

Generation Maintenance Application Center: Combustion Turbine Combined-Cycle Heat Recovery Steam Generator Maintenance Guide

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Abstract

This report identifies the maintenance activities for troubleshooting and maintaining the systems and components that are commonly associated with the heat recovery steam generator (HRSG) system at many combustion turbine combined cycle (CTCC) facilities. These systems include tube assemblies, stack, SCR, casing, steam drums, deaerator, piping and valves.

Information in this report was provided and reviewed by member utilities. Manufacturers' information and EPRI database information was utilized as a basis for this report.

Keywords

HRSG

Steam Generator

Selective Catalytic Reduction

Heat Recovery Steam Generator

Stack

Steam Drums

Deaerator



Product Description

This guide provides information to assist personnel involved with the maintenance of the heat recovery steam generator at a combustion gas turbine combined cycle facility, including good maintenance practices, preventive maintenance techniques and troubleshooting guidance.

Background

Combustion turbine combined cycle (CTCC) facilities utilize various components that can be unique to this particular type of power plant. As such, owners and operators of CTCC facilities may find that the EPRI PM Database (PMDB) only provides maintenance guidelines on those components that are common to a number of differing power plants. With the projected growth of CTCC facilities there is a need to provide maintenance guidance on the components unique to these facilities.

Objectives

This guideline document will provide information on the proper inspection and maintenance of the heat recovery steam generator system within a CTCC facility. It will address the system major components that may comprise a CTCC facility heat recovery steam generator system.

Approach

Information from member utilities and other industry sources was utilized as a basis for the report. A literature search of current related EPRI documents was conducted.

Manufacturer's related information was obtained from member utilities and a search of the internet. EPRI membership reviewed and provided input to the final document.

Results

The resulting guide provides a brief discussion of the major system components addressed and information on potential maintenance and troubleshooting practices for equipment components that can comprise the heat recovery steam generator system at a combustion turbine combined cycle facility.

Applications, Value, and Use

This report provides information, guidance, and technical information on the recommended maintenance activities for the component equipment comprising the heat recovery steam generator system at a CTCC facility. Use of this guide should provide plant engineering, operations and maintenance personnel with information that can be used to properly maintain plant equipment, extend equipment life and improve overall facility availability while reducing costs.

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Section 1: Introduction

1.1 Background

Combustion turbine combined cycle (CTCC) facilities utilize various components that can be unique to this particular type of power plant. As such, owners and operators of CTCC facilities may find that the EPRI Preventive Maintenance Database (PMDb) only provides maintenance guidelines on those components that are common to a number of differing power plants. With the projected growth of CTCC facilities there is a need to provide maintenance guidance on the components unique to these facilities.

This guideline document will provide information on the proper maintenance of the heat recovery steam generator system within a combustion turbine combined-cycle facility. It will address the system components that may comprise a CTCC facility heat recovery steam generator system.

Many combined cycle power plants in service today utilize a heat recovery steam generator (HRSG) system to capture residual heat from the combustion turbine exhaust and use it to generate clean superheated steam for the steam turbine and other process steam requirements at the plant site. HRSG's are designed to produce a given amount of steam at defined temperatures and pressures. Use of a HRSG helps allow the power plant unit to be more efficient and cost effective.

Although HRSG's can be located on several combined cycle applications including diesel generators, waste heat from coke ovens, or waste heat from other sources of energy, this report will focus on multi-pressure HRSG's commonly used with combustion turbine combined-cycle power generation applications.

1.2 Organization of the report

This guide is structured to provide guidance on the proper troubleshooting and maintenance practices for the components commonly comprising the heat recovery steam generator system at a combustion turbine combined-cycle facility at member utilities. Before performing maintenance on specific equipment, you should refer to the manufacturer's instructions and diagrams for your specific equipment.

This guide is divided into seven (7) sections and related appendices:

- Section 1 introduces the guide's introduction, purpose, organization, definitions and acronyms used for this report.
- Section 2 gives a technical description of horizontal and vertical HRSG's and their major components.
- Section 3 describes HRSG operational considerations and their potential effects on HRSG components.
- Section 4 describes typical inspection and troubleshooting activities on the major HRSG components.
- Section 5 describes the condition-based maintenance activities performed on major HRSG components
- Section 6 describes the typical preventive maintenance activities performed on major HRSG components
- Section 7 lists the references for sources utilized in this report.
- Section 8 will give a summary listing of the report's key points

1.3 Definitions and Acronyms

CTCC – Combustion Turbine Combined Cycle

PMDB – Preventive Maintenance Data Base (EPRI)

PSI – Pressure per Square Inch

PSID – Pressure per Square Inch Differential

HRSG – Heat Recovery Steam Generator

OEM - Original Equipment Manufacturer

HP – High Pressure

IP – Intermediate Pressure

LP – Low Pressure

PC – Pulverized Coal

SH – Superheat

FAC - Flow Accelerated Corrosion

EPRI – Electric Power Research Institute

UT - Ultrasonic/Ultrasound

NO – Nitrous Oxide

CO – Carbon Monoxide

1.4 Listing of Key Points

Throughout this report, key information is summarized in Key Points. Key Points are bold-lettered boxes that succinctly restate information covered in detail in the surrounding text, making the key point easier to locate.

The primary intent of a Key Point is to emphasize information that will allow individuals to act for the benefit of their plant. Electric Power Research Institute (EPRI) personnel who reviewed this report assisted in the selection of the information included in these Key Points

The Key Points are organized into four categories: Human Performance, O&M Cost, Technical, and Supervisory Observation. Each category has an identifying icon to draw attention to it for the benefit of readers who are quickly reviewing the report. The Key Points are shown in the following way:



Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent personal injury, prevent equipment damage, and/or improve the efficiency and effectiveness of the task.



Key O&M Cost Point

Emphasizes information that will result in overall reduced costs and/or an increase in revenue through additional or restored energy production.



Key Technical Point

Targets information that will lead to improved equipment reliability.



Key Supervisory Observation Point

Identifies tasks or series of tasks that can or should be observed by Maintenance First Line Supervisors to improve the performance of the Maintenance Staff and improve the reliability of the component.

1.5 Basic System Flow Path

HRSG's can be installed on all types of combustion turbine combined-cycle facilities fired with natural gas, light/heavy/crude fuel oils, or other liquid/gas fuels. The operating modes of combustion turbine combined-cycle applications will vary from base load to heavy cycling operations. HRSG designs will vary based on the specific design requirements of the owner for their specific combustion turbine facility application. There are numerous HRSG configurations, arrangements, and designs in operation worldwide.

Typically there are two basic types of HRSG arrangements, vertical or horizontal design. In vertical types of HRSG's, exhaust gas flows over horizontal tubes. In horizontal types of HRSG's, exhaust gas flows horizontally over vertical tubes. Vertical type HRSG designs have been typically preferred in Europe while horizontal HRSG type designs have been typically preferred by most United States designers. However, both styles can be found in power projects worldwide.

Vertical HRSG's will have the horizontal tube bundles supported by tube sheet plates hung from the top much like a conventional PC boiler. Top supported tubes bundle design allows for free downward thermal expansion of the tube sections as needed. Vertical HRSG will typically have forced circulation flow of the water through the tubes. However, some designs can be natural circulation. The horizontal tube bundle design allows for the vertical HRSG to be completely drainable which can be helpful for cycling operations.

Horizontal HRSG's will have the tube bundles hung vertically and supported from the top. Vertically hanging the tube bundles allow them to move freely up and down due to thermal expansion from varying exhaust gas temperatures at various loads. Horizontal HRSG's will typically have natural water circulation.

The casing of the HRSG will be insulated and lined with a floating liner that can move freely to accommodate thermal movements without warping or distorting across all operating ranges.

The feedwater system and tube heating arrangements can vary and will be designed for each specific HRSG application.



Section 2: System Components

Whether the heat recovery steam generator is of vertical or horizontal design, there will be one to three pressure levels of steam produced from the HRSG. Some HRSG's will have a reheat section while others will not. Some HRSG's will have supplemental duct firing while others will not.

Major components of a typical HRSG consist of the following:

- Tube Sections – Evaporator, Superheater, Reheater, and Preheater
- Economizers - High, Intermediate, and Low pressure
- Evaporators/Drums - High, Intermediate, and Low pressure
- Duct Burners and associated Burner Management Systems
- Selective Catalytic Reduction (SCR) system
- Carbon Oxide (CO) Catalyst System
- Pilot Cooling Air Blowers
- Piping and Drain Systems
- Ductwork - Expansion Joints, Isolation and Bypass Dampers
- Stacks - Normal and Bypass
- Temperature control systems - Attemperators
- Sootblowers
- Deaerator

The hot exhaust gas from the combustion turbine will enter the HRSG and pass over the pressure part tube sections. The pressure parts for a three pressure HRSG configuration will consist of an HP, IP, and LP sections. Some HRSG's will also have a Reheater section. The exhaust gas will typically first pass through the first sections of the HRSG that consist of the HP superheater, Reheater, and HP evaporator sections. Some units may have duct burners located within the early section of the HRSG for supplying process steam, helping produce steam so that the steam turbine output will remain constant in varying ambient air temperature conditions, or providing additional steam for peaking operations.

Typically near the middle of a three pressure HRSG the carbon monoxide (CO) and selective catalytic reduction (SCR) catalyst systems will be installed to help reduce Nitrogen Oxide (NOx) based on the site's environmental requirements. Ammonia gas will be injected into the exhaust gas stream after the CO catalyst and before the SCR catalyst section.

After the SCR section of a three pressure HRSG, the exhaust gas will typically pass over the HP economizer tube section, IP evaporator and economizer tube sections, and LP superheat, evaporator, and economizer sections before exiting through the stack.

Some applications may have bypass dampers and ducts where the combustion turbine exhaust gas can be diverted around the HRSG when there is no steam demand required or maintenance is required on the HRSG.

2.1 Horizontal HRSG Components

Most HRSG's currently used for combustion turbine combined cycle applications will be designed as multi-pressure units. Multi-pressure HRSG units are typically arranged with two (double pressure) or three (triple pressure) steam drums and associated tube sections for more efficient operation. Figure 2-1 shows a generic schematic of a triple pressure horizontal HRSG arrangement with high pressure (HP), intermediate pressure (IP), and low pressure (LP) drum and tube sections. This triple pressure design will be used for discussion within this document for horizontal HRSG's.

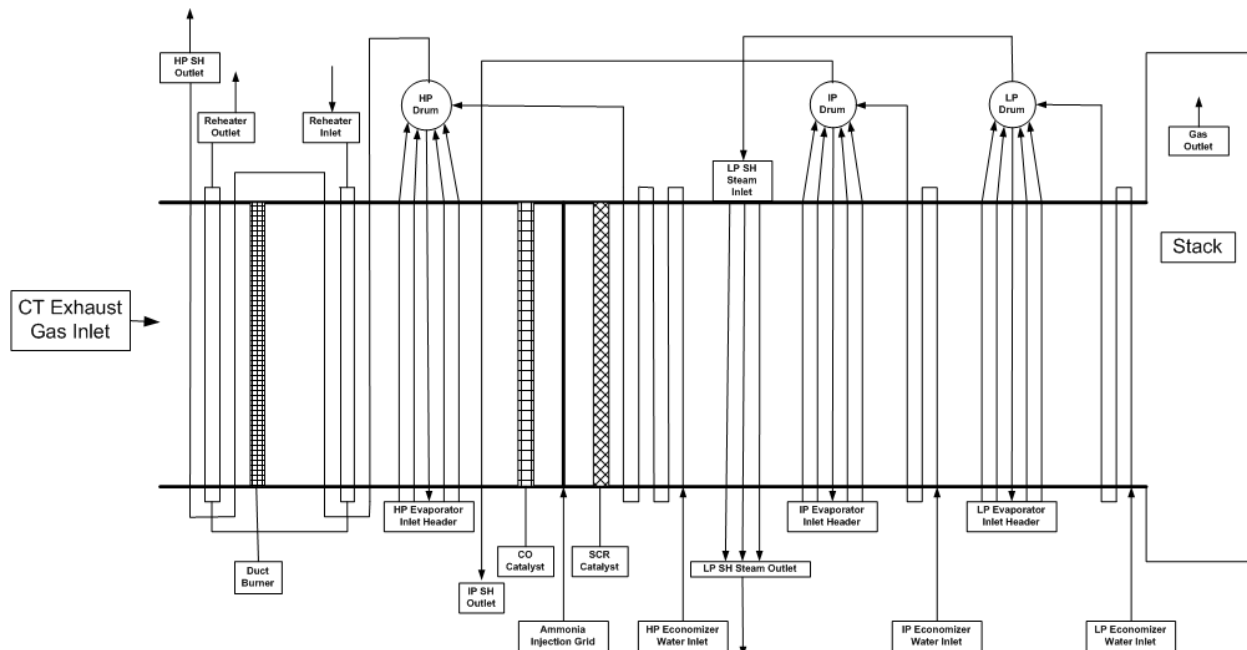


Figure 2-1
Horizontal HRSG Schematic

The three independent feedwater/steam sections will each consist of economizer, evaporator, and superheater heat transfer tube bundle elements. The tube bundles will typically be finned tubes arranged in vertical sections for ease of inspection, cleaning, and maintenance. The tube bundles will be top supported to allow for thermal expansion and will be further supported within the HRSG to eliminate gas flow induced vibration problems. Piping, drains, and instrumentation connections will be present as required for each section. Figure 2-2 shows an example of a horizontal HRSG.



*Figure 2-2
Horizontal HRSG Example*

Some combined cycle designs will have a deaerator tank to aid in reducing the condensable and non-condensable gases content of the condensate water prior to supply to the LP drum or economizer inlet header. The deaerator tank will typically be a pressure vessel consisting of spray nozzles, tray supports, baffles, impingement plates, and tray enclosures. Condensate water is sprayed into the steam heated deaerator tank where water treatment chemicals are injected. The water from the deaerator tank is used to supply the economizer inlet headers.

Some combined cycle units may use the LP drum as a deaerator for removal of the gases and chemical water treatment.

Other combined cycle designed units, removal of the condensable and non-condensable gases from the condensate water supply is done by the vacuum pumps near the condenser and a deaerator tank is not used.

2.1.1 Low Pressure System

The LP system is similar to a natural circulation boiler and consists of an economizer, a steam drum, an evaporator, a superheater, and associated valves and recirculation water pumps.

2.1.1.1 LP Economizer Section

The LP economizer section is located at the exit of the HRSG just before the stack. LP economizer inlet water is supplied from the unit's condensate feedwater system to an inlet header. The inlet condensate water temperature is required to be hotter than the exhaust gas dewpoint temperature to prevent cold end corrosion of the HRSG and stack metal components downstream of the economizer section. Some sites utilize a LP economizer recirculation pump system that takes some hot water from the LP economizer outlet header (hot water source may vary by OEM designs) and re-circulates the hot water to the LP economizer inlet header to help maintain the temperature of the exhaust gas above its dewpoint temperature. Figure 2-3 shows an example of a header with tube connections.



*Figure 2-3
Header and Tube Example*

The LP economizer section is designed to heat condensate feedwater to a temperature near the saturation steam temperature in the LP drum while at the same time minimize potential phase change in the economizer tubes during all HRSG operating conditions. The LP economizer outlet header discharges to the LP steam drum.

2.1.1.2 LP Steam Drum - Water Side

The incoming feedwater from the LP economizer is distributed within the steam drum via a distribution header. The distribution header consists of nozzles to direct the flow downward to mix with existing water in the drum. Sampling and chemical feed lines installed in the drum will allow for injection of chemicals used to maintain HRSG water chemistry requirements.

Actual hardware inside the drum will vary by OEM.

Multiple downcomers in the bottom of the LP drum will direct the water flow to the lower LP evaporator inlet headers. The downcomers are designed for natural circulation within the evaporator.

2.1.1.3 LP Evaporator Section

Water from the downcomers enters the LP evaporator inlet headers. Natural circulation causes saturated water/steam mixture generation in the vertical LP evaporator tubes which flows upward to the evaporator outlet headers and then to the steam side of the LP drum.

2.1.1.4 LP Steam Drum - Steam Side

The water/steam mixture is separated into steam and water by the steam drum internal separators. The separators remove the water from the mixture via centrifugal force where the water is returned to drum bottom for recirculation. The saturated steam then goes through a secondary separator system to remove additional water before exiting the top of the LP drum and is directed to the LP superheater inlet header.

Actual hardware inside the drum will vary by OEM.

2.1.1.5 LP Superheater Section

Steam from the LP superheater header passes through the vertical superheater tube bundles within the HRSG and increases in temperature. The LP superheater outlet steam is then discharged from the HRSG to be used within the power plant.

2.1.2 Intermediate Pressure System

The IP system is similar to a natural circulation boiler and consists of economizer, steam drum, evaporator, and superheater sections.

2.1.2.1 IP Economizer Section

Feedwater enters the IP economizer inlet header and flows through the vertical tube bundles. There may be multiple IP economizer vertical tube bundle sections. Each IP economizer section will have inlet and outlet headers. The heated water from the IP economizer sections enters the IP drum through an inlet nozzle.

2.1.2.2 IP Steam Drum - Water Side

Heated water from the IP economizer sections enters the IP drum through the inlet nozzle and is distributed along the drum via a header. The distribution header consists of nozzles to direct the flow downward to mix with existing water in the drum. Sampling and chemical feed lines installed in the drum will allow for injection of chemicals used to maintain HRSG water chemistry requirements.

Actual hardware inside the drum will vary by OEM.

Multiple downcomers in the bottom of the IP drum will direct the water flow to the lower IP evaporator inlet headers. The downcomers are designed for natural circulation within the evaporator.

2.1.2.3 IP Evaporator Section

Water from the downcomers enters the IP evaporator inlet headers. Natural circulation causes saturated water/steam mixture generation in the vertical HP evaporator tubes which flows upward to the evaporator outlet headers and then to the steam side of the IP drum.

2.1.2.4 IP Steam Drum - Steam Side

The water/steam mixture is separated into steam and water by the steam drum internal separators. The separators remove the water from the mixture via centrifugal force where the water is returned to drum bottom for recirculation. The saturated steam then goes through a secondary separator system to remove additional water before exiting the top of the IP drum and is directed to the IP superheater inlet header.

Actual hardware inside the drum will vary by OEM.

2.1.2.5 IP Superheater Section

Steam from the IP superheater header passes through the vertical superheater tube bundles within the HRSG and increases in temperature. There may be multiple IP superheater vertical tube bundle sections. The IP superheater outlet steam is then discharged from the HRSG and combines with the cold reheat steam.

2.1.3 High Pressure System

The high pressure system is similar to a natural circulation boiler and consists of an economizer, a drum, an evaporator, and multiple superheater sections.

2.1.3.1 HP Economizer Section

High pressure feedwater enters the HP economizer inlet header and flows through the vertical tube bundles. There will be multiple HP economizer vertical tube bundle sections. Each HP economizer section will have inlet and outlet headers. The heated water from the HP economizer sections enters the HP drum through an inlet nozzle.

2.1.3.2 HP Steam Drum - Water Side

Heated water from the HP economizer sections enters the drum through the inlet nozzle and is distributed along the drum via a distribution header. The distribution header consists of nozzles to direct the flow downward to mix with existing water in the drum. Sampling and chemical feed lines installed in the drum will allow for injection of chemicals used to maintain HRSG water chemistry requirements.

Actual hardware inside the drum will vary by OEM.

2.1.3.3 HP Evaporator Sections

Water from the drum downcomers enters the HP evaporator inlet headers. Natural circulation causes saturated water/steam mixture generation in the vertical HP evaporator tubes which flows upward to the evaporator outlet headers and then to the steam side of the HP drum.

2.1.3.4 HP Steam Drum - Steam Side

The water/steam mixture is separated into steam and water by the steam drum internal separators. The separators remove the water from the mixture via centrifugal force where the water is returned to drum bottom for recirculation. The saturated steam then goes through a secondary separator system to remove additional water before exiting the top of the HP drum and is directed to the HP superheater inlet header.

Actual hardware inside the drum will vary by OEM.

2.1.3.5 HP Superheater Sections

Steam from the HP superheater header passes through the vertical superheater tube bundles within the HRSG and increases in temperature. There will be multiple HP superheater vertical tube bundle sections. The HP superheater outlet steam is then discharged from the HRSG to the high pressure steam line to the main turbine. Figure 2-4 shows an example of HRSG superheater tubes.



*Figure 2-4
Superheater Tube Example*

2.1.4 Reheater System

Cold reheat steam is returned from the HP turbine and is combined with the IP superheater steam. The combined steam enters the reheater inlet header. The reheater steam passes through the reheater vertical tube bundles to gain temperature. There may be multiple reheater sections. The reheater steam will leave the HRSG at the reheat outlet header to the Reheat Main Steam line back to the IP turbine.

2.1.5 Attemperators

Attemperators are used to control outlet steam temperatures in the HP and IP steam systems as required to maintain design temperatures to the steam turbine during startups. Most HRSG attemperators are designed for minimal or zero flow at full load conditions. Condensate water from the plant feedwater system will be sprayed into the steam paths through a nozzle located within the attemperator piping section. There will be different nozzle designs based on the operating expectations of the HRSG and with different OEMs. Some attemperator piping sections will contain a renewable liner to take erosion wear from the spray water while other designs will not have a renewable liner. Improper operation of the attemperator can cause cracking and failure of the liner or steam piping, and fittings downstream of the attemperator or potential damage to the steam turbine blades. The steam piping is external to the HRSG and will therefore be a personnel safety issue at most combined cycle sites. Inspection and maintenance of the attemperator components and routine calibration of the control system are important. There should be drains between

the attemperator and the SH tube bundles to remove any water from a leaking attemperator valve. If water is allowed to flow to the SH tube bundles it can cause failure of tubes due to quenching.

2.1.6 Exhaust Gas Flow Path

Exhaust gas from the combustion turbine enters the HRSG and passes over the vertical tube sections heating the steam or water within the tubes. Exhaust gas inlet temperatures will typically be in the 1000-1200 deg F range depending on the specific combustion turbine used and ambient air temperatures. The exhaust gas will exit the HRSG at approximately 175 to 200 deg F (80 deg C to 93 deg C) to the stack.

Within the exhaust gas flow path, the HRSG may be equipped with CO and SCR catalyst sections to aid in meeting the site's environmental requirements. The CO catalyst section removes carbon monoxide from the exhaust gas flow. The SCR catalyst will reduce the amount of NO_x within the exhaust to meet the site's environmental requirements for NO_x emissions. Ammonia gas will be injected into the exhaust gas stream ahead of the SCR section for reaction within the catalyst.

2.1.7 Duct Burner System

Duct burners may be used in some HRSG applications. The burners are typically located near the HRSG inlet section but can be located within tube bundle sections. The burners will be gas fired horizontal burners housed in a rigid frame spaced across the exhaust gas flow path. Accessories to the duct burner system include the gas piping, valves, controls, gas pilots, igniters, flame scanners, and scanner cooling air piping.

2.1.8 Ductwork

The HRSG ductwork and casing will typically be fabricated and supported from carbon steel plates and structural members. Many modern HRSG's will be constructed in sections or modular designs for ease of shipping and field assembly. The structural casing joints will be seal welded to prevent air in-leakage. Exteriors of the HRSG will typically be painted to prevent rust and corrosion.

Entrance access doors will be positioned at strategic locations for inspections and maintenance needs for each section of the HRSG. Platforms, ladders, and stairways will be installed externally on the HRSG casing as needed to perform inspections and maintenance.

The ductwork will typically be lined with insulation covered by a metal cover plates. Insulation may be located on the ductwork casing interior, exterior, or a combination depending on the specific OEM design. The inlet ductwork sections will typically be lined with stainless steel plate materials to minimize erosion from the hot exhaust gas from the combustion turbine.

At a minimum, there will be a duct expansion joint between the combustion turbine exhaust gas discharge and the inlet duct of the HRSG. Some HRSG's may have an expansion joint between the HRSG exit and the stack.

2.1.9 Selective Catalytic Reduction

Emissions controls may also be located in the HRSG ductwork typically consisting of an SCR system to reduce nitrogen oxides (NO_x) and/or a Carbon Monoxide catalyst system to remove carbon monoxide (CO). The SCR NO_x catalyst performs best in temperatures between 650 °F (340 °C) and 750 °F (400 °C) which is typically near the HP evaporator section of the HRSG. Ammonia is injected via a grid system in front of the SCR catalyst to aid in NO_x removal. CO catalyst sections are typically located in front of the ammonia injection grid system. Accessories to the SCR include the ammonia system piping, valves, pumps, fans, and controls.

2.1.10 Gas Silencers

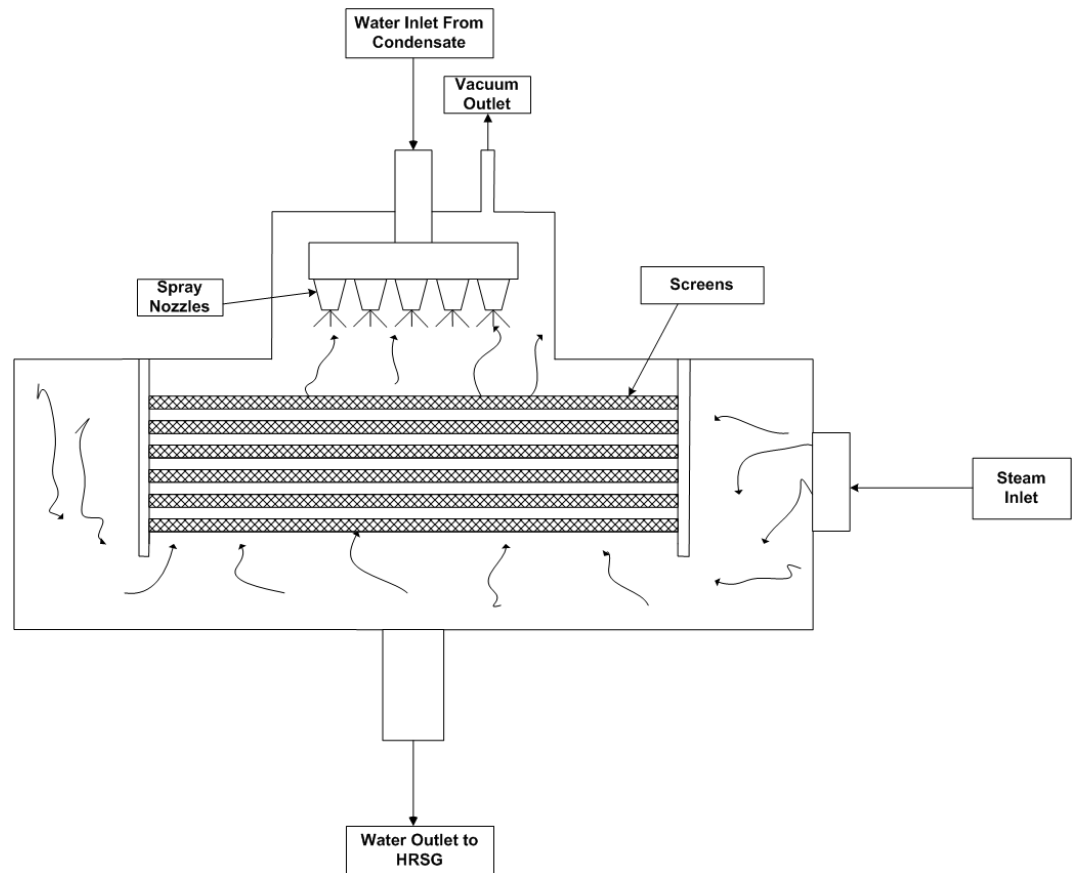
Gas silencers are used for some application to reduce noise levels of the HRSG flue exhaust to meet environmental requirements. The gas silencers may be located within the HRSG exit ductwork or the stack and consist of various OEM patented designs. Silencers are typically custom-engineered and made of materials to meet the site specific requirements.

2.1.11 Sootblowers

Some HRSG's may have sootblowers for exterior cleaning the tube bundle assemblies when the HRSG is in service. The requirement for sootblowers in combined cycle applications is typically based on the type of fuel used for the combustion turbine. Sootblowers if used will be designed and installed for the specific requirements at a specific combustion turbine combined cycle location.

2.1.12 Deaerator Tank

For some combined cycle designs, a deaerator tank may be present to aid in reducing the condensable and non-condensable gas content of the condensate water prior to supply to the LP drum or economizer inlet header. The deaerator tank will typically be a pressure vessel consisting of spray nozzles, tray supports, baffles, impingement plates, and tray enclosures. Condensate water is sprayed into the steam heated deaerator tank where it is passed over a set of trays that separates the gases from the water. The gases are vented out of the deaerator tank to atmosphere. The water collected in the bottom of the deaerator tank is used to supply the economizer inlet headers or LP drum. Typically deaerator tanks are located as high as possible above the HRSG to supply sufficient water flow to the economizer inlets or LP drum. Deaerator tank designs will vary by OEM. A typical spray type deaerator will be used in this report and is shown in Figure 2-5.



*Figure 2-5
Spray Deaerator Tank Example*

Some combined cycle units may use the LP drum as a deaerator for removal of the gases and chemical treatment.

Other combined cycle designed units, removal of the condensable and non-condensable gases from the condensate water supply is done by the vacuum pumps near the condenser and a deaerator tank is not used.

2.1.13 Stack

Each HRSG will have an outlet stack located at the exhaust gas exit end after the LP economizer section. The stack will be connected to the HRSG via a duct expansion joint or may be welded to the last HRSG casing module. Most stacks used for combined cycle applications will be fabricated from carbon steel plate and structural steel materials. The stack will have access doors for inspections, required environmental test connections, electrical lights/grounding connections, and access platforms/ladders, as required. Figure 2-6 shows an example of a HRSG stack.



*Figure 2-6
Horizontal HRSG Stack Example*

Many units will have a stack damper to keep heat inside the HRSG after a shutdown. Cycling units benefit from stack dampers with slower cool down of HRSG internal components during shutdowns and leads to faster startup times and less thermal stresses on the components to help extend their useable life.

Continuous Emission Monitoring (CEM) systems will typically be located on the stack.

Some combined cycle applications may have a bypass duct damper and stack arrangement for bypassing the exhaust gas flow from the HRSG. This is typically done when there is no steam demand required from the HRSG or for performing maintenance on the HRSG with the combustion turbine in operation.

2.1.14 Piping and Drain System

2.1.14.1 Drains

Piping and drains from the HRSG allows for each of the economizer, superheater, and reheater sections to be emptied for maintenance or to prevent water in tube bundle low points during start-ups. Drain valves may be manual or motor operated depending specific application and unit designs. Water drained from the HRSG goes to the blowdown sump or tank.

2.1.14.2 Continuous Blowdown System

The HRSG will have an independent continuous blowdown system consisting of piping, valves, and associated instrumentation and control equipment. The blowdown system collects drains from various HRSG sections to aid in maintaining proper boiler water chemistry.

The blowdown system will receive condensate and saturated steam during unit start-ups and continuous blowdown from the HRSG IP drum during operation. HRSG blowdown will be piped from the HRSG and collected in a vented blowdown tank to control steam flashing before draining to a blowdown sump. HRSG water collected in the blowdown sump will typically be pumped to the cooling tower basin for water recovery or used in another site process.

2.1.14.3 Nitrogen Piping

Many modern HRSG's will have external piping that will allow for internal nitrogen blanketing of the tube sections during periods of shutdown. The nitrogen piping connections will be to the inlet headers for each section.

2.2 Vertical HRSG Components

Most modern vertical HRSG's currently used for combustion turbine combined cycle applications are typically designed with two (double pressure) steam drums and associated tube sections for more efficient operation. Figure 2-9 shows an example of a vertical HRSG. Figure 2-10 shows a schematic of a double pressure vertical HRSG with high pressure (HP) and low pressure (LP) drum and tube sections. This double pressure design will be used for discussion within this document for vertical HRSG's.



*Figure 2-7
Vertical HRSG Example*

further support the tube bundles to eliminate gas flow induced vibration problems. Piping, drains, and instrumentation connections will be present as required for each section. Figure 2-12 shows an example of a tube bundle with baffles.



*Figure 2-9
Tube Baffle Example*

2.2.1 Low Pressure System

The low pressure (LP) section provides superheated LP steam for various uses throughout the plant, as well as heating of feedwater supplied to the HP, IP, and LP HRSG sections. It is the final section the exhaust gas flows through prior to exiting the HRSG prior to the stack. The LP system is similar to a natural circulation boiler and consists of an economizer, a steam drum, an evaporator, a superheater, and associated piping, valves, and recirculation water pumps.

2.2.1.1 LP Economizer Section

The LP economizer section is located at the exit of the HRSG just before the gas silencers and stack. LP economizer inlet water is supplied from the unit's condensate feedwater system to an inlet header. The inlet condensate water temperature is required to be hotter than the exhaust gas dew point temperature to prevent cold end corrosion of the HRSG and stack metal components downstream of the economizer section. Some sites utilize a LP economizer recirculation pump system that takes some hot water from the LP economizer

outlet header and re-circulates the hot water to the LP economizer inlet header to help maintain the temperature of the incoming LP economizer feedwater above the exhaust gas dew point temperature.

The LP economizer section is designed to heat condensate feedwater to a temperature near the saturation steam temperature in the LP drum while at the same time minimize potential phase change in the economizer tubes during all HRSG operating conditions. The LP economizer outlet header discharges to the LP steam drum.

2.2.1.2 LP Steam Drum - Water Side

The incoming feedwater from the LP economizer is distributed within the steam drum via a distribution header. The distribution header consists of nozzles to direct the flow downward to mix with existing water in the drum. Sampling and chemical feed lines installed in the drum will allow for injection of chemicals used to maintain HRSG water chemistry requirements.

Actual hardware inside the drum will vary by OEM.

Multiple downcomers in the bottom of the LP drum will direct the water flow to the lower LP evaporator inlet headers. The downcomers are designed for natural circulation within the evaporator.

2.2.1.3 LP Evaporator Section

Water from the downcomers enters the LP evaporator inlet header. Natural circulation causes saturated water/steam mixture generation in the horizontal LP evaporator tubes which flows upward to the evaporator outlet headers and then to the steam side of the LP drum.

There may be a start-up pump within the piping circuit from the LP drum to the LP evaporator inlet header to provide sufficient flow conditions during startup periods and prevention of steam flashing within the piping or tube bundles.

2.2.1.4 LP Steam Drum - Steam Side

The water/steam mixture is separated into steam and water by the steam drum internal separators. The separators remove the water from the mixture via centrifugal force where the water is returned to drum bottom for recirculation. The saturated steam then goes through a secondary separator system to remove additional water before exiting the top of the LP drum and is directed to the LP superheater inlet header.

Actual hardware inside the drum will vary by OEM.

2.2.1.5 LP Superheater Section

Steam from the LP superheater header passes through the horizontal superheater tube bundles within the HRSG and increases in temperature. The LP superheater outlet steam is then discharged from the HRSG to be used within the power plant.

2.2.1.6 Recirculation Water Pumps

Recirculation water pumps are located outside of the HRSG and are used to protect the low pressure economizer tube sections and stack from water/acid dew point corrosion due to exhaust gas condensation. A portion of the water from the LP economizer outlet (or other hot water source for some designs) is re-circulated and mixed with the feedwater entering the LP economizer inlet nozzle to increase the temperature of the incoming feedwater. This helps keep the final exhaust gas temperature above approximately 270 deg F (132 deg C). During startups, recirculation pumps also help to reduce thermal shock to the LP economizer tube panels due to the temperature differences between hot tube panels from the exhaust gas and a relatively cold feedwater supply.

2.2.2 High Pressure System

The high pressure system is similar to a natural circulation boiler and consists of multiple economizer sections, a drum, an evaporator section, and a superheater section.

2.2.2.1 HP Economizer Sections

High pressure feedwater from the HP feedwater pumps enters the first HP economizer inlet header and flows through the horizontal tube bundles to the first HP outlet header. The feedwater will then be sent to the second HP economizer inlet header and flows through the horizontal tube bundles to the second HP outlet header. The heated water from the second HP economizer section is discharged to the water side of the HP drum.

2.2.2.2 HP Steam Drum - Water Side

Heated water from the HP economizer sections enters the drum through the inlet nozzle and is distributed along the drum via a distribution header. The distribution header consists of nozzles to direct the flow downward to mix with existing water in the drum. Sampling and chemical feed lines installed in the drum will allow for injection of chemicals used to maintain HRSG water chemistry requirements.

Actual hardware inside the drum will vary by OEM.

2.2.2.3 HP Evaporator Sections

Water from the drum downcomers enters the HP evaporator inlet headers. Natural circulation causes saturated water/steam mixture generation in the horizontal HP evaporator tubes which flows upward to the evaporator outlet header outlet header and then to the steam side of the HP drum.

There may be a start-up pump within the piping circuits from the HP drum to the HP evaporator inlet headers to provide sufficient flow conditions during startup periods and prevention of steam flashing within the piping or tube bundles.

2.2.2.4 HP Steam Drum - Steam Side

The water/steam mixture is separated into steam and water by the steam drum internal separators. The separators remove the water from the mixture via centrifugal force where the water is returned to drum bottom for recirculation. The saturated steam then goes through a secondary separator system to remove additional water before exiting the top of the HP drum and is directed to the HP superheater inlet header.

Actual hardware inside the drum will vary by OEM.

2.2.2.5 HP Superheater Sections

Steam from the HP superheater inlet header passes through the horizontal superheater tube bundles within the HRSG and increases in temperature. The HP superheater outlet steam is then discharged from the HRSG to the high pressure steam line to the main turbine.

2.2.3 Duct Burner System

Duct burners may be used in some vertical HRSG applications. The burners are normally only found in the vertical HRSG inlet section and not within any tube bundles. The burners are typically gas-fired horizontal burners housed in a rigid frame spaced across the exhaust gas flow path.

2.2.4 Ductwork

The HRSG ductwork and casing will typically be fabricated and supported from the main steel structure members of the plant. Many modern HRSG's will be constructed in sections or modular designs for ease of shipping and field assembly. The structural casing joints will be seal welded to prevent air in-leakage.

Entrance access doors will be positioned at strategic locations for inspections and maintenance needs for each section of the HRSG. Platforms, ladders, and stairways will be installed externally on the HRSG casing as needed to perform inspections and maintenance.

The HRSG will require insulation to maintain the metal temperature higher than the gas dew point to prevent acid corrosion of the casing metals during operation. The amount and positioning of insulation internally or externally within the vertical HRSG will be determined by the CT exhaust gas temperature, whether duct firing is installed, and the environmental temperatures. Typically casing ductwork will be externally insulated at a minimum with the hotter inlet sections internally lined with insulation materials. The inlet duct will typically be lined with stainless steel plate materials to minimize erosion from the hot exhaust gas. Ductwork with duct firing capability will typically be internally lined with insulation covered by a metal cover plates. Cooler temperature upper ductwork sections of a vertical HRSG typically will only have insulation installed externally on the casing sections.

2.2.5 Selective Catalytic Reduction

Emissions controls may also be located in the HRSG ductwork typically consisting of an SCR system to reduce nitrogen oxides (NO_x) and/or a Carbon Monoxide catalyst system to remove carbon monoxide (CO). The SCR NO_x catalyst performs best in temperatures between 650 °F (340 °C) and 750 °F (400 °C) which is typically near the HP evaporator section of the HRSG. Ammonia is injected via a grid system in front of the SCR catalyst to aid in NO_x removal. CO catalyst sections are typically located in front of the ammonia injection grid system.

Protection not to poison or damage the catalyst is important when cleaning or repairing any upstream tubes or bundles in the case of a horizontal HRSG or downstream tubes or bundles for vertical HRSG units.

2.2.6 Gas Silencers

Gas silencers are used for some application to reduce noise levels of the HRSG flue exhaust to meet environmental local and government requirements. The gas silencers may be located within the HRSG exit ductwork or the stack and consist of various OEM patented designs. Silencers are typically custom-engineered and made of materials to meet the site specific requirements.

2.2.7 Stack

Each HRSG will have an outlet stack located at the exhaust gas exit end after the LP economizer section. Depending on the height requirements, the stack may be mounted on the HRSG structure for shorter stacks or on plant structural steel members for higher stack requirements. The stack will be connected to the HRSG via a duct expansion joint or may be welded to the last HRSG casing module. Most stacks used for combined cycle applications will be fabricated from carbon steel plate and structural steel materials. The stack will have access doors for inspections, required environmental test connections, electrical

lights/grounding connections, and access platforms/ladders, as required. External insulation may be required on the stack in cooler environmental areas to help maintain metal casing temperatures above the gas dew point temperature (typically 175-200 deg F, 80-93 deg C).

Stacks located above vertical HRSG's will typically contain a weather damper system within the stack to close during periods when the HRSG is not operating and prevent rain/snow from falling into the HRSG. The weather damper is typically opened and closed via an electric or pneumatic actuator system. The rain water is drained away via a drainage system

Some combined cycle applications may have a bypass duct damper and stack arrangement for bypassing the exhaust gas flow from the HRSG. This is typically done when there is no steam demand required from the HRSG or for performing maintenance on the HRSG with the combustion turbine in operation.

2.2.8 Deaerator Tank

For some combined cycle designs, a deaerator tank may be present to aid in reducing the condensable and non-condensable gases content of the condensate water prior to supply to the LP drum or economizer inlet header. The deaerator tank will typically be a pressure vessel consisting of spray nozzles, tray supports, baffles, impingement plates, and tray enclosures. Condensate water is sprayed into the steam heated deaerator tank where it is passed over a set of trays that separates the gases from the water. The gases are vented out of the deaerator tank to atmosphere. The water collected in the bottom of the deaerator tank is used to supply the economizer inlet headers or LP drum. Typically deaerator tanks are located as high as possible above the HRSG to supply sufficient water flow to the economizer inlets or LP drum.

Some combined cycle units may use the LP drum as a deaerator for removal of the gases and chemical treatment and a separate deaerator tank is not needed.

For other combined cycle designed units, removal of the condensable and non-condensable gases from the condensate water supply is done by the vacuum pumps near the condenser and a deaerator tank is not used.

2.2.9 Piping and Drain System

2.2.9.1 Drains

Piping and drains from the HRSG allows for each of the economizer, evaporator, and superheater tube bundles to be completely drainable for maintenance or to prevent water in tube bundle low points during start-ups. Drain valves may be manual or motor operated depending specific application and unit designs. Water drained from the HRSG goes to the blowdown sump.

2.2.9.2 Nitrogen Piping

Many modern HRSG's will have external piping that will allow for internal nitrogen blanketing of the tube sections during periods of shutdown. The nitrogen piping connections will be to the inlet headers for each section.



Section 3: HRSG Operational Considerations

As an integral part of the combined cycle plant operational unit, the HRSG is fitted to equipment supplied by others and attention must be given to equipment interfaces and operation instructions for all equipment. Proper alignment of the HRSG with other plant systems must take place for safe and efficient operation.

Many combined cycle gas turbine units in service today were designed for base load operation with limited planned starts but are currently operated in various modes including periods of base load, load following, two-shift, and peaking operations. Other units that were designed for limited or cycling operation are now base loaded. Current market demands require high operating flexibility from combustion turbine combined cycle units which have a direct effect on HRSG reliability and maintenance requirements including:

- faster hot and cold startups
- frequent unit load changes
- larger unit turn-down ratios
- increased sliding pressure operations of the steam turbine
- increased use of supplemental duct firing
- more complicated plant designs to gain thermodynamic efficiency
- more start-ups and shut-downs than originally designed
- larger and hotter gas turbine exhaust flows

The increased operation flexibility of many combined cycle gas turbine units has increased HRSG operation and maintenance costs for units designed for base load conditions. Flexible operating scenarios affect HRSG life expectations which can be severe and need to be considered when designing, operating, and maintaining the HRSG.

Many HRSG's currently within the power industry were designed for a slow, predictable start-ups and shutdowns with HRSG components heated and cooled in a controlled manner for long term reliability and service. However, changing gas prices, and regulations have resulted in many of these units operating different from original design with increased cycling and faster starts. This change in operation will have an effect on the life of the HRSG.

The HRSG original equipment manufacturer (OEM) Operation and Maintenance Manual must be read and understood before any operational activities are undertaken. Operation of the HRSG should be based on the original design temperature and pressure parameters and these should not be exceeded at any time. Maintaining OEM designed temperature and pressure parameters across each section of the HRSG is important in keeping stresses on HRSG components at acceptable levels for long term reliable operation.

Units operating outside the original design parameters should consider having an operational model or evaluation of the HRSG performed by the OEM or a qualified third party to aid in evaluating component damage mechanisms and the effects of flexible operations on the expected life of the HRSG. OEM's can perform a life cycle analysis similar to the one originally performed during the design stage based on the current operating parameters.

Some OEM's have developed dynamic life cycle analysis software tools that can utilize actual operating data and component monitoring data from the site distributed control system to develop a computer model of the HRSG and its components. Actual operating and monitoring data conditions can allow the OEM to analyze the impact of current operating practices on the existing HRSG components. This assists the owner/operator in evaluating the expected life of their HRSG components and in making economic decisions for repairing or replacing HRSG components in the future.



Key Technical Point

Some OEM's have developed dynamic life cycle analysis software tools for their HRSG's to forecast component life expectations by analyzing the impact of actual operating conditions.

3.1 Reliability and Durability Issues

Many gas turbine combined cycle power plant units are operated in different modes from the original base loaded mode envisioned when the unit was designed and purchased. Some units may be started and shutdown on a two shift basis, others may be operated at partial loads for extended periods of time, and others may be started and shutdown over longer term periods. The changing operating modes can cause extreme thermal stresses on HRSG components as rapid temperature changes often occur. The thermal stresses have a large effect on HRSG reliability and durability. HRSG components will be damaged by thermal stresses and affect the life of the unit. The impact and effects on similar components may be different for each HRSG and its operating environment.

Feedwater supply design and water chemistry practices can also affect life expectancy of an HRSG with flexible operations.

The largest damage issues affecting HRSG reliability and durability typically include the following:

- Low cycle fatigue
- Creep and oxidation damage due to high temperatures
- High cycle fatigue of gas path components
- Corrosion

Typically an individual HRSG reliability and durability is a function of a combination of issues. Good resources for information are EPRI Product ID 1004240 *Delivering High Reliability Heat Recovery Steam Generators and Product ID 1010440 Evaluation of Thermal-, Creep-, and Corrosion-Fatigue of Heat Recovery Steam Generator Pressure Parts*, March 2006.

3.1.1 Low Cycle Fatigue

Low cycle fatigue occurs when a component is subjected to cyclic stresses that would not normally fail it.

However over time, cyclic stresses will cause components to fail eventually. Cyclic stresses on HRSG components from normal operations are typically considered in OEM's original designs for expected number of cycles and operating parameters. An increase in actual operating scenarios can cause greater stresses than were considered in the original HRSG design. Low cycle fatigue usually increases with an increase of cyclic operations.

Gas turbine starts, trips, and stops also cause rapid extreme temperature increases and decreases in HRSG's. These cyclic rapid temperature changes cause low cycle thermal fatigue damage to HRSG tube and header pressure components. Typically low cycle fatigue HRSG problems show up in cracks in tube bends, tube attachments to headers, and cracks in headers and drums. HRSG tubes and connections may need to be redesigned or modified to handle the number of multiple rapid temperature changes experienced in actual operational situations.

3.1.2 Creep and Oxidation Damage

HRSG components can experience creep damage due to the HRSG operating at higher than expected temperatures for longer than expected times. This can be from extensive combustion turbine or duct firing for peak loads. HRSG components most likely at risk for creep damage are the superheater tubes, headers, and drums. Other components affected can include the piping, valves, attemperators, duct liners and casings.

Oxidation and exfoliation damage from the higher temperatures can occur on any metallic component located within the HRSG. Superheater, evaporator, economizer tube bundles are likely to see this type damage.

3.1.3 High Cycle Fatigue

Similar to low cycle fatigue, high cycle fatigue occurs when components are exposed to cyclic stresses. High cycle fatigue problems typically occur in the inlet duct and superheater tube bundles within the inlet gas flow region of the HRSG. The exhaust duct structural components also experience extreme gas flow conditions from the gas turbine exhaust gas.

3.1.4 Corrosion

Corrosion within a HRSG can take place on the inside or outside of the tubes and headers as well as on other metal components.

3.1.4.1 Inside Tube Corrosion

Corrosion on the inside of the tubes and headers are typically due to water treatment issues. Signs of corrosion may show up as deposits, pitting, or cracking of the tubes or headers. Maintaining the proper water chemistry for the specific HRSG is a must. EPRI Product ID 1019635 *Guidelines for Makeup Water Treatment* is a resource for assistance in water chemistry practices.

Flow Accelerated Corrosion (FAC) is a form of inside tube or header corrosion. There is likely to be areas within the HRSG tubes and headers where the velocity of the two-phase flow (water/steam) is above the limits necessary to erode the magnetite layer of the tubes. Also the water chemistry must be maintained such that the oxygen content of the water/steam is not too low to prevent a proper magnetite layer from forming while not too high to cause stress corrosion. EPRI Product ID 1023089 *Flow-Accelerated Corrosion (FAC) Fossil and Combined Cycle Self Assessment* should help you evaluate your situation. EPRI Product ID 1012762 *Heat Recovery Steam Generator Repair Welding Technologies to Address FAC in Tube Bends* can also be another resource. FAC is more likely to occur within the low pressure evaporator or low pressure drum areas where two-phase water conditions exist.

3.1.4.2 Exterior Tube Corrosion

Corrosion of the exterior of the tubes and other metal components of the HRSG are typically due to exposure of the components to water and impurities in the combustion turbine exhaust gases at temperatures less than the dew point (typically 175-200 deg F, 80-93 deg C). Long term overheating of the tube exteriors can also cause corrosion issues. Tube stress corrosion cracking of the tubes can occur due to fatigue such as long term creep from overheating, high/low cycle thermal, corrosion, or vibration issues. Tube bundles downstream of the SCR are suspect for fouling by ammonia salts and rusts that has flaked off HRSG carbon steel components. The amount of sulfur in the natural gas fuel and in the environmental air also has an effect on the rate of fouling. The amount of time the HRSG is not in service and left in a humid condition can affect the amount and rate of fouling. The low pressure economizer section is the most likely area for exterior corrosion damage. Figure 3-1 shows an example of an economizer tube with exterior corrosion.



*Figure 3-1
Economizer Tube Corrosion Example*

Section 4: Inspection and Troubleshooting

An HRSG is a complex piece of equipment and troubleshooting failure modes and mechanisms can be multifaceted and involve identification of multiple root cause findings. EPRI Product ID 1004240 *Delivering High Reliability Heat Recovery Steam Generators* and Product ID 1014197 *Examination of Heat Recovery Steam Generator Plants* are references that can assist HRSG operators with potential solutions to some industry documented problems that have been identified with operation and maintenance of HRSGs.

Troubleshooting and inspection of an HRSG begins with first understanding the way the unit is operated and review of the historical failure and repair data for the unit. Review of operating data while the unit is in operation and comparison to the OEM's original design values help identify some potential areas for the engineer to concentrate on during inspections. This is typically done before the unit comes off line for an outage inspection. A HRSG engineer also needs to understand how HRSG components can degrade or have failures when operated in your specific operating mode. This understanding of how HRSG components fail helps identify to the inspector items to specifically look for in your unit during an outage.

4.1 Internal Inspections

Internal inspections of a HRSG should occur at least on an annual basis. The purpose of the internal inspection is to visually inspect the interior components to identify items that need immediate maintenance or repair, identify items for future maintenance or repair, and to identify items that will need replacements or major upgrades during major outages. The internal inspection of the HRSG should begin after the HRSG unit is cooled down and drained. Scaffolding or a sky climber may be needed for inspection over the entire length of the vertical tube bundles of a horizontal HRSG unit.

The inspector should be made aware of any of following factors before starting an inspection:

- Past history of maintenance problems and repairs made.
- Past various modes of operation may determine what needs to be checked closer.
- Type of water treatment can effect what needs to be checked closely.



Key Technical Point

Internal inspection of a HRSG should occur at least on an annual basis.



Key Supervisory Observation Point

HRSG components should be inspected by teams or individuals based on their expertise.

- Type of fuels burned in the combustion turbine can have an effect on what needs to be checked closer.
- Operating performance information may help identify areas of concern before the unit is inspected. Actual operating data vs. expected.
- OEM inspection recommendations.
- Results from any inspections performed while the unit was in operations.

HRSGs are made up of a variety of subsystems and components that may require specific expertise to inspect each area. Having a team approach to inspections can allow for a team to concentrate on specific areas for potential items of concern to look. This keeps a single team from looking for every potential issue with the likeliness of missing something. HRSG inspections should be performed by a group approach consisting of teams or individuals that concentrate on specific areas or components of the HRSG based on their expertise. Personnel who perform inspections of HRSG's should attend training classes offered by the OEM or other industry experts for specific items to look for on their units based on their operation modes and procedures.

As an example, the following area breakdowns should be concentrated on by an experienced individual or team. Individuals or teams may participate in the inspection of multiple areas.

- A team to inspect all drums, headers, and deaerator interior components and to review water chemistry issues and practices
- A team to inspect all HRSG internal components including tube bundle assemblies and structural steel components
- A team to inspect the duct burner system
- A team to inspect the SCR and CO systems
- A team to inspect the stack, expansion joints, and HRSG structure systems
- A team to inspect the HRSG drainage system
- A team to inspect the controls and electrical components



Key Supervisory Observation Point

One of the best tools for a HRSG inspector to have is a digital camera.

One of the best tools HRSG team inspectors can utilize is a digital camera for taking pictures or digital scans of various areas of the unit during the inspection. Not only does it help document current findings but can help with planning for future inspections.

4.2 Structure Inspections

The HRSG structures are designed to thermally expand as a unit when the exhaust heat from the gas turbine enters the HRSG unit. Any damaged or misaligned component needs to be properly repaired and investigated for lack of or improper thermal movement. This includes the structural steel and piping to and from the HRSG.

For this report the HRSG structure consists of the following mechanical components:

- Exterior and interior casing, including insulation
- Inlet duct
- Inlet and outlet duct expansion joints
- Structural steel, including stairs and walkways
- Foundation, including slide plates
- Stack
- Stack Damper
- Exterior piping hangers and support steel
- Piping penetrations and seals

Instrumentation, piping, and electrical components will be covered in other sections.

Before performing an internal inspection of a HRSG make sure the site's confined space procedures are followed. If any scaffolding, ladder, or sky climber is used for elevated inspections make sure to follow the site's safety and fall protection procedures.

The exterior casing will have panels that cover insulation on the HRSG. The exterior casing can be inspected when the unit is in operation for signs of leaks, cracks, and mechanical integrity. The HRSG will operate under pressure from the exhaust gas and leakage should be to the outside. Thermography scans can be taken to help identify casing hot spots and overheating where insulation may be missing or damaged. Missing and damaged insulation should be replaced as found.

During operator rounds any vibrations or noises from the HRSG should be noted for further internal inspection at the next available outage. Loose liners, flow distribution screens, or tube bypass baffles can cause vibration noises during operation. Finding and correcting these problems before further damage within the HRSG is important as they can lead to other problems such as loss of insulation and development of hot spots. Vibrations over time can also cause support welds, bolted fasteners, studs, and other attachment hardware to fail over time. Vibrations of the external casings may also cause weld failures of support steel and walkways over time.

Thermography scans can also be used to identify inlet and outlet expansion joint leaks. The expansion joints should be inspected for leaks, corrosion, overheating, missing or broken cover plates, and signs of improper movement. Metal expansion joints should be inspected for cracking and corrosion. Belt or fabric type expansion joints should be inspected for tears and wear from exposure to the atmosphere. All expansion joint flange and seal welds should be inspected for cracks.



Key Human Performance Point

The site's confined space procedures should be followed for all internal HRSG inspections.



Key Technical Point

Any noises or vibrations found during HRSG operation should be investigated at the next available outage.

HRSG roof casing panels should be inspected for signs of corrosion and damage from standing water. The roof panels should be positioned for efficient run-off and drainage of water from rain or snow.

All HRSG exterior piping supports and hangers should be inspected for mechanical integrity. Any bent, loose, or damaged pipe hangers should be identified for repair. All piping penetrations, expansion joints, and seals should be inspected for signs of leakage, broken seals, and mechanical integrity. All piping should be inspected for bending, deflections, or corrosion.

The HRSG casing will have multiple access doors for entering and inspecting the various HRSG sections. Access doors can be inspected for signs of leakage, overheating, and mechanical integrity while the unit is in operation. When access doors are opened for entry into the HRSG, the seals and seal surfaces should be inspected for damage and corrosion. Damaged gaskets, insulation, and seals should be replaced as required.

The HRSG foundation should be inspected both when the unit is in operation and during shutdown. The concrete supports should be inspected for spalling, cracking, or settling. Structural steel, including stairs and walkways, should be inspected for broken welds and corrosion. Slide plates should show free movement with no signs of damage or binding. Slide plates should be cleaned and lubricated as required.

The stack casing and interior lining should be inspected for signs of corrosion, damage, or wear. Stack flow silencers, if present, should be inspected for mechanical integrity, alignment, and warpage. Stack structural steel supports should be inspected for broken welds, wear, and mechanical integrity. Stack concrete foundations should be inspected for spalling, cracking, or settling. Stack drains should be inspected for corrosion, damage, and drains free from blockage. Stack dampers should be inspected for proper movement and sealing. Damper components should be inspected for corrosion, damage, or wear. Damper mechanical drive units and linkage bearings should be serviced as required. EPRI Product ID 1018992 *Evaluating and Avoiding HRSG Pressure Part Damage Influenced by Stack Damper Operation* is a resource for assistance with stack dampers.

The HRSG inlet duct should be inspected for loose insulation liner plates, loose or missing plate attachment hardware, gaps in seals, and exposed insulation. Interior liners should be inspected for warpage and signs of overheating. Flow distribution plates, screens, and straighteners should be inspected for damage, wear, and structural integrity. Any debris found on the floor should be collected and analyzed to determine source and potential future repairs. Inspect duct flow silencers for mechanical integrity.

Table 4-1 shows some typical troubleshooting activities for duct burner components.

Table 4-1
Duct Burner Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
Igniters/Pilots	Observe flame condition while in operation	- Air/gas mixture wrong. - Flame not stable	Ensure air/gas mixture at OEM specifications	1012758
		Flame length too long or too short	- Exhaust flow distribution problems. - Burner realignment needed.	1012758
	Nozzles damaged	Inspect for pluggage, wear, fouling and misalignment	- Clean, repair, or replace air and gas nozzles as needed. - Ensure air/gas mixture at OEM specifications	1012758
Flame Scanners	Damaged or failed	Failed due to temperature	- Replace as needed. - Check for alignment and proper cooling air supply.	1012758
Baffles, Partition Plates	- Sagging - Out of alignment	Broken structural supports or welds	- Reposition and re-weld supports. - Ensure proper alignment.	1012758

4.3 Low Pressure System

The LP system typically consists of an economizer section, a steam drum, an evaporator section, a superheater section, and associated piping, valves, and recirculation water pumps.

Problems with the LP steam system can potentially be identified by comparing the actual operating temperature, flow, and pressure values to the OEM expected benchmark values for the operating scenario. Any significant differences are likely an indication of a problem. Differences should be verified and further studied to determine the root cause and corrective actions needed. Consistent readings between all redundant instrumentation, including transmitters, level gages, pressure switches, thermocouples, etc., should be verified on routine basis. Review of operating data and comparison to OEM expected benchmark values should take place at a minimum during start-ups, normal operation, and shutdowns.

During normal operation the LP system should be checked during operator rounds for steam/water leaks with repairs planned, scheduled, and made when the system can be made available. The recirculation pumps can be checked during operator rounds for unusual noises, vibration, or leaks.

The drum safety valves should be checked for leakage or mechanical integrity during operator rounds.

Corrosion, cracking, wear, and damage to drum surfaces, drum internal components, tube assemblies, and headers on the water side of the LP system equipment can be a sign of multiple wear or failure causes. There may also be multiple options for potential correction of the problems found within an individual HRSG. The following table 4-2 gives examples of some of the common failure items that may be found in an HRSG with some potential causes, and some potential repair or prevention options. It is important to document findings during an inspection with pictures, test samples, testing results, and written documentation to track the condition of each HRSG.

EPRI Product ID 1019801 *Monitoring and Controlling Carryover in Heat Recovery Steam Generators* is a source of steam drum issues to use as a reference.

EPRI Product ID 1019601 *Procurement Specification for Horizontal Gas Path Heat Recovery Steam Generator: Avoiding Thermal-Mechanical Fatigue Damage* is a resource to aid in potentially evaluating damage found In HRSG's.

Table 4-2
LP Section Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
Steam Drum	- Internal steam separation equipment cracked. - Welds broken or cracked.	Thermal stress	Repair or replace damaged equipment. Re-evaluate unit operating procedures.	1010440 1019601
	- Holes in steam separator equipment - Thinning of metal components.	Flow-Accelerated Corrosion	- Repair or replace - Take ultrasonic thickness (UT) readings of components with holes to determine extent of damage - Re-evaluate water chemical treatment procedures	1023089
	Pitting or scaling of metal surfaces	- Corrosion - Normal wear.	- Determine extent of pitting damage to see if further - Re-evaluate water chemical treatment procedures.	
	- Missing hardware on piping and separators - Spray nozzles damaged	- Normal wear - Vibration - Flow-accelerated corrosion	Repair or replace as needed Re-evaluate water chemical treatment procedures.	1023089
	- Manway door gasket surface cracked, pitted, or corroded. - Leaking	- Normal wear - Thermal stress - Failed or improper gasket - Steam cut - Misalignment	- Machine to OEM flatness specification as needed. - Replace gasket - Repair gasket surface. - Realign door.	

Table 4-2 (continued)
LP Section Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
	Excessive debris in bottom of drum	- Inadequate drum blowdown during operation - Flow-Accelerated Corrosion - Water treatment issues	- Analyze debris samples to determine source - Re-evaluate drum blowdown procedures - Re-evaluate water chemical treatment procedures.	1023089
	Blow down piping cracked	Thermal stress	Determine cause and correct	1010440
	Clogged nozzles or drains	Improper blowdown practices	Re-evaluate blow down procedures	1014196
	Internal corrosion	Normal use	Repair or replace as needed	
	Missing hardware or end caps	- Vibration - Normal use	Repair or replace as needed	
LP Headers	Cracked	- Thermal Stress - Fabrication weld defect	- Temperature swings due to controls - Repair as needed	1008092 1010440
	Internal pitting and corrosion	- Water treatment issues - Layup water treatment practices - Flow-Accelerated Corrosion	Re-evaluate water chemical treatment procedures	1008092 1012762 1023089
	External Corrosion	Water in-leakage	Determine source of water in-leakage and correct	1014302
	Loose or broken hanger supports	- Water hammer - Improper installation - Normal wear	- Adjust hanger as required - Determine cause of water hammer - Ensure proper piping movement when in operation	

Table 4-2 (continued)
LP Section Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
	Inspection bore hole steam leak	- Failed gasket/seal ring - Improper installation	- Replace gasket/seal ring - Properly install	
	Drain line from header - cracked weld at header	- Thermal stress - Corrosion - Normal wear - Drain pipe restrained form movement	- Perform dye penetrate test to verify crack - Repair by re-welding - Ensure pipe can move thermally with HRSG in operation	1016849 1014301 1019601 1010440 1015831 1014196
	LP tube to header weld cracking	- Thermal stress - Normal wear - Weld defect	- Perform dye penetrate test to verify crack - Repair by re-welding - Ensure tube properly supported to move thermally with HRSG in operation	1016849 1014301 1019601 1010440 1004875 1019802
LP Drains	Damaged duct penetration seal	- Mechanical wear - Pipe restrained - Corrosion from water	- Repair as found - Inspect and repair drain piping hangers and supports - Remove source of water damage	1014196 1015831
	Valve packing leak	Normal use	Repack	
	Valve seat leaks	- Normal use - Valve Operator malfunction	- Replace valve or repair seat - Calibrate operator stroke	

Table 4-2 (continued)
LP Section Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
LP Tubes	External corrosion	- Corrosion - Failure to run re-circulation pumps - Operating below acid dew point temperature - Water in-leakage	- Blast clean tubes - Properly operate re-circulation pumps - Determine cause of water in-leakage and correct	1014302
	External fouling of tubes and fins	- Ammonia salt deposits from natural gas - Sulfur from natural gas and air - Rust particles	- Blast clean tubes - Properly operate re-circulation pumps to keep tubes above dew point - Utilize HRSG heat systems when offline	1014302 1017629
	- Tube wear - Fins broken	- Vibration from exhaust gas flow - Tube to tube tie welds broken - Tube supports broken	- Repair tube tie welds - Ensure tube supports and baffles in place	1004875 1019802
	Tube bypass baffles missing or broken	- Vibration due to gas flows - Normal wear - Broken welds - Corrosion	- Repair damaged baffles - Replace missing baffles - Ensure baffles in place	
	Internal tube corrosion/pitting	Water chemistry practices	Re-evaluate water chemistry practices	1019799

Table 4-2 (continued)
LP Section Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
	Internal tube erosion	- Flow-accelerated corrosion - Water chemistry practices	Re-evaluate water chemistry practices	1012762 1023089 1019799 1014301
	Tube field weld cracks	- Weld defect - Manufacturing - Thermal stress	- Repair cracked welds - Review operations procedures	1019601 1010440 1004875 1019802

4.4 Intermediate Pressure System

The IP system typically consists of an economizer section, a steam drum, an evaporator section, a superheater section, and associated piping and valves. The IP section of the HRSG can also include the reheater section for heating the cold reheat steam returning from the steam turbine for some applications. The IP section of an HRSG operates very similarly as a natural circulation boiler. The IP section supplies process steam to be used within the combined cycle plant.

Problems with the IP steam system can potentially be identified by comparing the actual operating temperature, flow, and pressure values to the OEM expected benchmark values for the operating scenario. Any significant differences are likely an indication of a problem. Differences should be verified and further studied to determine the root cause and corrective actions needed. Consistent readings between all redundant instrumentation, including transmitters, level gages, pressure switches, thermocouples, etc., should be verified on routine basis. Review of operating data and comparison to OEM expected benchmark values should take place at a minimum during start-ups, normal operation, and shutdowns.

During normal operation the IP system should be checked during operator rounds for steam/water leaks with repairs planned, scheduled, and made when the system can be made available. The drum safety valves should be checked for leakage or mechanical integrity during operator rounds. Corrosion, cracking, wear, and damage to drum surfaces, drum internal components, tube assemblies, and headers on the water side of the IP system equipment can be a sign of multiple wear or failure causes. There may also be multiple options for potential correction of the problems found within an individual HRSG. The following table 4-3 gives examples of some of the common failure items that may be found in an HRSG with some potential causes, and some potential repair or prevention options. It is important to document findings during an inspection with pictures, test samples, testing results, and written documentation to track the condition of each HRSG.

EPRI Product ID 1019801 *Monitoring and Controlling Carryover in Heat Recovery Steam Generators* is a source of steam drum issues to use as a reference.

EPRI Product ID 1019601 *Procurement Specification for Horizontal Gas Path Heat Recovery Steam Generator: Avoiding Thermal-Mechanical Fatigue Damage* is a resource to aid in potentially evaluating damage found in HRSG's.

Table 4-3
IP Section Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
Steam Drum	- Internal steam separation equipment cracked. - Welds broken or cracked.	Thermal stress	Repair or replace damaged equipment. Re-evaluate unit operating procedures.	1019601 1010440
	- Holes in steam separator equipment - Thinning of metal components.	Flow-Accelerated Corrosion	- Repair or replace - Take ultrasonic thickness (UT) readings of components with holes to determine extent of damage - Re-evaluate water chemical treatment procedures	1023089
	Pitting or scaling of metal surfaces	- Corrosion - Normal wear.	- Determine extent of pitting damage to see if further - Re-evaluate water chemical treatment procedures.	
	- Missing hardware on piping and separators - Spray nozzles damaged	- Normal wear - Vibration - Flow-accelerated corrosion	Repair or replace as needed Re-evaluate water chemical treatment procedures.	1023089
	- Manway door gasket surface cracked, pitted, or corroded. - Leaking	- Normal wear - Thermal stress - Failed or improper gasket - Steam cut - Misalignment	- Machine to OEM flatness specification as needed. - Replace gasket - Repair gasket surface. - Realign door.	

Table 4-3 (continued)
IP Section Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
	Excessive debris in bottom of drum	- Inadequate drum blowdown during operation - Flow-Accelerated Corrosion - Water treatment issues	- Analyze debris samples to determine source - Re-evaluate drum blowdown procedures - Re-evaluate water chemical treatment procedures.	1012756 1023089
	Blow down piping cracked	Thermal stress	Determine cause and correct	1019601 1010440
	Clogged nozzles or drains	Improper blowdown practices	Re-evaluate blow down procedures	1014196
	Internal corrosion	Normal use	Repair or replace as needed	
	Missing hardware or end caps	- Vibration - Normal use	Repair or replace as needed	
Feedwater, Reheater, and IP Headers	Cracked	- Thermal Stress - Fabrication weld defect	- Temperature swings due to controls - Repair as needed	1019601 1010440
	Internal pitting and corrosion	- Water treatment issues - Layup water treatment practices - Flow-Accelerated Corrosion	Re-evaluate water chemical treatment procedures	1012762 1023089
	External Corrosion	Water in-leakage	Determine source of water in-leakage and correct	1014302
	Loose or broken hanger supports	- Water hammer - Improper installation - Normal wear	- Adjust hanger as required - Determine cause of water hammer - Ensure proper piping movement when in operation	

Table 4-3 (continued)
IP Section Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
	Inspection bore hole steam leak	- Failed gasket/seal ring - Improper installation	- Replace gasket/seal ring - Properly install	
	Drain line from header - cracked weld at header	- Thermal stress - Corrosion - Normal wear - Drain pipe restrained from movement	- Perform dye penetrate test to verify crack - Repair by re-welding - Ensure pipe can move thermally with HRSG in operation	1019601 1010440 1015831 1014196
	IP tube to header weld cracking	- Thermal stress - Normal wear - Weld defect	- Perform dye penetrate test to verify crack - Repair by re-welding - Ensure tube properly supported to move thermally with HRSG in operation	1019601 1010440 1004875 1019802 1016849
IP Drains	Damaged duct penetration seal	- Mechanical wear - Pipe restrained - Corrosion from water	- Repair as found - Inspect and repair drain piping hangers and supports - Remove source of water damage	
	Valve packing leak	Normal use	Repack	
	Valve seat leaks	- Normal use - Valve operator malfunction	- Replace valve or repair seat - Calibrate operator stroke	

Feedwater, Reheater, and IP Tubes	• External corrosion	• Corrosion • Failure to run re-circulation pumps • Operating below acid dew point temperature • Water in-leakage	• Blast clean tubes • Properly operate re-circulation pumps • Determine cause of water in-leakage and correct	1014302
	• External fouling of tubes	• Ammonia salt deposits from natural gas • Sulfur from natural gas and air • Rust particles	• Blast clean tubes • Properly operate re-circulation pumps to keep tubes above dew point • Utilize HRSG heat systems when offline	1014302 1017629
	• Cracked • Swollen	• Thermal stress • Overheating • Creep	• Review operations procedures • Review desuperheater operating procedures	1019601 1010440
	• Tube wear • Tube bundles misaligned or warped • Tube ties missing or broken	• Vibration from exhaust gas flow • Tube to tube tie welds broken • Tube supports broken • Overheating • Improper drainage during startup	• Repair tube tie welds • Ensure tube supports and baffles in place • Re-evaluate startup procedures • Check desuperheater for leakage	
	• Tube bypass baffles missing or broken	• Vibration due to gas flows • Normal wear • Overheating • Broken welds • Corrosion	• Repair damaged baffles and supports • Replace missing baffles • Ensure tube supports are in place	
	• Internal tube corrosion/pitting	• Water chemistry practices • Improper lay-up practices	• Re-evaluate water chemistry practices • Re-evaluate lay-up procedures	1019799

Table 4-3 (continued)
IP Section Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
	Internal tube erosion	- Flow-accelerated corrosion - Water chemistry practices	Re-evaluate water chemistry practices	1012762 1019799 1023089 1014301
	- Reheater tube hot spots - Reheater tubes warped	- Duct burner misaligned - Wet steam from desuperheater	- Realign duct burners - Inspect desuperheater for leakage	
	Tube field weld cracks	- Weld defect - Manufacturing - Thermal stress	- Repair cracked welds - Review operations procedures	1019601 1010440 1004875 1019802

4.5 High Pressure System

The HP system typically consists of an economizer section, a steam drum, an evaporator section, a superheater section, and associated piping and valves. The HP section of the HRSG can also include the reheater section for heating the cold reheat steam returning from the steam turbine for some applications. The HP section of an HRSG operates very similarly as a natural circulation boiler. The HP section supplies steam to the steam turbine of the combined cycle plant.

Problems with the HP steam system can potentially be identified by comparing the actual operating temperature, flow, and pressure values to the OEM expected benchmark values for the operating scenario. Any significant differences are likely an indication of a problem. Differences should be verified and further studied to determine the root cause and corrective actions needed. Consistent readings between all redundant instrumentation, including transmitters, level gages, pressure switches, thermocouples, etc., should be verified on routine basis. Review of operating data and comparison to OEM expected benchmark values should take place at a minimum during start-ups, normal operation, and shutdowns.

During normal operation the HP system should be checked during operator rounds for steam/water leaks with repairs planned, scheduled, and made when the system can be made available. The drum safety valves should be checked for leakage or mechanical integrity during operator rounds. Corrosion, cracking, wear, and damage to drum surfaces, drum internal components, tube assemblies, and headers on the water side of the HP system equipment can be a sign of multiple wear or failure causes. There may also be multiple options for potential correction of the problems found within an individual HRSG. The following table 4-4 gives examples of some of the common failure items that may be found in an HRSG with some potential causes, and some potential repair or prevention options. It is important to document findings during an inspection with pictures, test samples, testing results, and written documentation to track the condition of each HRSG. Figure 4-1 shows an example of warped tube within a tube assembly.



Figure 4-1
Warped Tube Example

EPRI Product ID 1019801 *Monitoring and Controlling Carryover in Heat Recovery Steam Generators* is a source of steam drum issues to use as a reference.

EPRI Product ID 1019601 *Procurement Specification for Horizontal Gas Path Heat Recovery Steam Generator: Avoiding Thermal-Mechanical Fatigue Damage* is a resource to aid in potentially evaluating damage found In HRSG's.

Table 4-4
HP Section Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
Steam Drum	- Internal steam separation equipment cracked. - Welds broken or cracked.	Thermal stress	Repair or replace damaged equipment. Re-evaluate unit operating procedures.	1019601 1010440
	- Holes in steam separator equipment - Thinning of metal components.	Flow-Accelerated Corrosion	- Repair or replace - Take ultrasonic thickness (UT) readings of components with holes to determine extent of damage - Re-evaluate water chemical treatment procedures	1023089
	Pitting or scaling of metal surfaces	- Corrosion - Normal wear.	- Determine extent of pitting damage to see if further - Re-evaluate water chemical treatment procedures.	1012756
	- Missing hardware on piping and separators - Spray nozzles damaged	- Normal wear - Vibration - Flow-accelerated corrosion	Repair or replace as needed Re-evaluate water chemical treatment procedures.	1023089
	- Manway door gasket surface cracked, pitted, or corroded. - Leaking	- Normal wear - Thermal stress - Failed or improper gasket - Steam cut - Misalignment	- Machine to OEM flatness specification as needed. - Replace gasket - Repair gasket surface. - Realign door.	

Table 4-4 (continued)
HP Section Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
	Excessive debris in bottom of drum	- Inadequate drum blowdown during operation - Flow-Accelerated Corrosion - Water treatment issues	- Analyze debris samples to determine source - Re-evaluate drum blowdown procedures - Re-evaluate water chemical treatment procedures.	1012756 1023089
	Blow down piping cracked	Thermal stress	Determine cause and correct	1019601 1010440
	Clogged nozzles or drains	Improper blowdown practices	Re-evaluate blow down procedures	1014196
	Internal corrosion	Normal use	Repair or replace as needed	
	Missing hardware or end caps	- Vibration - Normal use	Repair or replace as needed	
Economizer, Evaporator, and Superheater Headers	Cracked	- Thermal Stress - Fabrication weld defect	- Temperature swings due to controls - Repair as needed	1019601 1010440
	Internal pitting and corrosion	- Water treatment issues - Layup water treatment practices - Flow-Accelerated Corrosion	Re-evaluate water chemical treatment procedures	1012756 1023089
	External Corrosion	Water in-leakage	Determine source of water in-leakage and correct	1014302

Table 4-4 (continued)
HP Section Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
	Loose or broken hanger supports	- Water hammer - Improper installation - Normal wear	- Adjust hanger as required - Determine cause of water hammer - Ensure proper piping movement when in operation	
	Inspection bore hole steam leak	- Failed gasket/seal ring - Improper installation	- Replace gasket/seal ring - Properly install	
	Drain line from header - cracked weld at header	- Thermal stress - Corrosion - Normal wear - Drain pipe restrained from movement	- Perform dye penetrate test to verify crack - Repair by re-welding - Ensure pipe can move thermally with HRSG in operation	1019601 1010440 1015831 1014196
	Tube to header weld cracking	- Thermal stress - Normal wear - Weld defect	- Perform dye penetrate test to verify crack - Repair by re-welding - Ensure tube properly supported to move thermally with HRSG in operation	1019601 1010440 1004875 1019802 1016849
HP Drains	Damaged duct penetration seal	- Mechanical wear - Pipe restrained - Corrosion from water	- Repair as found - Inspect and repair drain piping hangers and supports - Remove source of water damage	
	Valve packing leak	Normal use	Repack	

Table 4-4 (continued)
HP Section Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
	Valve seat leaks	- Normal use - Valve Operator malfunction	- Replace valve or repair seat - Calibrate operator stroke	
Economizer, Evaporator, and Superheater Tubes	External corrosion	- Corrosion - Failure to run re-circulation pumps - Operating below acid dew point temperature - Water in-leakage	- Blast clean tubes - Properly operate re-circulation pumps - Determine cause of water in-leakage and correct	1014302
	External fouling of tubes	- Ammonia salt deposits from natural gas - Sulfur from natural gas and air - Rust particles	- Blast clean tubes - Properly operate re-circulation pumps to keep tubes above dew point - Utilize HRSG heat systems when offline	1014302 1017629
	- Cracked - Swollen	- Thermal stress - Overheating - Creep	- Review operations procedures - Review desuperheater operating procedures	1019601 1010440
	- Tube wear - Tube bundles misaligned or warped - Tube ties missing or broken	- Vibration from exhaust gas flow - Tube to tube tie welds broken - Tube supports broken - Overheating - Improper drainage during startup	- Repair tube tie welds - Ensure tube supports and baffles in place - Re-evaluate startup procedures - Check desuperheater for leakage	

Table 4-4 (continued)
HP Section Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
	• Tube bypass baffles missing or broken	• Vibration due to gas flows • Normal wear • Overheating • Broken welds • Corrosion	• Repair damaged baffles and supports • Replace missing baffles • Ensure tube supports are in place	
	• Internal tube corrosion/pitting	• Water chemistry practices • Improper lay-up practices	• Re-evaluate water chemistry practices • Re-evaluate lay-up procedures	1019799
	• Internal tube erosion	• Flow-accelerated corrosion • Water chemistry practices	• Re-evaluate water chemistry practices	1012762 1019799 1023089 1014301
	• Tube hot spots • Tube warped	• Duct burner misaligned • Wet steam from desuperheater	• Realign duct burners • Inspect desuperheater for leakage	
	• Tube field weld cracks	• Weld defect • Manufacturing • Thermal stress	• Repair cracked welds • Review operations procedures	1019601 1010440

4.6 SCR System

Emissions controls may also be located in the HRSG ductwork typically consisting of an SCR system to reduce nitrogen oxides (NO_x) and/or a Carbon Monoxide catalyst system to remove carbon monoxide (CO). The SCR NO_x catalyst performs best in temperatures between 650 °F (340 °C) and 750 °F (400 °C) which is typically near the HP evaporator section of the HRSG. Ammonia is injected via a grid system in front of the SCR catalyst to aid in NO_x removal. CO catalyst sections are typically located in front of the ammonia injection grid system.

The ammonia skid will be located separately from the HRSG and will supply ammonia in front of the NO_x catalyst section. Figure 4-2 shows an example of an ammonia mixing skid.



*Figure 4-2
Ammonia Mixing Skid Example*

The SCR catalyst life will be affected by a variety of operating factors including the temperature of the exhaust gas, the amount of sulfur in the exhaust gas, the NO/NO₂ ratio of the exhaust gas, and any fouling from debris within the exhaust gas flow. Protection not to poison or damage the catalyst is important when cleaning or repairing any upstream tubes or bundles for a horizontal HRSG. Protection in a vertical HRSG is required when cleaning or repairing downstream tubes or bundles.

Inspection of both the CO and NO_x catalyst will involve looking for fouling or pluggage of the sections. Fouling can be from rust or other debris moved through the unit from the exhaust gas. Pluggage may be from insulation that has come loose from failed liner sections. Perimeter and sectional baffles around the catalyst bed sections should be in place to not allow exhaust gas to bypass the catalyst. Insulation or other seal materials used between catalyst sections should be intact. Catalyst sections should be inspected for sagging to create gaps between sections.

Table 4-5 below provides some troubleshooting recommendations for a HRSG catalysts section.

Potential EPRI resources for combustion turbine applications of SCR systems include:

- Product ID 1014287 *Selective Catalytic Reduction (SCR) Procurement Guideline for Simple- and Combined- Cycles Combustion Turbines*
- Product ID 1021807 *General Application Maintenance Center: Selective Catalytic and Non-Catalytic System Maintenance Guide*
- Product ID 1022096 *Gas Turbine/Combined Cycle Post Combustion Emission Control Best Practices Guideline*

Table 4-5
SCR Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
CO Catalyst	- Missing or broken bypass baffles - Catalyst seals out of position	- Vibration - Missing or compacted seals	Repair or replace damaged equipment.	1022096
	- Pluggage - High delta exhaust gas pressure across section	- Rust or other debris from exhaust flow - Insulation materials - Flow distribution screen plugged	- Clean catalyst sections - Determine root cause of pluggage and correct - Clean flow distribution screen	1022096
	Catalyst sections eroded or damaged	- Debris in exhaust gas - Uneven exhaust flow - Physical damage	- Repair flow distribution screen - Remove pluggage - Install blanks or plugs in heavily damaged sections until replacement can be made.	1022096
	Catalyst poisoned	Take sample for analysis	Sample per performance monitoring and OEM recommendations	1022096
NOx Catalyst	- Missing or broken bypass baffles - Catalyst seals out of position	- Vibration - Missing or compacted seals	Repair or replace damaged equipment.	1021807
	- Pluggage - High delta exhaust gas pressure across section	- Rust or other debris from exhaust flow - Insulation materials - Gas Flow distribution screen damage	- Clean catalyst sections - Determine root cause of pluggage and correct - Repair gas flow distribution screen	1021807

Table 4-5 (continued)
SCR Troubleshooting and Inspection

Component	Observation	Potential Cause	Potential Repair or Prevention	Potential EPRI Product ID Reference
	Catalyst sections eroded or damaged	- Debris in exhaust gas - Physical damage	Install blanks or plugs in damaged sections until replacement can be made.	1021807
	Catalyst poisoned	Take sample for analysis	Sample per performance monitoring and OEM recommendations	1021807
	Ammonia injection grid nozzles worn or plugged	- Normal wear - Ammonium sulfate build-up - Improper mixing of injected ammonia	- Replace worn nozzles - Clean nozzles - Evaluate ammonia mixing skid equipment and operating procedures	1021807
	Ammonia injection grid nozzles misaligned	- Normal wear - Vibration	Realign nozzles as needed	1021807

4.7 Safety Valves

HRSGs will have multiple safety valves located on the various systems. A complete listing of the safety valves on each HRSG needs to be developed and maintained with a plan for inspection and rebuilt made for each safety valve. For most power plants, safety valves are disassembled, inspected, and rebuilt by a certified vendor on a 3 to 5 year basis to meet insurance or permitting requirements.

Each of the steam drums typically has a safety valve located on each end to meet permitting requirements for over pressurization. The steam lines to and from the HRSG will also typically have safety valves to protect the lines from over pressurization during normal and emergency operating situations.

Safety valves are routinely visually checked during operator rounds for signs of leakage and mechanical integrity. Typical failure mechanisms for safety valves are due to corrosion from atmospheric exposure, mechanical damage due to vibration or installation errors, or leakage due to excessive operations. Repairs or replacement of safety valves should be made as soon as the valve can be made available. Some sites may have spare safety valves for some applications. For many smaller safety valves it is likely to be cost effective to just replace them every 3 to 5 years. In service setting, testing, and resealing safety valves on steam lines and drums after rebuilds should be done by a certified vendor.

Typical safety valves include:

- Deaerator safety valve(s)
- Ammonia system including:
 - Storage tanks
 - Vaporizer vessels
 - Service lines
 - Unloading stations
- Duct burner system fuel supply piping.
- Nitrogen layup piping supply piping.

4.8 Attenuators

There are several telltale signs of attenuator problems or impending problems. Some can be identified by studying data from the owner's maintenance history data or by close inspection while the unit is online; others require internal inspection with the HRSG is out of service. The following are some aspects of the attenuator installation that should be checked while the boiler is operating.

- Steam temperature immediately downstream of the attenuator should be at least 15 deg F higher than the saturation temperature at all times (50 deg F is generally recommended), especially in plants with F-class turbines operating at loads less than 120 MW.

- Steam temperature drop across the attemperator when spray is not required should be zero.
- Control valve behavior as the valve shuts off when spray is no longer needed should approach shutoff decisively, and should not cycle or hunt its way down to a zero-flow condition.
- The attemperator supplier typically specifies a straight run of pipe upstream of the attemperator equivalent to two to eight pipe diameters; 12-20 diameters downstream. Figure 6-3 illustrates an attemperator installation with an insufficient run of straight pipe upstream of the spray nozzle.
- The location of thermocouple downstream of the attemperator should be far enough downstream (at least 25 ft) to ensure all water evaporates before reaching the instrument.
- Verify that the steam pipe slopes downward immediately after the attemperator and that it has a drip leg equipped with a level switch or steam trap to prevent the buildup of water leakage or condensate. Be sure that the blowdown mechanism is working properly.
- Monitor the control valve to ensure valve position has not changed significantly for a given operating condition. If the nozzle assembly were to fail completely, the flow coefficient (Cv) would be much higher than it would be if the spray nozzles were present. Thus the control valve would operate at a much lower percent-open condition than it would normally.

For additional guidance see EPRI product 1026632 - *Generation Maintenance Application Center: Combined Cycle Combustion Turbine Attemperator Maintenance Guide*

4.9 Inspection Tools Lists

Planned internal inspections of a HRSG should be performed by of qualified, experienced inspectors who are familiar with potential problem areas to inspect. It is good to have a team group approach to perform the inspections with each team assigned a specific area or item to inspect within their expertise. Potential examples may be one team inspecting the tube bundles and other items using scaffolding or sky climber; one team inspecting the stack, casing, structural support steel, and drain piping systems; and one team inspecting the drums, headers, attemperators, and valves.

Table 4-6 gives some of the basic tools and equipment needed to perform a typical HRSG during an outage.

Table 4-6
HRSG Inspection Tool List

HRSG Inspection Basic Tool List	
•	Portable Spot Lights or Flashlights with extra batteries. Bright beam preferred.
•	Metal or Paint Markers for identifying repair locations
•	Digital Camera to document findings
•	Chipping Hammer for cleaning scale and slag from tubes and headers
•	Wire Brush, Chipping Hammer, or Portable Grinder for cleaning scale and slag from tubes and headers
•	Scaffolding or Sky Climber to access tube bundles, burner and ammonia nozzles, and catalyst areas
•	Personal Protective Equipment
•	Mirrors for inspecting backside of tubes or tight areas such as inside headers
•	Magnets for removing metallic slag from drains and other small openings
•	Portable ultrasonic thickness meter for tube, casing, or structural member wall measurements
•	Dye Penetrate for checking welds and cracks in tubes and headers.
•	Portable Air Jacks for spreading tube bundles for further inspection. Safety blocks will be required before personnel enter any spread tube bundles.
•	Paint Thickness Gauges for measuring tube coating thicknesses
•	Tube OD Gauges to check for swelled tubes
•	Backpack or Tool Pouch for carrying above miscellaneous tools



Section 5: Condition-Based Maintenance Considerations

Condition-based maintenance is based on performing preventive maintenance activities on actual equipment condition rather than on fixed intervals. Condition-based maintenance may be called predictive maintenance at some locations.

There are many OEM's of HRSGs involving multiple and different design features. HRSGs are designed for each specific application and expected operating specifications. Typically a HRSG will be designed for a given number of cycles over a lifetime of 20 to 30 years. Every HRSG is therefore different and subject to its own set of unique maintenance opportunities. Units settle over time, are fabricated differently, have different OEM design features, have different water chemistry techniques, have operated in a variety of modes and conditions, operate in different environmental locations, and have been repaired or been modified from original design due to many reasons. All this leads to challenges when inspecting and performing predictive maintenance on a HRSG.

Condition-based maintenance activities for a HRSG include performance monitoring, operator rounds, and non-destructive evaluation (NDE) techniques performed on various HRSG systems. These activities help plan inspection, troubleshooting, and maintenance activities during outages for suspected problems areas to inspect or repair and help minimize outage durations.

NDE techniques to be used for inspections during a specific HRSG outage will depend on many factors including:

- Operating modes of the HRSG
- Known or suspected problems
- OEM recommendations
- Insurance or permitting requirements
- Outage schedule and other work being performed
- Budgetary considerations
- Accessibility of components

5.1 Performance Monitoring

Monitoring of operational and performance data gathered during operations from installed instrumentation is one of the first steps of predicting the condition of HRSG systems and components. Comparison of actual gathered data values to the OEM expected values or to historical benchmarked values is one of the first steps to take. Historical benchmarked values are based on actual data gathered during prior testing on a specific HRSG unit and are known to be desired values for the operation mode. Any significant differences should raise a concern and be investigated. The actual data values should be from the various modes of operation the HRSG typically experiences. For example, gathered data should be analyzed for start-ups, steady state operation, shutdowns, and in some cases when the unit is "bottled up" or maintained for daily cycling operations.



Key O&M Cost Point

Performance Monitoring is one of the first steps to take for determining HRSG conditions for reliable and overall efficient operations.

Some typical key items to monitor include:

- Instrumentation Consistency
- Stack Temperature
- Water and Steam Temperatures and Pressures
- Desuperheater Water Flow
- HRSG Efficiency

5.1.1 Instrumentation Consistency

It is important to have consistency between multiple transmitters, thermocouples, gages, level indicators, and other instrumentation. Differences in readings should be investigated and resolved as soon as found.

There should also be consistency between electrical and mechanical instrumentation on HRSGs, especially concerning the steam drums. Electronic and electrical instrumentation should match actual mechanical drum water level indicators and the actual water levels found during internal drum inspections. Operating at high drum water levels can lead to water carryover and cause thermal stresses on headers and tubes.

5.1.2 Monitor Stack Temperature

Monitoring the temperature of the exhaust gas temperature of the HRSG can help identify potential problems within the HRSG. High exit gas temperatures are typically an indication of inefficient operation. Inefficient operation is a sign that heat transfer is not occurring within the HRSG as expected. Some things to look for may include gas side tube fouling, insulation breakdown and fouling, or gas bypassing tube bundles. Low exit gas temperatures can cause corrosion in the back of the economizer and stack if below the acid dew point of the exhaust gas.

5.1.3 Monitor Water and Steam Chemistry, Temperatures and Pressures

Comparison of inlet and exit water and steam conditions in the LP, IP, and HP sections of the HRSG can help identify potential problems. Inlet and exit water and steam conditions at each section of the HRSG should be at OEM expected or to historical benchmarked values. Differences should be investigated. Inlet temperatures significantly less than expected can cause thermal shocks in the header or tube sections during operation. Lower exit temperatures may be a sign of gas side tube fouling, exhaust gas bypassing, or internal tube fouling or venting problems. Higher exit temperatures may be a sign of trapped air or improper venting within tubes or header.

5.1.4 Monitor Desuperheater Water Flows

A leaking or improperly controlled desuperheater can cause extensive damage to a HRSG, particularly a cycling unit. Any build up of excess water in headers or tubes causes concern for potential water hammer or thermal shock potential. Actual desuperheater water flows should be per the OEM expected values for the current operating mode and should be fairly steady during normal operations. Frequent and rapid movement of the desuperheater valve controls during steady state operations signify a problem that needs to be investigated and corrected as soon as possible.

5.1.5 Monitor HRSG Efficiency

An overall thermodynamic analysis of the HRSG with comparison to the OEM expected values will help identify areas of the HRSG that are not performing as expected. There are multiple vendors with performance monitoring software packages that can assist the site with modeling and evaluations. Monitoring the overall ratio of the heat input to the steam energy output shows the overall efficiency of the entire HRSG. This can be further broken down to monitoring the steam outputs of each section (HP/IP/LP) as compared to the OEM expectations or historical benchmarked values. Sections not performing as expected can be identified for problem investigations and inspections during the next outage.

5.2 Operator Rounds

Operator rounds are the systematic monitoring and inspection of equipment by personnel during system walk-downs of assigned areas while on shift. During these walk-downs one or more fundamental actions should occur depending on the operating parameter being monitored. These actions include:

- Check (examine, compare, or measure to verify the condition or validity),
- Inspect (examine to detect flaws or errors),
- Measure (judge, appraise or compare to a standard),

- Record (put in writing for future use as evidence of events) and
- Read (to interpret and understand the meaning).
- Communicate (inform others of equipment condition and change process as appropriate).

The plant operations group at each plant should have specific policies and procedures governing the conduct of equipment operator walk-downs that define how the rounds are developed and what actions should occur with their frequency. However, normal and recommended frequency is once per shift.

A reference for developing operator rounds is EPRI Product ID 1015834 *Operator Rounds Guideline*, March 2009.

Operator rounds for an HRSG and its auxiliary equipment should be specific for each individual unit and focus on identifying immediate maintenance needs and identify items or that may need further inspection during unit outages.

Table5-1 shows an example of an operator rounds checklist for a HRSG.

Table 5-1
Operator Rounds Checklist Example

HRSG Component	Task	Normal Range	Comments
Structure	Visually inspect casing exterior for steam, water, or exhaust gas leakage		
Inlet Expansion Joint	Visually inspect inlet expansion joint from gas turbine for leakage		
Structure	Inspect roof for debris and standing water		
Casing	Listen for any abnormal noises or vibrations		
Foundation	Visually inspect foundation for cracks or spalding		
Outlet Expansion Joint	Visually inspect outlet expansion joint to stack for leakage		
Stack	Verify damper is in correct position		
Stack Damper	Visually inspect damper drive mechanism		
Steam Drums	Visually inspect manway door, instrumentation, valves, safety valves, etc. for steam or water leaks		
Steam and Water Piping	Visually inspect for leaks and condition of pipe hangers and supports		

Table 5-1 (continued)
Operator Rounds Checklist Example

HRSO Component	Task	Normal Range	Comments
LP Recirculation Pump Assembly	Visually inspect pump, valves, and instrumentation for leaks		
LP Recirculation Pump Assembly	Inspect pump and motor bearing oil levels and temperatures		
LP Recirculation Pump Assembly	Check for unusual noises or vibrations		
Deaerator	Visually inspect tank, valves, and piping for steam or water leaks		
Deaerator	Listen for any unusual noises, water hammer, or vibrations		
Deaerator	Check for leaks		
Duct Burner Assembly	Visually inspect for proper alignment and any fuel or air leaks		
Duct Burner Assembly	Visually inspect fuel and air supply skid for leaks		
Ammonia System Skid	Inspect ammonia mixing skid for proper alignment and leaks		
Ammonia System Skid	Inspect mixing fan and motor bearing oil levels and temperatures		
Ammonia System Skid	Listen for any unusual noises or vibrations		
Drain System	Visually inspect for any steam or water leaks		
Drain System	Inspect pipe hangers and supports for damage		
Attemperators	Visually inspect for any steam or water leaks.		
Attemperators	Rotate and clean water supply strainers as needed		
Instrumentation	Leaks, failures, loose connections		

5.3 Non Destructive Evaluation Techniques

Some NDE techniques can be used with the HRSG in service while others are used during outages.

5.3.1 On-Line Condition-Based Maintenance Techniques

Condition-based maintenance techniques primarily used on HRSG equipment and systems when the unit is in operation are thermography infrared inspections and vibration testing/analysis.

5.3.1.1 Thermography

Thermography infrared inspections are used to show thermal differences on a component that may identify an electrical or mechanical problem. It is important to know what you are looking at and how to evaluate the differences when using this technique so it should be performed by trained site technicians or vendors.

Some of the items thermography techniques can be used on HRSGs to help identify problems include:

- Casing “hot spots” for insulation/refractory breakdowns
- Casing “cold spots” that may indicate a water leak.
- Duct cracks and access door seal leaks
- Expansion joint leaks
- Roof and floor piping penetrations seal conditions
- Leaking shutoff, drain, and safety valves
- Recirculation pump and motor bearing issues
- Ammonia mixing fan and motor bearing issues
- Electrical and switchgear issues

5.3.1.2 Vibration Techniques

Vibration testing and analysis techniques are used on HRSG systems typically associated with rotating equipment such as a pump, motor, fan, or blower. Vibration testing and analysis on recirculation pumps and motors and ammonia mixing fans should be done on a routine basis for most sites.

During operation there are often noises coming from the HRSG due to movement of various components typically caused by exhaust gas flows. This movement between components typically shows up as noise or vibration and usually will cause a failure over time in one or more of the components. Vibration analysis can sometimes be used to help identify the moving components based upon the noise and pulsations. Identifying the source of exhaust gas flow induced noises and pulsations within an HRSG can be a challenge and will vary based on each HRSG’s unique design and configuration. Several OEM’s have been

working on using vibration analysis techniques for their HRSGs to help analyze noise and pulsations for their specific units. It is important to know what vibration readings may mean for your specific design of HRSG and how to evaluate them. Using this technique for noises and pulsations should be performed by trained site technicians, the OEM, or vendors.

5.3.2 Off-Line Condition-Based Maintenance Techniques

Condition-based maintenance techniques primarily used on HRSG equipment and systems when the unit is in an outage are ultrasonic/ultrasound testing, dye penetrate testing, magnetic particle testing, radiography, replication testing, visual borescope inspections and tube sampling.

5.3.2.1 Ultrasonic/Ultrasound Testing

In HRSG's Ultrasonic/Ultrasound (UT) is used to measure the metal wall thickness of headers, riser piping, and steam drum internal components. UT is a good tool for locating and measuring flow-accelerated corrosion (FAC) effects. Areas frequently inspected using UT techniques are tube bends near the economizer upper and lower headers. UT is also used for inspecting drum internal components, metal thickness on steam separators, belly pans, baffles, piping, cyclones, attemperators, etc. This technique can also be used on tubes if they are not finned. A portable UT testing meter is a good tool for the HRSG inspector to have during his inspection. In some cases, if a problem is found using a portable simple UT meter, a more sophisticated UT testing technique and equipment may need to be performed by qualified technicians or vendors to further analyze the problem.

Some examples of ultrasonic technologies that are currently used within the industry for inspection of specific areas of the HRSG include:

- Linear Phased Array for tube and header welds
- Time-of Flight Diffraction for locating cracks in headers and pipes
- Focused Annular Array Imaging for finding creep damage in welds
- Long-Range Guided Wave for finned tube inspections

Use of a specific ultrasonic inspection technique for inspecting a HRSG component is typically based on OEM recommendations and/or physical accessibility of the component.

5.3.2.2 Dye Penetrate Testing

Dye penetrate testing (PT) is typically used to look for cracks on machined, ground, welded or cast components such as tubes and headers. Also sometimes called liquid penetrate testing, dye penetrate can locate small microscopic cracks and flaws not visual by the naked eye. The surfaces to be inspected by PT methods should be cleaned of scale and corrosion prior to applying dye penetrant and developer liquids. PT testing is typically looking for damage from thermal/mechanical stress or from a manufacturing defect. Some simple PT

techniques can be used by a HRSG inspector during outage inspections. HRSG areas frequently inspected using PT techniques include tubes at field or factory welds, header joints, tube attachments, and vent or drain piping.

5.3.2.3 Magnetic Particle Testing

Similar to dye penetrate testing, magnetic particle testing (MT) is typically used to look for cracks on machined or welded components such as headers or tubes. However, MT techniques have the ability to detect cracks that are located just below the surface of a ferrous component. MT uses a magnetic field or dc current applied to the component with fine iron or magnetic iron oxide particles suspended in liquid, often kerosene, sprayed over the component. The iron or magnetic iron oxide particles are often colored with fluorescent dyes. A crack or flaw below the surface with the magnetic field applied will cause the fine particles to buildup on the surface above the flaw. The particles can then be detected using an ultraviolet light. MT testing is typically looking for manufacturing defects. HRSG headers are frequent components inspected using MT techniques. This technique is performed by qualified technicians or vendors.

5.3.2.4 Radiography

Radiography techniques are used to locate cracks or flaws located deeper within a cast, forged, or welded component. HRSG headers, forged fittings, valves, or piping welds are frequent components inspected using radiography techniques. Small flaws can often be detected using radiography. Some detected flaws may be monitored over time to determine growth rate, severity, and risk of continued operation before repair. Highly specialized, radiography is performed by qualified technicians or vendors.

5.3.2.5 Replication Testing

Replication is a highly specialized technique used to detect early signs of creep or cracking in of HRSG tubes, headers, and piping components. Typically replication is used to verify suspected damaged located using other NDE techniques. The higher temperature sections of the HRSG consisting of special alloys such as P91/T91 materials are the likely components to have replication techniques performed. Replication inspects the microstructure of the component's surface for its metallurgical properties. The surface of the component to be tested will require polishing using fine grinding disks, etching the surface with an acid, and then preserving the components topography surface on a plastic film as a negative relief. The state of the base material on the film can be examined by a metallurgist to determine whether it has been damaged by improper heat treatment, exposure to fire or operation at excessive temperatures. Highly specialized, replication is only performed by qualified technicians or vendors.

5.3.2.6 Borescope Inspections

Borescope instrumentations are used for inspection work where the area to be inspected is inaccessible by other NDE testing techniques. A borescope is an optical device consisting of a rigid or flexible tube with an eyepiece on one end and an objective lens on the other end linked together by a relay optical system. When inserted into a remote area, the borescope illuminates the surface of the remote area to show the image from the objective lens to the viewer through the eyepiece or to be documented with a camera/video device. Borescope inspections typically are performed on HRSG waterside areas suspected for risk of internal tube cracking or pitting due to water chemistry issues, deposit formations due to water chemistry issues, or flow accelerated corrosion (FAC) damages.

Some areas may have removal handholds or inspection plugs for borescope inspections while other areas may require cutting a tube or pipe for access. HRSG areas most likely to be borescope inspected include:

- Economizer section inlets
- Economizer section outlets
- HP evaporator section outlets
- LP evaporator tubes
- Superheater section inlets
- Attemperators

EPRI Product 1008092 *Examination of Heat Recovery Steam Generator (HRSG) Plants - Assessment of Fiber-Optic Techniques*, November 2005 is a good reference for this type of inspection.

EPRI Product ID 1017635 *Study for Snake Robot Technology for Inspection of Headers and Tubes in Heat Recovery Steam Generators*, November 2009 is another good reference.



Section 6: Preventive Maintenance Considerations

Preventive maintenance activities are performed to prevent unsatisfactory equipment conditions or performance from occurring.

There are many OEM's of HRSGs involving multiple and different design features. Every HRSG may have different equipment specified by the OEM and is therefore subject to its own set of unique preventive maintenance opportunities. When in operation the primary equipment items that can have preventive maintenance performed are located on the outside of the HRSG.

Many preventive maintenance tasks should be performed during the gas turbine hot gas path or major inspection outages.

Preventive maintenance activities for a HRSG typically include:

- Servicing the LP economizer recirculation pump and motor
- Servicing the duct burners
- Servicing the ammonia dilution pumps
- Calibration of instrumentation
- Servicing of motor or pneumatic operated valves
- Inspection of external piping and pipe supports
- Servicing of soot blowers, if present
- Servicing of the stack damper drive mechanism
- Inspection and serving of the trace heating system
- Tube sampling

Table 6-1 contains a summary of typically preventive maintenance recommendations for these components.

6.1 LP Economizer Pump and Motor Service

The economizer pump and motor will vary based on the HRSG design and supplier. The units should be serviced per the OEM recommendations. Typically these pumps and motors will be internally inspected and rebuilt as required. The coupling alignment between the pump and motor should be checked annually due to vibration and frequent movement of the piping to the assemblies.

6.2 Duct Burner Service

Duct burner assemblies should be inspected and serviced based on the amount of their operation but at least inspected during a hot gas path or major inspection basis. Safety features such as the flame scanners and instrumentation should be inspect and calibrated on an annual basis.

6.3 HRSG Instrumentation Inspection

Instrumentation used on the HRSG typically consists of pressure, flow, level, and temperature measuring devices. The devices may be transmitters, sensors, thermocouples, RTD's, or indicators depending on the application and used for information or control of the unit.

The most critical instrumentation used for safety and control of an HRSG system typically will be in a redundant situation and should be evaluated using the site's performance monitoring system. Inspections and calibrations should occur when values differ for redundant instruments measuring the same conditions per the site procedures. Safety instrumentation, such as drum level or trip devices, should typically be inspected and calibrated on an annual basis.

6.4 Motor or Pneumatic Operated Valves

An HRSG will have multiple valves for isolation, bypass, block, drain, and other applications. Many of these valves will be capable for remote operation via an electric motor or pneumatic actuator drive to meet the operational requirements of the unit. Operation of these valves will vary as the unit is started or cycled. Typically these valves will be checked for leakage during operation with repairs made when found. Servicing of the electric motor or pneumatic actuators should be per the OEM recommendations. Typically these valves will be serviced during a gas turbine hot gas path or major inspection outage.

6.5 Piping and Supports

The HRSG piping and hangers should be inspected per the site's procedures. Typically the piping support hangers and attachment hardware will be inspected on an annual basis. The hanger will be inspected annually with the HRSG both in and out of operation for proper mechanical integrity and loading with adjustments or repairs made as problems are found.

6.6 Soot Blower Service

Soot blowers may be installed within the tube assemblies for some HRSG applications. Typically soot blowers and supply valves will be checked for leakage during operation with repairs made when found. Servicing of the electric motor or pneumatic drive assemblies should be per the OEM recommendations. Typically soot blowers will be serviced during a gas turbine hot gas path or major inspection outage.

6.7 Stack Damper Drive Assembly

Operation of stack isolation dampers will vary as the unit is started or cycled. Typically the drive, chains, linkages, etc. will be checked for proper position and operation during operation with repairs made when found. Servicing of the drive assemblies should be per the OEM recommendations. Typically stack damper drive assemblies will be serviced during a gas turbine hot gas path or major inspection outage.

6.8 Trace Heating System

Piping and instrumentation trace heating system criticality will vary by the site's location. Combined cycle units located in colder climate environments may need the trace heating system functional at all times to keep piping and instrumentation lines from freezing. At a minimum the trace heating system for critical and safety devices should be inspected on a quarterly basis for proper operation, especially for colder climate applications.

6.9 HRSG Tube Sampling

Some tube assemblies of the HRSG will be suspect for potential wear or chemical problems and these areas should be monitored on a routine basis. Some OEM's will recommend taking a tube sample section of the higher problem suspected areas on a routine basis to help determine the condition of the tubes and if water chemistry or operating procedures may need to be adjusted. Periodic sampling and analysis of HRSG tube sections should be performed per the OEM recommendations, results of water chemistry inspections, or based on predictive maintenance testing results. Analysis results can help the site or OEM to evaluate the condition of the tube assemblies and estimate future operating life of the tubes or need for internal chemical cleaning of the tubes.

Typically tube samples will be taken during gas turbine hot gas path or major inspection outages.

Table 6-1
HRSG Component Preventive Maintenance Task List

HRSG Major Component	Task	Frequency	Comments
LP Economizer Recirculation Pumps and Motors	Lubricate or change oil	Quarterly	Perform per OEM specifications
	Rebuild pump	As required.	Perform per OEM specifications. Typically during a hot gas path or major inspection.
	Check coupling alignment to motor	Annually	Re-torque mounting bolts as required
	Disassemble, clean, and internally inspect motor	5-8 years	Perform per OEM recommendations. Typically performed during a gas turbine major inspection.
	Rebuilt/replace relief valves	2-3 years	Perform per site procedures
Duct Burners	Clean and inspect burner assemblies	Annually	Perform per OEM specifications
	Inspect and calibrate flame scanner assemblies	Annually	Perform per OEM specifications
	Inspect igniter assemblies	Annually	
	Inspect fuel and air piping and controls	3-5 years	Typically performed during a hot gas path or major inspection.
Ammonia Dilution Pumps/Fans/Motors	Clean and internally inspect pumps/fans. Service bearings and replace seals/gaskets	Annually	
	Rebuild pump/fans rotors. Balance rotor assembly.	3-5 years	Typically performed during hot gas path or major inspections
	Calibrate instrumentation	Annually	
HRSG Instrumentation	Safety or critical devices	Annually	
	Non critical devices	3-5 years	Typically performed during hot gas path or major inspections

Table 6-1 (continued)
HRSG Component Preventive Maintenance Task List

HRSG Major Component	Task	Frequency	Comments
Electric Motor Valve Actuator	Lubricate bearings. Visually inspect internal areas for signs of wear. Calibrate strokes	3-5 years	Typically performed during hot gas path or major inspections
Pneumatic Valve Actuator	Lubricate bearings. Replace diaphragms and seals. Inspection positioner and solenoid valves. Calibrate strokes.	3-5 years	Typically performed during hot gas path or major inspections
Pipe Hangers	Mechanically inspect for integrity and proper loading.	2-5 years	Perform per site procedures
Soot Blowers	Service drive assembly. Lubricate bearings. Repack steam supply valves.	3-5 years	Typically performed during hot gas path or major inspections
Stack Damper Drive Assembly	Lubricate drive chain, linkage bearings and pivots.	Annually	Perform per OEM recommendations.
	Service drive assembly. Inspection chains, sprockets, bearings and pivots. Calibrate operating stroke.	5-8 years	Typically performed during hot gas path or major inspections
Trace Heating System	Critical and safety devices or colder climates	Quarterly	Perform inspections per site procedures.
	Devices located in warmer climates	Annually	Perform inspections per site procedures.
	Inspect and repair/re-insulate piping and instrument lines	Annually	Perform inspections per site procedures.
Tube Assemblies	Take tube sample section	5-8 years	Typically performed during hot gas path or major inspections



Section 7: Work Safety

The purpose of this section is to provide safety guidance for operations and maintenance personnel working on or around the fuel gas system installed at a gas turbine combined cycle facility. Guidance is also provided for CTCC owners that may be beneficial for enhancing their existing site-wide worker safety program.

7.1 General

Safety is a basic factor that must be considered at all times during the installation, operation, and maintenance of mechanical or electrical equipment. Through the use of proper tools, clothing and procedures, serious injury and property damage can be prevented. No amount of training or instruction can replace common sense, sound judgment, and acceptable work practices.

7.2 Safety Guidance for Maintenance Personnel [9]

The following section describes safety guidelines for maintenance personnel working on or around the combustion turbine, performing either preventive or corrective maintenance activities described in this report.

7.2.1 Personal Protective Equipment (PPE)

7.2.1.1 General

PPE includes clothing and other accessories designed to create a barrier between the user and workplace hazards. It should be used in conjunction with engineering work practices and/or administrative controls to provide maximum employee safety and health in the workplace. All contractors are responsible for providing training and insuring the proper use of required personal protective equipment.

7.2.1.2 Hard Hats

All employees, contract employees, subcontractors, visitors, and delivery personnel should be required to wear OSHA approved hard hats while at the CTCC facility except in designated areas.

7.2.1.3 Hearing Protection

All employees, contract employees, subcontractors, visitors, and delivery personnel should be required to wear appropriate hearing protection to reduce time weighted average exposure levels on noise to within OSHA permissible exposure limits.

7.2.1.4 Eye and Face Protection

All employees, contract employees, subcontractors, visitors, and delivery personnel should wear as a minimum; safety eyeglasses with side shields. More specialized eye protection should be required as work being performed demands. All eye wear should meet ANSI Z86.1-1968 standards.

7.2.1.5 Respiratory Protection

Respiratory protection that conforms to OSHA regulations should be used when engineering controls are not adequate to protect personnel from exposure to air contaminants. No technician may be assigned to wear a negative pressure respirator unless they have first been evaluated by a physician to determine their physical ability to wear the respirator and fit tested

7.2.1.6 Foot Protection

Steel toe safety shoes are recommended for all workers. Sneakers, sandals or canvas shoes are not adequate foot protection.

7.2.2 Safety Harnesses and Safety Nets

Safety harnesses, lifeline, and lanyards should be used only for employee safe guarding. Lifelines should be secured above the point of operation to an anchorage or structural member capable of supporting a minimum dead weight of 5,400 pounds. A lanyard should be a minimum of ½ inch nylon rope or equivalent with a maximum length to provide for a fall of less than 4 feet, or to keep the employee from contacting the next lower level.

Safety Harnesses should be worn when working on any structure, member, or device that is of a height of 4 feet or more above the next lower level, except when working on an approved scaffold.

Safety Nets should be provided when work places are more than 25 feet above the ground, water surface, or other surfaces where the use of ladders, scaffolds, catch platforms, temporary floors, safety lines or safety harnesses is impractical.

7.2.3 Fire Protection and Prevention

Maintenance personnel in the permanent plant facility should be responsible for the following:

- Reporting all fires in accordance with site-specific procedures, no matter how small
- Providing the appropriate manager(s) with locations and type of all combustible or flammable materials brought on to the CTCC facility
- Regarding fire prevention, personnel working on or around the combustion turbine should consider the following safety guidelines:
- Practice good housekeeping and not let combustible scrap or refuse accumulate.
- Smoke only in designated areas and do not smoke in areas where combustible or flammable material is in use.
- Store oily, paint soaked, or solvent soaked rags in covered metal containers.
- Cut or weld only when permitted to do so. Welding or cutting should not take place near locations where flammables are present. An approved fire extinguisher should be located at each welding or cutting area. Refer to the Welding and Cutting section for more details.
- Store combustible or flammable liquids in proper labeled containers, and use proper bonding and or grounding when transferring fuels.
- Report all fire hazards to the appropriate site management personnel.
- Open fires of any kind are not permitted.
- Ensure gas cylinders are transported and stored in a secured upright position. When stored, keep them at least 25 feet from oxygen cylinders.
- Ensure no material is stored within 3 feet of an electrical panel, outlet or fire suppression system and clear path is maintained.
- Prohibit smoking within 100 feet of any plant enclosure or gas piping and in the Maintenance Building and Substation Control Building.

7.2.4 Housekeeping and Foreign Material Exclusion

Maintenance personnel should adhere to the following guidance when working at combustion turbine facility:

- Keep aisles clear for safe passage of people and material.
- Clean up slippery substances, such as grease or oil spilled on floors or other work surfaces. Cover with sand or other non-slip material.
- Keep tools in boxes, racks, or trays when not in use.
- Do not leave nails, pieces of wood with protruding nails, and other sharp objects on floors and walkways. Store them where they cannot be stepped on.

- Keep exits clear. Keep fire extinguishers readily accessible and free of obstruction.
- Do not let materials such as scrap lumber, metal, and debris accumulate which might cause a tripping hazard.
- Dispose of empty bottles, cans, paper, and other containers by depositing them into the receptacles provided.
- Clean the job site at least daily and ensure debris is disposed of onsite, or offsite, in accordance with all EPA regulations.

7.2.5 Material Handling

The following safety guidance regarding material handling should be considered by maintenance personnel working at combined cycle combustion turbine facility.

- Use proper lifting techniques when handling materials. Lift heavy objects as instructed, with leg muscles and not with the back.
- Stored materials must not block exits, aisles, fire protection equipment, breakers, or passageways.
- Liquid containers shall be labeled.
- Pipe, conduit, and bar stock should be stored on racks or stacked and blocked to prevent movement.
- The quantity of materials stored on scaffolds, platforms, or walkways must not exceed what's required for 1 day's operation.
- Materials must never be thrown or dropped from a distance of more than 20 ft. The drop area must be barricaded to protect personnel from being struck by falling materials. Trash chutes are required for dropping materials from heights above 20 ft.
- Protruding nails must be bent or pulled when stripping forms or uncrating material.
- All ropes, chains, cables, slings, etc., and other hoist equipment must be inspected each time before use.
- A load should never be lifted and left unattended.
- Wear safety gloves when handling materials.
- Properly stack and secure all materials prior to lifting or moving to prevent sliding, falling, or collapse.

7.2.6 Rigging

In addition to the guidance noted below, maintenance personnel should consider the guidance provided in EPRI 1007914, “Lifting, Rigging, and Small Hoist Usage Program Guide”, and EPRI 1009706, “Rigger’s Handbook”.

- Rigging equipment should be inspected prior to use on each shift. Defective rigging should be removed from service.
- Before executing a lift, always be certain of the amount of the load which may be more than the weight of the item. Crane scales should be used to be certain of the loads that could exist due to binding, corrosion, hidden bolts, fluids, etc.,
- Rigging equipment should not be loaded in excess of recommended working load limits.
- Wire rope should be removed from service if there is a marked reduction in rope diameter, excessive broken wires, kink damage, or other mechanical damage.
- Never strain wire rope over sharp corners. Use softeners as required.
- Remember that increasing the angle between the legs of a sling, increases the load on each leg.
- Do not paint hooks.
- Only qualified personnel may be assigned to rigging operations.
- Rigging equipment is not permitted to work closer than 10 feet to any power line.
- All rigging devices should have permanently affixed identification stating size, grade, rated capacity, and manufacturer.
- “Shop- made” grabs, hooks, clamps or other lifting devices are prohibited.

7.2.7 Hand Tools and Power Tools

Maintenance personnel should adhere to the following guidance regarding the safe use of hand and power tools when working at combined cycle combustion turbine facility:

- All hand and power tools and similar equipment, whether issued by the employer or furnished by the employee, should be maintained in safe condition and properly stored.
- Wrenches should not be used when jaws are sprung to the point that slippage occurs.
- Impact tools, such as drift pins, wedges, chisels, etc. should be kept free of mushroomed heads.
- Wooden handles should be free of splinters, cracks, and be tight in the tool.

- Electric power operated tools should either be of the approved double insulated type or grounded in accordance with OSHA requirements.
- Any power-operated tools designed with guards should have the guard in place when in use.
- The use of electric cords for hoisting or lowering tools is not permitted.
- Only trained employees are allowed to operate power actuated tools.
- All power-actuated tools should be tested daily, and all defects are corrected before use.
- All power-actuated tools should be of the low velocity, cushioned pistol grip, and piston type design.
- Power-actuated tools should not be used in areas where hazardous, ignitable dust, gases, or liquids are present.
- All maintenance work on power-actuated tools must be performed according to manufacturer specifications and must be done by qualified persons only.
- All defective tools and equipment must be reported immediately in accordance with site procedures, and tagged “out of service”. Temporary and makeshift repairs are prohibited.
- Floor stand and bench mounted grinders should be provided with properly adjusted work rests and grinding wheel guards.
- Abrasive wheels and tools should comply with ANSI B7.1-1970, safety code for use, care, and protection of abrasive wheels.
- All employees using abrasive wheels should be protected by eye protection equipment appropriate to the equipment and task being performed.
- Gas powered tools should not be used in unventilated areas and gas should be dispensed from UL approved cans only. All gas-powered tools must be turned off before being refueled.

7.2.8 Welding and Cutting and other “Hot” Work

No “Hot” work should be permitted at the CTCC in the presence of flammable or combustible materials. Many facility owners use the Factory Mutual “Hot Work” permitting system for all heat or spark producing operations except in those areas designate by the owner as safe areas. Hot Work permits are issued by the CTCC site manager, and in accordance with site procedures.

7.2.9 Gas Welding and Cutting Safety

Maintenance personnel performing gas welding and cutting should adhere to the following guidance when working at combined cycle combustion turbine facility:

- Valve protection caps should be in place when moving, transporting, and storing compressed gas cylinders.
- Cylinders should be secured in an upright position on a cylinder truck by chain or other steadying device while in use.
- Cylinders containing oxygen, acetylene, or other fuel gas should not be taken into confined spaces.
- No defective or damaged cylinders should be used.
- Fuel gas hose and oxygen hose should be easily distinguishable from each other, without defects, and fitted with rotary motion disconnect fittings.
- Torches should be inspected at the beginning of each work shift. Defective torches should not be used.
- All torches should be fitted with approved flashback control devices.
- Torches should only be lighted by friction lighters or other approved devices, and not by matches or from hot work.
- Employees are required to wear the proper personal protective equipment such as coveralls, safety goggles, face shield, welding hood, welding jacket, etc., as demanded by the type of work completed.

7.2.10 Arc Welding and Cutting

Maintenance personnel performing arc welding and cutting should adhere to the following guidance when working at combined cycle combustion turbine facility:

- Any faulty or defective machines, cables, or electrode holders must be removed from service and reported to the supervisor.
- All welding, cutting cables, and connectors should be on a completely insulated and flexible type capable of handling the maximum current requirements of the work in progress.
- Only cable free from repair or splices for a minimum of 10 ft. from the end to which the electrode is connected should be used, except that insulated connectors or splices whose insulating quality is equal to that of the cable are permitted.
- Maintenance personnel are required to wear the proper personal protective equipment such as coveralls, safety goggles, face shield, welding hood, welding jacket, etc., as demanded by the type of work completed.

7.2.11 Electrical Safety

Maintenance personnel should adhere to the following electrical safety guidance when working at combined cycle combustion turbine facility:

- All electrical installations and temporary wiring should be made in accordance with the National Electric Code ANSI/NFPA latest edition and all Federal, State and local codes.
- Temporary lights will be equipped with guards. Broken burned out bulbs should be replaced.
- Temporary electric cords must be covered or elevated. They must be kept clear of walkways where they may be exposed to damage or create tripping hazards.
- Extension cords used with portable electric tools and appliances must be heavy duty (no less than 12 gauge conductors) of the three wire grounding type, and must conform to OSHA standards. No flat electrical cords should be allowed on site.
- Voltages must be clearly labeled on all electrical equipment and circuits. Circuits must also be clearly marked for the areas of service they provide.
- Prior to performing any work, electricians must “lockout and tagout” the equipment or machinery in accordance with sites lockout and tagout procedure.
- All temporary electrical circuits should be periodically inspected and properly maintained.

Note that many CTCC facility owners are subject to the Power Generation and Transmission OSHA standard 29 CFR 1910.269. Contractors working on CTCC premises may also be subject to portions of this regulation.

7.2.12 Lockout and Tagging of Circuits

Maintenance personnel should adhere to the following electrical safety guidance when lockout and tagging of circuits is required prior to working at a combined cycle combustion turbine facility:

- Controls that are to be deactivated during the course of work on equipment or circuits should be tagged/locked in accordance with site-specific tagging procedure.
- Equipment or circuits de-energized should be rendered inoperative and should have tags and/or locks attached at all points where such equipment or circuits can be energized.

7.2.13 Scaffolding

In addition to the guidance noted below, maintenance personnel should consider the guidance provided in EPRI 1007914, “Lifting, Rigging, and Small Hoist Usage Program Guide”, and EPRI 1009706, “Rigger’s Handbook”.

- All scaffolds should be erected in accordance with appropriate OSHA standards for the type and application used.
- The footing or anchorage for scaffolds should be sound, rigid, and capable of carrying the maximum intended load without settling or displacement.
- Guardrails, mid rails, and toe boards must be installed on all open sides of scaffolds 10 feet or more in height. Guardrails must be 2x4 inches or equivalent, supported at intervals of not more than 8 feet. Toe boards should be a minimum of 4 inches in height.
- Where persons are required to work, or pass under, the scaffolds should be provided with a screen between the toe board and rail, extending along the entire opening, consisting of # 18 gauge U.S. standard wire ½ inch mesh or equivalent.
- Overhead protection should be provided if maintenance personnel working on scaffolds are exposed to overhead hazards.
- Scaffold and their components should be capable of supporting without fail at least 4 times the maximum load intended.
- Any scaffolding including all accessories, damaged or weakened from any cause should be immediately repaired or replaced.
- All planking should be scaffold grade as recognized by approved grading rules for the species of wood used, and a full 2x10 thickness.
- An access ladder or equivalent safe access should be provided.
- Scaffold planks should extend at least 6 inches but no more than 12 inches over the end of the support.
- All scaffolds must be two planks wide; no employee may work from a single plank.
- Scaffold planks must be visually inspected before use. Damaged planks must be removed from service.
- Scaffold must be tied to the building or structure at intervals, which do not exceed 30 feet horizontally, and 26 feet vertically.
- Lean to scaffolds and makeshift platforms are prohibited.
- All scaffolds over ten feet high are required to have load footprints and limits that can be obtained from the scaffold manufacturer.

- When erecting and dismantling scaffolds, OSHA's Project Six-Foot Fall Protection Requirements must be followed.
- Ladders must be used to climb scaffolds at all times. Workers should never climb a scaffold's cross bracing. Both hands should be free of tools/materials when ascending or descending a scaffold. Employees should not propel themselves while working on scaffolds.

7.2.14 Floor and Wall Openings

Maintenance personnel should adhere to the following safety guidance regarding floor and wall openings when working on or around the combustion turbines:

- Floor openings should be guarded by a standard rail and toe board or cover. In general the railing should be provided on all exposed sides, except at entrances to stairways.
- Wall openings from which there is a drop of more than 4 feet and the bottom of the opening is less than 3 feet above the working surface will have a standard guardrail.
- Open sided floor or platforms 6 feet or more above the adjacent floors or ground level and runways 4 feet or more above the ground floor level should be provided with standard handrails and toe boards.
- Stairways having four or more risers should be equipped with standard stair railing on both sides.
- Guard rails and/or covers are not to be removed until other means of fall protection are in place. Employees installing or removing guarding or covers should be protected by alternative fall protection.
- Employees are prohibited in any area that could expose them to a fall unless proper fall protection procedures are in place.
- Stairways should be free of hazardous projections, debris, and other loose materials.

7.2.15 Cranes, Hoist, Elevators & Conveyors

In addition to the guidance noted below, maintenance personnel should consider the guidance provided in EPRI 1007914, "Lifting, Rigging, and Small Hoist Usage Program Guide", and EPRI 1009706, "Rigger's Handbook".

Maintenance personnel should adhere to the following safety guidance regarding the operation of cranes when working on or around the combustion turbines:

- All cranes must be operated and maintained in accordance with established standards, specifications, and limitations.
- Only trained, qualified employees are permitted to operate any crane or rigging equipment. Training includes an in-depth review of the operating characteristics and limitations of the equipment.
- A fire extinguisher is to be kept in the crane's cab at all times.

- “Shop-made” grabs, hooks, clamps, or other lifting devices are prohibited.
- A licensed engineer must inspect all lifting beams and spreader bars to make sure that they are the proper size for the capacity.
- Slings should not be shortened by using knots, bolts, or other make shift designs.
- Wire rope slings should be padded to protect against damage from sharp corners.
- Hard hats and proper personal protective equipment should be worn while operating or working close to a crane.
- Rated load capacities and recommended operating speeds, special hazard warnings, or instruments should be conspicuously posted.
- Cranes should be inspected prior to use each shift. Records of inspections should be kept as required by law.
- Hand signals to crane operators should be by ANSI standards for the type of crane in use.
- Accessible areas within the swing radius must be barricaded.
- Do not ride hook or load.
- Working safety latches are required on all crane hooks.
- Do not operate crane or bring its loads within 10 feet of electrical distribution lines.
- The use of a crane to hoist employees on a personnel platform is prohibited, except when the erection, use, and dismantling or conventional means of reaching the work site would be more hazardous or is not possible because of structural design or work site conditions. The following precautions are required when using cranes to hoist personnel:
 - Hoisting of the personnel platform should be performed in a slow, controlled manner with no sudden movements of the crane platform.
 - Load lines should be capable of supporting without failure at least ten times the maximum intended load.
 - A trial lift with the unoccupied personnel platform loaded at least to the anticipated lift weight of personnel and material, should be made from the ground level with full crane operational tests. The trial lift should be repeated prior to hoisting personnel any time the crane is moved and set up in a new location or returned to a previously used location. In every case the trial lift must be conducted at the beginning of every shift.

Employees should keep all body parts inside the platform during raising, lowering, or positioning. Employees being hoisted should remain in continuous sight of and direct communication with the crane operator. Employees occupying the personnel platform should use a body belt/harness system with the lanyard attached to the lower load block, overhaul ball, or structural member within the platform. Finally, hoisting of employees while the crane is traveling is prohibited.

7.2.16 Ladders

Maintenance personnel should adhere to the following safety guidance regarding ladders when working on or around the combustion turbines:

- All ladders should be inspected for defects prior to use. Any defective ladder should be removed from service and reported to your supervisor for repair or replacement.
- Portable ladders should be placed on a substantial base at a 4 to 1 pitch, have clear access at top and bottom, and extend at least 36 inches above the landing and be secured against movement when in use.
- Always face the ladder and use both hands when climbing up or down. If you have to raise or lower tools, use a line.
- Do not use metal ladders for electrical work or where they may contact electrical conductors.
- Do not use stepladders as strait ladders.
- Avoid over reaching when working from ladders.
- Manufactured ladders must comply with OSHA, ANSI, manufacturer and job specifications.
- The six- foot fall protection procedure applies when working from a ladder. All ladders should be secured with a rope or other substantial device.
- Ladders should be maintained free of lines, ropes, hoses, wires, cables, oil, grease, and debris. No objects should be left on ladders.
- Never stand or sit on the top rung of a stepladder.
- Never climb or work from the back of a ladder.
- Never work with another person on the same ladder.

7.2.17 Compressed Gas Cylinders

Maintenance personnel should adhere to the following safety guidance regarding the use of compressed gas cylinders when working on or around the combustion turbines:

- The protective caps of gas cylinders must be kept on all cylinders when not in use.
- All cylinders must be properly secured to prevent tipping.
- All gas cylinders whether in use or in storage must be secured in an upright position by some substantial means such as chains or ropes.
- Oxygen and Fuel gas cylinders in storage, must be separated from each other by a separation of 20 feet or by a 5-foot high barrier wall which has a minimum 1-hour fire rating.
- Compressed Gas cylinders should not be taken into confined spaces.

7.2.18 Permit Required Confined Spaces

Only contract employees who have been trained in compliance with OSHA confined space standard 29 CFR 1910.146 may enter permit required confined spaces. Only trained attendants should be used to monitor permit required confined spaces while authorized entrants are inside.

No person should enter a confined space until all preparations for entry have been completed, the permit has been approved, all conditions of site-specific entry procedures have been met, and the entry is authorized. Typically, no person should enter a confined space unless an attendant is on duty. The attendant must maintain visual and/or voice contact at all times with personnel in the confined space.

Personnel using monitoring equipment should be trained in its use and calibration. All electrical shock hazards should be protected by use of low-voltage systems and/or ground-fault protector. Explosion-proof electrical equipment is required for entry into spaces where potential fire and/or explosion exists.

No one should enter confined spaces without a permit. The CTCC facility owner should identify all confined spaces by sign, placard or other appropriate means. Individuals authorized to issue a confined space permit should be designated and identified to site maintenance personnel. The individual issuing the permit should personally inspect, examine and evaluate the confined space before entry and should assure that all hazards have been identified before allowing entry. They should also discuss the following with all personnel:

- Emergency procedures.
- What the emergency – standby person must do.
- How to request a re-check of the permit.
- What the permit does and does not authorize.
- The duration of the permit – one shift (or the duration of the entry, whichever is shorter).

The following work rules are unconditionally and automatically the requirements for confined space entry procedures:

- Ventilation should be of adequate volume to safely maintain the airflow within the confined space
- It is the responsibility of maintenance personnel to immediately report unsafe conditions.
- Adequate lighting should be provided.

- Lighting used must be explosion proof, 12- volt system or flashlight.
- Welding, cutting, brazing, and purging operations require specific requirements – consult with the individual issuing the permit and site-specific requirements.
- Chemicals used or transported inside the confined space require specific requirements – consult with the individual issuing the permit and site-specific requirements.

The following locations and structures are typically designated by CTCC facility owners as permit-required confined spaces at the power plant:

- Exhaust bearing tunnel
- Inlet air duct between the evaporative cooler and inlet silencers
- Inlet air duct between the inlet silencers and compressor
- Electrical vault
- Stack
- EHC skid reservoir
- Gas filter separator vessel
- Lube oil reservoir
- Turbine building ventilation fan and exhaust hood enclosures
- Evaporative cooler water supply valve pit
- Sump pits

7.3 Worker Safety and Health Guidelines for CTCC Facility Owners

7.3.1 General Safety Requirements for CTCC Facility Owners

Owners should provide a work place free of hazardous, unsanitary or dangerous conditions for all employees. It should be the responsibility of the owner to initiate and maintain such accident prevention programs, hazardous material programs, and other programs as may be necessary to comply with Federal, State, and Local regulations while performing work at the CTCC facility.

It should be the responsibility of the owner to assure that all subcontractors and contractor employees abide by the safety rules and regulations while on the CTCC facility. Technicians should stay in only their assigned work areas.

The owner should ensure that any GT technicians not bring any explosives, firearms, alcoholic beverages, or drugs on the CTCC property. GT technicians should wear appropriate clothing at all times. Short pants and shirtless attire are prohibited. Sturdy shoes with steel toes must be worn at all times. Safety glasses and hard-hats must be worn at all times.

Owners should ensure the following general work practices are followed during maintenance activities:

- Owners should not permit maintenance personnel to work in such proximity to any part of an electrical power circuit that the employee could contact the electrical power circuit in the course of work unless the employee is protected against electrical shock by de-energizing the circuit and grounding or guarding it effectively by insulation or other means.
- In work areas where the exact location of underground electrical cable(s) is unknown, employee using jackhammers, bars, or other hand tools, which may contact a line, should be provided with insulated protective gloves. All insulated protective gloves must be tested prior to use, in accordance with the National Electric Code.
- Before work is begun the owner should ascertain by inquiry, direct observation, or instruments, whether any part of an energized electrical power circuit, exposed or concealed is located so that the performance of the work may bring any person, tool, or machine into physical contact with the circuit. The owner should post and maintain proper warning signs where such a circuit exists. The owner should advise employees of the location of such line, the hazards involved, and the protective measures to be taken.

7.3.2 Occupational Safety and Health

Operation and maintenance activities associated in or around the CTCC facility may expose workers to physical and chemical hazards. Potential worker exposure to these hazards will be minimized through adherence to appropriate engineering controls, implementation of appropriate administrative procedures, use of personal protective equipment, and compliance with applicable health and safety requirements.

Formal health and safety procedures and programs should be established and implemented for maintenance and operations to control the various hazards and provide for a safe workplace. The site-specific injury and illness prevention programs and safety training programs, which are intended to protect worker health and safety during operation and maintenance activities, are described in the following sections.

7.3.3 Injury and Illness Prevention Programs

Prior to beginning construction activities, the CTCC facility owner should develop a site-specific construction injury and illness prevention program. Once the construction of the proposed project is complete, a site-specific injury and illness prevention program for operations and maintenance activities will be implemented.

7.3.3.1 Construction Injury and Illness Prevention Programs

Consistent with applicable state and OSHA's policy on multi-employer work sites, each CTCC facility owner should be responsible for the health and safety of its own employees. Periodic health and safety audits should be conducted by facility personnel to verify contractor and subcontractor compliance with contractual health and safety obligations.

7.3.3.2 Operations and Maintenance Injury and Illness Prevention Programs

Upon completion of construction, startup of the proposed project, and implementation of routine operations, the construction injury and illness prevention programs should transition into an operations-oriented program that reflect the hazards and controls necessary during routine operations and maintenance of the CTCC facility.

7.3.3.2.1 Injury and Illness Prevention Plan

The primary mitigation measures for worker hazards during normal plant operation and maintenance are contained in the IIPP, as required by state and OSHA requirements, and site-specific procedures. The written IIPP should designate an individual who is responsible for implementing the program. It also should describe safety training and procedures for tracking safety training. An IIPP should contain the following information and procedures:

- Identity of the person(s) with authority and responsibility for implementing the program;
- A system for ensuring that employees comply with safe and healthy work practices;
- A system for facilitating employer–employee communications regarding safety;
- Procedures for identifying and evaluating workplace hazards, including inspections to identify hazards and unsafe conditions;
- Methods for correcting unhealthy/unsafe conditions in a timely manner;
- An employee training program that includes:
 - Introducing the program;
 - Training of new, transferred, or promoted employees;
 - Training on new processes and equipment;
 - Supervisors training; and
 - Evaluation of contractor training.
- Methods of documenting inspections and training, and for maintaining appropriate records.

7.3.3.2.2 Emergency Action Plan

In addition to incorporating various safety and environmental features and design measures to minimize emergencies and their effects on public and worker safety, the CTCC facility should have a site-specific Emergency Action Plan. The Emergency Action Plan should address potential emergencies, including chemical releases, fires, bomb threats, pressure vessel ruptures, aqueous ammonia releases, and other catastrophic events. It should describe evacuation routes, alarm systems, points of contact, assembly areas, responsibilities, and other actions to be taken in the event of an emergency. The plan includes a layout map, a fire extinguisher list, and a description of arrangements with local emergency response agencies for responding to emergencies.

7.3.3.2.3 Hazardous Materials Management Program

The storage and handling of chemicals should follow applicable state and OSHA requirements to minimize risk to workers and the surrounding community. Chemicals should be identified and stored in appropriate chemical storage facilities. Bulk chemicals should be stored in aboveground storage tanks; other chemicals should be stored in their delivery containers. Chemical storage and chemical feed areas should be surrounded by temporary or permanent containment or curbing to contain leaks and spills. The containment areas should be sized to hold an appropriate volume (considering the potential for the local hazard contingencies).

Safety showers and emergency eyewash stations or bottles should be provided at all chemical treatment and storage areas, laboratories, and battery rooms in accordance with state and OSHA requirements (within 50 feet, or 10 seconds of travel time). Standard PPE for use during chemical handling activities should be provided.

Self-contained breathing apparatus sets should be available in the Control Room. First-aid kits should be located in work areas around the plant. Fire blankets and evacuation stretchers should be located in the control building. Standard PPE should be readily available for use during minor chemical spill containment and cleanup activities by plant personnel. Adequate supplies of absorbent material should also be available on site for minor spill cleanup. A hazardous material emergency response team, trained in managing the accidental release of the chemicals used and stored at the plant, should be available through contract.

Emergency contact numbers should be available to summon assistance from these contractors and for notification of local agencies. These procedures should be detailed in the Emergency Action Plan.

7.3.3.2.4 Personal Protective Equipment Program

PPE requirements for work at the CTCC facility should be identified during the job hazard analyses process. The PPE requirements should be developed and incorporated into the site-specific injury and illness prevention program. The PPE program should include the following:

- Hazard analysis and prescription of PPE;
- Personal protective devices;
- Head protection;
- Eye and face protection;
- Body protection;
- Hand protection;
- Foot protection;
- Safety belts and life lines;
- Protection for electric shock; and
- Respiratory protective equipment.

7.3.3.2.5 Operations and Maintenance Written Safety Program

Additional written safety programs will be developed and implemented as necessary to address hazards that are identified with operation and maintenance of the CTCC facility. These programs will be made components of the overall operations and maintenance injury and illness prevention program for the facility. These programs include, but are not limited to, the following:

- Blood-borne pathogens control program;
- Hazard communication program;
- Hearing conservation program
- Hazardous energy control program;
- Confined space entry program;
- Safe work practices program;
- Ergonomics program;
- General facility safety procedures:
 - Compressed gas safety procedures;
 - Heavy equipment safety procedures;
 - Hand tools and equipment guarding procedures;
 - Hoist and rigging safety procedures;
 - Slips, trips, and falls prevention procedures; and
 - Hot work safety procedures;

- Fall protection program;
- Contractor safety program; and
- Risk management plan

7.3.3 Safety Training Programs

To ensure that employees recognize and understand how to protect themselves from hazards at the CTCC facility, comprehensive training programs for maintenance and operations personnel should be implemented.

Operations and maintenance personnel should be given instructions regarding their responsibility for the safe conduct of their work. These instructions should be given at the time the employee is first hired and as an ongoing training program of hazard recognition and avoidance.

Employees will also be instructed in safety procedures pertinent to their employment tasks. Safe working conditions, work practices, and protective equipment requirements will be communicated in the following manner:

- A new, promoted, or transferred employee will receive safety training orientation;
- Safety meetings will be held with employees;
- “Toolbox/tailgate” safety meetings will be conducted periodically for each crew. General safety topics and specific hazards that may be encountered will be discussed. Comments and suggestions from all employees will be encouraged;
- A periodic staff safety meeting will be held for supervisors;
- Hazard communication training, including state-required hazardous material warnings and discharge prohibitions, will be conducted as necessary when new hazardous materials are introduced to the workplace;
- Material safety data sheets will be available as required for all appropriate chemicals;
- A bulletin board with required postings and other information will be maintained at the plant site; and
- Warning signs (e.g., hazardous waste storage area, confined space area) will be posted in hazardous areas that comply with applicable regulations (i.e., bilingual, font size).

Safety training should be provided to each maintenance technician as described below:

- A list of safe work rules for the CTCC facility should be explained to each new employee;
- A copy of the applicable Safe Work Practices should be given to each new employee. The provisions should be incorporated into training for the qualifications programs so that employees may fully understand what the protective provisions mean;
- The Hazard Communication Program and requirements for personal protection for the types of hazards that may be encountered at the CTCC facility site should be explained and documented;
- Unusual hazards that are found on site should be explained in detail to each new employee, including any specific requirements for personal protection; and
- Safety requirements for the new employee's specific job assignment will be explained by the foreman upon initial assignment and upon any reassignment.



Section 8: References

8.1 Referenced EPRI Product Reports

EPRI has developed many specialized technical reports within the last several years that address in detail many of the issues that have been observed within the industry. The following is a partial listing of such EPRI reports that were used for information and references in this report:

1012756 - *Heat Recovery Steam Generator (HRSG) Chemical Cleaning Guidelines Case Studies*, November 2006

1018993 - *Troubleshooting Guide for Thermal Transients in Heat Recovery Steam Generators (HRSG)*, November 2009

1019799 - *Heat Recovery Steam Generator Cycle Chemistry Instrumentation*, November 2010

1008092 - *Examination of Heat Recovery Steam Generator (HRSG) Plants - Assessment of Fiber-Optic Techniques*, November 2005

1015464 - *Optimization of Heat Recovery Steam Generator Startup and Shutdown in F-Class Units*, July 2009

1010440 - *Evaluation of Thermal-, Creep- and Corrosion-Fatigue of Heat Recovery Steam Generator Pressure Parts*, March 2006

1004875 - *HRSG Material Selection and Repair Guidelines*, March 2004

1019802 - *HRSG Material Selection and Repair Guidelines*, December 2010

1023092 - *Heat Recovery Steam Generator Material Selection Guideline*, December 2011

1013629 - *Proceedings: International Conference on Boiler Tube and HRSG Tube Failures and Inspections*, November 2–5, 2004

1017597 - *Heat Recovery Steam Generator Procurement Guideline: HRSG Design Best Practices and Specification for Cyclic Duty*, December 2009

1014197 - *Examination of Heat Recovery Steam Generator Plants Case Studies of Remote Visual Inspection Techniques*, March 2008

1010438 - *Cycle Chemistry Guidelines for Combined Cycle/Heat Recovery Steam Generators (HRSGs)*, March 2006

1014302 - *Development of Corrosion Resistant Coatings For The ID Surface Of HRSG Tubes*, March 2008

1015831 - *Development of Advanced Nondestructive Evaluation Techniques for Heat Recovery Steam Generators: HRSG Drain Examination*, March 2009

1023063 - *Boiler and Heat Recovery Steam Generator Tube Failures: Theory and Practice*, December 2011

1023089 - *Flow-Accelerated Corrosion (FAC) Fossil and Combined Cycle Self-Assessment Guideline*, December 2011

1022096 - *Gas Turbine/Combined Cycle Post-Combustion Emission Control Best Maintenance Practices Guideline: Selective Catalytic Reduction and CO Emission Control Technologies*, December 2011

1021121 - *Field Guide: Heat Recovery Steam Generator Tube Failure*, December 2010

1019753 - *Maintenance and Insurance Options for Managing Technical Risks in Combustion Turbine Projects*, December 2010

1018987 - *Evaluation of the Pulsed Eddy Current Inspection Technique Known as the Through-Fin Inspection System for Heat Recovery Steam Generators (T-FISH) as Applicable to Power Plants*, December 2009

1018992 - *Evaluating and Avoiding HRSG Pressure Part Damage Influenced by Stack Damper Operation*, December 2009

1017629 - *Heat Recovery Steam Generator (HRSG) Deposits: State of Knowledge Report*, November 2009

1017635 - *Study for Snake Robot Technology for Inspection of Headers and Tubes in Heat Recovery Steam Generators*, November 2009

1018993 - *Troubleshooting Guide for Thermal Transients in Heat Recovery Steam Generators (HRSG)*, November 2009

1015832 - *Remote Inspection Device – Heat Recovery Steam Generators*, March 2009

1015800 - *Lessons Learned in Startup and Commissioning of Simple-Cycle and Combined-Cycle Combustion Turbine Plants*, December 2009

1016849 - *Development of Methods to Repair Header Stub Tube Bends*, December 2008

1015798 - *Reliability and Availability of Gas Turbines and Combined-Cycle Plants*, December 2008

1014301 - *HRSG Repair Welding Technologies to Address FAC in Tube Bends*, March 2008

1014196 - *Guidelines on Optimizing Heat Recovery Steam Generator Drains*, December 2007

1014114 - *Compilation of EPRI Heat Recovery Steam Generator (HRSG) Guidelines*, December 2007

1012758 - *Evaluating and Avoiding Heat Recovery Steam Generator Tube Damage*, March 2007

1012762 - *Heat Recovery Steam Generator Repair Welding Technologies to Address FAC in Tube Bends*, March 2007

1012759 - *Guidelines for the Nondestructive Examination of Heat Recovery Steam Generators, Revision 1*, February 2007

1019601 - *Procurement Specification for Horizontal Gas Path Heat Recovery Steam Generator: Avoiding Thermal-Mechanical Fatigue Damage*

1026632 - *Generation Maintenance Application Center: Combined Cycle Combustion Turbine Attenuator Maintenance Guide*

Section 9: Summary List of Key Points

9.1 Key O&M Cost Points



Key O&M Cost Point

Emphasizes information that will result in overall reduced costs and/or increase in revenue through additional or restored energy production.

Page Number	Key Point
5-2	Performance Monitoring is one of the first steps to take for determining HRSG conditions for reliable and overall efficient operations.

9.2 Key Technical Points



Key Technical Point

Targets information that will lead to improved equipment reliability.

Page Number	Key Point
3-2	Some OEM's have developed dynamic life cycle analysis software tools for their HRSG's to forecast component life expectations by analyzing the impact of actual operating conditions.
4-1	Internal inspection of a HRSG should occur at least on an annual basis.
4-3	Any noises or vibrations found during HRSG operation should be investigated at the next available outage.

9.3 Key Human Performance Points



Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent personal injury, equipment damage, and/or improve the efficiency and effectiveness of the task.

Page Number	Key Point
4-3	The site's confined space procedures should be followed for all internal HRSG inspections.

9.4 Key Supervisory Observation Points



Key Supervisory Observation Point

Identifies tasks or series of tasks that can or should be observed by Maintenance First Line Supervisors to improve the performance of the Maintenance Staff and improve the reliability of the component.

Page Number	Key Point
4-2	HRSG components should be inspected by teams or individuals based on their expertise.
4-2	One of the best tools for a HRSG inspector to have is a digital camera.

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