligible)

Therefore, the maximum and mininum stresses, σurmax and σurmin, for the original bar thickness are:

$\sigma urmax := \sigma ryz \qquad \sigma urmax = 9794.7psi$

$\sigma urmin := 0 \cdot psi$ (Assumption 6) in Section 3.1)

Therefore, the stress intensity, SIur, is:

$SIur := \sigma urmax - \sigma urmin \qquad SIur = 9794.7psi$

The peak stresses, Spurmax and Spurmin, are calculated as follows. In Reference 14, theoretical studies are used for determining the stress concentration factors in structural members containing cracks. From Figure 10 of Reference 14, for a thin cross section of 3/32 in., the stress concentration factors are Kt = 1.7 (tension) and Kb = 2.2 (bending). In this analysis, a stress concentration factor of K = 2.2 will be applied directly to the stress intensities.

$K := 2.2$

$Spurmax := K \cdot \sigma urmax \qquad Spurmax = 21548.4psi$

$Spurmin := K \cdot \sigma urmin \qquad Spurmin = 0psi$

$Snr := Spurmax - Spurmin \qquad Snr = 21548.4psi$

The allowable number of cycles for the range of alternating stress intensity (Salt) modified by the ratio of modulus of elasticities for the fatigue curve, Efat, and the carbon steel bar, E, are calculated below:

$Efat := 30.0 \cdot 10^6 \cdot psi \qquad E := 26.98 \cdot 10^6 \cdot psi$

$Eratio := \frac{Efat}{E} \qquad Eratio = 1.112$

Therefore, the alternating stress intensity, Salt, and the number of allowable cycles, Na, are:

$Saltr := \frac{Snr \cdot Eratio}{2} \qquad Saltr = 11980.2psi$

From Figure I-9.1, Reference 4, for the ultimate strength of less than 80 ksi, the number of allowable cycles, Na, at Salt of 11,980.2 psi is infinity (∞). Therefore, the endurance limit is infinite per the ASME Code of Record (Reference 4) that was used in the original stress report (Reference 5).

6.3.3 Stresses in the Lower Weld Region

Stresses in the Lower Weld Area with Original Bar and Weld Thickness:

a,c

σlshear – Shear Stress:

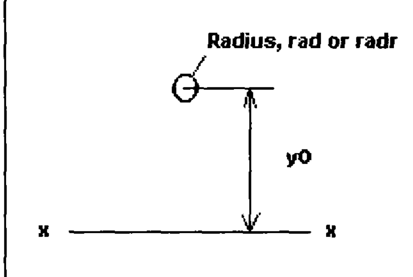
$Sm = 18400psi$ General Membrane Stress for Carbon Steel A-36 at 560 °F

$Sy = 27600psi$ Yield Stress for Carbon Steel A-36 at 560 °F

$\sigma lshear := \frac{WLx}{Alw}$ $\sigma lshear = 12.2psi$ < $0.6 \cdot Sm = 11040psi$

σlbend – Bending Stress:

a,c



$\sigma lbend := \frac{M1 \cdot cl}{IxO}$ $\sigma lbend = 1923.3psi$ < $1.5Sm = 27600psi$

Therefore, the stresses in the lower weld region are below the stress allowables if the bar is broken at tube row location 38 and no yielding occurs in this region. Since the bending stresses in the lower weld region are less than the bending stresses in the upper weld region, the endurance limit will also be infinite.

Stresses in the Lower Weld Area with Reduced Bar and Weld Thickness:

a,c

σlshearr – Shear Stress:

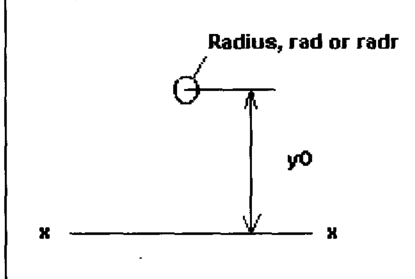
$Sm = 18400psi$ General Membrane Stress for Carbon Steel A-36 at 560 °F

$Sy = 27600psi$ Yield Stress for Carbon Steel A-36 at 560 °F

$$\sigma lshearr := \frac{WLrx}{Alwr} \qquad \sigma lshearr = 12.2psi \quad < \quad 0.6 \cdot Sm = 11040psi$$

σlbendr – Bending Stress:

a,c



$$\sigma lbendr := \frac{Mlr \cdot clr}{IxOr} \qquad \sigma lbendr = 2511psi \quad < \quad 1.5Sm = 27600psi$$

Therefore, the stresses in the lower weld region with a degraded bar thickness and weld size are still below the stress allowables if the bar is broken at tube row location 38 and no yielding occurs in this region. Since the bending stresses in the lower weld region are less than the bending stresses in the upper weld region with a degraded bar thickness, the endurance limit will also be infinite.

6.3.4 Deflection of the Batwing Bar

Two criteria are used in calculating the deflection of the batwing bar with both original and reduced bar thickness. The first criteria considered only the bar's normal weight when no flow loads are opposing the normal weight, such as during plant shutdown or standby operation. The second criteria considers both the bar's normal weight and the opposing flow due to the quasi-static pressure loads discussed in Reference 15. The calculations for these criteria are as follows:

1. Amount of Deflection of the Batwing Bar due to its Normal Weight:

A. With Original Bar Thickness:

a,c

For the Bar Deflection, y:

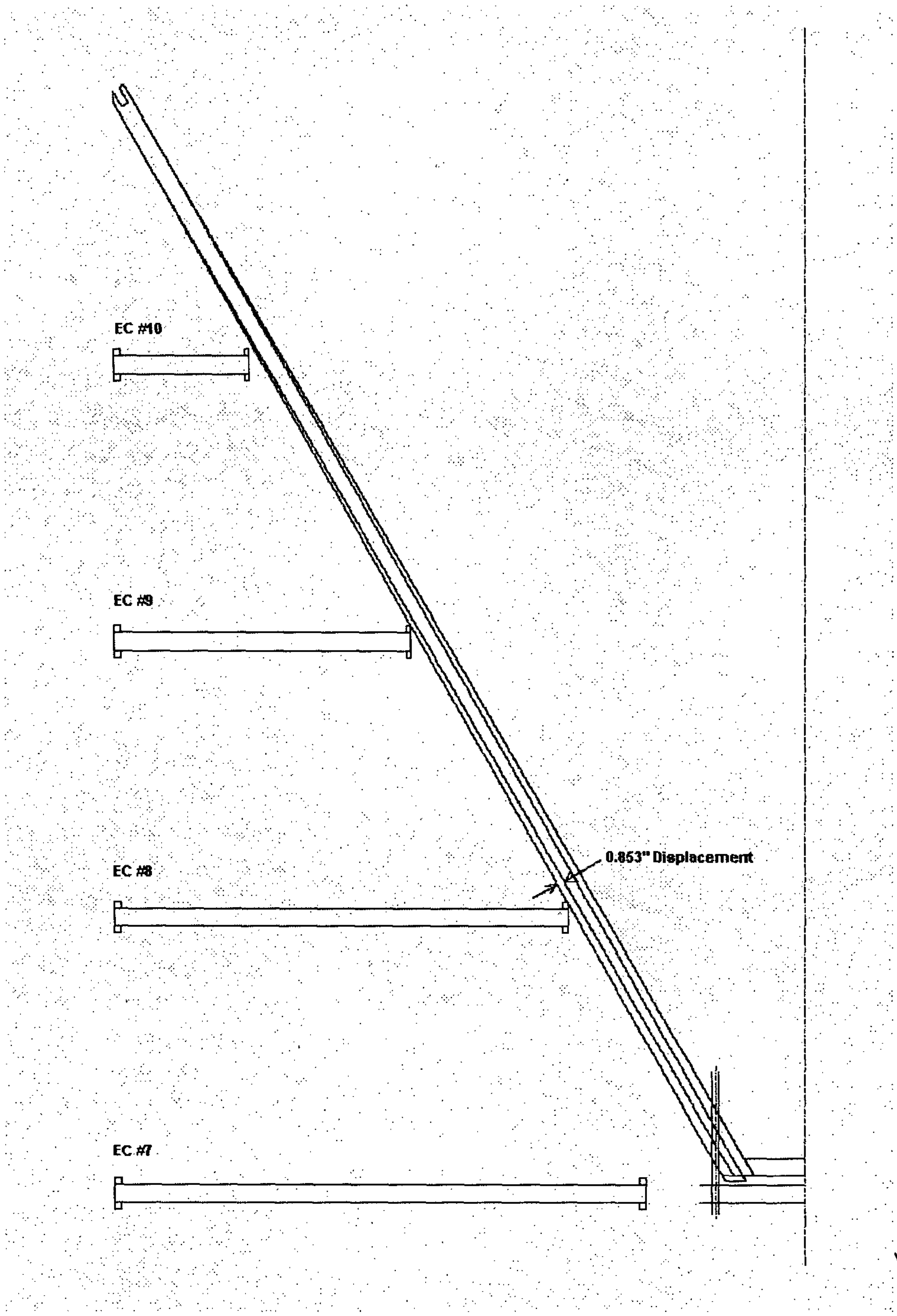
a,c

For the 3/4 x 3/4 Wrapper Bar, the Angle of Rotation or Twist, θ, and the Resulting deflection yy:

a,c

Therefore, the Original Bar will deflect under its own normal weight and will make contact with the first available egg crate support, i.e. EC #8 which is 0.853 inches away as shown in the following figure.

Radial Deflection of the Batwing Bar:



1. Amount of Deflection of the Batwing Bar due to its Normal Weight:
B. With Reduced Bar Thickness:

a,c

For the Bar Deflection, yr:

a,c

For the 3/4 x 3/4 Wrapper Bar, the Angle of Rotation or Twist, θ, and the Resulting deflection yyr:

a,c

Therefore, the Reduced Bar will deflect under its own normal weight and will make contact with the first available egg crate support, i.e. EC #8 which is 0.853 inches away.

2. Amount of Deflection of the Batwing Bar due to its Normal Weight minus the Opposing Flow due to the Quasi-static Loads:

A. With Original Bar Thickness:

a,c

For the Bar Deflection, y:

a,c

For the 3/4 x 3/4 Wrapper Bar, the Angle of Rotation or Twist, θ, and the Resulting deflection yy:

a,c

Therefore, the Original Bar will deflect under its own normal weight but will not make contact with the first available egg crate support, i.e. EC #8 which is 0.853 inches away. [

]a,c

2. Amount of Deflection of the Batwing Bar due to its Normal Weight minus the Opposing Flow due to the Quasi-static Loads: a,c

A. With Reduced Bar Thickness:

[ ]

For the Bar Deflection, yr: a,c

[ ]

For the 3/4 x 3/4 Wrapper Bar, the Angle of Rotation or Twist, θ, and the Resulting deflection yyr: a,c

[ ]

Therefore, the Reduced Bar will deflect under its own normal weight but will not make contact with the first available egg crate support, i.e. EC #8 which is 0.853 inches away. [

]a,c

6.3.5 Maximum Pressure in a Sentinel-Plugged Tube

Table 6-3 shows the spreadsheet developed to calculate fluid pressure in a sentinel-plugged tube during a LOCV transient. Other than the input values described in Section 6.2, fluid conditions are determined from the ASME Steam Tables.

As shown in the table and Figure 6-1, the maximum internal pressure in the tube occurs at 14 to 15 seconds into the transient and is equal to 5402.11 psia. This value is below the minimum external pressure of 6400 psia that would cause a tube plug to leak as shown in Reference 11. It should be noted that tube plug leakage is not a concern during this event since the sentinel plug is designed to leak. Any additional leakage would simply decrease the internal pressure in the tube more quickly.

The primary concern during this event is that the external pressure will not cause the tube plug to collapse or be ejected. In general, as shown in Reference 11, the plug will leak before it is ejected or collapses, thereby reducing the external pressure. However, in one case there was no leakage and the plug collapsed at 9500 psig. Since the external pressure on the sentinel plug will be considerable less than 9500 psig, there will be no adverse effect on the sentinel plug from a LOCV transient.

Another potential concern is that batwing wear scars in sentinel-plugged tubes will grow during the cycle and a LOCV transient will cause multiple tubes to burst during the subsequent overpressure condition in the tubes. If the total leak rate during the transient exceeds the make-up capacity of the charging pumps, the event must be considered a small break LOCA and additional analysis must be performed.

Assuming only one of the three charging pumps is available; make-up water capacity will be limited to 44 GPM. From Reference 12, a typical leak rate from a sentinel plug is approximately 0.1 GPM. From Reference 13, 129 sentinel plugs were installed. Thus, even if all tubes with sentinel plugs are assumed to fail, the leak rate will be less than 13 GPM. This value is well below the make-up capacity of a single charging pump.

It should also be noted that Reference 13 documented a review of the installation records for all the sentinel plugs. Only 10 of the 129 sentinel plugs were installed in tubes that had existing defects. Based on a conservative estimate of the flaw growth rate, only one of the ten tubes has the potential to have a flaw at the end of the cycle that could burst at 5400 psi. Since the primary to secondary leak rate for one sentinel-plugged tube will be less than 0.1 GPM, there are no concerns related to the effect of a LOCV on tubes with sentinel plugs installed or on the sentinel plugs themselves.

Table 6-3

Fluid Pressure as a Result of Loss of Condenser Vacuum Transient

a,c

Figure 6-1
Waterford 3 Steam Generator
Fluid Pressures During Loss of Condenser Vacuum Transient

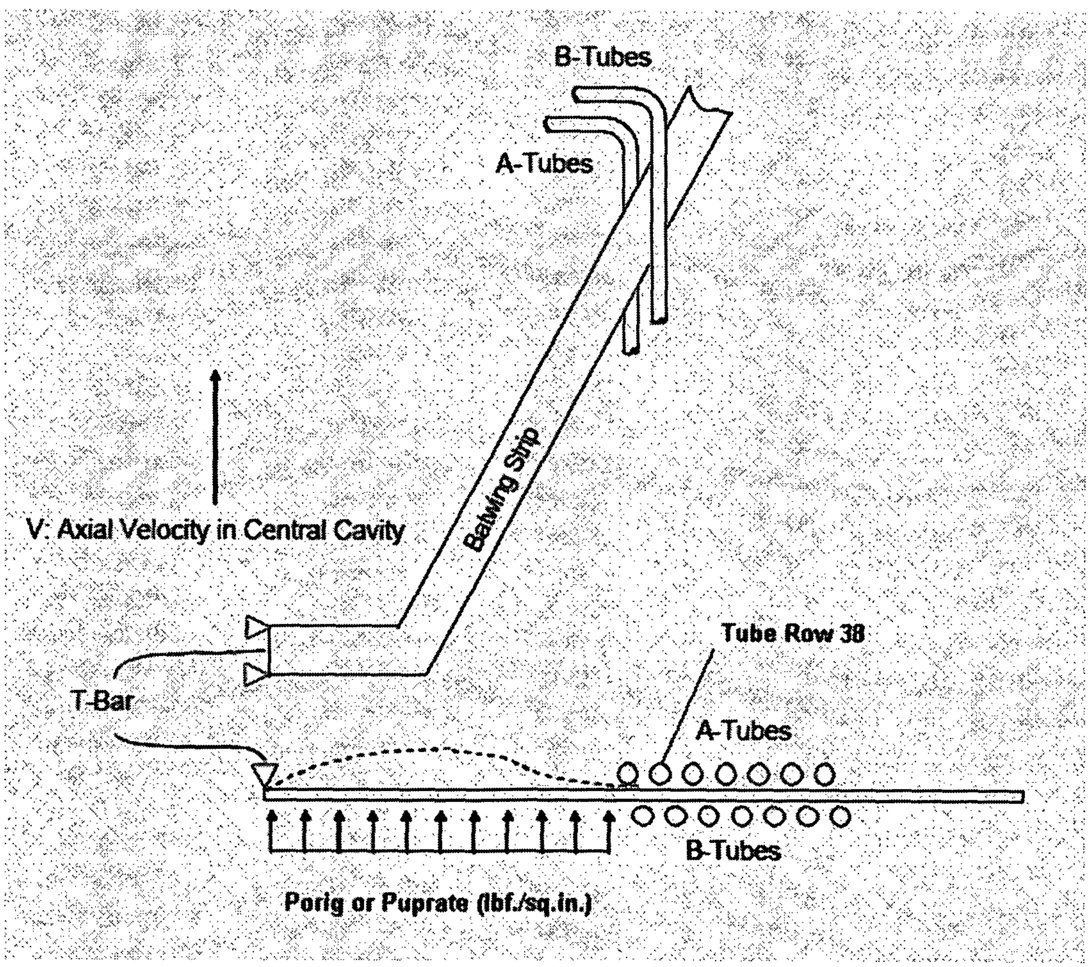
a,c

6.3.6 Effects of the Quasi-Static Pressure Loads on the Batwing Bar

Figure 6-2 represents the wear model with the quasi-static pressure load applied within the central cavity from Reference 15. This figure depicts the vector location of the quasi-static pressure loads (Porig or Puprate) which represent the maximum quasi-static pressure loads for 3390 MWt (Cycle 12) and 3716 MWt with 20% SGTP conditions, respectively. The projected area (Aproj) for the axial direction of the quasi-static pressure loads is conservatively assumed to extend to Tube Row 38 in Figure 6-2, even though the figure shows the quasi-static pressure load ending next to Tube Row 36. The projected area for the reduced bar thickness is Arproj.

Figure 6-2

Wear Model with Quasi-Static Pressure Load applied with the Central Cavity



The forces (Forig and Fuprate) that oppose the y or vertical component of the full Batwing Bar with the original thickness and the forces (Frorig and Fruprate) that oppose the y or vertical component of the full Batwing Bar with reduced bar thickness are calculated as follows:

For the full Batwing Bar with the original thickness, the y component of its weight, Wy, is 3.784 lbf., as calculated in Section 6.3.1.

a,c

[ ]

The maximum quasi-static pressure load is less than 10% of the y component of the Batwing Bar weight with the original bar thickness. Therefore, the failed Batwing Bar with the original bar thickness will not move during normal operation as a result of the maximum quasi-static pressure load application for either the 3390 MWt (Cycle 12) or 3716 MWt (20% SGTP) conditions.

For the full Batwing Bar with the reduced bar thickness, the y component of its weight, Wry, is 2.901 lbf., as calculated in Section 6.3.1.

a,c

[ ]

The maximum quasi-static pressure load is less than 10% of the y component of the Batwing Bar weight with the reduced bar thickness. Therefore, the failed Batwing Bar with the reduced bar thickness will not move during normal operation as a result of the maximum quasi-static pressure load application for either the 3390 MWt (Cycle 12) or 3716 MWt (20% SGTP) conditions.

Since the batwing bar with either the original or reduced bar thickness will not move during normal operation as a result of the maximum quasi-static pressure load application, the stress calculation and its method of analysis for the upper weld region in Section 6.3.2 remains the same.

7.0 References

1. "Nuclear Services Policies & Procedures," WP-4.5 Revision 7, "Design Analysis," effective November 30, 2004.
2. E-mail from Robert F. Keating on "Thoughts on the Separated Batwing Straps," dated May 05, 2005 (attached in Appendix B).
3. Westinghouse Drawing Nos.

   A. E-74270-289-001, Rev. 02, "Tube Support Details Waterford III Steam Generator."

   B. E-74270-291-001, Rev. 00, "Tube Details Waterford III Steam Generator."

   C. E-74270-271-013, Rev. 02, "Tube Bundle Assembly Waterford III Steam Generator."
4. ASME Boiler and Pressure Vessel Code, Section III for Nuclear Power Plant Components, 1971 Edition through Summer 1971 Addenda.
5. Westinghouse Report No. CENC-1246, "Analytical Report for Louisiana Waterford Unit No. 3 Steam Generator," September 1975.
6. "Formulas for Stress and Strain," by R. J. Roark and W. C. Young, McGraw-Hill Book Company, 5th Edition, 1975.
7. Mark's "Standard Handbook for Mechanical Engineers," 8th Edition, 1978.
8. E-mail from Daniel J. Meatheany on "Batwing Welds," dated May 10, 2005 (attached in Appendix B).
9. E-mail from Robert C. O'Quinn on "Digital photo for W3 Batwing," dated May 12, 2005 (attached in Appendix B).
10. NUREG/CR-6664, "Pressure and Leak-Rate Tests and Models for Predicting Failure of Flawed Steam Generator Tubes," US Nuclear Regulatory Commission, August 2000.
11. Westinghouse Test Report TR-9451-CSE95-1102, Revision 3, "Test Report for the Evaluation of a 0.75-Inch (MP) ABB/CE Mechanical Tube Plug Fabricated from Bar Stock for Use in ABB/CE Steam Generators," August 1999.
12. Westinghouse letter LTR-SGDA-05-102, "Waterford 3 Sentinel Plugs Description and Leak Rate," May 2005.
13. E-mail from William K. Cullen on "Sentinel Plugs and Overpressure Concern," dated May 14, 2005 (attached in Appendix B).
14. "The Fatigue Strength of Members Containing Cracks", by W. J. O'Donnell and C. M. Purdy, Transactions of the ASME, May 1964.
15. Westinghouse letter LTR-SGDA-06-181, "Effect of Multiple Batwing Failure on Thermal Hydraulics at Waterford 3 Steam Generators with Power Uprate and 20% SGTP," October 20, 2006.

Appendix A: Computer Run Logs

No configuration controlled computer codes are used in this analysis.

Appendix B: Supporting Documentation

Reference 2: Robert F. Keating E-mail on "Thoughts on the Separated Batwing Straps (Waterford 3)," dated May 05, 2005.

Robert F. Keating/North-America/Westinghouse@Exchange
05/05/2005 08:41 AM

To: Richard D. Reid/North-America/Westinghouse@Exchange, Bruce A. Bell/CENO/USNUS/BNFL-STEAM GENERATORS@ABB_USSEV_IMS
cc:
Subject: FW: Thoughts on the Separated Batwing Straps (Waterford 3)

Security Level:? Internal

-----Original Message-----
From: Maurer, Richard S. (Notes)
Sent: Wednesday, May 04, 2005 11:20 PM
To: Siska, Donald P. (Notes); Cullen, William K.; Keating, Robert F.; Hall, Jeffrey M.
Subject: Thoughts on the Separated Batwing Straps

Regarding the two competing failure mode possibilities discussed to date:

First Hypothesis
The second chemical cleaning dissolved or weakened the weld joining the diagonal and horizontal strip which comprise the lower batwing assembly.

The information supporting this hypothesis is our understanding (from verbal discussions with Dan Meatheany) that the iron step of the chemical cleaning process was particularly aggressive in STEAM GENERATORS 32. There is ECT data which clearly shows that the proximity of the eggcrate straps to the tube is further away than normal. However, the data is qualitative and has not been systematically evaluated or reported other than a very small sample of cold leg eggcrates in STEAM GENERATORS 32 which was done last evening. At our morning meeting today Dan indicated that the carbon steel corrosion was up to 0.021 inches in STEAM GENERATORS 32. I do not know if this is based on test coupons or a calculation. At any rate, this still would leave the batwing at 0.069 inches thick. There was also some speculation that perhaps the corrosion rate would be higher than even the test coupon or calculation showed high in the central cavity region where there isn't magnetite to absorb or buffer the solution. O.K., so assuming this to be true, the batwing is even thinner. Our initial information was that the weld joining the diagonal and horizontal strips was in three short areas (1/4", 1/2", 1/4") and that there was no weld filler material. So it does not require much imagination to envision the corrosive chemicals dissolving the weld resulting in an unrestrained lower end of the diagonal strap.

But there are a few troublesome considerations with this hypothesis. One, only two batwing straps out of almost 350 (between both SGs) have separated. They coincidentally happen to be immediately adjacent to one another. If it is only the dissolution of the weld material which caused the separation it would be a remarkable coincidence that they are adjacent to one another. If the weld is substandard it would be remarkable if there were only two of 350 and they are next to one another. Even if there were a very localized zone where the chemical solution is particularly aggressive it is unlikely that it would be so in such a small area on either side of one tube. So, the next logical deduction would be that all of the welds in the area along the central cavity region were exposed to similar conditions. If this were the case then there must have been some localized mechanical force which caused the two adjacent batwings to separate. But it does not seem likely that the fluid flow would be unique to such a small area; so then why have other welds not failed?

Second Hypothesis
The batwing did not fail at the weld but has been separated by wear from the tube itself.

The second chemical cleaning has dissolved much of the carbon steel as in the hypothesis above. The increased gap between the tube and supports allow a greater degree of relative movement between the two. The number of wear indications and rate of wear are clearly greater now than in the previous cycle, but we have not yet assessed this quantitatively. In terms of the numbers, there is no apparent bias to STEAM GENERATORS 32 which has the separated batwings. The tube line 83 in the middle of the two separated batwing straps which is located at the edge of the stay cylinder may be oscillating in the flow conditions now present in this area and the tube could be impacting the batwing strap on both sides. The tube has more mass and a greater potential to wear through the adjacent batwing supports due to the cable stabilizer which was installed through the u-bend.

If the first hypothesis is correct then any batwing strap in the general area along the central cavity region is equally susceptible, at least in STEAM GENERATORS 32. The near term remedy, in addition to stabilization, is the installation of sentinel plugs on all tubes along the stay cylinder and surrounding the area of tubes preventively plugged prior to operation. The sentinel plugs could be limited to STEAM GENERATORS 32 as this STEAM GENERATORS had significantly higher carbon steel corrosion. If the first hypothesis is correct there are no generic concerns for other C-E units which have not done chemical cleaning but have installed cable stabilizers in plugged tubes around the stay cylinder.

If the second hypothesis is correct, then STEAM GENERATORS 31 is equally susceptible unless an argument can be made that a certain degree of movement is necessary in order for a stabilized tube to wear through a batwing strap (not very convincing if all we have is general corrosion thinning estimates). If the second hypothesis is correct then sentinel plugs are required only in tube columns which have a stabilizer installed and adjacent tubes. If hypothesis two is correct then there are generic issues for other C-E plants.

The current plan is to de-plug three tubes immediately above the stabilized tubes on columns 84, 83, & 82 to conduct MRPC testing. We need to figure out whether this test will definitively discriminate the two hypothetical conditions. If it is the stabilized tube which has worn through the batwing as opposed to weld failure at the intersection of the diagonal and horizontal strips, then there may be evidence on the low frequency ECT data. Its something that we should probably mockup and test if hypothesis two is considered credible.

Don, I think that you mentioned in one of our phone calls that Bill Heilker recalled that an analysis had been done years ago which showed that the tube itself would not be expected to wear through a batwing strap. Could you find out whether this analysis considered the mass of the tube with a stabilizer installed and how sensitive the analysis is to freedom of movement within the gap between supports?

Talk to you in the A.M.

Thanks,
Rick

Reference 8: Daniel J. Meatheany E-mail on "Batwing Welds," dated May 10, 2005.

"MEATHEANY, DANIEL J" <DMEATHE@entergy.com>
05/10/2005 11:58 PM

To: Distribution list with 8 recipients.
"'Don Siska (estin.p.siska@us.westinghouse.com)'" < estin.p.siska@us.westinghouse.com>
"'Bob Keating'" <keatinrf@westinghouse.com>
"'cullenwk@westinghouse.com'" <cullenwk@westinghouse.com>
"O'QUINN, ROBERT C" <ROQUINN@entergy.com>
"WEBER, DARRELL" <DWEBE91@entergy.com>
"ROCKWOOD, KEITH J" <KROCKWO@entergy.com>
"ADDISON, EDWARD E" <EADDISO@entergy.com>
"GREESON, WILLIAM C" <WGREESO@entergy.com>

cc: Distribution list with 3 recipients.
"TUCKER, ODIE K" <OTUCKER@entergy.com>
"OSBORNE, RONALD L" <ROSBORN@entergy.com>
"RICKER, BRIAN KEITH" <BRICKER@entergy.com>
Subject: Batwing Welds

Security Level:? Internal

Don and Bob,

a,c

[ ]

Dan Meatheany

Reference 9: Robert O'Quinn E-mail on "Digital Photo for W3 Batwing," dated May 12, 2005.

"O'QUINN, ROBERT C" <ROQUINN@entergy.com>
05/12/2005 09:52 AM

To: "'Donald.P.Siska@us.westinghouse.com'" <Donald.P.Siska@us.westinghouse.com>
cc:
Subject: Digital photo for W3 Batwing

Security Level:? Internal

- W3_SG32_BW.JPG

a,c

Reference 13: William K. Cullen E-mail on "Digital Photo for W3 Batwing," dated May 14, 2005.

William K. Cullen/North-America/Westinghouse@Exchange
05/14/2005 11:34 AM

To: Donald P. Siska/CENO/USNUS/BNFL-STEAM GENERATORS@ABB_USSEV_IMS, "O'QUINN, ROBERT C" <ROQUINN@entergy.com>@SMTP@Exchange
cc: William K. Cullen/North-America/Westinghouse@Exchange
Subject: Sentinel plugs and overpressure concern

Security Level:? Internal

I have reviewed installation records for sentinel plugs with a breakdown as follows.

STEAM GENERATORS31

a,c

STEAM GENERATORS32

a,c

Bill Cullen

Figure 15.2-4 from the Waterford 3 FSAR

a,c

Figure 15.2-5 from the Waterford 3 FSAR

a,c

Calculation Note Number	Revision	Page
CN-SGDA-05-36-NP	1	41

Figure 15.2-7 from the Waterford 3 FSAR

a,c

[ ]

Checklist A: Proprietary Class Statement Checklist

a,c

Checklist B: Calculation Note Methodology Checklist

a,c

Checklist C: Verification Methodology Checklist

a,c

Additional Verifier's Comments

a,c

WESTINGHOUSE ELECTRIC COMPANY LLC

Calculation Note Number	Revision	Shop Order Number	Charge Number	Page
CN- SGDA-06-89-NP	1	120	116832-0229	1
Project	Releasable (Y/N)	Open Items (Y/N)	Files Attached (Y/N)	Total No. Pages
Loose Part Evaluation of Waterford Unit 3	Y	N	N	44

Title: Evaluation Of the Loose Part In the Secondary Side of Waterford Unit 3 –Model 70 OSG Steam Generator–Fall 2006 Outage

Author(s) Name(s)	Signature / Date	For Pages
T. S. Magge	***Electronically Approved****	All
Verifier(s) Name(s)	Signature / Date	For Pages
A.L. Thurman	***Electronically Approved****	All
Manager Name	Signature / Date	
P.R. Nelson	***Electronically Approved****	

"Notice- The use of the words flaw and/or defect, and failure and/or fracture as may be contained herein is derived directly from the ASME Code and used for that purpose only."

***** Electronically approved records are authenticated in the Electronic Document Management System.***

Westinghouse

Record of Revisions

Rev	Date	Revision Description
0	N/A	Non-proprietary version (Rev (0) was not required . This Revision (0) document does not exist.
1	See EDMS	Non-proprietary Version of CN-SGDA-06-89(Rev 1) was prepared at customer request.

Table of Contents

1.0 Introduction

1.1 BACKGROUND / PURPOSE

During the Fall 2006 refueling outage at Waterford Unit 3 SG 31 Model 70 OSG , Foreign Object Search and Retrieval (FOSAR) identified a screw in the secondary side of the steam generator. This is identified below.

This calculation note was prepared according to Westinghouse Procedure WP 4.5.

1.2 LIMITS OF APPLICABILITY

Waterford Unit 3 SG31-Model 70 OSG

2.0 Summary of Results and Conclusions

The effect of leaving the foreign object known to be present in the secondary side of the steam generators has been determined. Wear time calculations have been performed to estimate the amount of time necessary to wear the tube down to a minimum acceptable tube wall thickness of 28.8 mils. (60% remaining). These calculations have determined that the amount of time required for the foreign object identified required to wear a tube down to minimum allowable thickness of 0.0288"(60% remaining) is greater than one fuel cycle or 1.5 years.

The calculated wear times for the object known to be in the steam generator are shown in Table 2-1 for different orientations . As can be seen therein, the foreign object has wear times that exceed 1.5 years or one fuel cycle.

Missing Screw evaluated for two sizes.

Screw –Case 1) 1/8" diameter x 0.375 " long

Case 2) #8-32---0.164" diameter x 0.375" long

2) Bat wing piece—7." Long x 2.0" wide

Table 2-1

Case 1 –Screw- 1/8" diameter x 0.375" Long

Results of Wear Summary for Different Orientations

a,c

Loose Part -# 2 Batwing Wear Results

a,c

[ ]

3.0 Assumptions and Open Items

3.1 DISCUSSION OF SIGNIFICANT ASSUMPTIONS

The input constants for wear calculations in this analysis are based on the wear input data Reference 5, which are based on the References 2 and 3. These data are appropriate for use in this evaluation.

1. The objects are assumed to either (note the analysis considers both options):
   a. Remain stationary - When the objects are assumed to be stationary they do not move from that location for the entire period of time. All wear occurs on the tube(s) in contact with the object. This will result in deeper wear depths; or
   b. Move - When the objects are assumed to move, the velocity of the objects are the same as the fluid velocity outside the tube bundle. No credit is taken for reduction of the objects velocity as a result of impacting the various secondary side components.
2. The object is assumed to be present at the location where the secondary side cross flow fluid velocities and the turbulent amplitudes of tube vibration are largest (i.e., a peripheral location).
3. The object on the hot leg tubesheet is located on a sludge pile 7 inches deep. Objects in the steam generator are assumed to be on a sludge pile 7 inches high. The tubes are assumed to have an existing 20% through-wall wear scar and the structural limit for the tube for wear is 28.8 mils, 60% wall remaining. (Reference 5).

   The object only wears a single tube. With the entire work rate concentrated on a single tube, a reduced wear time will result.

3.2 OPEN ITEMS

None

4.0 Acceptance Criteria

The analysis will determine the amount of time required for the foreign object to wear the tube down to 28.8 mils of wall thickness (60% remaining) assuming the tube has an initial 20% through-wall wear scar. The minimum wear time should be greater than one fuel cycle or 1.5 years

5.0 Computer Codes Used In Calculation

Table 5-1
Summary of Computer Codes Used in Calculation

Code No.	Code Name	Code Ver.	Configuration Control Reference	Basis (or reference) that supports use of code in current calculation
1	WEART.xls	0	Reference 6	The spreadsheet was written to calculate the time required for a foreign object to wear down a tube to a given wear depth. This is the purpose for which it was used.
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

6.0 Calculations

Calculations have been performed to determine the limiting (shortest) time for the foreign object to wear a tube down to the minimum allowable tube wall thickness of 0.0288 inch (60% remaining) (Reference 2). Wear times are calculated by using the wear time spreadsheet WEART.XLS (Reference 6). The effects of impacting only have also been addressed.

The following section contains calculations performed to determine the effects of the loose part found inside the steam generator

6.1 METHOD DISCUSSION

The method of evaluation is done in the same way as is done in Reference 1 and it will not be repeated here.

6.2 INPUT

Loose part size = 1/8" dia x 0.375" long or # 8-32 size (0.164" 0 x 0.375" long- See. (Reference Appendix B-Correspondence)

1) Pre-existing wear depth = 0% (However, analysis conservatively assumes an initial 20% deep wear scar.)

2) Wear time Matrix Input = See Tables 6.2-1 obtained from Reference 5.

3) Tube dent size versus impact energy = See Figure 6.3-1 Obtained from Reference 7.

4) Vp = Peripheral Gap Velocity (ft/sec) = [ ]^{a,c}

5) P = Tube Pitch = 1.00 inch (Reference 2)

6) D = Tube Outside Diameter = 0.750 inch (Reference 2)

7) Density = 49.2 lbs/ft ^{3}(Reference E-mail dated 12/11/06)

8) t_{min} = 0.0288" (60% remaining)

Table 6.2-1

a,c

[ ]

6.3 EVALUATIONS, ANALYSIS, DETAILED CALCULATIONS AND RESULTS

Calculations were performed to determine the wear times of loose parts using the same assumptions used in Reference 1 and it is not repeated here.

Screw : Case 1) 1/8" dia x 0.375" long
Case 2) #8-32 size screw- 0.164" dia x 0.375" long

Table 6.3-1

No	Loose part	Flow area	wear height
Case 1	Screw -1/8" dia x 0.375"Long	[ ]^{a,c}	[ ]^{a,c}
Case 2	Screw -#10- size 0.164" dia x 0.375" L	[ ]^{a,c}	[ ]^{a,c}

Table 6.3-2

a,c

[ ]

Table 6.3-3

a,c

a,c

Table 6.3-4

[ ]

a,c

Table 6.3-5

a,c

Table 6.3-6

6.3.1 Batwing Piece Evaluation-(7.0" L x 2.0" wide)(D.Sisco)

To determine the effect of loose part wear at the tubesheet, it was assumed that half of the horizontal section (7 inches long by 2 inches wide broke off from the diagonal bar and fell to the central region of the tubesheet. Based on flow velocities in this region, the batwing piece could travel a small distance into the tube bundle. However, if it does, the flow rates decrease and the wear would be applied to more than one tube. The worst case would be if the piece fell vertically and leaned against the tube causing a 90° wear scar.

For conservatism, wear against a single tube is postulated. The cross flow velocity and density corresponding to the central region of the tubesheet, from Reference 3, is used for this location (see input parameters on page 22). As shown in Table 6.3.1, the wear time for this orientation shows acceptable wear time of greater than one cycle.

Note that there are two significant conservatisms associated with this evaluation. The flow velocity was assumed to be a shade flow when it was actually closer to an approach velocity. In addition, the batwing material was made from carbon steel. The reduction in wear coefficients would increase the time required to wear the tube to a 40% through-wall wear scar.

In conclusion, a 7-inch x 2" loose part made from batwing material can not cause a wear scar greater than 40% through-wall if it falls to the top of the tubesheet.

a,c

Table 6.3.1

In addition to wear, the potential for the batwing piece to cause damage to a tube from reverse flow during an accident was investigated. As described in LTR-SGDA-06-225, steam line break flow rates are assumed to be four times the normal flow rate or approximately 15 ft/sec. Based on tests performed by Westinghouse an object of this size could be expected to cause a dent in a steam generator tube of no more than approximately 11 mils. A dent of this size will not cause a tube leak.

Input used for Batwing Calc

a,c

a,c

6.4 IMPACTING ONLY CALCULATIONS

[ ]

Figure 6-1

a,c

7.0 References

1. "Calculation Note CN-SGD A-05-30, Revision 0, "Evaluation Of Foreign Objects in the Secondary Side of the Comanche Peak Unit 2 Steam Genertors- Spring 2005 Outage, D.P. siska. .
2. Calculation Note CN-SGDA-03-66 Revision 0, Flow –Induced Vibration Analy sis of Waterford-3 At 3716 Mwt Power Uprate Conditions, J. M. Hall
3. Calculation Note: CN-SGDA-03-25: Thermal Hydraulic Analysis Of Waterford-3 Steam Generators at 3716 Mwt Power Uprate Conditions, J. G. Thakkar.
4. E-mail from D. P. Siska , 12/11/2006 2:07 PM Gap Velocities and density for the Loose parts analysis., , (Appendix B, Page 24).
5. E-mail from D.P. Siska , " Wear input Spread sheet, (Appendix B, Page, Page 22).
6. Westinghouse Letter Report No. NSD-E-SGDA-99-234, "Engineering Services Abbreviated Y2K Assessment for SRANDPRO.XLS, DAMPING.XLS, WEART.XLS, FSTAR3_4.WKS, FSTAR7_8.WKS, and WEAKLINK.XLS", from Irina Haljasmaa to Distribution, June 28, 1999.
7. WTD-SM-75-115, "Tube Dent Experiments", J. A. Pyle, 1975.

Appendix A: Computer Run Logs

No Computer runs were generated

Computer Run Log Summary

None were generated

Appendix B: Supporting Documentation

-----Original Message-----
From: Siska, Donald P. (Notes)
Sent: Monday, December 11, 2006 9:35 AM
To: Magge, Tandav S.
Cc: Jenko, James X.; Hall, Jeffrey M.; Merkovsky, Daniel; Nelson, Peter R. (Notes)
Subject: Waterford Weart

Tandav,

Here is the weart spreadsheet I put together for Waterford last year. Note that we never formally used it so each of the inputs will have to be verified. I included a reference for each of the inputs (either a drawing or calc) so that should help. I will send a separate email with more information about the screw.

Thanks for your help.

Don

Waterford Batwing Wear Calc.xl...

-----Original Message-----
From: Siska, Donald P. (Notes)
Sent: Monday, December 11, 2006 10:09 AM
To: Neyman, Glen S. (Notes); Thakkar, Jivan G. (Notes)
Cc: Magge, Tandav S.; Hall, Jeffrey M.; WGREESO@entergy.com; Thakkar, Jivan G. (Notes); Baron, Jesse S.
Subject: FW: Picture of the Missing Screw

Glenn,
I know we talked about the subject screw but I don't remember what was said. Could you give me your best estimate of the type and size of the screw so we can do a more formal evaluation. An email response is fine. I believe it was found in the annulus not too far from the tube lane so the velocity should be pretty high.

Jivan,
Do you have the max fluid conditions for Waterford. Somewhere near the tube lane in the annulus.

Thanks,
Don

---------------------- Forwarded by Donald P. Siska/CENO/USNUS/BNFL-TEMP on 12/11/2006 09:44 AM ---------------------------

"O'QUINN, ROBERT C" <ROQUINN@entergy.com>
12/11/2006 09:23 AM

To: <Donald.P.Siska@us.westinghouse.com>
cc:
Subject: FW: Picture

Security Level:? Internal

-----Original Message-----
From: Glen.S.Neyman@us.westinghouse.com [mailto:Glen.S.Neyman@us.westinghouse.com]
Sent: Sunday, December 10, 2006 12:47 PM
To: O'QUINN, ROBERT C
Subject: Picture

AOI_2.jpg (206 KB)

- AOI_2.jpg

-----Original Message-----
From: Siska, Donald P. (Notes)
Sent: Monday, December 11, 2006 3:22 PM
To: Magge, Tandav S.
Cc: Thakkar, Jivan G. (Notes); Hall, Jeffrey M.
Subject: RE: *Picture of the Missing Screw*

Tandav,

Confirmed. That looks like the right data to be using.

Don

Tandav S. Magge/North-America/Westinghouse@Exchange
12/11/2006 02:55 PM

a,c

[ ]

Gap velocities for the weart calc should be adjusted as described by Jivan below. Let me know if you need anything else.

Don

--------------------- Forwarded by Donald P. Siska/CENO/USNUS/BNFL-TEMP on 12/11/2006 02:03 PM ---------------------------

Jivan G. Thakkar/CENO/USNUS/BNFL-TEMP
12/11/2006 12:53 PM (Phone: +1 423 752-2791, Dept.: SG Design and Analysis)

To: Donald P. Siska/CENO/USNUS/BNFL-TEMP@ABB_USSEV_IMS
cc:
Subject: Picture of the Missing Screw << OLE Object: StdOleLink >>

Security Level:? Internal

These are velocities in the annulus.
Gap velocities will be a factor of 3 higher, or 4, (P/(P-D)), if you want to be conservative.
Jivan

Donald P. Siska/CENO/USNUS/BNFL-TEMP
12/11/2006 11:46 AM (Phone: +1 423-752-2833, Dept.: SG Design and Analysis)

To: Jivan G. Thakkar/CENO/USNUS/BNFL-TEMP@ABB_USSEV_IMS
cc: Jeffrey M. Hall/North-America/Westinghouse@Exchange, Jesse S. Baron/North-America/Westinghouse@Exchange
Subject: Re: FW: Picture of the Missing Screw << OLE Object: StdOleLink >>

Security Level:? Internal

Thanks Jivan but please try to provide more significant figures the next time. On the other hand, nevermind.

Is the flow value just a free stream velocity or is it a gap velocity. If it is not a gap velocity, how do I change it into a gap velocity.

Thanks,
Don

Jivan G. Thakkar/CENO/USNUS/BNFL-TEMP
12/11/2006 10:49 AM (Phone: +1 423 752-2791, Dept.: SG Design and Analysis)

a,c

[ ]

Donald P. Siska/CENO/USNUS/BNFL-TEMP
12/11/2006 10:09 AM (Phone: +1 423-752-2833, Dept.: SG Design and Analysis)

To: Glen S. Neyman/CENO/USNUS/BNFL-TEMP@ABB_USSEV_IMS, Jivan G. Thakkar/CENO/USNUS/BNFL-TEMP@ABB_USSEV_IMS
cc: Tandav S. Magge/North-America/Westinghouse@Exchange, Jeffrey M. Hall/North-America/Westinghouse@Exchange, WGREESO@entergy.com, Jivan G. Thakkar/CENO/USNUS/BNFL-TEMP@ABB_USSEV_IMS, Jesse S. Baron/North-America/Westinghouse@Exchange
Subject: FW: Picture of the Missing Screw

Security Level:? Internal

Glenn,

I know we talked about the subject screw but I don't remember what was said. Could you give me your best estimate of the type and size of the screw so we can do a more formal evaluation. An email response is fine. I believe it was found in the annulus not too far from the tube lane so the velocity should be pretty high.

Jivan,
Do you have the max fluid conditions for Waterford. Somewhere near the tube lane in the annulus.

Thanks,
Don

---------------------- Forwarded by Donald P. Siska/CENO/USNUS/BNFL-TEMP on 12/11/2006 09:44 AM ---------------------------

"O'QUINN, ROBERT C" <ROQUINN@entergy.com>
12/11/2006 09:23 AM

To: <Donald.P.Siska@us.westinghouse.com>
cc:
Subject: FW: Picture

Security Level:? Internal

-----Original Message-----
From: Glen.S.Neyman@us.westinghouse.com [mailto:Glen.S.Neyman@us.westinghouse.com]
Sent: Sunday, December 10, 2006 12:47 PM
To: O'QUINN, ROBERT C
Subject: Picture

- AOI_2.jpg << File: AOI_2.jpg >>

-----Original Message-----
From: Siska, Donald P. (Notes)
Sent: Monday, December 11, 2006 4:41 PM
To: Magge, Tandav S.
Cc: Hall, Jeffrey M.
Subject: RE: Picture of the Missing Screw

Thanks Tandav.

Could you put a letter together with these results that can be transmitted through the Project Office. It would be nice if you could get it out this week.

Appreciate your help.

Don

Tandav S. Magge/North-America/Westinghouse@Exchange
12/11/2006 04:25 PM

To: Donald P. Siska/CENO/USNUS/BNFL-TEMP@ABB_USSEV_IMS
cc: Jeffrey M. Hall/North-America/Westinghouse@Exchange, Tandav S. Magge/North-America/Westinghouse@Exchange
Subject: RE: Picture of the Missing Screw

Security Level:? Internal

Don

I ran two cases-1) 1/8" dia x 0.3/8" long
Case 2) # 10-32 (size 0.164" dia) -Machinary Hand book

I used revised velocity and ran different cases. The minimum wear time is greater than 3 years.
I am herewith sending the calculated spreadsheet and the summary of the results.

Tandav

Waterford Batwing Wear Calc.ma... SummaryScrewwaterford.doc (39 ...

-----Original Message-----
From: Siska, Donald P. (Notes)
Sent: Monday, December 11, 2006 3:22 PM
To: Magge, Tandav S.
Cc: Thakkar, Jivan G. (Notes); Hall, Jeffrey M.
Subject: RE: Picture of the Missing Screw

Tandav,
Confirmed. That looks like the right data to be using.

Don

Tandav S. Magge/North-America/Westinghouse@Exchange

12/11/2006 02:55 PM

a,c

[ ]

a,c

a,c

a,c

a,c

[ ]

a,c

Checklist A: Proprietary Class Statement Checklist

a,c

Checklist B: Calculation Note Methodology Checklist

a,c

[ ]

a,c

Checklist C: Verification Methodology Checklist

a,c

Additional Verifier's Comments

Westinghouse

Westinghouse Electric Company
Nuclear Services
Waltz Mill Service Center
P.O. Box 158
Madison, Pennsylvania 15663
USA

Mr. Rex Putnam
Entergy Nuclear Operations
Waterford Nuclear Plant
17265 River Road
Killona, LA 70057

Direct tel: 724-722-5692
Direct fax: 724-722-5166
e-mail: stickemm@westinghouse.com

Our ref: CWTR3-06-94, Rev. 1

February 16, 2007

Entergy Nuclear Operations
Waterford 3
Batwing Loose Part Impact on Tube Rupture

Dear Mr. Putnam,

The purpose of this letter is to (1) evaluate the incremental impact of displaced and potential loose batwing parts on the probability for heat transfer tube rupture and (2) evaluate the impact of batwing loose part induced tube rupture on the hypothetical Main Steam Line Break (MSLB) analysis results. Potential batwing loose parts in steam generator 32 include (1) the long "hockey stick" formed by a diagonal bar and one half of a horizontal bar between columns 84 and 85 hot leg which has dropped down a few inches due to a failure of the wrapper bar weld, (2) the 7 inch long half horizontal bar, which is currently residing atop several twisted batwing ends on the cold side and (3) two 7 inch long half horizontal bars between column 82, 83 and 84 cold leg which have broken welds at the diagonal bars and can be anticipated to break off at their center slots.

All four of the loose and potential loose parts identified above are currently residing in the central tube bundle cavity, near the top. These or other similar loose objects have the potential to become active under flow loading during power operation. During power operation the flow patterns on the secondary (shell) side of the steam generators is radially inward into the central cavity from the tubesheet through the top (7^{th}) full "eggcrate" tube support and vertically upward throughout the cavity. It would not be possible for the batwing parts to migrate to the peripheral downcomer region or radially outward into the tube lane because of the strong radially inward flow. While it is possible that batwing parts might lodge between tubes on the edge of the central cavity near the tubesheet, several rows of those tubes are plugged and the inner row is mostly stabilized with stainless steel cables, which would preclude cascading tube damage.

Therefore it is concluded that there is no incremental impact of displaced and potential loose batwing parts on the probability for steam generator tube rupture. It then follows that there is no impact of batwing loose part induced tube rupture on the hypothetical Main Steam Line Break (MSLB) analysis results.

If you have any questions on this information, please contact Peter Nelson at 860-731-6689.

Very truly yours,

Mark M. Stickel
Customer Project Manager

/krs

cc: Bruce Williams
Dave Morris
Joe Kowalewski
Jim Wyble
Peter Nelson
Tony Dietrich
Dave Bonadies

Westinghouse

To: M.M. Stickel

cc: W.K. Cullen, T.A. Gurney, R.S. Maurer, J.F. Mermigos, S.R. O'Niell, D.G. Stepnick, G.W. Whiteman

Date: February 14, 2007

From: D.P. Siska
Ext: 423-752-2833
Fax: 423-752-2449

Your ref:
Our ref: LTR-SGDA-05-100-NP, Rev. 1

Subject **Westinghouse Recommendations to Address Detached Batwings in the Waterford 3 Steam Generators**

Reference:

1. Westinghouse Letter LTR-CDME-05-97, *Waterford 3 RF13 Stabilization and Plugging Plan: Option 1*, May 5, 2005.
2. Westinghouse Letter LTR-CDME-05-99, *Waterford 3 RF13 Stabilization and Plugging Plan: Option 2 SG32*, May 6, 2005.
3. Westinghouse Letter LTR-CDME-05-100, *Waterford 3 RF13 Stabilization and Plugging Plan: Option 2 SG31*, May 6, 2005.
4. Westinghouse Letter LTR-CDME-05-101, *Waterford 3 RF13 Stabilization and Plugging Plan: Option 3 SG32*, May 6, 2005.
5. Westinghouse Letter LTR-CDME-05-102, *Waterford 3 RF13 Stabilization and Plugging Plan: Option 3 SG31*, May 6, 2005
6. Westinghouse Calculation Note CN-SGDA-03-66, Revision 2, *Flow-Induced Vibration of Waterford 3 at 3716 Mwt Power Uprate Conditions*, March 2004.
7. Westinghouse Calculation Note CN-SGDA-05-36, Revision 0, Evaluation *of the Upper Batwing Weld for the Waterford 3 Steam Generators at 3716 MWt Power Uprate Conditions*, to be issued.

This letter was revised to change the classification from Proprietary Class 2 to Non-Proprietary Class 3.

Background

The Waterford 3 steam generator batwings provide tube support to prevent unacceptable tube vibrations during normal plant operation. They are not required to mitigate accident conditions (e.g., LOCA or steam line break). Thus, the actions presented herein address those actions necessary to reduce the potential for tube damage from flow-induced vibration and associated tube wear. Note that these actions assume that the upper weld that attaches the batwing to the wrapper bar is intact. Based on this assumption, the batwing, even if is detached at the lower attachment point, will provide support against tube vibration above partial eggcrate 9.

Although the specific root cause for the detached batwings has not yet been identified, there are several actions that can be taken that will reduce the potential for tube damage during the next operating cycle.

These actions are designed to take a "defense in depth" approach by addressing both the local issues associated with the two known batwing failures and by addressing the global issues associated with the potential for additional batwing failures during the upcoming operating cycle.

Actions to Address Known Batwing Failures in Steam Generator 32 (Option 1-32)

As noted above, the two batwings that have detached near their lower attachment point will still provide some amount of tube support above partial eggcrate 9. Hence, the only tubes that require plugging and/or stabilizing are those tubes that are adjacent to the failed batwings (columns 82, 83 and 84) and are located between partial eggcrates 8 and 9. The tubes in columns 82 through 84 below partial eggcrate 8 have already been preventively plugged.

The recommended plugging and stabilizing plan to address the known batwing failures is presented in Reference 1. This plan limits the motion of the failed batwings with strategically placed stabilizers and/or plugged tubes and provides protection against tube failure in tubes adjacent to these columns.

Actions to Address Potential Precursors in Steam Generators 32 and 31 (Options 2-32 and 2-31)

During the review of the eddy current results in steam generators 32 and 31, patterns emerged that might indicate an impending failure of another batwing. Several tubes along some columns have shown larger than expected growth rate in wear scars. Although the cause of this condition has not been determined, it could be related to more flexibility in the adjacent batwing. As a result, Westinghouse recommends additional plugging and stabilizing as detailed in References 2 and 3.

Actions to Address the Potential of Further Batwing Failures in Steam Generator 32 (Option 3-32)

Westinghouse has considerable data to define the batwing wear issue associated with intact batwings. However, these data can not be used to establish the behavior of detached batwings. While it is likely that future damage would be limited to the high-flow areas (i.e., those areas that have already been preventively plugged), additional tube damage interior to the tube bundle can not be ruled out. Therefore, Westinghouse recommends that potentially affected tubes in the stay cylinder region be "boxed-in" with sentinel plugs. The pattern to be used to install sentinel plugs is shown in Reference 4.

Actions to Address the Potential of Batwing Failures in Steam Generator 31 (Option 3-31)

Although there are no know failures of batwings in steam generator 31, a review of the eddy current results shows what may be precursors to a failure. Given that a root cause for the failures in steam generator 32 has not been identified, Westinghouse can not rule out potential similar batwing failures in steam generator 31. Therefore, Westinghouse recommends sentinel plugs also be installed in steam generator 31. The plugging pattern to be used is shown in Reference 5.

Basis for Repairs

As noted previously, the batwings are not required for accident mitigation. Therefore, the repairs (plugging, stabilizing and sentinel plugs) are primarily designed to address flow-induced vibration and associated tube wear. Short stabilizers installed in columns 63, 64, 112 and 113 near the stay cylinder are designed to protect against the possibility that part of the batwing may become a loose part.

The activities described above address the remedial actions necessary to minimize the possibility of significant tube degradation (i.e., wear scars greater than the structural limit) during the next operating cycle at Waterford 3. Specifically, these activities address the following conditions:

- Potential flow-induced vibration of the detached batwing. Fluid forces in the stay cylinder cavity or in the tube bundle will likely cause the detached batwing to vibrate in a manner not previously evaluated. Based on general vibration theory, the largest amplitudes of vibration will be near the detached end of the batwing. Amplitudes should decrease as the tube row numbers increase. Therefore, tubes along each detached batwing (those in columns 82, 83 and 84) have been plugged or plugged and stabilized up to partial eggcrate 9. After this location the vibration is expected to be sufficiently attenuated such that significant tube wear is not expected
- Unsupported tubes: The detached batwings may not provide the same support condition assumed in the Reference 6 vibration analysis. As described above, tubes that may experience unacceptable vibrations from this support condition have either been identified to be either plugged or plugged and stabilized.
- Batwings more likely to fail during the upcoming cycle: Eddy current results have been interpreted to indicate that additional batwings might be subject to failure during the upcoming outage. Appropriate tubes were identified to be plugged or plugged and stabilized to address this concern.
- Unexpected batwing failures during the upcoming cycle: Since the root cause of the detached batwing has not been determined, unexpected batwing failures must be considered during the upcoming cycle. It is Westinghouse's expectation that if tube damage from a detached batwing occurs, it would be most likely to occur in high flow areas near the stay cylinder. These areas have already been plugged or plugged and stabilized to address the previous batwing wear concerns.

  However, since the extent of tube damage that could be expected by a detached batwing has not been determined, sentinel plugs have been identified to be installed around the high flow region near the stay cylinder. They have been installed in those tubes considered to have the highest probability of tube damage if a detached batwing occurs during the cycle. While significant tube damage is not considered likely, the sentinel plugs will provide early detection of unexpected damage and allow the plant to shut down with a relatively small primary to secondary leak

Other Considerations

As discussed previously, the detached batwings are still credited with providing support for those tubes that go through partial eggcrates 9 and 10. To ensure the batwing will remain in place, the upper weld must be able to support the batwing during normal operation. Preliminary calculations have shown that because of the "dropped" batwing configuration, bending stresses on the weld exceed yield; however, it is not expected to fail. Westinghouse is currently documenting these evaluations in Reference 7.

Following plant restart, Westinghouse will perform additional calculations in an attempt to determine the potential tube damage that could occur from a detached batwing. It is anticipated that these calculations will support the Operational Assessment and allow Waterford to complete a full 18-month cycle. However, this condition has not previously been evaluated and additional study is required to determine the full effect of this condition

Conclusions

Completion of the above actions provides reasonable assurance that the detached batwings on either side of Column 83 in steam generator 32 will not cause tube wear to exceed the structural limit during the upcoming operating cycle. These actions also provide reasonable assurance that additional batwing failures in either steam generator 31 or 32 will not cause uncontrolled primary to secondary leakage.

Please call me at 423-752-2833 if there are any questions or if additional clarification is required.

Author: D.P. Siska
Steam Generator Design and Analysis

Reviewed By: J.M. Hall
Steam Generator Design and Analysis

Westinghouse

To: J. M. Hall
R. F. Keating
J. F. Mermigos
W. K. Cullen
E. P. Morgan

cc: D. P. Siska
B. A. Bell
K. E. Coe
J. G. Thakkar

From: D. S. Taylor
Ext: 724-722-5917
Fax: 724-722-5889

Date: February 13, 2007

Your ref:
Our ref: LTR-SGDA-05-107-NP

Subject **Westinghouse Review of Waterford III Steam Generator Manufacturing Records**

References:

1.) Combustion Engineering Shop Traveler 702289-001, "Bat Wing Assemblies," 12/13/72.
2.) Combustion Engineering Weld Inspection Record, Seam No. 101-289, Contract No. 74270, Job & Control No. 702289-001, 3/23/73.
3.) Combustion Engineering Weld Inspection Record, Seam No. 201-289, Contract No. 74270, Job & Control No. 702289-001, 3/23/73.
4.) Combustion Engineering Weld Inspection Record, Seam No. 101-289, Contract No. 74270, Job & Control No. 702389, 3/23/73.
5.) Combustion Engineering Weld Inspection Record, Seam No. 201-289, Contract No. 74270, Job & Control No. 702389-001, 3/23/73.
6.) Combustion Engineering Weld Inspection Form, Seam No. 1303-271, Contract No. 74270, Job & Control No. 702271-024, 1/19/74.
7.) Combustion Engineering Weld Inspection Form, Seam No. 1303-271, Contract No. 74270, Job & Control No. 702271-025, 3/28/74.
8.) Combustion Engineering Weld Inspection Form, Seam No. 1303-271, Contract No. 74270, Job & Control No. 702371-025, 2/4/74.
9.) Combustion Engineering Rejection Notice 4517, "Excess weld b/u where bat wings were . . . ," dated 3/25/74, approved 4/4/74.

Steam Generator Design & Analysis has reviewed the Combustion Engineering manufacturing records for the Waterford III steam generators in an effort to find information pertaining to the fabrication and assembly of the bat wing assemblies. The review was conducted due to the bat wing failures that were discovered during the Spring 2005 outage at Waterford III.

The review produced the Combustion Engineering shop traveler for the bat wing assemblies, which is documented in Reference 1 and provided in Attachment 1 of this letter. The shop traveler provides the manufacturing process followed during the assembly of the bat wings along with the shop sign-off for each process step. Based on a review of the shop traveler, no deviations, anomalies, or procedural changes were noted.

The weld inspection records/forms for the welding of the bat wing assemblies were also obtained. The weld inspection records/forms possess the inspectors' sign-offs after the completion of each weld. The inspection records for Seam No. 101-289 and Seam No. 201-289, which are the welds for assembling the individual bat wings, are documented in Reference 2 through Reference 5 and are also provided in Attachment 2. The inspection records for Seam No. 1303-271, which are the welds that attach the bat wing wrap-around bars to the individual bat wings, are documented in Reference 6 through Reference 8 and are provided in Attachment 3. Based on a review of the weld inspection records/forms, no deviations or anomalies were noted.

Finally, a review of the rejection notices for the Waterford III steam generators was performed and discovered Rejection Notice 4517, which is documented as Reference 9 and is provided in Attachment 4. Rejection Notice 4517 discusses [

]$^{a, c, e}$

If there are any questions or comments, please contact David Taylor at 724-722-5917.

Author: Electronically Approved *	Reviewed By: Electronically Approved *
D. S. Taylor	D. P. Siska
SG Design & Analysis	SG Design & Analysis

** Electronically Approved Records Are Authenticated in the Electronic Document Management System*

Attachment 1

Combustion Engineering Shop Traveler 702289-001

a, c, e

a, c, e

[ ] a, c, e

a, c, e

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a, c, e

Attachment 2

Combustion Engineering Weld Inspection Records for Seam No. 101-289 and Seam No. 201-289

a, c, e

a, c, e

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Attachment 3

Combustion Engineering Weld Inspection Forms for Seam No. 1303-271

a, c, e

a, c, e

a, c, e

a, c, e

Attachment 4

Combustion Engineering Rejection Notice 4517

a, c, e

a, c, e

Westinghouse

To: J. M. Hall
D. P. Siska
cc: Peter R. Nelson

From: J. G. Thakkar
Ext: (423)-752-2791
Fax: (423)-752-2449

Date: February 14, 2007

Your ref:
Our ref: LTR-SGDA-06-181-NP, Rev. 1

Subject: **Effect of Multiple Batwing Failure on Thermal Hydraulics at Waterford 3 Steam Generators with Power Uprate and 20% SGTP**

This letter transmits a report entitled "Effect of Multiple Batwing Failure on Thermal Hydraulics at Waterford 3 Steam Generators with Power Uprate and 20% SGTP."

The report is written to document results of quasi-static loads on the batwing tube supports within the central cavity and basic thermal hydraulic parameters calculated by the ATHOS code for Waterford Unit 3 steam generators operating at 3716 MWt power with 20% tube plugging.

Revision 1 is issued to further explain the basis for the assumption on Page 36. This assumption states that "Non-uniform spacing among the batwings may affect the secondary fluid density, but is assumed to be negligible."

Please contact the author at (423)752-2791 or Leah M. Cayton at (724) 722-6133 if there are any questions or if further clarification is required.

Author <u>**(Electronically Approved*)**</u>
J. G. Thakkar
Steam Generator Design & Analysis

Verifier <u>**(Electronically Approved*)**</u>
L. M. Cayton
Steam Generator Design & Analysis

// attachment

Electronically approved records are authenticated in the Electronic Document Management System.

LTR-SGDA-06-181-NP, Rev. 1

Effect of Multiple Batwing Failure on Thermal Hydraulics at Waterford 3 Steam Generators Power Uprate and 20% SGTP

February 14, 2007

Author: **(Electronically Approved*)**
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Table of Contents

1. Introduction

Waterford Unit 3 steam generators have experienced tube wear at the intersection of the batwings and tubes near the central stay cavity. It has been observed during the spring 2005 outage that two batwings failed and dropped to a lower elevation. Since it is clear that multiple batwings could fail, it is necessary to determine if the resulting change in batwing spacing geometry could significantly influence the thermal hydraulic characteristics within the central stay cavity. This evaluation of thermal hydraulics under the conditions of multiple batwings failure is a part of the Waterford 3 Failed Batwing Operational Assessment.

References 1 and 2 documented the ATHOS calculated thermal-hydraulic parameters and the quasi-static loads on the batwing strips within the central cavity region for the 3390 MWt (Cycle 12) and uprated 3716 MWt with 500 or 5.3% Steam Generator Tube Plugging (SGTP) conditions. This technical correspondence documents the effect of 20% SGTP at the uprated power, 3716 MWt conditions in the similar format.

Effect of multiple batwing failures on the thermal hydraulics will be determined. Calculations will be performed to evaluate the effects of flow redistribution as the batwing strips change their spacing between the neighboring batwings. Using the calculated thermal hydraulic parameters, a quasi-static load on the batwing strip will be estimated for use in a structural evaluation of the contact force between the batwing and tube.

2. Summary of Results and Conclusions

Waterford Unit 3 steam generators have experienced tube wear at the intersection of the batwings and tubes near the central stay cavity. During the spring 2005 outage, two batwings were observed to be broken at the horizontal base on the cold leg side. The spacing between these two broken batwings appears to narrow down from the regular spacing, as illustrated in Figure 2-1.

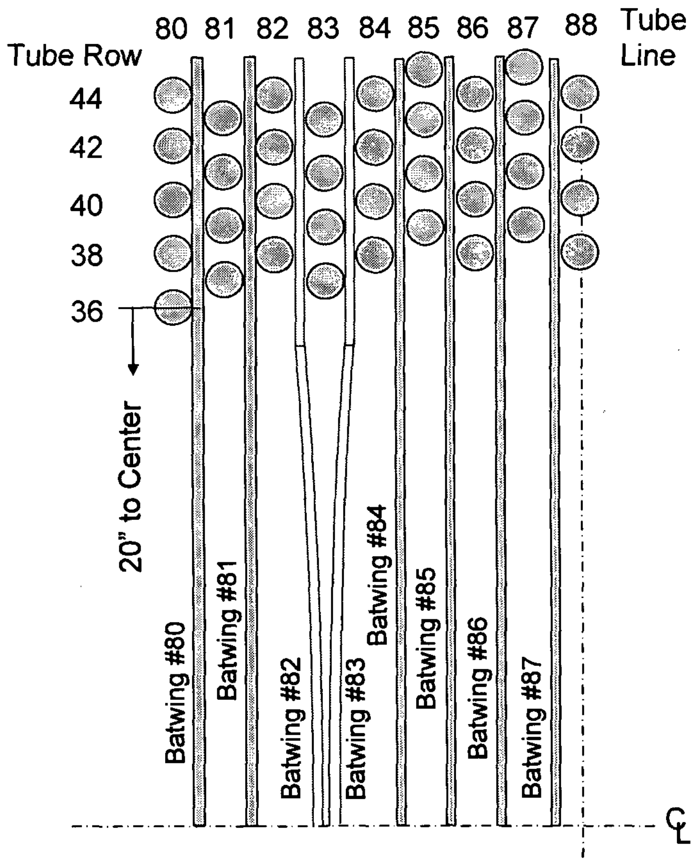

Figure 2-1 Narrowing Space between Failed Batwings

It is clear that multiple batwings could fail. It is necessary to determine the impact of batwing spacing change on thermal hydraulic characteristics within the central stay cavity. Changes in thermal hydraulic conditions can affect wear volume over years of operation. Wear volume calculation depends on contact force between the batwing and tube and sliding distance of tube under fluid dynamic pressure over the horizontal span of the U-bend. Both contact force and fluid dynamic pressure depend on fluid density and velocity at batwing within the central cavity and over the horizontal span of the tube-bend (see Figure 2-2).

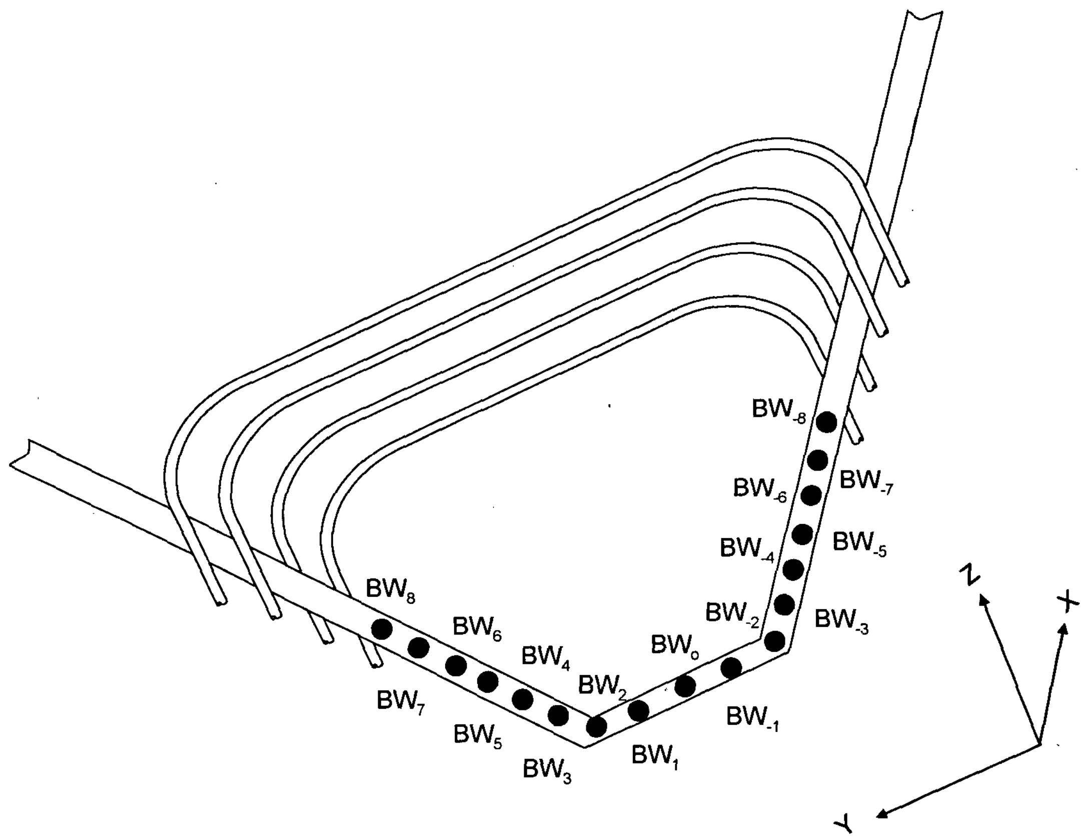

Figure 2-2 Locations of Velocity Assessment

Fluid density and velocity for these two regions can be assessed under non-failure and multiple-failure of the batwings. Velocity is assessed at 17 discrete points along the batwing (i.e. at BW_n points; 8 on hot and cold leg side each, and one point at the center). For the as-designed or the intact batwing the secondary fluid density, velocity, and dynamic pressure at the 17 points along batwing are calculated using the ATHOS model of the Waterford 3 steam generators. The dynamic pressure is used to obtain a quasi-static load on the batwing strip at each of the 17 points. Tables 2-1 and 2-2 provide an area-averaged value of the quasi-static load over the 9 points on the hot and cold leg, respectively. The tables include quasi-static loads for all three analyzed conditions, i.e. 3390 MWt with 4.7% SGTP (Cycle 12), and the uprated power level of 3716 MWt with 5.3% SGTP and 20% SGTP. These tables provide data for eight batwings within the central cavity region and one batwing outside the cavity. The tables compare the loads for both the as-designed (intact) as well as batwings with multiple failures.

a,c

Table 2-1
Waterford Unit 3 Steam Generators

a,c

Table 2-2
Waterford Unit 3 Steam Generators

3. Method Discussion

Tube wear at the intersection of the batwing and tubes has been calculated since 1985. Reference 3 documents the methodology for such wear calculation. The following is the review of the methodology that needs inputs from thermal hydraulics.

3.1 Methodology of Wear Volume Calculation

According to Reference 3, wear volume is calculated by the following expression.

$$W = KFLT \qquad (3\text{-}1)$$

Where,

W = volume of material worn away,
K = an empirical wear coefficient,
F = normal (or contact) force between the tube and batwing strip,
L = relative sliding distance per unit time between tube and batwing, and
T = time period.

In Equation (3-1), the contact force and sliding distance require thermal hydraulic parameters.

The contact force, F, is calculated by an appropriate finite element model, as described in Reference 3, with a quasi-static load, p, as defined below:

[ ]^{a,c} (3-2)

Where,

p = quasi-static load, lb_f/in^2, and
q = dynamic pressure, lb_f/ft^2.

The dynamic pressure is defined as follows:

$$q = \frac{\rho V^2}{2 g_c} \qquad (3\text{-}3)$$

Where,

ρ = density of steam-water mixture, lb_m/ft^3,
V = velocity of steam-water flow passing the batwing strip, ft/sec, and
g_c = unit conversion factor, 32.17 $lb_m\text{-}ft/lb_f\text{-}sec^2$.

Figure 3-1 depicts the applied quasi-static load. Note that this quasi-static load is distributed over the batwing span within the central cavity only, in other words, outside the tube bundle.

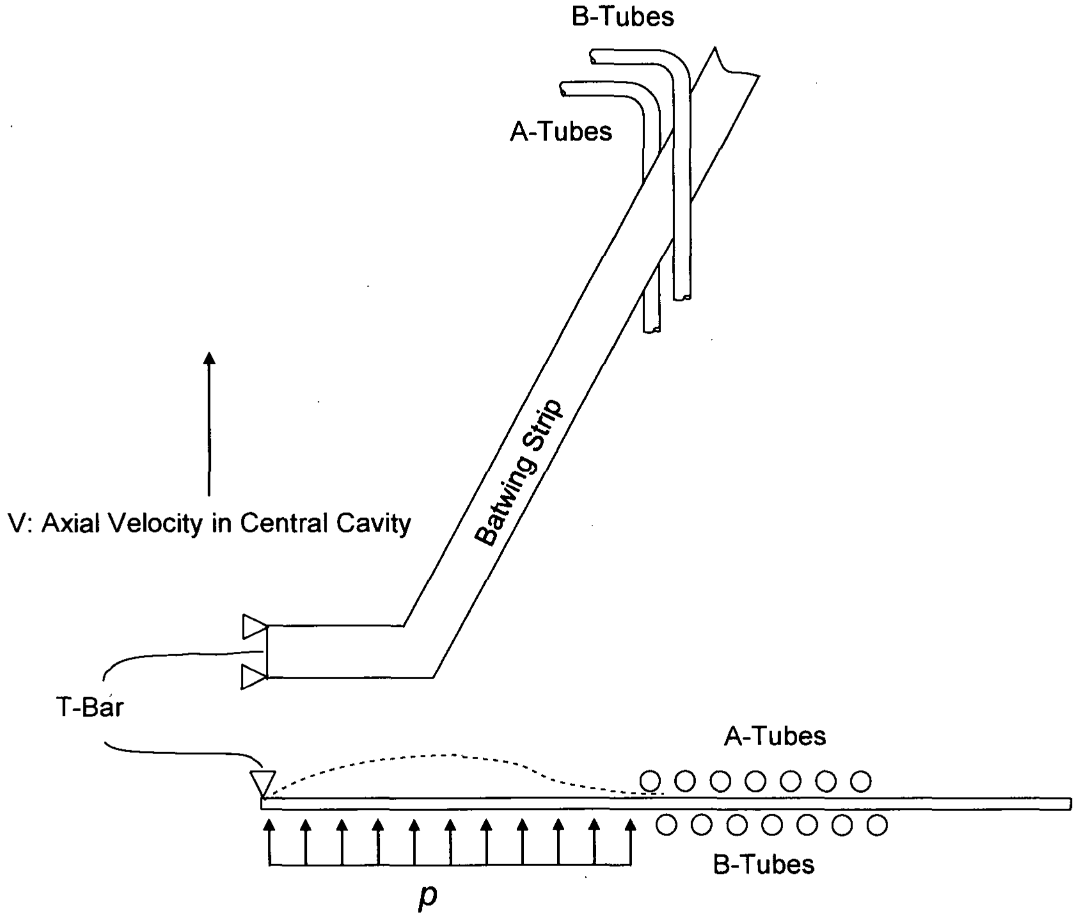

Figure 3-1 Wear Model with Quasi-static Load Applied within Central Cavity

Therefore, to allow the finite element model to determine the contact force, there is a need to provide a quasi-static load from Equation (3-2), and the dynamic pressure from Equation (3-3) that involves density, ρ, and velocity, V, over the batwing strip.

The sliding distance per unit time, L, is calculated by another appropriate finite element model, again as described in Reference 3, with a forcing function, G_{FT}, as defined below:

a,c

[ ] (3-4)

Where

a,c

[ ]

Figure 3-2 depicts the U-Tubes with the batwing strip with axial tube gap velocity to the horizontal span of tubes. Note that the forcing function, G_{FT}, depends on both the fluid density, ρ, and velocity, V_g.

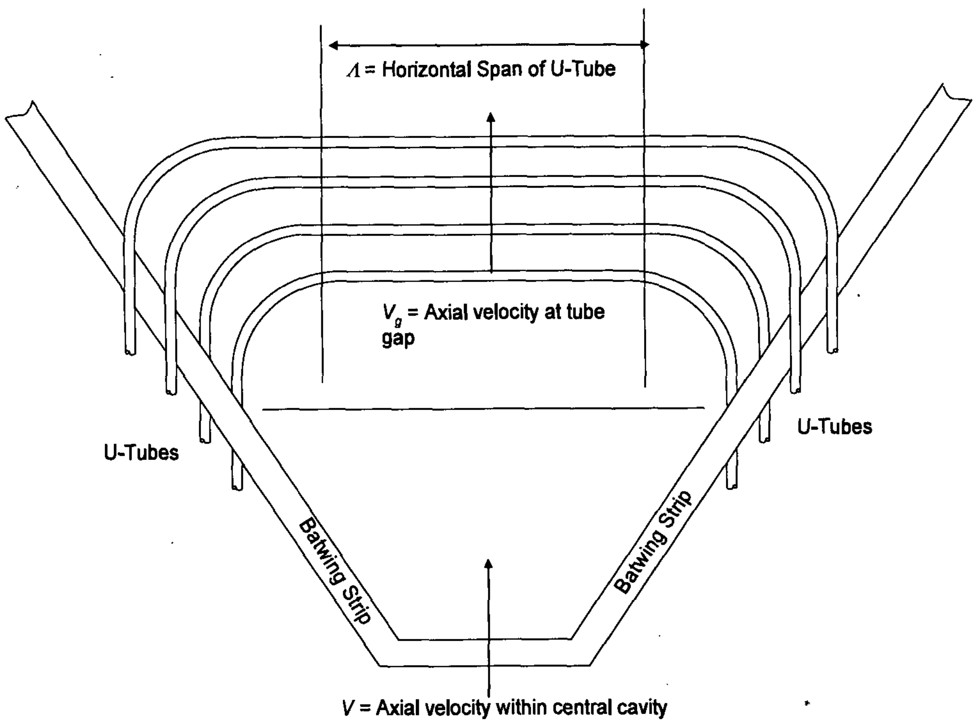

Figure 3-2 U-Tubes and Batwing Strip with Fluid Velocity Normal to Horizontal Span of Tubes

According to Reference 3, both the fluid density and velocity for the above expressions for calculation of wear volume were provided by model tests with water and air-water mixture. The test model also included measurements of forcing functions and thus the overall methodology was properly qualified. Once the methodology was verified, actual thermal hydraulic conditions were determined using the ATHOS3 Mod 01 (ATHOS) code (Reference 4). Note that the ATHOS code was developed and qualified by Electric Power Research Institute for nuclear steam generators. ATHOS code has been well accepted in the nuclear industry for calculating detailed thermal hydraulics conditions in the steam generator.

3.2 Thermal Hydraulic Inputs

The ATHOS3 code has been used to calculate density and velocity of steam-water mixture flow at selected locations within the central cavity. The ATHOS code calculates the three-dimensional thermal and hydraulic parameters including density and velocity on the secondary side of the steam generator. Such calculations have been performed for Waterford Unit 3 steam generators for the original power level of 3390 MWt and the uprated power level of 3716 MWt with 500 (5.3% SGTP) plugged tubes in Reference 5 and at 3716 MWt with 1870 (20% SGTP) plugged tubes in Reference 6. The results and model of ATHOS calculation for Waterford Unit 3 are documented and verified in References 5 and 6. Utilizing this verified ATHOS model and operating conditions from Reference 6, new calculations with the homogeneous modeling of two-phase flow are performed for the present evaluation, and appropriate results are extracted and documented in Appendices A, B and C.

Figure 3-3 illustrates the Waterford-3 steam generator which includes the batwing and grid support locations in the tube bundle. Figure 3-4 depicts the mesh layout of the ATHOS computational model that provides finer meshes in the upper tube bundle where the batwings are located. The batwings are not included in the computational model as the batwings are thin and lined up in the vertical directions and thus have a negligible impact on the predominantly axial flow in the U-bend region. Theses finer meshes will adequately define fluid conditions in the central cavity and U-Bend regions. Thermal and hydraulic parameters are similar between the original full power and uprated power conditions. Figures 3-5, 3-6, 3-7 and 3-8 show velocity vectors, velocity contours, density contours, and void fraction contours, respectively, at 3716 MWt with 20% SGTP, along the symmetry plane, IX=1 (middle of the hot leg) and IX=18 (middle of the cold leg).

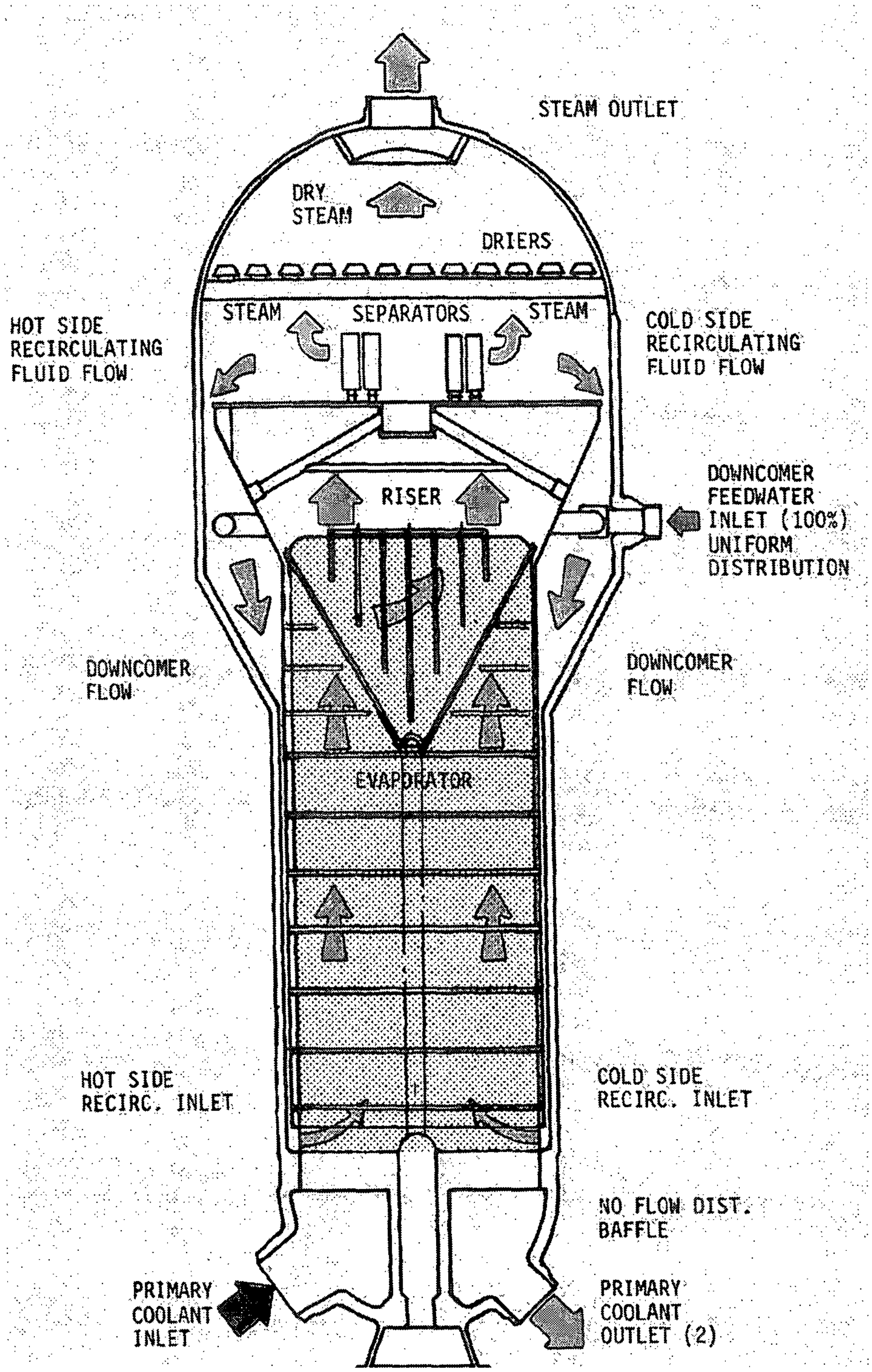

Figure 3-3 Schematic of the Waterford-3 Steam Generators

a,c

Figure 3-4 Mesh Layouts of the ATHOS Computational Model

a,c

Figure 3-5 Velocity Vectors along the Symmetry Plane

a,c

Figure 3-6 Velocity Contours along the Symmetry Plane

a,c

Figure 3-7 Fluid Density Contours along the Symmetry Plane

a,c

Figure 3-8 Void Fraction Contours along the Symmetry Plane

According to the methodology described in Section 3.1, fluid density and axial velocity are needed only for the batwings. It was decided that input for the horizontal span is not required for evaluation of the failed batwings. Figure 3-9 illustrates locations to define fluid density and axial velocity. For the batwing, there are 17 points for extracting fluid density and axial velocity from results of ATHOS calculation. All 17 points are on the Y-Z plane parallel to the lateral face of the batwing, but away from the batwing lateral surface by a normal distance of 0.388 inch in the direction of X-coordinate. According to the fluid density and velocity, the dynamic pressure (see Equation 3-3) can be calculated at each point and then a quasi-static load (see Equation 3-2) can also be calculated.

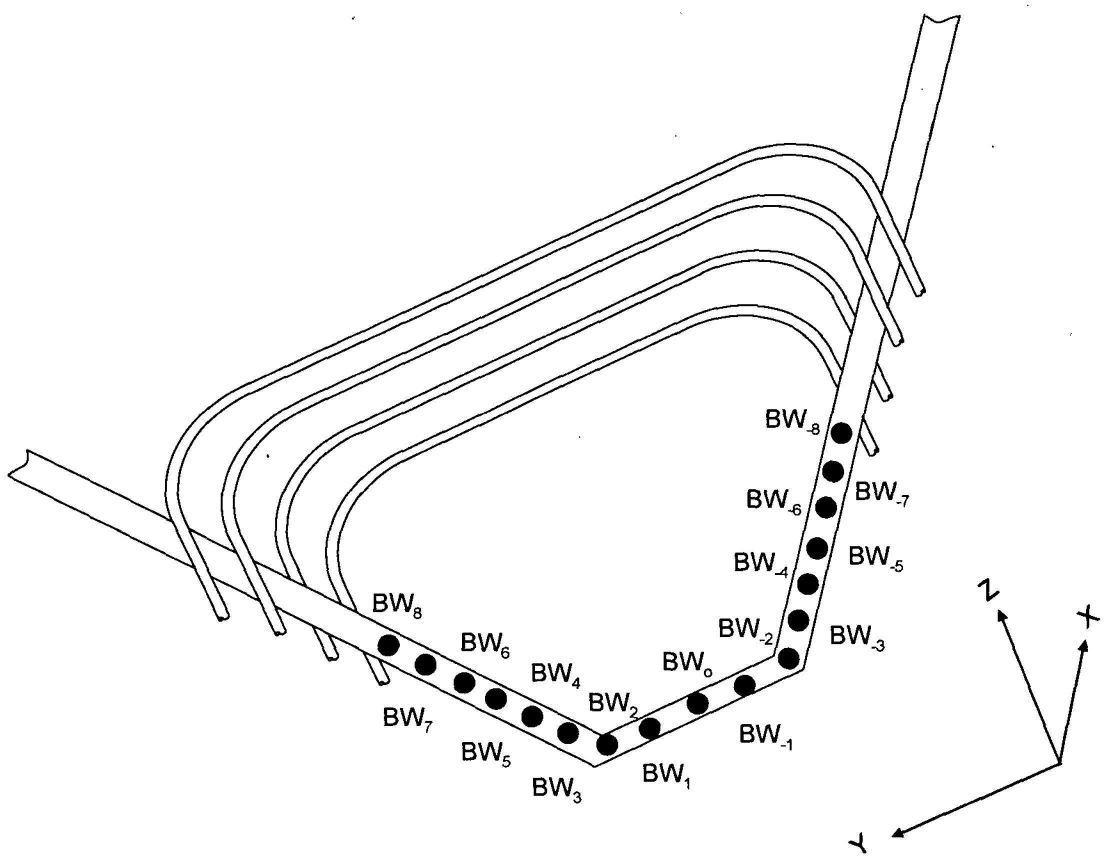

Figure 3-9 Locations of Thermal Hydraulic Inputs at Batwing and U-tube Horizontal Span

Table 3-1 tabulates batwings (see Figure 2-1) to be considered. These batwings cover those with the largest tube row in the central cavity as illustrated in Figure 3-10. These include two batwings marked in red which are found to be broken, as to be described in Section 4.

Table 3-1
Selected Batwings and Tubes for Defining Thermal/Hydraulic Conditions

Batwing #	T/H at Line #	T/H at Row #
80	80	38
81	81	39
82	82	40
83	83	39
84	84	40
85	85	41
86	86	40
87	87	41

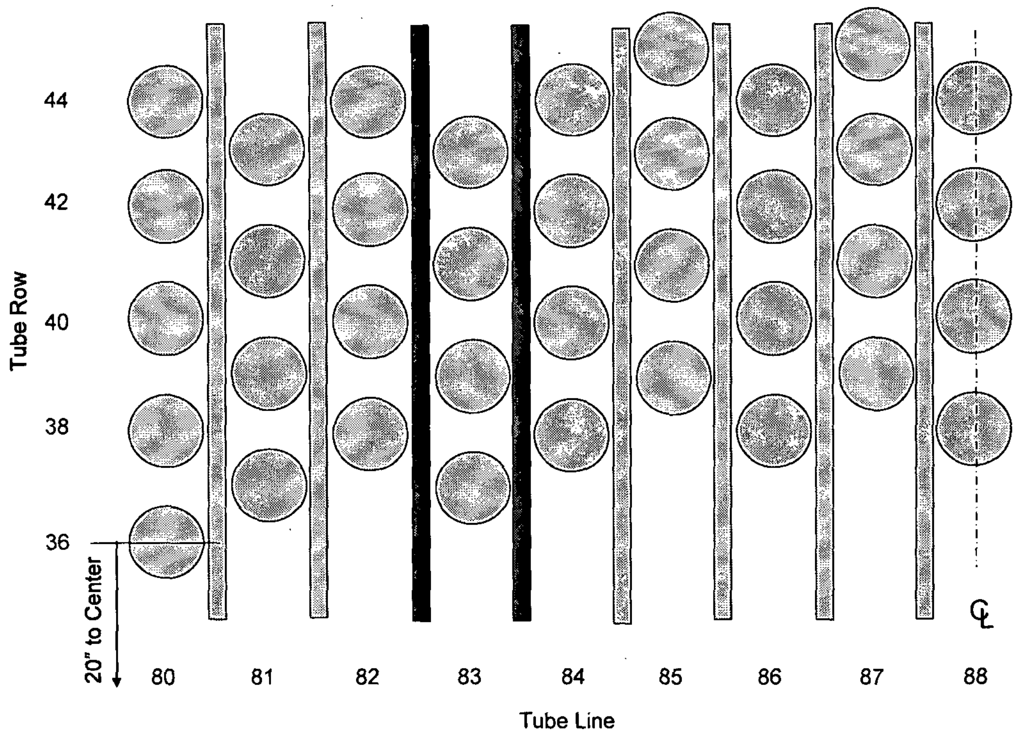

Figure 3-10 Batwings and Tubes Considered in Table 3-1

Appendix A tabulates coordinates of the 17 points for the batwings listed in Table 3-1. Velocity and density from ATHOS analysis are extracted for those points. Equations (3-2) and (3-3) are then used to calculate the quasi-static load at these points. Once quasi-static loads are obtained at these 17 points, area-averaged quasi-static load can be calculated for the hot and cold leg sides. In calculating area average, the point BW_0 is shared by both the hot and cold legs. Therefore, there are nine points on each leg. Table 3-2 provides area-averaged values for the nine selected batwings at the uprated power of 3716 MWt with 20% SGTP. References 1 and 2 include the corresponding values for the original design (3390 MWt) and the uprated power (3716 MWt with 5.3% SGTP) conditions. Table 3-2 presents results for the as-designed or the intact batwings. As shown in Appendix B, Batwing # 60 is outside the central cavity and the remaining ones are in the central cavity. For the configuration with failed batwings, equivalent table is presented in Sections 4 and 5.

Table 3-2
Quasi-static Load on As-Designed Batwing Strip at 3716 MWt with 20% SGTP a,c

4. Effect of Multiple Batwing Faliures on Thermal Hydraulics in Central Cavity

Figure 4-1 illustrates an intact batwing within the central cavity. There are two failed batwings located between tube lines 82–83 and 83–84 (see Figure 2-1). The failed batwing broke at the horizontal span. The break took place on the cold leg side, and the hot leg side is still supported by a vertical strip, at its original location. However, the cold leg side piece is free to move, as shown in Figure 4-2. It is translated by a distance 0.853" near the Eggcrate #8. Such a displacement is equivalent to a rotation of about 0.6°, and its horizontal span dropped vertically by approximately 0.6". The central cavity is approximately 40 inches in diameter and the horizontal span of the tube is also approximately 40 inches above the horizontal span of the batwing. The displacement of the broken batwing is very small compared to the central cavity diameter and the height of the horizontal span of the tube. Therefore, a small change in vertical position has a negligible effect on the thermal hydraulic conditions in the central cavity and the horizontal span of the tube. However, the spacing between batwings may either increase or decrease due to movement of the broken pieces. Effect of spacing change will be assessed below.

a,c

Figure 4-1 Batwing within Central Cavity

a,c

Figure 4-2 Vertical Displacement of Broken Cold Leg Piece of Batwing

Figure 4-3 identifies the locations of two failed batwings (i.e. between Tube Lines 82-83 and 83-84). If we were to identify the batwing by the lower number of the tube line, then the failed Batwings are #82 and #83. Evaluations will focus on Tube Lines 80 through 87 and thus Batwings #80 through #87. Figure 4-4 illustrates that the failed cold leg pieces between Batwings #82 and #83 have come closer. This demonstrates that spacing between the batwings can change if they break in a similar fashion as Batwings #82 and #83.

a,c

Figure 4-3 Failed Batwing between Tube Lines 82-83 and 83-84

Figures 4-5, 4-6 and 4-7 illustrate three possible spacing configurations among the failed and intact batwings. There can be many other configurations. However, we will concentrate on these three configurations and assess their potential in affecting the fluid velocity in the axial direction. We will idealize the configuration to a uniform spacing along the X-direction (i.e. normal to lateral face of the batwing). We will also consider an idealized configuration with three channels as a two-dimensional flow in the Y-Z plane with a finite height in Z-direction with each channel having different spacing (see Figure 4-8). The sole purpose is to assess effect of spacing on velocity with an assumption of equal pressure drop among three channels.

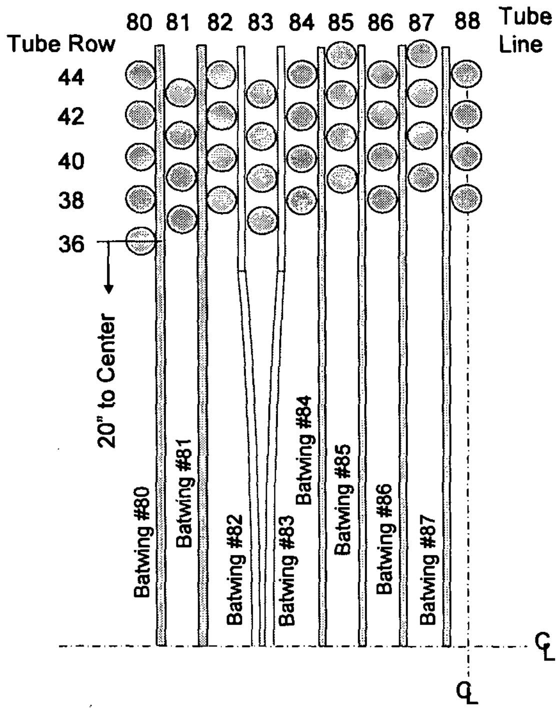

Figure 4-4 A Schematic of Failed Batwings Coming Closer

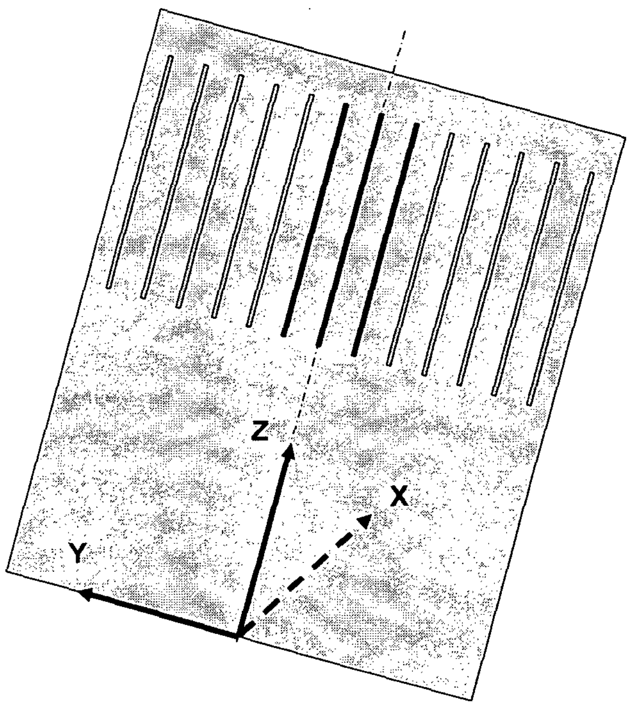

Figure 4-5 Equal Spacing among All Channels of Batwings

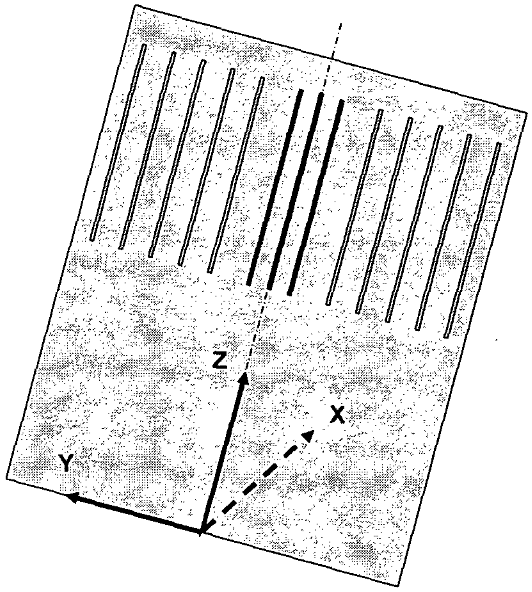

Figure 4-6 Unequal Spacing among All Channels of Batwings

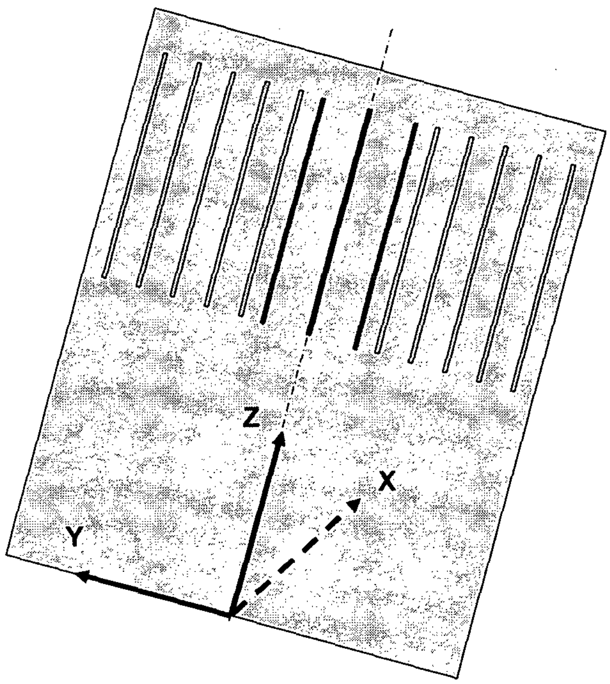

Figure 4-7 Other Unequal Spacing among All Channels of Batwings

In Figure 4-8, we consider that fluid flows axially along a channel, and write a pressure drop, Δp, through a unit height as follows.

a,c

[ ] (4-1)

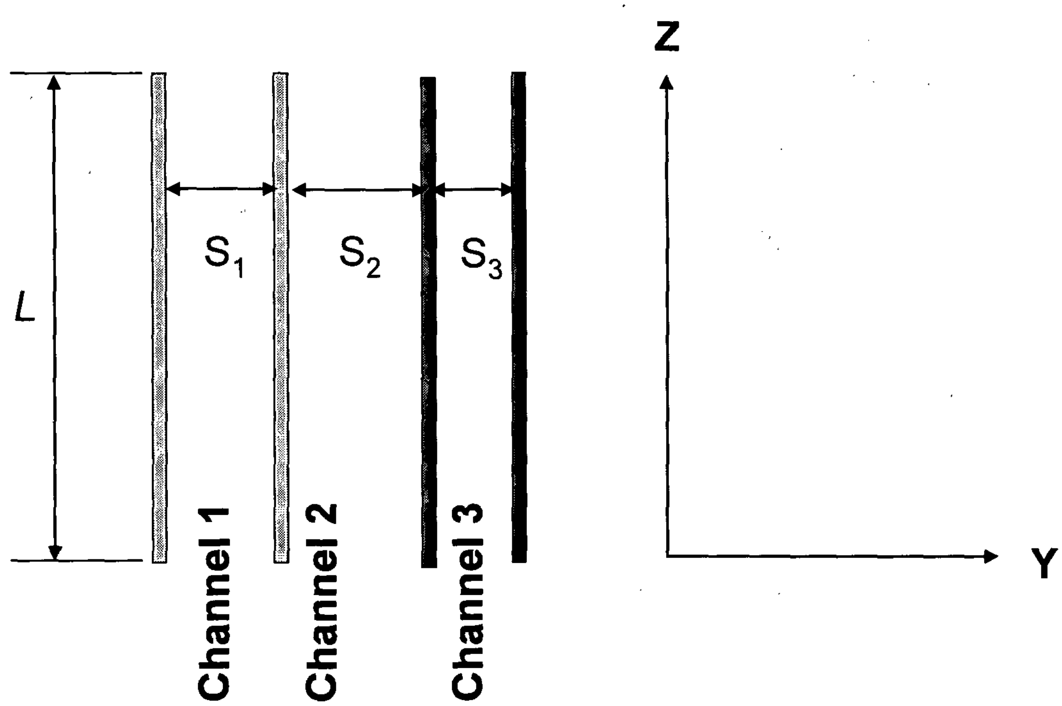

Figure 4-8 A Three Channel Model with Unequal Spacing

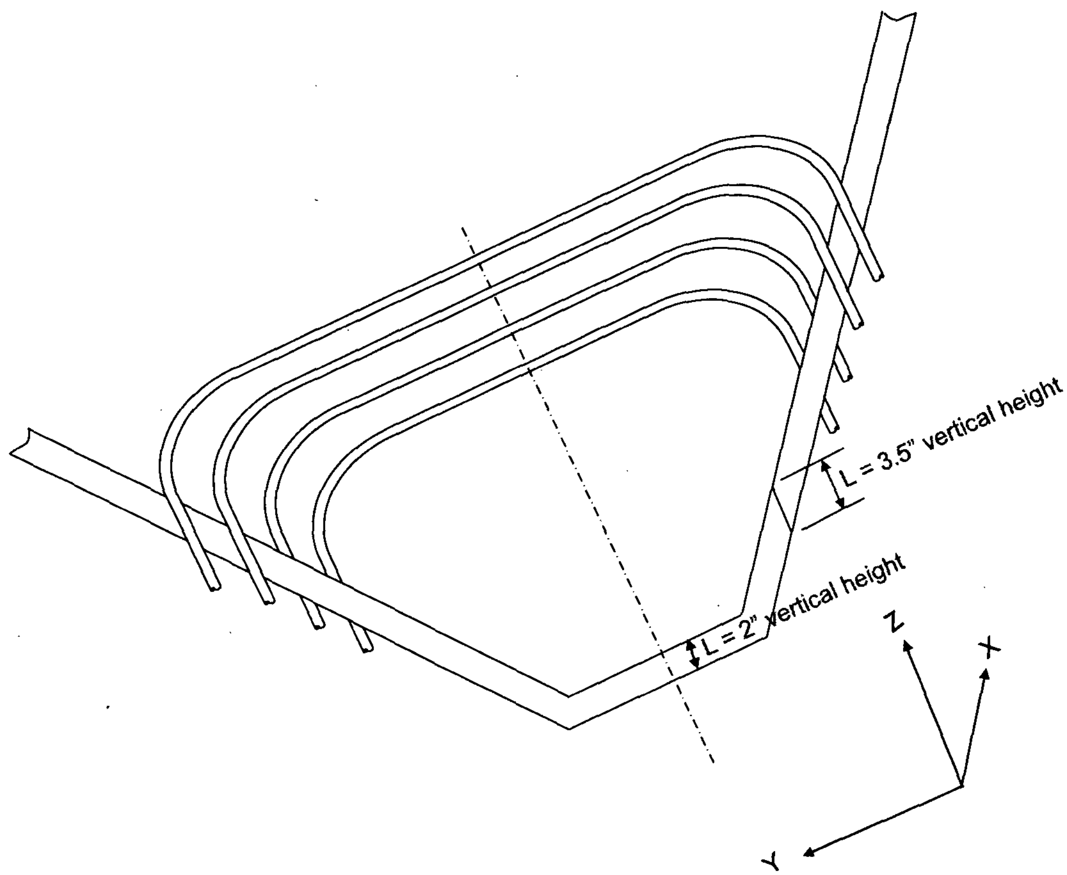

Figure 4-9 Vertical Characteristic Length of the Batwing Channels as Illustrated in Figure 4-8

As depicted in Figures 4-8 and 4-9, the vertical characteristic length of the batwing channels for vertical flow, L, is 2 inches in the horizontal span of the batwing and 3.5 inches away from the horizontal span. And as illustrated in Figure 4-4, spacing will vary in radial direction from the center towards the edge of the cavity. Channel 1 represents a channel formed by intact batwings with its spacing $S_1 = S = 0.776$". Channels 2 and 3 are subject to variation with $S_2 + S_3 = 2S$. We can choose to reduce S_3 and increase S_2, accordingly.

The friction factor for flow between parallel plates will be determined by the following correlation (Reference 7).

[ ]^{a,c} (4-2)

In addition, we have the following expressions:

[ ]a,c (4-3)

Where,
S = spacing of channel

$$W = \rho A V \quad (4\text{-}4)$$

Where,
W = flow rate
A = flow area = $S\Delta X$
ΔX = unit depth of the channel

Substituting Equations (4-2), (4-3) and (4-4) into Equation (4-1) yields the following

[ ]a,c

(4-5)

(4-6)

Within the central cavity, we can consider that flow is isothermal, and characteristic lengths L and ΔX are invariant among three channels. Therefore, C_p is constant. Therefore we can write the following three pressure drops:

[ ]a,c

[ ]a,c

[ ]a,c

Let us introduce the following:

[ ]a,c

[ ]a,c

And thus, it follows:

[ ]a,c

As assumed,

[ ]a,c

With the above relations, we obtain the following solutions.

[ ]a,c

(4-7)

(4-8)

(4-9)

Further, we obtain the following velocity ratio.

[ ]a,c (4-10)

[ ] a,c

(4-11)

(4-12)

Where,

V = fluid velocity through equal width channels

Finally, the velocity ratios as obtained by Equations (4-10), (4-11) and (4-12) allow us to assess the impact of batwing failure on fluid flow in the central cavity.

Table 4-1 tabulates results of flow splits and velocity among three channels under nine sets of channel spacing. As expected, bigger spacing channel (e.g., Channel 2) has higher flow rate (i.e. flow split, α), and greater velocity. In addition, velocity ratio of V_2/V peaks between Cases 6 and 7 with a value of 1.20.

Table 4-1
Flow Splits and Velocity under Altered Spacing due to Batwing Failure a,c

[ ]

We need the velocity to assess the effect of failed batwings on local dynamic pressure and thus quasi-static load to the batwing strip. As we discussed earlier, nine cases in Table 4-1 can be considered to be linked to each of the nine points along the batwing either on the hot leg or cold leg, as tabulated in Table 4-2. This link is a good approximation.

Table 4-2 Velocity Ratio for Channel 2

a,c

[ ]

5. Discussion

Calculation of wear volume of tube requires quasi-static load along the batwing within the cavity and dynamic pressure for the horizontal span of the tube. Values of quasi-static load for the as-designed or intact batwings are provided in Table 3-2 for the uprated power level of 3716 MWt with 20% SGTP. However, two batwings between Tube Lines 82-83 and 83-84 were broken at the horizontal base on the cold leg side, as illustrated in Figure 5-1. The cold leg piece dropped about 0.6" vertically, as illustrated in Figure 4-2, and it is now free to move laterally. Multiple failures of the batwings may take place and thus the broken pieces can displace from their original location as described above. However, the displacement is very limited; it dropped vertically only 0.6 inch due to the constraint of the partial Eggcrate #8 (see Figure 4-2). This drop of 0.6 inch is negligible compared to the total height of 105 inches (see Figure 4-2) of the failed batwings or the relative height of 20 inches within the central cavity (see Figure 5-2). Therefore, it is considered to have a negligible impact on fluid velocity due to a vertical drop of the batwing by a distance of less than one inch.

a,c

Figure 5-1 Intact and Failed Batwings

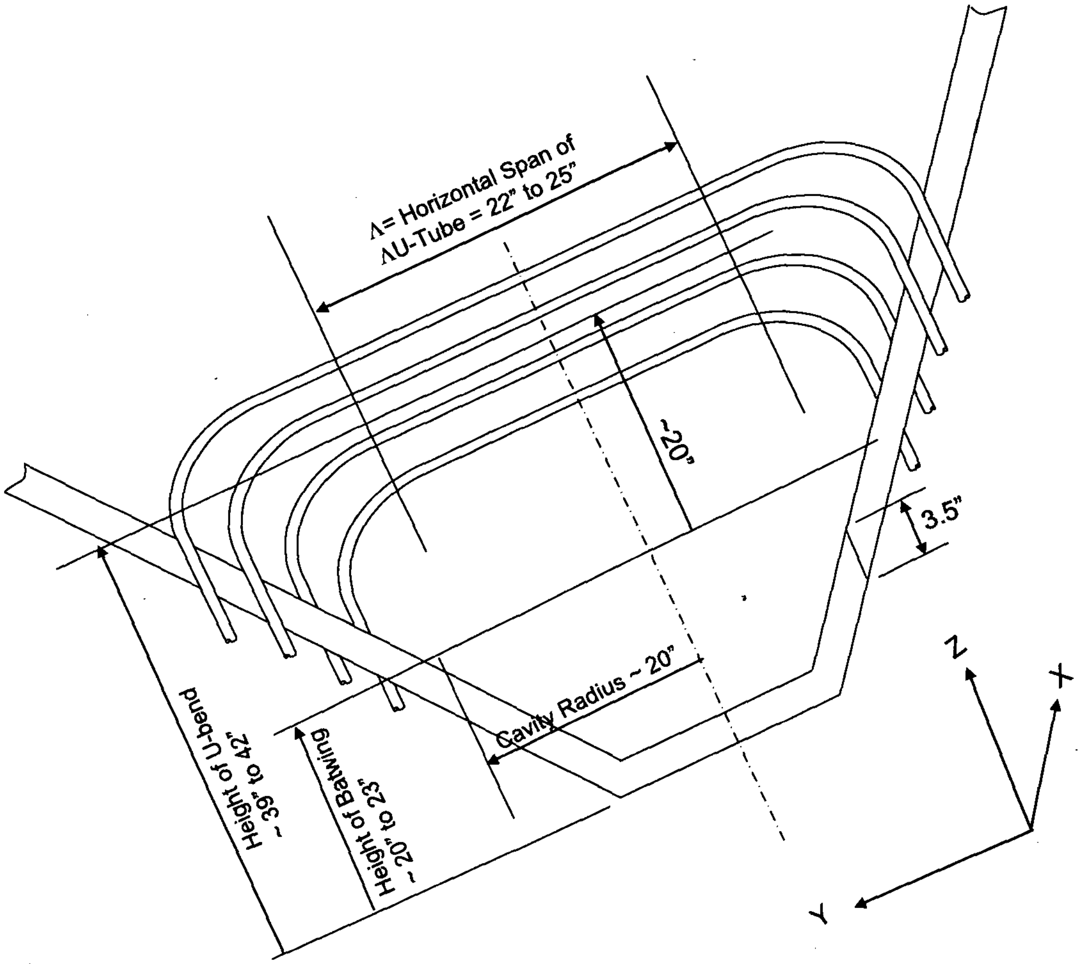

Figure 5-2 Dimensions of Central Cavity Radius, Batwing Heights and U-bend Tube Height (For Batwings between Tube Lines 80 through 98)

However, the broken pieces can move closer among themselves, and change the spacing between each neighboring batwings (see Figure 4-3). This change in the batwing spacing within the central cavity apparently could have significant impact on fluid velocity. An idealized model is developed in Section 4 for assessing such an impact (see Figure 4-8). Table 4-1 tabulates results of altered velocity for a parametric calculation over a variety of spacing. As shown, both Channels 1 and 3 have a reduction in velocity while Channel 2 shows an increase in velocity, as tabulated in Table 4-2. For conservative evaluation of quasi-static load to the batwing strip with failure, we recommend to use the results of Channel 2.

For convenience, Table 5-1 reproduces Table 4-2. Note that velocity for the intact batwings is represented by V which is obtained from ATHOS calculation and documented in Appendix A. Therefore, the ratio of V_2/V allows us to estimate the effect of the failed batwing on velocity V_2.

Table 5-1
Flow Splits and Velocity under Altered Spacing due to Batwing Failure

a,c

[ ]

Note that we have assumed that the failed batwing spacing does not affect fluid density. Therefore, we will use the density directly as calculated by ATHOS for the intact batwings. With both fluid density and velocity obtained as above, a dynamic pressure and thus quasi-static load on the batwings is calculated at nine points along both the hot and cold legs of the batwing. Finally, an area-averaged quasi-static load is determined for nine selected batwings. Results are tabulated in Table 5-2 for the power uprate conditions of 3716 MWt with 20% SGTP.

Table 5-2
Quasi-static Load on Failed Batwing Strip at 3716 MWt with 20% SGTP

a,c

[ ]

We have also assessed the impact of multiple batwing failures on fluid density and velocity to the horizontal span of the U-tubes. There are no changes in the tube pitch over the horizontal span. Therefore, the sole source of the potential impact should come from the displacement of the batwings, and the resulting change in the spacing between the batwings. At each radial location, the height of the batwing channel is only about 3.5 inches (see Figure 4-9). A velocity deviation from the regular value will start to dissipate once it passes the 3.5 inch height. There is a total height ranging from 40 inches (at the center of the cavity) to 20 inches (at the edge of the cavity) up to the elevation of the horizontal span of the tubes to be assessed (see Figure 5-2). Such a height of 40 to 20 inches would be sufficient for the perturbed velocity (max. 20%) to totally dissipate. In addition, the tube bundle, compared to the cavity, serves as a good flow rectifier that would thus tend to bring the fluid to a uniform velocity. Therefore any impact of the batwing failure on the velocity over the horizontal span of the tube-bend is negligible.

According to the above discussion, we can draw the following conclusions.

1. Failed batwings can result in non-uniform spacing among the batwings.

2. Non-uniform spacing among the batwings can lead to an increase in axial velocity of the fluid passing through the batwing channels within the central cavity.

3. Non-uniform spacing among the batwings may affect the secondary fluid density, but is assumed to be negligible. This assumption is reasonable because:

   The fluid density is a function of enthalpy and pressure. On the secondary side of the steam generator, the node-to-node pressure variation is small (<1psi) compared to the absolute pressure of ~800 psia. The change in enthalpy is a function of primary to secondary side heat transfer rate. In the batwing region, where the secondary fluid is a two phase mixture, the saturated boiling heat transfer coefficient is used by the ATHOS code (Reference 4). The boiling heat transfer coefficient is a function of local heat flux and an empirical constant which is a function of the operating pressure. Hence, with small pressure differences, local variations in velocity have negligible effects on both the local heat transfer rate and enthalpy and therefore fluid density.

   At each radial location, the height of the batwing channel is approximately 3.5 inches (Figure 4-9). Hence, the fluid enthalpy and density variations, resulting from non-uniform batwing spacing over a short distance, are negligible.

4. An increase in the axial velocity will occur in the channel with spacing greater than the regular value of 0.776 inch. The maximum increase is 20 percent.

5. Axial velocity of the fluid passing through the horizontal span of the tube-bend should not be affected by the batwing failure.

6. References

1. Westinghouse Correspondence, LTR-SGDA-05-211, Revision 1, "Effect of Multiple Batwing Failure on Thermal Hydraulics", December 13, 2005.
2. Westinghouse Correspondence, LTR-SGDA-05-222, "An Update to the Effect of Multiple Batwing Failure on Thermal Hydraulics", December 20, 2005.
3. CEN-328, "Remedy for Steam Generator Tube and Diagonal Strip Wear," March 1986, Combustion Engineering, Inc., Windsor, Connecticut.
4. Singhal, A. K. et al., "ATHOS3 Mod 01: A Computer Program for Thermal Hydraulic Analysis of Steam Generators, Volumes 1-3," EPRI-NP-4604-CCML, September 1990.
5. Westinghouse Calculation Note, CN-SGDA-03-25, "Thermal Hydraulic Analysis of Waterford-3 Steam Generators at 3716 MWt Power Uprate Conditions", May 2003.
6. Westinghouse Calculation Note, CN-SGDA-06-6, "Thermal-Hydraulic and Flow Induced Vibration Analyses of Waterford 3 Steam Generator at 3716 MWt Power for 20% Tube Plugging", March 2006.
7. Kays, W. M., "Convective Heat and Mass Transfer," McGraw-Hill, New York, 1966.

Appendix A: Thermal Hydraulic Conditions on Batwings and Tube Horizontal Spans

This appendix defines coordinates of selected points for defining thermal hydraulic conditions for both the batwings and the tube horizontal spans. Figure A-1 illustrates 17 selected points on the batwing and seven points on the horizontal span.

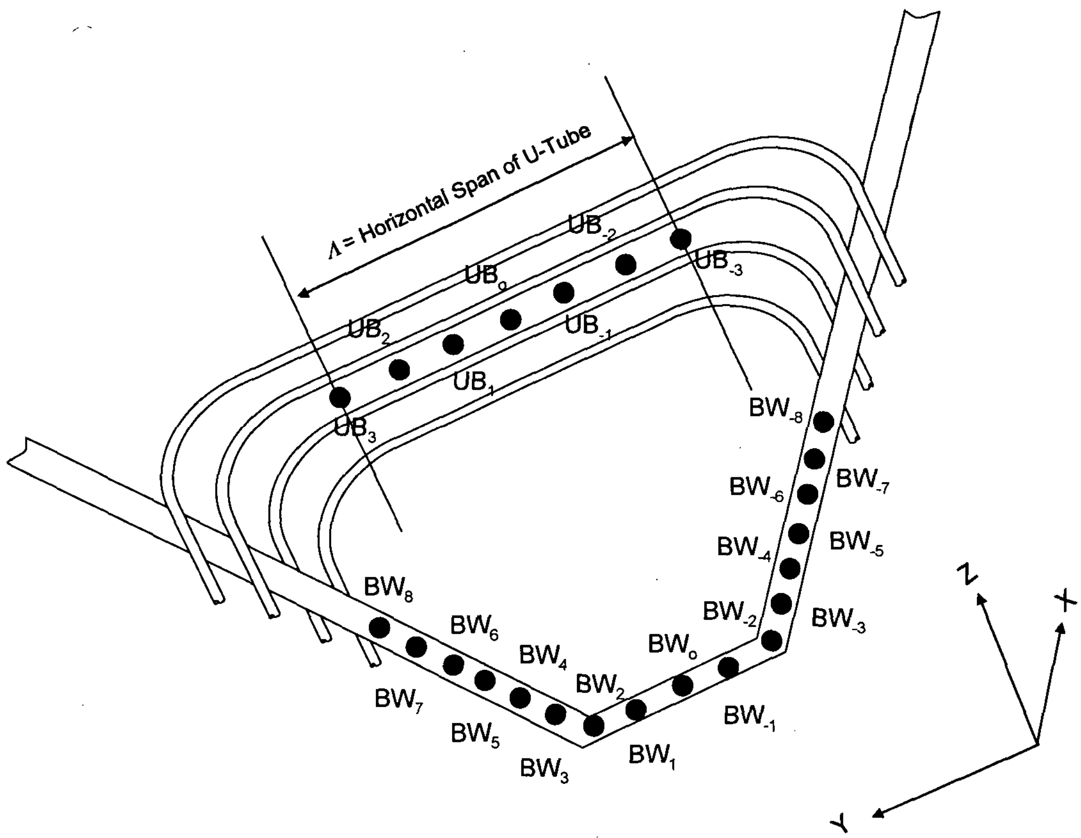

Figure A-1
Points for Defining Thermal Hydraulic Conditions
On the Batwing and the Horizontal Span

a,c

Figure A-2 Tube Map and Horizontal Meshes of ATHOS Model

Figure A-2 shows the mesh layout of the ATHOS model over the tube map. Figure A-3 depicts the coordinate system for the selected points. The origin is at the center of the top of tubesheet, the X-coordinate is along the tube lane, the Y-coordinate is along the symmetry line and points toward the hot leg side, and Z-coordinate is identical to that of ATHOS calculation model (Figure 3-4). The polar (cylindrical) coordinate system is used in the ATHOS model, where as this evaluation is performed in the Cartesian system. However, they can be readily converted to each other.

a,c

Figure A-3
Coordinate System for Identifying Points
On the Batwing and the Horizontal Span (see Figure A-1)

We will concentrate on Tube Lines 80 through 88 (the line of symmetry) and Batwings 80 through 87 and the associated tubes, one row from the outer tube. The following table identifies selected batwings and tubes for the evaluation:

a,c

[ ]

According to this coordinate system Tables A-1 through A-8 define coordinates for each set of batwing and tube as listed in the above table.

At locations shown in Tables A-1 through A-8, the calculated thermal-hydraulic parameters at the uprated power level of 3716 MWt with 20% SGTP are extracted from the ATHOS analysis. Values of fluid density, velocity, and void fraction are tabulated in Tables A-9 through A-16. The tables also include average value for the selected points (17 for the batwing and 7 for the U-Bend).

Table A-1
Coordinates for T/H Conditions
(For Batwing 80 and Tube Line 80 and Tube Row 38)

a,c

Table A-2
Coordinates for T/H Conditions
(For Batwing 81 and Tube Line 81 and Tube Row 39)

a,c

[ ]

Table A-3
Coordinates for T/H Conditions
(For Batwing 82 and Tube Line 82 and Tube Row 40)

a,c

Table A-4
Coordinates for T/H Conditions
(For Batwing 83 and Tube Line 83 and Tube Row 39)

a,c

Table A-5
Coordinates for T/H Conditions
(For Batwing 84 and Tube Line 84 and Tube Row 40)

a,c

Table A-6
Coordinates for T/H Conditions
(For Batwing 85 and Tube Line 85 and Tube Row 41)

a,c

Table A-7
Coordinates for T/H Conditions
(For Batwing 86 and Tube Line 86 and Tube Row 40)

a,c

Table A-8
Coordinates for T/H Conditions
(For Batwing 87 and Tube Line 87 and Tube Row 41)

a,c

Table A-9
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 80 and Tube Line 80 and Tube Row 38)

a,c

Table A-10
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 81 and Tube Line 81 and Tube Row 39)

a,c

[ ]

Table A-11
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 82 and Tube Line 82 and Tube Row 40)

a,c

Table A-12
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 83 and Tube Line 83 and Tube Row 39)

a,c

Table A-13
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 84 and Tube Line 84 and Tube Row 40)

a,c

Table A-14
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 85 and Tube Line 85 and Tube Row 41)

a,c

Table A-15
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 86 and Tube Line 86 and Tube Row 40)

a,c

Table A-16
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 87 and Tube Line 87 and Tube Row 41)

a,c

Appendix B: Thermal-Hydraulic Conditions on Batwing within Row 1 Tube

This appendix defines coordinate of selected points for calculating thermal-hydraulic conditions for batwing within tubes in Row 1. Figure B-1 illustrates three points for the selected batwing within Row 1 tubes.

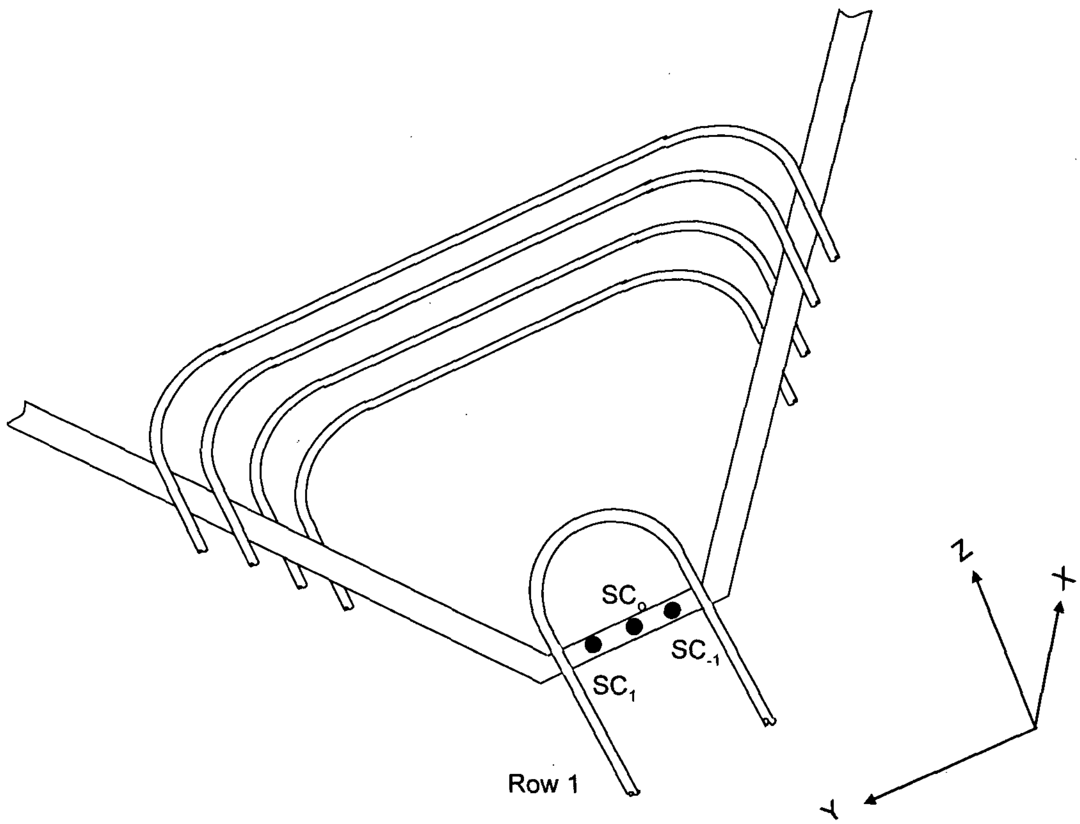

Figure B-1 Selected Points for Calculating Thermal Hydraulic Conditions For Batwings within Row 1

We selected the batwing between Tube Lines 60 and 61, and thus Table B-1 tabulates the coordinates to define three points that are outside the tube bundle. Similar to batwings as defined in Appendix A for larger tube rows. Table B-2 tabulates fluid density, velocity and void fraction for Batwing 60.

Table B-1
Coordinate for Thermal-Hydraulic Conditions
(For Batwing 60)

a,c

[ ]

Table B-2
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 60)

a,c

[ ]

Appendix C: Thermal-Hydraulic Conditions on Batwing

Coordinates of Batwing #69

Figure C-1 identifies locations of 17 points for extracting the secondary velocity, density, and flow area from ATHOS results, using the homogeneous model, for Batwing #69. Table C-1 lists coordinates for those 17 points for Batwing #69. There is no need to extract ATHOS results for the horizontal span of the U-bend.

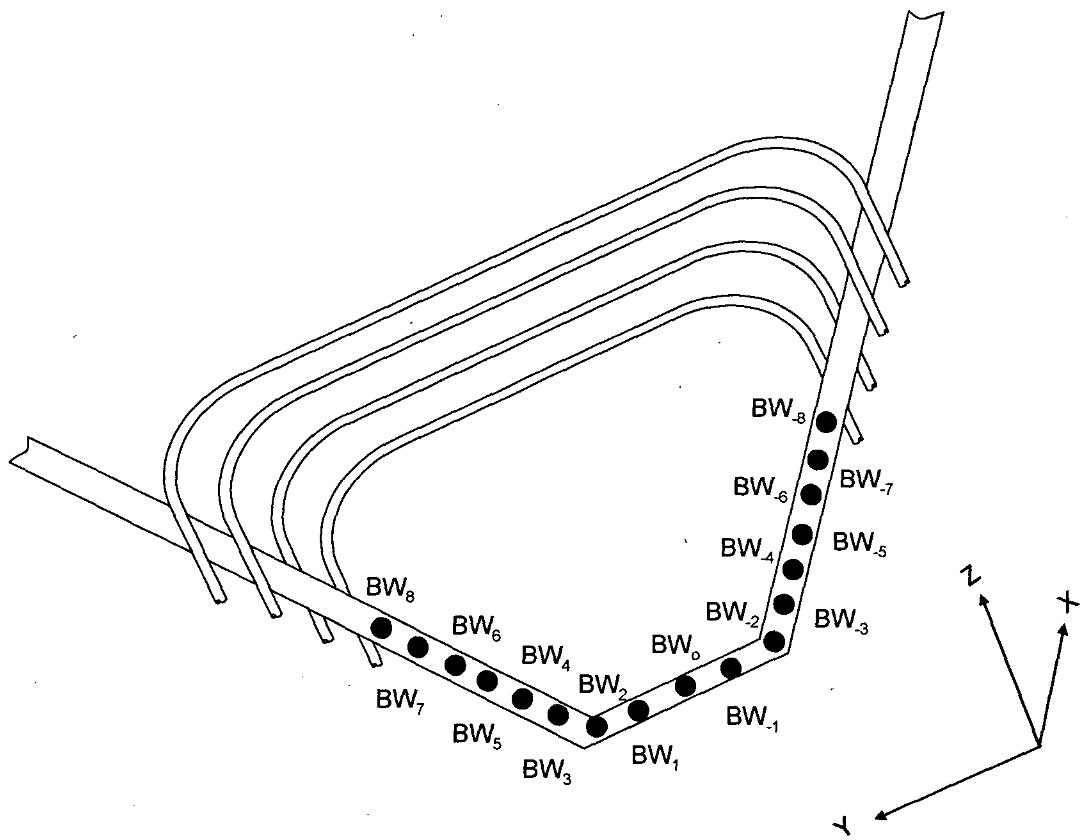

Figure C-1 Locations of 17 points for extracting velocity, density and flow area

Table C-1
Coordinates for T/H Conditions
(For Batwing 69)

a,c

[ ]

Table C-2
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 69)

a,c

Westinghouse

To: M.M. Stickel

Date: February 14, 2007

cc: D. Merkovsky, D.P. Siska, E.P. Morgan, G.W. Whiteman, A.L. Dietrich, P.A. Stancampiano, C.L. Hammer, B.A. Bell, J.M. Hall, J.G. Thakkar

From: J.S. Baron
Ext: 423.752.2849
Fax: 423.752.2731

Your ref:

Our ref: LTR-SGDA-06-199-NP Revision 1

Subject: **Evaluation of the Effect of Failed Batwings at Waterford 3 Operating at 3716 MWt Uprated Conditions with up to 20% Steam Generator Tube Plugging**

References:

1. CEN-328, Rev. 1, "Remedy For Steam Generator Tube And Diagonal Strip Wear Appendix 7.1 Wear Progression Analysis Results And Recommended Plugging Pattern For Songs 2, Songs 3, Waterford 3," Combustion Engineering, Inc. Windsor, Connecticut, July 1986.
2. CEN-328, Rev. 0, "Remedy For Steam Generator Tube And Diagonal Strip Wear Prepared for Palisades (Replacement Generators) Palo Verde Units 1, 2 and 3, St. Lucie Unit 2, Songs Units 2 and 3, Washington Nuclear Project 3, Waterford Unit 3," Combustion Engineering, Inc. Windsor, Connecticut, March 1986.
3. Not Used
4. Westinghouse Letter LTR-SGDA-06-181, "Effect of Multiple Batwing Failure on Thermal Hydraulics at Waterford 3 Steam Generators with 20% SGTP," J. G. Thakkar, October 20, 2006.
5. SG-SGDA-05-54, "Waterford 3 Steam Generator Cycle 14 Operational Assessment Concerning Tube Integrity Associated with Failed Batwing Assemblies," W. K. Cullen, December 2005.
6. Westinghouse Letter LTR-NEM-05-612, "Waterford 3 Failed Batwing Final Operational Assessment," J. Pelusi, August 8, 2005.
7. Westinghouse Calculation Note CN-SGDA-05-64 Revision 2, "Structural Analysis of Waterford 3 Batwings in Support of Tube Wear Evaluation," P. A. Stancampiano, October, 2006.
8. Westinghouse Calculation Note CN-SGDA-05-67 Revision 1, "Effect of Failed Batwings On Projected Tube Wear Rates At Waterford 3," J.S. Baron, October 31, 2006.
9. Westinghouse Letter LTR-SGDA-05-213, "Evaluation of Effect of Failed Batwings on Wear Rates and Attenuation At Waterford 3 For Cycle 14 Operation," J.M. Hall, December 22, 2005.
10. Westinghouse Calculation Note CN-SGDA-05-36 Revision 1, "Evaluation of Degraded Batwing Tube Supports in the Waterford 3 Steam Generators at 3716 MWt Power Uprate Conditions," B.A. Bell, November, 2006.

11. ASME Boiler and Pressure Vessel Code, Section III for Nuclear Power Components, 1971 Edition through Summer 1971 Addenda – ASME Code of Design for Waterford 3.

The purpose of this letter is to evaluate the effect of failed batwings on adjacent tube wear rates and to recommend tube, batwing upper weld and central stay cavity inspections. Additionally, this letter provides a technical basis for the operation of Waterford 3 steam generators (SGs) 31 and 32 in the acceptable failed batwing as-is configuration with appropriate considerations for plugging and/or stabilizing at 3716 MWt uprated conditions with up to 20% steam generator tube plugging (SGTP).

1.0 Introduction and Background

This letter summarizes the completed evaluations of failed batwings due to separation at the horizontal support notch and dropped or rotated about the upper weld and resting on a partial eggcrate in the Waterford 3 steam generator 32 (SG 32). This letter also addresses the potential failed and dropped batwings in SGs 31 and 32 under 3716 MWt uprated power conditions with up to 20% SGTP. These evaluations use methods that modify previous analyses to demonstrate the acceptability of the batwings (BWs) in the failed condition along with considerations for plugging and/or plugging and stabilizing potentially affected SG tubes. Figure 1-1 contains tubes recommended for plugging in SGs 31 and 32 as described in the original analysis (Reference 1). Figure 1-2 contains tubes plugged in Waterford 3 SG 32 during RF13. An operational assessment (OA) and wear evaluation of Cycle 14 operation has been completed (References 5 and 9). The results have been considered for this evaluation. The basis for tube acceptability was developed using both prior analyses along with current and potential future operational conditions. These evaluations utilize the current BW to tube wear model, as well as the tube and weld inspection programs that confirm the accuracy of that model. These evaluations conclude that the Waterford 3 SGs 31 and 32 are acceptable, as-is failed batwing configuration with appropriate considerations for plugging and/or stabilization, for operation without mechanical modification of the failed batwings under 3716 MWt uprated conditions with up to 20% SGTP.

A summary of considerations for potential batwing failure was prepared in Reference 6 and identified the actions necessary to resolve these issues. This letter addresses specific tasks related to attenuation of tube wear, and the potential for increased tube wear with the two failed batwings present in the Waterford 3 steam generators under 20% SGTP operating conditions. It also summarizes work performed to address the effects of failed batwings on previously generated workrates through the recommended use of a tube inspection program. An additional task involving the structural evaluation of the potentially degraded batwing tube weld supports has also been included.

All of these tasks address issues related to potential changes to the original workrate models. Since there would be multiple effects, there is a potential that combinations of these effects could result in different wear rates. This analysis (Reference 6) was then used to 1): determine the extent of rapid wear into the tube bundle (beyond those tubes plugged in the 1980's) and 2): to outline recommended SG tube and upper BW weld inspection procedures while Waterford 3 is operating under 3716 MWt uprated conditions with up to 20% SGTP.

2.0 Acceptance Criteria

The acceptance criteria used in the referenced calculations shall demonstrate that:

1) Tube wear rates associated with failed batwings do not result in tubes that exceed 40% wear depth in less than 1 full operating cycle during failed batwing as-is operation, with appropriate considerations for plugging and/or stabilizing, at uprated conditions and up to 20 % SGTP.

2) The batwing upper welds are structurally acceptable based on conservative analyses performed per Section III of the ASME Code (Reference 11).

3) The current de-plugging and eddy current inspection recommendation for RF14 is acceptable for identifying the conservatism of both the BW wear model and the Cycle 14 (OA) plugging and stabilization recommendations.

4) Upper weld inspections will verify the structural acceptability of the welds supporting the severed BW.

It should be noted that SG batwings and batwing upper welds are not pressure bearing components and as a result are not subjected to meeting ASME Section III criteria (Reference 11). However, the batwing upper weld regions are evaluated herein using the ASME code of record as a guide. The only component contacted by the batwings that is subject to Section III criteria are the steam generator tubes. SG tube integrity limits correspond to criteria set forth by NEI 97-06. Since ASME Section III structural requirements are implicit in the structural performance criterion of NEI 97-06, compliance with the NEI 97-06 indicates compliance with Section III requirements for the tubes. Upon completion of the LTR-SGDA-06-199 recommended actions taken during RF14 (and future outages) and with the current level of preventive plugging and/or stabilizing of tubes, SG tube integrity performance criteria will remain consistent with NEI-97-06.

3.0 Methods

Several analyses were used as a starting point. They include: 1) the analysis performed in the previous evaluation (Reference 9), 2) the test basis developed to address the original batwing problem in the mid 1980s, and 3) the current OA (Reference 5). References 1 and 2 contain specific details regarding results of analysis performed specifically for the Waterford 3 SGs. References 1 and 2 also include details and discussion regarding the original analysis and test basis performed to address BW wear for various model SGs. Since the original work from References 1 and 2 only addressed the condition where the batwings were not severed (intact), additional analysis was necessary to determine the effects of the batwing becoming severed at the central support bar as indicated in the Cycle 14 OA (Reference 5). The analyses summarized by this letter build on these previous efforts to qualify the Waterford 3 SGs for operation at 3716 MWt uprated and up to 20% SGTP conditions.

Previous efforts used the following workrate model to determine the potential for BW induced tube wear. Workrate uses both contact force and displacement per unit time in order to determine wear rate. The basis for this is defined using the Archard wear relationship:

$$Vol = K\,F\,D$$

Where,

Vol = Wear volume (in^3)
K = Wear Coefficient (in^2/lb)
F = Contact Force (lbs)
D = Sliding Distance (inch)

This can be re-arranged in to a workrate form:

$$Vol = K\,(WR)\,T$$

Where,

(WR) = Workrate = F D / t
F D = Force times distance or work per unit time –'t'
T = Time over which workrate (WR) occurs to produce wear volume 'Vol'

In the above workrate model, the contact force 'F' is a result of the secondary side flow forces acting on the BWs. This results in contact forces at the BW to tube wear site. A revision of the Waterford 3 SGs thermal hydraulic parameters and resulting flow forces acting on the BW (References 4 and 7) was necessary to perform the wear analysis for Waterford 3 under uprated power conditions with up to 20% SGTP. The displacement portion of the workrate results from tube motion, which supplies both the flow induced vibration (FIV) displacement per cycle along with the frequency of tube motion to define time. Since the failed BW does not significantly influence the tube dynamic response, both the displacement and frequency component of the workrate would not change in the post BW failure configuration.

The modified components of workrate under 3716 MWt uprated 20% SGTP conditions are the contact forces associated with BW to tube contact. The forces in both the pre- (intact) and post-sever condition have been determined using a non-linear ANSYS finite element model of the stay cavity region (Figures 3-1 to 3-5). Non-linearity was simulated by use of the large displacement option including stress stiffening, and compression-only gap elements used between the BW and tube contact locations. Included in this analysis were: 1) the effects of thinning of the BW as a result of chemical cleaning, 2) hinged batwings that were severed at the central slotted bar but had not yet dropped, and 3) the effect of multiple batwing failures.

Contact forces and displacements (for identification of additional tube interaction forces) were obtained for each of the locations where tubes would provide support to the BW under both a pre- and post-sever configuration. Plots of BW to tube contact forces (Reference 7) in both the pre- and post-sever conditions for Waterford 3 under 3716 MWt and 20% SGTP operation conditions can be found in Section 4. These forces were used in the current calculation to determine attenuation effects and changes to projected tube wear. Discussions of the implication of these changes are presented in subsequent sections of this letter.

The added task was that of structurally evaluating the BW upper welded support joints under degraded conditions due to chemical cleaning of the Waterford 3 steam generators operating at 3716 MWt uprated conditions with 20% SGTP. The degraded weld was evaluated for both the shear stress for the minimum weld shear area and the bending stress in the upper support region, as well as the endurance limit in this region per the ASME Code of Record (Reference 11) used in the original Waterford 3 steam generator stress report. The upper weld was analyzed assuming the longest batwing was not supported by the partial eggcrate and was free to deflect from its own weight.

Westinghouse considers an intact upper weld to be an important condition for long-term operation with degraded BWs. The failure of the upper weld coupled with a failure at the lower end could result in an unanalyzed tube support condition. As a result, it is important to inspect the upper weld regularly. Criteria to determine the acceptability of these welds are provided in subsequent sections. Recommendations for de-plugging and inspecting the affected tubing were developed to indicate the conservatism of the analytical model, as well as to evaluate the plugging and stabilization recommendations from the Cycle 14 OA (Reference 5). These recommendations will also be discussed in subsequent sections of this letter.

4.0 Batwing Sever Reaction Contact Force

The original BW to tube reaction force evaluation (Reference 9) considered potential for changes in BW to tube wear response in the post-sever condition due to a range of parameters including:

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[ ]

Various parameters that affect the above include:

a,c

[ ]

The above considerations were used in the development of the plots contained in Figures 4-1 through 4-4. These figures indicate the contact forces as a function of tube row in the pre- and post-sever conditions for nominal batwing thicknesses of 90 and 70 mils, with and without pre-existing wear as shown in the table below. Each plot has results presented for both the upper and lower BW contact location. Revision of the Waterford 3 operational parameters from 3716 MWt uprate with 5.3% SGTP to 3716 MWt uprate with 20% SGTP concluded that reaction forces calculated in Reference 9 are bounding (Reference 7). Therefore, the BW to tube reaction forces of Reference 9 may be conservatively used to develop wear projections.

Figure No	BW Thickness	Pre-Existing Wear
4-1	90 mils	No
4-2	90 mils	Yes
4-3	70 mils	No
4-4	70 mils	Yes

Note that the effects of multiple BW failures have been considered in all the figures and indicate that larger fluid forces occur with multiple BW failures (Reference 4). It is also possible that the BW could twist as a result of the applied load. It has been demonstrated that contact will likely occur at either the upper edge (Top) or lower edge (Bot) of the BW. As a result, the contact forces for both the Top and Bottom are presented in each figure. In addition, the lower plots contain results for both the 'severed' and the 'severed but pinned' condition. In the 'severed but pinned' condition, it has been assumed that the BW is severed but remains pinned at the center slotted bar.

In Figures 4-1 to 4-4, a vertical line is drawn at tube row 49 representing the last tube row plugged as a result of the original work performed in the 1980's. All tubes to the left of the vertical line have been removed from service. Tubes on the right hand side of the vertical line generally are still in service with the exception of tubes recently plugged for various reasons. As a result, the tubes of most interest are those to the right of the vertical line. These tubes are the tubes that are generally unplugged and the most susceptible to a leakage event if exposed to significant BW induced wear.

A review of these figures indicates Figure 4-2 (BW 90 mil thick with pre-existing wear) is the limiting case. Figure 4-2 demonstrates the largest contact force, measured in lbs, in the region not currently preventively plugged. As can be observed, there is a spike in reaction force at row 56 that continues up to row 62. These tubes are not within the locus of tubes plugged to address the original batwing wear problem. Tubes not plugged in the original BW wear problem are generally considered acceptable for 40 year operation. As a result, these tubes, located in rows 50 through 62, would be considered potentially susceptible to rapid BW induced tube wear once the BW fails. Since this is a triangular pitch SG, every other tube row is skipped when counting actual number of tubes. Essentially, seven tubes on either side of the failed batwing would be considered susceptible to rapid tube wear in the post-sever condition. These tubes should be removed from service if found associated with an adjacent failed BW.

5.0 Batwing Sever Tube Wear Rates

The tube with the largest increase in contact force after sever is a tube in Row 55 (R55) for the 90 mil case in a pinned condition with pre-existing tube wear under the enveloping Waterford 3 operational conditions. a,c

a,c

In light of these and potentially other factors a statement was made on page A 7-1 of Reference 1:

> *The wear progression analysis results represent wear of an average tube within a line; Specific tubes, affected by preloads and manufacturing tolerances, may exhibit greater than predicted wear during a particular fuel cycle while others may exhibit lesser wear.*

The current analysis does not change the applicability of this statement.

6.0 Wear Rate Progression – Effects of Wear Depth on Wear Rate

As the batwings wear deeper into the tubes, the amount of time required to wear into the next incremental depth would increase. Calculations have been performed to determine the increased wear time that would occur due to this effect. A summary of the results of these calculations identifying the correction factors used to address the effects of flat wear and curved or angle-contact BW induced tube wear can be found in Figures 6-1 and 6-2. The first figure contains a summary of factors for wear to 40% wear depth. The second curve contains a summary of factors for wear to 60% wear depth. Two curves are contained in each figure: one for angle contact, and one for straight or parallel contact. The information contained in the figure can be used to estimate the effect of increased wear depth on the change in wear rate.

7.0 Upper Batwing Weld Analysis

The detached or severed batwings in the Waterford 3 stay cavity remain supported at the upper weld region. An evaluation of the structural acceptability of this weld while the BW is in the detached condition was performed in Reference 10. The upper weld was analyzed assuming the longest batwing was not supported by the partial eggcrate and was free to deflect from its own weight. The resulting shear and bending stress as well as alternating stresses were evaluated by Reference 10 and the results are summarized as follows:

Table 7-1 Batwing Upper Weld Region Structural Analysis (Reference 10)

Location	Calculated Stress (psi)	Allowable Stress (psi)
Original Batwing Bar Thickness	263.7 (Shear)	0.6 Sm = 11,040
	9,870.9 (Bending)	1.5 Sm = 27,600
	12,073.3 (Alternating)	Salt = 12,500 for an infinite number of allowable cycles per Reference 11
Reduced Batwing Bar Thickness	202.2 (Shear)	0.6 Sm = 11,040
	9,794.7(Bending)	1.5 Sm = 27,600
	11,980.2 (Alternating)	Salt = 12,500 for an infinite number of allowable cycles per Reference 11

Based on the results in Table 7-1, it is concluded that the stresses in the upper weld regions are below their respective allowables and will not fail during operation of the Waterford 3 steam generators. The endurance limit for both the original and reduced batwing bar thicknesses in the upper and lower weld regions is infinite per the ASME Code of Record (Reference 11) used in the original stress report. It should be noted that considerations were made for the effect of quasi-static pressure loads associated with 3716 MWt and 20% SGTP (Reference 4). The conclusion was made that these loads are insufficient to overcome the weight of a failed batwing bar of either thickness during normal operation.

In the event that batwing upper weld locations at Waterford 3 are inspected to be of an unacceptable configuration, repair actions become required. An example of this postulated condition would be a single sided fillet weld is inspected to be present as opposed to the expected double sided fillet weld (one on each BW face). In conditions where a batwing upper weld repair becomes unfeasible, all tubes that contact the failed batwing will require plugging, sentinel plugging, or both plugging and stabilizing.

The Waterford 3 SGs are also designed to ensure that critical vibration frequencies are well out of the range expected during normal operation and during abnormal conditions. The tubing and BW supports are designed and fabricated with considerations given to both secondary side flow induced vibration (FIV) and reactor coolant pump (RCP) induced vibrations. In addition, the steam generator assemblies are designed to withstand the blow down forces resulting from the severance of the steam nozzle. None of the aforementioned design functions are adversely affected for the remaining active tubes in the bundle by the potential occurrence of degraded batwings.

8.0 Batwing Adjacent Tube, Upper Weld and Central Stay Cavity Inspections/Recommendations

8.1 Batwing Adjacent Tube Eddy Current Inspections and De-Plugging Recommendations

Tubes contained in Figure 1-1 were plugged as a result of work performed in 1986 to address the original batwing wear problem. This figure is a reproduction of Figure 7.1c found in Reference 1. Note that 284 tubes were recommended to be plugged but that a different number may have actually been plugged. Based upon the analysis performed to date along with the increased level of plugging performed to address the failed BW, the tubes currently plugged were determined acceptable for at least a single cycle of operation in Reference 9.

The purpose of de-plugging is to identify the conservatism of the analytical model for predicting wear due to dropped BWs, as well as to evaluate the plugging and stabilization recommendations from the Cycle 14 OA (Reference 5). This reference also provides recommendations for eddy current (ECT) inspections of tubes in the surrounding regions during the RF14 outage. If ECT identifies additional BWs that have been severed, these recommendations require plugging per Figure 8-2 adjacent to the severed batwing and stabilizing those with >30% wear. They also require plugging any tube with measured wear out to Row 84. Based on these criteria, the recommended Waterford 3 RF14 de-plugging is as follows.

- Row 59 / Column 83, Row 60 / Columns 82 and 84. These tubes are within the predicted zone of influence for detached batwings.
- Row 68 / Columns 82 and 84. These tubes are at the edge of the required plugging zone for new batwing failures.

The ECT results from the Row 59 and 60 tubes will be used to determine the conservatism of the analytical wear model. The results from the Row 68 tubes will be used to determine the conservatism of the plugging and/or plugging and stabilizing recommendations in the OA. Suggested courses of action based on ECT results are:

- If wear is less than 40% on all deplugged tubes, no changes to the analytical wear model or OA plugging and stabilization recommendations are required.
- If wear exceeds 40% on any tube, a new multiplier on the work rate must be calculated and changes to the plugging and stabilizing recommendations will be considered. However, the eddy current results from these tubes will not be the primary reason for changing the plugging recommendations in the OA since they are already considered conservative.

- If no wear is observed on any of the deplugged tubes, the model is shown to be highly conservative and plugging all tubes out to Row 68 is not necessary. Plugging/stabilization will be according to Figure 8-2.

Figure 8-1 is a flowchart of the above RF14 de-plugging recommendations as well as the suggested course of action based on ECT inspection results. In the event of further observed batwing failures during future outages at Waterford 3, a map summarizing recommendations regarding additional tube plugging is indicated in Figure 8-2.

8.2 Batwing Upper Weld Visual Inspection Recommendations

Failure of the upper weld coupled with a failure at the BW lower end could result in an unanalyzed support condition. Based upon the currently available information the batwing upper support welds should be inspected regularly. The inspection should concentrate on defects in the weld or heat-affected zone (HAZ) that would cause the weld to pull away from the wrap-around bar. These types of defects include large cracks or a lack of weld fusion indicated by a gap between the weld and base metals. The inspection should also address the analysis geometrical assumption of welds that are 0.094 inches thick and 0.374 inches long. The scenarios that could develop during inspections of these welds and HAZs include:

- No defects noted. No action necessary.
- Minor defects requiring engineering analysis.
- Major defects requiring repair of the weld (welding or mechanical).
- Weld is missing and the batwing is stuck in the tube bundle. Retrieval of the batwing and repair of the weld are required.
- Weld and batwing are missing and no retrieval is possible. Engineering justification and/or remedial action are required

Based on the existing analysis of the upper weld (Reference 10), there is a low probability that the weld would fail and the batwing would slide into the stay cavity. Any repairs needing to be performed on a defective weld using a repair weld or a mechanical attachment require design, analysis and mock-up testing of the repair method. As a result, it is not currently considered possible that repair of this form could be made during RF14. In the unlikely event that the inspection identifies a significant defect in an upper BW weld, additional plugging and/or plugging and stabilizing will be required.

8.3 Central Cavity Visual Inspection Recommendations

In addition to the eddy current and upper batwing weld inspections, Westinghouse recommends a visual inspection of the batwings from the upper stay cavity region. The focus of this inspection shall be to obtain data required to make supportable conclusions regarding the physical state of the batwings. Major points of this informational inspection shall be to:

- Determine if there are any differences between the current condition of the batwings and the conditions documented during RF 13.

- Document the failure location and overall condition of the affected batwings, in the event that additional batwing failures are identified.

Inspection of the Waterford 3 central stay cavity serves to provide information benefiting current/further recommendations or analyses that would need to be made as a result of the potentially degraded BWs.

9.0 Summary of Results and Conclusions

The following are assumed configurations for BW failure in the Waterford 3 central stay region:

- Single BW failure
- Multiple BW failures
- BW severed but not in a dropped configuration (supported at center of bundle)
- Original and thinned BW configuration
- Consideration for the effects of pre-existing tube wear
- Uprated operating condition to 3716 MWt with up to 20% SGTP.

The following is a summary of conclusions that can be made based on these BW configurations:

1) Wear rates will increase post BW failure by a factor of ~3 over both the non-failed/non-uprated condition.

2) 3716 MWt uprated loads with 5.3% SGTP generate higher BW to tube contact forces and therefore more conservative wear rates than those of 3716 MWt with 20% SGTP. However, the larger workrates associated with the limiting condition have been used in the analysis.

3) Zone of potentially affected tubes will penetrate into the bundle an additional ~7 tubes from the original plugging pattern on each side of the severed BW.

4) The recommended de-plugging and inspection plan will be used to determine the accuracy of the tube workrate models, along with the conservatism of the plugging and stabilization criteria contained in the Cycle 14 OA (Reference 5). Confirmation of the conservatism associated with the workrate model indicates that no additional BW to tube wear analyses will be required.

5) The recommended batwing upper weld inspection plan will verify the structural acceptability of the weld supporting the severed BW.

Based on the above, it is concluded that the degraded batwings will not adversely affect steam generator operational assessments during operation of Waterford Unit 3 at 3716 MWt uprated conditions with up to 20% SGTP. This conclusion can be made if it is confirmed by inspection that wear on all de-plugged tubes during RF14 is less than 40% wall loss, and the upper batwing weld remains intact. The conclusions and recommendations provided by this report are based on worst-case failed batwing wear conditions which bound current and potential future batwing failures.

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Reviewed By: D.P. Siska *
SG Design & Analysis

Figure 1-1
Original R1 Recommended Plugging Pattern SGs 31 and 32 (Reference 1)
Note that a different number of tubes may have actually been plugged.

a,c

Figure 1-2
Current Plugging Pattern – SG 32

a,c

Figure 3-1

a,c

FE Model ½ of the Batwing Located Between Tube Columns 87-88

Figure 3-2

a,c

FE Model ½ of the Batwing Located Between Tube Columns 87-88
Mesh Pattern of Brick Elements in Central Horizontal Strip

Figure 3-3

a,c

FE Model ½ of the Batwing Located Between Tube Columns 87 - 88
Mesh Pattern of Brick Elements at Adjacent Tube Rows 38, 39, 40 ...

Figure 3-4

a,c

FE Model of Full Batwing Located Between Tube Columns 87- 88

Figure 3-5

a,c

[ ]

FE Model of Full Batwing Located Between Tube Columns 87-88
Mesh Pattern of Brick Elements in Central Horizontal Strip

Figure 4-1
Contact Force Summary – Nominal BW Thickness (90 mil) No Pre-Existing Wear

a,c

Figure 4-2

Contact Force Summary – Nominal BW Thickness (90 mil) With Pre-Existing Wear (16 EFPY)

a,c

Figure 4-3

Contact Force Summary – Thinned BW Thickness (70 mil) No Pre-Existing Wear

a,c

Figure 4-4

Contact Force Summary – Thinned BW Thickness (70 mil) With Pre-Existing Wear (16 EFPY)

a,c

Figure 6-1

Wear Factor Vs. Initial Depth – Straight and Angle Contact

(Factor on Time Required to Reach 40% Wear Depth)

a,c

[ ]

Figure 6-2

Wear Factor Vs. Initial Depth – Straight and Angle Contact

(Factor on Time Required to Reach 60% Wear Depth)

a,c

Figure 8-1

RF14 De-Plugging Flow Chart

a,c

Figure 8-2

Waterford Plug/Stabilize Boundary Options

a,c

Westinghouse

To: J. M. Hall

Date: February 15, 2007

cc: P. R. Nelson

From: L. M. Cayton
Ext: (724)-722-6133
Fax: (724)-722-5889

Your ref:
Our ref: LTR-SGDA-06-221-NP

Subject: **Effect of Multiple Batwing Failure on Thermal Hydraulics at Waterford 3 Steam Generators with 3716 MWt Power Uprate and 20% SGTP**

This letter transmits the customer requested information from Reference 1, "Effect of Multiple Batwing Failure on Thermal Hydraulics at Waterford 3 Steam Generators with Power Uprate and 20% SGTP."

The Reference 1 was written to document results of quasi-static loads on the batwing strips within the central cavity and basic thermal hydraulic parameters, as calculated by the ATHOS code, for Waterford Unit 3 steam generators operating at 3716 MWt Power with 20% Tube Plugging.

Please contact the undersigned if there are any questions or if further clarification is required.

Author (Electronically Approved*)
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Steam Generator Design & Analysis

Verifier (Electronically Approved*)
J. G. Thakkar
Steam Generator Design & Analysis

// attachment

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Effect of Multiple Batwing Failure on Thermal Hydraulics at Waterford 3 Steam Generators with 3716 MWt Power Uprate and 20% SGTP

February 15, 2007

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Electronically approved records are authenticated in the Electronic Document Management System.

Table of Contents

1. Introduction

Waterford Unit 3 steam generators have experienced tube wear at the intersection of the batwings and tubes near the central stay cavity. It has been observed during the spring 2005 outage that two batwings failed and dropped to a lower elevation. Since it is clear that multiple batwings could fail, it is necessary to determine if the resulting change in batwing spacing geometry could significantly influence the thermal hydraulic characteristics within the central stay cavity. This evaluation of thermal hydraulics under the conditions of multiple batwings failure is a part of the Waterford 3 Failed Batwing Operational Assessment.

References 1 through 3 document the ATHOS calculated thermal-hydraulic parameters and the quasi-static loads on the batwing strips within the central cavity region for the 3390 MWt (Cycle 12) and uprated 3716 MWt with [ ]^{a,c,e} or 5.3% Steam Generator Tube Plugging (SGTP) conditions. This technical correspondence, documents the effect of 20% SGTP at the uprated power, 3716 MWt conditions in the similar format.

The effect of multiple batwing failures on the thermal hydraulics will be determined. Calculations will be performed to evaluate the effects of flow redistribution as the batwing strips change their spacing between the neighboring batwings. Using the calculated thermal hydraulic parameters, a quasi-static load on the batwing strip will be estimated for use in a structural evaluation of the contact force between the batwing and tube.

2. Summary of Results and Conclusions

Waterford Unit 3 steam generators have experienced tube wear at the intersection of the batwings and tubes near the central stay cavity. During the spring 2005 outage, two batwings were observed to be broken at the horizontal base on the cold leg side. The spacing between these two broken batwings appears to narrow down from the regular spacing, as illustrated in Figure 2-1.

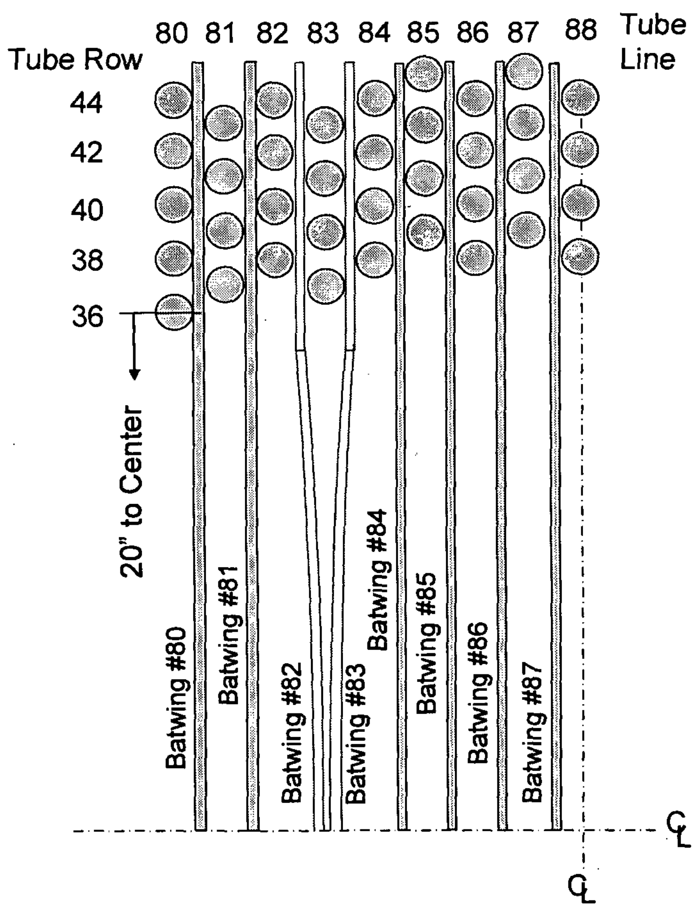

Figure 2-1 Narrowing Space between Failed Batwings

It is clear that multiple batwings could fail. It is necessary to determine the impact of the change of the batwing spacing on thermal hydraulic characteristics within the central stay cavity. Changes in thermal hydraulic conditions can affect wear volume over years of operation. Wear volume calculation depends on contact force between the batwing and tube and sliding the distance of the tube under fluid dynamic pressure over the horizontal span of the U-bend. Both contact force and fluid dynamic pressure depend on the fluid density and the velocity at the batwing within the central cavity and over the horizontal span of the tube-bend (see Figure 2-2).

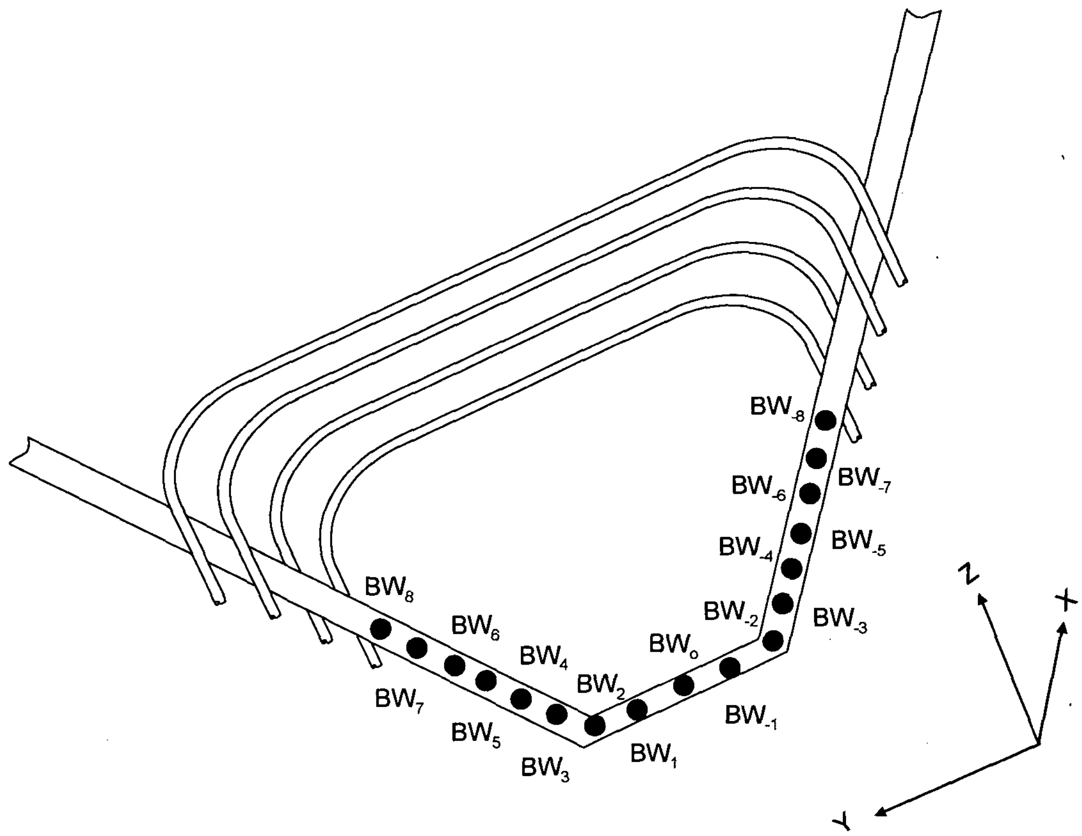

Figure 2-2 Locations of Velocity Assessment

Fluid density and velocity for these two regions can be assessed under non-failure and multiple-failure of the batwings. Velocity is assessed at 17 discrete points along the batwing (i.e. at BW_n points; 8 on hot and cold leg side each, and one point at the center). For the as-designed or the intact batwing the secondary fluid density, velocity, and dynamic pressure at the 17 points along batwing are calculated using the ATHOS model of the Waterford 3 steam generators. The dynamic pressure is used to obtain a quasi-static load on the batwing strip at each of the 17 points. Tables 2-1 and 2-2 provide an area-averaged value of the quasi-static load over the 9 points on the hot and cold leg, respectively. The tables include quasi-static loads for all three analyzed conditions, i.e. 3390 MWt with 4.7% SGTP (Cycle 12), and the uprated power level of 3716 MWt with 5.3% SGTP and 20% SGTP. These tables provide data for eight batwings within the central cavity region and one batwing outside the cavity. The tables compare the loads for both the as-designed (intact) as well as batwings with multiple failures.

a,c,e

a,c,e

3. Method Discussion

Tube wear at the intersection of the batwing and tubes has been evaluated in 1985 by CEN-328 (Reference 4), which documents the methodology for such wear calculation.

According to Reference 4, both the fluid density and velocity were provided by test models with water and air-water mixture. The test model also included measurements of forcing functions and thus the overall methodology was properly qualified. Once the methodology was verified, actual thermal hydraulic conditions were determined using the ATHOS3 Mod 01 (ATHOS) code (Reference 5). Note that the ATHOS code was developed and qualified by Electric Power Research Institute for nuclear steam generators. ATHOS code has been well accepted in the nuclear industry for calculating detailed thermal hydraulics conditions in the steam generator.

3.1 Thermal Hydraulic Inputs

The ATHOS3 code has been used to calculate density and velocity of steam-water mixture flow at selected locations within the central cavity. The ATHOS code calculates the three-dimensional thermal and hydraulic parameters including density and velocity on the secondary side of the steam generator. Such calculations have been performed for Waterford Unit 3 steam generators for the original power level of 3390 MWt and the uprated power level of 3716 MWt with [ ][a,c,e] (5.3% SGTP) plugged tubes in Reference 6 and at 3716 MWt with 1870 (20% SGTP) plugged tubes in Reference 7. The results and model of ATHOS calculation for Waterford Unit 3 are documented and verified in References 6 and 7. Utilizing this verified ATHOS model and operating conditions from Reference 7, new calculations with the homogeneous modeling of two-phase flow are performed for the present evaluation, and appropriate results are extracted and documented in Appendices A, B and C.

Figure 3-1 illustrates the Waterford Unit 3 steam generator which includes the batwing and grid support locations in the tube bundle. Figure 3-2 depicts the mesh layout of the ATHOS computational model that provides finer meshes in the upper tube bundle where the batwings are located. The batwings are not included in the computational model as the batwings are thin and lined up in the vertical directions and thus have a negligible impact on the predominantly axial flow in the U-bend region. These finer meshes will adequately define fluid conditions in the central cavity and U-Bend regions. Thermal and hydraulic parameters are similar between the original full power and uprated power conditions. Figures 3-3 through 3-6 show velocity vectors, velocity contours, density contours, and void fraction contours at 3716 MWt with 20% SGTP, along the symmetry plane, IX=1 (middle of the hot leg) and IX=18 (middle of the cold leg).

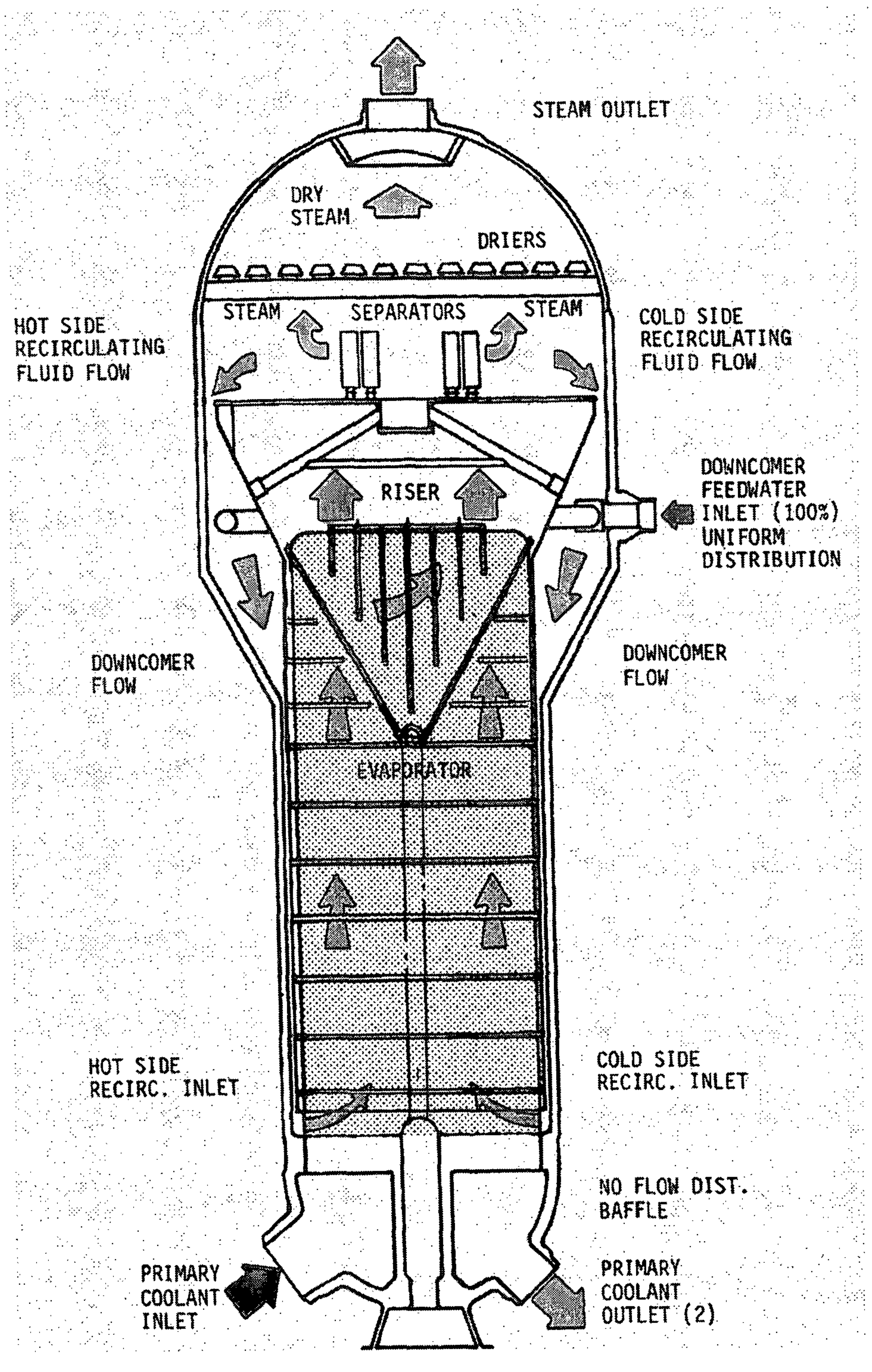

Figure 3-1 Schematic of the Waterford Unit 3 Steam Generators

a,c,e

[ ]

Figure 3-2 Mesh Layouts of the ATHOS Computational Model

a,c,e

[ ]

Figure 3-3 Velocity Vectors along the Symmetry Plane

a,c,e

Figure 3-4 Velocity Contours along the Symmetry Plane

a,c,e

Figure 3-5 Fluid Density Contours along the Symmetry Plane

a,c,e

Figure 3-6 Void Fraction Contours along the Symmetry Plane

Fluid density and axial velocity are needed only for the batwings. It was decided that input for the horizontal span is not required for evaluation of the failed batwings. Figure 3-7 illustrates locations to define fluid density and axial velocity. For the batwing, there are 17 points for extracting fluid density and axial velocity from results of ATHOS calculation. All 17 points are on the Y-Z plane parallel to the lateral face of the batwing, but away from the batwing lateral surface by a normal distance of 0.388 inch in the direction of X-coordinate. According to the fluid density and velocity, the dynamic pressure can be calculated at each point and then a quasi-static load can also be calculated.

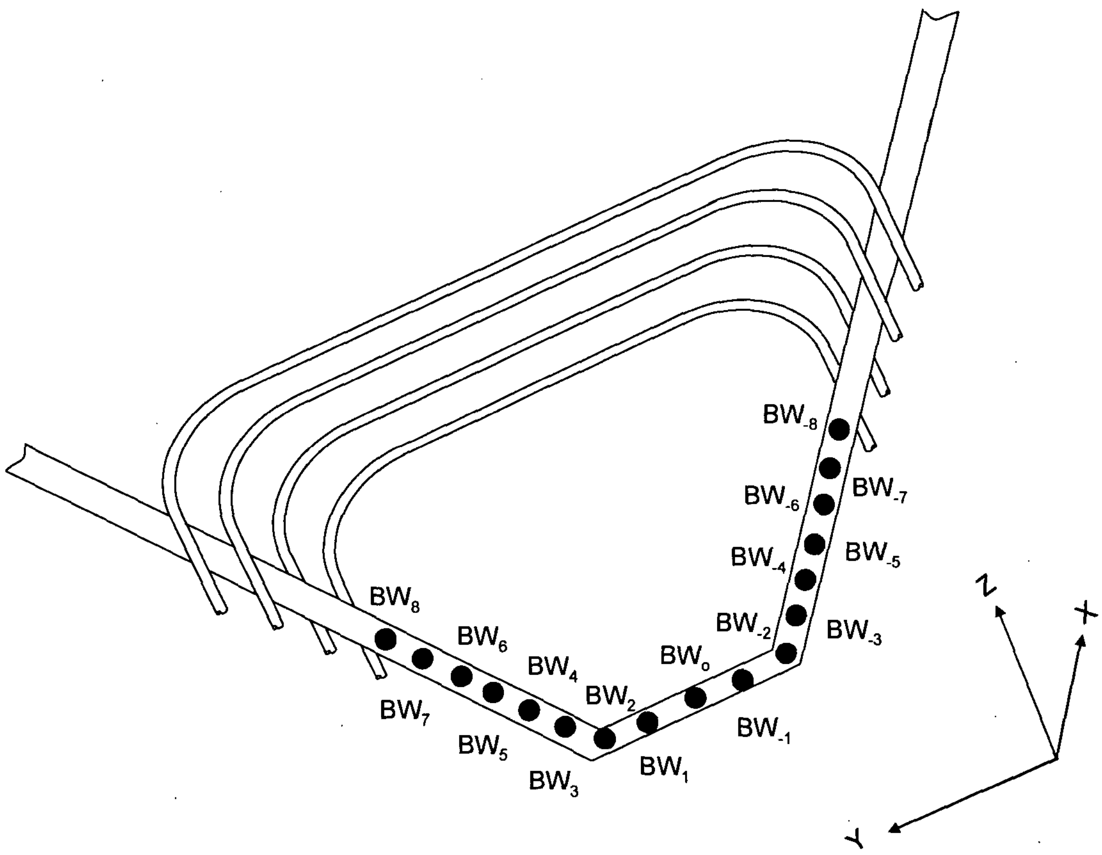

Figure 3-7 Locations of Thermal Hydraulic Inputs at Batwing and U-tube Horizontal Span

Table 3-1 tabulates batwings (see Figure 2-1) to be considered. These batwings cover those with the largest tube row in the central cavity as illustrated in Figure 3-8. These include two batwings marked in red which are found to be broken, as to be described in Section 4.

Table 3-1
Selected Batwings and Tubes for Defining Thermal/Hydraulic Conditions

Batwing #	T/H at Line #	T/H at Row #
80	80	38
81	81	39
82	82	40
83	83	39
84	84	40
85	85	41
86	86	40
87	87	41

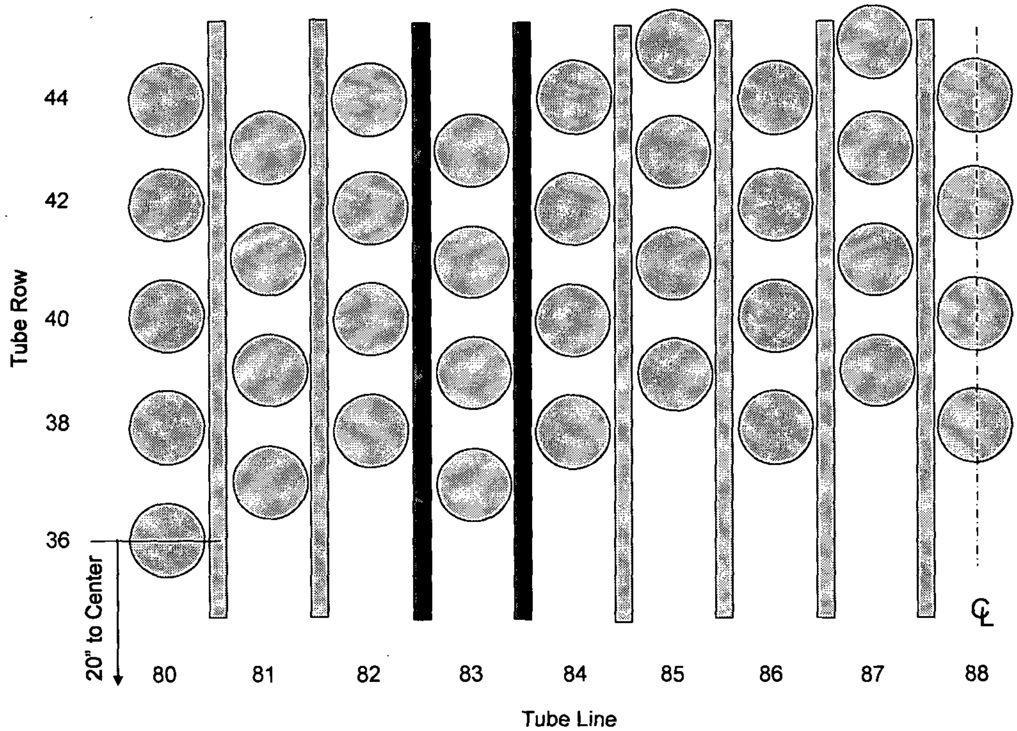

Figure 3-8 Batwings and Tubes Considered in Table 3-1

Appendix A tabulates the coordinates of the 17 points for the batwings listed in Table 3-1. Velocity and density from ATHOS analysis are extracted for those points. The quasi-static loads at these points are then calculated. Once these loads are obtained at these 17 points, area-averaged quasi-static load can be calculated for the hot and cold leg sides. In calculating area average, the point BW_0 is shared by both the hot and cold legs. Therefore, there are nine points on each leg. Table 3-2 provides area-averaged values for the nine selected batwings at the uprated power of 3716 MWt with 20% SGTP. References 2 and 3 include the corresponding values for the original design (3390 MWt) and the uprated power (3716 MWt with 5.3% SGTP) conditions. Table 3-2 presents results for the as-designed or the intact batwings. As shown in Appendix B, Batwing # 60 is outside the central cavity and the remaining ones are in the central cavity. For the configuration with failed batwings, equivalent table is presented in Sections 4 and 5.

Table 3-2
Quasi-static Load on As-Designed Batwing Strip at 3716 MWt with 20% SGTP a,c,e

4. Effect of Multiple Batwing Faliures on Thermal Hydraulics in Central Cavity

Figure 4-1 illustrates an intact batwing within the central cavity. There are two failed batwings located between tube lines 82–83 and 83–84 (see Figure 2-1). The failed batwing broke at the horizontal span. The break took place on the cold leg side and the hot leg side is still supported by a vertical strip, at its original location. However, the cold leg side piece is free to move, as shown in Figure 4-2. It is translated by a distance 0.853" near the Eggcrate #8. Such a displacement is equivalent to a rotation of about 0.6°, and its horizontal span dropped vertically by approximately 0.6". The central cavity is approximately 40 inches in diameter and the horizontal span of the tube is also approximately 40 inches above the horizontal span of the batwing. The displacement of the broken batwing is very small compared to the central cavity diameter and the height of the horizontal span of the tube. Therefore, a small change in vertical position has a negligible effect on the thermal hydraulic conditions in the central cavity and the horizontal span of the tube. However, the spacing between batwings may either increase or decrease due to movement of the broken pieces. The effects of spacing changes will be addressed below.

a,c,e

Figure 4-1 Batwing within Central Cavity

a,c,e

Figure 4-2 Vertical Displacement of Broken Cold Leg Piece of Batwing

Figure 4-3 identifies the locations of two failed batwings (i.e. between Tube Lines 82-83 and 83-84). If we were to identify the batwing by the lower number of the tube line, then the failed Batwings are #82 and #83. Evaluations will focus on Tube Lines 80 through 87 and thus Batwings #80 through #87. Figure 4-4 illustrates that the failed cold leg pieces between Batwings #82 and #83 have come closer. This demonstrates that spacing between the batwings can change if they break in a similar fashion as Batwings #82 and #83.

a,c,e

Figure 4-3 Failed Batwing between Tube Lines 82-83 and 83-84

Figures 4-5, 4-6 and 4-7 illustrate three possible spacing configurations among the failed and intact batwings. There can be many other configurations. However, we will concentrate on these three configurations and assess their potential in affecting the fluid velocity in the axial direction.

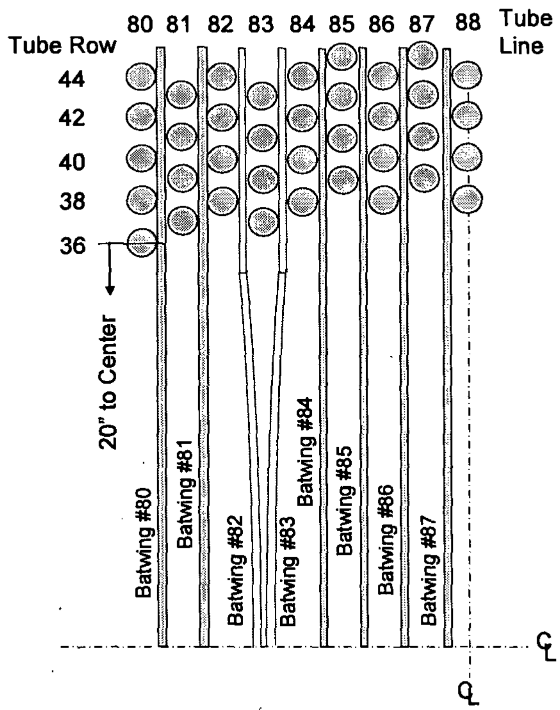

Figure 4-4 A Schematic of Failed Batwings Coming Closer

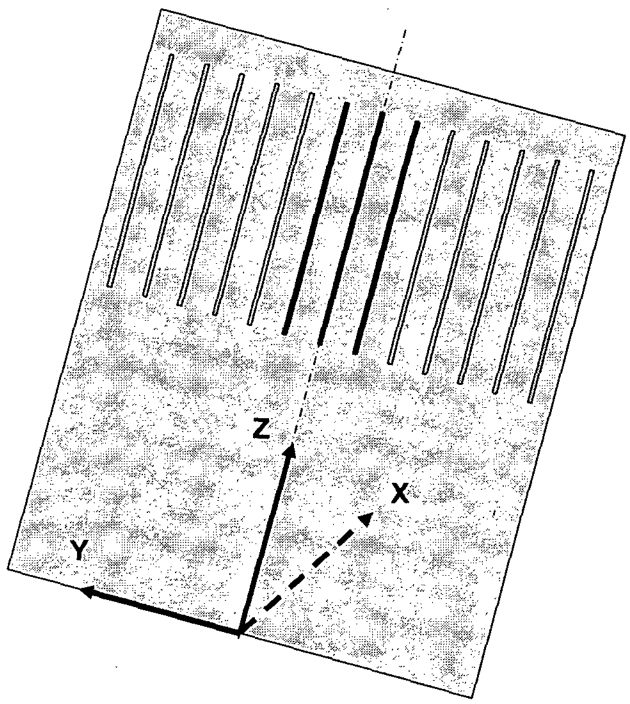

Figure 4-5 Equal Spacing among All Channels of Batwings

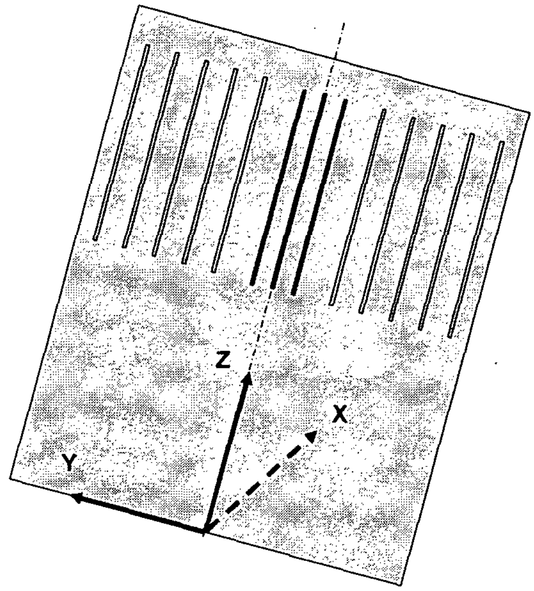

Figure 4-6 Unequal Spacing among All Channels of Batwings

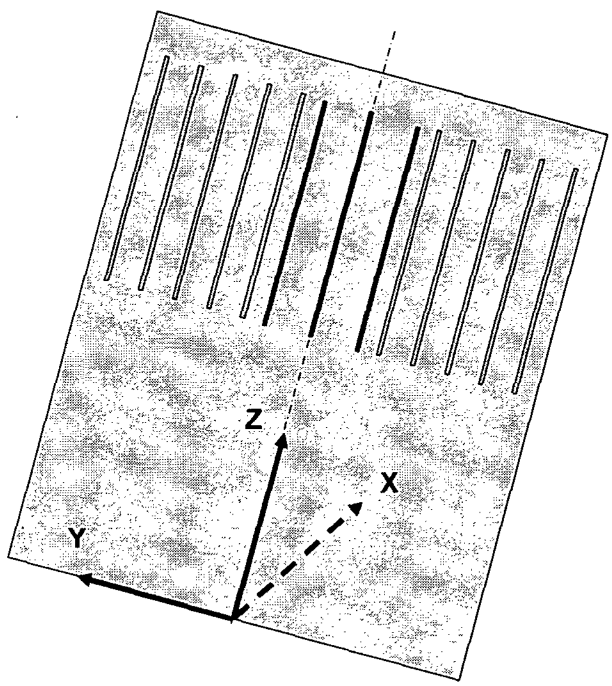

Figure 4-7 Other Unequal Spacing among All Channels of Batwings

Figures 4-8 and 4-9 depict the vertical characteristic length of the batwing channels for vertical flow, L, is 2 inches in the horizontal span of the batwing and 3.5 inches away from the horizontal span. As illustrated in Figure 4-4, spacing will vary in the radial direction from the center towards the edge of the cavity. Channel 1 represents a channel formed by intact batwings with its spacing $S_1 = S = 0.776$". Channels 2 and 3 are subject to variation with $S_2 + S_3 = 2S$. We can choose to reduce S_3 and increase S_2, accordingly.

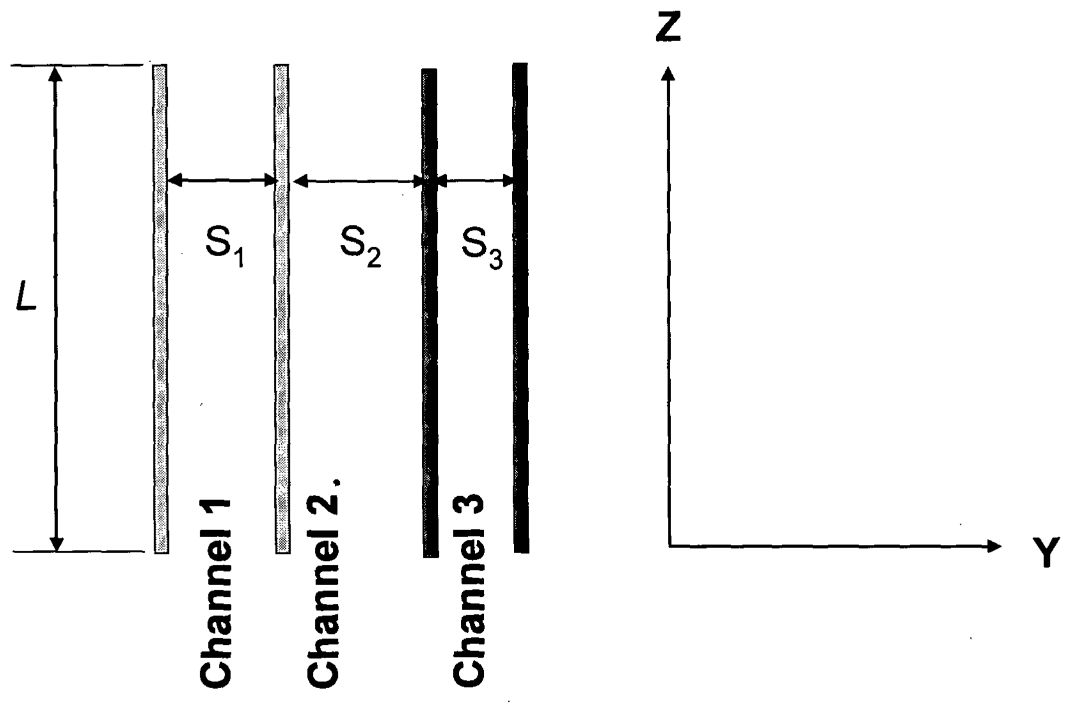

Figure 4-8 A Three Channel Model with Unequal Spacing

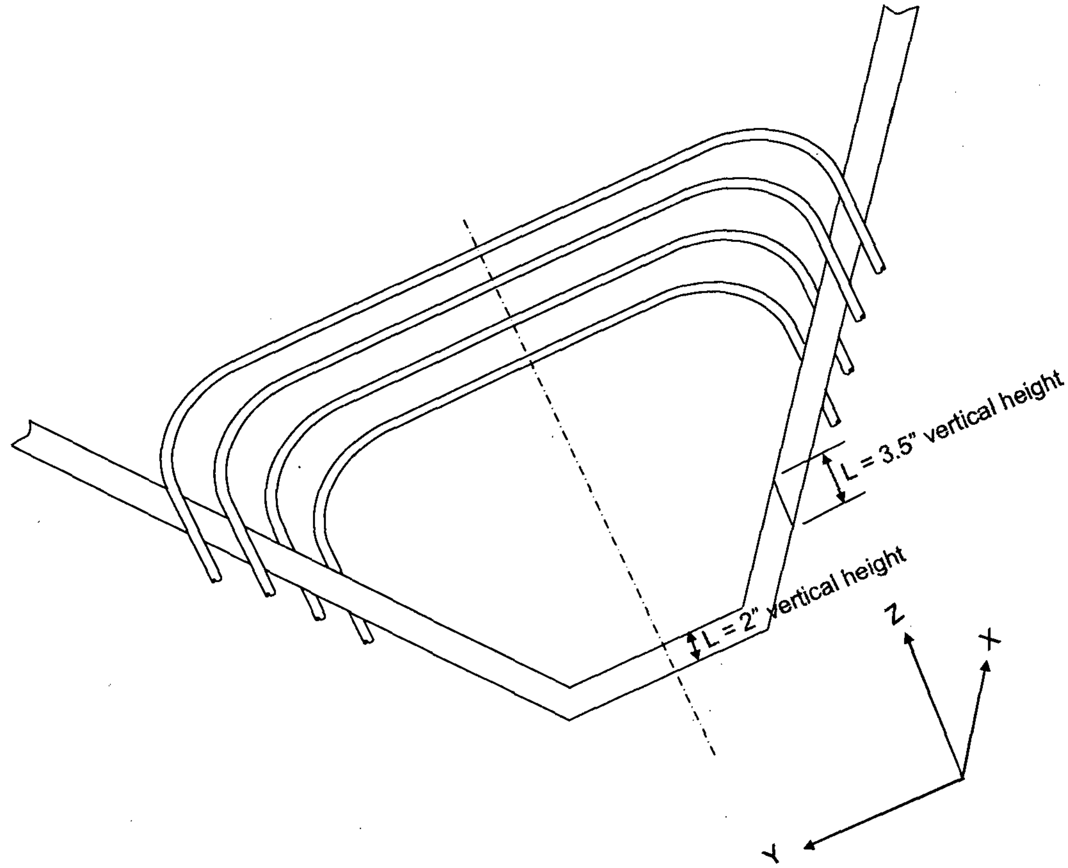

Figure 4-9 Vertical Characteristic Length of the Batwing Channels as Illustrated in Figure 4-8

The velocity ratios are obtained by solving the steady state equations for the conservation of mass and momentum among the channels with different spacing between the batwings. Within the central cavity, we can consider that flow is isothermal, and characteristic lengths L and ΔX are invariant among three channels. These ratios allow us to assess the impact of batwing failure on fluid flow in the central cavity.

Table 4-1 tabulates results of flow splits and velocity among three channels under nine sets of channel spacing. As expected, bigger spacing channel (e.g., Channel 2) has higher flow rate (i.e. flow split, α), and greater velocity. In addition, velocity ratio of V_2/V peaks between Cases 6 and 7 with a value of 1.20.

Table 4-1
Flow Splits and Velocity under Altered Spacing due to Batwing Failure

a,c,e

We need the velocity to assess the effects of failed batwings on local dynamic pressure and thus quasi-static loadings to the batwing strip. As discussed earlier, the nine cases in Table 4-1 can be considered to be linked to each of the nine points along the batwing either on the hot leg or cold leg as tabulated in Table 4-2. This link is a good approximation.

Table 4-2 Velocity Ratio for Channel 2

a,c,e

5. Discussion

Calculation of tube wear volume requires quasi-static load along the batwing within the cavity and dynamic pressure for the horizontal span of the tube. Values of quasi-static load for the as-designed or intact batwings are provided in Table 3-2 for the uprated power level of 3716 MWt with 20% SGTP. However, two batwings between Tube Lines 82-83 and 83-84 were broken at the horizontal base on the cold leg side, as illustrated in Figure 5-1. The cold leg piece dropped about 0.6" vertically, as illustrated in Figure 4-2, and it is now free to move laterally.

Multiple failures of the batwings may take place and thus the broken pieces can displace from their original location as described above. However, the displacement is very limited; it dropped vertically only 0.6 inch due to the constraint of the partial Eggcrate #8 (see Figure 4-2). This drop of 0.6 inch is negligible compared to the total height of 105 inches (see Figure 4-2) of the failed batwings or the relative height of 20 inches within the central cavity (see Figure 5-2). Therefore, it is considered to have a negligible impact on fluid velocity due to a vertical drop of the batwing by a distance of less than one inch.

a,c,e

Figure 5-1 Intact and Failed Batwings

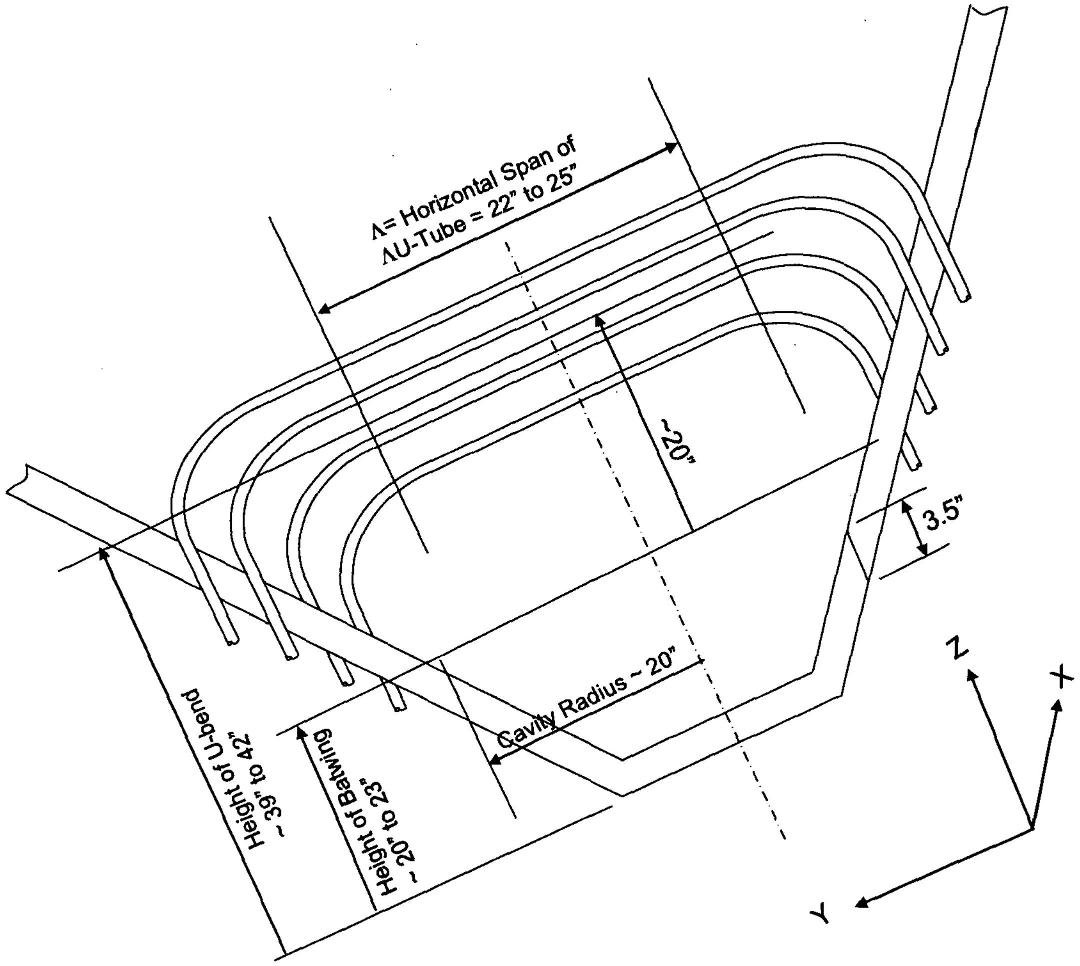

Figure 5-2 Dimensions of Central Cavity Radius, Batwing Heights and U-bend Tube Height (For Batwings between Tube Lines 80 through 98)

However, the broken pieces can move closer among themselves and change the spacing between each neighboring batwings (see Figure 4-3). This change in the batwing spacing within the central cavity obviously could have significant impact on fluid velocity. An idealized model is developed in Section 4 for assessing such an impact (see Figure 4-8). Table 4-1 tabulates results of altered velocity for a parametric calculation over a variety of spacing. As shown, both Channels 1 and 3 have a reduction in velocity while Channel 2 shows an increase in velocity, as tabulated in Table 4-2. For conservative evaluation of quasi-static load to the batwing strip with failure, it is recommended to use the results of Channel 2.

For convenience, Table 5-1 reproduces Table 4-2. Note that velocity for the intact batwings is represented by V which is obtained from ATHOS calculation and documented in Appendix A. Therefore, the ratio of V_2/V allows us to estimate the effect of the failed batwing on velocity V_2.

Table 5-1
Flow Splits and Velocity under Altered Spacing due to Batwing Failure

a,c,e

Note that we have assumed the failed batwing spacing does not affect fluid density. Therefore, we will use the density directly calculated by ATHOS for the intact batwings. With both fluid density and velocity obtained as above, a dynamic pressure and thus quasi-static load on the batwings is calculated at nine points along both the hot and cold legs of the batwing. Finally, an area-averaged quasi-static load is determined for nine selected batwings. Results are tabulated in Table 5-2 for the power uprate conditions of 3716 MWt with 20% SGTP.

Table 5-2
Quasi-static Load on Failed Batwing Strip at 3716 MWt with 20% SGTP

a,c,e

The impact of multiple batwing failures on fluid density and velocity to the horizontal span of the U-tubes has also been assessed. There are no changes in the tube pitch over the horizontal span. Therefore, the sole source of the potential impact should come from the displacement of the batwings, and the resulting change in the spacing between the batwings.

At each radial location, the height of the batwing channel is only about 3.5 inches (see Figure 4-9). A velocity deviation from the regular value will start to dissipate once it passes the 3.5 inch height. There is a total height ranging from 40 inches (at the center of the cavity) to 20 inches (at the edge of the cavity) up to the elevation of the horizontal span of the tubes to be assessed (see Figure 5-2). Such a height of 40 to 20 inches would be sufficient for the perturbed velocity (max. 20%) to totally dissipate. In addition, the tube bundle as compared to the cavity, serves as a good flow rectifier that would thus tend to bring the fluid to a uniform velocity. Therefore any impact of the batwing failure on the velocity over the horizontal span of the tube-bend is negligible.

According to the above discussion, we can draw the following conclusions.

1. Failed batwings can result in non-uniform spacing among the batwings.

2. Non-uniform spacing among the batwings can lead to an increase in axial velocity of the fluid passing through the batwing channels within the central cavity.

3. Non-uniform spacing among the batwings may affect the secondary fluid density, but is assumed to be negligible.

4. An increase in the axial velocity will occur in the channel with spacing greater than the regular value of 0.776 inch. The maximum increase is 20 percent.

5. Axial velocity of the fluid passing through the horizontal span of the tube-bend should not be affected by the batwing failure.

6. References

1. Westinghouse Correspondence, LTR-SGDA-06-181, "Effect of Multiple Batwing Failure on Thermal Hydraulics at Waterford 3 Steam Generators with Power Uprate and 20% SGTP", October 20, 2006.
2. Westinghouse Correspondence, LTR-SGDA-05-211, Revision 1, "Effect of Multiple Batwing Failure on Thermal Hydraulics", December 13, 2005.
3. Westinghouse Correspondence, LTR-SGDA-05-222, "An Update to the Effect of Multiple Batwing Failure on Thermal Hydraulics", December 20, 2005.
4. CEN-328, "Remedy for Steam Generator Tube and Diagonal Strip Wear," March 1986, Combustion Engineering, Inc., Windsor, Connecticut.
5. Singhal, A. K. et al., "ATHOS3 Mod 01: A Computer Program for Thermal Hydraulic Analysis of Steam Generators, Volumes 1-3," EPRI-NP-4604-CCML, September 1990.
6. Westinghouse Calculation Note, CN-SGDA-03-25, "Thermal Hydraulic Analysis of Waterford-3 Steam Generators at 3716 MWt Power Uprate Conditions", May 2003.
7. Westinghouse Calculation Note, CN-SGDA-06-6, "Thermal-Hydraulic and Flow Induced Vibration Analyses of Waterford 3 Steam Generator at 3716 MWt Power for 20% Tube Plugging", March 2006.

Appendix A: Thermal Hydraulic Conditions on Batwings and Tube Horizontal Spans

This appendix defines coordinates of selected points for defining thermal hydraulic conditions for both the batwings and the tube horizontal spans. Figure A-1 illustrates the 17 selected points on the batwing and seven points on the horizontal span.

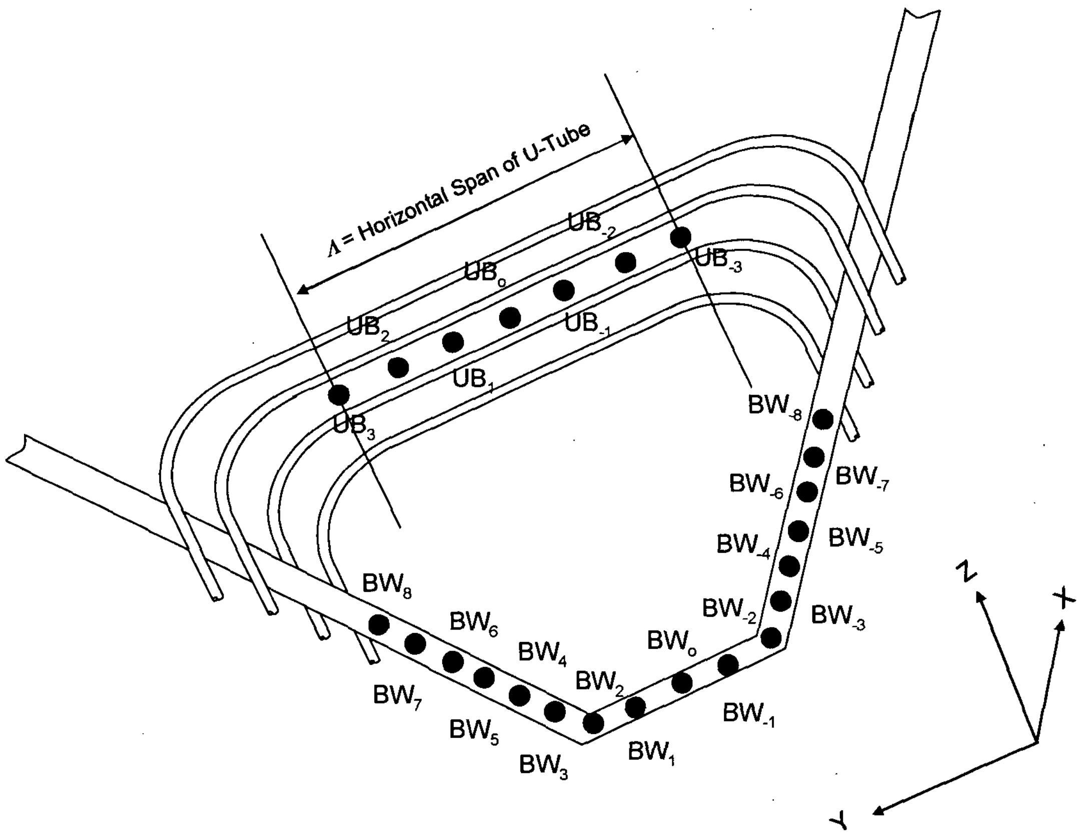

Figure A-1
Points for Defining Thermal Hydraulic Conditions
On the Batwing and the Horizontal Span

a,c,e

[ ]

Figure A-2 Tube Map and Horizontal Meshes of ATHOS Model

Figure A-2 shows the mesh layout of the ATHOS model over the tube map. Figure A-3 depicts the coordinate system for the selected points. The origin is at the center of the top of tubesheet, the X-coordinate is along the tube lane, the Y-coordinate is along the symmetry line and points toward the hot leg side, and the Z-coordinate is identical to that of ATHOS calculation model (Figure 3-4). The polar coordinate (or cylindrical) system is used in the ATHOS model, where as this evaluation is performed in the Cartesian coordinate system. However, they can be readily converted between each other.

a,c,e

Figure A-3
Coordinate System for Identifying Points
On the Batwing and the Horizontal Span (see Figure A-1)

We will concentrate on Tube Lines 80 through 88 (the line of symmetry) and Batwings 80 through 87 and the associated tubes, one row from the outer tube. The following table identifies selected batwings and tubes for the evaluation:

a,c,e

[ ]

According to this coordinate system Tables A-1 through A-8 define coordinates for each set of batwing and tube as listed in the above table.

At locations shown in Tables A-1 through A-8, the calculated thermal-hydraulic parameters at the uprated power level of 3716 MWt with 20% SGTP are extracted from the ATHOS analysis. Values of fluid density, velocity, and void fraction are tabulated in Tables A-9 through A-16. The tables also include average values for the selected points (17 for the batwing and 7 for the U-Bend).

Table A-1
Coordinates for T/H Conditions
(For Batwing 80 and Tube Line 80 and Tube Row 38)

a,c,e

Table A-2
Coordinates for T/H Conditions
(For Batwing 81 and Tube Line 81 and Tube Row 39)

a,c,e

Table A-3
Coordinates for T/H Conditions
(For Batwing 82 and Tube Line 82 and Tube Row 40)

a,c,e

Table A-4
Coordinates for T/H Conditions
(For Batwing 83 and Tube Line 83 and Tube Row 39)

a,c,e

Table A-5
Coordinates for T/H Conditions
(For Batwing 84 and Tube Line 84 and Tube Row 40)

a,c,e

[ ]

Table A-6
Coordinates for T/H Conditions
(For Batwing 85 and Tube Line 85 and Tube Row 41)

a,c,e

Table A-7
Coordinates for T/H Conditions
(For Batwing 86 and Tube Line 86 and Tube Row 40)

a,c,e

Table A-8
Coordinates for T/H Conditions
(For Batwing 87 and Tube Line 87 and Tube Row 41)

a,c,e

[ ]

Table A-9
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 80 and Tube Line 80 and Tube Row 38)

a,c,e

Table A-10
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 81 and Tube Line 81 and Tube Row 39)

a,c,e

Table A-11
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 82 and Tube Line 82 and Tube Row 40)

a,c,e

Table A-12
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 83 and Tube Line 83 and Tube Row 39)

a,c,e

Table A-13
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 84 and Tube Line 84 and Tube Row 40)

a,c,e

Table A-14
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 85 and Tube Line 85 and Tube Row 41)

a,c,e

Table A-15
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 86 and Tube Line 86 and Tube Row 40)

a,c,e

Table A-16
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 87 and Tube Line 87 and Tube Row 41)

a,c,e

Appendix B: Thermal-Hydraulic Conditions on Batwing within Row 1 Tube

This appendix defines the coordinates of the selected points for calculating thermal-hydraulic conditions for batwing within tubes in Row 1. Figure B-1 illustrates three points for the selected batwing within Row 1 tubes.

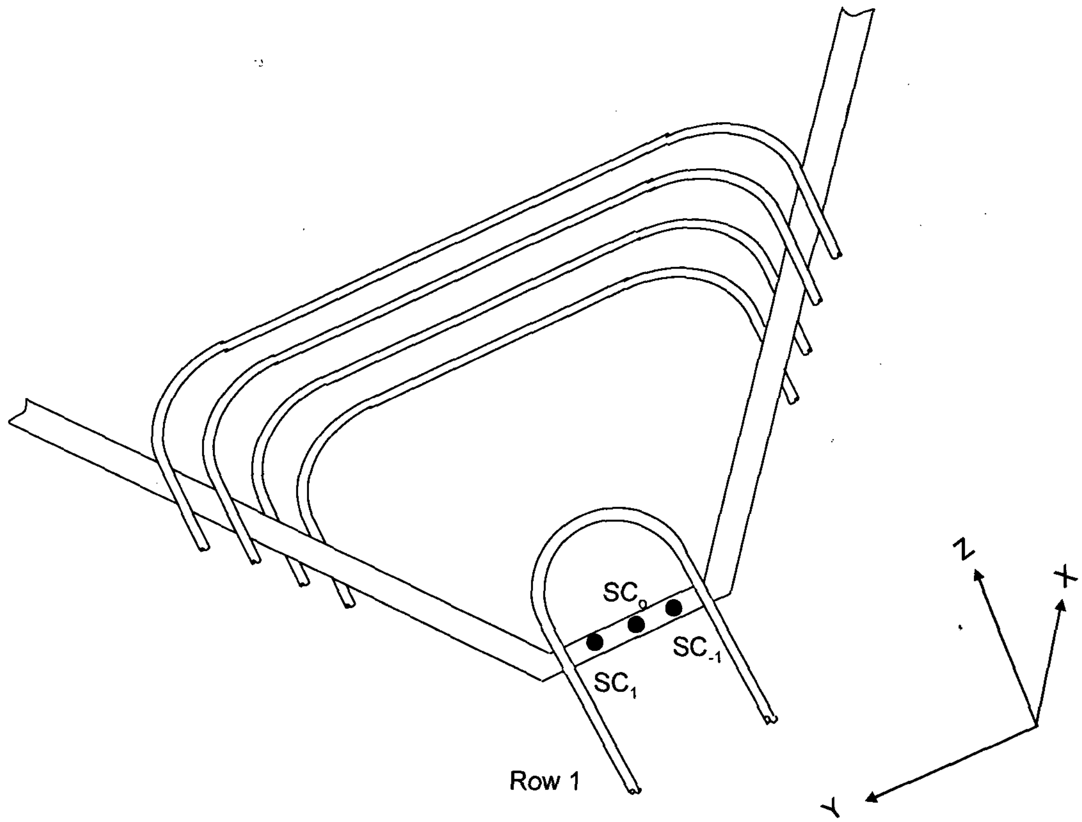

Figure B-1 Selected Points for Calculating Thermal Hydraulic Conditions For Batwings within Row 1

Batwings between Tube Lines 60 and 61 were selected, and thus Table B-1 tabulates the coordinates to define three points that are outside the tube bundle. Similar to batwings as defined in Appendix A for larger tube rows. Table B-2 tabulates fluid density, velocity and void fraction for Batwing 60.

Table B-1
Coordinates for Thermal-Hydraulic Conditions
(For Batwing 60)

a,c,e

[ ]

Table B-2
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 60)

a,c,e

[ ]

Appendix C: Thermal-Hydraulic Conditions on Batwing

Coordinates of Batwing #69

Figure C-1 identifies locations of 17 points for extracting the secondary velocity, density, and flow area from ATHOS results, using the homogeneous model, for Batwing #69. Table C-1 lists coordinates for those 17 points for Batwing #69. There is no need to extract ATHOS results for the horizontal span of the U-bend.

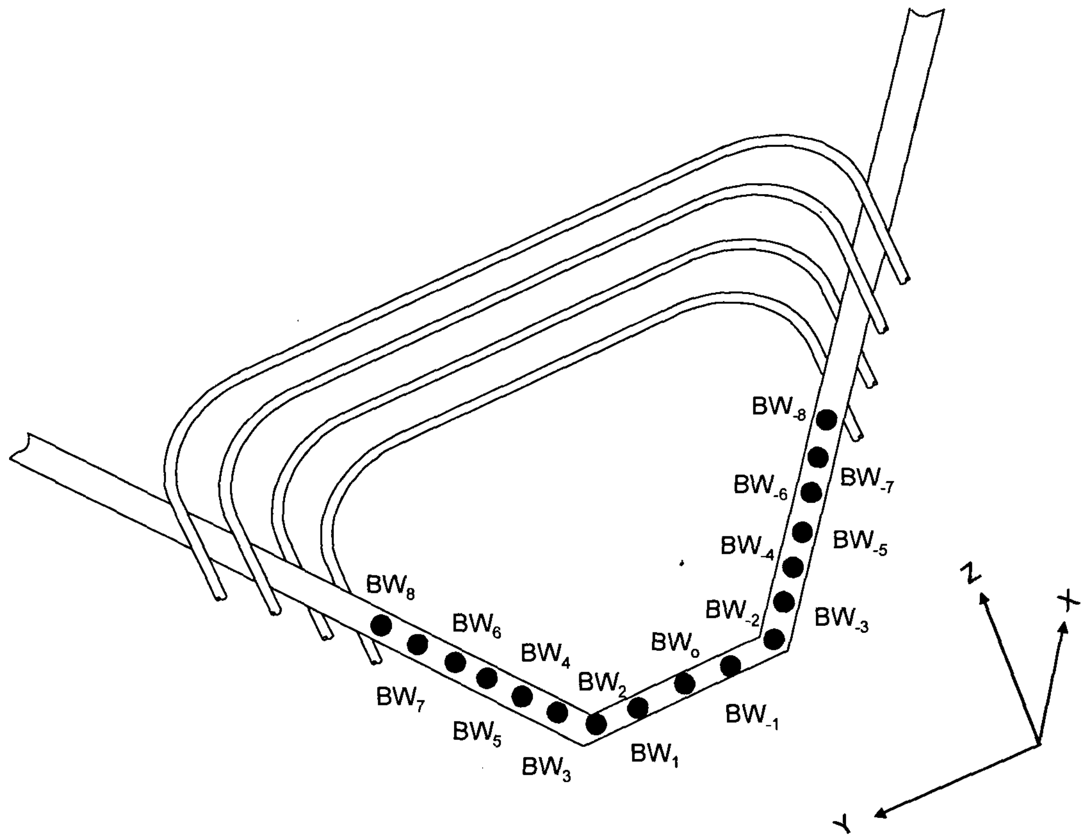

Figure C-1 Locations of 17 points for extracting velocity, density and flow area

Table C-1
Coordinates for T/H Conditions
(For Batwing 69)

a,c,e

Table C-2
Fluid Conditions at 3716 MWt with 20% SGTP
(For Batwing 69)

a,c,e

Westinghouse

To: J. M. Hall

cc: D. Merkovsky, G. W. Whitman, J. S. Baron, B. A. Bell, D. P. Siska, J. G. Thakkar, P. R. Nelson

Date: February 13, 2007

From: P. A. Stancampiano
Ext: 724-722-5886
Fax: 724-722-5889

Your ref:
Our ref: LTR-SGDA-06-225-NP

Subject: Evaluation of Steam Line Break Accident Condition Affecting Degraded Batwings at Waterford 3

References:

1. Calculation Note CN-SGDA-05-36, Rev. 1, "Evaluation of Degraded Batwing Tube Supports in the Waterford 3 Steam Generators at 3716 MWt Power Uprate Conditions," November 8, 2006.
2. Design Specification 09270-PE-120, Rev. 10, "Waterford Unit 3, Steam Generator Assemblies, Reactor Coolant System (RCS).

An evaluation has been performed for the postulated faulted steam line break (SLB) accident loading with respect to the degraded batwings observed in Waterford 3. The following assumptions apply to this evaluation:

The largest batwing between tube columns [ ]^{a,c,e} is assumed [ ]^{a,c,e}

The end of the batwing at the horizontal support bar in the cavity region is assumed [ ]^{a,c,e}

From page 7 of Reference 1, the SLB flow load is assumed to be [ ]^{a,c,e}

One side of the batwing (from the center of the horizontal support to the wrap around bar) weighs about [ ]^{a,c,e} and assuming [

]^a,c,e^ Under these conditions, the displaced bat wing will likely [

]^a,c,e^

The SLB is now assumed to occur [ ]^a,c,e^ The tube internal pressure is [ ]^a,c,e^ and the external pressure is [ ]^a,c,e^, Reference 2. A [ ]^a,c,e^ model of the tube in [ ]^a,c,e^ was employed to calculate a maximum $P_m + P_b$ stress intensity of [ ]^a,c,e^ This calculated maximum stress intensity of [ ]^a,c,e^ is well within the specified faulted allowable $P_m + P_b$ limit of [ ]^a,c,e^ for the Alloy 600 tube. The faulted limit for elastic analysis is given in Section 4.7.12.4 of Reference 2, since Appendix F of the ASME Code was not available in the Waterford 3 Construction Code Edition, 1971 through and including the Summer 1971 Addenda.

P. A. Stancampiano
Steam Generator Design and Analysis

Verified: J. X. Jenko
Steam Generator Design and Analysis

Westinghouse

To: J. M. Hall
D. P. Siska
D. Merkovsky
cc: R. E. Johnson
D. G. Slack

Date: February 14, 2007

From: J. S. Baron
Ext: (423)-752-2849
Fax: (423)-752-2449

Your ref:
Our ref: LTR-SGDA-06-228-NP

Subject: **Waterford 3 Batwing Upper Weld Evaluations in Support of the RF14 Outage.**

References:

1. "Marks' Standard Handbook for Mechanical Engineers" Tenth Edition, Avallone and Baumeister, The McGraw-Hill Company. New York, New York 1996.
2. Westinghouse and PCI Energy Services Email Correspondence, "*Re:Fw: Batwing Weld Dimensions – Critical Path*". From Jim J. Jesko to D. Merkvosky, December 12, 2006. – Attachment 5
3. ASME Boiler and Pressure Vessel Code, Section III for Nuclear Power Components, 1971 Edition through Summer 1971 Addenda – ASME Code of Design for Waterford 3.
4. Westinghouse Email Correspondence, "*Observations about Welds*". From Donald P. Siska to Michael D. Turnmire, December 12, 2006. – Attachment 6
5. Westinghouse Drawings for Waterford 3 Steam Generators:
   a. 74270-271-013 Revision 2 "Tube Bundle Assembly"
   b. 74270-289-001 Revision 2 "Tube Support Details"
   c. 74270-289-002 Revision 2 "Tube Support Details"
   d. 74270-271-007 Revision 4 "General Arrangement Elevation"
6. Westinghouse Calculation Note CN-SGDA-06-6, "Thermal-Hydraulic and Flow Induced Vibration Analyses of Waterford 3 Steam Generator at 3716 MWt Power for 20% Tube Plugging". B.A. Bell and J.G. Thakkar, March 28, 2006. – ATHOS flow data obtained from the program published in this report.

This letter transmits the results from the Waterford 3 batwing (BW) tube support to wrapper bar weld stress evaluations resulting from batwing failures in the central cavity in support of the ongoing RF14 outage. The evaluation results summarized in this letter address the following Action Items identified in the Waterford Analysis Requirements spreadsheet.

Item 1a – Weld Analysis (Batwing Sail Condition)
Item 1b – Welded Clip Analysis
Item 1c – Plastic Hinge / Cantilever Effect
Item 1cc – Plastic Hinge near Batwing Weld

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Item 1g – Determine Size of Weld to Take Hydraulic Loads
Item 1h – Determine Load required to Break Welds ("as-built" and "as-repaired")

Attachment 1 provides the results of the analyses performed for Item 1a. These results are summarized in Table 1. The flow loads on the portion of the batwing within in the central stay cavity are calculated with conservative assumptions regarding the orientation of the broken batwing relative to the flow direction and support from other internal structures and frictional restraint within the tube bundle. The calculated forces and moments on the weld, shown in Table 1, are believed to be extremely conservative and inconsistent with the conditions observed in the inspection as reported in Reference 4 and discussed below. Attachment 1 also shows the weld sizes that would be required to sustain these calculated flow loads as required by Action Item 1g.

Attachment 2, which addresses Action Items 1c and 1cc, calculates the plastic hinge moments for the batwing cross section within the central cavity, oriented to present the maximum sail area to the flow as well as in the notched region at the wrapper bar. These results, also shown in Table 1, indicate that the plastic hinge moment at the wrapper bar is about 200 in-lbf. Consequently, the maximum moment that could be transmitted to the attachment weld is limited to this value. Further, inspection of the batwings in this region shows no indication of permanent deformation or movement that would occur if the actual moment on the weld approached the plastic hinge value. Thus, it can be concluded that the actual moment applied to the welds was less than 200 in-lbf. This conclusion is further supported by other inspection results and calculations described below.

Attachment 2 also calculates the plastic hinge moment for the full batwing cross section to be approximately 112 in-lb along the width. This result supports the contention that the batwing could present a limited sail area to the dynamic pressure in the central cavity before sustaining substantial deformation and relieving the applied load. This further suggests that the flow loads transmitted to the wrapper bar weld are significantly less than the conservative estimate obtained in Action Item 1a.

The moments required to break the batwing to wrapper bar welds are calculated in Attachment 3 in response to Action Item 1b and 1h. The as-found weld geometry, reported in Reference 4, and the anticipated as-repaired weld geometry described in Reference 2 are addressed. The broken weld on the hot leg side had the largest weld section, 1/4 inch length and a 1/5 inch leg. The critical moment to fail this weld is calculated to be about 40 in-lb. This weld geometry is typical of numerous other welds which have not failed. Thus, it is reasonable to conclude that this failure resulted from an applied moment of approximately this magnitude. Otherwise, additional weld failures would have been expected. It should be noted that the allowable moment for the weld that failed on the cold leg side is estimated to be around 10 in-lb. This calculation is also used to evaluate the weld moment-to-break limit of the weld clip as illustrated in the attachment.

In contrast, the as-repaired weld configuration is a 1/4 inch fillet, 5/16 inch long on both sides of the batwing, the weld area along the batwing tip being conservatively neglected. The moment required to fail this as-repaired weld geometry is estimated to be about 224 in-lb. This moment carrying capability is more than five times the maximum moments that were likely experienced during the last operating cycle. For an applied moment 40 in-lb, the calculated stress in the as-repaired weld is less than 5 ksi. Therefore, fatigue failures of the as-repaired welds are unlikely.

Discussion of Inspection Observations

The following observations during the RF14 inspections provide further evidence that the proposed repairs are adequate to preclude further weld failure at the wrapper bar.

1. From the visual examination the welds appear to be quite small and poorly installed. This supports the contention that the loads applied to the welds are relatively small. Otherwise the number of broken welds would have been much greater.
2. The maximum moment to break the weld is only 40 in-lbs. This provides further evidence applied moments are about this magnitude.
3. Based on visual examination, there was no movement of the wrap-around bar.
4. Based on a review of the eddy current results, there are no indications that the batwings moved in a cyclical up-and-down movement. That is, there were no volumetric defects at any location above the normal location of the batwing. Thus, fatigue is not a likely cause of the weld failures.
5. Displacement of the batwing to reach 40 in-lbs is only 0.144 inches. This result is calculated in Attachment 4.
6. Likely root cause is a poor quality weld. The weld was smaller than designed and there was some indication of poor fusion. Therefore, it is possible that the weld broke at less than 40 in-lbs.

Conclusions

1. The weld failures were the result of under sized welds and poor weld quality. They resulted from flow load induced bending moments on the order of 40 in-lbs or less.
2. The proposed repair provides welds that are capable of sustaining moments up to 224 in-lb or more than 5 times the loads that likely caused the observed failures.
3. Calculations and inspection observations indicate that fatigue failures of the as-repaired welds are unlikely.

Please contact the undersigned at (423)752-2849 if there are any questions or if further clarification is required.

Author: J.S. Baron*
Steam Generator Design & Analysis

Verifier: R.E. Johnson*
Nuclear Component Engineering - 1

Table 1: Batwing Upper Weld Evaluation Summary

Evaluation	Description	Result	Comment
Batwing Sail Condition	Conservative approximations are made to identify maximum idealistic loading conditions at BW upper weld under conservatively high central cavity axial flow conditions.	R_x = 7.5 lbf R_y = 4.4 lbf Mr = 865 in-lbf	Conservatively identified reaction forces and moment at weld.
*Weld Size Requirement	The "as found" length of 3/16 inches was used to identify the required thickness to hold the conservative Batwing Sail Condition listed above.	tw = 1.24 in tw = 0.62 in	Required 3/16 inch long weld fillet thicknesses to hold a 200 in-lbf moment loading. Single and double fillet welds are listed respectively.
Plastic Deformation at Full and Critical Sections	Critical section of BW is considered for potential to plastically deform under moment loading.	$M_{plastic}$ = 200 in-lbf	Moment to cause plastic deformation at critical batwing "fork" section.
Load to Break Weld(s)	Current and repair weld configurations with potential repair component welds considered for moment to cause failure under ASME code.	M_{found} = 40.4 lbf-in $M_{repair1}$ = 80.8 lbf-in $M_{repair2}$ = 224 lbf-in M_{clip} = 575 lbf-in	Moment loads required to break "as found" and repair conditions under ASME code.
Batwing Deflection	Batwing vertical deflection is calculated when experiencing a 40 in-lbf moment load at the central cavity to tube bundle transition point.	ζ = 0.144 in	Batwing deflection is small when experiencing this type of loading mechanism.

*Weld sizes here are calculated for a 200 in-lbf moment as this is the load transfer capability of the batwing.

// attachment 1

Structural Evaluation of Batwing Sail Condition

The purpose of this evaluation is to conservatively calculate the idealized reaction moments and loads at the Waterford 3 batwing upper weld location. In an effort to create an idealistic loading condition at the weld, the following conservative assumptions are made:

a,c

Also determined from this evaluation are the weld sizes under both single and double fillet weld configurations that would be required to sustain these calculated flow loads, as required by Action Item 1g.

a,c

Weld Size Requirement to take Hydraulic Load

Sizing Requirement for a 200 lbf-in Load (See Attachment 2)

Case 1: Fillet Weld Present on One Side of 3/4 in Square Wrapper Bar

a,c

[ ]

Case 2: Fillet Weld Present on Two Sides (Front and Back) of 3/4in Square Wrapper Bar

a,c

[ ]

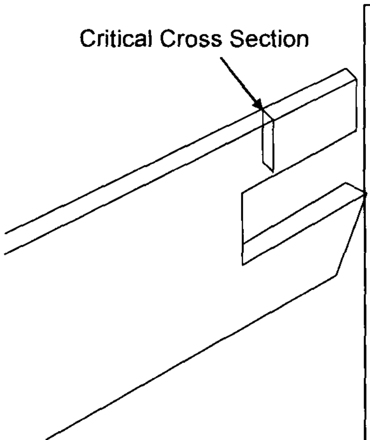
// attachment 2

Plastic Deformation Limit at Batwing Critical Cross Section

The critical cross section of the batwing configuration with single structural fillet welds only on one side is identified to be at the "fork" as illustrated below. This cross section is rectangular in shape and is identified in Reference 5b to be 0.09 inches thick and 0.578 inches in width nominally. The section is also offset from the BW centerline by 0.422 inches. This offset generates an eccentricity moment that will be calculated when considering plastic deformation at the critical section. Material of the BW cross section is assumed to be SA-36 Carbon Steel.

The calculations performed use basic stress equations to identify the plastic limit of the cross section (Reference 1). This calculation identified the maximum loading moment required to reach the plastic deformation limit of approximately 200 lbf-in. That is, the critical batwing cross section will start to bend and plastically deform when a loading moment of 200 lbf-in is experienced.

a,c



a,c

The full cross section of the batwing configuration is identified as illustrated below. This cross section is rectangular in shape and is shown in the Reference 5 drawings to be 0.09 inches thick and 2.00 inches in width nominally. Material of the BW cross section is assumed to be SA-36 Carbon Steel.

The calculations performed use basic stress equations to identify the plastic limit of the cross section (Reference 1). This calculation identified the maximum loading moment required to reach the plastic deformation limit of approximately 112 lbf-in. That is, the full batwing cross section will start to bend and plastically deform when a loading moment of 112 lbf-in is experienced.

a,c

[ ]

//attachment 3

Identification of Load Required to Break Weld

The purpose of this calculation is to determine the moment loading required to break the identified weld configuration. The methods used are based on basic stress analysis equations that can be found in Reference 1. The configuration considered will be the "as found" failed weld condition generated from Field Service Inspection observations (Reference 4 and Attachment 6). Also considered will be the two possible repair weld configurations that have been identified to date (Reference 2) and a potential weld clip repair component (Figure 1) that would be used to extend the weld length.

The "as found" condition can be described as a single 1/4 inch thick fillet weld with a length of 3/16 inches. The two repair conditions are double sided and also have a fillet thickness of 1/4 inch with lengths of 3/16 and 5/16 respectively (Reference 2). The weld clip is assumed to provide a weld length of 1/2 inch with a fillet thickness of 1/4 inches. Figure 2 is a representation of the relationship between weld length and fillet thickness with indications for the moment carrying capability for the desired geometry for a double sided weld configuration. This curve is based on the applicable calculations of this section.

The conservative approximation of neglecting any weld end geometries was made for these calculations. In the event that it may become necessary to consider these geometries, the modification method is outlined in the following sections with the example given for a 1/4 inch weld length and 1/8 inch fillet thickness. The method used in this evaluation follows those of basic stress and geometry calculations found in Reference 1.

"As Found" Condition (Reference 4)

Moment Load Required to Break Single Side Weld a,c

Repair Conditions

Moment Load Required to Break Double Side Weld

a,c

[ ]

Moment Load Required to Break Double Side Weld

a,c

[ ]

Welded Clip Repair Component

Figure 1: Weld Clip Repair Component

a,c

[ ]

Moment Load Required to Break Double Side Weld

a,c

[ ]

Figure 2

Double Sided Weld Length vs. Fillet Thickness

Indicated geometry is for single fillet of a double weld experiencing an in-plane moment

a,c

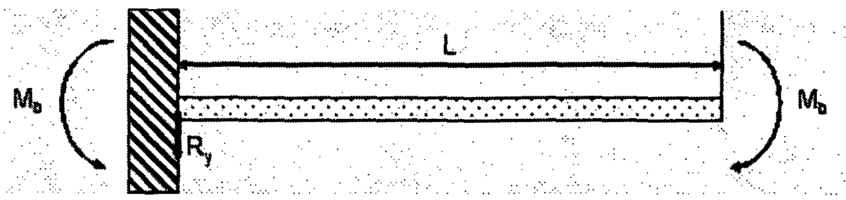
[ ]

Effective Length Method for Weld End Geometry Consideration

a,c

//attachment 4

This calculation will determine the approximate batwing deflection when experiencing a 40 in-lbf moment loading at the point where the BW transitions from the central stay cavity to the tube bundle. This transition occurs at Tube Row 38 which leads to a beam length of 112 inches (Reference 5b).



a,c

[ ]

//attachment 5

This attachment documents the Reference 2 communications regarding batwing repair weld dimensions.

a,c

//attachment 6

This attachment documents the Reference 4 communications regarding current batwing upper weld conditions.

a,c

Westinghouse

To: J. M. Hall
D. P. Siska
D. Merkovsky
cc: R. E. Johnson
D. G. Slack

Date: February 14, 2007

From: J. S. Baron
Ext: (423)-752-2849
Fax: (423)-752-2449

Your ref:
Our ref: LTR-SGDA-06-228-NP Revision 1

Subject: **Waterford 3 Batwing Upper Weld Evaluations in Support of the RF14 Outage.**

References:

1. "Marks' Standard Handbook for Mechanical Engineers" Tenth Edition, Avallone and Baumeister, The McGraw-Hill Company. New York, New York 1996.
2. Westinghouse and PCI Energy Services Email Correspondence, *"Re:Fw: Batwing Weld Dimensions – Critical Path"*. From Jim J. Jesko to D. Merkvosky, December 12, 2006. – Attachment 5
3. ASME Boiler and Pressure Vessel Code, Section III for Nuclear Power Components, 1971 Edition through Summer 1971 Addenda – ASME Code of Design for Waterford 3.
4. Westinghouse Email Correspondence, *"Observations about Welds"*. From Donald P. Siska to Michael D. Turnmire, December 12, 2006. – Attachment 6
5. Westinghouse Drawings for Waterford 3 Steam Generators:
    a. 74270-271-013 Revision 2 "Tube Bundle Assembly"
    b. 74270-289-001 Revision 2 "Tube Support Details"
    c. 74270-289-002 Revision 2 "Tube Support Details"
    d. 74270-271-007 Revision 4 "General Arrangement Elevation"
6. Westinghouse Calculation Note CN-SGDA-06-6, "Thermal-Hydraulic and Flow Induced Vibration Analyses of Waterford 3 Steam Generator at 3716 MWt Power for 20% Tube Plugging". B.A. Bell and J.G. Thakkar, March 28, 2006. – ATHOS flow data obtained from the program published in this report.

This letter transmits the results from the Waterford 3 batwing (BW) tube support to wrapper bar weld stress evaluations resulting from batwing failures in the central cavity in support of the ongoing RF14 outage. The evaluation results summarized in this letter address the following Action Items identified in the Waterford Analysis Requirements spreadsheet.

Item 1a – Weld Analysis (Batwing Sail Condition)
Item 1b – Welded Clip Analysis
Item 1c – Plastic Hinge / Cantilever Effect
Item 1cc – Plastic Hinge near Batwing Weld

Item 1g – Determine Size of Weld to Take Hydraulic Loads
Item 1h – Determine Load required to Break Welds ("as-built" and "as-repaired")

Attachment 1 provides the results of the analyses performed for Item 1a. These results are summarized in Table 1. The flow loads on the portion of the batwing within in the central stay cavity are calculated with conservative assumptions regarding the orientation of the broken batwing relative to the flow direction and support from other internal structures and frictional restraint within the tube bundle. The calculated forces and moments on the weld, shown in Table 1, are believed to be extremely conservative and inconsistent with the conditions observed in the inspection as reported in Reference 4 and discussed below. Attachment 1 also shows the weld sizes that would be required to sustain these calculated flow loads as required by Action Item 1g.

Attachment 2, which addresses Action Items 1c and 1cc, calculates the plastic hinge moments for the batwing cross section within the central cavity, oriented to present the maximum sail area to the flow as well as in the notched region at the wrapper bar. These results, also shown in Table 1, indicate that the plastic hinge moment at the wrapper bar is about 200 in-lbf. Consequently, the maximum moment that could be transmitted to the attachment weld is limited to this value. Further, inspection of the batwings in this region shows no indication of permanent deformation or movement that would occur if the actual moment on the weld approached the plastic hinge value. Thus, it can be concluded that the actual moment applied to the welds was less than 200 in-lbf. This conclusion is further supported by other inspection results and calculations described below.

Attachment 2 also calculates the plastic hinge moment for the full batwing cross section to be approximately 112 in-lb along the width. This result supports the contention that the batwing could present a limited sail area to the dynamic pressure in the central cavity before sustaining substantial deformation and relieving the applied load. This further suggests that the flow loads transmitted to the wrapper bar weld are significantly less than the conservative estimate obtained in Action Item 1a.

The moments required to break the batwing to wrapper bar welds are calculated in Attachment 3 in response to Action Item 1b and 1h. The as-found weld geometry, reported in Reference 4, and the anticipated as-repaired weld geometry described in Reference 2 are addressed. The broken weld on the hot leg side had the largest weld section, 1/4 inch length and a 1/5 inch leg. The critical moment to fail this weld is calculated to be about 40 in-lb. This weld geometry is typical of numerous other welds which have not failed. Thus, it is reasonable to conclude that this failure resulted from an applied moment of approximately this magnitude. Otherwise, additional weld failures would have been expected. It should be noted that the allowable moment for the weld that failed on the cold leg side is estimated to be around 10 in-lb. This calculation is also used to evaluate the weld moment-to-break limit of the weld clip as illustrated in the attachment.

In contrast, the as-repaired weld configuration is a 1/4 inch fillet, 5/16 inch long on both sides of the batwing, the weld area along the batwing tip being conservatively neglected. The moment required to fail this as-repaired weld geometry is estimated to be about 224 in-lb. This moment carrying capability is more than five times the maximum moments that were likely experienced during the last operating cycle. For an applied moment 40 in-lb, the calculated stress in the as-repaired weld is less than 5 ksi. Therefore, fatigue failures of the as-repaired welds are unlikely.

Discussion of Inspection Observations

The following observations during the RF14 inspections provide further evidence that the proposed repairs are adequate to preclude further weld failure at the wrapper bar.

1. From the visual examination the welds appear to be quite small and poorly installed. This supports the contention that the loads applied to the welds are relatively small. Otherwise the number of broken welds would have been much greater.
2. The maximum moment to break the weld is only 40 in-lbs. This provides further evidence applied moments are about this magnitude.
3. Based on visual examination, there was no movement of the wrap-around bar.
4. Based on a review of the eddy current results, there are no indications that the batwings moved in a cyclical up-and-down movement. That is, there were no volumetric defects at any location above the normal location of the batwing. Thus, fatigue is not a likely cause of the weld failures.
5. Displacement of the batwing to reach 40 in-lbs is only 0.144 inches. This result is calculated in Attachment 4.
6. Likely root cause is a poor quality weld. The weld was smaller than designed and there was some indication of poor fusion. Therefore, it is possible that the weld broke at less than 40 in-lbs.

Conclusions

1. The weld failures were the result of under sized welds and poor weld quality. They resulted from flow load induced bending moments on the order of 40 in-lbs or less.
2. The proposed repair provides welds that are capable of sustaining moments up to 224 in-lb or more than 5 times the loads that likely caused the observed failures.
3. Calculations and inspection observations indicate that fatigue failures of the as-repaired welds are unlikely.

Please contact the undersigned at (423)752-2849 if there are any questions or if further clarification is required.

Author: J.S. Baron*
Steam Generator Design & Analysis

Verifier: R.E. Johnson*
Nuclear Component Engineering - 1

Table 1: Batwing Upper Weld Evaluation Summary

Evaluation	Description	Result	Comment
Batwing Sail Condition	Conservative approximations are made to identify maximum idealistic loading conditions at BW upper weld under conservatively high central cavity axial flow conditions.	R_x = 7.5 lbf R_y = 4.4 lbf Mr = 865 in-lbf	Conservatively identified reaction forces and moment at weld.
*Weld Size Requirement	The "as found" length of 3/16 inches was used to identify the required thickness to hold the conservative Batwing Sail Condition listed above.	tw = 1.24 in tw = 0.62 in	Required 3/16 inch long weld fillet thicknesses to hold a 200 in-lbf moment loading. Single and double fillet welds are listed respectively.
Plastic Deformation at Full and Critical Sections	Critical section of BW is considered for potential to plastically deform under moment loading.	$M_{plastic}$ = 200 in-lbf	Moment to cause plastic deformation at critical batwing "fork" section.
Load to Break Weld(s)	Current and repair weld configurations with potential repair component welds considered for moment to cause failure under ASME code.	M_{found} = 40.4 lbf-in $M_{repair1}$ = 80.8 lbf-in $M_{repair2}$ = 224 lbf-in M_{clip} = 575 lbf-in	Moment loads required to break "as found" and repair conditions under ASME code.
Cycles to Failure	Approximate cycles to failure conservatively assuming completely reversed loading to the yield point.	N_{found} = 3650 cycles N_{repair} = 1E6 cycles	Repaired condition weld has a much higher cycle to failure rating than the "as found" condition.
Batwing Deflection	Batwing vertical deflection is calculated when experiencing a 40 in-lbf moment load at the central cavity to tube bundle transition point.	ζ = 0.144 in	Batwing deflection is small when experiencing this type of loading mechanism.

*Weld sizes here are calculated for a 200 in-lbf moment as this is the load transfer capability of the batwing.

// attachment 1

Structural Evaluation of Batwing Sail Condition

The purpose of this evaluation is to conservatively calculate the idealized reaction moments and loads at the Waterford 3 batwing upper weld location. In an effort to create an idealistic loading condition at the weld, the following conservative assumptions are made: a,c

[ ]

Also determined from this evaluation are the weld sizes under both single and double fillet weld configurations that would be required to sustain these calculated flow loads, as required by Action Item 1g.

a,c

Weld Size Requirement to take Hydraulic Load

Sizing Requirement for a 200 lbf-in Load (See Attachment 2)

Case 1: Fillet Weld Present on One Side of 3/4 in Square Wrapper Bar

a,c

[ ]

Case 2: Fillet Weld Present on Two Sides (Front and Back) of 3/4in Square Wrapper Bar

a,c

[ ]

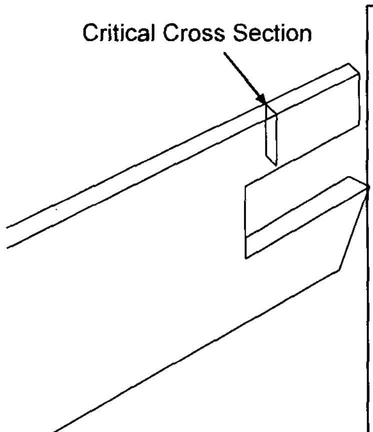
// attachment 2

Plastic Deformation Limit at Batwing Critical Cross Section

The critical cross section of the batwing configuration with single structural fillet welds only on one side is identified to be at the "fork" as illustrated below. This cross section is rectangular in shape and is identified in Reference 5b to be 0.09 inches thick and 0.578 inches in width nominally. The section is also offset from the BW centerline by 0.422 inches. This offset generates an eccentricity moment that will be calculated when considering plastic deformation at the critical section. Material of the BW cross section is assumed to be SA-36 Carbon Steel.

The calculations performed use basic stress equations to identify the plastic limit of the cross section (Reference 1). This calculation identified the maximum loading moment required to reach the plastic deformation limit of approximately 200 lbf-in. That is, the critical batwing cross section will start to bend and plastically deform when a loading moment of 200 lbf-in is experienced.

a,c



a,c

The full cross section of the batwing configuration is identified as illustrated below. This cross section is rectangular in shape and is shown in the Reference 5 drawings to be 0.09 inches thick and 2.00 inches in width nominally. Material of the BW cross section is assumed to be SA-36 Carbon Steel.

The calculations performed use basic stress equations to identify the plastic limit of the cross section (Reference 1). This calculation identified the maximum loading moment required to reach the plastic deformation limit of approximately 112 lbf-in. That is, the full batwing cross section will start to bend and plastically deform when a loading moment of 112 lbf-in is experienced.

a,c

[ ]

//attachment 3

Identification of Load Required to Break Weld

The purpose of this calculation is to determine the moment loading required to break the identified weld configuration. The methods used are based on basic stress analysis equations that can be found in Reference 1. The configuration considered will be the "as found" failed weld condition generated from Field Service Inspection observations (Reference 4 and Attachment 6). Also considered will be the two possible repair weld configurations that have been identified to date (Reference 2) and a potential weld clip repair component (Figure 1) that would be used to extend the weld length.

The "as found" condition can be described as a single 1/4 inch thick fillet weld with a length of 3/16 inches. The two repair conditions are double sided and also have a fillet thickness of 1/4 inch with lengths of 3/16 and 5/16 respectively (Reference 2). The weld clip is assumed to provide a weld length of 1/2 inch with a fillet thickness of 1/4 inches. Figure 2 is a representation of the relationship between weld length and fillet thickness with indications for the moment carrying capability for the desired geometry for a double sided weld configuration. This curve is based on the applicable calculations of this section.

The conservative approximation of neglecting any weld end geometries was made for these calculations. In the event that it may become necessary to consider these geometries, the modification method is outlined in the following sections with the example given for a 1/4 inch weld length and 1/8 inch fillet thickness. The method used in this evaluation follows those of basic stress and geometry calculations found in Reference 1.

Appropriate considerations have been made for potential cyclical loading of the Waterford 3 batwing upper weld region. Utilizing the conservative assumption that both the "as-found" and repaired condition welds experience a moment to the point of yielding, the completely reverse cycle stress is calculated. A Fatigue Reduction Factor of Safety (FRFS) of 4.0 is also used. The results are approximate cycles to failure for the repaired weld condition exceeding those of the "as found" condition.

"As Found" Condition (Reference 4)

Moment Load Required to Break Single Side Weld

a,c

Repair Conditions

Moment Load Required to Break Double Side Weld

a,c

[ ]

Moment Load Required to Break Double Side Weld

a,c

[ ]

Welded Clip Repair Component

Figure 1: Weld Clip Repair Component

a,c

[ ]

Moment Load Required to Break Double Side Weld

a,c

[ ]

Figure 2

Double Sided Weld Length vs. Fillet Thickness

Indicated geometry is for single fillet of a double weld experiencing an in-plane moment

a,c

[ ]

Effective Length Method for Weld End Geometry Consideration

a,c

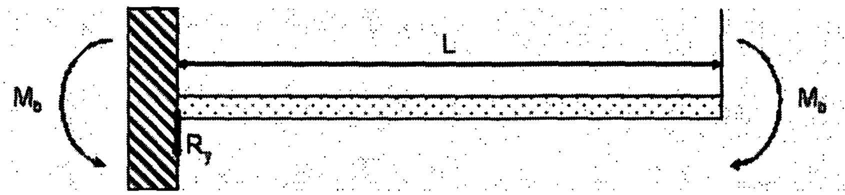
[ ]

Potential Cyclical Loading Considerations

a,c

//attachment 4

This calculation will determine the approximate batwing deflection when experiencing a 40 in-lbf moment loading at the point where the BW transitions from the central stay cavity to the tube bundle. This transition occurs at Tube Row 38 which leads to a beam length of 112 inches (Reference 5b).



a,c

[ ]

//attachment 5

This attachment documents the Reference 2 communications regarding batwing repair weld dimensions. a,c

//attachment 6

This attachment documents the Reference 4 communications regarding current batwing upper weld conditions.

a,c

Westinghouse

To: J. M. Hall
cc: D. Merkovsky, D. P. Siska, J. G. Thakkar, G. W. Whitemen, P. R. Nelson

Date: Feb. 13, 2007

From: J. D. Key
Ext: (423)-752-2807
Fax: (423)-752-2449

Your ref:
Our ref: LTR-SGDA-06-229-NP

Subject: **Waterford 3 Steam Generator Stability Ratios and Turbulent Amplitudes for Tube Rows in the Central Cavity without Batwing Support**

References:

1. Westinghouse Calculation Note, CN-SGDA-06-6 Rev. 0, "Thermal-Hydraulic and Flow Induced Vibration Analyses of Waterford 3 Steam Generator at 3716 MWt Power for 20% Tube Plugging", March 2006.
2. Westinghouse Internal Correspondence LTR-SGDA-06-226 "Tube Location Specific Thermal Hydraulic Data for Waterford 3 Steam Generators with 3716 MWt Power Uprate and 20% SGTP", December 14, 2006.

This letter transmits the results of the Flow Induced Vibration (FIV) analysis of the limiting tube locations (refer to Figures 1 and 2) in four tube zones. The thermal-hydraulic data for these tube locations is obtained from References 1 and 2. The FIV analysis results are in the attached Table 1. These FIV analyses are performed using the same methodology as discussed in Reference 1. The files for the FIV analyses are "attached" to this document in Electronic Data Management System.

Author (**Electronically Approved***)
J. D. Key
Nuclear Component Engineering - 1

Verifier (**Electronically Approved***)
B. A. Bell
Steam Generator Design & Analysis

// attachment

Electronically approved records are authenticated in the Electronic Document Management System.

TABLE 1

Waterford SG Stability Ratios and Turbulent Amplitudes for Tube Rows Missing a Batwing

(at 3716 MWt Power for 20% Tube Plugging defined in Reference 1)

Plugging Zone		Tube Row	Limiting Column	Stability Ratio SR	Turbulent Amplitude (mils) a,c	Bounded Rows in Columns 63-113
Outer Tubes		147	95			121 to 137
		144	106			
		138	112			
		136	112			
E/C 10 Zone	4 Vertical Supports	120	112[1]			115 to 119
	3 Vertical Supports	114	112			113 to 84
E/C 9 Zone		83	113			82 to 50
		80	112			
E/C 8 Zone[2]		49	113			None
		40	112			

Notes:

1. Thermal Hydraulic data from Column 138 conservatively used.
2. Rows in Eggcrate Zone 8 were not shown acceptable.

FIGURE 1
Tube Bundle Plan View with Selected Tube Rows

a,c

FIGURE 2

Upper Tube Bundle Support Details with Selected Tube Rows

a,c

Westinghouse

To:	J. M. Hall D. P. Siska D. Merkovsky P. R. Nelson		Date: February 14, 2007
cc:	R. E. Johnson A.L. Thurman	J. S. Baron D. P. Popovich D. S. Taylor	P.A. Stancampiano
From:	Steam Generator Design & Analysis		Your ref:
Ext:	(724)-722-6172		Our ref: LTR-SGDA-06-236-NP, Rev 2
Fax:	(724)-722-5909		

Subject: **Evaluation of Upper Weld Clip and Attachment Welds to Batwing for Waterford 3 Steam Generators**

References:

1. LTR-SGDA-06-228, Rev 1, "Waterford 3 Batwing Upper Weld Evaluations in Support of the RF14 Outage," December 16, 2006.
2. Westinghouse Calculation Note: CN-SGDA-06-90, "Evaluation of Upper Weld Clip and Attachment Welds to Batwing for Waterford 3 Steam Generators," December 15, 2006.
3. Westinghouse Drawing: 1C83484, Rev 1, (7 sheets), "Waterford 3 Steam Generator Repair Batwing Weld Clips – Left Side.
4. Westinghouse Drawing: 1C83485, Rev 1, (7 sheets), "Waterford 3 Steam Generator Repair Batwing Weld Clips – Right Side

An evaluation was performed for a weld clip to be applied at the top of the batwings in order to connect the batwings to the wrapper bar. Additionally, the welds from a batwing to a weld clip and the welds from a weld clip to the wrapper bar were evaluated.

A maximum moment loading has been identified in Reference 1 as 200 inch*lb that could be transmitted from a batwing to the wrapper bar and that is the load level that is used in order to evaluate the weld clip. The shape of the weld clip analyzed is as shown on the Reference 3 and 4 drawings. Two sheets from the Reference 3 drawing are attached as typical examples. Relative to the sketch that was included with Revision 0 of the original letter, the drawings now have specified angles to fit the wrapper bar and separate drawings have been developed in order to fit the right side and left side. The angles in the final design are such that the clips are kept in-line with the plane of each associated batwing. The critical dimension of [ ][a,c,e] (see reference dimension near top of each sheet) has not been reduced in the transition between the sketch and the drawings. Therefore, the structural margin also is not reduced. With the above identified loading, it is found that a 10% positive margin exists at the weakest section of the weld clip. The American Society of Mechanical Engineers (ASME) Code limit of 1.5*Sm for bending was utilized for the evaluation. Thus, it is determined that the weld clip is capable of transmitting the specified maximum moment loading. The results of the evaluation have been documented as Reference 2.

Some notes in regard to limits used: The 1.5*Sm limit is for short-term loading as opposed to fatigue type loading. It is assumed that for the required operation period of one refueling cycle fatigue loading is negligible.

Of the two welds evaluated, the lower weld (from the batwing to the weld clip) is the more limiting. The lower weld is determined to have a positive margin of 28% relative to the 200 inch*lb specified maximum load. Thus, it is capable of transmitting the specified maximum load while remaining attached. The analysis is based on a failure shear stress limit of 0.6*Su that is used for evaluation of the lower fillet welds. Due to on-going design revisions, the criteria used at the upper attachment welds is more conservative (but is still less limiting than the lower welds – thus it is not a primary concern.) All the fillet welds were analyzed as 1/4 inch size fillet welds. The upper welds (clip to wrapper bar) were evaluated based on a fillet weld on each side of the clip and having an engagement length of [ ][a,c,e] on each side. The lower welds were evaluated based on having a fillet weld on each side and having an engagement length of [ ][a,c,e] on each side. The results are summarized in Table 1. Reference 2 is updated in order to reflect the shorter weld utilized at the lower fillet welds relative to Revision 0 of the original letter and also the revised failure criteria.

In summary, it is determined that both the weld clips and associated welds will be capable of transmitting the specified maximum loads when installed according to the above requirements.

Item	*Loading*	*Margin %*
Weld Clip	200 in*lb	10
Upper Attachment Weld (weld clip to wrapper bar)	200 in*lb	45
Lower Attachment Weld (batwing to weld clip)	200 in*lb	28

Table 1: Summary of Loads and Design Margins for Weld Clip and Welds

Author: ***Electronically Approved****
Robert Waldby
Steam Generator Design & Analysis

Verifier: ***Electronically Approved****
Alan Thurman
Steam Generator Design & Analysis

Attachment: Westinghouse Drawing: 1C83484, Rev 1, (sheets 1 & 3 only attached)

Electronically approved records are authenticated in the Electronic Document Management System

a,c,e

[ ]

a,c,e

Westinghouse

To: J. M. Hall
cc: D. Merkovsky, G. W. Whitman, J. S. Baron, B. A. Bell, D. P. Siska, J. G. Thakkar, P. R. Nelson

Date: February 15, 2007

From: P. A. Stancampiano
Ext: 724-722-5886
Fax: 724-722-5889

Your ref:
Our ref: LTR-SGDA-06-238-NP

Subject: Tube-Batwing Contact Force Attenuation Results For Degraded Batwings at Waterford 3

References:
1. Letter LTR-SGDA-06-225, Rev. 0, "Evaluation of Steam Line Break Accident Condition Affecting Degraded Batwings at Waterford 3," December 15, 2006.
2. Calculation Note CN-SGDA-05-64, "Structural Analysis of Waterford 3 Batwings in Support of Tube Wear Evaluation," Rev.2, October 27, 2006.
3. CN-SGDA-05-67, Rev. 0, "Effect of Failed Batwings on Projected Tube Wear Rates at Waterford 3," December 21, 2005.

The primary purpose of this letter is to document the attenuation of contact forces between the degraded batwings at Waterford 3 and the adjacent steam generator tubes. The degraded batwings are assumed to be [ ]^{a,c,e} batwing is achieved. In addition, the maximum [ ]^{a,c,e}, Reference 1, is assumed such that both the [ ]^{a,c,e} in Figure 1 to maximize the reactions on the tubes. The [ ]^{a,c,e}

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Pittsburgh, PA 15230-0355

The initial gap size between tubes and batwing, specified for these contact elements, is [

]^{a,c,e}

where: [

]^{a,c,e} In addition, tube and batwing wear at the contact points will effectively increase the above calculated gaps between the batwings and the adjacent tubes. Tube and batwing wear calculations [ ]^{a,c,e} of service at Waterford 3 are documented in Reference 3. Using these wear estimates, the initial gaps (see above) are increased to account for [ ]^{a,c,e} of service, as listed in Table 1.

The [ ]^{a,c,e} model of the batwings, described in Reference 2 was modified to accept the aforementioned [ ]^{a,c,e} loadings. Table 2 lists the four various worst case tube-batwing [ ]^{a,c,e} combinations, which were run with the modified [ ]^{a,c,e} model. [ ]^{a,c,e} calculated tube contact force results (FZ in lbf) are listed in Tables 3 through 6 for the four cases in Table 2 for each tube row into the bundle at the top and bottom edges of the batwing between tube columns [ ]^{a,c,e} at each side, A or B in Figure 1.

The results in Tables 3 through 6 are similar to those obtained in Reference 2, with the maximum occurring at [ ]^{a,c,e} Again, the contact forces fall off rapidly in magnitude into the bundle.

P. A. Stancampiano
Steam Generator Design and Analysis

Verified: J. X. Jenko
Steam Generator Design and Analysis

Table 1

[

][a,c,e]

[

]a,c,e

Figure 1
Schematic of Batwing, Adjacent Tubes and Out-of-Plane Loading

Table 2

[

]a,c,e

Table 3

[

]a,c,e

[

]a,c,e

Table 4

[

]a,c,e

[

]a,c,e

Table 5

[

]a,c,e

[

]a,c,e

Table 6

[

]a,c,e

[

]a,c,e

Westinghouse

To: M. Stickle
cc: P. Nelson
D. Siska

Date: February 15, 2006

From: J. M. Hall
Ext: 724 722-5134
Fax: 724 722-5889

Your ref:
Our ref: LTR-SGDA-06-240-NP

Subject: **Evaluation of Potential Secondary Side Loose Parts Resulting From Batwing Welding and The Effects of Increased Tube Temperatures in Waterford 3 Steam Generators**

References: 1. LTR-SGDA-06-237, "Evaluation of Secondary Side Loose Parts Identified in Waterford Unit 3 Model 70 OSG Steam Generator During the Waterford Fall 2006 Outage", December 2006.

Introduction

During the fall 2006 outage at Waterford 3, additional material is to be applied to the batwing to wrap around bar to increase the size of the attachment weld. During mockup testing, it was determined that small pieces of weld material would be generated, and a concern was raised that not all of these pieces could be captured by the foreign material exclusion barrier. In addition, a concern was raised that the temperature of the tube could increase due to the close proximity of the tubes to the welding tool. The purpose of this letter is to document the effects of these potential loose parts and the increased temperature on the SG tubes.

Potential Loose Welding Fragments (Loose Parts)

Figure 1 contains a photograph of the type of material that could be produced. The size of the material ranges from small sand like pieces, to pieces as large as ~3/16 inch. Nearly all of the material is either spherical or nearly spherical. During the mock up testing, samples of this material was captured in a container containing water. Water will also be present inside the SG during the actual welding process. As a result, it is reasonable to assume that similar size pieces could also be

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generated inside the SG during the actual repair. In addition, during mock up testing a small amount of loose weld wire material was generated. The largest piece observed is approximately 3/8 inch long and 1/32 inch in diameter. Since these objects are metallic, there is a potential that if the objects are not removed from the SG, the objects could begin to wear into a SG tube.

A review of the potential for these objects to wear tubes has been performed by comparison to what is judged to be a more limiting object evaluated in Reference 1. This more limiting object is screw, # 8-32 (0.164" diameter) x 0.375" long. The evaluation showed that the time required for the object to wear a tube down to the minimum acceptable tube wall thickness of 0.0288" (60% remaining tube wall) while in the most limiting orientation is greater than 3 years or two fuel cycles. This conclusion would also be appropriate to address the types of objects generated during the welding process.

In addition, an analysis has also been performed to determine the effects on the tubes should the assumed loose parts begin to migrate and repeatedly contact the tubes (impacting-only analysis). The analysis has determined that the energy which the postulated loose object would impart on a tube during repeated collisions is sufficiently low such that significant deformation of the tubes due to impacting-only is not expected.

Effect of Welding On the Nearby Tubes

The welding tool will be relatively close to the tubes when the additional material is deposited on the batwing to wrap around bar attachment location. At this location, the temperature of the tube could be expected to increase as a result of radiant heating. In response to this, a temperature probe was used during mock up testing to determine the actual temperature of the tube during the welding process. Table 1 contains a summary of the PCI test report that determined that excessive levels of heat were not introduced during welding. The tests were performed on 12-17-06, and witnessed by the author, where it was determined that the maximum temperature noted during the welding process was [ ][a, c]. Note that this temperature was obtained without the protective barrier in place which is to be located between the welding tool and the SG tubes. Since a protective barrier is planned to be used during the actual welding process, reduced levels of tube temperature would be expected vs. those observed in the test.

The magnitude of these temperatures are judged to be sufficiently low that tube degradation would not be projected to occur during the welding process as a result of radiant heat developed during welding of the batwing.

Summary

In summary, the analysis has determined that continued SG operation with the type of objects that could be present in the secondary side as a result of the welding process will not adversely affect steam generator tube integrity during the next operating cycle. In addition, the magnitude of the tube temperatures associated with radiant heat generated during the welding process are judged to be sufficiently low that tube degradation associated with radiant heating would not be projected to occur during the welding process.

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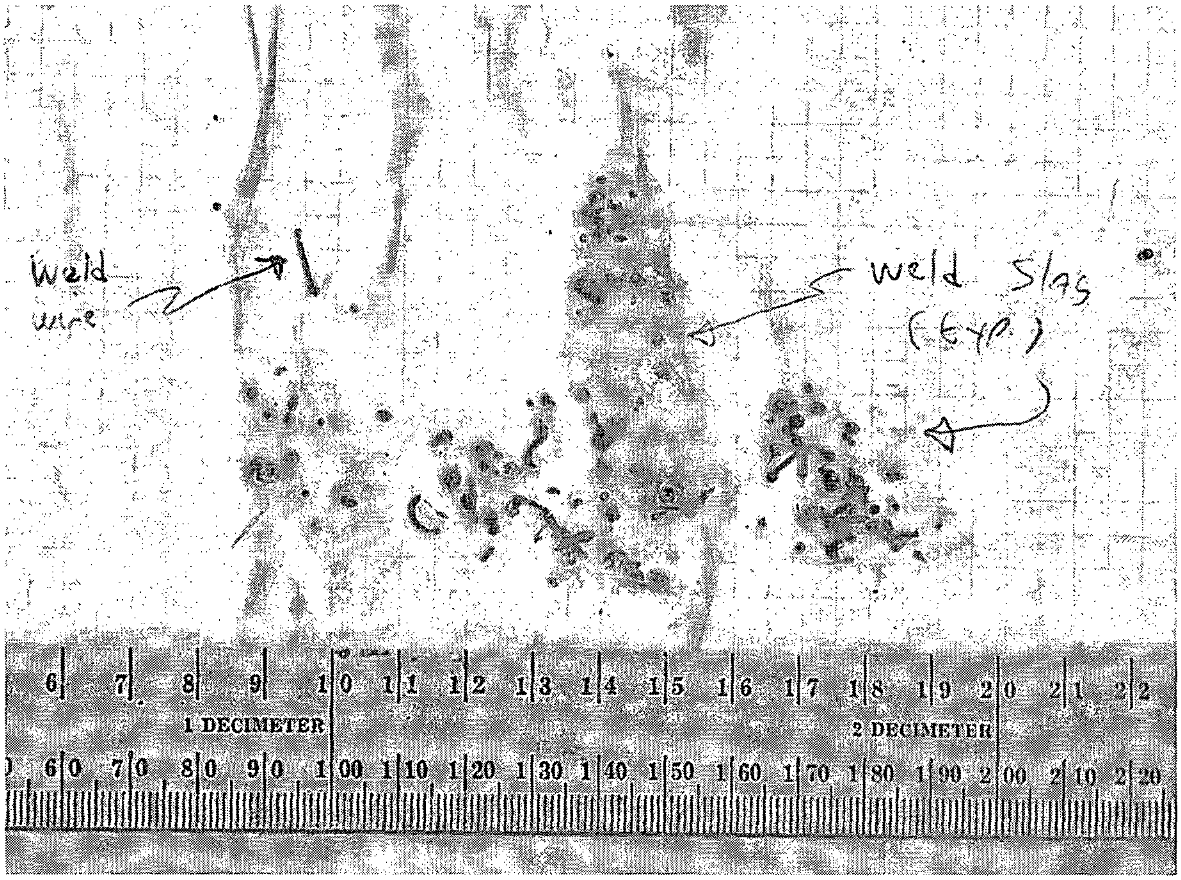
Figure 1
Photograph of the Objects



Note that the photographs contain additional shadows that are a result of the photographic process used to obtain the above picture.

Table 1
Temperature Record

a, c

LTR-SGDA-06-243-NP Rev. 1

Input To The Preliminary OA To Address Detached Batwings in the Waterford 3 Steam Generators

February 2007

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Executive Summary

During the prior (R13) outage both visual and eddy current inspections were performed in the central stay cavity region of Steam Generators 31 and 32 at Waterford 3. These inspections determined that two batwings were not longer attached to the central support in the central cavity region of SG 32. No other degradation of the batwings were noted in SG 32 although inspection of the upper weld of this SG determined that only one of the two welds were present. All of the batwings remained attached to the upper location at the wrap around bar. Inspection of SG 31 concluded that no noticeable degradation of any batwing component was present. An operational assessment was made that concluded that the steam generators could operate for at least one fuel cycle of operation without excessive tube wear occurring in any of the non-repaired tubes in either steam generator.

The recent inspections of SG 32 during the current R14 outage determined that the batwings in the central stay region experienced significant deformations with various levels of twisting and bending of the batwing. In addition, the visual inspection of the batwing to wrap around bar attachment welds, located at the upper attachment point on the periphery of the SG tube bundle, determined that the welds were not as-designed and that two of the batwing to wrap around bar welds had failed. One batwing with a failed weld was displaced approximately 7 tube rows and was found adjacent to ~Row 140. The other batwing did not displace significantly. The inspection of SG 31 did not find any displaced batwings or failed welds, but did find one batwing that only had one of the two fillet welds present in one batwing. The batwings are not a safety component but two pressure boundary concerns were identified: wear of tubes in the event of a missing or significantly displaced batwing and tube wear due to loose parts from batwing displacements or broken batwing parts.

Several analyses were performed to determine the effects of the revised configuration. These included an analysis of the increased flow loads resulting from the increased batwing area exposed to the central cavity flow. Two general concerns were addressed in this analysis. These included the potential for an increased number of active tubes near the central cavity region to experience significant wear, and the potential for batwing to wrapper bar weld failure. The data and analysis contained in this report indicate that the previous plugging program would be sufficient with respect to wear of central stay cavity batwing induced tube wear. However, it could not be concluded that additional batwing to wrapper bar welds would not fail. As a result, additional weld material was recommended at the batwing locations in SG 32. In addition, a repair program, which includes solid plugs, sentinel plugs and various size tube stabilizers was developed to provide a defense in depth approach to assure that any non-plugged tube would not experience leakage due to a failed batwing or loose parts that could develop as a result of a batwing failure.

1.0 Effect of Revised Batwing Orientation on Previous Wear Potential Estimate

1.1 Methods

The analysis performed in the previous evaluation and the test basis developed to address the original batwing problem in the mid 1980s were used as a starting point. Reference 14 contains specific details regarding results of analysis performed specifically for the Waterford 3 SG. Reference 15 contains details and discussion regarding the original analysis and test basis performed to address BW wear for various model SGs. Since the original work only addressed the condition where the batwings were not severed (intact), additional analysis was necessary to determine the effects of the batwing becoming severed at the central support bar.

In the original analysis the model used to determine the potential for BW induced tube wear used a workrate model. Workrate uses both contact force and displacement per unit time in order to determine wear rate. The basis for this is defined using [

]a,c The displacement portion of the work result from the tube motion that supplies both the flow induced vibration (FIV) displacement per cycle along with the frequency of tube motion to define time.

Since the failed BW does not significantly influence the tube dynamic response, both the displacement and frequency component of the workrate would not change in the post BW failure configuration. The components of workrate that would change are the forces associated with the BW-tube contact. The forces in both the pre (intact) and post sever condition have been determined using a non-linear Ansys finite element model. These forces have been used in the current calculation to determine attenuation effects and changes to projected tube wear.

As stated above, the resulting effects due to severing the BW at the support bar in the cavity were determined using a non-linear Ansys finite element model of the stay cavity region. Non-linearity was simulated by [

]$^{a, c}$

1.2 Results

The recommendations regarding plugging of tubes due to failed batwings are contained in Reference 1. These recommendations were developed by a model that determined the batwing to tube interface loads for both the severed and un-severed conditions. In addition, the analysis determined how far into the SG tube bundle the batwing reaction forces could travel before attenuation to a no load condition. Various cases were addressed that considered the effects of gaps and prior wear along with various thicknesses of batwings that could be present. The objective was to envelop the creditable geometric conditions that could be present at Waterford and account for wear and also any chemical cleaning effects. The effects of uprate, multiple batwing failure and tube plugging level were also included. Revised wear rates were calculated based upon the severed and also the un-severed condition. Through this analysis it was determined that wear rates of some tubes could increase significantly but would still be acceptable for remaining active tubes for at least one fuel cycle.

However, the actual tube plugging pattern was conservatively determined by [

]a, c This was considered a reasonable approach since, although it was believed that the model was appropriate, there was not any empirical data available at the time to validate the method. However, the model has since been validated by the recent de-plugging and inspection of five tubes that were adjacent to batwings that dropped during the prior outage. This inspection determined that essentially no level of wear was observed in the post-batwing drop condition (Reference 12). Since the analysis would have predicted at least some, albeit small level of wear, this serves as a reasonable validation that the methods and models used are a credible tool for predicting conservative rates of tube wear on a cycle-to-cycle basis.

The RF 14 (12/06) visual inspection of SG 32 has determined that some of the batwings are in a more deformed orientation than that which was observed in the prior outage. Some of the batwings are deformed and rotated such that an additional moment could be applied to the batwing, potentially resulting in additional batwing force attenuation affects. A review of the inspection data was performed in order to understand the potential configurations that could be experienced by the batwing. There are multiple orientations possible and it was determined that it would be best to determine a limiting or worst case condition. Since there were many possible orientations, it was decided that a maximum applied force and moment method would be used. The maximum force that was determined assumed that the batwing was rotated such that it experienced the largest possible force associated with the secondary side flow. This condition would envelope the case where multiple batwing failures would occur, as considered in a prior analysis (Reference 1), since the maximum possible load regardless of batwing configuration has been used in the analysis. The resulting maximum moment was determined by calculating the limit moment that would be required to develop a plastic hinge at the point where the batwing contacted the first tube. Any moment larger than that would result in plastic deformation of the batwing and would reduce not only the bending moment, but also the direct force associated with the secondary side flow.

The results of the analysis determined that there was some additional attenuation of contact force into the SG tube bundle. The highest tube row that had any reaction force associated with a failed batwing was Row 62. For the limiting case for the currently found conditions, where the limit load approach has been used, the maximum affected tube row increase from Row 62 to Row 69 (Reference 11). However, it must be noted that the level of contact force associated with this condition is still relatively small. To put this in perspective, [

]a, c

Figure 1-5 and 1-6 contain plots of the limiting condition with respect to attenuation. The applied force associated with the limit load is located on the left side of the plot. The location of the tubes is noted by the black vertical lines. Since this is a triangular pitch, the tubes are located in a staggered configuration on each side of the batwing. Figure 1-5 contains a plot of batwing/tube reaction forces obtained from the non-linear finite element model. The forces are noted in red and are scaled according to the magnitude of the force. As would be expected, [

]$^{a, c}$

Since all tubes below Row 62 (or the equivalent, based upon column number) are to be removed from service if a dropped batwing is noted, a review of the current analysis results was limited to tubes located beyond Row 62. The objective of the review was to identify the maximum tube contact force associated with a failed batwing that was subjected to [

]$^{a, c}$

The [ ]$^{a, c}$ value is that associated with the pre-uprate condition. Although the [ ]$^{a, c}$ value has been determined using uprated conditions and considers the effect of increased tube plugging levels, there is still a correction required to account for additional components of the workrate, i.e. displacements. Reference 1 contains a description of the method used to correct for uprate effects as they relate to the displacements. The relationship included [

]$^{a, c}$

As a result, it would take on the order of 35 years for this tube to wear down to 30% wear depth. Since these steam generators will be inspected each outage, any significant levels of wear would be detected prior to reaching the 40% through wall limit.

Note that in both the original batwing wear analysis (Reference 2) and that of Cycle 14 (Reference 1), it was recognized that there are many factors that could influence the actual rate of tube wear vs. that obtained through testing and analysis. These effects include:

- [
-
-
-]a, c

In light of these and potentially other factors a statement was made on page A7-1 of Reference 2:

> *The wear progression analysis results represent wear of an average tube within a line; Specific tubes, affected by preloads and manufacturing tolerances, may exhibit greater than predicted wear during a particular fuel cycle while others may exhibit lesser wear.*

The current analysis does not change the applicability of this statement.

Figure 1-1

a, c

Figure 1-2

a, c

Figure 1-3

a, c

Figure 1-4

a, c

Figure 1-5

Plan View of FE Calculated Tube Contact Forces
Force Vector Lengths Are Scaled by Magnitude

a, c

Figure 1-6

Plan View of FE Calculated Tube Contact Forces
Same as Figure 1-5, Except Force Vector Lengths Are Uniform

a, c

2.0 Potential Migration of Loose Parts in the Tube Lane During an Accident

Based on an ATHOS analysis of the Waterford 3 steam generators (Figure 1), the central cavity region at the top of the tubesheet has a small flow velocity from the cold leg to the hot leg. This velocity could cause a loose part to migrate from the central cavity into the tube bundle. However, in this case, the movement of the loose part would be from a higher flow region to a lower flow region. Westinghouse has performed a loose part evaluation of a typical broken batwing part in the central cavity region using the highest velocities in this region. Although it is difficult to determine the limiting size of a loose part, a loose part equal to one-half the length of the horizontal strip was chosen (7 inches long by 2 inches wide). This particular loose part was then oriented such that it leaned against the tube and caused a 90° wear angle with the full 14 in^2 surface area projecting into the flow. It should be noted that any long piece that fell vertically would not be stable in that orientation. That is, it would fall on its side and initiate wear on several tubes, which would not be as severe as if the wear occurred on a single tube.

The results of these evaluations (Reference 3) show the flow rates in the central cavity or just into the tube bundle are not capable of causing a wear scar that would reach the tube's plugging limit (40% through-wall) within one cycle of operation. It should also be noted that all tubes in the periphery of the central cavity are plugged and many are stabilized. Thus, loose parts that would be typical of a broken batwing piece (up to 14 in^2) are not expected to be a significant concern with respect to tube integrity in this region of the tube bundle.

A detailed review of the lower batwing assembly identified at least one piece that had broken off but remained captured above the existing batwings. Thus, there is evidence that the flow could move loose parts up in the tube bundle as well as down. If a batwing bar broke at both the upper weld and at the lower assembly, it could move down at a 60-degree angle until it contacted eggcrate 6 or the tubes on the other side of the tube bundle. Alternatively, and more likely, it would be restrained by friction between the tubes and the upward flow and not move significantly from its original position. Once the plant shut down, the reduced effects of flow could allow the batwing to fall through the central cavity to the tubesheet.

If a loose batwing contacted tubes on the other side of the tube bundle, there would be no concern because most tubes on the inside of the central cavity have long stabilizers installed and the whole region is surrounded by sentinel plugs. If the batwing gets between tubes and extends into the tube bundle, it is possible that vibration of the batwing from flow in the central cavity could cause wear on active tubes. However, sentinel plugs are installed immediately beyond the stabilized tubes. Thus, significant wear would be detected and the plant shutdown before significant tube damage could occur. It should also be noted that previous test of tubes with batwing wear scars (Reference 4) have shown that tube with typical batwing wear scars exhibit "leak-before-break" characteristics.

With respect to accident conditions (feedwater or main steam line break), the region of the tube bundle at the tube lane could experience a certain amount flow away from the central cavity. However, the high flow rate during these events are of relatively short duration (on the order of minutes) and insufficient to cause wear to a point where the tube would leak. Although it is possible that a loose part from a broken batwing could impact against a tube, the probability that it would cause a leak is remote. Note that a loose part that is 7" x 2" x 0.09" would only weigh approximately 0.38 lbs. Even if it was traveling at a flow velocity equal to 15 ft/sec (four times the normal flow in this region), test data developed by Westinghouse (Reference 3) shows it would result in a tube dent of only about 11 mils. Based on this evaluation, it is concluded that loose parts dropping to the top of the tubesheet are not likely to result in tube integrity issues.

3.0 Bent or Folded Batwing Considerations

The prior analysis and recommendations (Reference 1) were generated for the conditions where the batwings were assumed to be severed, but remained in a relatively nominal location. The analysis did not address the potential for the batwings to become located above the center bar and as a result have a potential for large levels of bending and folding over in the cavity above the horizontal batwing region. An initial review to determine the potential for the batwing to contact a tube indicates that the batwing could potentially contact the vertical portion of the tube directly adjacent to the failed and folded batwing. This would be the case for batwings located in all regions of the central stay region including both the centermost portion of the bundle and the tubes located in the flanks near the tube lane.

In this instance, the batwing could potentially begin to wear one or more tubes. In instances such as this it is would not be unrealistic to assume that large wear rates would occur. Therefore the affected tubes have been recommended to be stabilized to prevent severance of the tube. If this were not performed, then there would be a potential for additional failures of neighboring tubes that could eventually result in failure of an active tube such as that which occurred at Ginna. As a result, a mitigation strategy should be employed in these instances.

With respect to Waterford, although all of the tubes in the center cavity stay region are removed from service, not all tubes have stabilizers installed at the square bend portion of the tube. Short stabilizers are installed in some tubes in both the hot and cold legs however, these stabilizers do not extend up to the batwing area. Since there may be a potential for wear to occur on these tubes and the there are some un-stabilized tubes, Westinghouse recommends that sentinel plugs be installed in the "flanks" of the central cavity. This region includes the low row tubes (approximately Row 1 through Row 9), where only short stabilizers are currently installed, and higher row tubes (approximately Row 32 through Row 45), where no sentinel plugs were previously installed. Installation of sentinel plugs in these locations will completely surround the central cavity and provide early indication of problems if unexpected conditions occur.

4.0 Potential for Failure of Batwings In Non-Central Stay Cavity Region

A review of Reference 5 shows that the contact forces of the batwings against the tubes decreases rapidly as the flow loads and free span length of the batwing diminishes. For example, there is a significant decrease in the contact force of batwing 69 compared to the contact force of batwing 87. A review of the lower batwing visual inspection data appears to confirm that there are lower flow loads on those batwings near the edge of the central cavity. This decrease in flow loading continues as the batwings exit the stay cylinder region. Although flow rates vary within the tube bundle, they remain considerably less that those in the central cavity.

In addition to the decreased flow loadings, the batwings outside the central cavity have a negligible free span length compared to those within the central cavity. Figure 2 shows the lower batwing assembly with the Row 1 tubes. Since the Row 1 tubes have a bend radius of 2.5 inches, the longest span length before the tubes provide support is only 5 inches. Support from higher tube rows is then provided every one inch thereafter. Conversely, the free span of the longest batwings in the stay cylinder is approximately 58 inches. Given that flow loadings on the batwings are lower and that the free span length is smaller by an order of magnitude, it is concluded the batwings outside the central cavity are adequately supported. Batwing failures in this region of the tube bundle would not be expected.

5.0 Fabrication Differences Between SG 31 and 32

Westinghouse researched the original fabrication records for the Waterford 3 steam generators (CE contract number 74270). No significant differences between the two steam generators could be determined. Based on this review, the thermal-hydraulic evaluations for both steam generators are identical. The analytical evaluations of the two steam generators are also identical. However, the visual inspection of the batwing to wrapper bar welds determined that a double fillet weld was generally used in SG 31 and a single fillet weld was used in SG 32.

6.0 Summary of Historical Design Considerations

Combustion Engineering (CE) built four plants that had carbon steel batwings; St. Lucie 2, SONGS 2 & 3 and Waterford 3. Palo Verde 1, 2 and 3 and the Palisades replacement steam generators also had batwings but the material was changed from carbon steel to ferritic stainless steel. Korean units at YGN and UCN as well as the Palo Verde RSGs do not have batwings (characterized by the horizontal or "dogleg" section). Instead they have diagonal supports that come to a "V". The "V" is surrounded by a 6-inch square tube that is slotted to accept the diagonal bars.

Vertical supports, which are attached to crescent plates and I-beams, also attach to the diagonal bars. These supports decrease the ability of the bar to bend in the axial direction. In the central cavity, there are additional supports that reduce the free span of the diagonal bar. The Korean units have one free span support on hot leg side and one support on the cold leg side. The Palo Verde RSGs have two free span supports on each side.

It should be noted that the purpose of the additional supports was to ensure the diagonal bars would retain more stiffness and, together with a good upper bundle supports, eliminate wear in the tubes around the central cavity. Although the amount and severity of the wear has decreased, it has not been eliminated. It was not until flow baffles were placed in the central cavity of the UCN 5 design at the upper full eggcrates that the wear problem was eliminated.

7.0 Upper Batwing Weld Considerations

During the initial evaluation of detached batwings in RF13, the integrity of the upper weld where the batwing attaches to the wrap-around bar was identified as a key requirement to maintain proper tube support. As a result, a visual inspection and detailed analysis was performed to document the acceptability of these welds. As the detailed evaluations were beginning, Westinghouse was asked to provide a judgment regarding the acceptability of the welds. Based on an assumption of relatively low flow loadings, a judgment was made that the welds would be acceptable. This judgment was documented in Reference 16, which was issued on May 6, 2005. Following an inspection of the welds, the detailed analysis was completed and documented in Reference 17, which was issued on May 27, 2005. The analysis confirmed the Westinghouse judgment that the as-found weld condition in RF 13 was acceptable. To confirm the welds remained intact, Westinghouse recommended that the upper batwing welds be inspected each outage.

During RF14 a more detailed visual inspection of the upper welds was performed. The inspection results are discussed in Section 7.1.1 and show that two of the welds had failed. Although the root cause of the broken welds has not been determined, the inspection results indicate that the welds were smaller than required by the design drawings and appeared to have poor fusion. These factors were not identified during the RF13 inspection. In addition to poor fusion, it was possible that twisting of the batwings in the central cavity could expose more of the batwing surface area to the flow and increase loads above the value assumed in Reference 17.

To address the potential for increased flow loadings, the batwing to wrap-around bar attachment point was re-welded during RF14. All accessible locations where the batwings went through the central cavity in steam generator 32 were re-welded. As described in Section 7.2.1, these welds were then reanalyzed and shown acceptable for the worst-case flow loadings. Based on the inspection findings from RF14 and the analysis in Section 7.2.1, Westinghouse is confident that the upper batwing welds in steam generator 32 will remain intact.

7.1 Inspection Results

7.1.1 Welds

The video tape of the hot leg weld between Columns 108 and 109 was examined to determine the size of the broken weld. This batwing appears to have displaced only about 0.1 inch from its original welded position (Reference 6).

The weld remnant that remains on the wrapper bar is approximately 1/4 inch tall, 0.3 inches wide at the base, and about 1/2 inch in length (along the batwing bar). There is no weld remnant visible on the batwing bar. It appears as though there was poor adhesion (fusion) between the wrapper and batwing bars in either of the failed welds. The face of the weld remnant that was in contact with the batwing is visible for tens of seconds in the video. The imprint of the batwing bar is visible in the remnant. The imprint of the beveled face (0.14 inch high) is visible from top to bottom, with a 0.03 inch rim at the top that was above the beveled face (on the vertical face), and another narrow rim at the bottom that wrapped under the batwing bar (in a narrow gap between the batwing bar and the wrapper bar) for 0.03 inch (the width of the batwing bar at the end of the bevel). The length of this imprint along the batwing bar is about 1/4 inch. This implies a contact surface area between the batwing bar and the wrapper bar of (0.14 + 0.03 + 0.03) x 1/4 = 0.05 square inch.

Note that the face of the weld remnant that was in contact with the batwing exhibits highlights (bright spots) that are characteristic of older deposits, and are not consistent with a freshly exposed surface. This condition was interpreted as a rough surface with many angled faces - perhaps a rough fracture face.

Additional documentation of the above observations is provided in Reference 6.

7.1.2 Eddy Current

Westinghouse has completed thermal-hydraulic evaluations of the upward forces in the central cavity region of the Waterford steam generators. These forces are sufficient to move the batwing in the vertical direction and potentially cause fatigue of the upper batwing weld. The only forces counteracting the uplift loads are friction between the batwing and the tubes, resistance from the weld and possible torsion from the wrap-around bar.

Based on a review of visual inspection data, it appears unlikely that the batwings could move strictly in the vertical direction. As soon as the batwing begins to twist, flow forces will cause a detached batwing to move in a direction normal to the twisted batwing. In addition, the twisting of the batwing may cause increased friction between the tubes and the batwing. Thus, it is unlikely that the flow forces will cause the batwing to move straight up.

To determine if there were a number of up and down cycles for the broken batwing, Westinghouse reviewed eddy current data (Reference 7) for all tubes whose batwings traverse the central cavity. In particular, Rotating Pancake Coil (RPC) data was obtained for all tubes with broken batwings up to Row 70. The RPC inspection took data from the 7th eggcrate past the batwing and up to the first vertical support. The premise of this review was that any batwing moving up and down would cause wear on at least some of the tubes it contacted. There was no indication of volumetric defects at any location in the free span above the normal batwing position in any of the RPC data.

In addition to the RPC data, bobbin data was reviewed for the columns where the batwing to wrapper bar weld broke. Full-length bobbin data were obtained in all open tubes in columns 84, 85, 108, and 109. If there were any new calls in the freespan that changed from history back to 1994, they would have been reported as a bobbin I-code (e.g., either DFI or ADI). The bobbin I-code then would have been tested by RPC. If degradation were found, the RPC would have an I-code on it (e.g., SVI). Following a review of the data base, it was confirmed that there were no SVI codes (Reference 7)

Based on the low probability of batwing movement in the vertical direction and no eddy current indication of volumetric defects above the normal location of the batwing, Westinghouse concludes that a fatigue failure of the upper welds in steam generators 32 is unlikely.

7.2 *Batwing to Wrap Around Bar Weld Stress Analysis*

This section summarizes the results of the batwing to wrap around bar weld analysis contained in Reference 8.

7.2.1 *Summary of Stress Analysis Results*

Westinghouse has completed the evaluation of the increased weld size in the attachment weld between the batwing and the wrap-around bar. Detailed results are contained in Reference 8. A summary of the following analytical evaluations follow.

- [
-
-
-]a, c
- Determine Load required to Break Welds (As-built and as-repaired)

The flow loads on the portion of the batwing within in the central stay cavity were calculated with conservative assumptions regarding the orientation of the broken batwing relative to the flow direction and support from other internal structures and frictional restraint within the tube bundle. The calculated forces and moments on the weld are believed to be extremely conservative and inconsistent with the conditions observed in the inspection as reported in Reference 6 and discussed below. Reference 8 also shows the weld sizes that would be required to sustain these calculated flow loads as required by other analytical evaluations.

Reference 8, which also addresses the [

]a, c This conclusion is further supported by other inspection results and calculations described below.

Note that it as been assumed in the analysis that the fluid forces applied to the end of the batwing in the central cavity region produced loading on the batwing and resulted in failure of the weld. This is a reasonable scenario in light of the evidence, however it has been suggested that there are other loadings that could have resulted in failure of the weld. This includes potential thermally induced stresses resulting from heat up of the SG tube bundle. However, these types of stresses are considered to be reasonably small in light of the flexibility of the batwing/wraparound bar assembly. As a result, it is judged to more likely that the secondary side fluid forces played the dominate factor in the failure of the weld.

Reference 8 also calculates [

]$^{a, c}$ This further suggests that the flow loads transmitted to the wrapper bar weld are significantly less than the conservative estimate described above.

The moments required to break the batwing to wrapper bar welds are also calculated in Reference 8. The as-found weld geometry, as reported in Reference 6, and the anticipated as-repaired weld geometry are addressed. The broken weld on the hot leg side had the largest weld section, ¼" length and a 0.20" leg. The critical moment to fail this weld is calculated to be [

]$^{a, c}$

In contrast, the as-repaired weld configuration is a ¼" fillet, 5/16" long on both sides of the batwing. The moment required to fail this as-repaired weld geometry is estimated to be about 224 in-lb or more than five times the maximum moments that were likely experienced during the last operating cycle. For an applied moment 40 in-lb, the calculated stress in the as-repaired weld is less than 5 ksi.

Reference 8 also assesses the fatigue resistance of the as-found and as-repaired welds. With a fatigue strength reduction factor of 4 for the fillet welds, the alternating stress for the as-repaired welds is slightly less than 10 ksi which is acceptable for infinite cycles. Therefore, fatigue failures of the as-repaired welds are unlikely. The as-found welds are predicted to have an alternating stress in excess of 55 ksi and a fatigue limit of 3650 cycles.

7.2.2 Discussion of Inspection Observations

The following observations during the Waterford RF14 inspections provide further evidence that the proposed repairs are adequate to preclude further weld failure at the wrapper bar.

1. From the visual examination the welds appear to be quite small and poorly installed. This observation supports the contention that the loads applied to the welds are relatively small. Otherwise the number of broken welds would have been much greater.

2. The maximum moment to break the weld is 40 in-lbs. This provides further evidence that applied moments are about this magnitude.
3. Based on visual examination, there was no movement of the wrap-around bar.
4. Based on a review of the eddy current results, there was no indication that the batwings moved in a cyclic up-and-down movement. That is, there were no volumetric defects at any location above the normal location of the batwing nor any that could be associated with the batwing in a post drop configuration as demonstrated by de-plugging the five tubes from the previous outage (Reference 12). Thus, fatigue is not a likely cause of the weld failures.
5. Displacement of the batwing to reach 40 in-lbs is 0.144 inches.
6. The likely root cause is a poor quality weld. The weld was smaller than designed and there was some indication of poor fusion. Therefore, it is possible that the weld broke at less than 40 in-lbs.

7.2.3 Discussion of Welds in Steam Generator 31

As shown in Figure 3 (Reference 8), all of the welds in steam generator 31 have the size to resist an 80 in-lb moment except for the one weld that was single sided. That batwing is being treated as a potential failed weld and all tubes in contact with the batwing are being plugged, sentinel plugged or plugged and stabilized. Figure 4 shows the particular plugging pattern used.

Based on the observations made in steam generator 32, any weld that could withstand a 40 in-lb moment did not break. In addition, there was no visual observation of any batwing bar at any location higher than its normal elevation, and there was no indications of vertical movement in the post drop condition. Also, as described in Section 7.1.2, a review of the eddy current inspection results revealed no evidence of any movement of the batwings above their normal location. Based on these observations, it was concluded that should any of the batwing bars break at the center notch in steam generator 31 during the upcoming cycle, the welds would not expect to exceed the yield stress of the material. In addition the displacements necessary to produce a fatigue failure would not be expected to occur, hence fatigue would also not be expected.

7.2.4 Conclusions

1. The weld failures were the most likely the result of under sized welds coupled with a poor weld quality. Calculations indicate that the weld that failed could have experienced flow load induced bending moments on the order of 40 in-lbs or less.
2. The proposed repair provides welds that are capable of sustaining moments of up to 224 in-lb or more than 5 times the loads that likely caused the observed failures.

3. Calculations, visual and eddy current inspection observations indicate that fatigue failures of the as-repaired welds are unlikely.

8.0 Effect of Steam Line Break on Degraded Batwings

An evaluation has been performed for the postulated faulted steam line break (SLB) accident loading with respect to the degraded batwings observed in Waterford 3 in Reference 9. The following assumptions apply to this evaluation:

- The largest batwing between tube columns 87 and 88 is assumed to be fully severed at both the center of the horizontal support bar and at the outer weld that attaches the diagonal bar to the wrap around bar.
- The end of the batwing at the horizontal support bar in the cavity region is assumed twisted by 90° such that the 2-inch wide face is normal to the flow stream and conservatively experiences the maximum dynamic pressure vertical drag force of about 34 lbf.
- Based on previous calculations performed for Waterford, the SLB flow load is assumed to be four times the normal flow load or in this case, 4 x 34 = 136 lbf.

One side of the batwing (from the center of the horizontal support to the wrap around bar) weighs about 7.5 lbf and assuming no frictional resistance, the severed batwing will be displaced upward by the normal flow which produces the aforementioned upward force of 34 lbf. Under these conditions, the displaced bat wing will likely come to rest against the horizontal runs of the tubes in Rows 38 and 39 due to the normal flow condition.

The SLB is assumed to occur at hot standby conditions. The tube internal pressure is 2235 psig and the external pressure is 980 psig (544°F) at hot standby, Reference 2. A finite element (FE) model of the tube in Row 38 was employed to calculate a maximum $P_L + P_b$ stress intensity of 54 ksi for a vertical load of ½ of 136 or 68 lbf at the center of the horizontal span. This calculated maximum stress intensity of 54 ksi is well within the specified faulted allowable $P_L + P_b$ limit of 3.6 S_m = 84 ksi (at 560°F) for the Alloy 600 tube.

Therefore, potential batwing loose parts accelerated by the high flow rate accompanying an SLB will not stress the tubes beyond the limits specified in the ASME Code.

9.0 Wrap-Around Bar Analysis For Failed Weld Condition

The wrap-around bar analysis was performed to determine the limiting torque capability of the wrap-around bar. Once this value is determined, the limiting number of failed batwings applying torque to the wrap-around bar can be determined.

The analysis of the wrap-around bar was performed using the following methodology. Details are provided in Reference 13.

- [
-
-]a, c

The acceptance criterion was based on NB-3227.2 of the ASME Code Section III. A torsional stress limit of 0.8 of the material yield strength was chosen, which would allow for limited plasticity. Large deformations would not occur until significantly higher torsional loads were applied.

The following conclusions were obtained from this analysis

- Assuming an applied torque of [ ]a, c the maximum acceptable number of failed batwings would be approximately 56.
- Assuming a torque of [ ]a, c the acceptable number of failed batwings is 20.
- It should be noted the analysis using [ ]a, c Therefore, the wrapper bar will not be subject to a primary stress failure, even if more than 56 batwings are postulated as failed. It should also be noted that the flow loads on the failed batwings would tend to rotate the wrapper bar away from the outer perimeter tubes. That rotation would also be further limited by contact with the shroud. This further indicates that the perimeter tubes are not in danger of damage from the wrap-around bar.
- The finite element model results correlate well with the classical solution. The ANSYS torsional reaction loads on the wrapper bar are the same as used in the classical stress calculations.

- It should also be noted that the addition of proposed batwing weld clips to facilitate connecting the wrapper bar to the batwings will have an insignificant effect on the wrapper bar torsional stress calculation. The clips weigh 0.2 lbs each and contribute negligible torque to the critical wrapper bar section which is analyzed for a total torque of several thousand in-lbs for the cases evaluated.

Based on this analysis, no additional tube plugging is required to address the potential failure of the wrap-around bar.

10.0 Flow-Induced Vibration Analysis For Missing Batwing Condition

Westinghouse performed detailed vibration analyses at the outermost tube rows and at the edges of the partial eggcrates. The analysis methodology used was identical to that used for the uprate. These analyses were performed to determine the regions most susceptible to flow-induced vibration (FIV) in the event a batwing failed and could no longer provide support for the tubes. The results of these analyses are provided in Reference 10.

These analyses show that the regions most susceptible to FIV are the outermost tubes (near Row 147) and those tubes inboard of partial eggcrate 8 (near Row 48). Based on these results, Westinghouse recommends that sentinel plugs be installed at the outermost row of tubes and a row of tubes just below partial eggcrate 8. The sentinel plugs in the outermost rows provide protection against a batwing bar that slips partially into the tube bundle. In this case, the outermost tubes are the most unstable tubes without a batwing. If the batwing bar slips all the way into the tube bundle such that all tubes in a particular column do not have a batwing, the tubes around Row 48 are the most unstable. Thus, this plugging pattern protects the steam generators from both a partially slipped batwing and one that slipped completely out of the tube bundle.

The sentinel plugging described above is shown in the plugging maps for both steam generators 31 and 32 in Figures 4 and 5.

11.0 Discussion of Wear at R67 C99

The following was obtained from Reference 18.

At RF14 a 31%TW wear scar was reported by bobbin coil analysis on R67 C99, BW9 +2.74 inches. RPC data shows the observed wear scar is located above the current elevation of the batwing associated with this wear scar. The batwing is confirmed to have failed at the horizontal bar and experienced a vertical downward displacement, thus the wear scar should not be located adjacent to the batwing in its' current position. RPC data also shows the shape of the wear scar to be tapered and thus consistent with the shape of wear scars associated with non-failed batwings. This information was previously transmitted to NRC.

A history review of the R67 C99 bobbin data from RF13 shows a 15%TW wear scar is present. This history review also shows the batwing in its' original position; the edge of the batwing and elevation of the wear scar are coincident. Thus the Cycle 14 growth associated with this wear scar is 16%TW.

The distribution of wear depth reports was evaluated to determine if there is a systematic difference between areas of the SG (i.e., stay cavity versus non stay cavity). The overall wear distribution for the entire SG, for the stay cavity columns (columns 62 to 114), and for tube columns outside of the stay cavity were considered. These distributions are essentially identical for all areas, thus there is no systematic difference in observed wear depths within the stay cavity area.

The distribution of wear growth was evaluated to determine if there is a systematic difference between areas of the SG. The overall wear growth distribution for the entire SG, for the stay cavity columns (columns 62 to 114), and for tube columns outside of the stay cavity were considered. These distributions are essentially identical for all areas, thus there is no systematic difference in observed wear growth within the stay cavity area.

For SG32, the largest wear growth observed for Cycle 14 was 23%TW (observed outside of stay cavity), thus the 16%TW growth observed for R67 C99 represents a value that is near the tail of the distribution. A similar observation was also reported at the RF13 outage. At RF13 a 20%TW growth was associated with a failed batwing; the wear scar location was consistent with the original batwing elevation and no wear in the batwing dropped location was reported. The largest wear growth reported for Cycle 13 was 22%TW, and is not associated with a failed batwing.
In conclusion, the data associated with R67 C99 is shown to be consistent with observations reported at RF13, and the %TW growth associated with this indication, while larger than most of the wear growth data, is not the largest growth within the SG.

Wear growth rate data for Cycle 13 and Cycle 14 were compared. In general, the Cycle 13 growth rates bound the Cycle 14 growth rates. Table 1 of Reference 18 presents a summary of pertinent growth data for Cycles 13 and 14. Data is provided for all locations, eggcrates, BW1 (hot leg batwing), BW5 (center vertical strap), and BW9 (cold leg batwing). Average values are calculated with negative growth data set to zero. All wear growth data developed herein includes indications with data management reports for both the RF14 and RF13 outages. The growth data is also supplemented with history lookup data for newly reported indications at RF14 with a depth of 20%TW or greater. All newly reported wear scars did not have a history review performed as those with RF14 depths <20%TW will not have growth values which affect the upper tail of the growth distribution.

In addition, the overall wear depth distribution for RF14 is bounded by RF13. At RF14, only 1 tube was reported to contain a wear scar with depth >40%TW. At RF13, 6 tubes were reported with wear depth >40%TW. The average reported wear depth for SG32 at RF14 (16.9%TW) is bounded by the average reported wear depth at RF13 (17.9%TW). When the observed depth distributions and growth rate data are considered, in can be concluded that operation during Cycle 14 at extended power uprate conditions has not negatively affected SG tube wear growth rates.

12.0 Plugging and Stabilizing Recommendations

As a result of the analysis of the current and potential future condition, a series of general tube repair recommendations have been made:

1. For failed batwings, complete the plugging program contained in Reference 1.
2. For batwings with a failed weld. Install plugs, stabilizers and sentinel plugs in an acceptable pattern along the entire length of the batwing from the outermost tube row to the central stay region if not already performed.
3. For loose parts in the uppermost portion of the SG, install long stabilizers in accessible tubes in the central stay cavity and install sentinel plugs on tubes surrounding the entire central stay cavity (complete the sentinel plug fence).
4. Install sentinel plugs on outer row tubes bounded by column 64 to 112 to address the potential for a missing batwing at the outermost portion of the bundle resulting in large FIV tube displacement.
5. Install sentinel plugs on unplugged tubes inboard to eggcrate eight bounded by column 64 to 112. This is the location of stability ratios that are larger than those near the periphery of the tube bundle.

Figure 4 and 5 contains tubesheet maps of the repair plan developed to address the items indicated above. Note that these maps contain both the proposed repair plan and the repair plan performed in prior outages. The proposed repair plan also uses relevant features of the prior repair plan to address the recommendations listed above.

13.0 Conclusions

The following are salient points regarding the inspection and analysis results presented in the prior sections of this document.

1. Changes to the configuration of the lower batwings will increase the attenuation length of the batwing vibration into the tube bundle. However, wear rates outboard of Row 62 will remain below 40% through-wall over a single cycle of operation.
2. Loose parts from broken batwings are considered likely to occur with the SG in a failed BW condition. For loose parts that fall to the tubesheet, there is little risk that significant tube wear will occur. However, stabilizers and one row of sentinel plugs are in place between potential loose parts and active tubes.
3. Flow rates in the central cavity may be sufficient to bend the batwings to a point where they could contact other tubes. In general, other tubes within reach of the batwings are already plugged so significant tube damage would not be expected. However, to ensure potential tube damage will be limited, most tubes adjacent to the central stay region have a long stabilizer installed. In addition, there is at least one row of sentinel plugs are in place between the bent batwings and active tubes.
4. Batwings outside of the central cavity region are not susceptible to failure. Decreased flow loadings and, more importantly, a large decrease in the free span between the tubes results in a much lower probability of failure. If a failure does occur, the batwing will remain captured between the tubes.
5. The weld failures were the most likely the result of under sized welds and poor weld quality. However, if the welds were of acceptable quality the moment required to yield the material is on the order of [ ]$^{a, c}$ or less.
6. The proposed weld repair provides an attachment that is capable of sustaining moments up to [ ]$^{a, c}$ or more than five times the loads that likely caused the observed failures.
7. Calculations, visual and ECT inspection observations indicate that fatigue failures of the as-repaired welds are unlikely.
8. A loose part accelerated by steam line break flow loads will not damage a tube beyond the ASME Code limit for faulted events.
9. The batwing attachment to the wrap-around bar will remain intact for at least 20 failed batwing and most likely more than 50. If the wrap-around bar does fail, the loads from the batwings will rotate it away from the peripheral tube such that no further tube damage would be expected.
10. Flow induced vibration analyses of tubes without batwing showed two areas of concern; the outermost tubes and tube inboard of partial eggcrate 8. These areas are addressed by installing sentinel plugs as shown in Figures 4 and 5.

14.0 References

1. Westinghouse letter LTR-SGDA-06-199, *Evaluation of the Effect of Failed Batwings at Waterford 3 Operating at 3716 Mwt Uprated Conditions with up to 20% Steam Generator Tube Plugging*, November 2006.
2. Westinghouse Report CEN-328, *Remedy for Steam Generator Tube and Diagonal Strip Wear*, March/April 1986.
3. Westinghouse Letter LTR-SGDA-06-237, *Evaluation of Secondary Side Loose Parts Identified in Waterford Unit 3 Model 70SG Steam Generator During the Waterford Fall 2006 Outage*, December 2005.
4. Westinghouse Report CENC-1699, *Leak Rate and Burst Tests of Steam Generator Tubes with a Simulated Wear Condition from Batwings*, July 1985
5. Westinghouse Calculation Note CN-SGDA-05-64, Revision 1, *Structural Evaluation of Waterford 3 Batwings in Support of Tube Wear Evaluations*, November 2006.
6. Westinghouse letter LTR-CDME-06-195, *As-Found Condition of Waterford 3 SG Batwings During RF14*, December 2006
7. Email from William J. Spence, ECT Level III Analyst, dated December 13, 2006 (Attached as Appendix A).
8. Westinghouse letter LTR-SGDA-06-228, *Waterford 3 Batwing Upper Weld Evaluations in Support of the RF14 Outage*, December 2006.
9. Westinghouse letter LTR-SGDA-06-225, *Evaluation of Steam Line Break Condition Affecting Degraded Batwings at Waterford 3*, December 2006.
10. Westinghouse letter LTR-SGDA-06-229, *Waterford 3 Steam Generator Stability Ratios and Turbulent Amplitudes for Tube Rows in the Central Cavity without Batwing Support*, December 2006.
11. LTR-SGDA-06-238, "*Tube-Batwing Contact Force Attenuation Results For Degraded Batwings at Waterford 3*", December 2006.
12. MRS-TRC-1796, "*Transmittal of Eddy Current Results for Waterford SG 32 De-Plugged Tubes*", December 2006.
13. LTR-NCE-06-169, Rev. 1, "*Waterford 3 Steam Generator Batwing Wrapper Bar Evaluation*", December 13, 2006.
14. CEN-328, Rev. 1, "Remedy For Steam Generator Tube And Diagonal Strip Wear Appendix 7.1 Wear Progression Analysis Results And Recommended Plugging Pattern For Songs 2, Songs 3, Waterford 3", Combustion Engineering, Inc. Windsor, Connecticut, July 1986.
15. CEN-328, Rev. 0, "Remedy For Steam Generator Tube And Diagonal Strip Wear Prepared for Palisades (Replacement Generators) Palo Verde Units 1, 2 and 3, St. Lucie Unit 2, Songs

Units 2 and 3, Washington Nuclear Project 3, Waterford Unit 3", Combustion Engineering, Inc. Windsor, Connecticut, March 1986.

16. Westinghouse letter LTR-SGDA-05-100, "Westinghouse Recommendations to Address Detached Batwings in the Waterford 3 Steam Generators", May 2005.

17. Westinghouse Calculation Note CN-SGDA-05-36, Revision 0, "Evaluation of the Upper Batwing Weld for the Waterford 3 Steam Generators at 3716 Power Uprate Conditions", May 2005.

18. LTR-CDME-07-9, "Transmittal of Waterford SG32 R67 C99 Wear Discussion", January 2007.

a, c

Figure 1

[ ]

Figure 2

S.G. LOWER "BATWING" ASSEMBLY

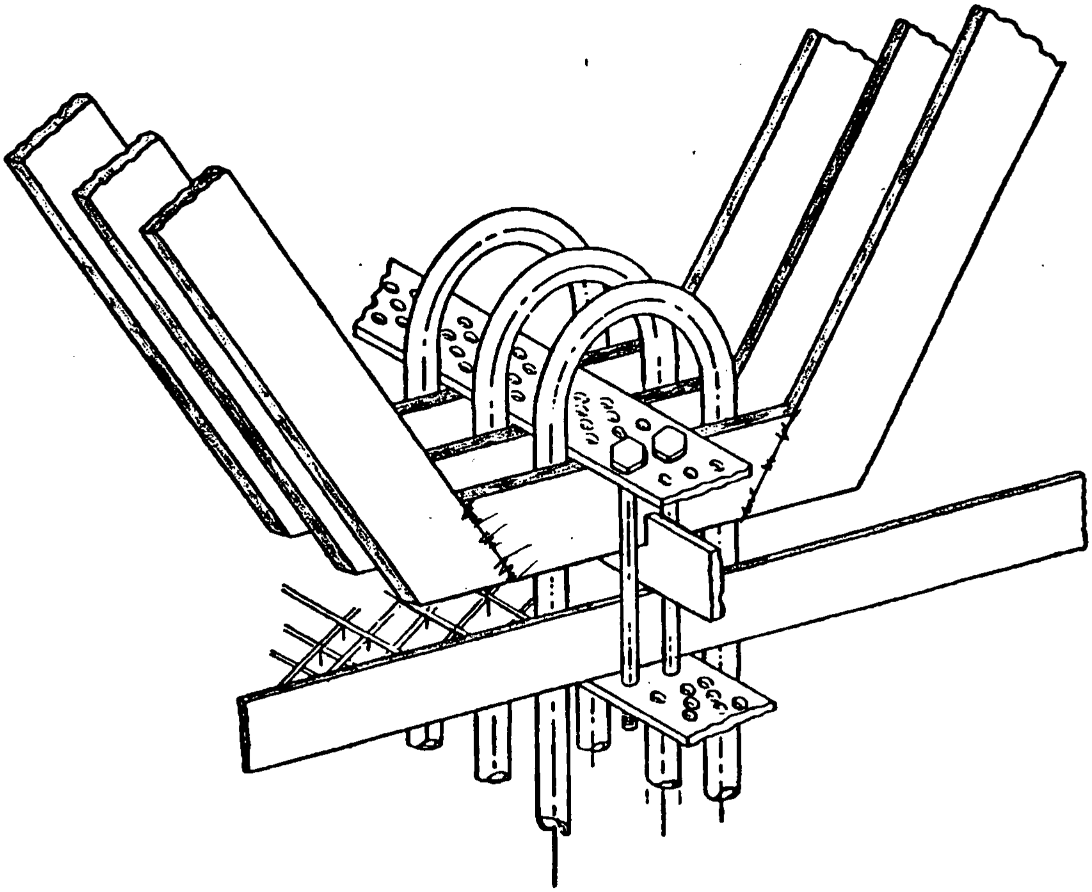

Figure 3

a, c

[ ]

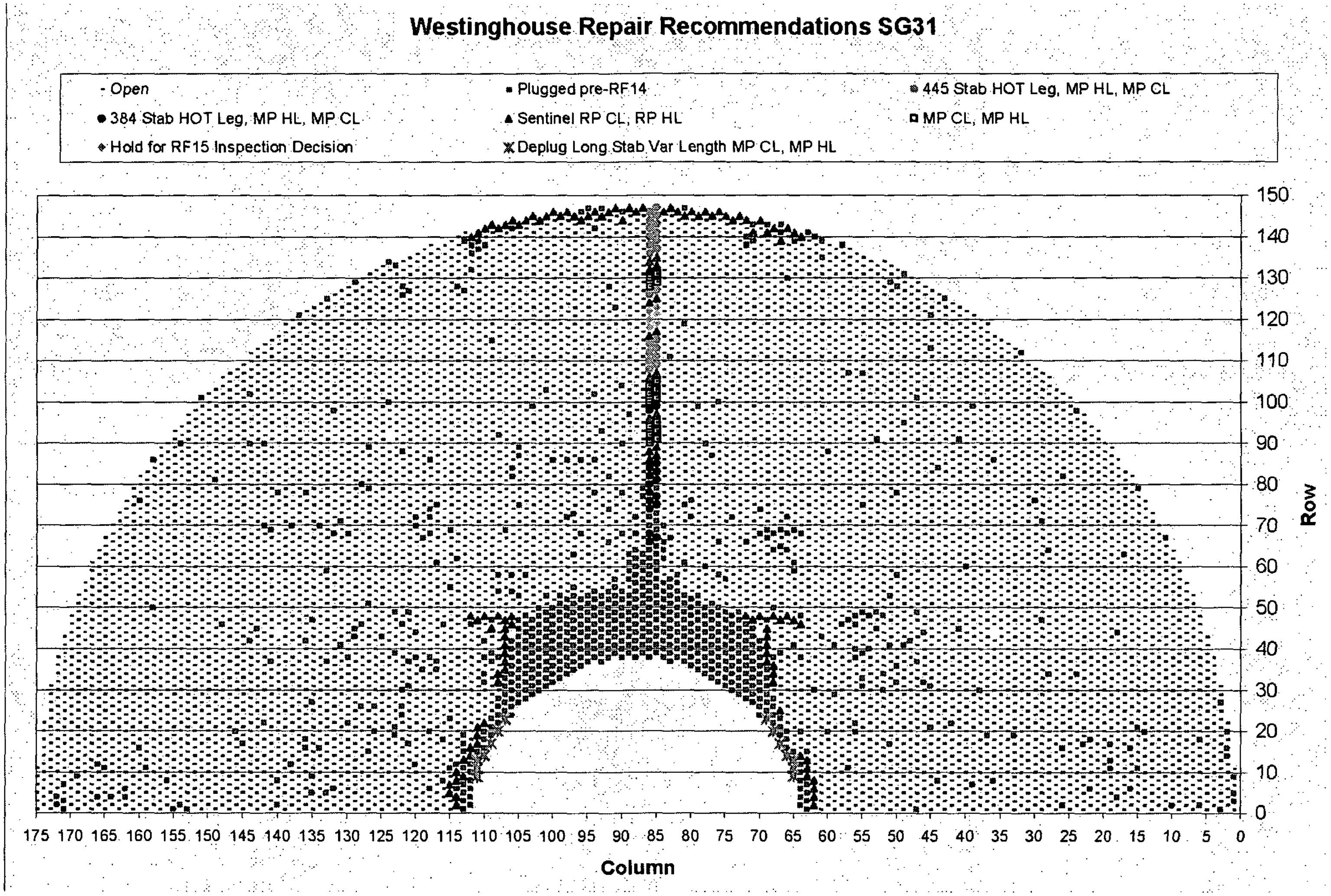
Westinghouse Repair Recommendations SG31
- Open
Plugged pre-RF14
445 Stab HOT Leg, MP HL, MP CL
384 Stab HOT Leg, MP HL, MP CL
Sentinel RP CL, RP HL
MP CL, MP HL
Hold for RF15 Inspection Decision
Deplug Long Stab Var Length MP CL, MP HL
Row
Column
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
175 170 165 160 155 150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0

Figure 4

Westinghouse Repair Recommendations SG32

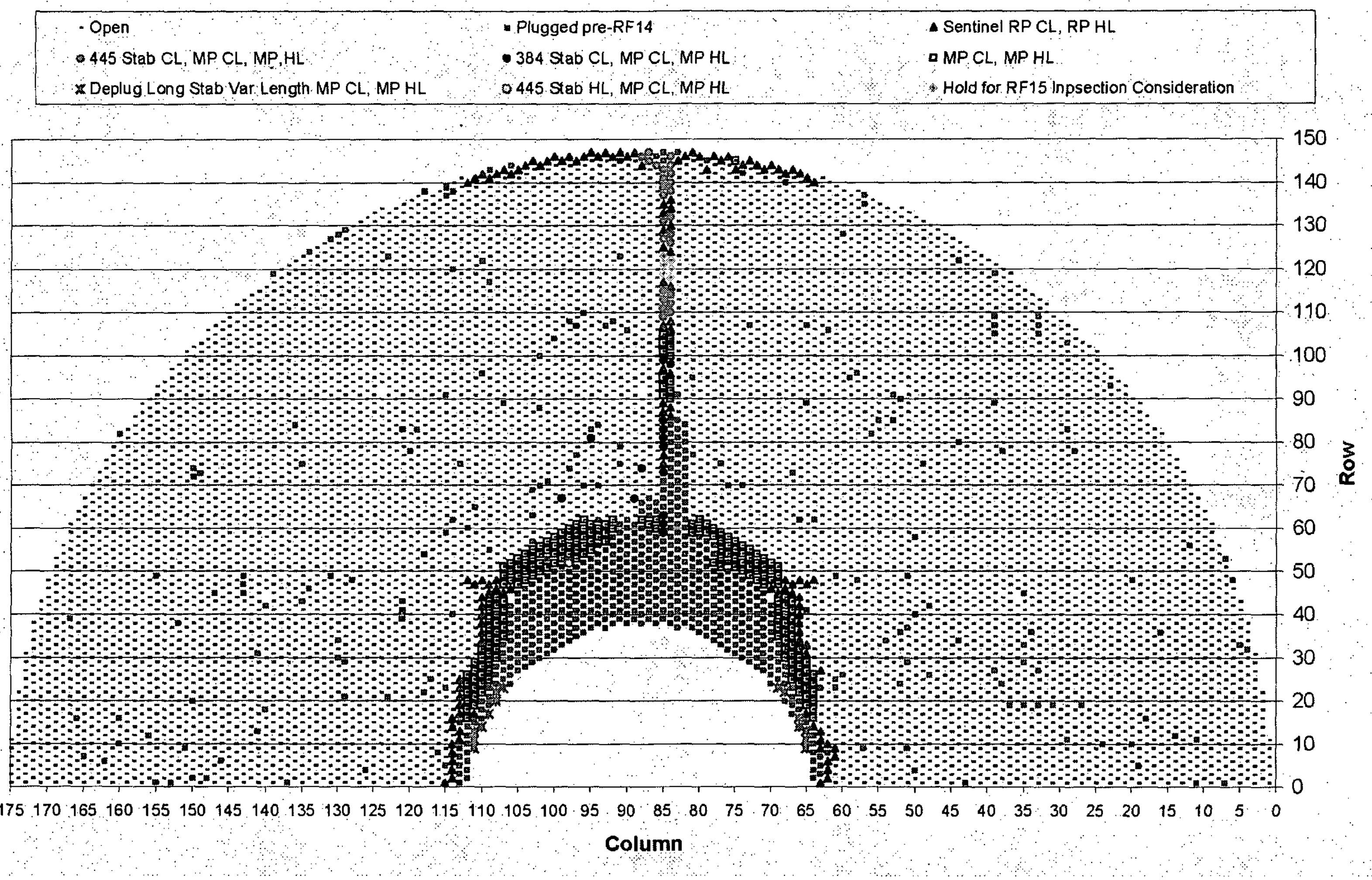

Figure 5

Appendix A

William J. Spence/North-America/Westinghouse@Exchange
12/11/2006 02:54 PM

To: Donald P. Siska/CENO/USNUS/BNFL-TEMP@ABB_USSEV_IMS, Jeffrey M. Hall/North-America/Westinghouse@Exchange
cc:
Subject: Waterford 3 Batwing Wear
Security Level:? Internal

Westinghouse has performed 100% bobbin testing in all open tubes in columns 84, 85, 108, and 109.
If there were any new calls in freespan that changed from 1994 history, they would have been
reported as a bobbin I code (DFI or ADI). The bobbin I code then would have been RPC tested and if degradation existed then the RPC would have an I code on it (for wear-SVI).

I have searched the data base for any SVI indications in the batwing region (BW1 through BW9)
and no RPC 'I' codes currently exist.

William J Spence 12/13/06
William J. Spence

Westinghouse

To: M. M. Stickel
cc: T. A. Gurney, P. R. Nelson, D. P. Siska
M. W. Gibson, J. S. Wyble, W. K. Cullen
D. G. Stepnick, G. H. Stevens

Date: February 16, 2007

From: Steam Generator Design and Analysis
Ext: (724) 722 5458
Fax: (724) 722 5889
Your ref:
Our ref: LTR-SGDA-06-248-NP

Subject: **Waterford 3 Sentinel "Ribbed" Mechanical Plugs-Description and Leak Rate**

References:

1. Westinghouse Drawing 1B79262, Revision 1, "Tapered Mechanical Plug Outline for 3/4 O.D. x 0.055 Wall, 3/4 O.D. x 0.048 Wall Tubes.
2. Westinghouse Drawing 1B81639, Revision 0, "Sentinel Mechanical Plug Outline for 3/4 O.D. x 0.055 Wall, 3/4 O.D. x 0.048 Wall Tubes.
3. Westinghouse Drawing 1B81638, Revision 0, "Sentinel Mechanical Plug Assembly for 3/4 O.D. x 0.055 Wall, 3/4 O.D. x 0.048 Wall Tubes.
4. NUREG/CR-6664, "Pressure and Leak-Rate Tests and Models for Predicting Failure of Flawed Steam Generator Tubes," United States Nuclear Regulatory Commission, Washington, D.C., August 2000.
5. Westinghouse Letter LTR-SGDA-05-102, "Waterford 3 Sentinel Plugs Description & leak Rate," R. F. Keating, May, 11, 2005.
6. Westinghouse Calculation Note CN-SGDA-03-59, Revision 0, "Waterford-3, Basis for 3/4" Westinghouse Ribbed Mechanical Plug for 3716 Mwt Uprate."
7. WCAP-12299, Revision 1,"Alloy 690 Tapered Mechanical Plug Summary Qualification Report," December 1989

To address engineering concerns associated with tube wear in the Waterford 3 steam generators (SGs), a number of mechanical "rolled" and "ribbed" plugs are to be installed. Several of these plugs are of the sentinel "ribbed" plug type, so designated because of their role in alerting the plant operators to the potential for large primary-to-secondary leak associated with tube wear. Previously, the sentinel "rolled" plug description and leak rate for use at Waterford 3 was discussed in Reference 5. This letter is addressing the use of the sentinel "ribbed" plug for Waterford 3.

The sentinel "ribbed" mechanical plug is a modification of the standard "ribbed" mechanical plug which has been evaluated and qualified for use at Waterford 3 (Reference 6). The test program for the qualification of the "ribbed" mechanical plug is documented in WCAP-12299 (Reference 7). The sentinel "ribbed" plugs are fabricated from the standard "ribbed" tube plugs, e.g., Reference 1, except that a small hole, [ ]^{a,c,e} in diameter, is machined thru the pressure boundary to permit a controlled leakage in the event the tube wall becomes perforated. The qualification of the standard "ribbed" mechanical plug is directly applicable to the sentinel "ribbed" mechanical plug.

The sentinel "ribbed" plug is depicted on outline Drawing 1B81639 (Reference 2). The sentinel "ribbed" plug hole details are shown on 1B81638 (Reference 3).

The historical philosophy for the use of sentinel plugs has been to box or fence tubes that have already been plugged and may be susceptible to further wear to the extent they become separated and begin to wear on a neighboring tube. If the neighboring tube is simply plugged, the plant operator would not receive knowledge of the tube activity. By putting a small hole in the plug, if the neighboring tube becomes worn all the way through the wall, the controlled primary-to-secondary leak provides notice during the operation of the plant. The controlled leak rate is significant and perforation of a single tube with a sentinel plug would be expected to result in the plant being shut down to investigate the condition of the tube bundle.

The Westinghouse sentinel plugs for use at Waterford 3 have a nominal [ ]^{a,c,e} diameter hole [ ]^{a,c,e}. The same parameters that were provided in Reference 5 for the "rolled" sentinel mechanical plug are used to calculate the leak rate for the "Ribbed" sentinel mechanical plugs. The leak rate in gallons per minute, Q is given by,

[

]^{a,c,e} The expected leak rate through the hole in a single plug is [ ]^{a,c,e} if the parent tube becomes perforated.

If there are any questions please contact the undersigned.

James X. Jenko
Steam Generator Design and Analysis

Verified by:

Michael J. Sredzienski
Nuclear Component Engineering

Verified by:

Pete A. Stancampiano
Steam Generator Design and Analysis

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CE POWER SYSTEMS

CDCC#54575

NUCLEAR POWER SYSTEMS

COMBUSTION ENGINEERING, INC.
COMPONENTS ENGINEERING
Chattanooga, Tennessee

E-2005

TUBES AND TUBE SUPPORTS

SS-113	74270
CALCULATION NO.	CONTRACT NO.
LOUISIANA	STEAM GENERATOR
CUSTOMER	COMPONENT

L. D. Cliff	Structural Engineer	8/18/75
PREPARED	TITLE	DATE
D. G. Clark	Structural Engineer	8/29/75
CHECKED (Full Review)	TITLE	DATE
P. L. Anderson	Supervisor	8-29-75
REVIEWED	TITLE	DATE
[signature]	Manager	9-2-75
APPROVED	TITLE	DATE

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ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-113
SHEET 1 OF 117
CHARGE NO. 74270
DATE 7-21-75 BY [signature]
DESCRIPTION TUBES AND TUBE SUPPORTS
CHECK DATE 7-21-75 BY [signature]

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DESCRIPTION TUBES AND TUBE SUPPORTS

NUMBER SS-113
SHEET 2 OF 117
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1. ABSTRACT

This analysis presents the structural and fatigue evaluation of the tubes and tube supports. Stresses considered are those resulting from pressure, fluid flow, vibration and thermal conditions.

This analysis is made in accordance with the 1971 ASME Boiler and Pressure Vessel Code, Section III for Nuclear Vessels and includes addenda through Summer 1971.

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

NUMBER SS-113

SHEET 47 OF 117

DATE 7-21-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

NUMBER 55-113

SHEET 48 OF 117

DATE 7-21-75 BY Cliff

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

DESCRIPTION TUBES AND TUBE SUPPORTS

NUMBER SS-113

SHEET 50 OF 117

DATE 7-21-75 BY [illegible]

CHECK DATE 8-19-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74770

TUBES AND TUBE SUPPORTS

NUMBER SS-113
SHEET 51 OF 117
DATE 7-21-75 BY [illegible]
CHECK DATE 8-19-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74770

NUMBER SS-113

SHEET 53 OF 117

DATE 7-21-75 BY Cliff

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

NUMBER SS-113

DATE 7-21-75 BY Clif

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

DESCRIPTION TUBES AND TUBE SUPPORTS

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DATE 7-21-75 BY [illegible]

CHECK DATE 8-19-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

DESCRIPTION TUBES AND TUBE SUPPORTS

NUMBER SS-113

SHEET 56 OF 117

DATE 7-21-75 BY Cliff

CHECK DATE 8-19-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

NUMBER SS-113

SHEET 59 OF 117

DATE 7-15-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

NUMBER SS-113

SHEET 67 OF 117

DATE 7-21-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

NUMBER SS-113

SHEET 69 OF 117

DATE 7-21-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 55-113

SHEET 70 OF 117

CHARGE NO. 74270

DATE 7-21-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

NUMBER SS-113

SHEET 72 OF 117

DATE 7-21-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

NUMBER SS-113

SHEET 74 OF 117

DATE 7-21-75 BY [illegible]

TUBES AND TUBE SUPPORTS CHECK DATE 8-19-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-113

SHEET 75 OF 117

CHARGE NO. 74270

DATE 7-21-75 BY [illegible]

CHECK DATE 8-19-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-113

SHEET 77 OF 117

CHARGE NO. 74370

DATE 7-21-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

NUMBER SS-113

SHEET 80 OF 117

DATE 7-21-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

NUMBER SS-113

SHEET 81 OF 117

DATE 7-21-75 BY Cliff

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

NUMBER SS-113

SHEET 83 OF 117

DATE 7-21-75 BY Clift

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

NUMBER SS-113

SHEET 91 OF 117

DATE 7-21-75 BY Cliff

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74770

NUMBER SS-113

SHEET 93 OF 117

DATE 7-21-75 BY Clift

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 7 270

NUMBER SS-113

DATE 7-21-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

NUMBER SS-113

SHEET 99 OF 117

DATE 7-21-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

DESCRIPTION TUBES AND TUBE SUPPORTS

NUMBER SS-113

SHEET 101 OF 117

DATE 7-21-75 BY C.L.

CHECK DATE 8-19-75 BY Fisk

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

DESCRIPTION TUBES AND TUBE SUPPORTS

NUMBER SS-113

SHEET 103 OF 117

DATE 7-21-75 BY GCG

CHECK DATE 8-19-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-113

SHEET 104 OF 117

CHARGE NO. 74270

DATE 7-21-75 BY [illegible]

DESCRIPTION TUBES AND TUBE SUPPORTS

CHECK DATE 8-19-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

DESCRIPTION PIPES AND PIPE SUPPORTS

NUMBER SS-113

SHEET 105 OF 117

DATE 7-21-75 BY [signature]

CHECK DATE 8-19-75 BY [signature]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-113

SHEET 108 OF 117

CHARGE NO. 74770

DATE 7-21-75 BY [illegible]

DESCRIPTION TUBES AND TUBE SUPPORTS

CHECK DATE 9-19-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74270

TUBES AND TUBE SUPPORTS

NUMBER SS-113

SHEET 111 OF 117

DATE 7-21-75 BY [illegible]

CHECK DATE 8-19-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER SS-113

SHEET 115 OF 117

CHARGE NO. 74270

DATE 7-21-75 BY [illegible]

DESCRIPTION TUBES AND TUBE SUPPORTS

CHECK DATE 8-19-75 BY [illegible]

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT. CHATTANOOGA. TENN.

NUMBER SS-113

SHEET 116 OF 117

CHARGE NO. 74770

DATE 7-21-75 BY GMA

TUBES AND TUBE SUPPORTS

CHECK DATE 8-19-75

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COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. 74770

DESCRIPTION TUBES AND TUBE SUPPORTS

NUMBER SS-113

SHEET 117 OF 117

DATE 7-21-75 BY [illegible]

CHECK DATE 8-19-75 BY [illegible]

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Attachment 4
To
W3F1-2007-0010

Westinghouse Affidavit Regarding Proprietary Information

Westinghouse

Westinghouse Electric Company
Nuclear Services
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355
USA

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555-0001

Direct tel: (412) 374-4643
Direct fax: (412) 374-4011
e-mail: greshaja@westinghouse.com

Our ref: CAW-07-2246

February 19, 2007

APPLICATION FOR WITHHOLDING PROPRIETARY
INFORMATION FROM PUBLIC DISCLOSURE

Subject: LTR-SGDA-06-221-P, "Effect of Multiple Batwing Failure on Thermal Hydraulics at Waterford 3 Steam Generators with 3716 MWt Power Uprate and 20% SGTP (Proprietary)," et al See Table 1 (page 5)

The proprietary information for which withholding is being requested in the above-referenced reports is further identified in Affidavit CAW-07-2246 signed by the owner of the proprietary information, Westinghouse Electric Company LLC. 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 2.390 of the Commission's regulations.

Accordingly, this letter authorizes the utilization of the accompanying affidavit by Entergy Corporation.

Correspondence with respect to the proprietary aspects of the application for withholding or the Westinghouse affidavit should reference this letter, CAW-07-2246, and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

B. F. Maurer, Acting Manager
Regulatory Compliance and Plant Licensing

Enclosures

cc: Jon Thompson (NRC O-7E1A)

bcc: J. A. Gresham (ECE 4-7A) 1L
R. Bastien, 1L (Nivelles, Belgium)
C. Brinkman, 1L (Westinghouse Electric Co., 12300 Twinbrook Parkway, Suite 330, Rockville, MD 20852)
RCPL Administrative Aide (ECE 4-7A) 1L (letter and affidavit only)
G. W. Whiteman, Waltz Mill
J. M. Hall, Waltz Mill
P. R. Nelson, Waltz Mill

CAW-07-2235

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

ss

COUNTY OF ALLEGHENY:

Before me, the undersigned authority, personally appeared B. F. Maurer, 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 Company LLC (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:

B. F. Maurer, Acting Manager
Regulatory Compliance and Plant Licensing

Sworn to and subscribed before me
this 19th day of February, 2007

Notary Public

COMMONWEALTH OF PENNSYLVANIA
Notarial Seal
Sharon L. Markle, Notary Public
Monroeville Boro, Allegheny County
My Commission Expires Jan. 29, 2011
Member, Pennsylvania Association of Notaries

(1) I am Acting Manager, Regulatory Compliance and Plant Licensing, in Nuclear Services, Westinghouse Electric Company LLC (Westinghouse), 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 rule making proceedings, and am authorized to apply for its withholding on behalf of Westinghouse.

(2) I am making this Affidavit in conformance with the provisions of 10 CFR Section 2.390 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 Westinghouse 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 2.390 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 that 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 10 CFR Section 2.390, 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 the documents listed in Table 1 below. These documents are for submittal to the Commission and are being transmitted by Entergy Corporation Application for Withholding Proprietary Information from Public Disclosure to the Document Control Desk. The proprietary information as submitted for use by Westinghouse for Waterford Unit 3 is expected to be applicable to other licensee activities related to the acceptability of remedial actions taken to address subsequent plant operation with degradation occurring in the secondary side of steam generators. These documents are being provided in response to an NRC request to review Westinghouse proprietary documents generated during the Waterford Unit 3 RF13 and RF14 outages associated with steam generator batwing failures.

Table 1 List of Documents with Proprietary Information (each dated February 2007)	
Letter Number	Title
LTR-SGDA-06-221-P	Effect of Multiple Batwing Failure on Thermal Hydraulics at Waterford 3 Steam Generators with 3716 MWt Power Uprate and 20% SGTP (Proprietary)
09720-PE-120-R7-P, Rev. 7	Project Specification for Steam Generator Assemblies for Waterford Unit No. 3 (Proprietary)
SS-113-74270-P	Tubes and Tube Supports (Proprietary)
LTR-SGDA-05-107-P	Westinghouse Review of Waterford III Steam Generator Manufacturing Records (Proprietary)
LTR-SGDA-06-228-P, Rev. 0	Waterford 3 Batwing Upper Weld Evaluations in Support of the RF14 Outage (Proprietary)
LTR-SGDA-06-228-P, Rev. 1	Waterford 3 Batwing Upper Weld Evaluations in Support of the RF14 Outage (Proprietary)
LTR-SGDA-06-199-P, Rev. 1	Evaluation of the Effect of Failed Batwings at Waterford 3 Operating at 3716 MWt Uprated Conditions with up to 20% Steam Generator Tube Plugging (Proprietary)
LTR-SDGA-06-240-P	Evaluation of Potential Secondary Side Loose Parts Resulting from Batwing Welding and the Effects of Increased Tube Temperatures in Waterford 3 Steam Generators (Proprietary)
LTR-SGDA-06-243-P, Rev. 1	Input to the Preliminary OA to Address Detached Batwings in the Waterford 3 Steam Generators (Proprietary)
LTR-SGDA-06-248-P	Waterford 3 Sentinel "Ribbed' Mechanical Plugs – Description and Leak Rate (Proprietary)
LTR-SGDA-06-229-P	Waterford 3 Steam Generator Stability Ratios and Turbulent Amplitudes for Tube Rows in the Central Cavity Without Batwing Support (Proprietary)
LTR-SGDA-06-181-P, Rev. 1	Effect of Multiple Batwing Failure on Thermal Hydraulics at Waterford 3 Steam Generators with Power Uprate and 20% SGTP (Proprietary)
LTR-SGDA-06-225-P	Evaluation of Steam Line Break Accident Condition Affecting Degraded Batwings at Waterford 3 (Proprietary)
LTR-SGDA-06-238-P	Tube-Batwing Contact Force Attenuation Results for Degraded Batwings at Waterford 3 (Proprietary)
LTR-SGDA-06-236-P, Rev. 2	Evaluation of Upper Weld Clip and Attachment Welds to Batwing for Waterford 3 Steam Generators (Proprietary)
CN-SGDA-05-36-P, Rev. 1	Evaluation of Degraded Batwing Tube Supports in the Waterford 3 Steam Generators at 3716 MWt Power Uprate Conditions (Proprietary)
CN-SGDA-06-89-P	Evaluation of the Loose Part in the Secondary Side of Waterford Unit 3 – Model 70 OSG Steam Generator – Fall 2006 Outage (Proprietary)

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

(a) Provide documentation of the analyses, methods, and remedial actions (e,g, tube plugging and stabilization) taken to support plant operation with degradation occurring in the secondary side of steam generator components.

(b) Assist the customers in obtaining NRC approval of remedial actions taken to support subsequent action with degradation occurring in the secondary side of steam generator components.

Further this information has substantial commercial value as follows:

(a) Westinghouse plans to sell the use of similar information to its customers for the 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 calculation, evaluation 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.

Further the deponent sayeth not.

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 2.390 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) 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 2.390(b)(1).

COPYRIGHT NOTICE

Entergy Corporation

Letter for Transmittal to the NRC

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

Enclosed is one copy each of the Proprietary Class 2 (-P) and Non-Proprietary Class 3 (-NP) versions of the documents identified in Table 2 below:

Table 2 List of Documents with Westinghouse Proprietary Class 2 and Non-Proprietary Class 3 Information (each dated February 2007)	
Letter Number	Title
LTR-SGDA-06-221-P, -NP	Effect of Multiple Batwing Failure on Thermal Hydraulics at Waterford 3 Steam Generators with 3716 MWt Power Uprate and 20% SGTP (Proprietary/Non-Proprietary)
09720-PE-120-R7-P, -NP, Rev. 7	Project Specification for Steam Generator Assemblies for Waterford Unit No. 3 (Proprietary/Non-Proprietary)
SS-113-74270-P, -NP	Tubes and Tube Supports (Proprietary/Non-Proprietary)
LTR-SGDA-05-107-P, -NP	Westinghouse Review of Waterford III Steam Generator Manufacturing Records (Proprietary/Non-Proprietary)
LTR-SGDA-06-228-P, -NP, Rev. 0	Waterford 3 Batwing Upper Weld Evaluations in Support of the RF14 Outage (Proprietary/Non-Proprietary)
LTR-SGDA-06-228-P, -NP, Rev. 1	Waterford 3 Batwing Upper Weld Evaluation in Support of the RF14 Outage (Proprietary/Non-Proprietary)
LTR-SGDA-06-199-P, -NP, Rev. 1	Evaluation of the Effect of Failed Batwings at Waterford-3 Operating at 3716 MWt Uprated Conditions with up to 20% Steam Generator Tube Plugging (Proprietary/Non-Proprietary)
LTR-SDGA-06-240-P, -NP	Evaluation of Potential Secondary Side Loose PartsResulting from Batwing Welding and the Effects of Increased Tube Temperatures in Waterford 3 Steam Generators (Proprietary/Non-Proprietary)
LTR-SGDA-06-243-P, -NP, Rev. 1	Input to the Preliminary OA to Address Detached Batwings in the Waterford 3 Steam Generators (Proprietary/Non-Proprietary)
LTR-SGDA-06-248-P, -NP	Waterford 3 Sentinel "Ribbed' Mechanical Plugs – Description and Leak Rate (Proprietary/Non-Proprietary)
LTR-SGDA-06-229-P, -NP	Waterford 3 Steam Generator Stability Ratios and Turbulent Amplitudes for Tube Rows in the Central Cavity Without Batwing Support (Proprietary/Non-Proprietary)
LTR-SGDA-06-181-P, -NP, Rev. 1	Effect of Multiple Batwing Failure on Thermal Hydraulics at Waterford 3 Steam Generators with Power Uprate and 20% SGTP (Proprietary/Non-Proprietary)
LTR-SGDA-06-225-P, -NP	Evaluation of Steam Line Break Accident Condition Affecting Degraded Batwings at Waterford 3 (Proprietary/Non-Proprietary)
LTR-SGDA-06-238-P, -NP	Tube-Batwing Contact Force Attenuation Results for Degraded Batwings at Waterford 3 (Proprietary/Non-Proprietary)
LTR-SGDA-06-236-P, -NP, Rev. 2	Evaluation of Upper Weld Clip and Attachment Welds to Batwing for Waterford 3 Steam Generators (Proprietary/Non-Proprietary)
CN-SGDA-05-36-P, -NP, Rev. 1	Westinghouse Evaluation of Degraded Batwing Tube Supports in the Waterford 3 Steam Generators at 3716 MWt Power Uprate Conditions (Proprietary/Non-Proprietary)
CN-SGDA-06-89-P, -NP	Evaluation of the Loose Part in the Secondary Side of Waterford Unit 3 – Model 70 OSG Steam Generator – Fall 2006 Outage (Proprietary/Non-Proprietary)

Also enclosed is Westinghouse authorization letter CAW-07-2246 with accompanying affidavit, Proprietary Information Notice, and Copyright Notice.

As the documents listed in Table 2 contain information proprietary to Westinghouse Electric Company LLC, it is supported 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 2.390 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 2.390 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-07-2246 and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.