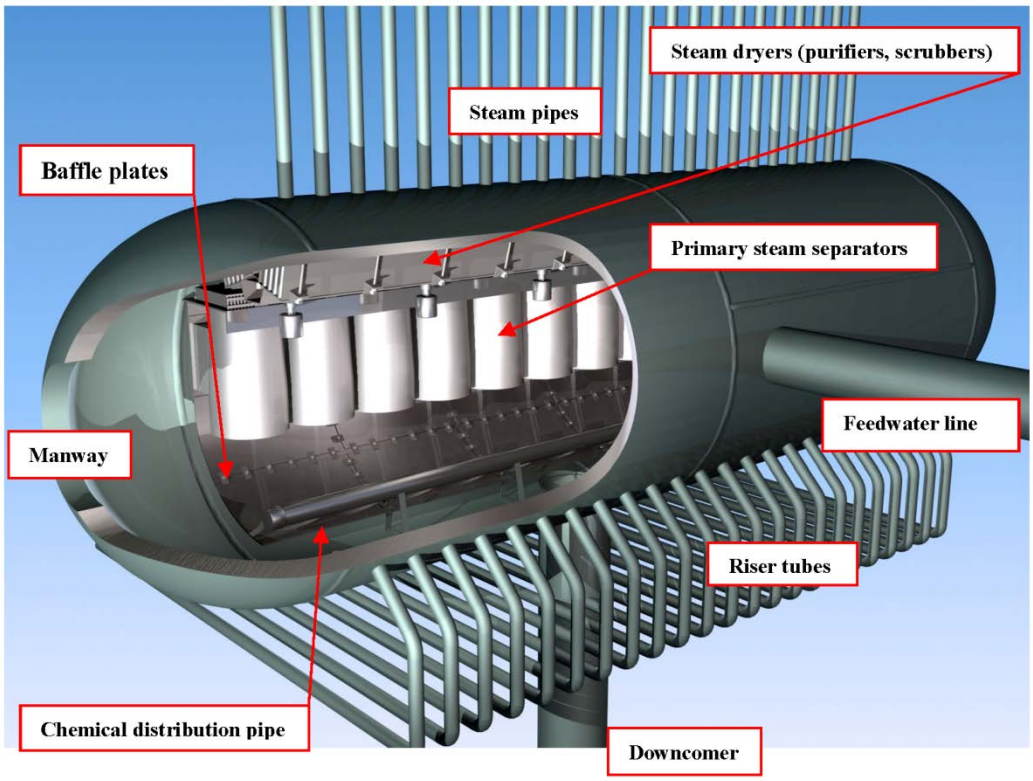
EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Nondestructive Evaluation and Diagnostic/Troubleshooting Guide for Steam Drums

3002003422



Nondestructive Evaluation and Diagnostic/Troubleshooting Guide for Steam Drums

3002003422

Technical Update, July 2014

EPRI Project Manager

S. Walker

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

REFERENCE HEREIN TO ANY SPECIFIC COMMERCIAL PRODUCT, PROCESS, OR SERVICE BY ITS TRADE NAME, TRADEMARK, MANUFACTURER, OR OTHERWISE, DOES NOT NECESSARILY CONSTITUTE OR IMPLY ITS ENDORSEMENT, RECOMMENDATION, OR FAVORING BY EPRI.

THE FOLLOWING ORGANIZATIONS PREPARED THIS REPORT:

Electric Power Research Institute (EPRI)

Intertek AIM

PIKA Solutions

Yagen Consulting, Inc.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

Electric Power Research Institute, EPRI, and TOGETHER…SHAPING THE FUTURE OF ELECTRICITY are registered service marks of the Electric Power Research Institute, Inc.

Copyright © 2014 Electric Power Research Institute, Inc. All rights reserved.

ACKNOWLEDGMENTS

The following organizations prepared this report:

Electric Power Research Institute (EPRI)
1300 West W. T. Harris Blvd.
Charlotte, NC 28262

Principal Investigator
S. Walker

Intertek AIM
601 West California Avenue
Sunnyvale, CA 94086

Principal Investigators
C. Lee
F. Faham
H. Vaillancourt

PIKA Solutions
200 Spotted Dog Ct.
Watsonville, CA 95076

Principal Investigator
S. Paterson

Yagen Consulting, Inc.
366 Shoreline Place
Decatur, IL 62521

Principal Investigator
J. Yagen

This report describes research sponsored by EPRI. EPRI acknowledges the following individuals from Intertek for their contributions to this report:

Tom Burnett Kevin Hara Doug Hilleman
Andrew Holuszko Jim Yavelak

This publication is a corporate document that should be cited in the literature in the following manner:

Nondestructive Evaluation and Diagnostic/Troubleshooting Guide for Steam Drums. EPRI, Palo Alto, CA: 2014. 3002003422.

ABSTRACT

The steam drum is the largest and most expensive to replace component in the boiler. As such, acomprehensive diagnostic monitoring and examination program is essential to ensure reliable and safe operation of the steam drum. The examination program should include pre-outage planning, preparation of safe access, examinations and justified repairs during outages, and post-outage evaluations and documentation. Planning an examination of a drum involves many steps prior to the actual examination, including:

- Review of the design and operational history of the drum
- Review of past examinations, including the history of damage and repairs, and any prior fitness-for-service analyses
- Review of diagnostic monitoring data and any additional instrumentation that may have been installed

During outages, trained plant personnel will provide and maintain safe access for inspectors performing internal and external examinations of the drums and supports. Thorough external and internal visual examinations, performed by trained authorized jurisdictional and/or insurance inspectors, performed annually should identify any major damage or evidence of damage-precursors.

During scheduled extended outages or when damage is detected during an examination, more extensive examinations should be performed. Selected portions of the drum internals should be removed to provide access to the drum internal surfaces. The scope of detailed drum examinations tends to emphasis examinations performed from inside the drum. Comprehensive external surface examinations of drums are sometimes performed but, in most cases, would require extensive removal of asbestos insulation.

Visual, videoborescope, magnetic particle, and various ultrasonic examination techniques are commonly used for locating discontinuities. AC potential drop and ultrasonic testing techniques are commonly used for sizing discontinuities. Exploratory grinding may be used to verify crack size measurements.

Fitness-for-service evaluations are used to determine if discontinuities are acceptable or require removal and repair. After each outage, all the drum examinations, discontinuity evaluations, excavations, and repairs should be documented and communicated to salient persons. The overall asset integrity management process then begins again with the updated pre-outage planning.

Keywords

Diagnostic monitoring
Lower water-wall drum
Mud drum
Nondestructive examination
Steam drum

CONTENTS

1 **INTRODUCTION 1-1**

Background 1-1

Objectives 1-1

Work Scope 1-1

2 **STEAM DRUMS AND LOWER WATER-WALL DRUMS 2-1**

Steam Drums 2-1

Introduction 2-1

Steam-Water Separation 2-4

Lower Water-Wall Drum 2-5

Drum Design and Materials 2-6

Drum Control Logic 2-7

3 **COMMON DAMAGE MECHANISMS AND LOCATIONS 3-1**

4 **PRE-OUTAGE ACTIVITIES 4-1**

Proactive Troubleshooting Auditing Questions 4-1

Introduction 4-1

Design Attributes 4-1

Fabrication Attributes 4-1

Operating History 4-2

Maintenance 4-2

Diagnostic Monitoring of Drums 4-3

Introduction 4-3

DCS Data Points 4-3

Drum Level 4-4

Cycle Chemistry 4-5

Thermocouples 4-5

Strain Gauges 4-7

Safety 4-8
Requirements for NDE of Steam Drums and Lower Water-Wall Drums 4-8
NDE Techniques 4-9
NDE Technicians 4-9
Pre-Job Qualification 4-10
Post-Job Equipment Check 4-10
Control of NDE 4-10

***5* NONDESTRUCTIVE EXAMINATION OF DRUMS 5-1**
Introduction 5-1
Annual Steam Drum Examinations 5-1
Comprehensive Steam Drum Examinations 5-1
Examination Planning 5-1
NDE Techniques 5-3
Introduction 5-3
Visual Examination 5-4
Videoborescope Examination 5-6
Magnetic Particle Examination 5-7
Liquid Penetrant Examination 5-8
Exploratory Grinding 5-8
AC Potential Drop 5-9
Ultrasonic Examination 5-9
Surface Preparation for Ultrasonic Examinations 5-9
Ultrasonic Thickness Measurements 5-10
Flaw Detection 5-10
Flaw Sizing 5-11
Radiography Examination 5-13
Acoustic Emission Monitoring 5-13
Metallurgical Replication 5-13
Boat Samples 5-13
Documentation of Indications 5-15

Drum Examination Methodologies 5-18
Case Study 1: Estimates of Crack Growth 5-19
Case Study – Rolled-in Tubes....5-25
System Calibration, Scanning, and Reporting 5-26
Scanning....5-26
Reporting 5-26

***6* KNOWLEDGE/TECHNOLOGY GAPS AND NEEDED RESEARCH....6-1**

***7* REFERENCES 7-1**

LIST OF FIGURES

Figure 1-1 Roadmap for the examination of a steam or lower water-wall drum. 1-2
Figure 2-1 Typical natural circulation boiler steam drum. 2-2
Figure 2-2 Natural and forced circulation loops. 2-3
Figure 2-3 Typical natural circulation boiler steam drum cross section, showing the drum internals..... 2-4
Figure 2-4 Forced circulation steam drum cross section. 2-5
Figure 2-5 Typical lower water-wall drum, also known as a *mud drum*. 2-6
Figure 3-1 Drawing illustrating typical locations of damage external to the steam drum. The letters refer to the damage mechanisms summarized in Table 3-1 and discussed in detail in Table 3-2 (A), Table 3-4 (C), Table 3-5 (D), and Table 3-9 (H)..... 3-3
Figure 3-2 Drawing illustrating typical locations of damage internal to the steam drum. The letters refer to the damage mechanisms summarized in Table 3-1 and discussed in detail in Table 3-3 (B), Table 3-6 (E), Table 3-7 (F), Table 3-8 (G), Table 3-10 (I), and Table 3-11 (J). 3-4
Figure 3-3 Drawing illustrating typical locations of damage internal to the lower water-wall drum. The letters refer to the damage mechanisms summarized in Table 3-1 and discussed in detail in Table 3-3 (B), Table 3-7 (F), Table 3-8 (G), and Table 3-10 (I)..... 3-5
Figure 4-1 Locations where diagnostic monitoring instrumentation may be placed..... 4-6
Figure 4-2 Locations of mid-wall thermocouples at the top and bottom of the drum. 4-7
Figure 4-3 Strain gauges added to a drum hanger rod. 4-8
Figure 4-4 Roadmap for qualification of NDE contractors, procedures, and technicians..... 4-9
Figure 5-1 Cutaway view of a drum that shows areas where drum internals have been removed to provide access to tubes and ligament areas for examination. 5-3
Figure 5-2 Surface indications found during visual examination. The locations were marked for further disposition by exploratory grinding. 5-5
Figure 5-3 Stains on the internal surface of the steam drum. These indicate variations in water level during operation, which may have a detrimental effect on boiler and superheater tubing. 5-6
Figure 5-4 Black light photograph of indications in a ligament area found using magnetic particle examination. 5-7
Figure 5-5 Liquid penetrant examination of a tube borehole. 5-8
Figure 5-6 Drum borehole cracks with similar surface dimensions on the borehole and drum internal surfaces may have significantly different crack depths and crack tip shapes..... 5-12
Figure 5-7 Location of a boat sample taken from a ligament area..... 5-14

Figure 5-8 Boat samples taken from the ligament area of a drum. 5-14
Figure 5-9 Visual determination of the length of an indication using a measuring tape. 5-15
Figure 5-10 A dental molding material replica and clear masking tape impression can provide permanent records of magnetic particle testing indications. Dental molding material is especially useful if the local surface geometry, such as an excavation groove, weld toe, or other curved geometry, needs to be recorded. 5-16
Figure 5-11 Example of phased array equipment, setup, and scanning information. Adapted from [18]. 5-16
Figure 5-12 Example of phased array instrument settings. 5-17
Figure 5-13 Phased array ultrasonic examination sector chart and associated sketches made by the NDE technician to document their interpretation of the discontinuity's location, orientation, size, and (most likely) type. Adapted from [18]. 5-18
Figure 5-14 A major crack surrounded by other minor cracks and flaws. 5-19
Figure 5-15 Liquid penetrant examination of a drum showing numerous indications in the ligaments and tube boreholes. 5-20
Figure 5-16 Map of wet fluorescent magnetic particle examination of a drum. Locations chosen for crack sizing by ACPD and ultrasonic examination are indicated by the numbered boxes. 5-21
Figure 5-17 Comparison of ACPD and ultrasonic crack depth measurement results for the first examination. 5-23
Figure 5-18 Comparison of ACPD and ultrasonic crack depth measurement results before and after chemical cleaning (after the first examination). 5-23
Figure 5-19 AC potential drop measurements of crack depth from three successive examinations. 5-24
Figure 5-20 Ultrasonic measurements of crack depth from three successive examinations. 5-25
Figure 5-21 Results of the special case examination where calibration was unavailable and a unique ultrasonic technique was implemented to give a "go/no go" result for the client. 5-27
Figure 5-22 Material samples removed from the body and ligament areas of a lower water-wall drum where leaks had occurred. 5-28

LIST OF TABLES

Table 3-1 Summary of common damage mechanisms. 3-2
Table 3-2 Damage mechanism A, riser tube corrosion fatigue. 3-6
Table 3-3 Damage mechanism B, pitting/general corrosion. 3-8
Table 3-4 Damage mechanism C, nozzle and tube penetration thermo-mechanical fatigue. 3-10
Table 3-5 Damage mechanism D, drum distortion. 3-12
Table 3-6 Damage mechanism E, downcomer/feedwater corrosion fatigue. 3-14
Table 3-7 Damage mechanism F, rolled tube joint caustic stress corrosion cracking. 3-16
Table 3-8 Damage mechanism G, ligament corrosion fatigue. 3-18
Table 3-9 Damage mechanism H, riser tube bend corrosion fatigue. 3-20
Table 3-10 Damage mechanism I, longitudinal and circumferential weld corrosion fatigue. 3-22
Table 3-11 Damage mechanism J, liner thermal fatigue. 3-24
Table 3-12 Damage mechanism K, equalizing pipe thermo-mechanical fatigue. 3-26
Table 3-13 Damage mechanism L, manway weld thermal fatigue. 3-28
Table 3-14 Damage mechanism M, Drum internals: thermal fatigue, thermo-mechanical fatigue, pitting or corrosion. 3-30
Table 4-1 Sample DCS data points for a 2037-psig (14.15-MPa) steam drum in a unit using phosphate cycle chemistry treatment. 4-4
Table 5-1 Summary of the results of crack sizing in tube boreholes using multiple NDE methods. 5-22

1
INTRODUCTION

Background

The steam and lower water-wall drums (see Section 2) are the largest and most expensive component in the boiler. As such, a comprehensive diagnostic monitoring and examination program is essential to ensure reliable and safe operation of the steam and lower water-wall drums. These drums are prone to a number of different damage mechanisms (see Section 3). Drum examination methods and scope should be taken into account and all possible damage mechanisms addressed.

The successful examination of the steam and lower water-wall drums is based on many factors, but preparation is the key. Review of troubleshooting audit questions, distributed control system (DCS) data, diagnostic monitoring data, and prior examination results and analyses are key pre-outage activities (see Section 4). Given the examination scope, the appropriate nondestructive examination (NDE) techniques should undergo field calibration, and the technicians should undergo qualification before the actual examination.

Once the examination begins, verification of results should be performed by the use of multiple NDE techniques (see Section 5) and technicians. If indications are found, disposition of the indications must be performed. Should the indications be monitored or repaired? Are operational, maintenance, or design changes required?

Finally, once the examination is complete, what lessons were learned, and when does the next examination need to be scheduled?

Figure 1-1 shows a roadmap for steam and lower water-wall drum examinations.

Objectives

The objectives of this report are the following:

- To provide a guideline for the examination of steam and lower water-wall drums
- To provide a methodology to determine the scope of an examination by the systematic review of data
- To understand the aspects of various NDE techniques used to examine drums

Work Scope

The objectives of this report were achieved by a review of prior and new research and experience with steam and lower water-wall drums.

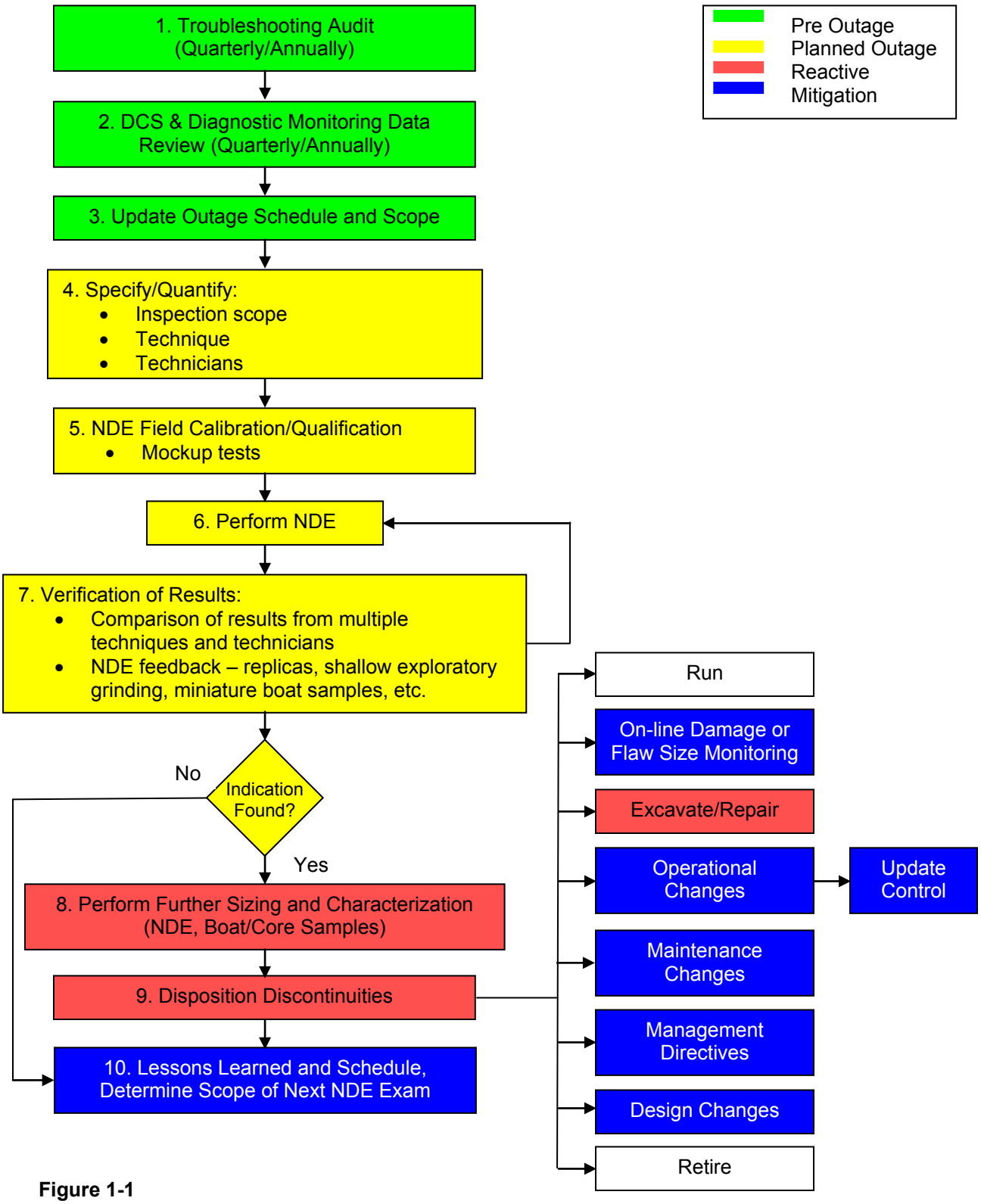


Figure 1-1
Roadmap for the examination of a steam or lower water-wall drum.

2
STEAM DRUMS AND LOWER WATER-WALL DRUMS

Steam Drums

Introduction

Steam drums (Figure 2-1) serve several purposes that contribute to the operation of a boiler:

- Separate and distribute saturated steam from the steam-water mixture returning from the heated boiler tubes (riser tubes). Proper steam separation is crucial to avoid the following:
  - Carryover of water droplets into the superheater where thermal shock may occur when the droplets hit the hot tubing.
  - Carryover of solids dissolved in the steam-entrained water droplets into the superheater and turbine. Boiler water may contain contaminants from makeup water, treatment chemicals, and condensate system leaks. The solubility of these solids is less in steam than in water. Small amounts of water droplet carryover may result in dramatically increased volumes of contaminants in the steam.
  - Carryunder of steam in the water exiting the drum through the downcomers, where residual steam can reduce the effective hydraulic pumping head and affect circulation.
- Mix the feedwater (from the economizer) with the saturated water remaining after steam separation (returning from the riser tubes).
- Mix water treatment chemicals.
- Purify the steam by removing contaminants.
- Remove some of the water (blowdown) to control the boiler water chemistry (solids content).
- Provide limited water storage to accommodate rapid changes in boiler load.

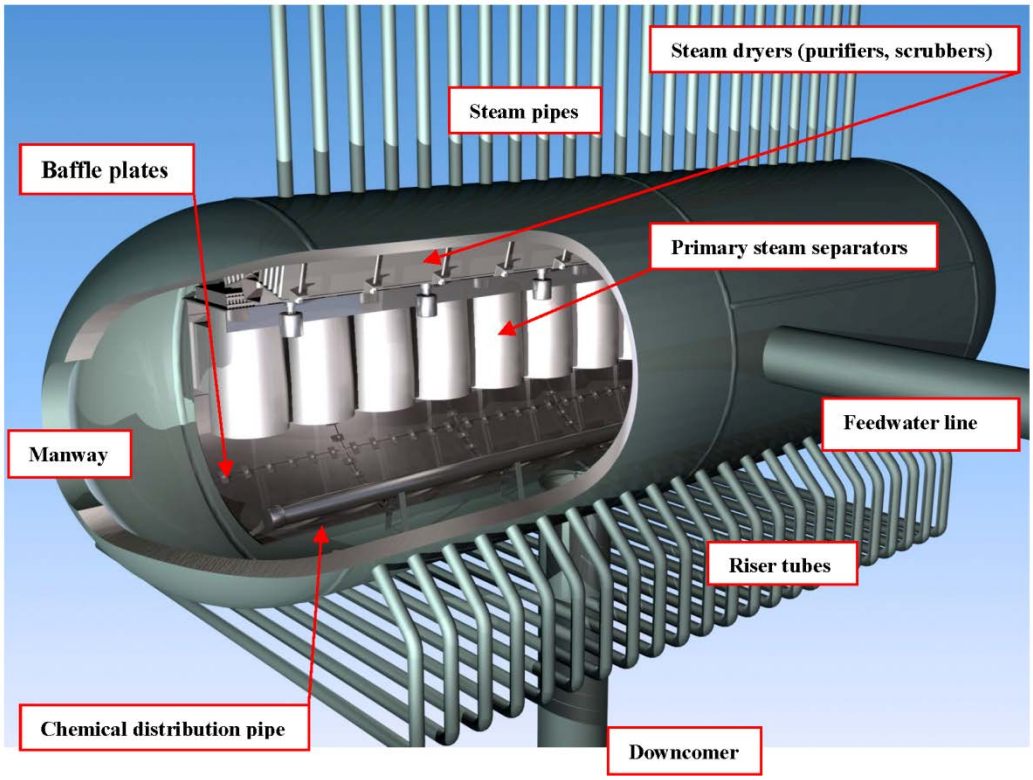


Figure 2-1
Typical natural circulation boiler steam drum.

Steam drums are part of the circulation loop of the boiler. The circulation in a boiler is typically either natural or controlled circulation (Figure 2-2). Natural circulation systems depend solely upon the fluid static head difference between the downcomers and the heated circuits (riser tubes) to produce circulation and to maintain sufficient fluid mass velocity and steam-water mixture quality for adequate furnace wall cooling. Controlled circulation systems employ circulating water pumps placed in the downcomers leading from the drum. These boiler water circulating pumps provide ample head to allow both higher drum pressures and the use of smaller diameter riser tubes in the furnace. Most of these units use orifices in the lower water-wall drums to distribute the water into the riser tubes.

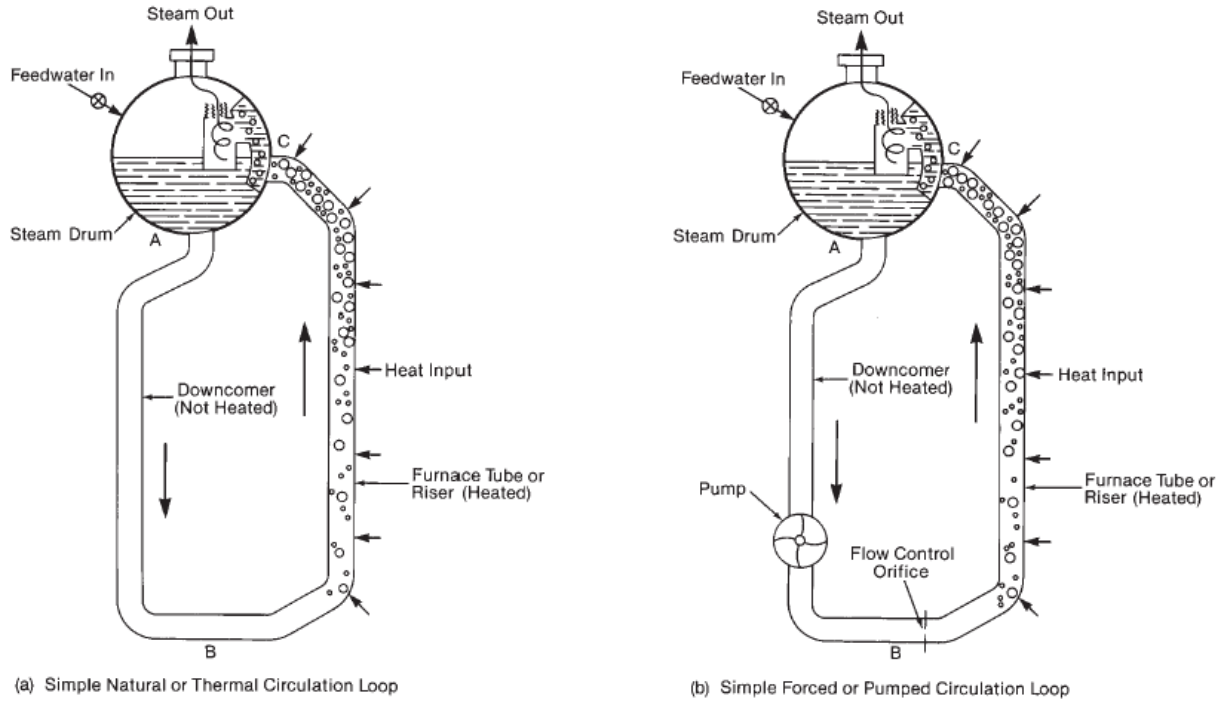


Figure 2-2
Natural and forced circulation loops. Courtesy of The Babcock & Wilcox Company [4].

The steam drum is comprised of internal components along with penetrations and their associated nozzles of various size and function. The drum internals typically include the following components:

- Baffles (used to change the direction of flow)
- Separators (used to route the purified steam from the drum to the superheater)
- Steam purifiers (washers and screen dryers)
- Distribution headers (for feedwater and chemical additions)

The penetrations and the associated nozzles of interest include:

- Those that bring the feedwater from the economizer to the drum (feedwater)
- Those that bring the steam-water mixture from the water walls to the drum (risers)
- Those that bring the water from the drum to the lower water-wall header (downcomers)
- Those that route the purified steam from the drum to the superheater
- Those that serve for the injection of chemicals for water treatment
- Those that serve to remove fluid during blowdown to either lower the water level in the drum or lower the solids in the boiler water

Steam-Water Separation

The cross-section of a natural circulation steam drum shown in Figure 2-3 illustrates the general arrangement of the baffle plates, primary cyclone separators, secondary separator elements (scrubbers), and downcomer and feedwater inlets. The blowdown connections are not shown.

The steam-water separation process involves

- Baffle-assisted primary separation – Simple screens and baffle arrangements greatly improve the steam-water separation process.
- Mechanical primary separators – Centrifugal force or radial acceleration is used almost universally for modern steam-water separators.
- Secondary scrubbers – Scrubbers provide a large surface that intercepts water droplets as the steam flows sinuously between closely fitted plates. Steam velocity is kept low, and water is drained from the bottom of the assembly.

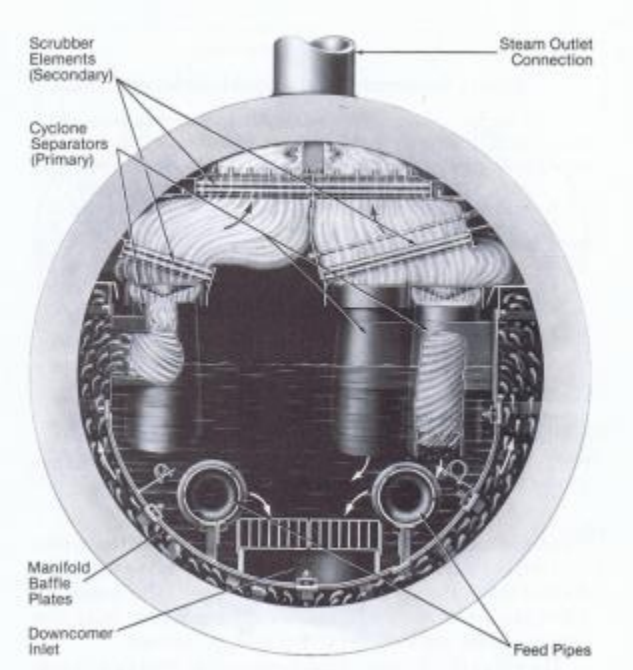
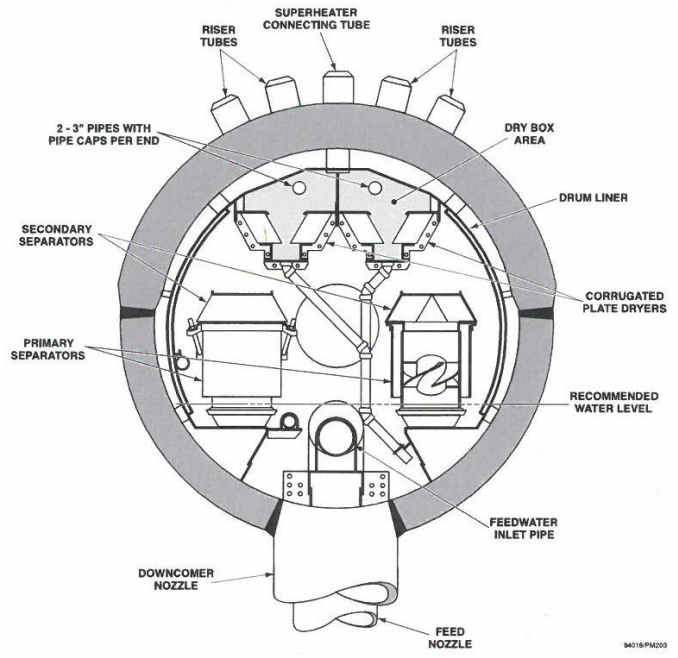


Figure 2-3
Typical natural circulation boiler steam drum cross section, showing the drum internals. Courtesy of The Babcock & Wilcox Company [5].

Steam-water separation takes place in two stages. The primary separation removes nearly all the steam from the water so that very little steam is recirculated from the bottom of the drum through the downcomers toward the heated tubes.

The steam leaving the primary separators in high-pressure boilers typically still contains too much liquid in the form of contaminant-containing droplets for satisfactory superheater and turbine performance. The steam is, therefore, passed through a secondary set of separators or scrubber elements for final droplet removal.

Figure 2-4 shows the cross section of a controlled circulation steam drum. One distinction to note is that the riser tubes in the controlled circulation steam drum enter the top of the drum, as opposed to entering the side of the natural circulation steam drum. Through-wall cracks or perforations in the drum manifold baffle plates in the region of the dry box may allow boiler water to bypass the primary and secondary steam-water separation and steam dryer devices, which would result in carryover of water droplets and contaminants into the superheater and steam turbine [6].



1 inch = 2.54 cm

Figure 2-4
Forced circulation steam drum cross section [6].

Lower Water-Wall Drum

Some boiler configurations include a lower water-wall drum that acts as an intermediate collection point for the subcooled water coming either from the downcomers or from a series of heat-absorbing tubes known as the *boiler bank* or *steam-generating bank* (Figure 2-5). This lower drum is often called a *mud drum*, due to sediment from the boiler water tending to collect at this location.

The lower water-wall drum serves multiple purposes that contribute to the operation of the boiler:

- Equalizes water distribution coming from a smaller number of downcomers to a larger number of furnace riser tubes.
- Provides a low point where iron and copper deposits can collect and be removed during outages. Blowdown valves are provided in the lower water-wall drum to help this process.

- On controlled circulation units, provides an ideal place to install and maintain orifices in the tube stubs leading to the furnace riser tubes. These orifices allow for engineered distribution of the water to the furnace riser tubes. Screens are often provided to protect the orifices from being plugged.

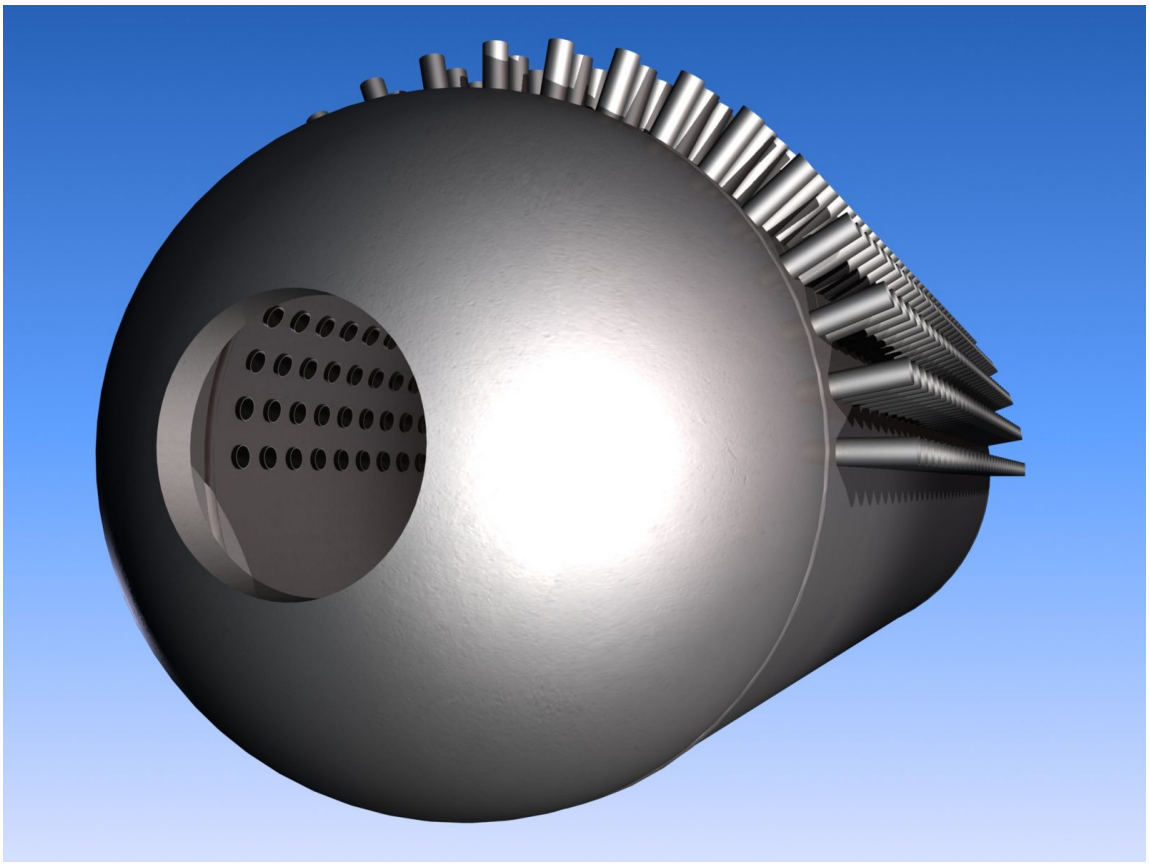


Figure 2-5
Typical lower water-wall drum, also known as a *mud drum*.

Drum Design and Materials

The steam drum is sized to accommodate the number of steam separators necessary for the largest expected boiler load (maximum steam flow rate) and to accommodate the changes in water level that occur during the expected load changes. The necessary volume is critical to prevent excessive water rise into the steam separators.

In order to contain the boiler pressure at operating temperatures, the drum must meet some basic requirements. Most steam drums in the United States are designed using the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PV) to provide the basic requirements.

General requirements for all methods of construction are found in Part PG of the ASME B&PV Code, Section 1.

Requirements for boilers fabricated by welding are found in Part PW of the ASME B&PV Code, Section 1.

Steam drums are typically of an all-welded or a rolled-in tube design. The all-welded design is used primarily in boilers operating at pressures of 1800–2800 psig (12.512–19.407 MPa). Drums with rolled-in tube seats typically operate at pressures approximately 1450 psig (10.099 MPa) and below.

Drum Control Logic

Drum water level is one of the most important measurements for safe and reliable boiler operation [7]. Feedwater exits the economizer through one or more outlet headers and enters the steam drum through a distribution system, which provides an even distribution of the feedwater from one end of the drum to the other. This prevents any major disturbance of the drum water level. The water level in the drum is maintained by controlling feedwater flow to the economizer. A three-element controller, using signals from the boiler drum level, main steam flow, and feedwater flow, controls boiler feedwater flow during normal operation.

3
COMMON DAMAGE MECHANISMS AND LOCATIONS

The major regions of concern for steam drums and lower water-wall drums are the pressure boundary regions such as penetrations for riser tubes, downcomers, and feedwater, along with the circumferential and longitudinal welds joining the drum shell. Additional areas of concern include tube boreholes, ligament areas between tube boreholes, internal steam drum liner, and riser tubing outside the steam drum. Common damage mechanisms include general and pitting corrosion along with fatigue associated with corrosion and/or thermally induced strains.

The most common damage mechanisms and descriptions of their locations are summarized in Table 3-1. Illustrations of steam and lower water-wall drums depicting the typical locations of potential damage mechanisms A through J listed in Table 3-1 are shown in Figures 3-1 through 3-3. Tables 3-2 through 3-14 provide further descriptions of each damage mechanism summarized in Table 3-1 along with the following:

- Possible diagnostic troubleshooting monitoring
- Auditing questions to determine the likelihood of each damage mechanism
- Where damage occurs
- NDE methods to detect damage
- How to quantify the severity of damage
- Acceptance limits, if applicable
- Repair/replace options
- Other potential damage mechanisms

Table 3-1
Summary of common damage mechanisms.

Item	Components	Locations	Description of Damage	Detailed Description
A	Steam drum	Horizontal sections of riser tubing external to drum	Corrosion fatigue, pitting corrosion	Table 3-2
B	Steam and lower water-wall drums	Internal surface of drum	Wall loss due to corrosion and oxidation	Table 3-3
C	Steam drum	Nozzles, riser tubes, feedwater pipes, superheater outlet tubes, and attachment welds on external drum surface	Thermo-mechanical fatigue	Table 3-4
D	Steam drum	Major support welds, seam welds, girth welds, refractory on external drum surface	Drum distortion (humping)	Table 3-5
E	Steam drum	Downcomer/feedwater penetration area on the internal drum surface	Corrosion fatigue	Table 3-6
F	Steam and lower water-wall drums	Closely spaced ligament region (rolled tube seats) on the internal drum surface	Tube seat seepage/stress corrosion cracking	Table 3-7
G	Steam and lower water-wall drums	Closely spaced ligament region (welded tube seats) on the internal drum surface	Corrosion fatigue	Table 3-8
H	Steam drum	Riser tube bends external to the drum	Corrosion fatigue, pitting corrosion	Table 3-9
I	Steam and lower water-wall drums	Longitudinal and circumferential welds on the internal drum surface	Corrosion fatigue, pitting corrosion	Table 3-10
J	Steam drum	Interior drum liner	Thermal fatigue	Table 3-11
K	Lower water-wall drums	Equalizing line – Pipes running between front and rear drums	Thermal fatigue	Table 3-12
L	Steam and lower water-wall drums	Manway welds on the internal drum surface	Thermal fatigue	Table 3-13
M	Steam drums	Drum internals	Thermal fatigue, thermo-mechanical fatigue, pitting, corrosion	Table 3-14

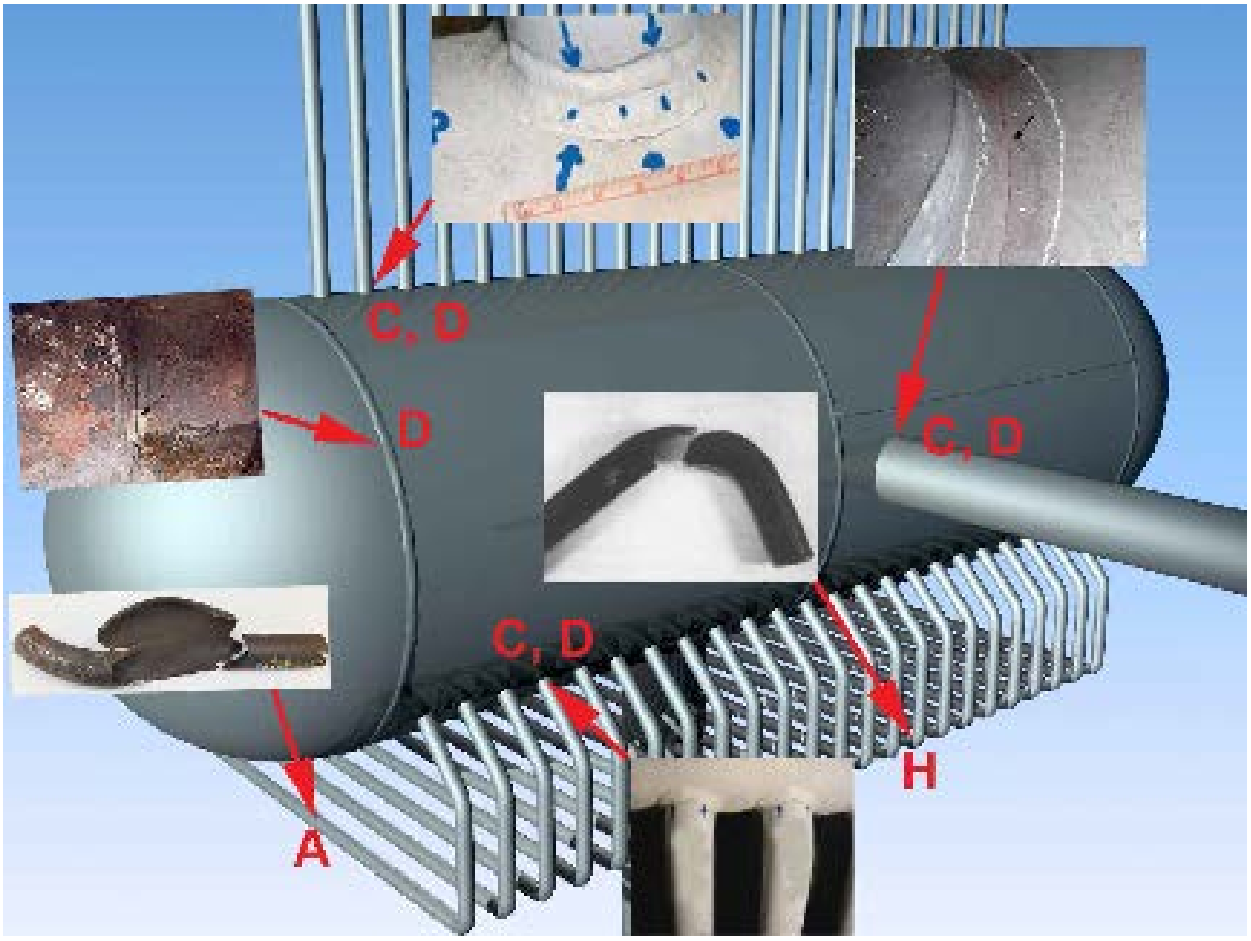


Figure 3-1
Drawing illustrating typical locations of damage external to the steam drum. The letters refer to the damage mechanisms summarized in Table 3-1 and discussed in detail in Table 3-2 (A), Table 3-4 (C), Table 3-5 (D), and Table 3-9 (H).

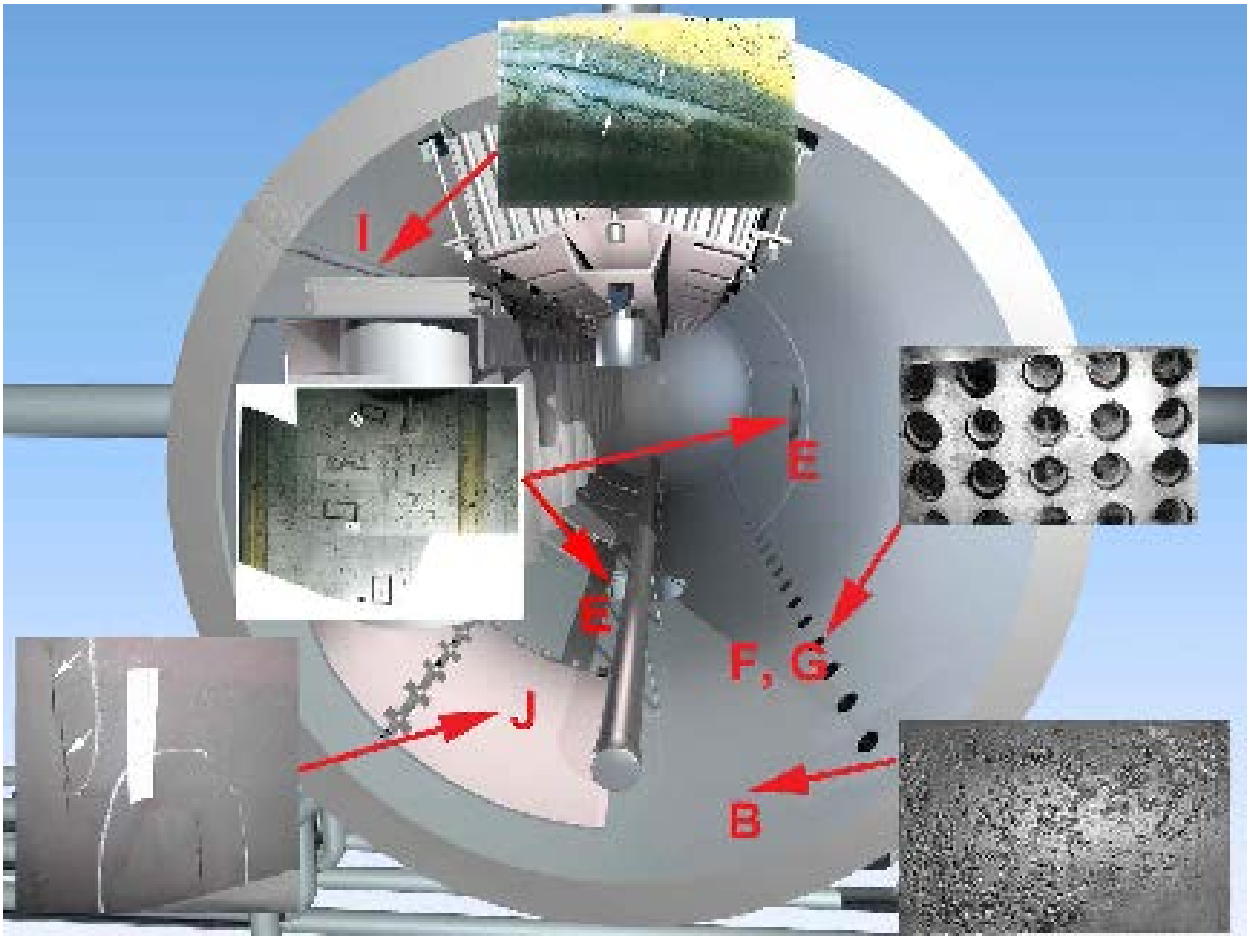


Figure 3-2
Drawing illustrating typical locations of damage internal to the steam drum. The letters refer to the damage mechanisms summarized in Table 3-1 and discussed in detail in Table 3-3 (B), Table 3-6 (E), Table 3-7 (F), Table 3-8 (G), Table 3-10 (I), and Table 3-11 (J).

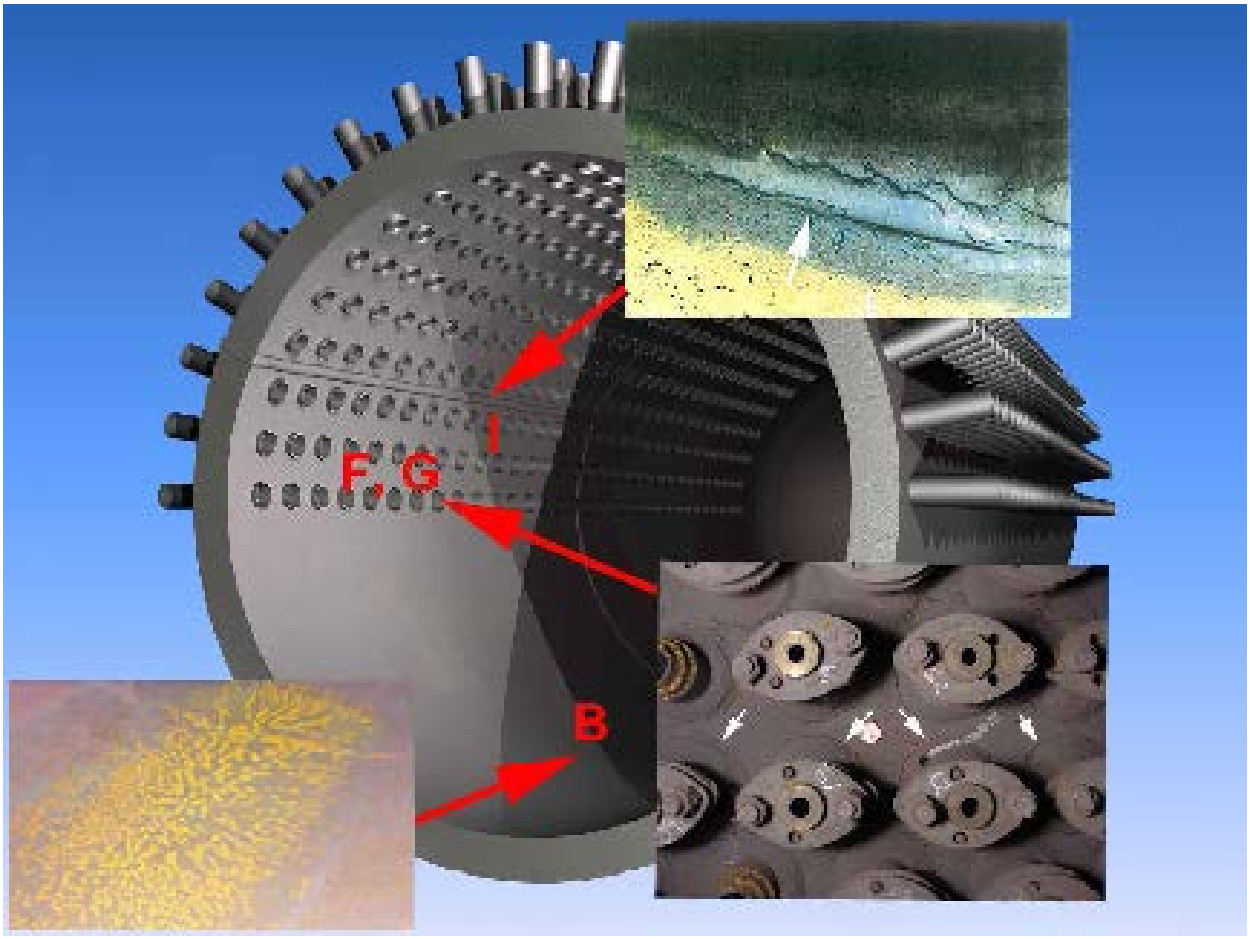


Figure 3-3
Drawing illustrating typical locations of damage internal to the lower water-wall drum. The letters refer to the damage mechanisms summarized in Table 3-1 and discussed in detail in Table 3-3 (B), Table 3-7 (F), Table 3-8 (G), and Table 3-10 (I).

Table 3-2
Damage mechanism A, riser tube corrosion fatigue.

<table>
<tr><th colspan="2">DAMAGE MECHANISM A
Riser Tube Corrosion Fatigue</th></tr>
<tr><td colspan="2">SUMMARY OF MECHANISM:
Corrosion fatigue can occur at the internal surface of horizontal or sagging runs that are difficult to drain. Damage is in the form of cracks aligned parallel to the tube axis. Damage at these locations can occur due to inadequate flushing following chemical cleaning, out-of-service oxygen pitting, and localized pitting due to improper chemical cleaning. Damage has been observed spanning the 5–7 o’clock positions of the tube.</td></tr>
<tr><td>APPEARANCE OF DAMAGE:

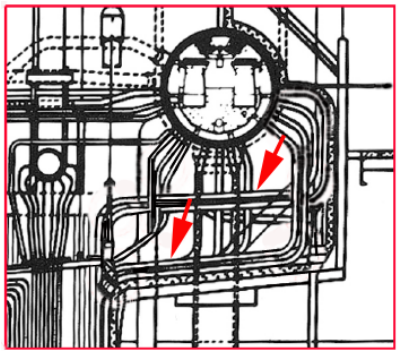

Corrosion fatigue failure of a riser tube, resulting in a blowout-type rupture.</td><td>
Typical locations of horizontal runs of riser tubing (arrows).</td></tr>
<tr><td colspan="2">POSSIBLE TROUBLESHOOTING MONITORING:
Acoustic emission.</td></tr>
<tr><td colspan="2">AUDITING QUESTIONS (Section 4):
Operation History
• What is the cumulative number of equivalent starts that the drum has been subjected to?
• What is the cumulative number of equivalent operating hours that the drum has been subjected to?
• Does the drum have a history of uneven water levels from one end to the other?
Maintenance
• What is the history of flaws and repairs to the drum?
• What significant results were found in the boiler inspector reports?
• What are the past examination intervals of the drum?</td></tr>
<tr><td colspan="2">WHERE DAMAGE OCCURS:
Along the internal surface of horizontal or sagging tubing.</td></tr>
<tr><td colspan="2">HOW TO FIND DAMAGE:
Visual testing and videoborescope examinations, radiography.</td></tr>
</table>

Table 3-2 (continued)
Damage mechanism A, riser tube corrosion fatigue.

DAMAGE MECHANISM A **Riser Tube Corrosion Fatigue**
HOW TO QUANTIFY THE SEVERITY OF THE DAMAGE: Ultrasonic testing techniques or ac potential drop.
WHAT IS ACCEPTABLE: Varies depending on the tube geometry and the operating pressure. Perform minimum wall calculations based on operating stress.
REPAIR OPTIONS: Replace tubing.
OTHER POTENTIALLY ACTIVE DAMAGE MECHANISMS: Pitting corrosion.

Table 3-3
Damage mechanism B, pitting/general corrosion.

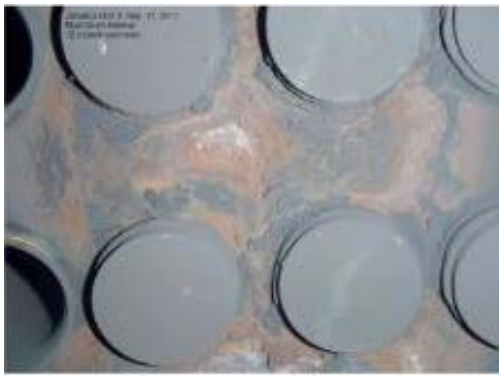
<table>
<tr><th colspan="2">DAMAGE MECHANISM B
Pitting/General Corrosion</th></tr>
<tr><td colspan="2">SUMMARY OF MECHANISM:
Damage to the drum is primarily due to metal loss from corrosion and oxidation. These forms of damage occur during extended outages (oxygen pitting), acid attack, and chelant attack.</td></tr>
<tr><td>APPEARANCE OF DAMAGE:

Appearance of general corrosion on interior drum surface.</td><td>
Internal drum surface in closely spaced ligament region.</td></tr>
<tr><td colspan="2">POSSIBLE TROUBLESHOOTING MONITORING:</td></tr>
<tr><td colspan="2">AUDITING QUESTIONS (Section 4):
Operating History
• What is the cumulative number of equivalent starts that the drum has been subjected to?
• What is the cumulative number of equivalent operating hours that the drum has been subjected to?
• Does the drum have a history of uneven water levels from one end to the other?
Maintenance
• What is the history of flaws and repairs to the drum?
• What significant results were found in the boiler inspector reports?
• What was the date of the last drum examination?</td></tr>
<tr><td colspan="2">WHERE DAMAGE OCCURS:
Internal surface of the drum.</td></tr>
<tr><td colspan="2">HOW TO FIND DAMAGE:
Visual testing.</td></tr>
<tr><td colspan="2">HOW TO QUANTIFY THE SEVERITY OF THE DAMAGE:
Ultrasonic wall thickness, exploratory grinding, ac potential drop.</td></tr>
</table>

Table 3-3 (continued)
Damage mechanism B, pitting/general corrosion.

DAMAGE MECHANISM B **Pitting/General Corrosion**
WHAT IS ACCEPTABLE: Perform a fitness-for-service analysis to determine suitability for continued operation.
REPAIR OPTIONS: Weld repair.
OTHER POTENTIALLY ACTIVE DAMAGE MECHANISMS/LOCATIONS: Pitting and/or corrosion fatigue is likely at other locations such as water-wall tubing, feeder pipes, riser tubes, and downcomers.

Table 3-4
Damage mechanism C, nozzle and tube penetration thermo-mechanical fatigue.

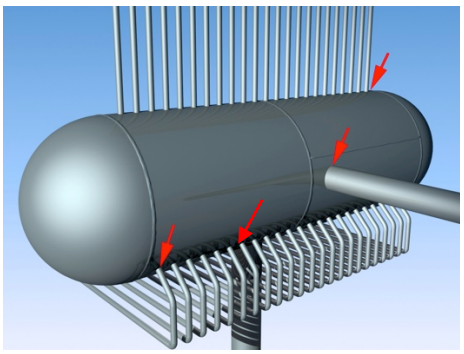
<table>
<tr><th colspan="2">DAMAGE MECHANISM C
Nozzle and Tube Penetration Thermo-Mechanical Fatigue</th></tr>
<tr><td colspan="2">SUMMARY OF MECHANISM:
Thermo-mechanical fatigue is a form of thermal fatigue. It is distinct from other forms of thermal fatigue (for example, thermal shock) in that the thermal stress causing the damage is created by mechanical constraints that do not permit the normal expansion or contraction during startups, shutdowns, and thermal transients. This condition results in thermally induced stresses, which—if repeated a sufficient number of times—will produce cracking at the highest stress locations. This damage mechanism is found on the external surfaces of the drum at nozzles and other welded attachments.</td></tr>
<tr><td>APPEARANCE OF DAMAGE:

Nozzle and tube penetrations on exterior drum surface (arrows) where thermo-mechanical fatigue damage can occur.</td><td>
External surface of a downcomer nozzle showing two cracks.</td></tr>
<tr><td colspan="2">POSSIBLE TROUBLESHOOTING MONITORING:</td></tr>
<tr><td colspan="2">AUDITING QUESTIONS (Section 4):
Operating History
• What is the cumulative number of equivalent starts that the drum has been subjected to?
• What is the cumulative number of equivalent operating hours that the drum has been subjected to?
Maintenance
• What is the history of flaws and repairs to the drum?
• What significant results were found in the boiler inspector reports?
• What are the past examination intervals of the drum?</td></tr>
<tr><td colspan="2">WHERE DAMAGE OCCURS:
External surfaces at nozzles and other welded attachments.</td></tr>
<tr><td colspan="2">HOW TO FIND DAMAGE:
Visual testing, magnetic particle testing, ultrasonic testing.</td></tr>
</table>

Table 3-4 (continued)
Damage mechanism C, nozzle and tube penetration thermo-mechanical fatigue.

DAMAGE MECHANISM C **Nozzle and Tube Penetration Thermo-Mechanical Fatigue**
HOW TO QUANTIFY THE SEVERITY OF THE DAMAGE: Ultrasonic testing techniques, exploratory grinding, ac potential drop.
WHAT IS ACCEPTABLE: Perform a fitness-for-service analysis to determine suitability for continued operation.
REPAIR OPTIONS: Weld repair.
OTHER POTENTIALLY ACTIVE DAMAGE MECHANISMS: Pitting corrosion.

Table 3-5
Damage mechanism D, drum distortion.

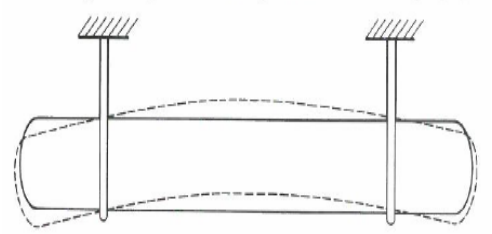
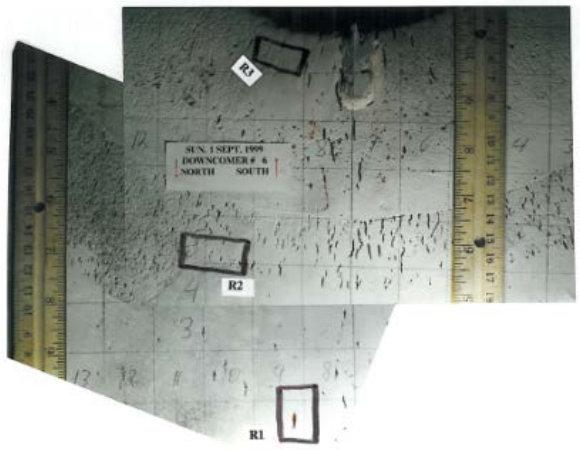
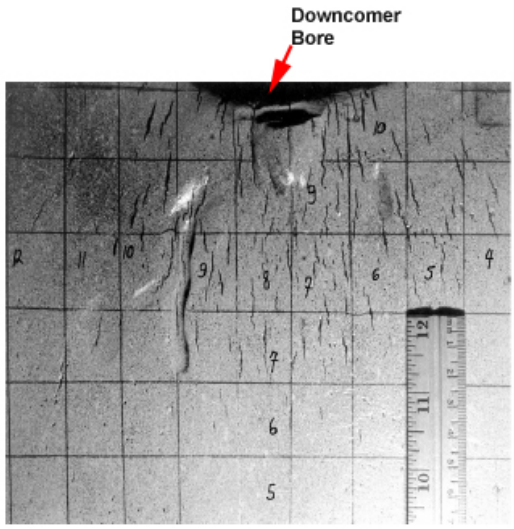
DAMAGE MECHANISM D **Drum Distortion (Humping)**
SUMMARY OF MECHANISM: Drums can have top-to-bottom temperature differences. Generally, only small differences result when pressure changes are made under load. The greatest top-to-bottom temperature differences develop during pressure reduction, with little or no steam flow being taken from the drum. The bottom of the drum is essentially at saturation temperature since it is in contact with water, while the top of the drum has the equivalent of slightly superheated steam in contact with it. If drum pressure is lost very rapidly during the idle period, a top-to-bottom differential will develop, and the drum will hump. Drum humping can also result during cold starts as the water will heat very quickly in the drum, and the bottom half of the drum will expand much more quickly than the upper half.
APPEARANCE OF DAMAGE:  Schematic presentation of severe drum distortion.
POSSIBLE TROUBLESHOOTING MONITORING: Strain gauges, thermocouples.
AUDITING QUESTIONS (SECTION 4): Design Attributes • What are the drum shell dimensions? • What are the safety margins on ligament design? • Given the drum materials, dimensions, nozzle configurations, and annual number of start-stop cycles: – What are the permissible drum shell metal through-wall temperature gradients? – What are the permissible drum shell metal temperature ramp rates? – What are the permissible drum shell metal top to bottom temperature gradients? Fabrication Attributes • Have weld repairs been performed on the drum? If so, have the repairs been documented? Operating History • What is the cumulative number of equivalent starts that the drum has been subjected to? • How is drum top-off with a hot drum performed (for example, high-pressure feedwater heaters in/out of service)?

Table 3-5 (continued)
Damage mechanism D, drum distortion.

DAMAGE MECHANISM D **Drum Distortion (Humping)**
Maintenance • What is the history of flaws and repairs to the drum? • What significant results were found in the boiler inspector reports? • What are the past examination intervals of the drum?
WHERE DAMAGE OCCURS: Refractory damage, major support welds, seam welds, girth welds, and the generating tubes between the steam and lower water-wall drums.
HOW TO FIND DAMAGE: Visual testing, magnetic particle testing, ultrasonic testing, radiography.
HOW TO QUANTIFY THE SEVERITY OF THE DAMAGE: Ultrasonic testing techniques, exploratory grinding, ac potential drop.
WHAT IS ACCEPTABLE: Perform a fitness-for-service analysis to determine suitability for continued operation.
REPAIR OPTIONS: Weld repair.
OTHER POTENTIALLY ACTIVE DAMAGE MECHANISMS: None identified.

Table 3-6
Damage mechanism E, downcomer/feedwater corrosion fatigue.

<table>
<tr><th colspan="2">DAMAGE MECHANISM E
Downcomer/Feedwater Corrosion Fatigue</th></tr>
<tr><td colspan="2">SUMMARY OF MECHANISM:
Corrosion fatigue occurs due to the combined effects of cyclic strains and a corrosive environment. In this case, the cyclic strains are typically thermally induced. At the downcomers, crack initiation and propagation are a result of continued mixing in the downcomer, resulting in colder flow at the internal surface. The feedwater penetration area has the greatest thermal differential because the incoming feedwater can be several hundred degrees below drum temperature. Downcomer cracking is likely caused by the combination of poor boiler water chemistry, leading to pitting corrosion, and moderate cyclic stressing due to thermal/pressure transients.</td></tr>
<tr><td>APPEARANCE OF DAMAGE:


Internal surface of downcomer showing an extensive cracking network. Damage may not be visible from the external surface since cracking initiates from the inner surface of the drum.</td><td>

Internal surface of drum displaying an array of cracks adjacent to the bore of a downcomer.</td></tr>
<tr><td colspan="2">POSSIBLE TROUBLESHOOTING MONITORING:
Acoustic emission.</td></tr>
<tr><td colspan="2">AUDITING QUESTIONS (Section 4):
Design Attributes
• What are the drum shell dimensions?
• What are the safety margins on ligament design?
• Given the drum materials, dimensions, nozzle configurations, and annual number of start-stop cycles:
– What are the permissible drum shell metal through-wall temperature gradients?
– What are the permissible drum shell metal temperature ramp rates?
– What are the permissible drum shell metal top-to-bottom temperature gradients?</td></tr>
</table>

Table 3-6 (continued)
Damage mechanism E, downcomer/feedwater corrosion fatigue.

DAMAGE MECHANISM E **Downcomer/Feedwater Corrosion Fatigue**
Operating History • What is the cumulative number of equivalent starts that the drum has been subjected to? • What is the cumulative number of equivalent operating hours that the drum has been subjected to? • How is drum top-off with a hot drum performed (for example, high-pressure feedwater heaters in/out of service)? • Does the drum have a history of uneven water levels from one end to the other? Maintenance • What is the history of flaws and repairs to the drum? • What significant results were found in the boiler inspector reports? • What was the date of the last drum examination? • What are the past examination intervals of the drum?
WHERE DAMAGE OCCURS: At the internal surfaces of feedwater and downcomer tubing; the internal surface of the drum surrounding the penetrations.
HOW TO FIND DAMAGE: Visual testing and videoborescope examinations, radiography.
HOW TO QUANTIFY THE SEVERITY OF THE DAMAGE: Ultrasonic testing techniques, exploratory grinding, ac potential drop.
WHAT IS ACCEPTABLE: Perform fitness-for-service evaluation to determine suitability for continued operation.
REPAIR OPTIONS: Replace tubing.
OTHER POTENTIALLY ACTIVE DAMAGE MECHANISMS: Pitting corrosion.

Table 3-7
Damage mechanism F, rolled tube joint caustic stress corrosion cracking.

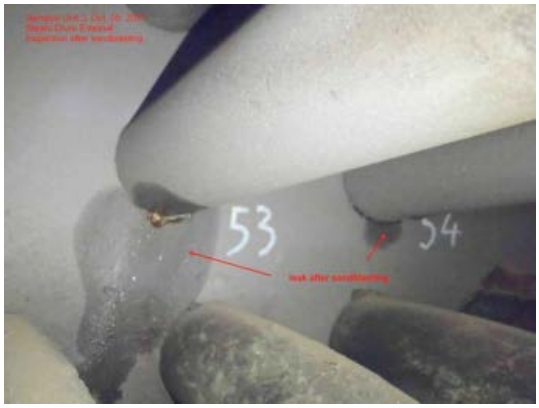
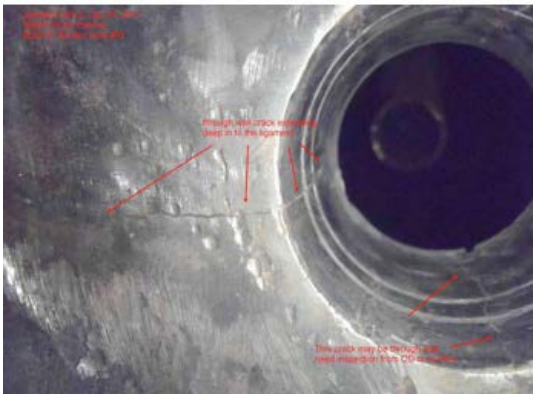
DAMAGE MECHANISM F **Rolled Tube Joint Caustic Stress Corrosion Cracking**	
SUMMARY OF MECHANISM: Stress corrosion cracking is the result of the combined effects of stress (applied or residual), a corrosive environment, and a susceptible material. This mechanism is unique to steam and lower water-wall drums where the tubes are pressed or rolled into the internal header surface rather than welded. A problem with this design is tube seat seepage (slight leaking of water through the rolled joint). If the leak is not stopped, the high residual stresses from the tube rolling operation combined with concentrated water treatment chemicals can lead to cracking in the drum.	
APPEARANCE OF DAMAGE: **Leaks discovered after insulation removal**  Seepage emanating from the faying surface between screen tubes and the steam drum viewed from the drum exterior.	**Cracking in the tube bore and drum surface**  View from the internal drum surface revealing cracking in the tube bore and drum surface.
POSSIBLE TROUBLESHOOTING MONITORING: Acoustic emission.	
AUDITING QUESTIONS (Section 4): Design Attributes • What are the drum shell dimensions? • What are the safety margins on ligament design? • Given the drum materials, dimensions, nozzle configurations, and annual number of start-stop cycles: – What are the permissible drum shell metal through-wall temperature gradients? – What are the permissible drum shell metal temperature ramp rates? – What are the permissible drum shell metal top-to-bottom temperature gradients?	

Table 3-7 (continued)
Damage mechanism F, rolled tube joint caustic stress corrosion cracking.

DAMAGE MECHANISM F **Rolled Tube Joint Caustic Stress Corrosion Cracking**
Operating History • What is the cumulative number of equivalent starts that the drum has been subjected to? • What is the cumulative number of equivalent operating hours that the drum has been subjected to? • How is drum top-off with a hot drum performed (for example, high-pressure feedwater heaters in/out of service)? • Does the drum have a history of uneven water levels from one end to the other? Maintenance • What is the history of flaws and repairs to the drum? • What significant results were found in the boiler inspector reports? • What was the date of the last drum examination? • What are the past examination intervals of the drum?
WHERE DAMAGE OCCURS: Rolled joints at tube seats and surrounding drum material.
HOW TO FIND DAMAGE: Visual testing, liquid penetrant testing, magnetic particle testing.
HOW TO QUANTIFY THE SEVERITY OF THE DAMAGE: Ultrasonic testing techniques, exploratory grinding, ac potential drop.
WHAT IS ACCEPTABLE: Perform a fitness-for-service analysis to determine suitability for continued operation.
REPAIR OPTIONS: Re-rolling of tube seats or seal welding; weld repair drum cracks.
OTHER POTENTIALLY ACTIVE DAMAGE MECHANISMS: Pitting and general corrosion.

Table 3-8
Damage mechanism G, ligament corrosion fatigue.

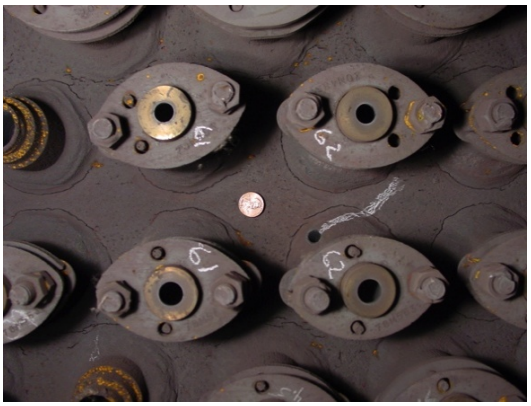
<table>
<tr><th colspan="2">DAMAGE MECHANISM G
Ligament Corrosion Fatigue</th></tr>
<tr><td colspan="2">SUMMARY OF MECHANISM:
Corrosion fatigue can occur in the closely spaced ligament regions of the steam drum and lower water-wall drum. Cracking tends to be circumferential or axially oriented in the tube and/or the drum. Corrosion fatigue occurs due to the combined effects of cyclic strains and a corrosive environment. Cracking is likely due to the combination of poor boiler water chemistry, leading to pitting corrosion, and moderate cyclic stressing due to thermal/pressure transients.</td></tr>
<tr><td>APPEARANCE OF DAMAGE:

Internal surface of lower water-wall drum, displaying circumferential cracks following the welds joining the penetrations to the drum.</td><td>
Corrosion fatigue cracking in the steam drum wall. Note the closely spaced penetrations.</td></tr>
<tr><td colspan="2">POSSIBLE TROUBLESHOOTING MONITORING:
Acoustic emission, thermocouples.</td></tr>
<tr><td colspan="2">AUDITING QUESTIONS (Section 4):
Design Attributes
• What are the safety margins on ligament design?
Operating History
• What is the cumulative number of equivalent starts that the drum has been subjected to?
• What is the cumulative number of equivalent operating hours that the drum has been subjected to?
• Does the drum have a history of uneven water levels from one end to the other?
Maintenance
• What is the history of flaws and repairs to the drum?
• What significant results were found in the boiler inspector reports?
• What was the date of the last drum examination?
• What are the past examination intervals of the drum?</td></tr>
</table>

Table 3-8 (continued)
Damage mechanism G, ligament corrosion fatigue.

DAMAGE MECHANISM G **Ligament Corrosion Fatigue**
WHERE DAMAGE OCCURS: In the closely spaced ligament regions of the steam drum and lower water-wall drum.
HOW TO FIND DAMAGE: Visual testing, magnetic particle testing.
HOW TO QUANTIFY THE SEVERITY OF THE DAMAGE: Ultrasonic testing techniques, exploratory grinding, ac potential drop.
WHAT IS ACCEPTABLE: Perform a fitness-for-service analysis to determine suitability for continued operation.
REPAIR OPTIONS: Weld repair.
OTHER POTENTIALLY ACTIVE DAMAGE MECHANISMS: Pitting corrosion.

Table 3-9
Damage mechanism H, riser tube bend corrosion fatigue.

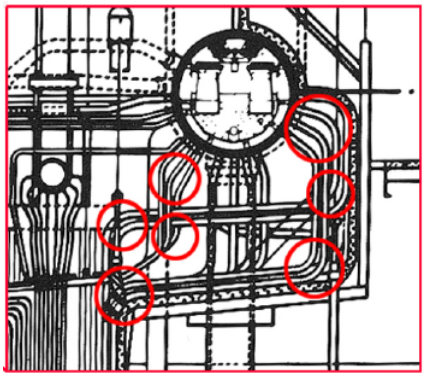
DAMAGE MECHANISM H **Riser Tube Bend Corrosion Fatigue**	
SUMMARY OF MECHANISM: Corrosion fatigue can occur at the internal surfaces of bends in riser tubing. Damage is typically in the form of cracks oriented parallel to the bend axis. Conditions that lead to corrosion fatigue include poor water chemistry control (for example, periods of high dissolved oxygen or pH excursions in the boiler water) and cycling conditions that lead to flexing of the bends.	
APPEARANCE OF DAMAGE:  Blowout-type rupture at riser bend due to corrosion fatigue.	 Sectional side view of the region surrounding a steam drum illustrating the locations of riser bends.
POSSIBLE TROUBLESHOOTING MONITORING:	
AUDITING QUESTIONS (Section 4): Operating History • What is the cumulative number of equivalent starts that the drum has been subjected to? • What is the cumulative number of equivalent operating hours that the drum has been subjected to? • Does the drum have a history of uneven water levels from one end to the other? Maintenance • What is the history of flaws and repairs to the drum? • What significant results were found in the boiler inspector reports? • What was the date of the last drum examination? • What are the past examination intervals of the drum?	
WHERE DAMAGE OCCURS: Along the internal surfaces of riser bends.	

Table 3-9 (continued)
Damage mechanism H, riser tube bend corrosion fatigue.

DAMAGE MECHANISM H **Riser Tube Bend Corrosion Fatigue**
HOW TO FIND DAMAGE: Videoborescope examination.
HOW TO QUANTIFY THE SEVERITY OF THE DAMAGE: Ultrasonic testing techniques, radiography, ac potential drop.
WHAT IS ACCEPTABLE: Varies depending on the tube geometry and the operating pressure. Perform minimum wall calculations based on operating stress.
REPAIR OPTIONS: Replace tubing.
OTHER POTENTIALLY ACTIVE DAMAGE MECHANISMS: Pitting corrosion.

Table 3-10
Damage mechanism I, longitudinal and circumferential weld corrosion fatigue.

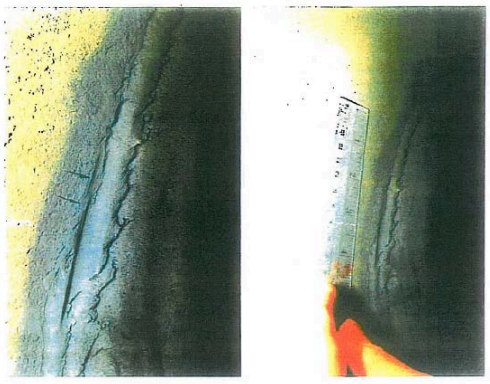
DAMAGE MECHANISM I **Longitudinal and Circumferential Weld Corrosion Fatigue**
SUMMARY OF MECHANISM: Corrosion fatigue can occur on the internal surface of the steam and lower water-wall drums along longitudinal and circumferential welds. Damage at these locations can occur due to inadequate flushing following chemical cleaning, out-of-service oxygen pitting, and localized pitting due to improper chemical cleaning.
APPEARANCE OF DAMAGE:  Grooves formed along the weld toe of a circumferential weld on the internal surface of a lower water-wall drum.
POSSIBLE TROUBLESHOOTING MONITORING: Acoustic emission.
AUDITING QUESTIONS (Section 4): Operating History • What is the cumulative number of equivalent starts that the drum has been subjected to? • What is the cumulative number of equivalent operating hours that the drum has been subjected to? • Does the drum have a history of uneven water levels from one end to the other? Maintenance • What is the history of flaws and repairs to the drum? • What significant results were found in the boiler inspector reports? • What was the date of the last drum examination? • What are the past examination intervals of the drum?
WHERE DAMAGE OCCURS: Along the weld toe of internal longitudinal seam and circumferential welds.

Table 3-10 (continued)
Damage mechanism I, longitudinal and circumferential weld corrosion fatigue.

DAMAGE MECHANISM I **Longitudinal and Circumferential Weld Corrosion Fatigue**
HOW TO FIND DAMAGE: Visual testing, liquid penetrant testing, magnetic particle testing.
HOW TO QUANTIFY THE SEVERITY OF THE DAMAGE: Ultrasonic testing techniques, exploratory grinding, ac potential drop, radiography.
WHAT IS ACCEPTABLE: Perform a fitness-for-service evaluation to determine suitability for continued service.
REPAIR OPTIONS: Grind to remove damage and/or weld repair.
OTHER POTENTIALLY ACTIVE DAMAGE MECHANISMS: Pitting corrosion.

Table 3-11
Damage mechanism J, liner thermal fatigue.

DAMAGE MECHANISM J **Liner Thermal Fatigue**
SUMMARY OF MECHANISM: Thermal fatigue is the result of repeated strains caused by variations in temperature where relative movement or differential expansion is constrained. Damage is also promoted by rapid changes in surface temperature that result in a temperature gradient across the thickness or length of a component. The most important influencing factors are the magnitude of the temperature change and an increasing number of cycles. The appearance of thermal fatigue damage is in the form of multiple parallel cracks.
APPEARANCE OF DAMAGE:  Typical appearance of thermal fatigue cracks in a steam drum liner.
POSSIBLE TROUBLESHOOTING MONITORING: Acoustic emission, thermocouples.
AUDITING QUESTIONS (Section 4): Operating History • What is the cumulative number of equivalent starts that the drum has been subjected to? • What is the cumulative number of equivalent operating hours that the drum has been subjected to? • Does the drum have a history of uneven water levels from one end to the other? Maintenance • What is the history of flaws and repairs to the drum? • What significant results were found in the boiler inspector reports? • What was the date of the last drum examination? • What are the past examination intervals of the drum?

Table 3-11 (continued)
Damage mechanism J, liner thermal fatigue.

DAMAGE MECHANISM J **Liner Thermal Fatigue**
WHERE DAMAGE OCCURS: Steam drum liner.
HOW TO FIND DAMAGE: Visual testing, liquid penetrant testing, magnetic particle testing.
HOW TO QUANTIFY THE SEVERITY OF THE DAMAGE: Ultrasonic testing techniques, exploratory grinding, ac potential drop.
WHAT IS ACCEPTABLE: Perform a fitness-for-service analysis to determine suitability for continued operation.
REPAIR OPTIONS: Weld repair or replace liner.
OTHER POTENTIALLY ACTIVE DAMAGE MECHANISMS: Pitting corrosion.

Table 3-12
Damage mechanism K, equalizing pipe thermo-mechanical fatigue.

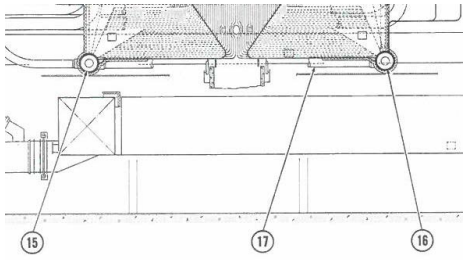
DAMAGE MECHANISM K **Equalizing Pipe Thermo-Mechanical Fatigue**
SUMMARY OF MECHANISM: Thermo-mechanical fatigue is a form of thermal fatigue. It is distinct from other forms of thermal fatigue (for example, thermal shock) in that the thermal stress causing the damage is created by mechanical constraints that do not permit the normal expansion or contraction during startup, shutdowns, and thermal transients. This condition results in thermally induced stresses, which—if repeated a sufficient number of times—will produce cracking at the highest stress locations. Controlled circulation boilers use downcomer circulation pumps to control circulation. Equalizing pipes running between the front and rear lower water-wall drums may have differential thermal expansion due to pumps in/out of service, causing a twisting action on the pipe-to-drum welds.
APPEARANCE OF DAMAGE:  Welds in crossover pipe between front and rear drum where thermo-mechanical fatigue damage can occur.
POSSIBLE TROUBLESHOOTING MONITORING:
AUDITING QUESTIONS (Section 4): Operating History • What is the cumulative number of equivalent starts that the drum has been subjected to? • What is the cumulative number of equivalent operating hours that the drum has been subjected to? Maintenance • What is the history of flaws and repairs to the drum? • What significant results were found in the boiler inspector reports? • What are the past examination intervals of the drum?
WHERE DAMAGE OCCURS: External surfaces at the pipe connections to the lower water-wall drums.
HOW TO FIND DAMAGE: Visual testing, magnetic particle testing, ultrasonic testing.

Table 3-12 (continued)
Damage mechanism K, equalizing pipe thermo-mechanical fatigue.

DAMAGE MECHANISM K **Equalizing Pipe Thermo-Mechanical Fatigue**
HOW TO QUANTIFY THE SEVERITY OF THE DAMAGE: Ultrasonic testing techniques, exploratory grinding, ac potential drop.
WHAT IS ACCEPTABLE: Perform a fitness-for-service analysis to determine suitability for continued operation.
REPAIR OPTIONS: Weld repair.
OTHER POTENTIALLY ACTIVE DAMAGE MECHANISMS: Pitting corrosion.

Table 3-13
Damage mechanism L, manway weld thermal fatigue.

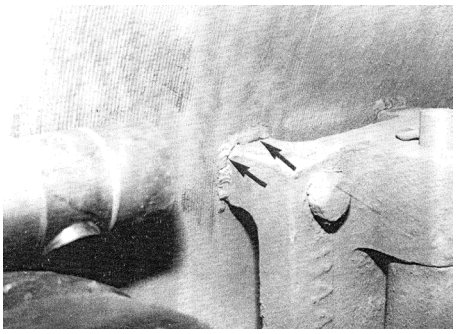
DAMAGE MECHANISM L **Manway Weld Thermal Fatigue**
SUMMARY OF MECHANISM: Thermal fatigue of the drum occurs due to the repeated start-stop cycles of the boiler, and changes in load during operation. Poorly blended fillet welds on the manways cause high stress concentrations that may eventually cause cracking to occur.
APPEARANCE OF DAMAGE:  Crack-like indications were found at both manway hinge-to-shell fillet welds.
POSSIBLE TROUBLESHOOTING MONITORING:
AUDITING QUESTIONS (Section 4): Operating History • What is the cumulative number of equivalent starts that the drum has been subjected to? • What is the cumulative number of equivalent operating hours that the drum has been subjected to? Maintenance • What is the history of flaws and repairs to the drum? • What significant results were found in the boiler inspector reports? • What are the past examination intervals of the drum?
WHERE DAMAGE OCCURS: Internal surfaces of the drum shell at the manway welds.
HOW TO FIND DAMAGE: Visual testing, magnetic particle testing.
HOW TO QUANTIFY THE SEVERITY OF THE DAMAGE: Exploratory grinding.

Table 3-13 (continued)
Damage mechanism L, manway weld thermal fatigue.

DAMAGE MECHANISM L **Manway Weld Thermal Fatigue**
WHAT IS ACCEPTABLE: Perform a fitness-for-service analysis to determine suitability for continued operation.
REPAIR OPTIONS: Weld repair, blending of the welds
OTHER POTENTIALLY ACTIVE DAMAGE MECHANISMS: None identified.

Table 3-14
Damage mechanism M, Drum internals: thermal fatigue, thermo-mechanical fatigue, pitting or corrosion.

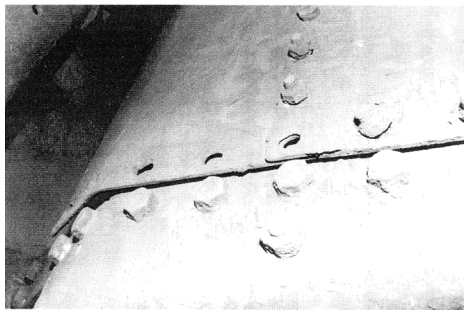
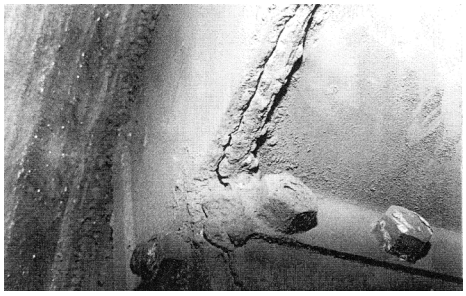
<table>
<tr><th colspan="2">DAMAGE MECHANISM M
Drum Internals: Thermal Fatigue, Thermo-Mechanical Fatigue, Pitting, or Corrosion</th></tr>
<tr><td colspan="2">SUMMARY OF MECHANISM:
Damage to the internal components of the drum may occur over the life of the drum and should be monitored at each examination. Thermal fatigue, thermo-mechanical fatigue, pitting, and corrosion are the mechanisms that may affect the internal components.</td></tr>
<tr><td>APPEARANCE OF DAMAGE:

Missing and damaged bolts from the baffle plate.</td><td>
Crack on the end of a baffle plate.</td></tr>
<tr><td colspan="2">POSSIBLE TROUBLESHOOTING MONITORING:</td></tr>
<tr><td colspan="2">AUDITING QUESTIONS (Section 4):
Operating History
• What is the cumulative number of equivalent starts that the drum has been subjected to?
• What is the cumulative number of equivalent operating hours that the drum has been subjected to?
Maintenance
• What is the history of flaws and repairs to the drum?
• What significant results were found in the boiler inspector reports?
• What are the past examination intervals of the drum?</td></tr>
<tr><td colspan="2">WHERE DAMAGE OCCURS:
Internal components of the drum.</td></tr>
<tr><td colspan="2">HOW TO FIND DAMAGE:
Visual testing, magnetic particle testing.</td></tr>
<tr><td colspan="2">HOW TO QUANTIFY THE SEVERITY OF THE DAMAGE:
Exploratory grinding, if applicable.</td></tr>
</table>

Table 3-14 (continued)
Damage mechanism M, Drum internals: thermal fatigue, thermo-mechanical fatigue, pitting or corrosion.

DAMAGE MECHANISM M **Drum Internals: Thermal Fatigue, Thermo-Mechanical Fatigue, Pitting, or Corrosion**
WHAT IS ACCEPTABLE: Missing bolts should be replaced, and internal components repaired or replaced. Perform a fitness-for-service analysis to determine suitability for continued operation, if necessary.
REPAIR OPTIONS: Weld repair, blending of the welds, repair or replace internal components.
OTHER POTENTIALLY ACTIVE DAMAGE MECHANISMS: None identified.

4
PRE-OUTAGE ACTIVITIES

Proactive Troubleshooting Auditing Questions

Introduction

A proactive troubleshooting audit should be performed before the outage to help plan the examination activities. Indications of problems that have occurred or will occur may be determined by the answers to these questions. Typical questions are listed below.

Design Attributes

1. What are the drum shell dimensions (diameter, wall thickness, ligament borehole diameter, and spacing)?
2. What are the safety margins on ligament design?
3. Given the drum materials, dimensions, nozzle configurations, and annual number of start-stop cycles:
   A. What are the permissible drum shell metal through-wall temperature gradients?
   B. What are the permissible drum shell metal temperature ramp rates?
   C. What are the permissible drum shell metal top-to-bottom temperature gradients?
4. What is the corrosion fatigue design life of the drum shell borehole ligaments (that is, how many design basis ambient cold starts can be tolerated by the borehole ligaments and nozzles)?

Fabrication Attributes

1. What is the drum material specification? Was the drum material fabricated using fine-grain steel-making practice?
2. Have weld repairs been performed on the drum? If so, have the repairs been documented?

Operating History

1. What is the cumulative number of equivalent starts that the drum has been subjected to? Equivalent starts are a function of:
   A. Number of stops and starts.
   B. Differences between the actual and the manufacturer's recommended shutdown and startup procedures.
   C. Drum top-to-bottom and through-wall temperature gradients caused by drum top-ups, subcooling, and the ability of the controlled circulation pumps to maintain circulation during layup.
   D. Drum shell internal surface metal temperature changes and ramp rates.
   E. Drum pressure changes and ramp rates.
2. What is the number of cumulative equivalent operating hours? Equivalent operating hours are a function of:
   A. On-load hours.
   B. Layup hours.
   C. Layup practices.
   D. The unit's layup, startup, and on-load cycle chemistry practices and history.
3. What is the hydrotest history?
   A. How often has the drum been hydrotested?
   B. When was the last hydrotest?
   C. Was the hydrotest temperature greater or less than the fracture appearance transition temperature (FATT)?
   D. Was the hydrotest pressure greater or less than the maximum allowable working pressure (MAWP)?
4. How is drum top-off with hot drum performed (for example, high-pressure feedwater heaters in or out of service)?
5. Does the drum have a history of uneven water levels from one end to the other?

Maintenance

1. What is the history of flaws and repairs to the drum?
2. What significant results were found in the boiler inspector reports?
3. What was the date of the last drum examination?
4. What are the past examination intervals of the drum?
5. What is the history of chemical cleaning (for example, dates, method, amount of iron removed)?
6. What are the sizes and locations of known discontinuities in the drum?

7. Are the local boiler drum level gauge glasses consistent with the control room drum level indications?
8. Have the drum and boiler relief valves been checked for leak through?
9. What is the history of alarms for the drum? Typical alarms include:
   A. Exceeding the deviation limit for drum pressure
   B. Exceeding the deviation limit for feedwater flow
   C. Exceeding the high drum water level
   D. Exceeding the low drum water level

Diagnostic Monitoring of Drums

Introduction

Many of the questions raised in the Troubleshooting Audit section are dependent on data available from the distributed control system (DCS). Temperature or pressure excursions, alarms, trips, and level transmitter data are all important indicators of the condition of the drum. Operational data, including startups, shutdowns and load follows, should be reviewed.

The condition of the steam drum may also be monitored by the installation of additional diagnostic monitoring equipment. Additional thermocouples and strain gauges are potential diagnostic tools that can be used with a drum.

DCS Data Points

The steam drum can be monitored by reviewing the relevant data points available in the DCS. The alarm history for water level and temperature and pressure indications may be found in the DCS. Trip information related to these parameters is also available. No alarm incident may be considered trivial; damage to the drum can occur in a relatively short time if the alarm is left unattended.

Examples of available drum data points and their limits are given in Table 4-1.

Table 4-1
Sample DCS data points for a 2037-psig (14.15-MPa) steam drum in a unit using phosphate cycle chemistry treatment.

Monitored Parameter	Design Full Load	Low Limit	High Limit
Economizer inlet feedwater temperature	464°F (240°C)	N/A	506°F (263.3°C)
Drum pressure changes	See shutdowns and startups procedure specifications.		
Drum shell metal temperature ramp rate (for ambient cold starts)	Depends on the anticipated annual stops/starts.		
Drum shell metal temperature ramp rate (for hot starts)	Depends on the anticipated annual stops/starts.		
Boiler drum level	+1 inch (+25.4 mm)	-6 inches (-152.4 mm)	+6 inches (+152.4 mm)
Boiler drum pressure	2037 psig (14.15 MPa)	N/A	2200 psig (15.27 MPa)
Feedwater (economizer inlet) pH, cation conductivity, and dissolved oxygen		pH: 9.2 CC: N/A DO: N/A	pH: 9.8 CC: <2.0 µS/cm DO: <10.0 µg/kg
Downcomer water pH and cation conductivity		pH: 9.0	pH: 9.3 CC: <10.0 µS/cm
Saturated steam cation conductivity and sodium concentration			CC: <0.2 µS/cm Na: <2.0 µg/kg

Drum Level

The ability to determine the drum level at all times is critical to the operation of the boiler. Because of this, Section I, PG-60.1.1, of the ASME Boiler and Pressure Vessel Code has very specific requirements. Each boiler will have at least one water gauge glass, typically in combination with remote water-level indicators.

The history of low or high water-level alarms should be reviewed; additional analysis may be performed by reviewing temperature and pressure data if issues have occurred. The levels on each end of the drum should be compared to ensure that they are even during operation, including startups, shutdowns, and load follows.

Cycle Chemistry

The cycle chemistry instrumentation should be reviewed in accordance with the relevant EPRI or international cycle-chemistry guidelines for instrumentation and control/action limits [8–12].

Saturated steam and continuous blowdown (or downcomer) water samples are typically continuously monitored for various attributes such as cation conductivity (that is, conductivity after cation exchange), sodium levels, etc. The boiler will also have sampling lines for "grab" samples that are used to verify or calibrate the continuous monitoring instrumentation or may be used to measured parameters such as total iron or copper. Grab samples are typically taken once a shift or may be taken far more frequently to troubleshoot out-of-specification chemistry issues. Control charts for the core cycle-chemistry parameters should be prepared to determine the severity and frequency of out-of-tolerance readings.

Thermocouples

Steam drums have pressure transducers, but often do not have installed thermocouples (TCs). The reason for this is that since the drum is both unheated and at saturation pressure, the pressure transducers may provide sufficient information for controlling shutdowns and startups. A TC is a relatively inexpensive diagnostic device that can provide valuable information regarding transients and upsets that the pressure transducers will not identify.

Heating and cooling rate rules have been established that limit the thermal stresses seen by drums [13, 14]. Permissible temperatures, in turn, may be established for the drums and verified using TCs. Typical TC installations include:

- Axial locations: at each end and the center of the drum
- Elevations: at the top, bottom, and middle of the drum
- Radial locations: at the outer surface [13] or, for more accurate evaluations, at the mid-wall thickness of the drum [14]
- Other locations for TCs include on the riser tubes entering the bottom of the drum to monitor the temperature of the inside of the drum shell or on the downcomers to monitor for subcooling.

Figure 4-1 shows typical locations for diagnostic monitoring equipment on the drum. Figure 4-2 shows typical mid-wall TC locations at the top and bottom of the drum.

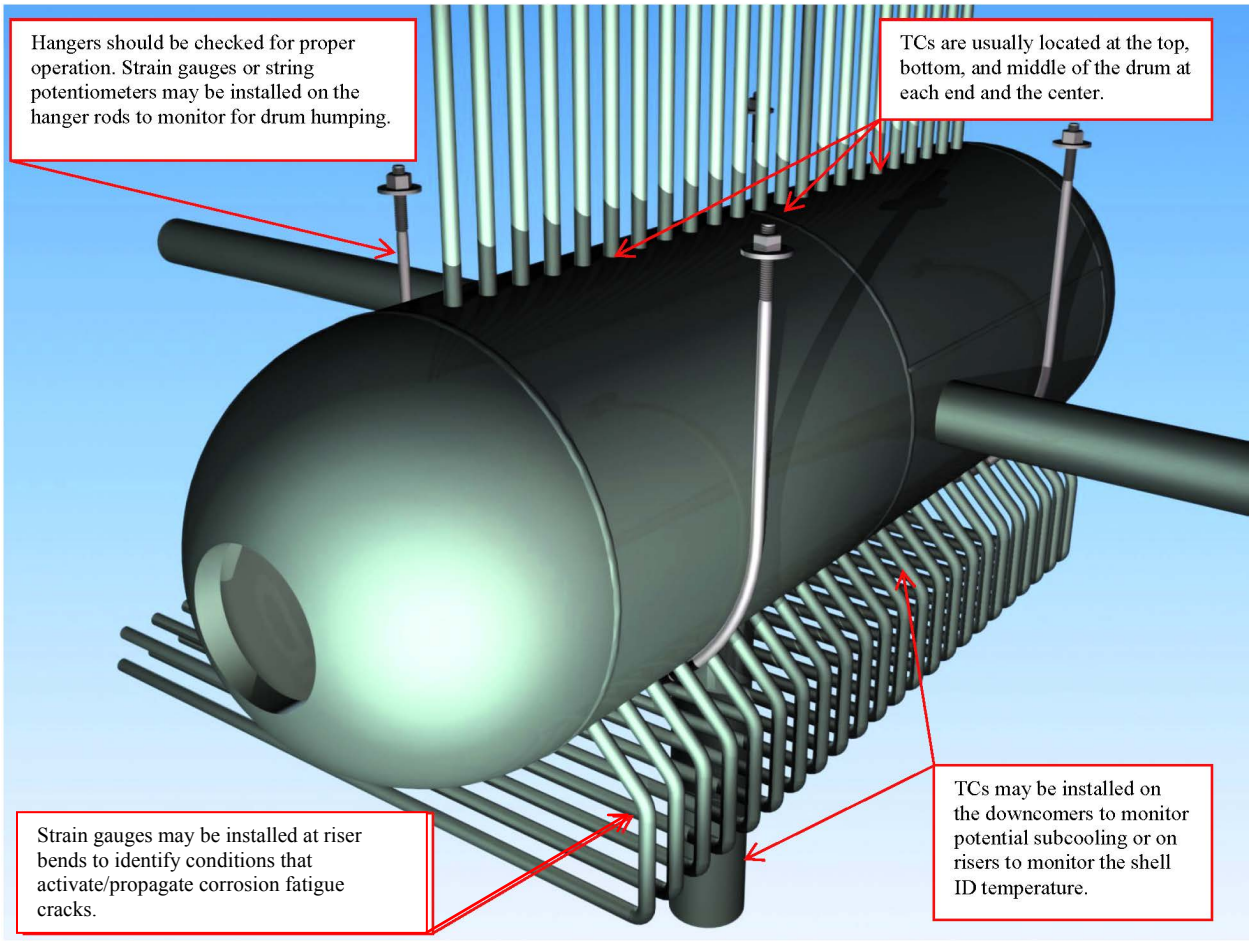


Figure 4-1
Locations where diagnostic monitoring instrumentation may be placed.

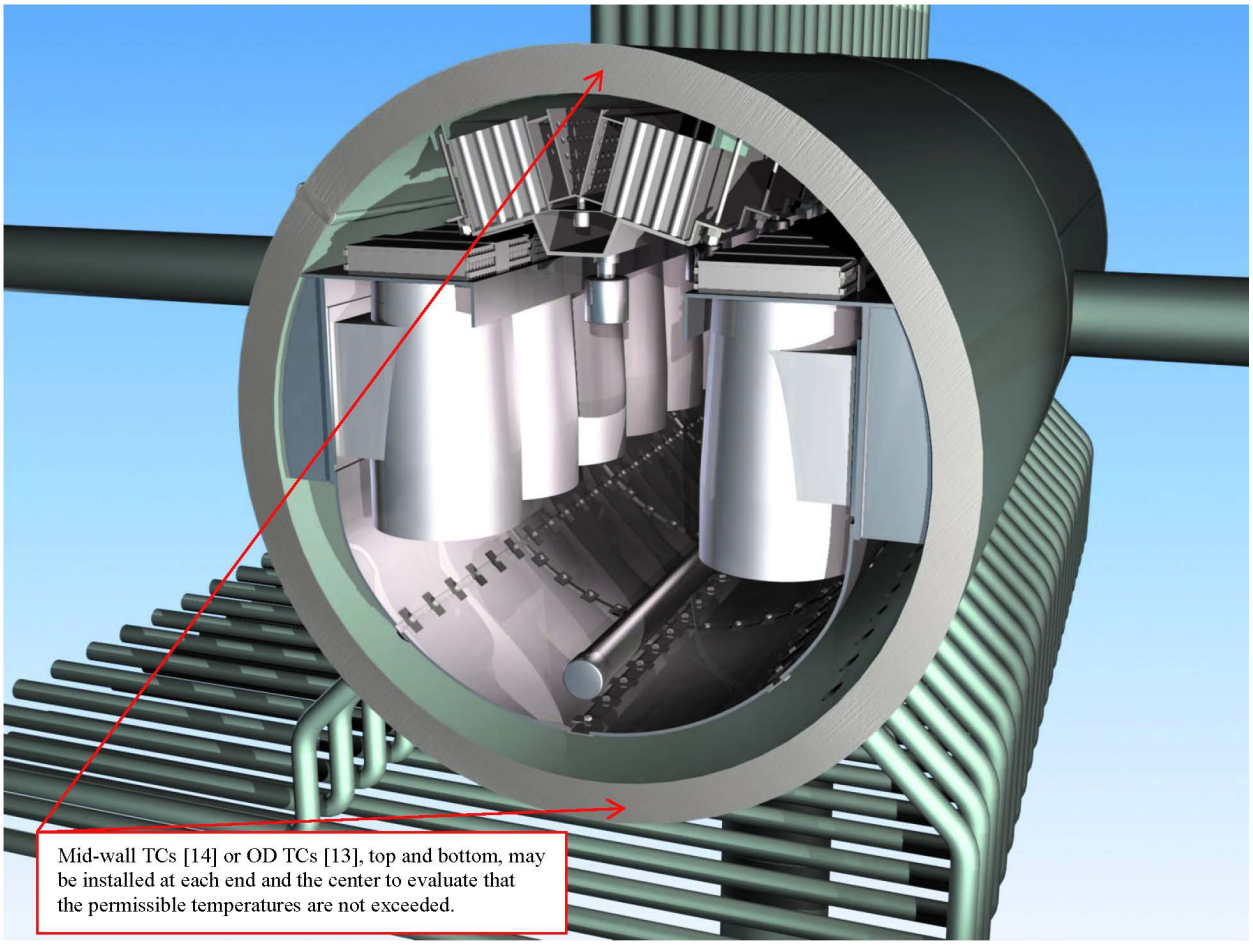


Figure 4-2
Locations of mid-wall thermocouples at the top and bottom of the drum.

Strain Gauges

Strain gauges may be installed to determine the strain at high-stress locations. For a unit that is experiencing significant stop/start or significant load-following events and is suspected of having damaging transients, a finite element analysis should be performed. Based on the result of the analysis, strain gauges should be installed at carefully selected drum shell ligament or nozzle locations to monitor the transients.

Strain gauges may be installed at the riser tube bends to identify the operating events and conditions that may be activating or propagating corrosion fatigue–type cracks (Figure 4-1).

Strain gauges are also effective diagnostic tools for measuring drum movement during operation (Figure 4-1). Figure 4-3 shows biaxial strain gauges placed on the drum hanger rods. The strain gauges were placed here because of the failure of a hanger at one of the drum ends due to drum humping.

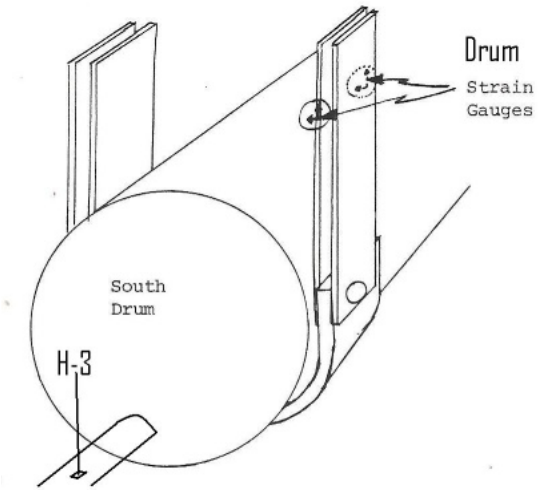


Figure 4-3
Strain gauges added to a drum hanger rod.

Safety

There are many physical and chemical hazards that exist in a power plant. The steam drum and lower water-wall drums are considered confined spaces. Prior to making the drum examination, the inspector should be aware of the hazards that may be encountered en route to the drum.

Requirements for NDE of Steam Drums and Lower Water-Wall Drums

Figure 4-4 shows a roadmap for the qualification of NDE contractors, procedures, and technicians.

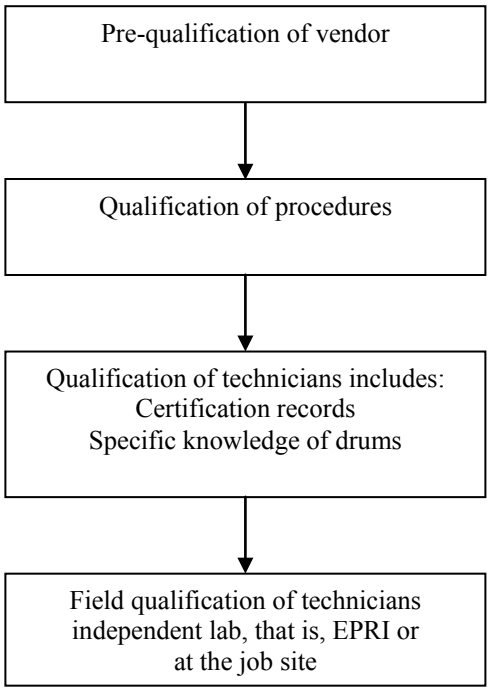


Figure 4-4
Roadmap for qualification of NDE contractors, procedures, and technicians.

NDE Techniques

Minimum requirements for NDE techniques can be obtained from the applicable standards, for example, American Society for Nondestructive Testing (ASNT), ASME Section V, British Standard (BS), European Union Standards (EN), and International Organization for Standardization (ISO).

NDE Technicians

NDE personnel should be certified to applicable standards and organizations, for example, ASNT TC1A (USA), National Board Inspection Code (NBIC) (USA), ISO 9712 (International), EN 473 (Europe), EN 45013 (Europe), Can/CGSB-48.9712 (Canada), Personnel Certification in Non-Destructive Testing PCN/GEN/92 (UK), Certification Scheme for Weldment Inspection Personnel (CSWIP) (UK), Japanese Society for Non-Destructive Inspection.

It is the duty of plant personnel to verify that the inspector has the necessary qualifications and a valid NDE certificate for the specific type of examination to be carried out.

Pre-Job Qualification

Pre-job qualification tests may be given to the NDE technicians who will be performing the examinations, whether they are employees of the utility or contractors. The tests may be in the form of:

- Written (or verbal) test: The inspectors should be tested for their knowledge of drum operation and what type of defects to look for prior to the examination.
- Practical test: The inspectors should be tested prior to the examination (at the plant or at a third-party qualifying company, for example, EPRI) by performing their examinations on a sample with known defects with the equipment, calibration blocks, procedures, and reporting records that will be used in the actual examination.

Inspectors should confirm prior to the examination that their NDE equipment is functioning properly and calibrated appropriately for each component to be examined. Calibration documents should be provided by the inspectors or their supervisor to the plant.

Post-Job Equipment Check

Inspectors should confirm the correct operation of their equipment by performing examination on their initial calibration block at the completion of the examination. The equipment should be cleaned and stored properly for the next use.

Control of NDE

The utility representative should review these documents and determine that the NDE organization is providing personnel who are qualified and certified in the NDE methods being used.

The utility representative should retain a copy of the quality control (QC) manual provided by the NDE organization. If this is a controlled copy, the NDE organization should send the updates, and the utility representative should update the QC manual. The utility representative should also retain a copy of the personnel qualification and certification records for all NDE personnel working on site.

The organization performing NDE should submit copies of the NDE procedures to be used for the job. Personnel qualifications should be submitted to the utility representative who is overseeing the examination.

The NDE reports created for all examinations should contain enough information to be able to accurately locate, characterize, and size any indications found during the examinations. The reports should contain:

- The purchase order number, plant name, unit name, description of indications, and location of indications within the drum.
- The location of indications must be documented so that repeat examinations of the location can be performed. The locations can be documented by a variety of means, including punch marks or photographs.
- The NDE technician doing the work should sign the report(s).

5
NONDESTRUCTIVE EXAMINATION OF DRUMS

Introduction

Annual Steam Drum Examinations

Boiler examinations in the United States are mandated and regulated by the applicable jurisdiction. The jurisdictions adopt codes and standards by which boiler examinations and any subsequent repairs are made. Authorized inspectors (AI) are commissioned by the National Board of Boiler Inspectors, whether they are from the jurisdiction or the owner's insurance company.

Yearly drum examinations with possible exceptions for longer time intervals (per jurisdiction) are required. These examinations are not the focus of this EPRI guide. These mandated examinations are typically limited-scope visual examinations performed by National Board Inspection Code– (NBIC-) trained inspectors, performed with all the drum internals remaining in place.

Comprehensive Steam Drum Examinations

The utility representative who is overseeing examinations should be familiar with the properties of the materials used and the manufacturing processes used in the fabrication of steam drums and lower water-wall drums. The representative must be aware of defects that can develop from these materials and manufacturing processes over time. The representative must also be aware of the defects that develop from the operation of steam drums and lower water wall drums, including the approximate hours and cycles until their onset.

Examination Planning

The scope of the examination of a steam drum is based on a number of factors; including the duration of the outage, operation of the boiler, previous examination damage, and repair history. The manufacturer's Service Information Letters or Plant Service Bulletins will also provide guidance as far as what issues to expect. There are database-driven risk assessment models available from consultants and insurance companies that can be used to forecast what damage may be anticipated for a given drum design, vintage, and operating/maintenance history.

Removal of the steam drum internals is necessary to provide access to the tubes and ligament areas underneath (Figure 5-1). The scope of the removal of the internals must be determined by each utility; however, there are a few factors that should be considered:

- The areas where internals have been removed during previous examinations.
- The locations of damage found during previous examinations.
- Indications found during previous examinations that require monitoring.
- Results of previous fitness-for-service analyses performed, if any.
- The history of water chemistry issues, if any.
- New areas that should be uncovered if previous examinations of boreholes, welds, and ligaments have found indications.
- New areas that might need to be uncovered during the current examination if indications are found during the current examination.
- The type of operation of the unit. If the unit is heavily cycled, more locations should be uncovered and inspected.

An external examination of the drum will require the removal of insulation. The scope of the removal of the insulation must be determined by each utility; however, there are a few factors that should be considered:

- Any visible leaks or insulation damage that has been found in the current or previous examinations
- Damage that has been known to occur or has been found in the current or previous examinations
- Internal damage that is found, making the drum internals difficult to remove

All repairs should be reexamined after one year of operation. Surface indications that were considered acceptable at the last examination should be monitored. If there is no record of past damage and the drums have been in operation as intended by the designers, periodic examinations are typically recommended to be performed every three to five years.

Examination locations may be prepped using wire wheels, wire brushes, or flapper wheels. Sandblasting should never be used due to the potential for masking surface-connected indications.

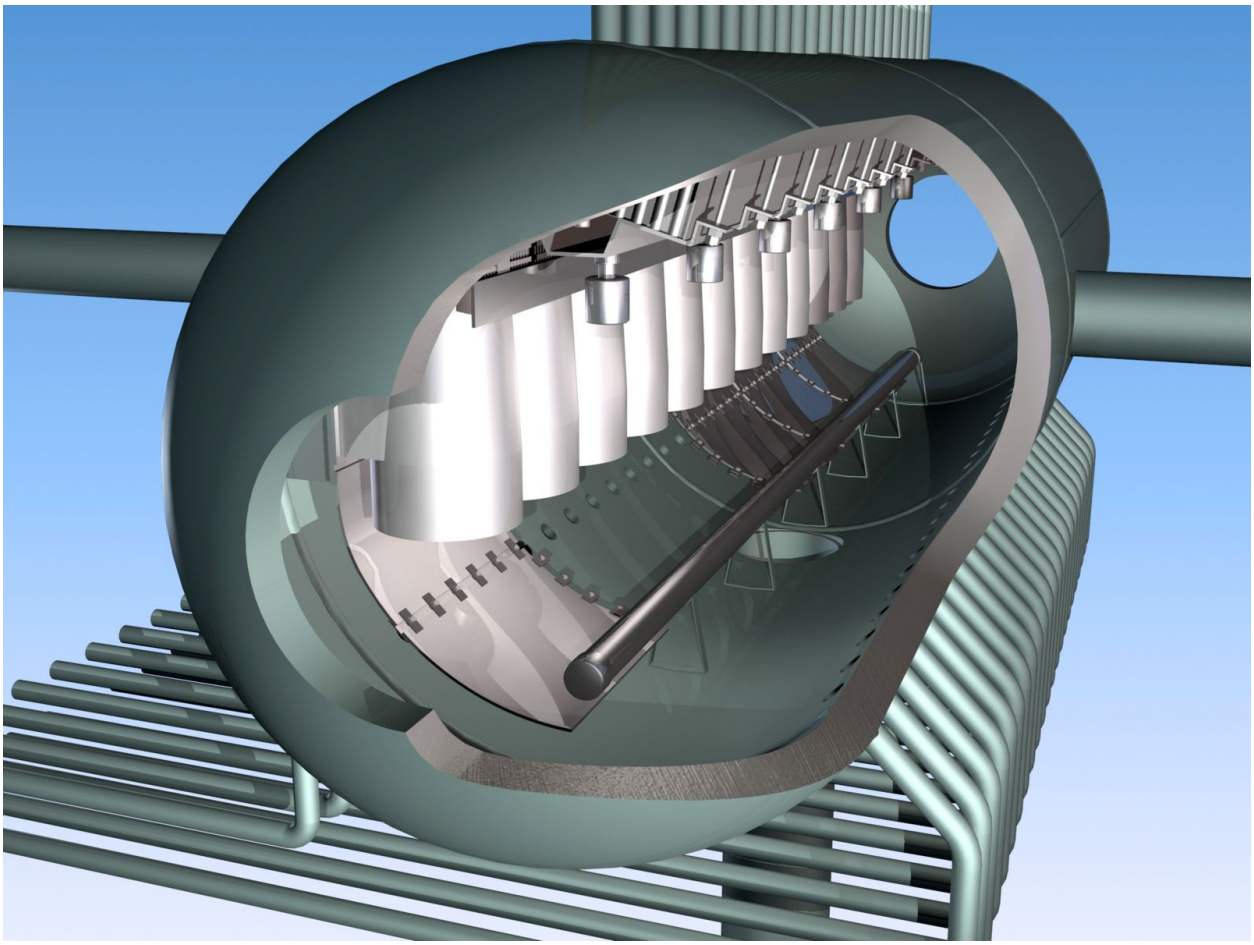


Figure 5-1
Cutaway view of a drum that shows areas where drum internals have been removed to provide access to tubes and ligament areas for examination.

NDE Techniques

Introduction

A drum examination consists of several techniques, including:

- Visual examination
- Videoborescope examination
- Magnetic particle examination
- Liquid penetrant examination
- Exploratory grinding
- Alternating current potential drop (ACPD)
- Ultrasonic examination
- Radiography examination

- Acoustic emission monitoring
- Metallurgical replication
- Boat samples

Whereas visual examination and magnetic particle and liquid penetrant testing can detect surface-breaking indications, those methods provide no information on the depth of the crack. If the crack must be removed from a component, it is necessary to know precisely how much metal should be removed by exploratory grinding to remove the entire crack. This may mean multiple applications of magnetic particle or liquid penetrant testing to establish that the crack has been eliminated.

Ultrasonic examination can be used to provide crack depth information, but this is difficult for cracks that are shallow and close to the ultrasonic probe. Ultrasonic flaw sizing is also difficult to apply on complex or tightly radiused surfaces, such as drum boreholes, baffle plate bolt holes, etc.

ACPD can make these crack depth measurements, even on tightly curved surfaces. Application of ACPD allows the depth of exploratory grinding to be determined beforehand, resulting in a time savings by minimizing the need for repeat examinations using other techniques.

Visual Examination

The main examination technique for drums is visual. The inspector, using a bright light and a wire brush, can inspect all visible welds and nozzles in the drum. An angle mirror can be used to help see the locations that are not readily visible. When an indication is found during visual examination; it can be marked with chalk, paint, or soapstone to be revisited with another NDE technique (Figure 5-2).

Typical items to look for during visual examination are:

- Indications that were to be monitored and measured and that were left in place after previous examinations.
- Any previous weld repairs
- Indications on penetration welds
- Indications on longitudinal welds
- Indications on girth welds
- Ligament cracking
- Indications on the non-pressure-boundary attachment welds
- Indications at the penetration/drum interface on the external surface
- Deposits on the drum bottom
- Stains indicative of variable water levels
- Looseness of the vertical cyclone separators or “cans”
- Damage to manifold baffle plates

- Damage to chemical feed pipes
- Damage to the liners
- Any missing or damaged nuts/bolts
- Damage to the drum hanger supports or insulation material

After the examinations, a final crawl-through should be performed before the drum is closed to ensure that there are no loose items that can potentially damage the downstream systems.



Figure 5-2
Surface indications found during visual examination. The locations were marked for further disposition by exploratory grinding.

Figure 5-3 shows stains indicative of water-level variations in the steam drum. Variations in drum water level may have a detrimental effect on boiler and superheater tubing. Drum water-level controls were recommended in this case to be reconditioned or replaced to avoid frequent trips.



Figure 5-3
Stains on the internal surface of the steam drum. These indicate variations in water level during operation, which may have a detrimental effect on boiler and superheater tubing.

Videoborescope Examination

Videoborescope examination is very commonly performed in the drum nozzles, riser tubes, and inaccessible regions where the drum internals have not been removed.

The amount and length of the examination of riser tubes is based on a number of factors, including access, the results of previous examinations, tube failures, tube repairs, and replacement history. Industry experience has shown that the examination should be performed through at least the first or second bends in the tubes.

If no significant deterioration has been observed over the previous years, the videoborescope examination can be typically performed every three to five years, with a minimum of 15% of the tubes from each end of the drum or 30% of the tubes along the drum (where accessible). These percentages may be determined and modified based on the past experience of the inspector and the historical data of the drum.

If indications are found, the examination should be performed in each accessible tube. If there were any indications left alone during the previous examination or if any weld repairs or replacements were performed, the videoborescope examination should be performed in each accessible tube after one year of operation.

In order to determine if there are cracks in the drum baffle plate at the dry box location of an Alstom-controlled circulation unit, a wet drum or cold water test should be performed [6]. For this examination, the drum water level is established below the level of the manway doors, and the dry box examination is performed through the previously made examination ports (usually two on each end) by removing the pipe plugs.

Magnetic Particle Examination

Wet fluorescent or dry magnetic particle examination can locate very fine and very shallow cracks in the drum surface. Use of magnetic particle examination can ensure that the entire surface-connected discontinuity is identified.

Key factors that are necessary to produce optimal magnetic particle examinations include:

- Adequate cleaning of the surfaces to be inspected
- Contour profiling weld toes with rollover, undercutting of sharp weld toe angles
- Verification of the magnetic field strength and angular crack detection capability of the magnetic particle yoke
- Appropriate lighting for the specific magnetic particle method used

Figure 5-4 shows the use of black light to accentuate indications found in a ligament area with wet fluorescent magnetic particle examination.

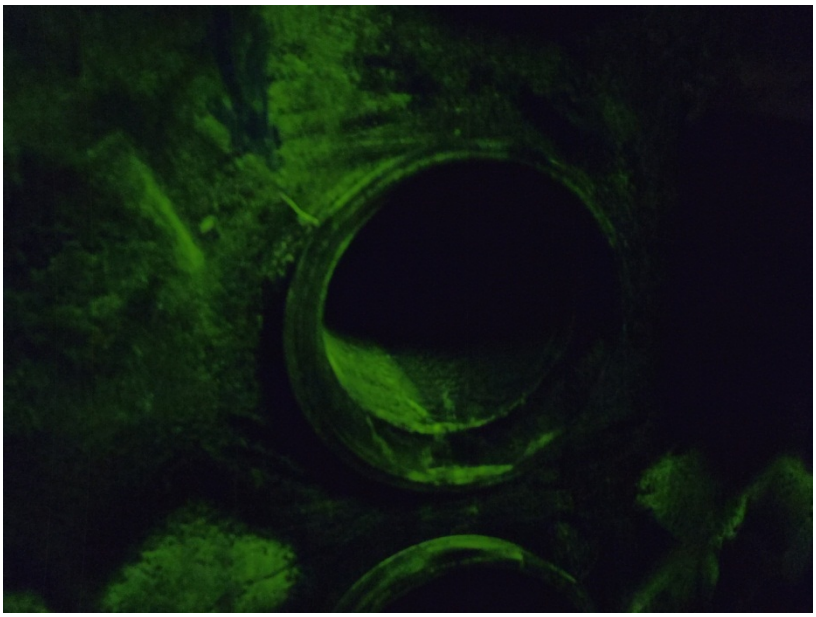


Figure 5-4
Black light photograph of indications in a ligament area found using magnetic particle examination.

Liquid Penetrant Examination

Liquid penetrant examination should be performed on non-magnetic components or overlays (if any). Penetrant examinations may also be used to locate and size surface-connected indications observed by magnetic particle, as dye penetrant and developer in some situations may make the indications easier to document. Liquid penetrant examinations may be a preferred examination method in locations with complex geometries, such as boreholes, where the access for magnetization required to perform magnetic particle examinations is challenging. Figure 5-5 shows the use of liquid penetrant to examine a tube borehole.

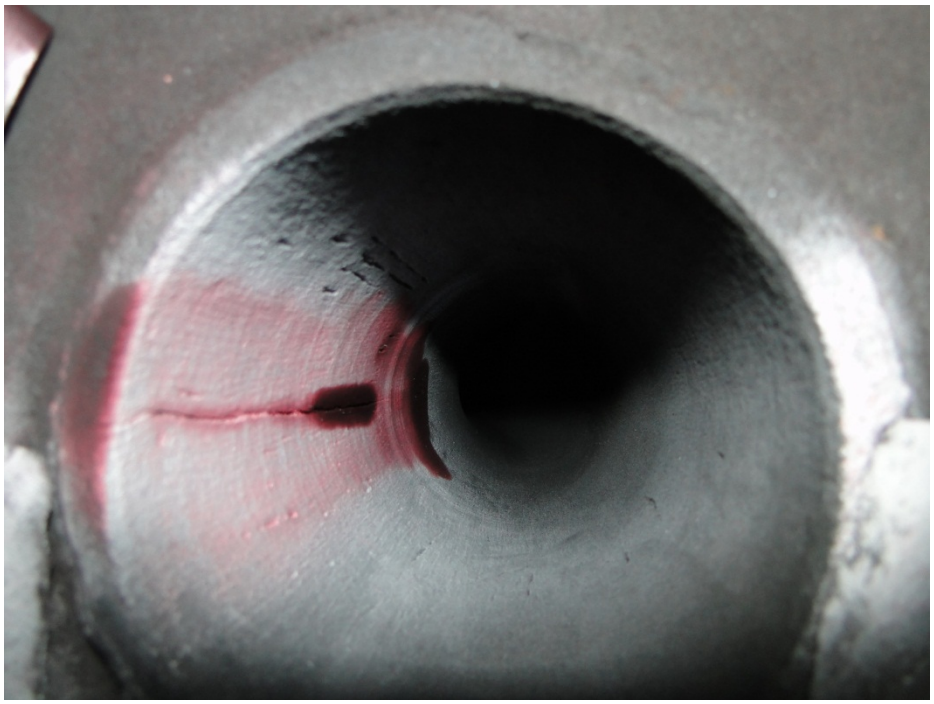


Figure 5-5
Liquid penetrant examination of a tube borehole.

Exploratory Grinding

A light surface grinding is commonly used to evaluate surface indications found during an examination. When an indication is revealed, cross grinding is performed where the indication is widest and perpendicular to the direction of the indication. NDE should be performed again after cross grinding. This process should be repeated until a certain depth (mutually agreed upon between the inspector and the plant engineering supervisor) is reached. If the indication still remains, an ACPD or ultrasonic examination method should be performed to size the indication.

After evaluation is completed, all sharp surfaces and edges created by surface grinding should be blended in order to avoid stress riser locations. The depth of the exploratory grinding should be noted in the NDE report. Dental molding or similar dimensionally stable moldable material can be used to document the excavation shapes and depths if needed.

AC Potential Drop

The ACPD technique is a very effective means of measuring the depth of a drum borehole ligament or other surface-connected indications. ACPD is not a practical method of locating surface-connected cracks and is, thus, used after the indications have been discovered and located using visual, magnetic particle, or liquid penetrant methods.

A calibration block made of the same material that is to be tested, with a tapered electric-discharge-machined notch, is used to calibrate the zero and gain settings prior to measurements. After calibration, the zero setting is then reset on the component to be examined at an indication-free location.

The cleanliness of the examination surface and probe tips is a key factor for accurate ACPD measurement. The examination surface should be lightly ground with a powered wire wheel or sanded with emery paper and then wiped with a chemical cleaner (for example, liquid penetrant cleaner) to remove the grinding residue. Probe tips can be contaminated by occasional arcing or oxidization over time. When instrument calibration becomes difficult or repeated measurements have excessive variations, the probe tips should be lightly wiped with emery paper and a chemical cleaner. If the surface to be examined and the probe tips are not cleaned sufficiently, unstable readings or lack of repeatability from one measurement to the next may occur.

Although ACPD measurements are relatively simple to make and interpret, this technique requires some skill in the placement of the probes across a crack and also in the interpretation of the readings when cracks are in close proximity to edges, corners, or other discontinuities.

Depth sizing errors in ferromagnetic material in the range of 3%–15% are expected and, in some situations, may be up to 30%. The tendency, in general, is to undersize the true crack depth using the ACPD technique. The measured crack depth value gets closer to the actual crack depth value as the number of crack branches and the angle between the crack and the surface normal get smaller. The inspector can establish with this method that the indication is at least the measured value depth, which is very important information in determining rejectable indications and for estimating grind-out depths.

Ultrasonic Examination

Surface Preparation for Ultrasonic Examinations

Time and effort must be expended in preparing the internal surface of the drum where the transducer will be used, as the signal-to-noise ratio is directly affected by the quality of the surface. A new drum has a surface roughness of 0.0008–0.004 inch (0.02–0.1 mm) on the plate. At a weld, the surface roughness is 0.002–0.004 inch (0.05–0.1 mm). After 40 years of service, the surface roughness will typically be 0.004–0.060 inch (0.1–1.5 mm) due to corrosion. The surface will have to be sanded with progressively finer grits (finishing at 220 grit) until the surface is returned to new drum surface roughness [15, 16].

Ultrasonic Thickness Measurements

Ultrasonic measurements of wall thickness are performed to determine localized or general wall thinning on the drum wall material and to map out the local wall thickness, geometry, and presence of laminations within the examination region prior to performing angle beam flaw locating/sizing-type ultrasonic examination. If the examination history of the steam drum and associated tubing does not indicate any corrosion/erosion problems, a routine ultrasonic wall thickness examination is typically recommended to be performed every three to five years, which includes:

- On each side of the girth welds, at least at the quarter points around the circumference (eight readings)
- Above and below the seam welds near the ends and in the middle of the weld length (six readings)

If an area with wall thinning is observed, a grid can be drawn on the area, and more frequent thickness readings can be recorded. The minimum recorded value should be compared to the minimum required wall thickness value for the drum. This can be calculated in accordance with the applied codes and standards.

Depending on the degree of wall thinning, the corrective action (for example, monitoring by more frequent examinations or repairing) should be determined by experienced engineers. A fitness-for-service analysis may also be performed to determine the severity of an indication.

Flaw Detection

Since most of the thermal and mechanical stresses occur on the internal surface of the drum and there is better access from the internal surface of the drum (the external surface is insulated), ultrasonic examinations are sometimes not performed unless there is a specific reason to expect subsurface indications or if there is a reason to use ultrasonic examination for depth sizing of surface-connected cracks such as borehole cracks. One of the possible reasons to have subsurface indications in a steam drum may be original or repair weld defects. Ultrasonic examination is recommended to be performed on the girth weld and seam welds at least once, in order to detect weld defects from fabrication or repairs. Although geometrically challenging, ultrasonic examinations performed at the drum shell internal surface may be used to examine attachment nozzle welds located on the external surface of the drum shell.

Angle beam ultrasonic examinations are performed in order to detect, locate, characterize, and size subsurface indications on the girth and seam welds of the drum or to determine the subsurface shape (depth) of surface-connected borehole ligament cracks.

Manual single-angle pulse-echo, linear phased array, and focused beam phased array angle beam ultrasonic examinations have all been used for steam drum examinations performed at the internal surface of the drum shell.

Automated ultrasonic examination systems have been used to perform examination of drums from the external surfaces of the drum shell, but these require removal of the external lagging and insulation, which in older units may contain asbestos.

It is recommended that full-size sketches of the geometry, including best estimates of the configurations of any welds in the examination region, be made to select the optimal beam angles and scanning positions. ASTM E164 (Standard Practice for Ultrasonic Contact Examination of Weldments) provides useful guidance that can be adapted to ultrasonic examination of drum shell circumferential and longitudinal welds performed at the internal surface.

Drums have typically been made from carbon steel plate; although when there is a need for additional strength or less weight, they may be made from manganese-molybdenum steel plate. The plate specifications most often specified for drum fabrication are [17]:

- SA-212 Grade B carbon steel (coarse grain [CG] practice), discontinued in 1967 and replaced by SA-515 Grade 70 (CG practice) and SA-516 Grade 70 (fine grain [FG] practice)
- SA-299 carbon steel (CG practice implied)
- SA-302 Grade B, 1.3 manganese - 0.5 molybdenum steel (CG practice implied),
- SA-515 Grade 70 carbon steel (CG practice)
- SA-516 Grade 70 (FG practice)

CG drum materials may, in some cases, alter the capability of ultrasonic examinations. If the drum was manufactured using CG material, it is important to verify (through field verification) that the ultrasonic equipment and procedure is satisfactory. This may require using lower frequency transducers than would be adequate for FG materials. In addition, the large grain sizes cause angle diffusion, that is, a 45° angle is no longer 45° in the material. In the case of CG materials, a calibration block of the same material is especially important to be able to take into account the material properties. The NDE technician should be able to demonstrate that they can adequately detect, locate, and size real or artificial discontinuities in the drum that is being examined.

Flaw Sizing

For sizing the length and through-wall depth of indications in drum welds and other damage-prone locations, the following ultrasonic testing flaw-sizing techniques are used:

- Amplitude
- Amplitude drop (that is, 6 dB)
- Crack tip diffraction
- Time of flight diffraction
- Phased arrays

Amplitude-based sizing is seldom used when sizing accuracy is critical. The beam distance corrected signal amplitude is proportional to the effective surface area of the discontinuity, but the amplitude is also a function of the flaw type, orientation, relative size of the ultrasonic testing beam compared to the discontinuity, and the attenuation of the signal that is controlled by the transducer-to-component coupling.

Amplitude drop is perhaps the most common method of sizing discontinuities, especially for determining their length. Once the maximum distance-corrected signal amplitude of the discontinuity is found, the transducer is moved along the length of the discontinuity until the distance-corrected amplitude on the ends drops to ~1/2 the maximum value. For depth sizing, the bottom and top positions of the discontinuity are estimated using geometry, beam distance values, and calibration of the beam spread of the transducer.

One of the most accurate discontinuity depth sizing methods is the "tip diffraction" or "time-of-flight diffraction" method. As long as there are no other reflected or diffracted signals that make the tip diffraction signals confusing, the crack size is easily estimated using time of flight values and simple geometry relationships. This method is especially useful for surface-connected cracks on the opposite surface from the transducer that are shallow enough that the crack corner and crack tip are both well within the spread of the sound beam.

The sound amplitude drop method of discontinuity sizing can be readily implemented using phased arrayed ultrasonic examinations, especially if beam focusing is also used so that the beam spread at the location of the indication is minimized and the reflected sound amplitude at the edges of the discontinuity falls off rapidly. If beam focusing is not performed and the shift in beam entry position for each beam angle is not accounted for, then the apparent size of the indications shown in phased array sector charts will be larger than the true size.

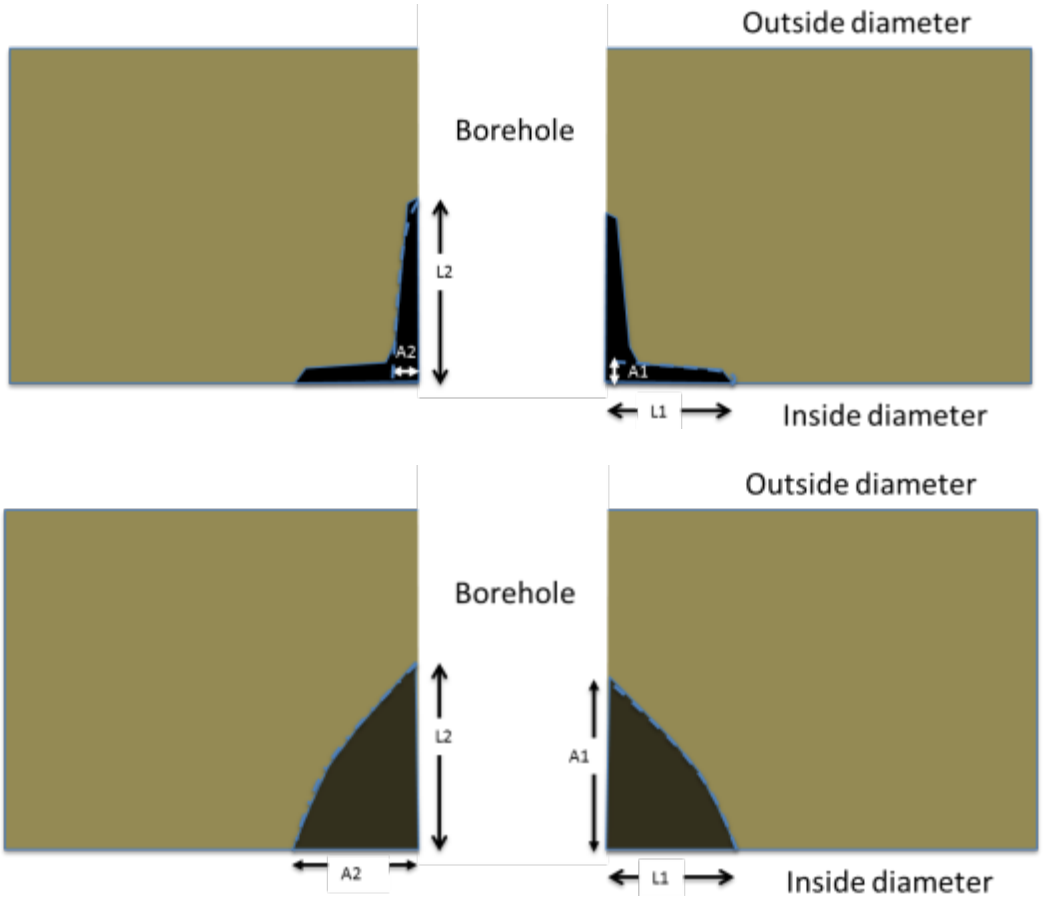


Figure 5-6
Drum borehole cracks with similar surface dimensions on the borehole and drum internal surfaces may have significantly different crack depths and crack tip shapes.

Radiography Examination

Generally, radiography is used to examine welds. The most common use in power plants is for examining original construction or repair welds. It is ideal for detecting rounded or cylindrically shaped flaws, such as porosity or slag inclusion, that are common to welds [19]. Access and safety issues involved make radiography a less often used method for examining drums.

Acoustic Emission Monitoring

For some situations, acoustic emission monitoring of steam drums may be useful. Acoustic emission can identify the operating events that may be activating or propagating damage, provide information on the location of damage, and also provide sufficient information to allow for safe continued operation until other nondestructive methods can be used to characterize and size the acoustic emission indications. It can be performed without removal of insulation and under high temperature. All (100%) of the drum and the drum nozzle regions can be inspected while in service using acoustic emission. It can detect a significant flaw and its location and determine if a known flaw is growing; however, it cannot size flaws or replace a proper fitness-for-service evaluation. Also it cannot detect flaws that are not actively propagating.

No steam drums in the power industry are currently equipped with an acoustic emission system, but other pressure vessels have been. This is an area for potential future research.

Metallurgical Replication

Metallurgical replication is performed to identify the crack mode, size, and initiation time. With respect to the crack mode, replication would show the profile of the crack on the internal surface of the drum as well as any microstructural changes near the crack that may have occurred as a result of the prior years of service. The replication film is stuck on a slide with an adhesive tape to be processed in the laboratory and evaluated under a microscope. If there is an area of interest on a slide that is considered for future viewing, it can be marked with a permanent marker on the back side of the slide. The location of the replication can be documented photographically before peeling it off the drum surface. The oxide scale thickness along the crack surfaces can be used in estimating the crack initiation time.

Boat Samples

Boat samples may be removed from the drum to perform a metallurgical analysis of the sample. Figure 5-7 shows the location of a boat sample taken from the drum, which includes a crack propagated from inside the borehole. Figure 5-8 shows the boat samples taken from the ligament area of the drum.



Figure 5-7
Location of a boat sample taken from a ligament area.



Figure 5-8
Boat samples taken from the ligament area of a drum.

Documentation of Indications

The first step in disposing of any indication is to ensure that the total extent of the indication is known and measured.

The results for all examination locations should be reported in examination reports. Equipment, calibration, test information (when appropriate), and detailed indication location data should be listed in this report both to document the examination and to be able to monitor indications during future examinations. A permanent punch mark on the drum showing the indication length and location; photographs showing the location of the indication (both a close-up with a ruler and an overall view showing major components in the vicinity of the indication); a screen shot of the indication; and a sketch illustrating the location, orientation, size, and shape of the indication should sufficiently document an indication.

If a location is not fully inspected, the approximate percentage and area (for example, north side of weld, from the 9 o'clock to the 3 o'clock position) that was inspected should be noted. It should also be noted if the indication was repaired, left in place, or removed by light surface grinding. If repaired or removed by light surface grinding, the depth at which the indication was removed should also be recorded, as well as the method of reexamination used to confirm the removal.

Figure 5-9 shows the measurement of a crack using a measuring tape placed along the surface of the drum.



Figure 5-9
Visual determination of the length of an indication using a measuring tape.

A rubber replica and tape impression of a magnetic particle testing indication will provide an easy and effective method of documenting the indication morphology (Figure 5-10).



Figure 5-10
A dental molding material replica and clear masking tape impression can provide permanent records of magnetic particle testing indications. Dental molding material is especially useful if the local surface geometry, such as an excavation groove, weld toe, or other curved geometry, needs to be recorded.

Figures 5-11 through 5-13 show examples of the documentation required for an ultrasonic indication.

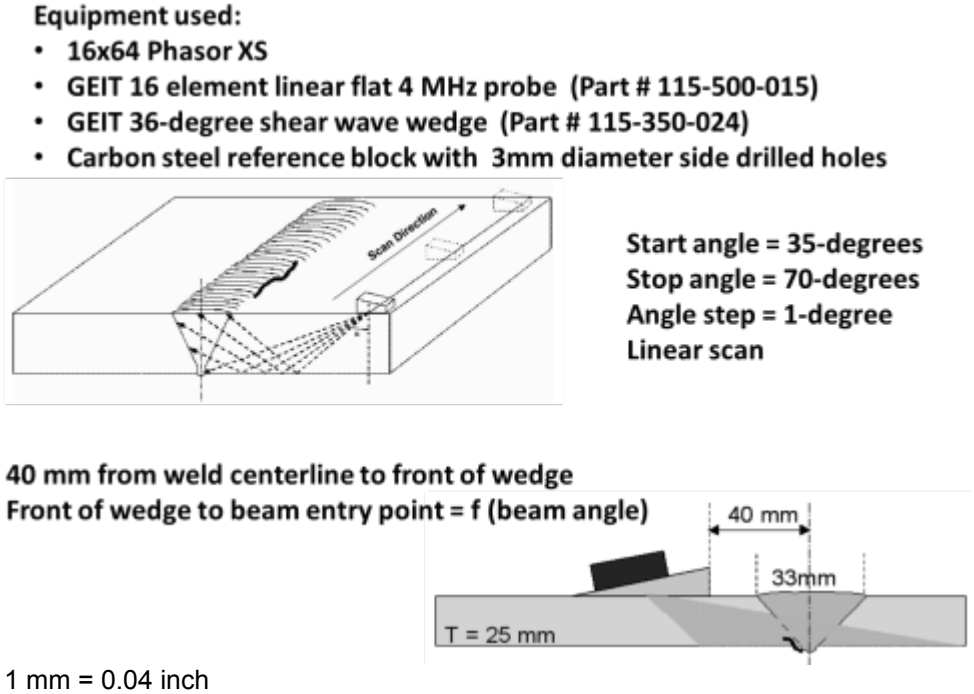


Figure 5-11
Example of phased array equipment, setup, and scanning information. Adapted from [18].

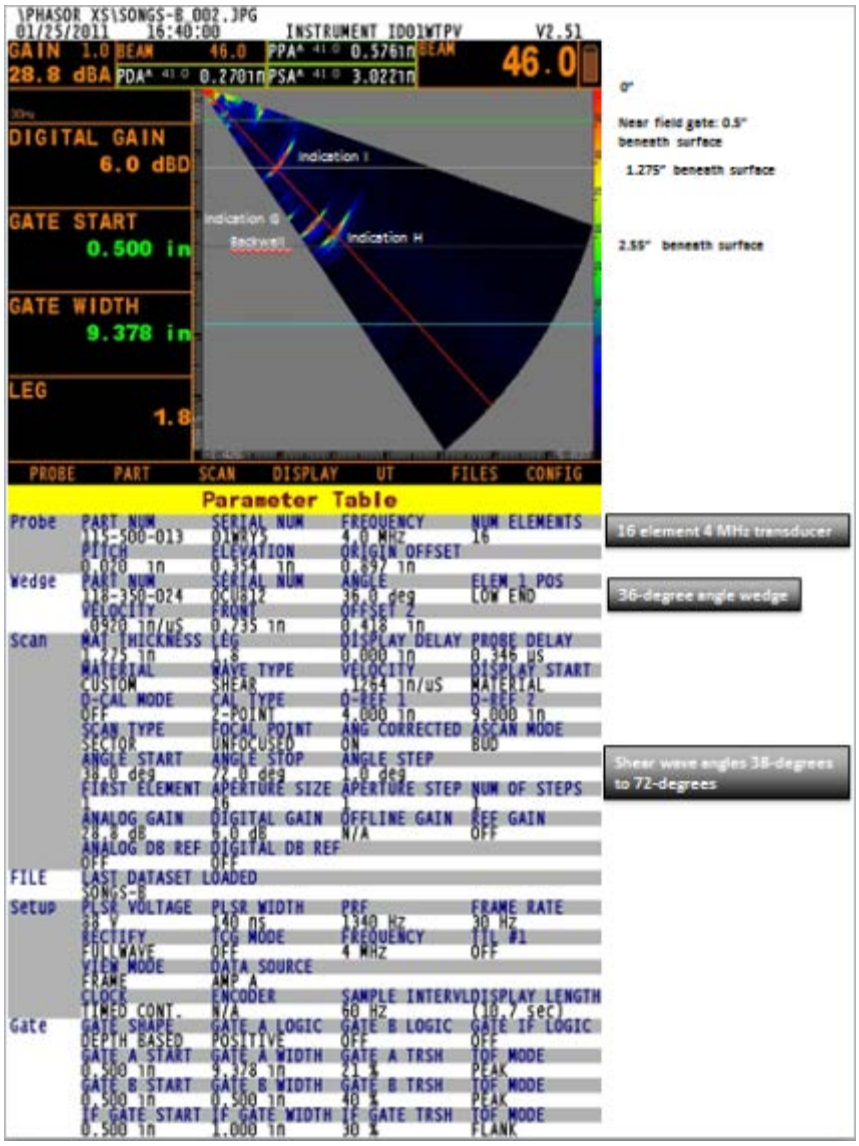
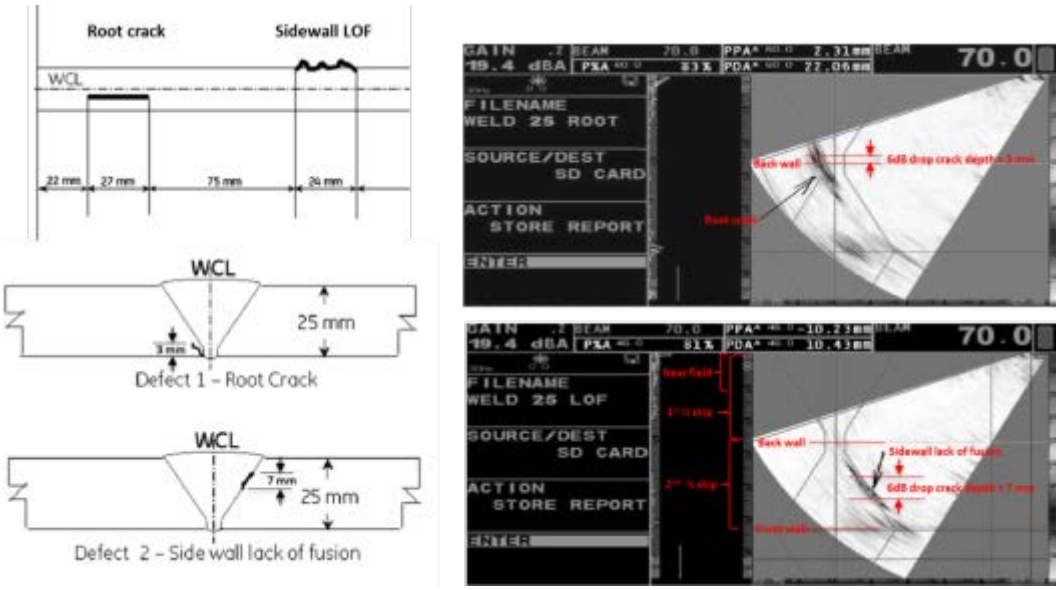


Figure 5-12
Example of phased array instrument settings.



1 mm = 0.04 inch

Figure 5-13
Phased array ultrasonic examination sector chart and associated sketches made by the NDE technician to document their interpretation of the discontinuity's location, orientation, size, and (most likely) type. Adapted from [18].

Drum Examination Methodologies

If visual or videoborescope examinations reveal indications in the riser tubes or downcomers, ultrasonic shear wave examination is recommended to be performed from external surfaces of the downcomers or riser tubes in order to confirm and size the indications. This may require removing insulation at the locations where tube internal surface indications were revealed. Any tube segment with cracking that exceeds the permissible length and through-wall depth or corrosion that violates the minimum permissible wall thickness should be removed.

Ultrasonic examinations can also be used to examine nozzle attachment welds or other crack-prone drum shell locations where indications or cracking might not be internal surface connected or could be missed by visual, magnetic particle, or liquid penetrant examination.

In the case of surface-connected borehole cracks, the depth and shape of the cracks should be determined with ultrasonic examination and/or ACPD since borehole cracks with similar surface dimensions can have significantly different shapes and depths.

In each of these situations, it is important to map out the local geometry, dimensions, and most likely weld profile to help in the setup scanning methods to be used and to help in the interpretations of indications. Use of calibration blocks that are closely similar to the drum detail, flaw sizes, and orientations that are anticipated will greatly enhance ultrasonic examinations, regardless of the ultrasonic method used.

Often there are situations where some thought has to be given on how to determine the size of an indication. Figure 5-14 shows a major crack with numerous minor cracks surrounding it. A general approach to determining the size of the major crack would be to try a variety of approaches and to use the most conservative results. For example, the size of the major crack could be estimated using:

- ACPD (calibration of the measurement could be obtained by measuring one of the other flaws, and perform exploratory grinding to determine the flaw depth).
- Time-of-flight diffraction (if the opposite side of the drum is available)
- Back scatter
- Pulse echo
- Phased array

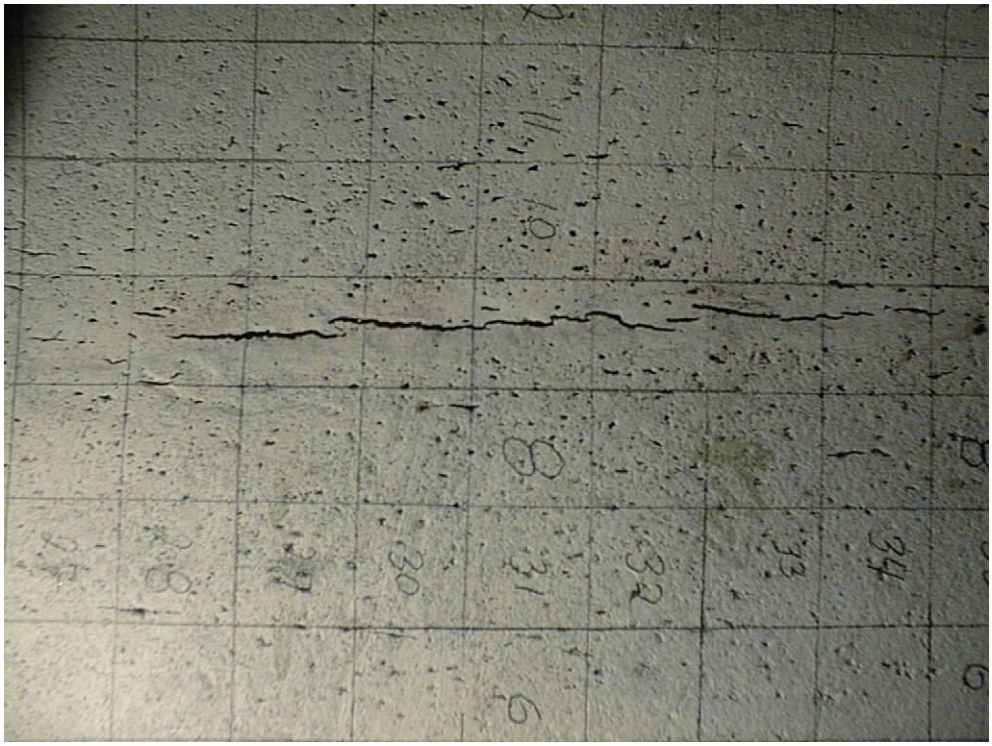


Figure 5-14
A major crack surrounded by other minor cracks and flaws.

Case Study 1: Estimates of Crack Growth

An examination was performed on a drum where extensive damage was found in several of the generator tube rows. Liquid penetrant and then wet fluorescent magnetic particle examinations were performed, and then both ACPD and ultrasonic examination were used in the worst case areas to size the cracks (Figure 5-15).



Figure 5-15
Liquid penetrant examination of a drum showing numerous indications in the ligaments and tube boreholes.

A methodology was required to report the results that would indicate the severity of damage seen in the areas examined. Figure 5-16 shows the results of the examination. A decision was made to categorize the damage as:

- Light – Less than five indications
- Moderate – Ten indications with a length of 0.50 inch (12.7 mm) or less
- Heavy – Ten or more indications with a length of 0.50 inch to 1.00 inch (12.7 mm to 25.4 mm)

The heaviest damage can be seen to occur in the center of the drum. A review of the boiler chemistry history indicated that there were periods when the boiler was operated outside the normal chemistry control ranges. In addition, there had been a recent low drum level occurrence due to the loss of a boiler feed pump. It was recommended that the utility consider upgrading the present control system, including an upgrade to the DCS that would give them the capability to review any operations over a period of time that are outside the normal operating parameters. It was also recommended that additional TCs be added to the steam drum. A fitness-for-service analysis was performed to determine the acceptable flaw size.

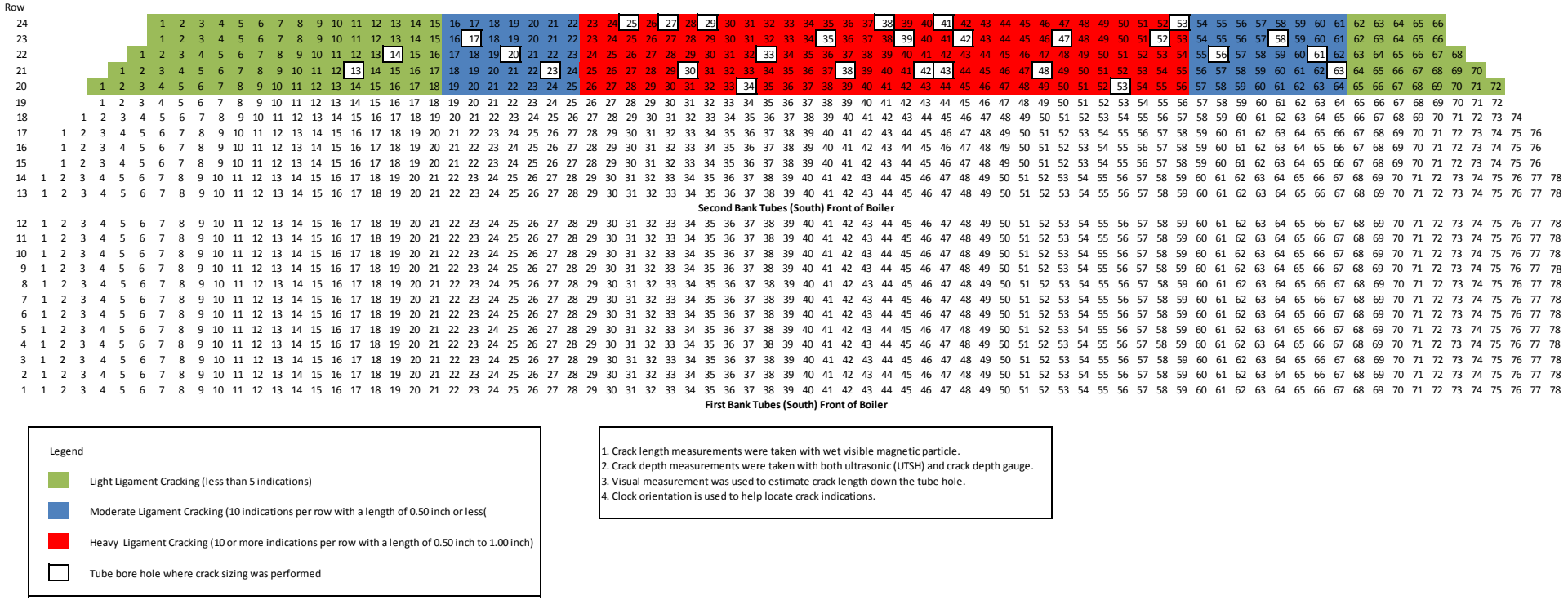


Figure 5-16
Map of wet fluorescent magnetic particle examination of a drum. Locations chosen for crack sizing by ACPD and ultrasonic examination are indicated by the numbered boxes.

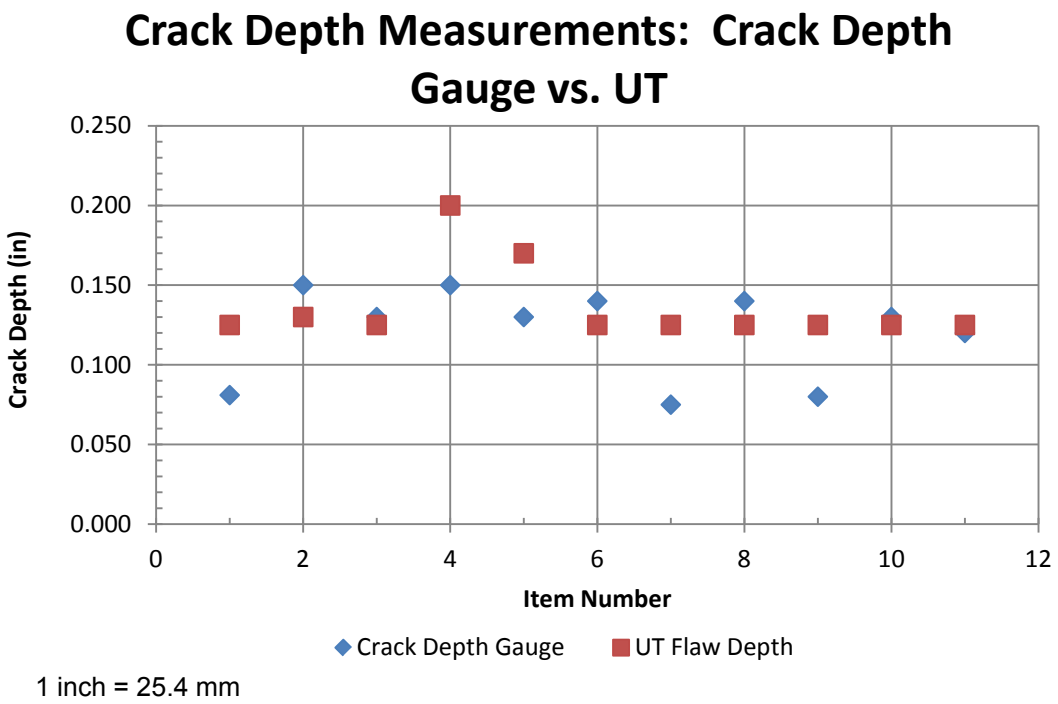
A second examination was performed five months later, and a third examination was performed a few weeks after the second examination and after a chemical cleaning. These examinations included crack sizing of locations examined during the first examination, as well as additional locations chosen by the NDE technician. Table 5-1 shows a partial summary of the results of the third examination. Location, orientation, length, two measurements of depth (ultrasonic examination and ACPD), and a visual examination of length down the boreholes are given.

Table 5-1
Summary of the results of crack sizing in tube boreholes using multiple NDE methods.

Row	Tube	Indication Number	Indication Orientation Transverse = to Drum Axis Longitudinal = along Drum Axis	WFMT Length (inches)	UTSH Depth (inches)	PDCD Depth (inches)	VT Length down borehole (inches)	Clock Orientation
20	34	1	Transverse	0.125	0.125	0.121	0.125	12:00
20	34	2	Longitudinal	0.251	0.125	0.141	0.125	2:30
20	34	3	Longitudinal	0.187	0.191	0.181	0.125	3:00
20	34	4	Longitudinal	0.125	0.125	0.121	0.125	8:00
20	34	5	Longitudinal	0.125	0.125	0.131	0.125	8:30
20	34	6	Longitudinal	0.125	0.125	0.121	0.750 +	9:00
20	34	7	Longitudinal	0.625	0.125	0.131	0.125	9:01
20	53	1	Longitudinal	0.187	0.125	0.131	0.750 +	3:00
20	53	2	Longitudinal	0.251	0.125	0.121	0.125	4:00
20	53	3	Longitudinal	0.125	0.161	0.171	0.750 +	9:00
20	53	4	Longitudinal	0.125	0.125	0.121	0.125	9:01
20	53	5	Longitudinal	0.312	0.125	0.111	0.125	10:00
21	13	1	Longitudinal	0.125	0.125	0.131	0.125	3:00
21	13	2	Longitudinal	0.187	0.125	0.141	0.125	3:30
21	13	3	Longitudinal	0.251	0.125	0.121	0.251	4:00
21	13	4	Longitudinal	0.125	0.125	0.141	0.125	8:00
21	13	5	Longitudinal	0.251	0.125	0.131	0.501	9:00
21	23	1	Transverse	0.501	0.125	0.131	0.501	12:00
21	23	2	Longitudinal	0.187	0.125	0.131	0.125	2:00
21	23	3	Longitudinal	0.251	0.125	0.121	0.251	3:00
21	23	4	Longitudinal	0.125	0.125	0.141	0.251	8:00
21	23	5	Longitudinal	0.125	0.125	0.131	0.125	8:30
21	23	6	Longitudinal	0.125	0.125	0.121	0.321	9:00
21	23	7	Longitudinal	0.125	0.125	0.121	0.125	9:30
21	23	8	Longitudinal	0.125	0.125	0.121	0.125	10:00

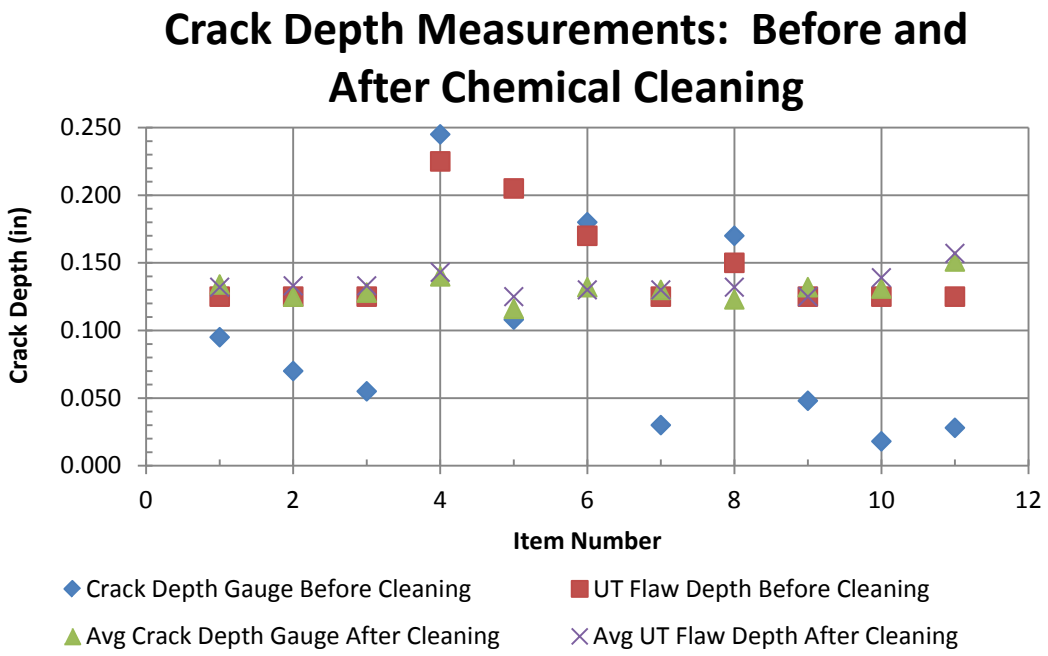
1 inch = 25.4 mm

Figures 5-17 and 5-18 show a comparison of ACPD and ultrasonic measurements at the same locations for the three examinations. Figure 5-17 shows the results of the first examination. Figure 5-18 shows both the results of the second examination five months later and the results of the third examination, which took place a few weeks after the second examination and after chemical cleaning of the drum. The figures show a reasonable comparison between the results. The results also tend to match better after the chemical cleaning that was performed before the third examination than for the previous examinations. In addition, the ACPD measurements tend to undersize crack depth in comparison to the ultrasonic results, as stated above.



1 inch = 25.4 mm

Figure 5-17
Comparison of ACPD and ultrasonic crack depth measurement results for the first examination.



1 inch = 25.4 mm

Figure 5-18
Comparison of ACPD and ultrasonic crack depth measurement results before and after chemical cleaning (after the first examination).

These examinations were performed to determine the crack growth and crack growth rate at these locations. Both methods appear to show that there was crack growth. However, in this case, there was no crack growth or effect of chemical cleaning on crack depth. Iron oxides were suspected to be removed from the cracks during the chemical cleaning, which influenced the characteristics of the crack and the sensitivity of the measuring devices. In addition, the "after" examination was more comprehensive than the previous examinations, including the use of calibration blocks and the experience gained performing the first examination. Figures 5-19 and 5-20 show a comparison of ACPD and ultrasonic examination results, respectively, for the three examinations.

The data shown in Figures 5-17 through 5-20 highlight important concepts regarding the NDE of drums:

- Precise documentation of the location and size of the cracks is essential; crack growth and crack growth rate cannot be accurately estimated if the locations are not known.
- Thorough review of the results is important. While the depth measurements seemed to indicate that growth occurred, the NDE technicians realized that the second and third examinations benefited from the "lessons learned" from the initial examination, so that the results of the later examinations were considered more accurate.
- Knowledge of the history of the drum is important. The chemical cleaning that occurred between the second and third examinations was suspected to have an effect on the NDE results, so a true "apples to apples" comparison was not possible.

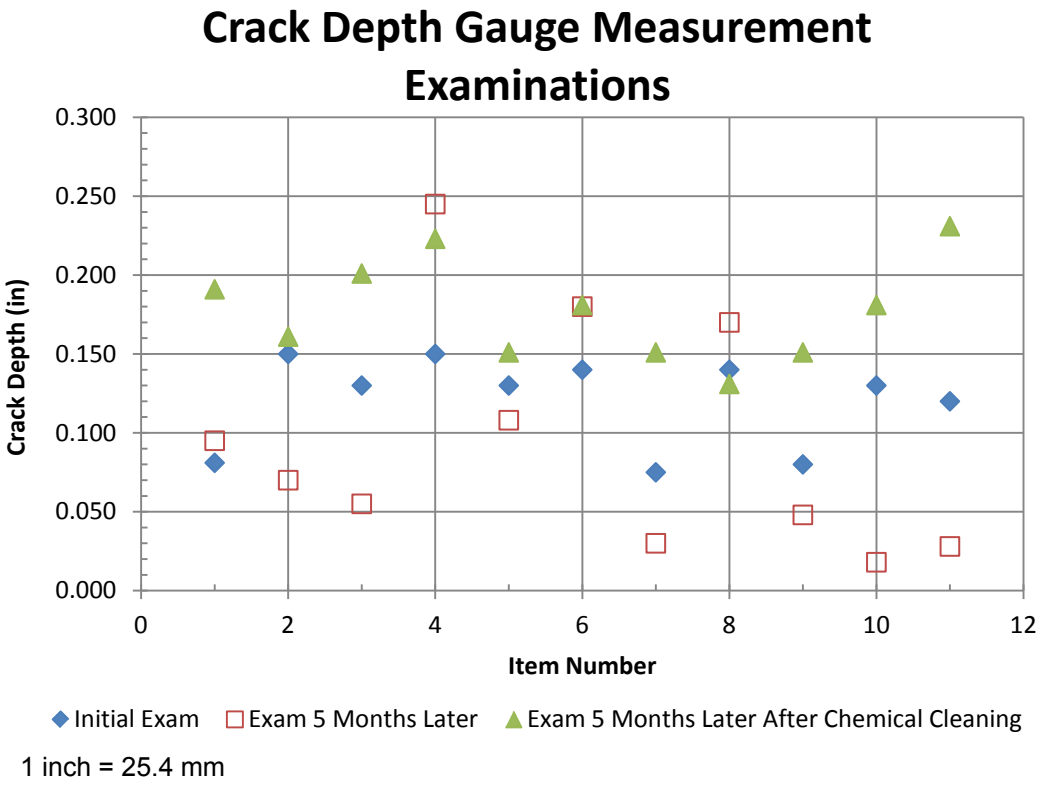
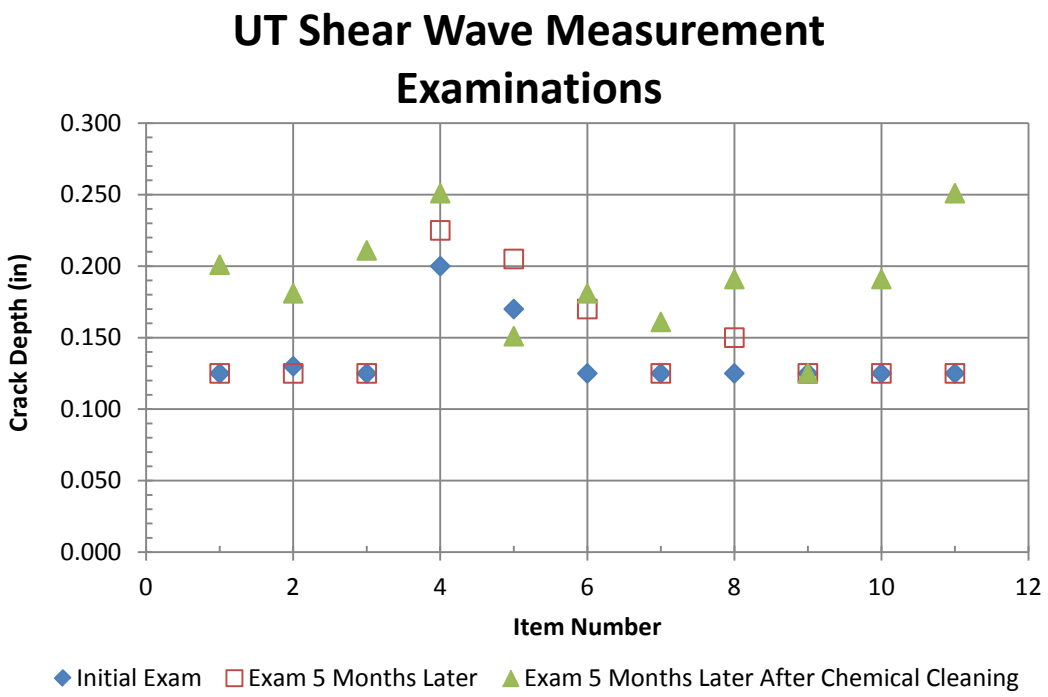


Figure 5-19
AC potential drop measurements of crack depth from three successive examinations.



1 inch = 25.4 mm

Figure 5-20
Ultrasonic measurements of crack depth from three successive examinations.

Case Study – Rolled-in Tubes

An examination was performed on a lower water-wall drum due to suspected leakage at the location of the tube attachments to the drum. Subsequent removal of insulation revealed that the leakage was due to cracks in the lower water-wall drum. The cracks were found radiating from the boreholes where the rolled-in tubes were attached to the drum.

During the on-site investigation, several of the tubes were removed from the boreholes to allow further examination of the ligaments. Examination within the boreholes revealed through-wall cracks that appeared to have larger crack openings inside the boreholes as compared to the crack openings visible on the internal and external surfaces of the drums. This suggested the possibility that the cracks had initiated within the boreholes and then propagated to the surface.

Ultrasonic examination was deemed the only practical method to examine both tube bores where tubes had not been removed and much of the external surface that was inaccessible due to insulation or obstructions. Ultrasonic examination was performed to detect and evaluate any radially oriented crack-like indications at the affected tube bores. The area of examination was defined as the drum wall thickness volume adjacent to the tube bores. The examination coverage included the ligament areas of the tube bores.

Situations may arise where quantitative results are difficult to produce, due to a variety of factors. In this case, the external surface of the drum was unavailable for examination, and no calibration block was available.

A specific ultrasonic technique was developed using an angle beam shear wave with the primary angle at 45° for this examination. The technique detectability level was confirmed by obtaining the responses from the "natural" visible flaws inside the drum where the tubes had been removed. This referenced ultrasonic examination was considered "for information purposes only." It employed the specific examination methodology described below.

System Calibration, Scanning, and Reporting

Due to the lack of a specific calibration standard (other than the existing flaws visible at the surface of the drums and in the boreholes), the system sensitivity was set to produce 100% screen response from a 0.040 inch (approximately 1 mm) deep notch in a 1.5-inch- (38-mm-) thick flat steel plate. In order to minimize the sound beam spread, a 2.2 MHz transducer with 0.5-inch- (12.7-mm-) diameter crystal was selected. The 45° replaceable search unit wedge was used.

Scanning

The scanning level was at +6 dB of the reference level in order to increase the flaw detectability and compensate for the surface irregularities. Scanning involved the circumferential movement of the probe around the tube bore with the probe directed near the tube bore tangent area. After finishing one scan (the entire 360° around the tube bore), the probe was then turned 180°, and the scan was repeated.

Reporting

All relevant linear indications with "apparent" (at least 2:1) signal-to-noise ratios were noted. All noted ultrasonic responses were categorized, based on their ultrasonic persistence, length, and amplitude. The following categories were established:

- Level 1 - a slight indication noted; characterized by a single peak signal with the signal amplitude not exceeding 50% reference and no, or very little, apparent radial depth
- Level 2 – a moderate indication noted; characterized by a single and/or multi-peak signal with the amplitudes between 50% and 100% reference level and an apparent radial depth
- Level 3 – a significant indication noted; characterized by a broad, multi-peak signal, with the signal amplitude over the reference level and an evident radial depth

In addition, the responses were, very generally, categorized based on their ultrasonic signal origins as follows:

- External – primary originating from or near the drum external surface
- MD - primary originating from the drum mid-wall volume zone
- Internal – primary originating from or near the drum internal surface
- T – originating from the entire wall volume

The results of the examination were used by the customer as a "go/no go" examination. Figure 5-21 shows the results of the examination in an easy-to-review graphical format.

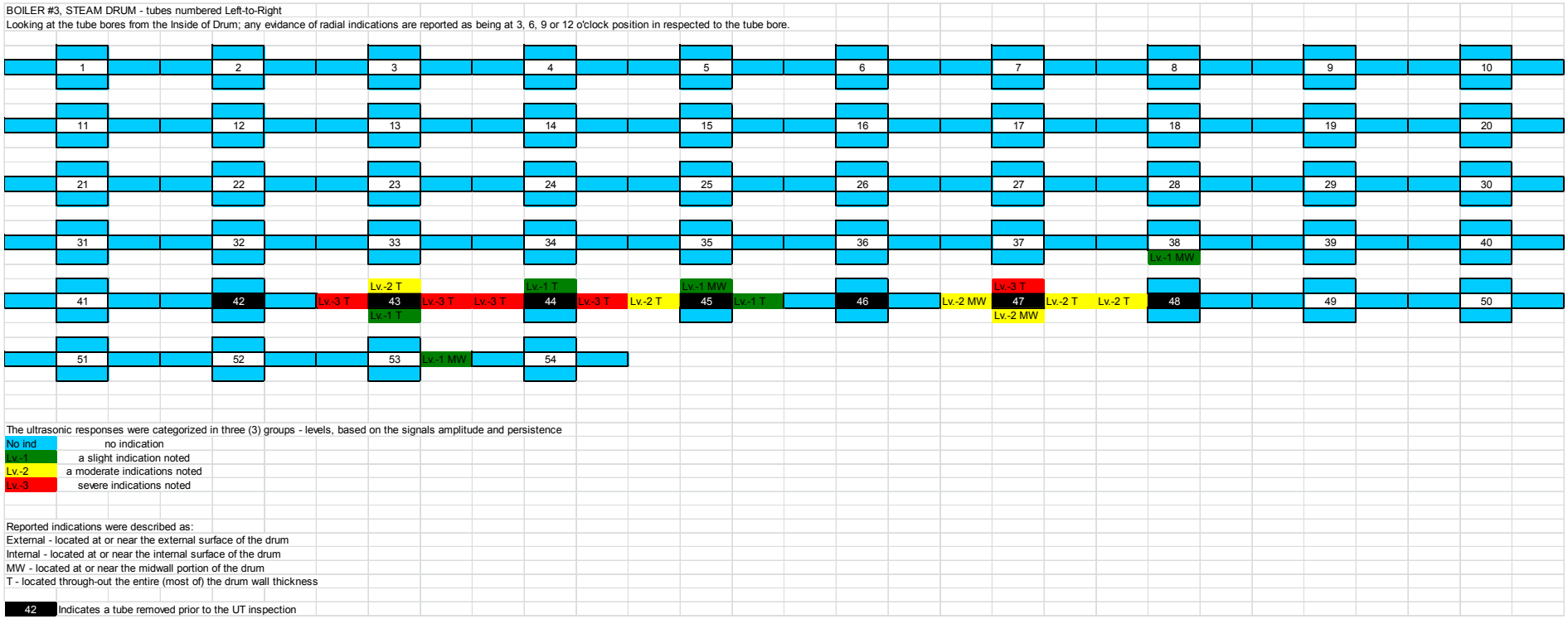


Figure 5-21
Results of the special case examination where calibration was unavailable and a unique ultrasonic technique was implemented to give a "go/no go" result for the client.

Figure 5-22 shows material samples taken from the body and ligament areas of the drum.



Figure 5-22
Material samples removed from the body and ligament areas of a lower water-wall drum where leaks had occurred.

6
KNOWLEDGE/TECHNOLOGY GAPS AND NEEDED RESEARCH

Although drum examinations have been performed for many years, the effectiveness of these nondestructive examinations and pre-outage troubleshooting audits or on-line diagnostic monitoring has not been evaluated in meaningful ways. Thus plant owners often perform examinations that may not be optimal or may have unknown accuracy. To overcome these deficiencies, the following research is recommended:

- Develop and perform field trials to determine the effectiveness of acoustic emission as a drum diagnostic/damage monitoring tool.
- Collect samples of retired cracked drums for use in qualification of NDE equipment/methods/procedures.
- Design and fabricate realistic drum nozzle/borehole ligament calibration blocks, and use them to demonstrate calibration/qualification and the accuracy of (i) ultrasonic examination and (ii) ACPD gauges.
- Demonstrate the effectiveness of existing drum nozzle borehole ligament and nozzle weld region examination tools that require minimal removal of the drum internals or removal of external (often asbestos) insulation.

7
REFERENCES

1. *Thermal Fatigue of Fossil Boiler Drum Nozzles*. EPRI, Palo Alto, CA: 2005. 1008070.
2. *Investigation of Cracking in Fossil Boiler Drums – Finite-Element and Fracture Mechanics Analyses*. EPRI, Palo Alto, CA: 2005. 1011916.
3. *Investigation of Cracking in a Fossil Natural Circulation Boiler Drum – Finite Element and Fracture Mechanics Analyses*. EPRI, Palo Alto, CA: 2006. 1013268.
4. Babcock & Wilcox Company. *Steam – Its Generation and Use*. 40th ed. The Babcock & Wilcox Company, Barberton, OH 1992, pp. 1–7, Figure 14.
5. Babcock & Wilcox Company. *Steam – Its Generation and Use*. 40th ed. The Babcock & Wilcox Company, Barberton, OH 1992, pp. 5–13, Figure 19.
6. Alstom Power Service. Service Information Letter (SIL) No. 487-1, Alstom Power Service, Windsor, CT 2006.
7. Babcock & Wilcox Company. *Steam – Its Generation and Use*. 40th ed. The Babcock & Wilcox Company, Barberton, OH 1992, pp. 41–49.
8. *Cycling, Startup, Shutdown, and Layup Fossil Plant Cycle Chemistry Guidelines for Operators and Chemists*. EPRI, Palo Alto, CA: 2009. 1015657.
9. *Comprehensive Cycle Chemistry Guidelines for Fossil Plants*. EPRI, Palo Alto, CA: 2011. 1021767.
10. The International Association for the Properties of Water and Steam. *Technical Guidance Document: Volatile Treatments for the Steam-Water Circuits of Fossil and Combined Cycle/HRSG Power Plants*, The International Association for the Properties of Water and Steam, 2010.
11. The International Association for the Properties of Water and Steam. *Technical Guidance Document: Phosphate and NaOH Treatments for the Steam-Water Circuits of Drum Boilers of Fossil and Combined Cycle/HRSG Power Plants*, The International Association for the Properties of Water and Steam, 2011.
12. The International Association for the Properties of Water and Steam. *Technical Guidance Document: Instrumentation for Monitoring and Control of Cycle Chemistry for the Steam-Water Circuits of Fossil-Fired and Combined-Cycle Power Plants*, The International Association for the Properties of Water and Steam, 2009.
13. Babcock & Wilcox Company. *Steam – Its Generation and Use*. 40th ed. The Babcock & Wilcox Company, Barberton, OH 1992, pp. 43–45.

14. *Evaluation of Thermal-, Creep- and Corrosion-Fatigue of Heat Recovery Steam Generator Pressure Parts Evaluation of Thermal-, Creep- and Corrosion-Fatigue of Heat Recovery Steam Generator Pressure Parts*. EPRI, Palo Alto, CA: 2006. 1010440.

15. J. Krautkramer, H. Krautkramer, *Ultrasonic Testing of Materials*, Springer-Verlag Berlin Heidelberg, New York, NY 1983.

16. M. Moles, "Ultrasonic Phased Array," *The NDT Technician*, ASNT, Columbus, OH, 2012.

17. *Fracture Toughness of Aged Boiler Drums*. EPRI, Palo Alto, CA: 2007. 1013359.

18. S. Anandamurugan, "Manual Phased Array Ultrasonic Technique for Weld Application," presented at the National Seminar & Exhibition on Non-Destructive Evaluation, NDE 2009, December 10–12, 2009.

19. *Guidelines for the Nondestructive Evaluation of Boiler Components*. EPRI, Palo Alto, CA: 2007. 1012194.

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent approximately 90 percent of the electricity generated and delivered in the United States, and international participation extends to more than 30 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

Together…Shaping the Future of Electricity

© 2014 Electric Power Research Institute (EPRI), Inc. All rights reserved.
Electric Power Research Institute, EPRI, and TOGETHER…SHAPING THE FUTURE OF ELECTRICITY are registered service marks of the Electric Power Research Institute, Inc.

3002003422

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com