BOILER LIFE EXTENSION— A NEW LEASE ON LIFE

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ABSTRACT

Over the past decade, the Electric Utility Industry has been plagued with such problems as depressed load growth, high costs of new plant construction, long lead times, lengthy siting procedures, conformance to strict new source performance standards and protesting rate payers. It is not surprising that programs for extending the useful operating life of fossil fired generating stations are receiving considerable attention. A Life Extension Program for older units is a cost effective means of deferring new capacity.

A Life Evaluation Study is the first step in the decision process to determine if further Life Extension consideration is warranted. This study is designed to assess the present condition, identify potential problem areas, and provide remaining life estimation for major and critical components of the boiler and associated equipment. Detailed evaluations including review, inspection, non-destructive/destructive examination, and engineering analysis comprise a major part of the Life Evaluation Study. A detailed report provides recommendations for monitoring, repair and/or modifications to extend the useful life of the boiler in accordance with the owner's operational requirements. This paper outlines Riley Stoker's approach to Boiler Life Extension.

INTRODUCTION

A Boiler Life Extension Program provides the owner with an assessment of the present physical state of his equipment and identifies the repairs and/or modifications necessary to extend the operating life. This information is needed to allow for sound decisions based on economics, projected load growth, system capacity and time required to implement change.

In recent years, many utilities have changed the duty cycle on their existing boilers. In most cases, the units were not designed for service under these revised operating conditions. As a result, the owner has experienced a higher rate of failures, forced outages and availability loss. Life Extension evaluates and recommends changes consistent with the current and future operational requirements of the owner.

For various reasons, many generating units are operated well below their rated capacity. A Life Extension Program may provide owners the information to overcome these restrictions, and provide for an increase in rated output. Also, Life Extension can provide an owner relief from meeting the current performance standards imposed on new units.

Depending on operational requirements and the condition of the equipment, some utilities may require only small expenditures beyond normal maintenance costs to upgrade their equipement for Life Extension purposes. The return on investment is often realized in a very short period through reduced maintenance and production costs. Since fuel costs represent the single largest contribution to a plant's operating budget, an increase in unit efficiency will result in significant savings.

As an original equipment manufacturer, Riley Stoker provides the expertise, information, and generic experience necessary for meaningful and effective performance of a Boiler Life Evaluation Study.

LIFE EVALUATION STUDY

Riley's Life Evaluation Study encompasses four separate and distinct phases, which are:

- Review
- Inspection
- Analytical
- Reporting

REVIEW PHASE

This initial phase is comprehensive in nature, and serves to provide a current data base which helps determine specific areas to focus on during the inspection and analytical phases of the evaluation. The review tasks include:

Review Operating History

The Utilities internal records and Riley's field service records are reviewed for unit performance, changes in operation, abnormal events, failures, forced outages, unit availability and maintenance history. A portion of this information can be obtained from a prereview questionnaire, furnished by Riley and filled out by the utility for each unit.

Review Design Documentation

A review of original design specifications, operating and engineering procedures, drawings; stress and performance analysis calculations; temperature, pressure and flow rate histograms, support loads, etc. is performed.

Interview Utility Personnel

The plant operation, engineering and maintenance personnel are interviewed to supplement the documentation and operational history reviews.

Review Boiler Operation

Prior to an outage, a review of actual operating procedures is conducted at the plant. Boiler operation during startup, shutdown and ramping modes is monitored. The unit is walked down while on-line to observe operating conditions, expansion movements, and any obvious external problem areas.

The review tasks should be scheduled to occur one to three months ahead of the planned outage. This will allow for sufficient time for completion of the historical and documentation reviews necessary to develop unit and component histograms, and for identification of the plant preparatory items needed for the physical inspection of the boiler.

During the review phase, particular attention is given to the records of abnormal events. These type of events are generally unique and impact every unit. They consist of unplanned events and those postulated to occur very infrequently. Unusual events such as rapid temperature or pressure excursions, caused by unforseen system operational effects, can result in severe overheating, overstress, and thermal shock loadings. External effects, such as a hurricane, can cause excessive wind loadings. Human error, such as failure to remove temporary support stops after an outage, can cause excessive thermal expansion loadings. The records of such identified abnormal events can provide valuable background information, both on the present condition of the boiler and to the cause of any actual failures or suspected problem areas.

When all the review tasks have been completed, the pertinent information is summarized and a detailed inspection plan finalized. The information from the review phase helps identify those areas warranting non-destructive and destructive examinations and detailed engineering analysis. The original equipment manufacturer's experience and knowledge of generic problem concerns, combined with unit historical data, is invaluable to both the review and inspection phases of a Life Evaluation Study.

INSPECTION PHASE

The physical inspection of the boiler and equipment is performed during an outage by a multi-disciplined team consisting of Performance Analysis, Stress Analysis, Service and Construction personnel. The specific tasks that comprise the inspection phase include:

Walkdown

A unit walkdown is performed with visual inspection of all boiler equipment and components identified herein. Measurements and photographs are taken, as appropriate, and observations recorded for such items as structural damage, interferences, malfunctions and misalignment. Also, areas of potential concern such as visible corrosion, erosion, pluggage, swelling, bowing and sagging are noted. The visual inspection includes components of the following boiler regions and equipment.

Boiler Pressure Parts

Furnace, Roof and Floor
Economizer, Superheater and Reheater
Drums and Headers, including Hangers and
Expansion Joints

Boiler Structure

Main Hanger Rods
Buckstays
Suspension Level Steel

Boiler Setting

Casing, Lagging, Refractory and Insulation
Furnace Hopper and Lower Seals
Dead Air Space
Penthouse

Air And Flue Gas Systems

Air Preheater
Fans
Air And Gas Ducts

Fuel System

Windbox
Burners
Coal Handling System

Miscellaneous

Sootblowers

Nondestructive Examination

Nondestructive examinations are utilized to obtain a more complete picture of a boiler component's condition. Selection of locations for examination is based on:

- An observed problem such as visible swelling or sagging.
- A suspected problem component based on historical records or stress analysis.
- Potential high stress areas.
- Engineering judgement.

The following simplified nondestructive testing techniques can be utilized.

- Ultrasonic measurement
- Dye penetrant examination
- Magnetic particle examination
- Borescope inspection
- Replication

Ultrasonic thickness measurements are taken in representative boiler tubes. Based on these measurements and visual inspection, tube samples are usually chosen for further in-house wastage and metallurgical studies.

Liquid dye penetrant or magnetic particle examinations are performed on selected welds on components such as elbows, tees, nozzles, fabricated branch connections, header tube connections, support attachments, and dissimilar metal joints; associated with the steam drum, superheater, reheater, economizer, and hopper headers and piping. The purpose of these examinations is to detect early crack initiation in the welds and adjacent heat-affected zones. An example of typical tube connector fatigue cracks, detected by magnetic particle examination, is shown in Figures 1 and 2.

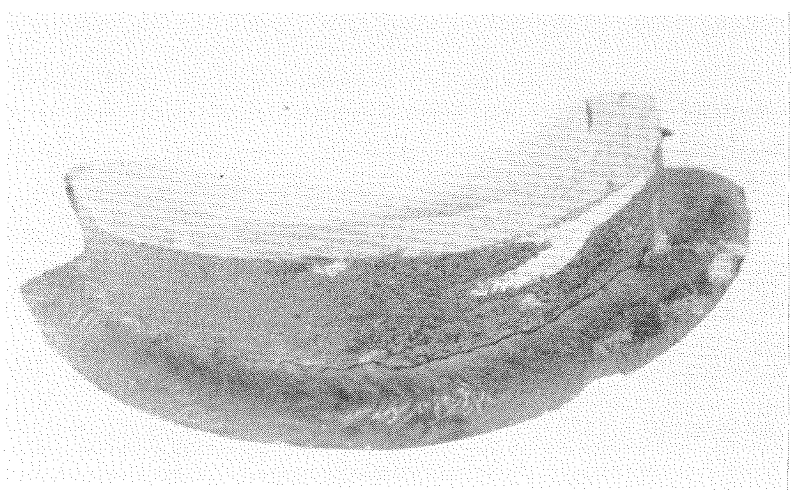

Figure 1 *A portion of a header tube connection showing circumferential fatigue cracking at the weld.*

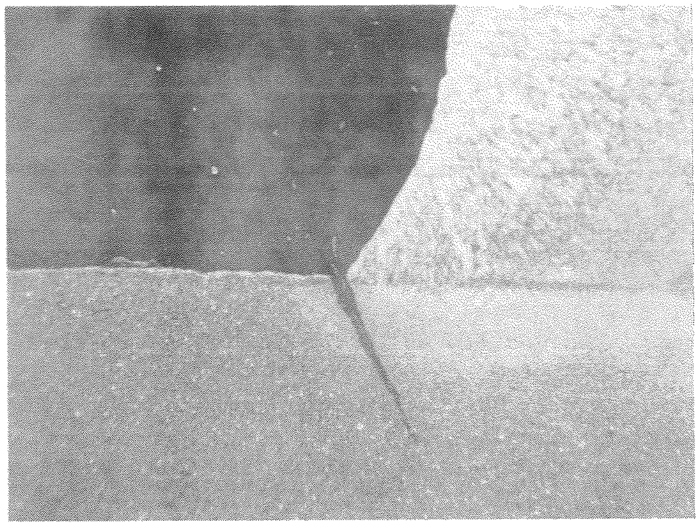

Figure 2 A transverse view of header tube connection showing fatigue crack initiated at toe of fillet weld.

Borescope inspection is performed on selected headers, such as economizer inlet and superheater and reheater outlet, to determine internal conditions. Figures 3, 4 and 5 show internal cracking in the header and tube connectors of an economizer inlet header. The cracks are caused by corrosion fatigue, induced by repeated occurrences of cold water (thermal cycling) entering the header. A borescope inspection of this header would have identified the cracking much earlier and allowed for timely corrective action.

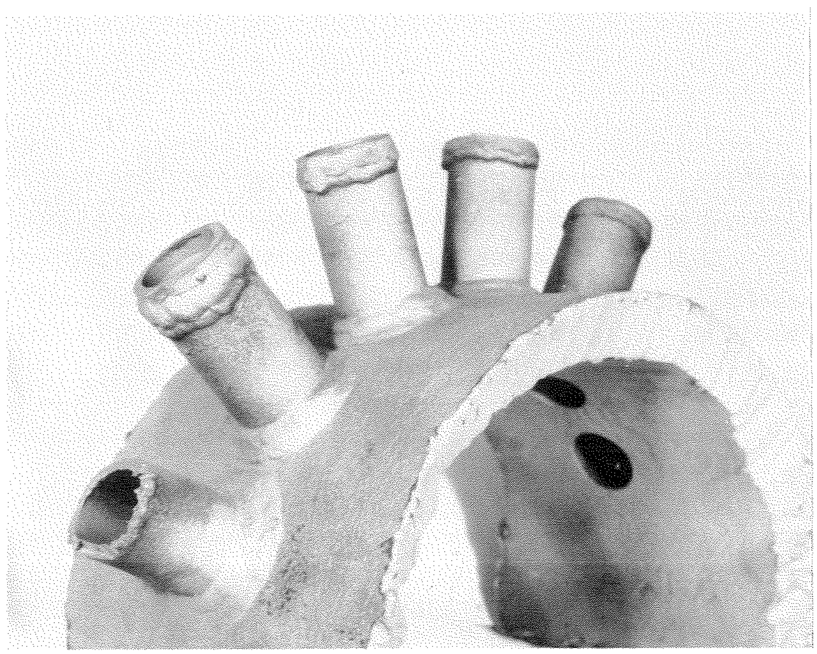

Figure 3 A portion of an Economizer Inlet Header with internal cracking.

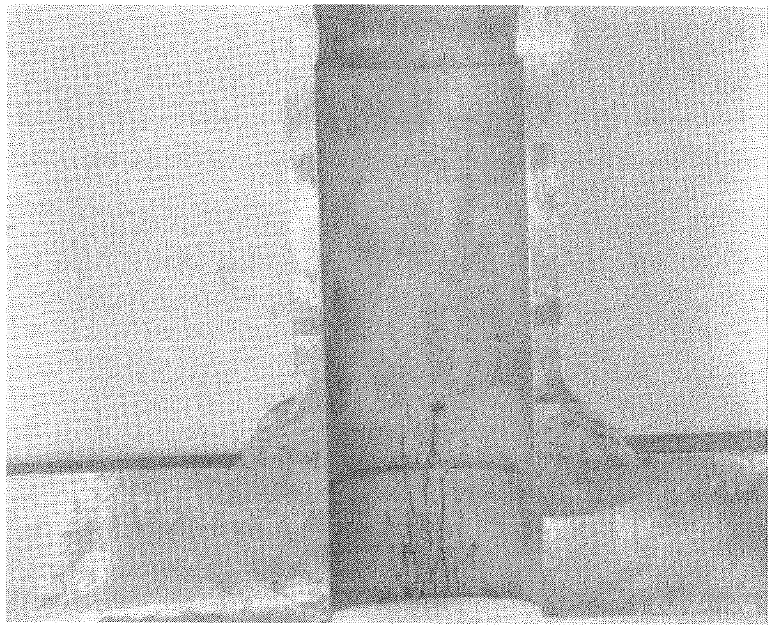

Figure 4 *View showing internal cracking along the tube connector and bore of an Economizer Header.*

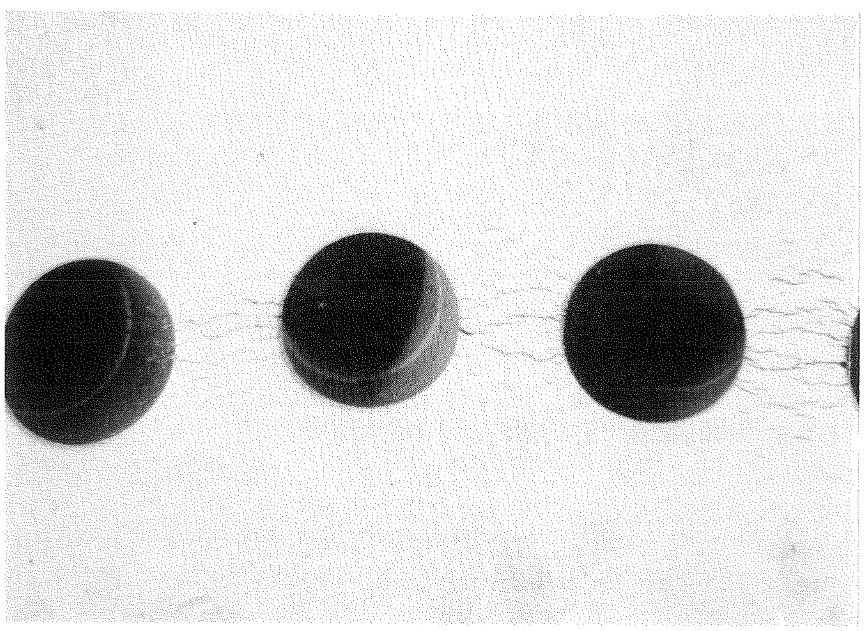

Figure 5 *View showing internal cracking in the ligament field of header from corrosion fatigue by thermal stressing.*

Field surface replication is performed on suspected problem components, such as those with visible swelling or sagging, and at representative high temperature/high stress locations, such as the block forged tee on a superheater outlet header. The replication method of nondestructive examination produces a record of the present material condition at a location. It allows for examination of the microstructure, which can show the existence of micro-cracks, spheroidization, graphitization, creep voids and creep void link-ups.

Replication is a technique for obtaining an image of a component's surface, with sufficient retention of fine structure to allow for later laboratory examination, without having to remove a metal sample. Initially, in the replication process, several steps of grinding and polishing are performed on a selected location. The polished surface is then etched to reveal the microstructure. Replica samples are taken from the etched surface using a softened plastic film. The film is then preserved for future laboratory evaluation; where optical and/or scanning electron miscroscopy are used to examine the replica samples.

The replication technique is gaining more widespread utilization in the fossil plant industry. It has been used in German plants since 1977. Neubauer and Wedel[1] have employed the method to detect cracks and cavities mostly in welds and bends on high temperature power plant piping. Figures 6 and 7 show photomicrographs, at two magnifications, from a typical replica taken at a location on superheater outlet piping.

Destructive Examination

During the field inspection, representative locations for core and/or boat samples of headers or piping, and boiler tube samples are chosen for further in-house laboratory examination, especially for areas of potential or actual failure. Typically, superheater, reheater and selected waterwall tube samples are essential for remaining boiler life predictions.

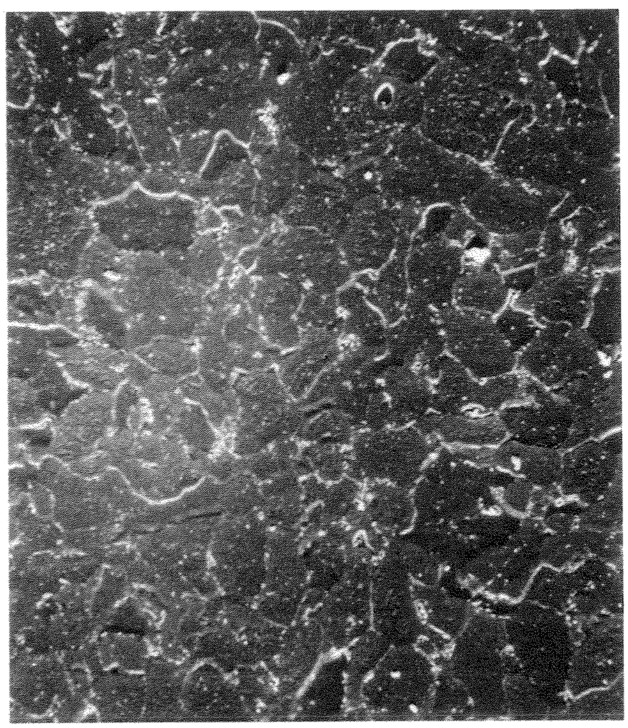

Figure 6 Scanning Electron Photomicrograph (500X) of replica revealing a Ferrite Matrix with Spheroidized Carbides and Grain Boundary Precipitates. - Courtesty of Teledyne Engineering Services.

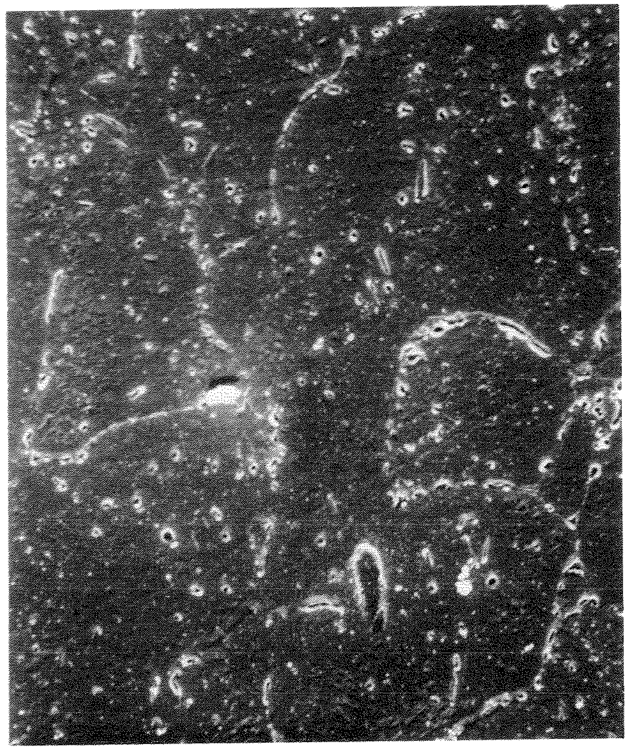

Figure 7 Scanning Electron Photomicrograph (1000X) of same replica showing evidence of isolated creep of microvoids which appear as bright spots. - Courtesy of Teledyne Engineering Services.

ANALYTICAL PHASE

The following analytical tasks form an integral part of the Life Evaluation Study:

Wastage Study

Wastage studies are performed on the boiler tube samples. The field ultrasonic thickness readings are correlated with physical measurements of the sample tubes. Internal and external deposits are analyzed to determine the cause of possible erosion and corrosion, to ascertain the current condition and to estimate the remaining service life of the boiler tubes.

Metallurgical Evaluation

The sample replicas are examined in the laboratory using optical or scanning microscopy. The current microstructure will reveal the presence of any creep voids or void link-ups along grain boundaries. This will determine the need for any immediate remedial repair, or the need for any future monitoring to observe creep void growth rates.

Laboratory analysis of metal samples, from header or piping components, are performed to ascertain the present condition of the material. The results of the metallurgical evaluations are important guides to the direction of the stress analysis.

Boiler Duty Cycle Evaluation

It is very common for boilers of the twenty to thirty year vintage, which were originally designed as base loaded units, to have been used for cycling and/or peaking duty in recent years. The designs and operating characteristics of base load, cycling and peaking units are quite different, and much emphasis is placed on a changed mode of boiler operation in the Life Evaluation Study.

Base load units are designed to operate round the clock, for long periods of time, at essentially constant load, at or near rated output.

Peaking units operate round the clock when system conditions require, but frequently the load on the unit varies rather widely in accordance with system requirements. Typically, the peak output would occur for short periods during weekdays. The operating conditions most different from a base loaded unit are; higher steam flow, higher steam pressure and lower feedwater temperature.

Cycling units are generally started and shutdown to a hot standby condition daily as system conditions require, to meet peak power demands. For base load designed boilers used as cycling, rigorous demands are placed on the operating conditions, which require variable pressure values throughout the load range. The daily shutdowns, hot and cold startups and rapid load responses, inflict severe thermal cyclic stresses and overtemperature conditions that may not have been accounted for in the original design.

A changed mode of boiler operation impacts all aspects of a Life Evaluation Study including; the review and inspection phases, and the metallurgical, stress and performance analysis portions of the study.

Stress Analysis

Various stress analysis tasks are performed for selected critical boiler components and locations, to assist in the remaining life estimations. Typical components chosen for evaluation include; drums, headers, piping and tubes, with their associated nozzles, tees, branch connections, elbows, welded attachments and dissimilar metal welds.

Stress analysis calculations to code rules are performed, taking into consideration the normal sustained loadings of pressure, deadweight and thermal expansion. Specified occasional loadings, such as earthquake or valve thrust, are also accounted for. The effects of malfunctioning equipment or abnormal loadings, such as waterhammer, which are identified in the review of records are also considered. The actual operating conditions are compared to the specified conditions; and the "as-walked" condition of headers, piping, supports, expansion joints, etc. is compared with the "as-designed" condition. The effects of any differential thermal expansions and associated physical restrictions are noted and evaluated.

Simplified fatigue calculations are performed, with importance placed on a changed mode of boiler operation. Revised pressure, temperature and flow excursions are derived, and actual metal temperature values utilized. Thermal gradient analyses are performed, for input to the fatigue evaluations, with the more severe transients taken into consideration. Components such as header nozzles and spray stations, with thermal sleeves, are evaluated for fatigue life considerations.

For high temperature/stress components, such as a block tee on a superheater header, simplified creep calculations are performed. Classical methods, such as the Larson-Miller Life Prediction Curves[2], which are based on material stress rupture values at temperature, are used for the creep evaluations. Where necessary, creep-fatigue interactions are considered for components, utilizing elastic or inelastic techniques. The cumulative damage factors from both failure modes are summed and compared to an allowable. The elevated temperature rules from ASME Code Case N-47[3] are used as a guidance for the creep and creep-fatigue evaluations.

For problem components showing evidence of severe cracking, it may be necessary to employ state of the art fracture mechanics techniques to determine an estimation for remaining life.

Performance Analysis

A complete performance review is conducted, based on up to date and accurate boiler operating data. This information is evaluated and compared to the original design values. Desired operating conditions, such as pressure and load ramp rates are established, particularly for a change mode of boiler operation. This will include the generation of a computerized heat transfer model to simulate the various ramp rates, using actual boiler performance as the existing base. Limitations or deficiencies are identified from the computer modeling. These deficiencies may be addressed through redesign of circuitry, upgrade of material, changes in operating philosophy and external system additions, where possible. A predicted performance tabulation with curves is prepared, reflecting the revised unit operating philosophy.

REPORTING PHASE

A preliminary report, documenting initial inspection findings and conclusions is prepared. This report will provide the owner with information on the present condition of the boiler, and those areas or components warranting attention for the immediate or short term.

A final report containing an executive summary, analytical results, assessment on state of equipment, and recommended actions to extend the equipment's operating life will be issued. This report will prioritize those actions in accordance with the following categories:

1) Necessary and warranting immediate attention
2) Necessary but can be deferred
3) Should be considered for plant improvement, but not mandatory for Life Extension

The report will also provide estimates on costs and scheduling to implement actions as noted and to provide recommendations for monitoring, and revised operational and maintenance procedures. Following the submittal of the final report, a meeting with the owner is arranged to discuss the evaluation, findings, and recommendations.

SUMMARY

This paper has presented the methodology of Riley Stoker's Boiler Life Extension Program. The main emphasis has been placed on the Life Evaluation Study where the present condition of the boiler and equipment is ascertained through a systematic process of review, inspection, and analytical evaluation. This process, as described herein, features a "once-through" type of approach; however, each Life Evaluation Study is unique in that it can vary significantly from unit to unit depending on the owner's wishes and needs, and on the amount and intensity of failure analysis required.

Much detail has been focussed on the nondestructive examinations and analytical evaluation of the critical boiler pressure parts. Those which experience severe loadings, and those which have a history of potential failure. However, the Life Evaluation Study encompasses all of the boiler parts and equipment, as listed herein. All obvious and suspected problem areas discovered during the physical inspection, are given special consideration in the analytical evaluation portion of the study.

The principal goal in the Life Extension Process is to defer capital expenditures for new capacity additions. There are, however, added benefits which may be realized through implementation of a Life Extension Program, and are summarized as follows:

- A detailed reporting of current physical condition of equipment.
- A determination of the feasibility, scheduling and cost to extend the boiler's operating life for a designated period of time.
- A determination if boiler uprating can be accomplished in a Life Extension Program.
- A determination if improvement in operating efficiency and boiler availability can be accomplished in a Life Extension Program.
- A definition of the boiler operational requirements in the extended life period.
- Documentation of the unit's condition for insurance carrier purposes.

REFERENCES

1. Neubauer, B. and Wedel, U., "Restlife Estimation of Creeping Components By Means Of Replicas", ASME International Conference on Advances in Life Prediction Methods, Albany, N.Y., April, 1983.

2. Larson, F.R and Miller, J., Trans. ASME, July 1952, p. 765-775.

3. ASME Boiler and Pressure Vessel Code, Code Case N-47-21, "Class 1 Components in Elevated Temperature Service", dated December 11, 1981.