A DB RILEY TECHNICAL PUBLICATION

RECENT EXPERIENCE IN CONDITION ASSESSMENTS OF BOILER HEADER COMPONENTS AND SUPPORTS

by

James P. King
DB Riley, Inc.
Worcester, Massachusetts

Presented at the
1996 ASME Pressure Vessels and Piping Conference
July 21-26, 1996
Montreal, Quebec, Canada

RST-143 change number to RPI-0135.2

DEUTSCHE BABCOCK
DB RILEY, INC.
Post Office Box 15040
Worcester, MA 01615-0040
http://www.dbriley.com

RECENT EXPERIENCE IN CONDITION ASSESSMENT OF BOILER HEADER COMPONENTS AND SUPPORTS

by
James P. King
DB Riley, Inc.

ABSTRACT

This paper provides recent experience in the condition assessment of boiler header components and supports in fossil fired power plants. Condition assessment programs for boiler headers are now scheduled more frequently due to the current practices of cyclic operation and extended life for older boilers.

Typical assessment tasks as applicable to all boiler headers are described herein. Examples of common problems, with recommended actions, for each type of header are presented. This includes internal bore hole and ligament cracking, and external tube connector weld cracking. Emphasis will be focused on the historical cracking problems associated with economizer inlet and secondary superheater/reheater outlet headers.

INTRODUCTION

Condition assessment programs are now routinely scheduled for boiler headers and their components as part of annual or major outages of fossil fired power plants. This is due in part to the aging of the equipment and to the cyclic type of operation or load following, currently utilized for most units.

A typical condition assessment program for these boiler pressure components would consist of visual and fiberoptic/video inspections, diametrical measurements, ultrasonic thickness testing, magnetic particle examination, tube sample metallurgy and metallographic replication with hardness testing. Based on the results of these tasks, further metal sampling, ultrasonic shear wave testing and analytical studies may be necessary.

Common examples of problem areas associated with the different boiler headers and their components and supports are described herein with an emphasis placed on the major inlet and outlet headers, namely the economizer inlet and high temperature superheater/reheater outlet headers.

BACKGROUND

Headers are an integral part of the water and steam circuits of fossil fired boilers. They are designed to the rules of the ASME Code, Section 1 (Reference 1), to withstand the pressure and temperature service conditions imposed by a design specification. Header components with their associated problems can be grouped according to their operating temperature. High temperature steam carrying headers are of significant concern because they have a finite creep life. The lower temperature water carrying and steam cooled headers are not susceptible to creep damage.

The high temperature headers include the superheater and reheater outlets which operate at temperatures in excess of 900°F. These headers experience the effects of creep under normal conditions. In addition to the material degradation resulting from creep, high temperature headers can also experience thermal and mechanical fatigue. Creep stresses combined with thermal fatigue stresses can lead to a failure much sooner than creep acting alone. Factors influencing creep-fatigue in headers are combustion, steam flow and boiler load. These factors can cause temperature gradients resulting in high localized header stresses. In addition to the effects of temperature variations, the external stresses associated with header expansion and piping loads must be included. In a cycling unit, header expansion may result in fatigue cracks at support attachments, moment restraints and tube stub to header welds. Steam piping flexibility can cause excessive loads to be transmitted to a header outlet nozzle. The subject of the interactions between steam piping and boiler headers is presented in detail in the Reference 2 paper.

The low temperature headers are those operating at temperatures below the creep range. These include waterwall and economizer headers, and superheater inlet and intermediate headers. Any damage to low temperature headers is generally caused by corrosion, erosion, thermal stresses and fatigue. Water carrying headers are typically located outside of the gas stream. One exception is the economizer inlet header, which may be in the gas stream, and is subject to the unique problems associated with cyclic operation. These problems are described more fully in the next section of this paper.

ECONOMIZER INLET HEADER

Most mid and large size utility boilers have an economizer section. The economizer is a heat recovery device, usually located in the convection or back pass, which is designed for the transfer of heat from the external flue gases to the incoming colder feedwater. The feedwater enters the boiler through the economizer inlet header.

During the course of boiler operation, the economizer inlet header can be subjected to several different types of header component failures, due to the temperatures and thermal transients imparted by today's cycling, load following, and peaking modes. These potential failures include: internal bore hole and ligament cracking, external tube stub to header weld cracking and internal erosion of the outlet tubes. The subject of tube stub to header weld cracking is described in detail later in this paper.

Internal Tube Erosion

Internal tube erosion has been found primarily in headers with an underdrilled design. This design incorporates holes drilled in the header which are much smaller than the inside diameter of the outlet tubes. This enables a build up of pressure drop in the economizer section of the boiler, which assists in evening out the flow distributions in the economizer tubes, especially during lower load operation. The erosion can occur on the ID surface of the outlet tubes adjacent to the header wall, and can be caused by the effects of feedwater velocity and corrosive elements in the water. A check on this tube thinning should be accomplished by ultrasonic thickness testing, especially for tubes in the vicinity of the header inlet nozzles.

Internal Bore Hole And Ligament Cracking

The more serious internal header bore hole and ligament cracking is a result of thermal shocking due to cycling type duty. Common types of operation are overnight reduction in load or boiler shut off. For the latter case, a daily morning boiler re-start will introduce colder feedwater into a warmer header with resultant thermal shocking. This temperature difference can be as high as 3000°F. After several thousand of these events, internal fatigue cracking will initiate and propagate in the higher stress ligament fields of the header wall between bore holes, and also longitudinally along the bore hole surfaces. Figures 1 and 2 depict this type of cracking. Periodic internal inspection of an economizer inlet header should be performed by use of fiberoptic or video probes as a check on this internal cracking. Again, the regions of the inlet nozzles should be inspected first. Headers with an underdrilled design are not as susceptible to the cracking, since their ligament efficiency is much higher.

Recommendations to alleviate this cracking condition include a review of boiler operating practices, incorporation of a continuous trickle feed during shut off periods, and installation of a downcomer recirculation system.

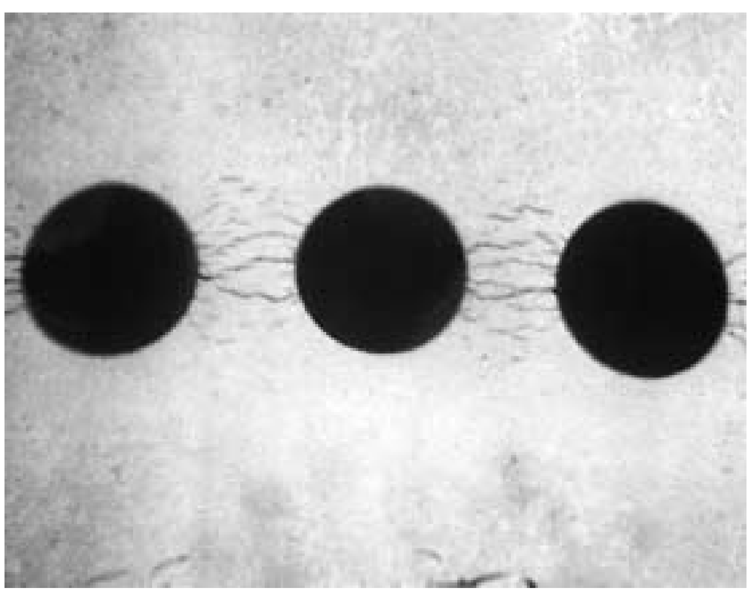

Figure 1 Inside Surface of Economizer Inlet Header Showing Circumferential Ligament Cracking

Figure 2 Sample Piece of Economizer Inlet Header Showing Cracking in Header Bore Hole and Tube Connector

The Reference 3 paper, and the Reference 4 Electric Power Research Institute guideline document address the subject of economizer inlet header cracking in detail.

Once this type of internal cracking is found, the header has a finite life, since repair of internal originating cracks is not possible due to lack of access. An accurate determination of the crack depths should be made, using ultrasonic shear wave techniques. The crack depth information should then be input to stress analysis and fracture mechanics calculations for a definitive remaining component life assessment. Based on these results, measures to alleviate the thermal shocking should be incorporated, along with scheduled monitoring of the crack depths, with an ultimate component replacement date established. A part of the recommended actions may be a change in boiler operating conditions, such as a reduction in pressure and/or essentially base loaded duty, with a minimal number of transients allowed.

HIGH TEMPERATURE OUTLET HEADERS

The high temperature superheater and reheater boiler outlet headers connect to the main steam and hot reheat piping lines, respectively, in supplying steam to the turbine. The operating temperatures for these headers are typically around 1000°F, which is in the creep range. In addition, the headers are susceptible to thermal fatigue due to the effects of the temperature imbalances and transients associated with cyclic type operation. For these headers, potential causes for concern include: internal bore hole and ligament cracking and external weld cracking at tube nipples, nozzles, and hanger plates and moment restraints.

Internal Bore Hole And Ligament Cracking

As for the economizer inlet header, the presence of internal bore hole and ligament cracking is a fairly common occurrence in high temperature outlet headers which have been in service for more than fifteen years. These headers experience the combined effects of high temperature creep and thermal fatigue. The main factors influencing creep-fatigue are combustion, steam flow and boiler load. These factors can contribute to variations in heat input to individual superheater and reheater tubes. When these variations are combined with steam flow differences between tubes within a row, significant variations in steam temperatures entering a header can occur. Changes in boiler load further aggravates the temperature difference between the individual tube legs and the bulk header.

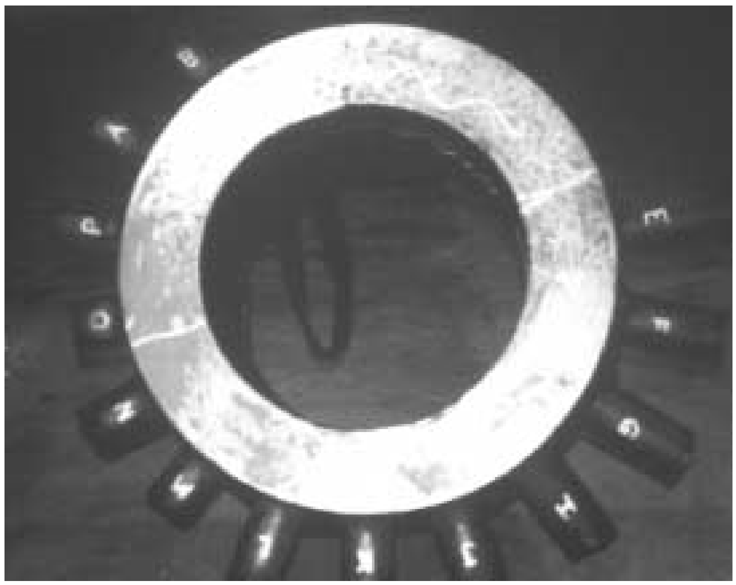

Figure 3 Sample Piece of
Radiant Superheater Outlet Header

This type of internal ligament cracking, as shown in Figure 4, from the Figure 3 sample piece of header, can be easily detected by a planned fiberoptic or video probe examination. The presence of creep in header components can be ascertained by outside diameter measurements as a check on swelling, and by external metallographic replication as a check on the surface microstructure. When internal ligament cracks are found in a high temperature header, ultrasonic shear wave testing should be employed to determine the crack depths. Repairs for this cracking condition are not possible due to the lack of access to the ID surfaces. Again, a stress analysis and fracture mechanics study should be performed to determine an accurate remaining life value for the component. The Reference 5, BLESS computer program, is a powerful tool currently used to provide failure evaluations for headers with internal cracking. The BLESS code is capable of performing deterministic and probabilistic remaining life estimates for boiler header components. The Reference 6 paper presents a case history of a cracked header investigation using the BLESS program.

The Reference 7 paper presents a recent remaining life assessment of a secondary superheater outlet header with internal ligament cracking, using state of the art analytical and nondestructive testing techniques.

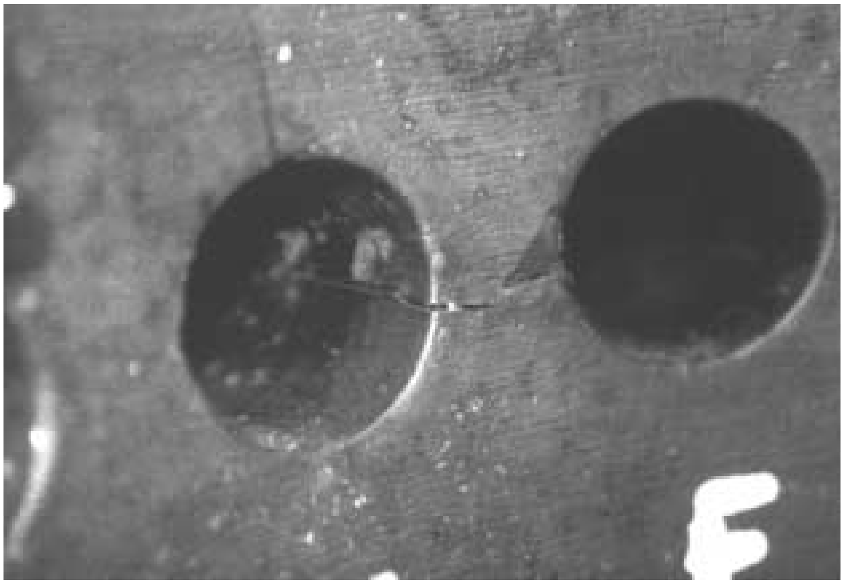

Figure 4 Closeup View of Inside Surface of Header Sample Piece Showing Cracking in Circumferential Ligament Field and Bore Hole

External Header Cracking

External cracking in tube connectors, nozzles and support plate welds is a very common problem found in all headers on a boiler, but is especially prevalent in high temperature outlet headers. This weld component cracking is caused by differential thermal expansion or constraint of thermal expansion, resulting from frequent cycling type boiler operation. The mode of failure is thermal expansion fatigue, sometimes in conjunction with high temperature creep. This type of cracking can most often be found by visual inspection and by wet fluorescent magnetic particle testing. Repair of this cracking can be accomplished by grinding and welding procedures. However, an engineering study should be performed in order to accurately determine the root cause failure. This study should include a review of available component temperature data from thermocouple, etc., during normal steady state and load swing operating periods.

The most common external cracking is at the weld joining the inlet or outlet tube stubs to a header. Sometimes the cracking can be severe enough to cause a tube leak. A single header can have hundreds of these welded joints. The quality of the original welds can be a factor, by way of stress intensification, in the initiation of the cracking. A typical tube stub to header weld is shown in Figure 5. The relative difference in size between the two components tends to make this connection a highly stressed location. In many cases cracking has been found to have initiated in or adjacent to the weld, including locations of weld undercut. Figure 6 and 7 show a typical superheater or reheater outlet header located in the penthouse with the inlet tubing routed from the furnace, through the roof seats, to the header. Figure 7 depicts the differential thermal expansion which can occur between the header and the furnace roof tubes, which has a direct effect on the header inlet tubes. During daily load swing operation, the inlet tubes will be subject to the axial expansion/contraction of the header, in combination with the radial expansion effects imposed by the tube routing flexibility, or lack of same. After several thousand events, crack initiation will result at tube locations with the stiffest routing, highest local steam temperatures and with the poorest quality welds. As mentioned earlier, an engineering study, including a review of temperatures and tube flexibility stresses, is required to consider all of the many variables in determining a course of action to minimize future re-occurrences of the header tube stub cracking. The Reference 8 paper provides some background and case studies of typical header tube nipple failures.

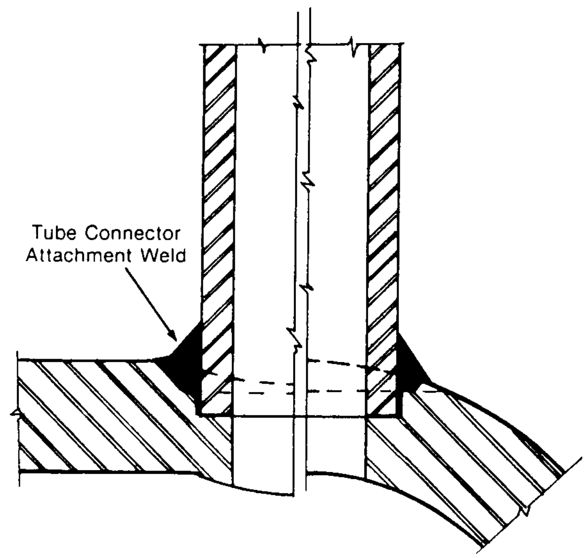

Figure 5 Typical Tube Connector to Header Junction

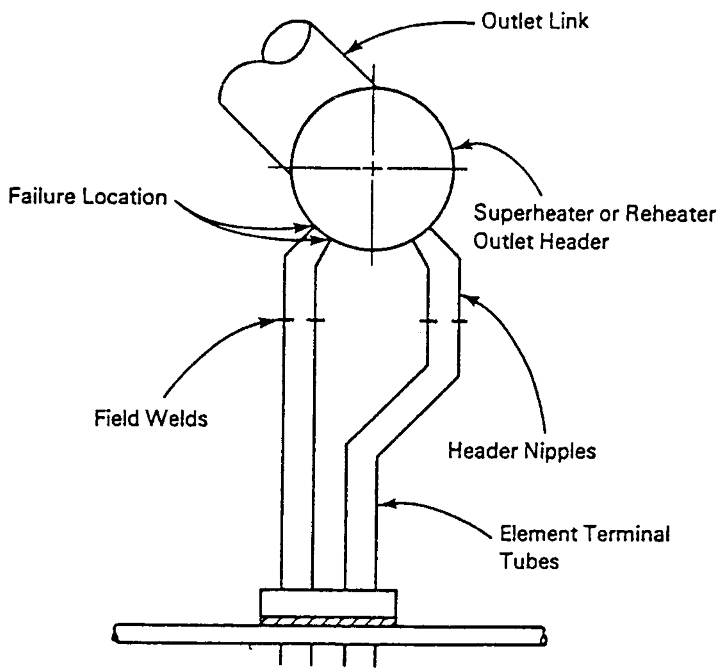

Figure 6 End View of High Temperature Header Showing Differences in Inlet Tube Routing and Flexibility

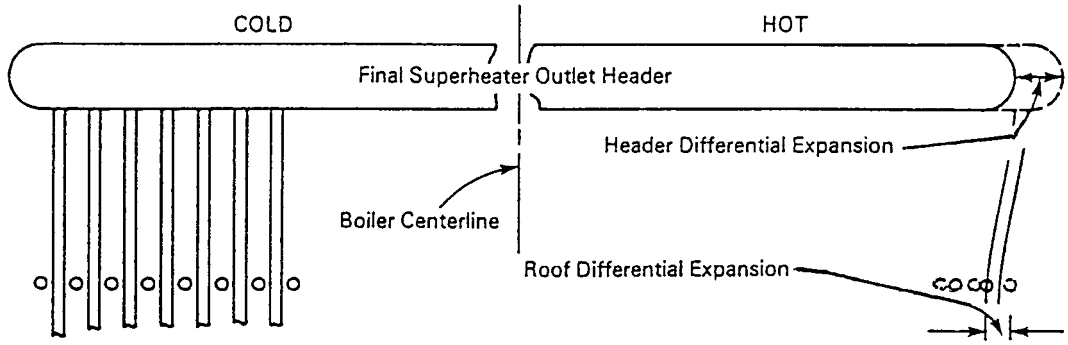

Figure 7 Front View of Figure 6 Outlet Header Showing Differential Expansion (Axial) Between Header Tubes and Furnace Roof Tubes

A review of the Reference 9 paper has provided some items for consideration in the assessment of superheater header cracking. For this study, a combination of higher than expected temperatures and thermal stresses, hanger malfunctions, complex local geometries, stress concentrations and thermal transients led to fatigue and creep cracking that shortened the life of the components. For the study, a detailed three-dimensional stress and heat transfer analysis, and beam structural analysis were performed. In addition, an extensive temperature distribution survey was conducted with thermocouples. Of interest, from the results of the study, is the significant effects of header top-to-bottom gradients. The gradient values were found to be low during normal operation, but during the latter part of startup and shutdown events, they increased substantially causing severe bending stresses. Also, the study results revealed stress concentration values in the range of 2.2 to 2.9 in the region of the header bore holes.

SUMMARY

Recent experience in problem areas encountered with critical boiler header components and supports has been presented herein. Emphasis has been focused on the major inlet and outlet headers of a boiler, namely the economizer inlet header and the high temperature superheater and reheater outlet headers.

The typical failures and problems associated with these headers, together with their resolutions, have been described. Most often, these problems were found during scheduled boiler inspection and condition assessment programs. Today's operational practices, including cyclic operation and extended life for older boilers, have accelerated the propensity for cracking and eventual failures in critical pressure components such as headers, piping and tubing.

For the economizer inlet header, the potential failure locations include: internal bore hole and ligament cracking, external tube stub to header weld cracking, and internal erosion of the outlet tubes.

For the high temperature superheater/reheater outlet headers which are subjected to the combined effects of creep and thermal fatigue, problem locations include: internal bore hole and ligament cracking and external weld cracking at tube stubs, nozzles and hanger plates.

Table I provides a summary of these boiler headers, including the types and causes of damage applicable to each, with the recommended inspection and nondestructive testing tasks and remedial action required.

Table I Typical Boiler Critical Header Component Problem Areas

Component	**Damage Type**	**Failure Cause**	**Inspection/ NDT Techniques**	**Remedial Actions**
Economizer Inlet Header	Bore hole and ligament cracking	Thermal fatigue	Internal video, UT shear wave, Metal sample	Operational change, Monitoring, Eventual replacement
Economizer Inlet Header	Tube ID thinning	Erosion-corrosion	UT thickness	Repair/replace
Economizer Inlet Header	Tube stub weld cracking	Thermal expansion fatigue	Visual inspection MT examination	Repair
High Temperature Superheater/ Reheater Outlet Headers	Bore hole and ligament cracking	Thermal fatigue and creep	Internal video, UT shear wave, Metal sample, replication	Operational change, Monitoring, Analytical study, eventual replacement
High Temperature Superheater/ Reheater Outlet Headers	Tube stub, nozzle and attachment weld cracking	Thermal expansion fatigue and creep	Visual inspection, O.D. measures, MT examination, Replication, Hardness testing	Analytical study Repair

RECOMMENDATIONS

Condition assessment programs for critical boiler headers should be incorporated into the outage planning for each unit. Programs should be scheduled for three to five year intervals, depending on the age of the boiler, the type of operation and the severity of problems experienced to date.

A program should consist of the visual inspections and nondestructive and metallurgical testing tasks, as described in the text and presented in Table I.

For a header found to have internal bore hole and ligament cracking, the recommended actions include the following: First, document the findings with a video tape recording. This can prove valuable for later review, using video analyzing equipment. The next on-site task would be to perform ultrasonic shear wave testing, using the latest techniques such as tip diffraction to obtain an estimate of crack depths, especially in the ligament fields. This information, along with material property data and operating parameters, is then input to stress analysis and fracture mechanics calculations in order to confirm the suitability for continued operation, and to provide a definitive remaining life value for the component. The taking and analyzing of a metal boat sample from the outside surface will provide much information on the current microstructural condition and on the crack morphology. These results are also factored into the remaining life derivation. When the component is ultimately replaced, pieces of the header can then be evaluated to provide additional data on the root cause of the cracking.

For the more common case of header to tube connector weld cracking, repair or replacement is much more easily accomplished due to the external access. The cracking is usually found in the toe of the weld in the tube or header metal heat affected zone. A repair method will involve grinding out the cracks, with confirmation by dye penetrant testing, and then re-welding, utilizing the appropriate pre- and post-weld heat treatment procedures. In the re-welding process, smooth, blend grinding steps should be done for the weld exterior to insure minimizing the joint stress intensification factor.

REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section 1, Power Boilers, 1995 Edition.

2. King, J., "The Interactions Between Steam Piping and Boiler Outlet Headers in Fossil Power Plants," ASME PVP - Volume 282. Presented at the ASME Pressure Vessels and Piping Conference, Minneapolis, MN, June, 1994.

3. Hunter, J.; King, J. and Bauer, J.; "Boiler Life Extension Recent Observations and Evaluations of Economizer Inlet Header Cracking." Presented at the Joint Power Generation Conference, Portland, OR, October, 1986.

4. Electric Power Research Institute Document No. GS5949 entitled, "Guidelines for the Prevention of Economizer Inlet Header Cracking in Fossil Boilers," dated November, 1989.

5. Harris, D.O.; Wells, C.H.; Bloom, J.M.; Schultz, C.C.; Grunloh, H.J.; Ryder, R.H.; and Viswanathan, R.; "BLESS; Boiler Life Evaluation and Simulation System A Computer Code for Reliability Analysis of Headers and Piping:, ASME PVP-Vol. 251, Reliability and Risk in Pressure Vessels and Piping. Presented at the ASME Pressure Vessels and Piping Conference, July 1993, Denver, CO.

6. Roland, R.; King, J. and Kalmanovitch, D., "Failure Analysis Study of a Cracked Superheater Outlet Header," Presented at the Fourth EPRI Conference on Fossil Plant Inspections, San Antonio, TX, January, 1994.

7. Rosario, D.; Riccardella, P.; Bisbee, L.; Luttrel, M.; Nelson, S.; Eastman, A.; and Rogers, M., "Remaining Life Assessment of a Secondary Superheater Outlet Header." ASME PVP-Vol. 303. Presented at the ASME Pressure Vessels and Piping Conference, Honolulu, HI, July, 1995.

8. King, J. and Bauer, J., "Recent Experience in Boiler Header Tube Nipple Failure," EPRI Conference on Boiler Tube Failures in Fossil Plants, Atlanta, GA, November, 1987

9. Ganta, B.R., "An Analytical Study of a Secondary Superheater Outlet Header and Supporting System to Reduce Stub Tube Weldment and Borehole Cracking." Presented at the ASME Pressure Vessels and Piping Conference, June 1994, Minneapolis, MN.