TXU Power

TXU Power
Comanche Peak Steam
Electric Station
P. O. Box 1002 (E01)
Glen Rose, TX 76043
Tel: 254 897 5209
Fax: 254 897 6652
mike.blevins@txu.com

Mike Blevins
Senior Vice President &
Chief Nuclear Officer

Ref: GL 2004-01

CPSES-200501652
Log #TXX-05146

August 4, 2005

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

SUBJECT: COMANCHE PEAK STEAM ELECTRIC STATION (CPSES)
UNIT 1, DOCKET NO. 50-445
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION,
RE: CPSES RESPONSE TO GENERIC LETTER 2004-01

REF: 1. TXU Power letter, logged TXX-04182, from Mike Blevins to the U. S. Nuclear Regulatory Commission, dated October 14, 2004.
2. TXU Power letter, logged TXX-05020, from Mike Blevins to the U. S. Nuclear Regulatory Commission, dated February 3, 2005.

Gentlemen:

By means of the letter in Reference 1 above, TXU Generation Company LP (TXU Power) submitted the licensee response to Generic Letter 2004-01; "Requirements For Steam Generator Tube Inspections." Since that submittal, NRC staff has raised questions concerning the ability of steam generator tube in-service inspection techniques to detect flaws located in the parent tube behind the nickel band of an Alloy 690 TIG or Alloy 800 repair sleeve. This letter is meant to address the staff's request for additional information and to provide the latest information and engineering analysis related to this issue.

Attachment 1 of this letter contains the restated NRC staff questions and TXU Power's response. Attachment 2 of this letter contains a safety assessment as requested in Generic Letter 2004-01, Requested Information #3, to address this condition since there are questions remaining about the ability of our current in-service inspection to perform this inspection consistent with the NRC position stated therein.

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In summary, TXU Power acknowledges that the nickel band region of the sleeve/tube assembly is part of the pressure boundary of the repaired tube, and as such is normally subject to routine in-service inspection. However, it is TXU Power's position that for a postulated condition of degradation in the parent tube radially adjacent to the sleeve's nickel band, the remaining tube/sleeve hardroll joint length above the nickel band will provide anchorage consistent with the design requirement. Therefore, an in-service inspection capability within this region of the parent tube is not required to ensure structural or leakage integrity such that the design requirements and GDC 14 are satisfied for the tube/sleeve hardroll joint.

The enclosure to this letter contains a revised engineering position paper developed for the Westinghouse Owners Group (WOG) to support this position. The prior revision of this position paper was previously submitted by TXU Power via Reference 2.

This communication contains the following new commitments which will be completed during the Unit 1 Eleventh Refueling Outage (1RF11) as described:

Commitment Number	Commitment
27353	a minimum of 20% of all in-service TIG sleeves will be inspected full length using the +Pt coil.
27354	supplemental analyst training will be provided to sensitize the analysts to axial PWSCC potential within the parent tube adjacent to the nickel band and microlok band regions in TIG and Alloy 800 sleeves.
27355	100% of the Alloy 800 sleeves, first installed at the last outage (1RF10), will be inspected full length using the +Pt coil (required per Revision 6 of the EPRI PWR SG Examination Guideline).

If there are any questions concerning this submittal, please contact Mr. Bob Kidwell at (254) 897-5310.

I state under penalty of perjury that the foregoing is true and correct.

Executed on August 4, 2005.

Sincerely,

TXU Generation Company LP

By: TXU Generation Management Company LLC
Its General Partner

Mike Blevins

By: [signature]
Fred W. Madden
Director, Regulatory Affairs

RJK
Attachments:
Attachment 1; "Response to Request for Additional Information"
Attachment 2; "Safety Assessment"
Enclosure; WOG-04-518, Revision 1, dated July, 2005

c - B. S. Mallett, Region IV
M. C. Thadani, NRR
Resident Inspectors, CPSES

Attachment 1 to TXX-05146

Response to
Request for Additional Information

1. ***Clarify whether the +Pt coil is capable of detecting all flaw types which may be present in the parent tube behind the sleeve's nickel band, consistent with the inspection requirements of your Technical Specifications in conjunction with Criteria IX, XI, and XVI of 10 CFR Part 50, Appendix B.***

Although, the parent tube can be adequately inspected adjacent to the microlok region, inspection adjacent to the nickel band is limited. The TIG sleeve standards employed at Comanche Peak include 0.375 inch long, 50%, 70%, and 100%TW axial ID EDM notches centered on the microlok and nickel bands. Examination of these standards indicate that all notches in the microlok band region are readily detectable with the +Pt coil. Within the nickel band region the 70% and 100%TW axial ID EDM notches are readily detectable with the +Pt coil with typical phase responses. A signal with appreciable amplitude is observed coincident with the 50% notch; however the influence of the nickel band creates distortion of the phase response not present in the response of the 70% and 100%TW EDM notches. Such distorted signals, which still retain amplitude response well above the nickel band background, may not be reported due to this phase distortion. Supplemental analyst training will be provided to sensitize the analysts to axial PWSCC potential within the parent tube adjacent to the nickel band and microlok band regions in TIG and Alloy 800 sleeves.

Based on a comparison of EDM notch and actual stress corrosion crack (SCC) +Pt amplitude responses for similarly shaped flaws, a 70%TW SCC indication in the parent tube adjacent to the nickel band is expected to retain a signal to noise ratio of about 2 and judged to be readily detectable. Estimation of the signal response for a 50%TW SCC indication in the parent tube adjacent to the nickel band indicates that the signal to noise ratio is expected to be >1 and detection capabilities are judged possible, but possibly marginal for this depth of degradation.

The design of the +Pt coil is such that similar amplitudes for axial and circumferentially oriented flaws would be produced given equal depth and length. Thus, within the nickel band region, detection of axial and circumferential degradation of at least 70%TW is judged to be readily detectable with the +Pt coil.

The flaw detection discussion above applies to both TIG and Alloy 800 sleeved tubes.

2. ***If you conclude that the +Pt coil is capable of detecting all flaw types which may be present in the parent tube behind the sleeve's nickel band, including those flaws which may exceed the applicable tube repair criteria, provide the technical basis which supports your conclusions (e.g. technique qualification data).***

The qualification of the +Pt coil for TIG sleeve installations is contained within 96-OSW-003-P Revision 00, "EPRI Steam Generator Examination Guidelines Appendix H Qualification for Eddy Current Plus-Point Probe Examination of ABB-CE Welded Sleeves." This report qualified the +Pt coil for detection purposes consistent with Revision 5 of the EPRI PWR SG Examination Guideline, which was the applicable revision of the document at the time of qualification. For the postulated flaw locations within the pressure boundary portion of the parent tube it was judged that detection capabilities were consistent with the technical specifications. Revision 5 of the EPRI PWR SG Examination Guideline specified a range of qualification depths of 60%TW and greater. The discussion related to detection capabilities in the response to question 1 indicates that actual degradation of 70%TW in the parent tube adjacent to the nickel band would be readily detectable while 50%TW degradation of the parent tube could be detectable, but at a reduced probability.

If you conclude that full compliance with the TS in conjunction with Criteria IX, XI, and XVI of 10 CFR Part 50 Appendix B requires corrective actions, discuss your proposed corrective actions as requested in GL 2004-01, Requested Information #2. In addition, if the inspections are not being performed consistent with the NRC position on the requirements, submit a safety assessment as requested in GL 2004-01, Requested Information #3.

As a supplemental response to previously submitted information per requested information #2 of GL 2004-01, both longer and near term actions, to address the limitation of inspections behind the nickel band, are provided. These actions have been entered into the site's corrective action program and will be tracked accordingly.

The longer term corrective action relies on the elimination of the TIG and Alloy 800 sleeves resulting from the replacement of the Unit 1 Steam Generators scheduled for the spring of 2007 during the 1RF12 refueling outage. As such, following the inspection scheduled for this fall, only one full cycle of operation remains with TIG and Alloy 800 sleeves installed. A license amendment request to remove both the Alloy 690 TIG and the Alloy 800 sleeve tube repair methods from the CPSES Technical Specifications is in development to support replacement of the Unit 1 steam generators. Any subsequent planned use of these repair methods will require approval of a separate licensee submittal requesting their use in that application.

Near term actions are directed toward the planned scope and extent of the 1RF11 inspection program scheduled this fall. Specifically, a minimum of 20% of all in service TIG sleeves will be inspected full length using the +Pt coil. In addition, supplemental analyst training will be provided to sensitize the analysts to axial PWSCC potential within the parent tube adjacent to the nickel band and microlok band regions in TIG and Alloy 800 sleeves. Likewise, 100% of the Alloy 800 sleeves, first installed at the last outage (1RF10), will be inspected full length using the +Pt coil (required per Revision 6 of the EPRI PWR SG Examination Guideline). Note that the 2004 installation of Alloy 800 sleeves included a +Pt inspection of the parent tube in the hardroll joint region prior to Alloy 800 sleeve installation. No degradation was reported for these tubes at this location. Once the Alloy 800 sleeve is installed the parent tube is isolated from contact with the primary fluid, thus degradation is not expected to occur in this region. Each of the above inspections for the TIG and Alloy 800 sleeves will include the parent tube behind the sleeves in the hardroll joint region. Further, recent development efforts using the Ghent-3/4 probe indicate increased detection capabilities of tube degradation within highly conductive deposits. It is judged that the Ghent-3/4 probe would reliably detect 50%TW parent tube degradation within the nickel band region. An assessment of the potential value added by use of the Ghent-3/4 probe during the 1RF11 outage, at the sleeve hardroll joint region, is in progress.

The corrective actions discussed above are judged to be appropriate and conservative since the potential for a circumferentially oriented flaw to exist within the short axial distance of the nickel band is limited due to the performance history of full depth roll expanded tubing and the application of shot peening prior to operation. Additionally, both axial and circumferential flaws >70% TW are indeed detectable in the parent tube behind the nickel band and would result in appropriate repair. Finally, notwithstanding the presence or detection of SCC in this location, Enclosure 1 concludes that for an assumed condition where the hardroll joint length is effectively reduced by a factor of 2, that the joint length continues to satisfy design requirements. Specifically, for the conservatively assumed condition where the nickel band region provides no structural or leakage integrity, the remaining hardroll joint length provides structural capabilities in excess of the CPSES Unit 1 three times normal operating pressure differential end cap load and is expected to remain leak tight during all plant conditions.

In response to requested information #3 of GL 2004-01, the structural capability of a TIG or Alloy 800 sleeve joint (fundamentally there is no difference between these two joint designs) where the effective joint length is assumed to be half of the design length applied to the length above the nickel band region, will exceed the design document requirement and the associated loading consistent with draft Regulatory Guide 1.121. Both first slip and peak load capabilities of the postulated joint condition exceed the three times normal operating pressure differential end cap loading thus structural integrity capability is provided. Reiterating, Enclosure 1 concludes that 70%TW degradation of the parent tube adjacent to the nickel band is expected to be readily detectable with the +Pt coil and that 50%TW degradation in this region could be detected, but at a reduced probability. As the original basis of the technical specification 40% (by NDE) repair limit included an allowance of 10% for NDE uncertainty, detection of degradation of 50%TW in the parent tube is possible. Additionally, the technical specification does not include detection at an associated probability and confidence level. Although this is not a definitive statement of compliance with the technical specification, Enclosure 1 concludes that the conservative assumed condition of an effective joint length of 0.55" for the Alloy 800 sleeve and 0.625" for the TIG sleeve will provide for structural capability in excess of the design document requirements. Thus the safety significance of a non detected flaw of 50% to 70%TW in the parent tube adjacent to the nickel band region of the sleeve is acceptably low. Refer to the safety assessment provided in Attachment 2 of this letter for further discussion.

Additional information requested to support a structural and leakage integrity assessment of the sleeve joint.

- ***"...data supporting the statement that first slip for a 0.55 inch joint length would occur at approximately 2000 lb (including the roll torque and material properties) to ensure that the most limiting sleeve/tube assembly would have adequate integrity".***

Since the development of the original issue of Enclosure 1 (previously submitted by Reference 2) a review of ABB-CE documentation revealed a summary report of TIG sleeve roll joint testing performed in 1991. TR-ESE-887, "Test Report for the Qualification of the Roll Transition Zone Sleeve Rolled Joint for Westinghouse D Series Steam Generators," describes mechanical testing performed on TIG sleeve roll joints.

Of particular importance in this document is first slip load test data for varying torque levels. Samples were rolled into tube in tubesheet samples then subjected to 23000 mechanical cycles with an alternating load from 0 to 1000 lb compressive. After cyclic loading hydrostatic and helium leak testing was performed with no reported leakage for nominal torque applications, even in the case of axial scratching applied to the sleeve OD and tube ID. Hydrostatic test pressures were a differential of 2000 psi secondary to primary, then 3150 and 4000 psi differential primary to secondary. The range of acceptable torque values for the TIG sleeve is 90 to 175 in-lb. A regression to this data indicates that the expected first slip load is approximately 2532 lbf at a lower 95% prediction interval for an installation torque of 90 in-lb. Reconciling the reduced joint length on first slip loads indicates that first slip loads do not decrease linearly with reduced joint length. Available data indicates that for 0.50 and 1 inch joint lengths that the 0.5 inch joint length peak load capacity is approximately 80% of the 1 inch joint length peak load capacity. If this percentage is applied to the first slip load data, for a 0.55 inch joint length the first slip load is approximately 2000 lbf while the peak load is approximately 3660 lbf. Therefore, this assessment is conservative based on a review of the Comanche Peak installation torque data which shows the applied torque value was a nominal (120 to 130 in-lb).

It should be noted that while first slip loads are expected to exceed the maximum end cap loading associated with a safety factor of 3, that peak loads control the structural integrity performance of the joint and warrant consideration. Enclosure 1 establishes the similarity of the hard roll joints applied for TIG, Alloy 800, and HEJ sleeves and thus qualifies the use of the HEJ data for evaluating the TIG and Alloy 800 sleeves. The document also introduces an evaluation of joint integrity using the original TIG joint qualification data which was not considered in the initial issue of Enclosure 1.

The 0.55 inch roll joint length discussed in Enclosure 1 applies to the Alloy 800 sleeve, which uses a 1.1 inch hardroll joint length. The roll length applicable to the TIG welded sleeves used in the evaluation is 0.625 inch. Therefore, for the TIG sleeve, the first slip loads would be greater than the value developed for the Alloy 800 sleeve. Note that the first slip load developed for the Alloy 800 sleeve exceeds the three times normal operating pressure differential end cap load of approximately 1486 lb for Comanche Peak. Enclosure 1 also discusses peak load capabilities of the postulated degraded roll expansion joint highlighting the importance of considering peak load capabilities and not first slip load capabilities in any assessment of joint integrity.

To better understand the inherent integrity provided by roll expansion joints, the system construction is discussed below. The SG tube is roll expanded into the tubesheet using a "step roller", which has an indexing roller cage that allows for discrete axial displacements of the rolls with reference to the thrust reaction collar. This process includes a nominal ¼ inch overlap for each two successive roller steps. For those plants that have reported PWSCC at roll overlaps the orientation of these indications has been predominantly axial. The length of these indications is also limited to the overlap distance of ¼ inch. The process of mechanical roll expansion results in wall thinning of the tube with large radial preload post rolling. Thus the tube is in a compressive state post rolling. Development of axial degradation within this region does not result in a complete loss of contact between the tube and tubesheet. Subsequent sleeve installation and rolling produces a normal force that is transferred through the tube wall to the tubesheet. This normal force produces a condition where the combination of the normal force and coefficient of friction provide some measure of axial load bearing capability. This component was conservatively neglected in the development of Enclosure 1. In the unlikely event of a complete circumferential separation of the parent tube, the existing mechanical roll expansion above the separation provides for anchorage of the tube in the tubesheet. Likewise, the existing mechanical roll expansion below the postulated separation point and tube to tubesheet weld provide for anchorage of the tube in the tubesheet. This condition does not result in a reduction of tube radial preload as could be postulated for axial degradation in the parent tube. Thus, it is likely that the axial load bearing capability of the sleeve will be unaffected by a postulated circumferential separation of the parent tube. Therefore, the development of first slip loads in excess of the three times normal operating pressure differential for effective roll lengths of 0.55 and 0.625 inch provides for a condition where the probability of gross rupture is zero.

Furthermore, the sleeve assembly includes a joint at both ends; a mechanical roll expanded joint at the lower end and a welded joint at the upper end. Enclosure 1 has established that the lower joint will continue to provide for axial load bearing capability in excess of the three times normal operating pressure differential for any postulated degradation condition in the parent tube adjacent to the nickel band. For evaluation purposes it will be assumed that the sleeve lower joint is postulated to experience slippage in the axial direction. For such an event to occur the parent tube would have to experience a complete circumferential separation near the top of tubesheet such that end cap loads lift the tube and sleeve in the axial direction, thereby overcoming the inherent integrity characteristics of the lower roll joint. The length of the sleeve assembly limits the installation to about 10 tubes from the tube bundle periphery. After about ½ inch of axial displacement the lifted tube interacts with surrounding tubes in the U-bend region. Thus, gross failure of the sleeved tube assembly (lower joint is lifted out of the tubesheet) cannot occur, under any postulated condition. The sleeve OD in the roll region cannot be less than the tube ID based on the mechanical rolling process and compressive radial preload inherent to the process. The only postulated consequence of this extreme condition would be primary to secondary leakage through the sleeve to tube interface. However, Enclosure 1 presents a basis that concludes that any postulated leakage through the assumed joint condition is so low that it can be neglected.

- ***"...justification for the use of a nominal (rather than actual joint lengths in assessing the adequacy of a joint".***

The nominal 1.1 and 1.25 inch joint lengths are defined by the roll pin flat length, which is produced typically to extremely tight tolerances. By design, roll pin dimensions must be tightly controlled for proper operation. Manufacture to these dimensions is accomplished only by grinding, due to the hardness of the roll pin, which is a tightly controlled process. The actual interaction length between the sleeve and tube exceeds the nominal joint length by approximately 0.03 to 0.04 inch due to stretching of the sleeve material around the roll pin.

Attachment 2 to TXX-05146

Safety Assessment

Safety Assessment

TXU Power acknowledges that the parent tube adjacent to the sleeve hardroll must be present in order for the sleeve hardroll joint to perform as designed. Thus, the parent tube in this region should normally be inspected so that parent tube conditions that could challenge structural and leakage integrity of the sleeve are detected. However, it is TXU Power's position that for a postulated condition of degradation in the parent tube radially adjacent to the sleeve's nickel band, the remaining tube/sleeve hardroll joint length above the nickel band will provide anchorage consistent with the design requirement. Therefore, in-service inspection capabilities of this region of the parent tube radially adjacent to the sleeve nickel band are not required to ensure structural or leakage integrity of the tube/sleeve hardroll joint. The technical basis for this position is a Westinghouse Owners Group Engineering (WOG) Position Paper, which is provided as Enclosure 1 to this letter.

Future PWSCC development of this region of the parent tube is unlikely for the following reasons:

- Previous testing and analysis performed by Westinghouse indicates that for the expanded tube condition, residual stresses are compressive, and thus are not of the appropriate direction for PWSCC development. Finite element modeling of tube and sleeve joint conditions confirms that the tube ID will remain in a compressive residual stress condition with installation of a sleeve.
- PWSCC development below the expansion transition is believed to normally be associated with abnormal tubesheet hole or roll conditions. While full depth roll expanded SG tube designs (such as CPSES Unit 1) have developed PWSCC degradation at the roll overlap elevations on a very small number of tubes, the axial extent of these indications is limited to the stress field created by the overlap length (1/4 inch).
- These tubes were shotpeened prior to operation from above the top of tubesheet to just above the tube end. Application of shot peening prior to operation has resulted in a limited PWSCC occurrence at Comanche Peak whereas similar units that did not peen have experienced large numbers of tubes affected with PWSCC at the expansion transition and at roll overlaps.
- The incidence of expansion transition and tubesheet region PWSCC at Comanche Peak has been minimal.
- The Unit 1 steam generators are scheduled to be replaced during the refueling outage at the end of the next operating cycle (1RF12) in the Spring of 2007, limiting the time period within which substantial degradation might develop.
- 100% Plus Point coil examination of the parent tubes in the tube/sleeve hardroll joint region was performed to verify that the tube was free of detectable degradation in this area prior to Alloy 800 sleeve installation during the Unit 1 tenth refueling outage (1RF10).

In conclusion, steam generator operability is maintained because the plant is in compliance with the steam generator program elements of NEI 97-06 Revision 1, dated January 2000.

Enclosure 1 to TXX-05146

WOG-04-518
Engineering Position Paper
On NDE Issues Related to TIG and Alloy 800 Sleeves
with Regard to Sleeve Nickel Band NRC Discussion, Revision 1

Dated July, 2005

NDE Issues Related to TIG and Alloy 800 Sleeves with Regard to Sleeve Nickel Band
NRC Discussion

Revision 1

Background

NRC has questioned NDE capabilities regarding the SG parent tube adjacent to installed TIG and Alloy 800 sleeve nickel band regions. Recent inspection results from C-E plants indicate a potential for PWSCC degradation at this elevation. The documents that define the TIG sleeve design that address definition of the pressure boundary, CEN-630-P Revision 2, "Repair of ¾" OD Steam Generator Tubes Using Leaktight Sleeves," June 1997 (approved by NRC), and 96-OSW-003-P, Revision 0, "EPRI Steam Generator Examination Guidelines Appendix H Qualification for Eddy Current Plus Point Probe Examination of ABB CE Welded Sleeves," April 1996, do not specify the parent tube behind the sleeve as part of the pressure boundary. However, the parent tube adjacent to the sleeve hardroll joint must be present in order for the sleeve hardroll joint to perform as designed thus the parent tube in this region must be inspected so that parent tube conditions that could challenge structural and leakage integrity of the sleeve hardroll joint are detected. This position paper defines a level of parent tube degradation in the hardroll joint region that would necessitate repair of the sleeved tube by plugging, even though the design document per 10 CFR 50 Appendix B Criterion XI does not require routine in service inspection of this region. This paper also establishes a technical basis that indicates that the sleeve hardroll joint above the nickel band region provides sufficient structural and leakage integrity that the design requirements and GDC 14 are satisfied. By establishing these performance characteristics in service inspection of the parent tube adjacent to the nickel band region is not required for continued operability of the sleeved tube, however, any degradation detected within the parent tube adjacent to the nickel band will be repaired by plugging.

A telecon between NRC and industry was conducted on August 3, 2004 in which a generalized position was discussed. NRC issued several questions via email on August 9, 2004 in response to this telecon. The discussion provided below attempts to answer these questions.

Pertinent Issues

Typical sleeve design criteria address structural anchorage of the sleeve within the tube and leakage characteristics.

Structural anchorage has evaluated both (upper and lower) sleeve joint independently against axial forces developed commensurate with draft RG 1.121, that is, both the upper and lower joint should provide anchorage consistent with axial forces developed through end cap loading at a pressure differential of three times normal operating conditions pressure differential ($3\Delta P_{NO}$). This requirement includes a large inherent conservatism (for all cases except a potentially severed tube at the top of tubesheet) since the upper and lower joints of the sleeve are obviously coupled, and both joints react end cap loading at $3\Delta P_{NO}$.

Leakage characteristics for abnormal joint lengths have been determined by test, and past qualifications have shown that both typical and abnormal hardroll configurations of the lower sleeve joint to be leak tight at steam line break (SLB) conditions.

The qualification and performance of the sleeve joint is predicated on "presence" of a tube, thus the tube should be considered in the in service inspection plan for TIG sleeved tubes. The technical discussion provided below will show that postulated degradation within the parent tube coincident to the nickel band does not prevent the joint from meeting the design requirement, thus a basis can be formed to reduce the NDE requirements for the parent tube adjacent to the nickel band.

The original sleeve stress evaluation prepared in the supporting WCAP reports is not affected by this evaluation as the ASME Code stress evaluation applies to the non-expanded sleeve lengths.

Issue Resolution

The NRC questions transmitted by email on 8/3/2004 involved several topics. These topics can be summarized as

- Load bearing capability of the TIG and Alloy 800 sleeve joint for limited effective joint lengths
- Consistency of TIG and Alloy 800 sleeve joint design and performance with existing HEJ test data
- Overall tube anchorage in the tubesheet
- Leakage integrity of postulated limited effective length TIG and Alloy 800 sleeve joints

The discussion provided below addresses these topics.

Load Bearing Capability of TIG and Alloy 800 sleeve joint for limited effective joint lengths

It is the industry position that the inherent robust characteristics of mechanical roll joints satisfy the structural design requirement in the presence of postulated PWSCC degradation of the parent tube outboard of the sleeve nickel band region. This statement is supported by previous testing work performed as part of the hybrid expansion joint (HEJ) sleeve qualification. In this program "abnormal" joint conditions were tested to determine structural and leakage characteristics. The HEJ sleeve design does not include a nickel band or microlok band as do the TIG and Alloy 800 sleeve designs. The microlok region in particular is intended to increase the coefficient of friction between the tube and sleeve thus creating a greater reactionary load capability, thus the HEJ results presented below are expected to be conservative. Westinghouse data shows that coefficient of friction values for the microlok region can be bounded at the lower end by a value of 0.3, which is greater than the value of 0.2 typically used for previously performed similar evaluations regarding rolled joints. Also, particularly for the explosively expanded tube to tubesheet joint configuration, the sleeve mechanical roll "embeds" the sleeve into the tube ID surface, creating a mechanical interference fit between the sleeve and tube ID. Thus, not only must the sleeve to tube interface friction resistance be overcome to result in relative motion between the tube and sleeve, but the mechanical interference at the upper edge of the hardroll expansion must be overcome also.

The nominal hardroll flat length for the TIG sleeve is 1.25" with a nominal installation torque value 130 in-lb and an acceptable torque range of 90 to 175 in-lb. The nominal hardroll flat length for the Alloy 800 sleeve is 1.1" with a nominal installation torque value 130 in-lb and an acceptance torque range of 100 to 160 in-lb. These values are consistent for ¾" and 7/8" OD tubing installations. The typical wall thinning achieved in these sleeves is 3 to 6%. If it is assumed that the nickel band area supplies no axial load bearing capability, the effective lengths of the two joint designs are 0.625" for the TIG sleeve and 0.55" for the Alloy 800 sleeve.

It should be noted that degradation of the parent tube adjacent to the nickel band would be expected to result in a condition where the tube section with degradation has some measure of residual preload capacity. The tube in tubesheet expansion process results in a residual preload between the tube and tubesheet. If the tubesheet could be removed, the tube OD would expand to a larger diameter. This would be the case even for a tube with a single 100%TW axial indication that extends for the entire length of the nickel band. In this case the free ends of the tube would tend to separate due to the residual radial preload in the tube. As the tubesheet would restrain this motion, a preload condition will exist. The subsequent sleeve installation would provide a path to transfer the hardroll expansion loads to the tubesheet through the tube material. While the axial load bearing characteristics of such a condition would not be expected to be consistent with a non degraded tube, neglecting this condition is conservative.

Abnormal joint length test data for HEJ sleeves for 7/8" diameter tubes is provided in WCAP-13088. Joint lengths of 1.44 inch, 1 inch, and 0.75 inch were used however, it cannot be determined if the 1 and 0.75 inch joint lengths were prepared by machining a nominal joint to these lengths or whether the joints were produced with only these lengths of engagement between the sleeve and roller. For purposes of this evaluation, it is assumed that these joints were produced by engaging the sleeve and roller over the listed joint length, which is quite conservative when torque per unit area is compared below for the various designs. WCAP-13698 presents HEJ joint integrity test data for ¾" diameter tubes.

For 1 inch HEJ length installed at 130 in-lb and tested at room temperature, first slip loads were approximately 5000 lb, and peak load capability was approximately 8500 lb. For a 0.75 inch HEJ length first slip load was 3190 lb with a peak load of 8340 lb. These peak loads are consistent with full length HEJs. First slip loads for normal length HEJ joints were approximately 3720 to 4875 lb. These data confirm that peak load is relatively independent of joint length and also suggest that the 0.75 and 1 inch joint length specimens were produced by engaging the roller with the sleeve for the indicated length. At the onset of slippage galling between the tube and sleeve produces peak loads that are reduced to a function of the material properties. If the available first slip data are plotted and a curve fit to this data, at 0.55 inch joint length the expected first slip load is approximately 2000 lb. Peak load capability would be expected to be slightly reduced from the peak load data discussed above, but not significantly, and would remain well above the $3\Delta P_{NO}$ design requirement. Based on the available data peak load capability at 0.55 inch is expected to exceed 7000 lb. At operating temperatures the thermal expansion characteristics of the tubesheet, tube, and sleeve result in a radial preload condition that is elevated above room temperature. Thus, the expected elastic joint anchorage characteristics would be expected to be increased for operating temperature conditions barring tube material property variance.

Further abnormal joint condition testing work was performed using rolling torques well below the acceptable level. In these tests a 1.44" roll joint length was used with an 80 in-lb applied torque. Axial load capability testing performed at 600°F shows the peak tensile load capacity was approximately 7500 lb, which is consistent with typical tube/sleeve hardroll joints. First slip data was not recorded for these tests. This data suggests that axial load capability is relatively constant for tube/sleeve joint assemblies that provide apparent wall thinning within the specified ranges. Comparison of room temperature and elevated temperature data shows the elevated temperature axial load capabilities are consistent with the room temperature data. The increase in radial contact load due to thermal expansion compensates for the reduction in material properties.

The supporting WCAP reports note that tests were also conducted using tubes with 360° circumferential separations of the parent tube near the top of the hardroll joint region but did not quantify the length of the joint. The load capability data for this condition is consistent with non degraded parent tubes, which is expected for the location of the tube separation as the joint is intact over most of its design length thus axial load capability should be relatively unaffected. Leakage testing also showed no leakage at SLB pressure differential following fatigue testing. Leakage testing was performed at 600°F. A postulated circumferential flaw in the parent tube would not significantly affect the axial load capability of the tube/sleeve joint as the tube would continue to provide positive radial preload with the tubesheet, and thus with the sleeve.

For all available nominal and abnormal HEJ joint lengths, Figure 1 plots first slip load as a function of applied torque per unit area. Figure 2 plots peak load as a function of applied torque per unit area. The TIG and alloy 800 sleeve torque per unit area values are also included on these plots for comparison purposes. These figures show that axial load capability does not vary significantly with substantial variation in torque per unit area. The reduced first slip performance of the 0.75 inch HEJ joint sample (3190 lb first slip load at 72 in-lb/in^2) may be related to excessive wall thinning which can produce a less than optimum joint.

If it is postulated that an axial PWSCC indication was present in the tube prior to sleeve installation and this indication is located entirely within the bounds of the sleeve nickel band, the above data demonstrates that the lower joint region will continue to provide an anchorage consistent with the design requirement if it is assumed that no contribution to anchorage is provided by the sleeve/tube assembly in the nickel band region. This assumption is quite conservative since the tubesheet restrains the tube radially, and postulated axial degradation of the parent tube will still provide some measure of radial load capability when the sleeve is installed.

Therefore, it is the industry position that for a postulated condition of degradation in the parent tube radially adjacent to the sleeve nickel band, that the remaining tube/sleeve hardroll joint length above the nickel band will provide anchorage consistent with the design requirement, and that reduced NDE capabilities within the parent tube due to the presence of the sleeve nickel band does not effect structural or leakage integrity of the tube/sleeve hardroll joint.

It should be noted that recent TIG and Alloy 800 sleeve installations have included a Plus Point coil examination of the parent tube in the tube/sleeve hardroll joint region prior to sleeve installation to verify that the tube is free of detectable degradation in this area. For these cases, future PWSCC development of the parent tube is unlikely for the following reasons. First, the tube/sleeve interface will isolate the parent tube from the primary fluid, thus effectively eliminating one contributor to PWSCC initiation. Second, previous testing and analysis performed by Westinghouse indicates that for the expanded tube condition, that residual stresses are compressive, and thus are not of the appropriate direction for PWSCC development. PWSCC development below the expansion transition is believed to be associated with abnormal tubesheet hole conditions. While full depth roll expanded SG tube designs have developed PWSCC degradation at the roll overlap elevations, the axial extent of these indications is limited to the stress field created by the overlap length (1/4 inch). The only plant with full depth roll expanded tube in tubesheet joints that has installed TIG and Alloy 800 sleeves is Comanche Peak Unit 1. These tubes were shotpeened prior to operation from above the top of tubesheet to just above the tube end. The incidence of expansion transition and tubesheet region PWSCC at Comanche Peak has been minimal. Finite element modeling of tube and sleeve joint conditions confirms that the tube ID will remain in a compressive residual stress condition with installation of a sleeve.

Table 1 presents a comprehensive summary of HEJ testing data that supports the conclusion that peak loads are relatively independent of roll joint length and applied torque. Note that the peak loads listed can represent the true peak load or the load at 1 inch of sleeve deflection, in which case the true peak load may not be achieved. The WCAP does not identify the condition reflected in the peak load data. The ¾" data set specifies when general yielding of the sleeve occurred. The 7/8" test data does not make this specification therefore the indicated first slip loads may represent a general yielding of the sleeve and not the true first slip. All data was evaluated assuming the indicated first slips are representative of the true first slip and true peak load capability. For those samples with both first slip and peak load data, the average peak to first slip load ratio is 1.83, indicating that peak loads are nearly twice the first slip load data.

<u>Consistency of TIG and Alloy 800 sleeve joint design and performance with existing HEJ test data</u>

The above abnormal HEJ joint tests involved sleeve wall thinning ranging from 4.0% to 8.6%. This range is consistent with the wall thinning associated with the TIG and Alloy 800 sleeves. As the wall thinning is consistent for all sets it is reasonable to conclude that the TIG and Alloy 800 sleeve designs will provide axial load bearing capability consistent with the HEJ data on a unit length basis.

The HEJ abnormal joint test data include variations in effective joint length and applied torque. If the applied torque is divided by the effective contact area for each of the specimen configurations, the specimens exhibit values ranging from 22.4 in-lb per square-inch for the 1.44 inch length joint length specimens to 72.6 in-lb per square-inch for the ¾ inch length joint specimens. As stated above, the exact installation configuration cannot be determined for the ¾" and 1" joint length samples. If these samples were prepared by producing a nominal joint and machining to the indicated joint length the in-lb per square-inch value is 25.2. The TIG and Alloy 800 sleeve designs supply approximately 56.0 in-lb per square-inch based on the nominal installation torque. As the HEJ abnormal joint test data shows the peak load capacity is relatively unaffected over a wider range of torque per unit length, the same conclusions would apply to the TIG and Alloy 800 sleeves. Thus, it is acceptable to evaluate the TIG and Alloy 800 sleeve limited length configurations by comparison with the HEJ data.

The above discussion is provided to show that as long as the defined sleeve wall thinning is achieved, that performance characteristics of roll expanded joints are extremely robust, and will satisfy the design requirements even under abnormal conditions.

The discussion to this point has concentrated on HEJ joint characteristics. ABB test report TR-ESE-887, "Test Report for the Qualification of the Roll Transition Zone Sleeve Rolled Joint for Westinghouse D Series Steam Generators," April 1991 presents qualification data related to the initial design verification of the TIG sleeve hardroll joint and includes data for varying installation torque conditions and varying tube hole dimensions. The data presented in this paper will concentrate on the test report data related to installation torques at the nominal to lower end of the acceptable range and tube holes ranging from nominal to large, as these conditions would represent the limiting condition for joint structural capability. Table 2 presents a summary of the TR-ESE-887 data. Note that the normal sleeve installation process includes two roll applications. Some samples include multiple rolls at differing torque values. If the minimum wall thinning was not achieved the sample was rerolled at a higher torque value. Calculation of torque per unit area values (used later) was based on the largest applied torque value.

Qualification samples were assembled then subjected to 23,000 axial load cycles ranging from 0 to 1000 lb compressive plus 700 simulated cycles that mimic the plant heatup-cooldown cycle. The data presented in Table 2 provides structural capabilities after cyclic testing. Samples were tested using a tensile test machine first at 2000 lbf on the push and the pull, then to failure to a maximum applied test load of approximately 4000 lbf. For those samples that did not slip at the point of test termination the maximum applied load is indicated.

All samples were subjected to a hydrostatic leak test with a secondary to primary differential pressure of 2000 psi, primary to secondary pressure differential of 3100 and 4000 psi, and helium leak testing after cyclic testing. No leakage was reported for these tests for roll torques within the acceptable range in the absence of axial scratching of the tube/sleeve.

For samples Q-7 and Q-9, two 4 mil deep, 1.25 inch long axial scratches were applied to the sleeve 180 degrees apart, centered axially on the microlok to nickel band interface. A 45 degree deburring tool was used to apply the scratches. At this depth the scratch affected the base metal. Thus for the 4 mil deep scratches the maximum width of the microlok and nickel band metal deformation was approximately 3.3 mils. Both samples had detectable helium leakage. Sample Q-7 leaked during the hydrostatic tests at 500 psi. Hydrostatic leak rates were not measured. Sample Q-9 leaked during the secondary side hydrostatic test at 2000 psi and at 1000 psi during the primary side hydrostatic test. For samples Q-7A, Q-9A, and Q-15A, the sleeves were scratched in the same manner and two, 2 inch long, 2mil deep axial scratches were applied to the tube. The maximum width of the tube metal deformation was approximately 1.66 mils. Neither of these samples leaked, indicating a threshold for no leakage of at least 105 in-lb torque. It should be noted that this threshold for no leakage of 105 in-lb torque is well below the nominal installation torque of 130 in-lb for TIG and Alloy 800 sleeves. Also, use of a deburring tool for application of the scratches to the tube and sleeve are considered extreme cases of metal deformation that are judged to result in a flow area width that bounds true PWSCC degradation for this region of the tube.

The data of Table 2 was plotted on Figure 3 to evaluate the relationship between applied torque and first slip load. Those data in which the test was halted without slippage are included in the regression using the maximum recorded load and therefore are conservative additions to the data set as the true first slip was not achieved. As shown by the regression the nominal expected peak load capability at the nominal torque of 130 in-lb for the TIG sleeve is approximately 4000 lbf. The previous discussion regarding HEJ sleeve joints indicates that the first slip loads can be reduced for reduced joint lengths but peak loads are consistent for abnormal and normal joint lengths including the 1.44 inch joint length installed with 80 in-lb. The same premise should apply for the TIG and Alloy 800 sleeve joints. Thus, for an assumed condition where degradation of the parent tube adjacent to the nickel band has resulted in a condition where no load bearing capability is provided, the nominal joint first slip axial load bearing capability at 90 in-lb should be approximately 3300 lbf, well above the three times normal operating pressure differential end cap load of 1506 lbf for any operating plant with installed TIG or Alloy 800 sleeves that uses ¾" OD tubing. Two of the axially scratched samples had first slip loads lower than the rest of the population. Figure 3 includes a supplemental regression that shows how the regression is affected if these data are not included. If this regression is extended to 135 in-lb which is the applied torque level of the HEJ 0.75 and 1 inch abnormal joint test samples, the regression and the HEJ abnormal data produce nearly identical results. All TIG sleeve joint data including the axially scratched samples was considered in development of the regression that is used for comparison against the design requirement. For example purposes a lower 95% prediction bound was developed for the data set including the axially scratched samples. Using this lower bound, the expected axial load capability is approximately 2500 lbf at 90 in-lb applied torque.

These data show that joint length has little effect upon peak load capability. Obviously there are limits to which this conclusion applies as a very short joint length would not exhibit peak loads similar to a nominal joint length. The discussion surrounding the HEJ joint data assumed that a ½ reduction in joint length would result in a ½ reduction in first slip loads with a much lesser reduction in peak loads. During development of the F* alternate repair criterion, pull force testing was performed for varying joint length conditions at equivalent torque installation values. This data shows (taken from Westinghouse Calculation Note SM-86-87) that for minimum surface roughness conditions the ½ inch joint length pull force was 80% of the 1 inch joint length pull force. The joint lengths considered in this comparison are similar to the TIG sleeve joint lengths being considered. Thus for a TIG sleeve installed at 90 in-lb, a postulated joint length of ½ of nominal would exhibit a first slip load of about 80% of 2500 lb, or 2000 lb, at a lower 95% prediction bound. Peak loads would be expected to be 1.83 times greater than first slip loads, or about 3660 lb.

As a check of this first slip value, the TIG sleeve first slip force data can be used to estimate normal forces between the tube and sleeve by applying a coefficient of friction. For tube in tubesheet applications a lower bound coefficient of friction of 0.2 has been used in past evaluations. Westinghouse has used a lower bound coefficient of friction of 0.3 for the microlok region. Thus, an aggregate coefficient of friction of 0.25 could be applied for a typical TIG sleeve joint. In this application the area of interest becomes the microlok region which must now be shown to exhibit axial load capabilities greater than the limiting three times normal operation end cap load. The first slip data were used with a 0.25 coefficient of friction to develop normal forces between the tube and sleeve. The resultant normal forces were reduced by ½, then a 0.3 coefficient of friction applied to this reduced normal force. The applied torque data was then plotted against the calculated first slip loads based on normal forces divided by two and coefficient of friction of 0.3. A regression was fit to this data and a lower 95% prediction developed. At 90 and 130 in-lb the lower 95% prediction first slip loads are 1519 and 1866 lbs, respectively. While this calculation indicates a first slip load modestly less than suggested by test data (1519 lb versus 2000 lb) it should be noted that the coefficient of friction used is a conservatively established lower bound value. For example, use of a microlok region coefficient of friction of 0.4 gives a calculated first slip load of 2025 lbf at a lower 95% prediction for an installation torque of 90 in-lb.

It should be noted that both a postulated circumferentially separated tube and tube with 100%TW axial degradation in the parent tube adjacent to the nickel band would not result in a condition where no axial load bearing capability is realized for the nickel band region. For the circumferentially separated tube the parent tube above and below the separation would continue to provide residual radial preload stress between the tube and tubesheet as well as tube and sleeve, thus axial load capabilities would be expected to be only minimally influenced by the circumferential separation. A similar conclusion is made for a postulated 100%TW axial flaw within the parent tube adjacent to the nickel band. In this case the tube may experience a greater residual radial preload reduction however the tube OD dimension would not changed as the OD geometry is controlled by the tubesheet hole. Installation of the sleeve would result in a normal residual preload between the sleeve and tube and tube and sleeve. This preload would provide for a measure of axial load bearing capability through application of the residual normal preload and coefficient of friction between the components.

Overall Tube Anchorage in the Tubesheet

The parent tube existing above the hardroll joint region would continue to provide additional support to the tube/sleeve joint region, even though this area is not considered part of the pressure boundary for the installed TIG sleeve condition. Axial loads would continue to be transferred through the tube for the case of multiple axial indications in the parent tube at any elevation above the sleeve to tube hardroll joint. Circumferential degradation of the parent tube above the sleeve to tube hardroll joint could only affect tube anchorage if the degradation extends for approximately 280 degrees arc length with a depth of 100%TW over this length. For postulated circumferential indications below the top of tubesheet expansion transition the tube cannot experience a bending failure, thus the tube is loaded only in tension. Furthermore, the installation of the sleeve will isolate this portion of the tube from the primary fluid. Discussion provided above shows the residual stresses in the expanded tube below the expansion transition are compressive, and that an external stress riser then must be present for PWSCC flaw initiation. Such conditions are associated with localized anomalies. This discussion neglects the increased tube to tubesheet anchorage afforded by the installation of the sleeve.

For the case of postulated circumferential degradation of the parent tube adjacent to the nickel band, the inherent radial preload imparted by the tube expansion process and installation of the sleeve would not significantly be reduced due to the presence of circumferential degradation. As the tube radial preload, or a significant portion thereof would be preserved, the radial preload that in turn provides axial load bearing capability between the tube and the tubesheet would be maintained.

Leakage Integrity

Leakage testing at 600°F for the nominal, 1 inch, and ¾ inch HEJ lengths shows no leakage at a pressure differential of 3106 psi following fatigue cycling. The 1.44 inch HEJ joint length with 80 in-lb applied torque shows no leakage at SLB pressure differential. Thus, the available HEJ abnormal joint test data suggests that leakage integrity is provided for torque per unit area values ranging from 22.4 to 72.6 in-lb/in^2 and that presence of the nickel band is not required for leakage integrity at a high probability. In the unlikely event that degradation of the parent tube adjacent to the sleeve nickel band is present the nickel band would be expected to further reduce the leakage probability. The TIG joint leakage testing suggests that leakage could be experienced at the minimum acceptable applied torque if the leakage path is introduced across the entire hardroll joint length. However, this statement is based on an extreme mechanical modification to the sleeve and tube. Degradation in the parent tube adjacent to the microlok region postulated to support a leak path is expected to be detected with the +Pt coil. Note the above discussion shows no leakage for scratched tubes and sleeves at torque values above minimum acceptable value but below nominal. Additional sources also suggest that roll joint lengths >0.50 inch exhibit a negligible leakage potential. Testing performed during development of the F* alternate tube repair criterion indicate that for intact roll joint lengths of 0.50 inch and greater that no leakage at SLB conditions was observed. This joint uses a nominal 35 in-lb torque for ¾ inch OD tubing with a 1.25 inch roll length.

Report CEN-617-P Revision 1, "Steam Generator Tube Repair for Tubes Containing Westinghouse Mechanical Sleeves Using Leak Limiting I690 Sleeves" presents leak test data for a sleeve designed to be installed inside of an existing HEJ sleeved tube that had experienced degradation of the parent tube in the upper HEJ joint region. The joint design of this sleeve included two 1 inch long hydraulically expanded lengths separated by 0.5 inch. Roll expansion is not used in this design.

The measured maximum leak rate prior to cyclic testing for the lower joint at room temperature and 1500 psi primary to secondary pressure differential was 0.22 cc/min, or 0.00006 gal/min. After cyclic testing the joints were found to be leaktight. This data is judged to represent a bounding condition for hardroll joints as the hydraulic expansion would not produce a condition where a residual radial preload between the tube and sleeve is present and a small gap between the tube and sleeve can be present due to nature of the expansion process. At SLB conditions the leak rate could be an order of magnitude greater than the normal operating condition value. However, the difference in thermal expansion coefficients between the tube and sleeve would result in a reduced tube to sleeve gap and thus would effectively reduce leakage through the joint. Note that for this design the lower joint is actually produced within the freespan region of tubing. Joint tightness due to thermal effects would be further increased for a TIG or Alloy 800 sleeve joint when the thermal expansion characteristics of the tubesheet are considered.

For the TIG or Alloy 800 sleeve the residual radial preload between the tube and sleeve can be approximated by dividing the first slip load by a coefficient of friction. The regression of first slip force on applied torque indicates that for a 90 in-lb applied torque the lower 95% prediction bound first slip load is 2532 lbf. For an aggregate coefficient of 0.3 (0.2 applied to nickel band, 0.4 applied to microlok band) the normal force is 8440 lbf with an associated contact pressure of 3236 psi, determined by dividing the normal force by the total TIG joint surface area. Note that increasing the coefficient of friction results in a lower radial preload force. Thus a microlok band coefficient of friction of 0.4 versus the lower bound value of 0.3 was applied. WCAP-14797 Revision 2, "Generic W* Tube Plugging Criteria for 51 Series Steam Generator Tubesheet Region WEXTEX Expansions" includes constrained crack leak test data in which the tube to tubesheet crevice width was tightly controlled. Tube cracks were developed by applying a 50%TW EDM and cyclic loading to develop fatigue cracks extending from the EDM notch. The contact pressure for the leak test was applied through internal pressurization and thermal expansion difference between the tube and collar materials; the tubes were not WEXTEX expanded. This test data indicates that as the contact pressure between the tube and tubesheet is increased leak rate subsequently decreases. These samples were configured such that the upper crack tip was located at the top of the tubesheet simulant collar; thus there was no effective crevice length and the test investigated the effects of contact pressure upon leakage. For a contact pressure approximately equal to the driving pressure at SLB pressure conditions of 2650 psi, 600°F leak rates are in the range of 1×10^{-3} to 1×10^{-5} gpm. For the installed sleeve condition a metal to metal fit between the tube and sleeve above the nickel band of 0.55 to 0.625 inch is included for an assumed condition of 100%TW degradation of the parent tube over the entire nickel band region length. The WCAP-14797 data indicates that doubling the crevice length has the effect of reducing leak rate by about ½. When crevice length and contact pressure are simultaneously considered the leak rate is reduced by about 1/10th. This metal to metal fit coupled with a minimum contact pressure of 3236 psi will effectively reduce the potential for leakage to a negligible level. Note that in the WCAP-14797 constrained crack leak tests the primary fluid had direct communication with the cracks whereas the installed sleeve condition would require leakage past the nickel band to crack interface. The installed sleeve hardroll joint location is at the approximate neutral axis of the tubesheet thus tubesheet bow effects do not influence sleeve joint leakage.

Recent TIG sleeve operating performance shows a modest number of collapsed or potentially collapsed sleeves. The theory behind the collapse is that primary fluid enters the tube to sleeve annulus region during startup conditions prior to increasing temperature. The difference in thermal expansion characteristics produces a tighter configuration at operating temperatures. These occurrences are not believed to be related to potential degradation of the parent tube. The Comanche Peak experience has shown the highest percentage of collapsed or partially collapsed sleeves of about 8% of all installed TIG sleeves (approximately 60 out of 735). The Spring 2004 Alloy 800 sleeve installation at Comanche Peak involved a Plus Point examination of the parent tube in the sleeve hardroll joint region prior to installation. No degradation was reported at this location for the approximate 550 tubes that received Alloy 800 sleeves. Therefore, it is unlikely that 60 sleeves either collapsed or partially collapsed observed at the 2004 inspection contained parent tube indications. To date, less than 10 tubes out of over 18000 tubes have been reported to contain PWSCC at the top of tubesheet hardroll expansion transition, which is the point of highest residual stress in the tube. Recent inspection results from SONGS 2 shows that for the length of tubing from 10 inch to 12 inch below the top of tubesheet, which is the approximate elevation of the sleeve hardroll joint, that only 41 indications were reported for over 17000 active tubes. For this inspection all tubes were inspected to at least 17 inches below the top of tubesheet. Therefore, it is unlikely that the 10 collapsed sleeves reported at this outage were influenced by PWSCC of the parent tube adjacent to the sleeve nickel band.

The source of the collapsed condition is believed to be related to several possible causes, a tooling issue related to a specific lot of roll expanders, localized geometry variations in the tube that are not overcome by the sleeve roll expansion, and disruption of the microlok and nickel band regions during sleeve insertion. Westinghouse is currently investigating the tooling issue. An ovalized tube hole could present a condition where the tube to sleeve interface presents a limited arc length region where leak tightness is reduced at ambient temperature but not present at operating temperature. If the sleeve OD surface is scratched or marred during installation a localized leak path may be produced, but again is eliminated at operating temperatures. While these postulated causes for sleeve collapse represent a subsequent inspection issue, they do not represent an operating or safety issue.

The available information indicates that there is no relation between the recently observed sleeve collapse occurrences and postulated degradation of the parent tube in the nickel band region.

NDE Qualification

The original NDE qualification of the TIG sleeve inspection technique was performed according to the standards defined by the controlling industry document at that time, which was Revision 5 of the EPRI PWR SG Examination Guidelines. The design document concludes that the +Pt coil met the Appendix H standards for qualification. These standards were a probability of detection of 0.8 at 90% confidence for degradation of 60%TW or greater.

Current NDE Capabilities

As indications within the parent tube adjacent to the sleeve nickel band do not affect the structural or leakage capability of the sleeve joint, detection of degradation does not affect the ability of the joint to continue to perform its design function. Evaluation of calibration standards with 70% and 100%TW, 0.375 inch length axial EDM notches in the parent tube behind the nickel band shows these limited length notches are readily detectable with Plus Point RPC probes. While SCC indications offer a more challenging condition for detection compared to EDM notches, the condition that would potentially affect leakage integrity of the joint would be the case where the parent tube axial degradation extends from above to below the nickel band region. For this case, meaningful degradation of the parent tube is expected to be readily detectable using current techniques.

Evaluation of the TIG sleeve eddy current standards developed for Comanche Peak show that the 70% and 100%TW axial EDM notches in the parent tube adjacent to the nickel band are readily detectable with the +Pt coil. A 50%TW axial EDM notch is also present in this standard is observable however the signal characteristics show distortion of the signal not present in the response of the 70 and 100%TW notches. Comparison of the EDM notch signal amplitudes adjusted consistent with previous evaluations that have examined EDM notch and true SCC responses suggests that 70% axial SCC degradation within the parent tube adjacent to the nickel band is expected to be readily detectable using the +Pt coil while detection of 50% degradation depths are possible but at a lesser likelihood. A similar result is expected for circumferential degradation.

The observed circumferential degradation at significant depths below the top of tubesheet in units with sleeves or considering sleeving has involved limited arc lengths, and a postulated separated tube adjacent to the sleeve nickel band is not expected within these SGs. If this condition were assumed to be present, it is expected that this condition would be detectable despite the NDE challenges associated with the sleeve nickel band. Both a postulated separated tube, and tube with a 100%TW SCC flaw extending for an arc length commensurate tensile overload capacity of the tube at $3\Delta P_{NO}$ conditions (approximately 280 degrees arc length) are expected to be readily detectable using current eddy current techniques. The Plus Point amplitude responses for both of these would be substantially larger than the EDM notch response of the standard due to the SCC length at 100%TW. Therefore, circumferential degradation of the parent tube that could possibly influence the axial load transference capability of the tube is expected to be detected.

Conclusion

The above discussion supports a position that in service, non destructive examination of the parent tube adjacent to the nickel band region of sleeve, for tubes with installed TIG or Alloy 800 sleeves is not required to support continued operability of the sleeved tube consistent with the original design requirements of the sleeve. For the extremely conservative assumption that the portion of the sleeve to tube hardroll joint adjacent to the nickel band does not provide any axial load bearing capability, the minimum first slip load is estimated at 2000 lbf, while the minimum peak load is estimated at 3660 lbf. These values exceed the maximum postulated end cap load at three times normal operating pressure differential for any operating plant with TIG or Alloy 800 sleeves of 1506 lbf. Leakage testing subsequent to cyclic testing of abnormal condition HEJ sleeve joints with joint characteristics well below the level associated with nominal TIG and Alloy 800 sleeve installations show no primary to secondary leakage at operating or SLB conditions. Despite this position, any detectable degradation of the parent tube adjacent to the sleeve hardroll region will be removed from service upon detection. For any parent tube degradation depth adjacent to the nickel band region, structural and leakage integrity is expected to be maintained during all postulated operating and accident conditions.

Thus, it is possible that degradation of the parent tube adjacent to the nickel band may be present at levels consistent with the technical specification repair limit, however, this degradation will not affect the structural or leakage integrity of the sleeved tube and the associated safety significance of such a condition is negligibly low.

Table 1 Summary of HEJ Joint Test Data									
						Push Test	Pull Test		
Tube OD (inch)	Sleeve Torque (in-lb)	Hardroll Joint Length (inch)	Torque per unit area (in-lb/in^2)	Temp. Condition	Slip Force (lb)	Max Force or Force at 1" Deflection or Buckling Load (lb)	Slip Force (lb)	Max Force or Force at 1" Deflection (lb)	Comments
7/8	135	2.156	25.01	600 F	3900	6325			
7/8	135	2.156	25.01	600 F			3720	6000	
7/8	135	2.156	25.01	RT			4875	7485	
7/8	130	2.156	24.08	600 F		7620			(1)
7/8	130	2.156	24.08	600 F				>6470	(1)
7/8	130	2.156	24.08	RT		>5010			(1)
7/8	130	0.900	24.08	RT		7880			(1)
7/8	130	0.900	24.08	600 F				8200	(1)
7/8	130	0.900	24.08	600 F				7880	(1)
7/8	130	2.156	24.08	600 F		7120			(1, 2)
7/8	130	2.156	24.08	RT		7880			(1, 2)
7/8	130	0.900	57.69	600 F		6510			(1, 2)
7/8	80	1.44	22.18	RT		6920			(1)
7/8	80	1.44	22.18	600 F				7700	(1)
7/8	90	1.44	24.96	RT		7300			(1)
7/8	90	1.44	24.96	RT		7510			(1)
7/8	80	1.44	22.18	600 F				7480	(1)
7/8	80	1.44	22.18	600 F		6450			(1)
7/8	90	1.44	24.96	600 F				7240	(1)
7/8	90	1.44	24.96	600 F		6680			(1)
7/8	135	1.00	53.92	RT			5130	8580	
7/8	135	1.00	53.92	RT			4880	8410	
7/8	135	0.75	71.89	RT			3190	8340	
3/4	115	2.156	24.97	RT	3700	7350			(3)
3/4	115	2.156	24.97	600F	3580	7120			
3/4	115	2.156	24.97	600 F			3480	6250	
3/4	115	2.156	24.97	RT	4250	7440			(3)
3/4	95	2.156	20.63	RT			4300	6350	
3/4	95	2.156	20.63	600 F	3000	7270			(3)
3/4	125	2.156	27.14	600 F			3400	6160	
3/4	140	2.156	30.40	RT			4290	7020	

(1): Tube roll expansion length was 1.5" simulating a tube condition of incomplete expansion prior to installation of sleeve.

(2): Tube separated near hardroll joint upper end prior to sleeve installation for simulation of 100%TW, 360 degree circumferential flaw.

(3): Load at start of non-linear deflection, could represent general yielding of sleeve material and not first slip load.

Table 2
TIG Sleeve Roll Joint Qualification Data Summary
(1.25" hardroll flat length)

Sample	Tube ID (inch)	Sleeve Roll Torque (in-lb)	Torque per unit area (in-lb/in^2)	Cyclic Test Observations	Pull Test (2000 lbf)	Push Test (2000 lbf)	First Slip Load (lbf)
Q-6	0.694	66, 66	24.22	No slippage	No slippage	No slippage	2140
Q-8	0.694	70, 75, 110	40.36	No slippage	No slippage	No slippage	3880
Q-23	0.694	82, 88	32.29	No slippage	No slippage	No slippage	3120
Q-22	0.694	117, 124	45.50	No slippage	No slippage	No slippage	>4000 (4)
Q-20	0.694	90, 87	31.92	No slippage	No slippage	No slippage	3580
Q-11 (1)	0.683	90, 90	33.56	No slippage	No slippage	No slippage	>3900 (4)
Q-18 (1)	0.683	97, 120	40.27	No slippage	No slippage	No slippage	>3800 (4)
Q-10 (1)	0.683	81, 90	33.56	No slippage	No slippage	No slippage	3200
Q-15 (2)	0.683	68, 70, 112	41.76	No slippage	No slippage	No slippage	3750
Q-16 (2)	0.683	97, 120	44.74	No slippage	No slippage	No slippage	>4000 (4)
Q-17 (2)	0.683	86, 90	33.56	No slippage	No slippage	No slippage	3300
Q-7 (3)	0.683	97, 89	33.18	No slippage	No slippage	No slippage	3800
Q-9 (3)	0.683	93, 95	35.42	No slippage	No slippage	No slippage	3720
Q-7A (3)	0.683	99, 113	42.13	No slippage	No slippage	No slippage	3000
Q-9A (3)	0.683	100, 130	48.47	No slippage	No slippage	No slippage	3150
Q-15A (3)	0.683	113, 105	39.15	No slippage	No slippage	No slippage	>4000 (4)

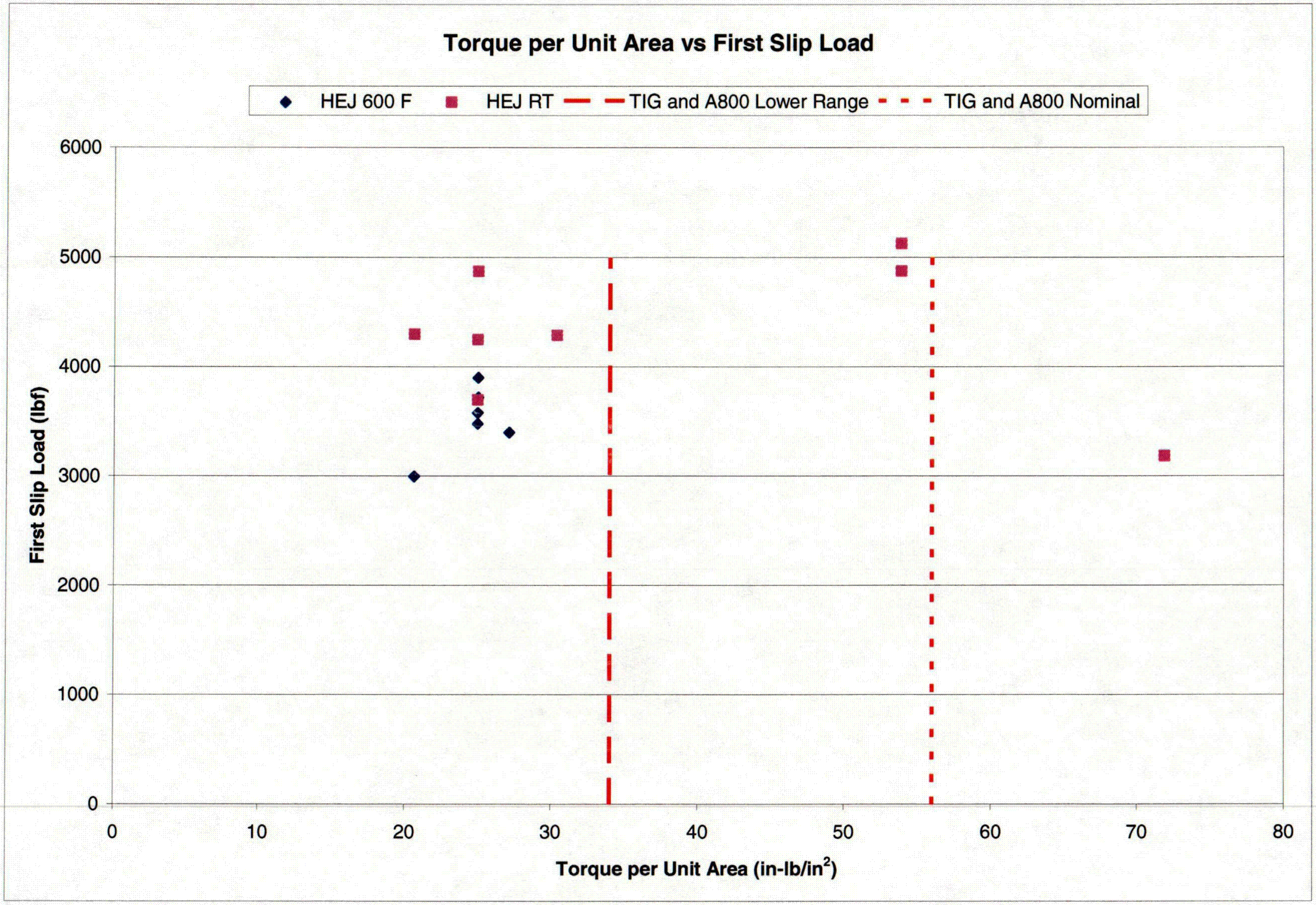
(1): Roll centerline 0.18" high

(2): Roll centerline 0.18" low

(3): Axial scratch samples

(4): Test terminated prior to achieving a first slip condition thus actual first slip load is greater than the indicated value.

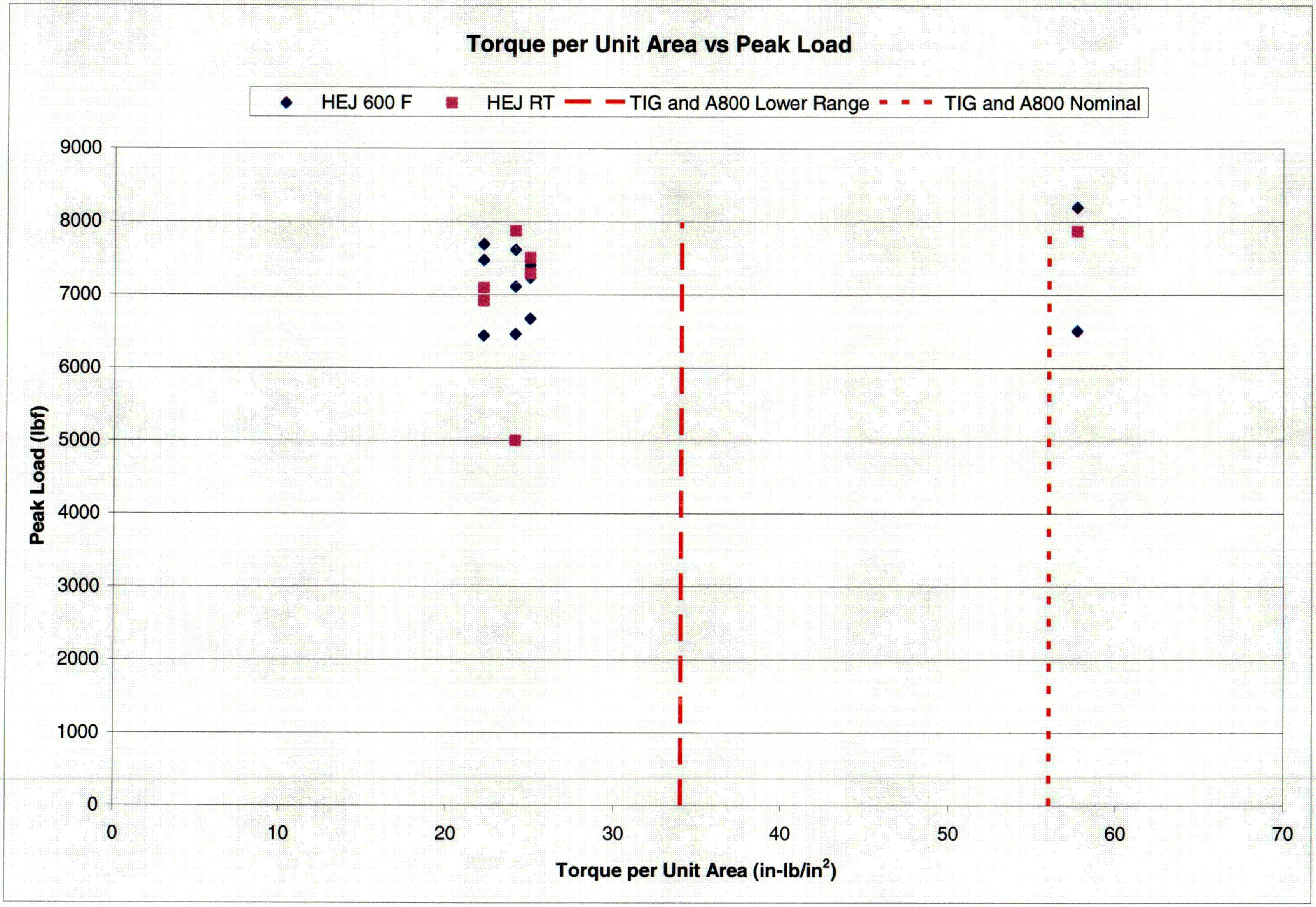
Figure 1



Torque per Unit Area vs First Slip Load
HEJ 600 F
HEJ RT
TIG and A800 Lower Range
TIG and A800 Nominal
6000
5000
4000
3000
2000
1000
0
First Slip Load (lbf)
0
10
20
30
40
50
60
70
80
Torque per Unit Area (in-lb/in^2)

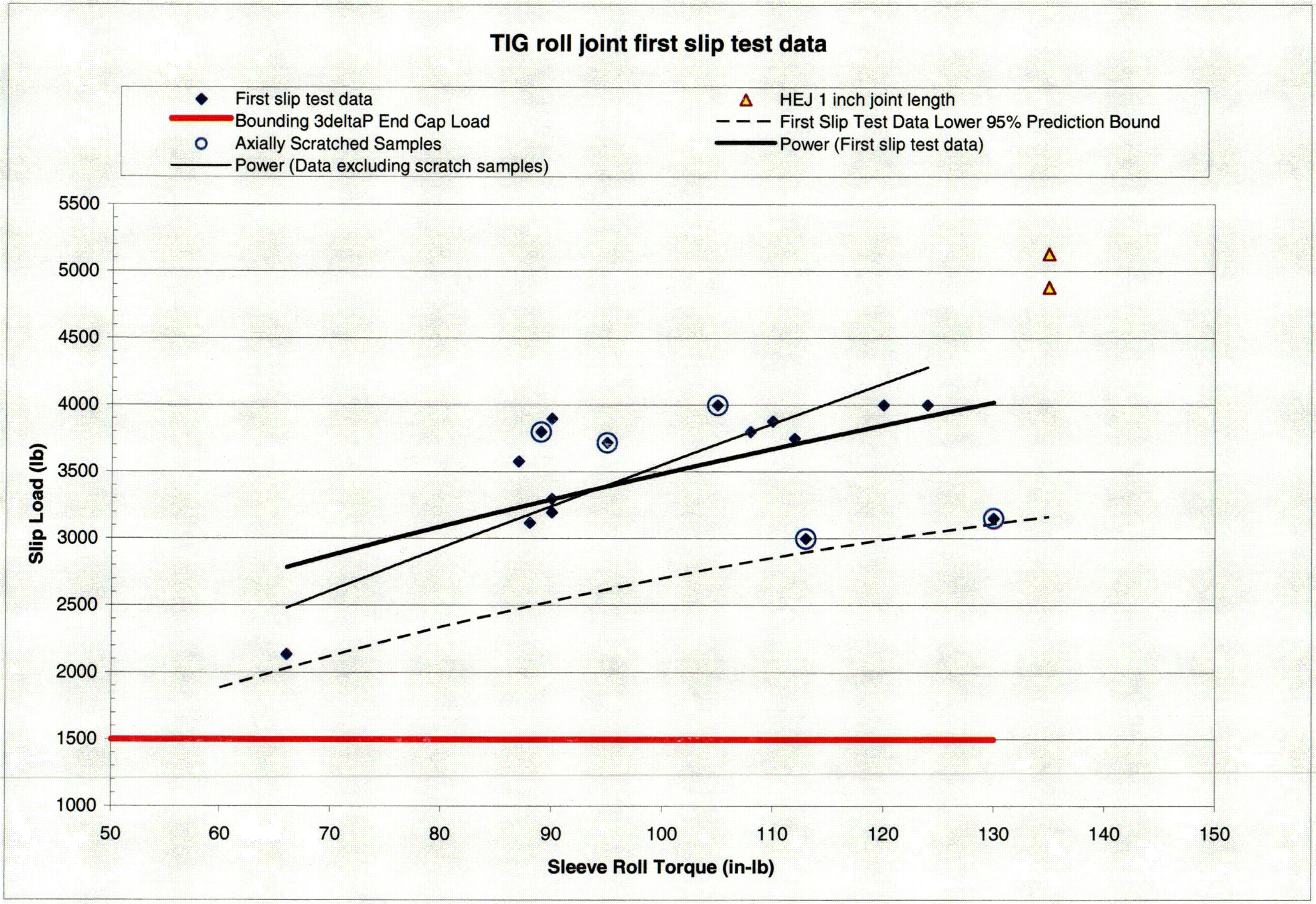
C01

Figure 2



Torque per Unit Area vs Peak Load
HEJ 600 F
HEJ RT
TIG and A800 Lower Range
TIG and A800 Nominal
Peak Load (lbf)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
10
20
30
40
50
60
70
Torque per Unit Area (in-lb/in²)

Figure 3


TIG roll joint first slip test data
First slip test data
Bounding 3deltaP End Cap Load
Axially Scratched Samples
Power (Data excluding scratch samples)
HEJ 1 inch joint length
First Slip Test Data Lower 95% Prediction Bound
Power (First slip test data)
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
Slip Load (lb)
50
60
70
80
90
100
110
120
130
140
150
Sleeve Roll Torque (in-lb)

C03