NSD-E-SGDA-99-349
SG-99-10-002

FROM: Steam Generator Design & Analysis
WIN: 224-5694
DATE: 10/05/1999
SUBJECT: Presentation Materials on Laser Welded Sleeve Code Compliance (Non-Proprietary Class 3)

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Attached please find a copy of the non-proprietary presentation materials used during the September 30 meeting with the NRC dealing with the issue of Laser Welded Sleeve Code Compliance. If you have questions, please contact the undersigned. By copy of this letter you are requested to forward a copy of the presentation materials to the appropriate parties at the NRC.

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LWS Code Compliance

September 30, 1999

Westinghouse Electric Co.
Nuclear Services Division

Westinghouse Representatives

- Richard Smith - Advanced Technical Engineer: Steam Generator Design and Analysis
  - Tech Lead for LWS WCAP Addendum (Presenter)
- Bob Keating - Consulting Engineer: SG Integrity
- Gary Whiteman - Advanced Technical Engineer: Regulatory and Licensing Engineering
- Warren Bamford - Fellow Engineer: Structural Mechanics Technology
  - ASME Code Section XI Committee Member

Discussion Topics

- Purpose of Meeting
- Background
- ASME Code Design Criteria
- Weld Configuration (Mechanical / Thermal Loads)
- Design Qualification Results (WCAP Addenda)
- NRC Staff Queries / Westinghouse Responses
- LWS Evaluation Summary
- Conclusion (Relative to LWS Qualification)

Purpose of Meeting

- Present Westinghouse response to NRC RAI for Laser Welded Sleeves (LWS)
- Obtain NRC concurrence regarding structural qualification of LWS

Background

- LWS originally designed in 1987 to replace a section of the tube pressure boundary in <u>operating SGs</u>
  - Minimum average weld width established as 15 mils to comply with ASME Code Design by Analysis rules in Section III
  - Minimum local weld width of 15 mils for inspection purposes
- Review of analysis by Westinghouse in 1998 led to the conclusion that Code Design by Analysis criterion for the primary stress limit was not met

Background

- Code compliance demonstrated by test / analysis in 1998 WCAP Addenda

ASME Code Design Criteria

- Potential failure modes and stress categories
  - Primary stress limits to prevent plastic deformation with nominal factor of safety on the ductile burst pressure, e.g., SF of 3 on S_U
  - Primary plus secondary limits to prevent excessive plastic deformation leading to incremental collapse, i.e., ratcheting, and validate elastic fatigue analysis
  - Peak stress controlled to prevent fatigue failure as a result of cyclic loadings (U<1.0)

LWS Weld Configuration

- Shear in the weld resulting from end cap pressure
  - Mechanical load
  - Limiting load occurs when tube is fully severed below weld

a,c

LWS Weld Configuration

- Maximum thermal load occurs in an intact tube, not locked at the TSPs
- Below the weld the tube is at T_S and the sleeve is at T_P giving a bigger ΔT
- Different α's for sleeve and tube

a,c

WCAP-13088, R. 4, Add. 1

- Primary Stress Limit – Design by Test (NB-3649)
  - Primary stress requirement for non-locked tube
    - Demonstration of weld strength by test, i.e., $\geq$ 4800 psi at 650°F (3 ΔP)
  - Burst pressure greater than P_B of weakest link in the pressure boundary system using

$$P_B = \frac{2St}{D_o}$$

WCAP-13088, Add. 1 (Cont.)

- The ASME Code identifies t as the "minimum specified wall thickness of the [weakest] pipe"
  - Since Section XI addresses repair of operating SG, Westinghouse based t on the minimum thickness to meet the Code design requirements
    - In accord with RG 1.121, i.e., $3 \cdot \Delta P_{NOp}$
    - In accord with NEI 97-06

WCAP-13088, Add. 1 (Cont.)

- Burst pressure requirement of 4800 psi (3 x Design Pressure ΔP) established for tests
- Minimum factor of safety in burst tests > 3.5
    - Based on sample where tube failed
- For welds made within field process parameters, tube burst beyond 3 ΔP in 12 of 12 samples - Weld is not the weak link in the system
- Conclusion: ASME design criteria satisfied for Primary Stress

WCAP-13088, Add. 1 (Cont.)

- Maximum Range of Stress Intensity Limit (for repaired tube weld) – Design by Analysis
  - Design requirement: Prevent incremental distortion, e.g., ratcheting to failure
  - Weld implicitly meets $3 \cdot S_m$ because of constraints by the sleeve and the tube
    - Both tube and sleeve remain elastic
    - Loading is displacement controlled
    - Both tube and sleeve fixed at lower end
  - Conclusion: Ratcheting cannot occur / Design requirement satisfied

WCAP-13088, Add. 1 (Cont.)

- Design Requirement for Fatigue - Design by Analysis
  - Design requirement: Fatigue usage < 1.0
  - Full duty cycle of events considered
  - Applicable strength reduction factor applied
  - Calculated usage = [ ]^{a,c} with K_e included)
  - Conclusion: Design requirement satisfied
  - Note: [

]^{a,c}

NRC Staff Queries

- **Does the design of the sleeve installation meet Section III of the ASME B&PV Code?**
  - If the weakest link is the sleeve with a drawing minimum allowed t of [ ]^{a,c} mils, then P_B = 8000 psi

<u>Response</u>:

- The ASME Code does not provide a definition of t, the minimum specified thickness, for this case
- A test pressure objective of 8000 psi results in a factor of safety of 5.0. This is inconsistent with ASME Code design philosophy that is based on a factor of safety of 3.0.

NRC Staff Queries (Cont.)

<u>Response</u>: (Cont.)

- Test results show the weld is stronger than the weakest link
- Westinghouse maintains that the test pressure objective of $\geq$ 4800 psi meets the design criteria of the ASME Code
- The sleeve is installed in tubes in operating plants that may be degraded elsewhere and not removed from service where 3 ΔP criterion of 4800 psi is acceptable

NRC Staff Queries (Cont.)

- **Clarify whether the weld (which is loaded in pure shear) satisfies the $3 \cdot S_m$ requirement of the ASME Code.**

Response:

- The $3 \cdot S_m$ limit is exceeded for three loading cases
- The Code provides the means for acceptance when $3 \cdot S_m$ limit is exceeded
  - Shakedown to elastic action must be assured
  - A K_e factor should be used in the fatigue usage calculation

NRC Staff Queries (Cont.)

Westinghouse (Cont.):

- Shakedown to elastic action is assured by the geometric constraints of the sleeve and tube
- The weld satisfies the fatigue requirements of Section III of the ASME Code
  - With K_e applied, the usage factor, U, is [ ]^{a,c}
- Additional criteria for Simplified Elastic-Plastic Analysis are also satisfied

LWS Evaluation Summary

- The design meets the primary stress requirements of the ASME Code as demonstrated by the burst resistance in excess of $3 \cdot \Delta P_{Design}$
- The design meets the ASME Code requirements for resistance to ratcheting
- The design meets the ASME Code requirements for resistance to fatigue
- The weld is not the weakest link in the pressure boundary system

Evaluation Summary (Cont.)

- The design is for installation in an operating SG for the repair of degraded tubes and falls under the requirements of Section XI
- The direction of Section XI is to consider the actual conditions of the plant as opposed to the original design conditions

Conclusion

- The design of the LWS weld as presented by Westinghouse in WCAP-13088, Revision 4, Addendum 1 and as supplemented herein meets the requirements of the ASME Code for repair of SG tubing in operating plants