**BW B&W NUCLEAR TECHNOLOGIES**

**ENGINEERING INFORMATION RECORD**

Document Identifier 51-1239602NP-00

Title Point Beach 2 Repair Roll Qualification

| PREPARED BY: | | REVIEWED BY: | |
|---|---|---|---|
| Name W.D. Belden | | Name E B Polstra | |
| Signature [signature] | Date 11-13-95 | Signature [signature] | Date 11-14-95 |

Technical Manager Statement: Initials [initials]

Reviewer is Independent.

Remarks:

This document summarizes the qualification of a tube roll repair process to repair tubes with defects within the tubesheet region of the steam generators at Point Beach 2. This document is the non-proprietary version of 51-1239602-00.

## RECORD OF REVISION

| Revision | Section | Description |
|---|---|---|
| 00 | All | Original Release |

TABLE OF CONTENTS

## TABLE OF CONTENTS-CONTINUED



## LIST OF TABLES



## LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| PWSCC | Primary Water Stress Corrosion Cracking |
| PB-2 | Point Beach 2 |
| IP-2 | Indian Point 2 |
| SCC | Stress Corrosion Cracking |
| ECT | Eddy Current Testing |
| IGA | Inter-granular Attack |
| SAI | Single Axial Indications |
| MAI | Multiple Axial Indications |
| RPC | Rotating Pancake Coil |
| F* | F Star |
| NDE | Nondestructive Examination |
| ID | Inner Diameter |
| OD | Outer Diameter |
| 2D | Two Dimensional |
| 3D | Three Dimensional |
| EFPY | Effective Full Power Year |
| RFO | Refueling Outage |

## 1.0 INTRODUCTION

### 1.1 Background

Eddy current inspection of steam generator tubes at Point Beach 2 during RFO U2R21 has resulted in the detection of numerous indications within the tubesheet region. These indications are predominantly identified as single or multiple axial indications (SAI or MAI) which require repair or plugging per the current plant technical specification. The indications are characterized as OD initiated intergranular attack (ODIGA) and OD stress corrosion cracks (ODSCC). Some indications have been characterized as IDSCC in the existing tube roll transitions.

Such indications represent well documented degradation mechanisms in RSGs. The occurrence of secondary side intergranular corrosion has been strongly correlated with the accumulation of sludge within the tubesheet crevice which is aggravated by the potential concentration of caustic from secondary system chemistry coupled with the boiling crevice conditions. IDSCC occurs in susceptible alloy 600 material under the combined action of primary water, elevated temperature, and sustained tensile stresses which exist in the roll transition region of the tubes.

The number of tubes with indications detected at PB-2 is such that removing all of them from service would produce unacceptable primary coolant flow rate through the steam generators. Thus, a repair method is required to maintain the maximum number of tubes in service for continued operation. One such repair method is to perform a tube roll expansion (repair roll) within the tubesheet bore above the existing degraded location.

### 1.2 Purpose

The purpose of this document is to provide a technical justification to implement a tubesheet region repair roll in degraded steam generator tubes at Point Beach 2. A re-roll or repair roll which is installed above the degraded region of tubing provides a frictional joint of undegraded tubing within the tubesheet bore, creating a new primary pressure boundary within the tube. The structural aspects of the repair must be demonstrated in accordance with NRC Regulatory Guide 1.121, by establishing an engagement distance sufficient to withstand the greater of 3 times normal operating differential pressure or 1.43 times the worst faulted condition differential pressure. This engagement length is typically referred to as F* and conservatively assumes the tube can sever immediately below the F* rolled region. The leakage associated with the roll repair must also meet requirements for maintaining plant leakage within technical specification limits.

## 1.3 Organization of Report

This report provides a description of the intended repair roll design for Point Beach 2. A verification of the design is presented through evaluation against [ c

]. Consideration of differences between the [ c ] is included in the overall determination of an appropriate F*/repair roll distance for Point Beach 2.

## 2.0 EXECUTIVE SUMMARY

Eddy current inspection of steam generator tubes at Point Beach Unit 2 during RFO U2R21 has revealed numerous tubes with indications within the tubesheet region. These indications have been characterized as axial defects which exceed the current plugging limit for the tubes. The indications have been predominantly attributed to corrosion attack in the crevice region between the tube and tubesheet. Some defects are also associated with stress corrosion cracking of the tube roll transitions.

A process has been developed to repair these tubes, allowing them to remain in service. This tube repair roll process consists of creating a new, mechanical tube to tubesheet structural joint above the region of tube defects.

This type of repair [ c

].

The qualification of the mechanical joint is based on establishing a mechanical roll length, F*, which will carry all of the structural loads imposed on the tubes. A series of tests and analyses were performed to establish this length. Tests that were performed included leak, tensile, locked tube, fatigue, ultimate load, and eddy current measurement uncertainty. The analyses evaluated plant operating and faulted loads in addition to tubesheet bow effects.

The final required repair roll length was determined to be [c] which includes [c] for ECT uncertainty. However, the field process has been set to deliver a [c] nominal length ([c] minimum), for conservatism. The operational leak rates for 2000 repaired tubes is expected to be less that [ c ] GPD.

It is known that the tubes are susceptible to stress corrosion, thus the new roll transitions will eventually exhibit defects, as the existing roll transitions have. However, as experience at Point Beach 2 has shown, these defects are axial in nature and can be readily detected by eddy current inspection. Thus, there are no new safety issues with this repair.

## 3.0 REPAIR ROLL DESCRIPTION

### 3.1 Design

The roll joint consists of installing [c] roll expansions in the region of unexpanded tubing above the degraded section within the tubesheet. [ c ]. The pertinent aspects of the repair roll design are the same as a previously qualified design [8.3]. [ c ]. Figure 3.1 provides a sketch of the repair roll.

The objective of the [ c ] roll is to achieve a [ c ] inch effective expansion above any defects to satisfy F* requirements [8.2 & 8.11]. The field process nominal installation length for the repair roll is [ c ].

### 3.2 Installation

The repair roll is performed remotely using a manipulator and a standard plugging or sleeving type tool head. A control system is used to position and install the new roll expansion. The required torque is [ c ].

### 3.3 Process Verification

Standard pre-repair roll eddy current techniques are used to identify candidate tube locations for repair and determine where the uppermost defect is located. After repair roll installation, bobbin profilometry or equivalent techniques are used to generate a plot which identifies the new roll expansion and roll length with respect to the existing defect and required F*. These techniques are also used to verify that there are no defects in the F* region.

**Figure 3.1 Tube Repair Roll Sketch**

[

c

]

## 4.0 DESIGN REQUIREMENTS

### 4.1 General

The US NRC Regulatory Guide 1.121 [8.5] and the ASME Boiler and Pressure Vessel Code [8.6] prescribe safety factors of 3 on normal operating and 1.43 on faulted condition differential pressure, respectively. These factors provide the basis for establishing a suitable F* repair length at Point Beach 2 [8.2].

The repair roll shall be of sufficient length such that the expansion alone (without any support from the original tube expansion and weld below) provides the necessary structural strength to satisfy the normal and faulted tube loadings.

In addition, the roll shall provide a mechanical seal between the existing tube and tubesheet above the degraded region. The new joint shall provide leak limiting capability, assuming a full 360° circumferential sever immediately below the new roll region. Leakage must be maintained well below the technical specification limits for [ c ]. The technical specification leakage limit at Point Beach 2 is 500 GPD (0.35 GPM) for both steam generators.

### 4.2 Design and Operational Loading Conditions

A conservative set of design and operational loading conditions for the Point Beach 2 steam generators is provided in Table 4.1 [8.1]. [ c

] are included in parentheses where they differ from Point Beach 2.

### 4.3 Repair Life

The life of the repair roll should be evaluated for potential future degradation based on the nature of the identified tube damage mechanisms.

Table 4.1 Point Beach 2 (W-44 Series) Performance Characteristics

[

c

]

## 5.0 DESIGN VERIFICATION

The design verification as described in this section develops the Point Beach 2 specific required F* length for the repair roll. This development begins by comparing the design and operating conditions for Point Beach 2 to those of Indian Point 2. A summary of the analysis methodology and results is provided which includes comparisons of the results for the two plants based on the differences used to bound operating and faulted conditions. Additionally, a summary of the F* and repair roll testing is provided which supports the analysis in determining the final F* length. The process NDE requirements follow which describe the necessary post-repair roll verification actions and provide a review of previous testing methods and associated uncertainties.

### 5.1 Comparison of Point Beach 2 and Indian Point 2

#### 5.1.1 Steam Generator Design

The steam generators at both PB-2 and IP-2 are Westinghouse Series 44 steam generators. All of the critical physical design characteristics and materials of construction are equivalent and are summarized in Figure 5.1 [8.1].

#### 5.1.2 Design and Operating Conditions

The performance characteristics of PB-2 and IP-2 are identified in Table 4.1. The key factors that affect the F* or repair roll length are:

[

c

]

The pressure differentials are used in the analysis to calculate the loads and stresses imposed on the tubes during normal, faulted, and locked tube conditions. The calculated loads are then multiplied by the applicable safety factors as described in Section 4.1.

The primary inlet, outlet, and steam temperatures factor into the analysis by determining the effect on the preload strength as a result of the expansion differences between the tube and tubesheet. In addition, these temperatures also factor into the joint loading effects associated with tubes which potentially become locked within support plates.

**Figure 5.1 W-44 General Arrangement**

[

c

]

5.2 Analysis

5.2.1 F* Review

[ c

] F* length necessary to sustain operating and faulted condition loads. Because all the F* qualification testing was done at room temperature, the results of the testing must be adjusted to actual steam generator (SG) operating temperature and pressure conditions. An equation was derived to relate the results of room temperature testing to the (SG) operating conditions based on standard stress equations. The equation for F* length is derived by beginning with a relationship which defines the pull-out load for the outer surface of the rolled joint between the tube OD and tubesheet bore. This pull-out load equation is defined as:

[

c

]

[

c

]. The analysis results are summarized in Table 5.2.1.

**Table 5.2.1 Comparison of Analysis Results**

[

c,d

]

Based on review of the results from Table 5.2.1, the following observations are provided:

[

c

]

### 5.2.2 Tubesheet Bow

The effect of tubesheet bow, as previously mentioned, is accounted for in the results of Table 5.2.1. Tubesheet bow tends to negate some of the joint holding force (radial stress) inherent from the rolling process, pressure tightening effects through hoop loading, and thermal tightening effects based on expansion differences of the tube and tubesheet materials. This reduction in radial stress is the result of tubesheet bore hole dilation caused by flexure of the tubesheet under a primary-to-secondary differential pressure.

[

c

].

### 5.2.3 Summary

The analysis of the PB-2 operating conditions shows that the IP-2 analysis [ c ]. This is true because the limiting PB-2 operating condition for determining F* is [ c ]. Also, the test loads utilized in the IP-2 qualification [ c ] the normal, faulted, and locked tube conditions of PB-2. In terms of application, the repair roll at PB-2 can be applied up to [ c ] and is supported by analysis [8.8].

## 5.3 Testing

Mechanical tests were performed during the IP-2 F* qualification to evaluate various F* lengths at room temperature conditions. The test data was then corrected by the analysis to obtain the final F* length for operating conditions as described in Section 5.4.

Tests performed consisted of leak and load testing, pressure and thermal cycling, and ultimate load tests. Normal operation, faulted, and locked tube conditions were simulated during testing. A total [ c ] tested [8.2].

The applicability of the testing for PB-2 consists of evaluating the operating pressure differentials to determine their effects on the leak and load test conditions. The PB-2 normal condition pressure differential is [ c

]. Comparing the leak test conditions shows that the normal operating test pressure [ c

]. The faulted leak test pressure [
c ].

### 5.3.1 Leak Testing

The leak testing [ c

]. If the initial average leak rate is conservatively applied to 500 tube ends in each channel head of the two Point Beach 2 steam generators (2000 total tube ends), the total leak rate would [ c
]. The leak testing [ c

] if applied to the 2000 tube ends.

### 5.3.2 Tensile Testing

A load application test was performed using the greater of the Reg. Guide 1.121 or ASME prescribed loads. As shown in Table 5.2.1, [ c ]. The load actually used [ c
]. All of the specimen's roll joints [ c
] the test load.

5.3.3 Locked Tube Test

A second test was performed to evaluate locked tube loads. For this test the tube [ c

]. All of the specimens tested supported the locked tube load.

5.3.4 Fatigue Test

Pressure cycling was performed [ c

]

5.3.5 Ultimate Load Test

The final test performed was an ultimate load test where the tube joints [ c

] The final pullout loads were used to establish the F* length as discussed in Section 5.4.

5.3.6 Summary

Review of all tests performed shows that the key critical parameter for test applicability [

c

].

## 5.4 Point Beach 2 F* Length Determination

As described in Section 5.2, the room temperature testing is adjusted for operating/faulted conditions under which the F* criteria will be applied. [ c

] Using the numbers from Table 5.2.1 the equations simplify as follows:

[

c

]

**Table 5.4.1 Comparison of F* Lengths**

[ d

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

]

5.5 Non-Destructive Examination Requirements

The final F* criteria that is developed for PB-2 must also be inspectable using standard steam generator eddy current techniques. Post-repair roll bobbin profiles are required to verify expansion, show the new roll transition(s), and provide measurements of the new undegraded roll length for evaluation against F*. Measurement tolerances associated with remote eddy current measurements must be factored into the final F* value. Bobbin and RPC eddy current methods were both used to verify the accuracy and uncertainty in determining F* lengths in 7/8" tubing [8.2]. This testing was performed to determine the error associated with the NDE method that will be used in the steam generator to define the actual locations of the defect and the roll transition.

Analysis was performed to determine the distance from the bottom end of the upper roll transition to the simulated F* sever. Each eddy current pull was analyzed two times, and a total of five analysts examined the data for an independent review and to determine differences among analysis techniques. [ c

]. Therefore, the final F* length for Point Beach 2 is:

[ c

]

The ability to detect the new roll transitions in the presence of crevice sludge and defects was also investigated [8.3]. The results [ c

].

## 6.0 EVALUATION OF REPAIR ROLL LIFE

### 6.1 Tube Integrity in Repair Roll

The tube degradation mechanisms at Point Beach 2 have been characterized as ID PWSCC and OD IGA. These degradation mechanisms in the elevated stress regions associated with a roll transition can potentially limit the life of the repair roll.

Non-destructive eddy current examinations, laboratory examinations of pulled tube samples, and accelerated corrosion tests have all shown that PWSCC will occur in the roll transitions of alloy 600 tubing. An evaluation of PWSCC was performed which optimistically predicts the new roll transition will last as long as the original roll transition while pessimistic projections indicate cracks initiating within 2 EFPY [8.3]. [ c

].

Point Beach Units 1 and 2 use once-through cooling and initially, both units operated on phosphate water chemistry. Evaluation of leachate from tubesheet crevices at Point Beach indicate that the impurities in the crevices were moderately alkaline forming. Examinations of removed tubes have indicated that caustic conditions caused, or at least initiated, IGA/SCC in tubesheet crevices. However, it is possible that caustic conditions were present during an early phosphate water chemistry period during which IGA/SCC initiated, and that the IGA/SCC then propagated under less alkaline conditions during AVT water chemistry.

Laboratory tests indicate that tensile stresses accelerate the rate of SCC, and moderately affect the rate of IGA. The operating temperature can also affect the corrosion rate in the roll transitions. For example, intergranular corrosion tends to occur mainly in the elevated temperature region of the hot leg versus the cold leg. This is evidenced at Point Beach Unit 1, where a reduction in hot leg temperature from 597F to 557F dramatically reduced the number of detected new defects. Therefore, the presence of the high stress area in the new roll transition, along with the high hot leg temperature (599F) do increase the possibility of OD intergranular corrosion [8.7]. [ c
].

In conclusion, a realistic prediction for time to cracking [

c

].

## 6.2 Tube Integrity Below the Repair Roll

[ c

], may promote "Obrigheim" denting of the tubes at some point in the future. The phenomena of "Obrigheim" denting occurs when an annular space around the tube OD fills with water which is not allowed to escape during plant heatup. The trapped water may be the result of a restricted path that becomes completely sealed by the difference in expansion characteristics between the tube and tubesheet. During heatup, the trapped water expands creating a dent in the tube large enough to reduce the yielding pressure.

[ c

].

## 7.0 CONCLUSIONS

The design verification of a tubesheet repair roll for PB-2 has been [ c ]. This evaluation has shown that application of a tubesheet region repair roll at Point Beach 2 [ c ]. The following conclusions are also provided.

- A total PB-2 F* length of [ c ] is structurally adequate to satisfy all of the loading requirements for the NRC Regulatory Guide 1.121 and the leakage limits of the Point Beach 2 technical specification. This F* length is [ c ].

- The qualification [ c ] during potential future roll transition crack initiation.

- Normal operating condition pressure differential leakage rates are expected to be well within the plant normal operating technical specification leakage limits of 500 GPD. If 1000 tube ends per generator were repaired, the amount of expected leakage would be less than [ c ] under normal operating conditions.

- The RPC and visual inspections performed [ c ].

- The new roll transition area of a field repair roll joint may develop PWSCC or OD initiated intergranular attack at some point in the future. However, ECT inspections of repair rolled tubes during subsequent PB-2 outages will detect any cracks before they can cause significant primary to secondary leakage with respect to the plant's administrative and technical specification limits.

- A summary of the recommended design parameters for a field implemented repair roll joint is as follows:

  [ c

  ]

## 8.0 REFERENCES


8.1 BWNT Doc. 51-1239600-00, "Technical Requirements for Point Beach 2 F*/Roll Length Qualification". **PROPRIETARY**

8.2 BWNT Doc. 43-10195P-01, "W-44 F* Qualification Report". **PROPRIETARY**

8.3 BWNT Doc. 51-1232768-00, "Indian Point 2 Re-Roll Design Verification Report". **PROPRIETARY**

8.4 BWNT Doc. 32-1239608-00, "Point Beach Unit 2 F* Calculations". **PROPRIETARY**

8.5 NRC Regulatory Guide 1.121 (Draft), "Bases for Plugging Degraded PWR Steam Generator Tubes".

8.6 "ASME Boiler and Pressure Vessel Code", Section III, Subsection NB and Division I Appendices, 1989 Edition.

8.7 EPRI TR-103824, "Steam Generator Reference Book", December 1994.

8.8 BWNT Doc. 32-1228961-02, "F* Calculation for W-44 RSG's". **PROPRIETARY**

8.9 "3D Elastostatic Thermal-Structural Analysis of the Tubesheet in a U-tube Heat Exchanger and Consequent Flexibility Analysis of Typical U-tubes", Y.S. Garud and K.E. Watkins, 11th International Conference on Structural Mechanics in Reactor Technology, February 1991.

8.10 "Experience and Status on Primary System Components After 15 Years of Operation in the Nuclear Power Plant Obrigheim", H. Schenk, E. Pickel, and R. Bartsch, Nuclear Engineering and Design, 1984.

8.11 NRC SER "Issuance of Amendment for Indian Point Nuclear Generating Unit No. 2 (TAC No. M89373)", Docket 50-247, Ammendment 180, March 13,1995.