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ACC.01: Guidelines for Internal Inspection of Air-Cooled Condensers

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Introduction

The employment of air-cooled condensers (ACCs) in fossil fueled power-generating facilities has increased dramatically early in the 21st century. These condensers are massive structures at power plant sites, because a large cooling surface is required to compensate for the relatively poor heat capacity of air, in comparison with that of water. As experience has been gained in operating and maintaining facilities with ACCs, it has become clear that corrosion of steam-side surfaces can be a significant problem for unit operation. In particular, iron oxide transport can introduce a large quantity of contaminants to the condensate / boiler feedwater, and through-wall penetrations of cooling tubes can cause significant air inleakage, potentially leading to reduced condenser performance and permitting ingress of air.[1]

As a consequence of these issues, internal inspection of ACCs has become increasingly recognized as an important activity for unit outages.[2] The guideline that follows is provided to assist in carrying out such inspections in a comprehensive manner, to understand why specific data and information is gathered, and to use this information to quantify the condition of the ACC with regard to internal corrosion. Furthermore, the inspection should provide an evaluation of the chemistry program and its ability to mitigate corrosion or require modification. The checklist provided at the end of the guideline is intended for use during the performance of inspections.

In addition to observations regarding corrosion, mechanical integrity of components should be included in the inspection, particularly any evidence of cracks, pipe movement, flange loosening or erosion.

Note: The information contained in this Guideline is believed to be accurate based on available knowledge. It is the responsibility of any user of this Guideline to confirm the accuracy of information herein, and to apply the information appropriately, to any specific case.

Plant Configuration

Specific characteristics of a power-generating facility can be important in terms of the impact of certain inspection results on plant operations. For example, a once-through generating unit is much less tolerant than a drum unit to particulate (iron oxide) contamination in feedwater, but also will probably have equipment to limit such transport (condensate polishing and filtration). The presence of condensate polishing has implications regarding the limitations of certain operational measures, such as high pH operation to reduce iron transport. Other general characteristics of plant design and performance, such as backpressure, air inleakage rate, and condensate temperature, can be useful as background data that may prove valuable in comparisons between units.

ACC Configuration

ACC designs are regularly evolving as suppliers identify changes intended to improve performance or ease of operation; therefore, specifying the manufacturer does not, in itself, adequately explain the design. Cooling tube length and shape, the number of rows of tubes, external fin material, the number of fans and their operational flexibility, mist-enhanced-cooling, external tube cleaning systems, the shape of cooling tube entries, suitable drainage of condensate during unit shutdowns, and steam / condensate velocity are some of the characteristics that may influence internal corrosion. A condensate deaerator is sometimes included to reduce the impact of air inleakage. A parallel wet-dry cooling system (water cooled condenser + air cooled condenser) will operate very differently from a unit that has only an ACC, with steam velocities in the ACC considerably reduced when the water-cooled condenser is operating, along with lower condensate temperatures in hot weather.

The most common current design for heat exchange tubing is single-row carbon steel with airside aluminum coating and aluminum fins; this design balances cost and performance factors. Multi-row carbon steel tubes with carbon steel fins and airside zinc coatings have also been frequently used. In a few cases stainless steel tubing has been employed, but the steamside material is almost universally carbon steel.

Operation

The environment to which internal ACC components are exposed is steam / condensate exhaust that has exited the low pressure steam turbine. Operating criteria and practices in this environment can greatly influence internal corrosion of ACCs. It has been clearly demonstrated that a higher steam cycle pH correlates with reduced iron transport.[3-5] Ammonia is the standard chemical employed for steam condensate pH control, although other chemicals have been used.[6,7] Oxygen has no impact on ACC component corrosion when operating, although it contributes to corrosion of wet components during off-line periods.

The steam cycle chemistry program and control ranges, iron transport data, unit cycling patterns, condensate temperature, and feedwater purity during unit startups are items of particular relevance to ACC corrosion. The condition of the ACC during off-line periods should be documented; although special layup treatment is not generally employed for ACCs, standing water can be minimized or removed, and/or increasing the pH just prior to shutdown, to reduce off-line corrosion. If available, isolation of upper ducts can allow retention of ammonia for extended off-line periods, thereby reducing corrosion in standing water.

Frequency of Inspection

If possible, thorough inspection of the ACC periodically during its construction is strongly recommended. Steam cycle contamination by excess weld flux and miscellaneous construction debris of all types has caused difficulties with initial unit startup, including failure to achieve the original equipment manufacturer (OEM) steam cycle purity requirements (Photo 1). Component failures have been attributed to construction debris that was not adequately cleaned from the system.

The rate of wall loss due to ACC steam cycle corrosion is typically not rapid. Through wall leaks in thin walled ACC tubes may take a decade or more to develop (Photo 2). Iron transport, on the other hand, can occur virtually from the time of initial unit operation. In order to establish a baseline and to document corrosion-susceptible areas, a newly-commissioned ACC should be inspected within the first few months, or at the first scheduled outage, if possible. Subsequently, annual inspections should be adequate, unless specific concerns exist that would require more frequent observation. If the first three or four inspections show little change in corrosion location or extent, and there are no significant changes in operating patterns or chemistry control, bi-annual inspections may be deemed adequate thereafter.

Although lower ducts are accessed with little difficulty, it is probably unrealistic to expect that more than one or two of the upper ducts in a unit will be inspected during an outage. The plant should select a specific upper duct to inspect repeatedly, so that any changes can be observed and documented, ideally by both photography and with waterproof markings, so that the same areas can be easily identified and compared in future inspections. The preferred duct for repeat inspection will generally be one that is closest to the turbine exhaust, where steam velocity should be the highest. Other upper ducts should be inspected on a scheduled basis as able, perhaps on a rotating basis, to ensure that unique or unforeseen problems are not occurring in them. The lower duct should be traversed from the turbine to the risers, in all areas visually accessible.

Preparation for Inspection

The “Visual Inspection Worksheet” at the end of this document provides a checklist of areas that should be included in the inspection. Basic items to facilitate the inspection can be organized as a tool kit, to include portable lights, small inspection mirrors, camera, flashlights, chalk / paint markers, measuring tape, scraping tool, sampling bags, bucket, and any other unit-specific needs.

Safety

Serious hazards exist for persons inspecting ACCs, and careful planning is necessary to minimize the potential for personal injury. One potential hazard is falling. The fan deck of ACCs is commonly 80 to 100 feet above the ground, generally reached by a lengthy climb on a permanent staircase, unless an elevator (lift) is available. Protective rails are typically well-placed to minimize risk. Reaching the upper distribution duct, however, may be more challenging. While some units are constructed with permanent ladders and platforms to provide easy access to a manway on the side of the duct, others may require scaffolding or placing a temporary ladder, followed by a difficult climb on handrails to the top to reach a manway (Photos 3, 4). Fall protection is required in such cases.

ACC ductwork is generally defined as a 'confined space,' and breathing air quality should be ensured before entering a duct and monitored while inside the duct. In addition, work within the duct involving volatile or flammable solvents can be very hazardous, and should not be undertaken without careful planning to insure these solvent vapors are adequately removed; continuous monitoring and air flow should be maintained at all times when personnel are within ducts. Lighting may be poor, with flashlights perhaps the only light source. Certain areas of ductwork offer a slipping hazard when walking on curved surfaces, particularly in wet areas or in colder climates where ice may form. Sharp edges may be present on support structures, or may develop due to flow-accelerated metal loss. Covers over drain ports may be displaced, resulting in tripping danger; large open drain piping in the lower duct can constitute a fall hazard. Personnel may travel a considerable distance from entry ports during inspection, and the upper ducts in particular have cross-braces that could obstruct personnel removal in an emergency situation, so a confined space rescue plan should be in place. Plant procedures for lockout-tagout, confined space and fall protection must be followed.

Physical (Visual) Inspection for Corrosion

Photographic documentation of ACC duct surfaces and cooling tube entry points is essential for characterizing internal corrosion. Although any areas that appear abnormal must be recorded, it is important to document the appearance of "normal" areas as well. Items of particular interest include deposit color, areas where color changes, regions that appear to be bare metal, positions of flow disruptions that may have led to flow-accelerated metal loss, and regions showing heavy deposition or significant depth of metal loss. Fiber optics examination of heat exchange tubing may provide useful information, and if carried out, should be recorded.

DHACI Criteria for Quantifying ACC Corrosion

A criteria for quantitatively defining the internal corrosion status of ACCs has been established and is known as DHACI (Dooley Howell ACC Corrosion Index).[2] The index separately describes corrosion in the lower and upper sections of the ACC with a number for the upper duct and letter for the lower duct, e.g. 2B, according to the following:

Upper Section (upper duct / header, cooling tube entries) - rate **1**, **2**, **3**, **4** or **5**, where **1** is minimal corrosion and **5** is poor condition.

1. Tube entries in relatively good condition; possibly some areas with dark deposits in first few inches of tube interior. No corrosion or flow-accelerated corrosion (FAC). (Photo 5)

2. Various black/grey deposits on tube entries as well as flash rust areas, but no white (bare metal) areas. Minor corrosion/FAC. (Photo 6)

3. Few bare metal areas on a number of tube entries. Some black areas of deposit. Moderate corrosion/FAC. (Photo 7)

4. Widespread bare metal areas on/at numerous tube entries. Extensive areas of black deposition adjacent to bare metal areas within tubes. Serious corrosion/FAC. (Photo 8)

5. Most serious. Holes in the tubing or welding. Obvious corrosion on many tube entries. (Photo 9)

Lower Section (turbine exhaust, lower distribution duct, risers) - rate **A**, **B** or **C**:

A. Ducts have no indication of damage. (Photo 10)

B. Minor bare metal areas on generally grey ducts. Some 'tiger striping' appearance with darker grey/black areas demonstrating flow-accelerated damage. Overall assessment is 'minor damage.' (Photo 11)

C. Multiple, widespread areas of bare metal in the turbine exhaust and at abrupt changes in flow direction (e.g. where steam flow enters vertical riser from lower distribution duct). White (bare metal) areas are evident indicators of metal loss. Severe local damage exists. (Photo 12)

The index provides a number (from 1 to 5) and a letter (from A to C) to describe / rank an ACC. For example, 3C would indicate moderate corrosion at tube entries, but extensive corrosion in the lower ducts. The DHACI can be used to track changes that occur in a particular ACC resulting from changes in steam cycle chemistry, or can be used to compare the condition of different ACCs.

Inspection Regions

Low Pressure (LP) Turbine Exhaust (Photo 13)

Steam exiting the LP turbine may impinge directly on baffles or ducts; therefore, the area is susceptible to significant FAC. Metal loss and black iron oxide at this location appears similar to that at the turbine exhaust in a water cooled condenser.[8,9]

Ductwork from LP Turbine to Lower Distribution Duct (Photo 14)

A very large-diameter section of duct typically extends from the turbine exhaust to the lower distribution duct. High-energy steam / drain returns into this duct may be associated with bare metal where duct walls are impacted. Structural supports in the general steam path are also susceptible to impingement by main steam flow. Flow disruption by protruding weld seams may result in FAC at or immediately downstream of the welds.

Lower Distribution Duct (including entries to riser ducts) (Photo 15)

The diameter of the lower distribution duct typically decreases with distance from the turbine exhaust duct. The entry into risers is a turbulent location that should be examined for bare metal.

Upper Distribution Duct and Entry Baffle (Photo 16)

This duct may have a redder oxide than other ducts in the ACC. The baffles and entry region may show FAC due to turbulent flow. Note that the diameter of the upper distribution duct typically decreases from the inlet to the outlet end.

Tube Inlet Region (Photo 17)

It is important to inspect the tube inlet region carefully, as bare metal has been found to be widespread due to two-phase fluid, a turbulent 90-degree turn into the tubes, and (often) a weld-lip that increases local turbulence. Additionally, this is the only region in ACCs where through-wall penetrations due to FAC have occurred; tubes are by far the thinnest-walled area in the ACC (commonly 1.5 mm (0.059”) tube wall). The first few inches into certain tubes are commonly found to contain patches of black deposit alternating with either bare metal or flash-rusted metal. It has been observed in some cases that the tube entries closer to the duct inlet are more severely corroded than those further downstream. The trough between tubesheets retains standing water in some designs, demonstrating that off-line rusting contributes iron oxide to condensate. Cross-beams above the tubesheet are frequently found to exhibit bare metal on the side facing steam flow, and often tube entries with the most corrosion are located beneath these cross-bars, where turbulence is greater.

Other Internal Components

In the high-energy environment of an ACC, there is potential for a variety of types of mechanical damage. While these are not detailed in this guideline, advantage should be taken during the inspection to look for evidence of cracking (especially near welds, Photo 18); support structures that have been damaged or failed; and high-energy steam dump baffles etc.

Expansion joints in the ACC ducts, as well as the turbine-to-condenser connection, may be inspected internally, provided sufficient planning has been made to allow access to these areas.

Note: Presentations discussing this and other issues involved with air cooled condensers can be viewed on the website of the Air Cooled Condenser Users Group at http://acc-usersgroup.org/.

References

[1] Howell, A.G., Pritekel, R.J. and Dooley, R.B., "Steam Cycle Chemistry and Air-Cooled Condensers." PowerPlant Chemistry 9 (5), 2007.

[2] Dooley, R.B., Aspden, J.D., Howell, A.G. and du Preez, F., "Assessing and Controlling Corrosion in Air-Cooled Condensers." PowerPlant Chemistry 11 (5), 2009.

[3] Prust, A., "Converting a Supercritical Unit from AVT(O) to OT." PowerPlant Chemistry 10 (6), 2008.

[4] Richardson, I., "Air-Cooled Condensers – Chemistry Implications at Kogan Creek Power Station." PowerPlant Chemistry 11 (9), 2009.

[5] Phala, S., Aspden, D., du Preez, F., Goldschagg, H. and Northcott, K., "Corrosion in Aircooled Condensers – Understanding and Mitigating the Mechanisms". API Power Chemistry Conference. Sunshine Coast, Queensland, Australia. May 2008. Downloadable at: http://acc-usersgroup.org/wp-content/uploads/2011/02/API-Powerchem-Paper.pdf

[6] Bignold, G.J., "The Behaviour of Ammonia, Amines, Carbon Dioxide and Organic Anions during Condensation in an Air-Cooled Condenser." PowerPlant Chemistry 8 (2), 2006.

[7] Stroman, B., "Amines in Air Cooled Condensers." Presented at the 6th Annual meeting of the Air Cooled Condenser Users Group. http://acc-usersgroup.org/wp-content/uploads/2014/10/Amines-in-Air-Cooled-Condensers.Bill-Stroman-KAAM-Group.pdf

[8] Howell, A.G., "Carbon Steel Corrosion in Water-Cooled Condensers." PowerPlant Chemistry 10 (12), 2008.

[9] Howell, A.G., "Carbon Steel Corrosion in the Low Pressure Turbine Exhaust Environment." PowerPlant Chemistry 12 (11), 2010.

Photos

Photo 1: Debris in lower ACC header; weld flux containing high concentrations of fluorine.

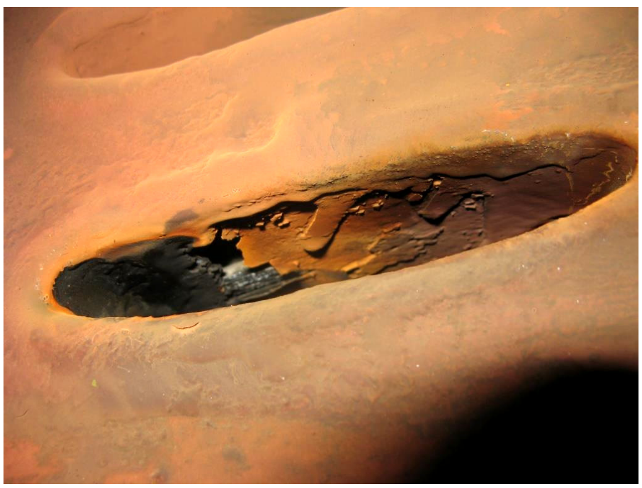

Photo 2: Leak at ACC tube entry

Photo 3: Permanent ladder access to upper duct, with permanent platforms at manways.

Photo 4: Upper duct with difficult access to manway on top side.

Photo 5: Tube entry DHACI rating 1

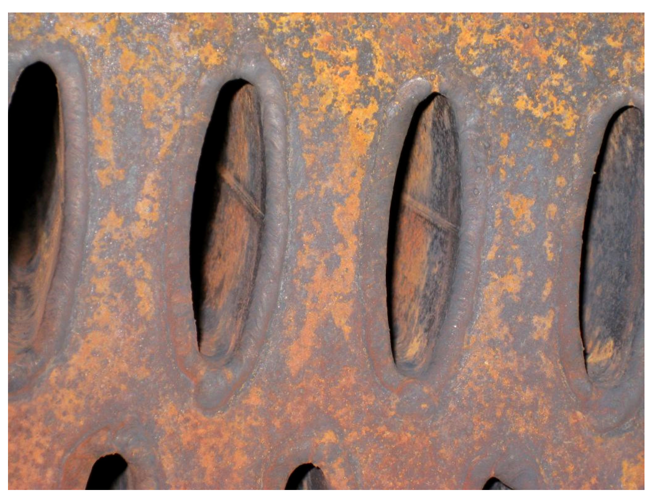

Photo 6: Tube entry DHACI rating 2

Photo 7: Tube entry DHACI rating 3

Photo 8: Tube entry DHACI rating 4

Photo 9: Tube entry DHACI rating 5

Photo 10: Lower duct DHACI rating A

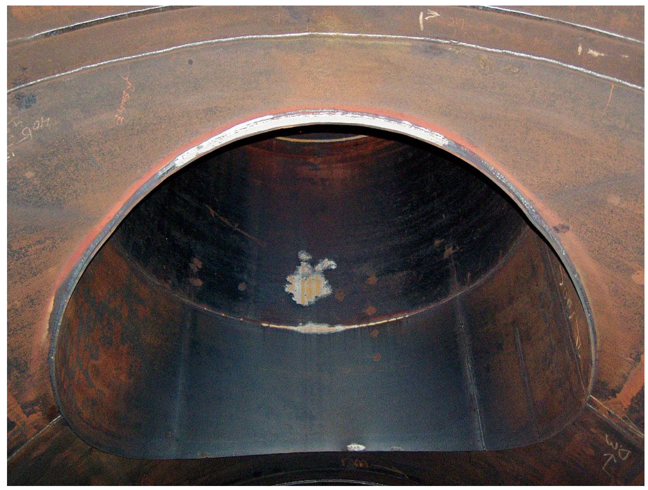

Photo 11: Lower duct DHACI rating B

Photo 12: Lower duct DHACI rating C

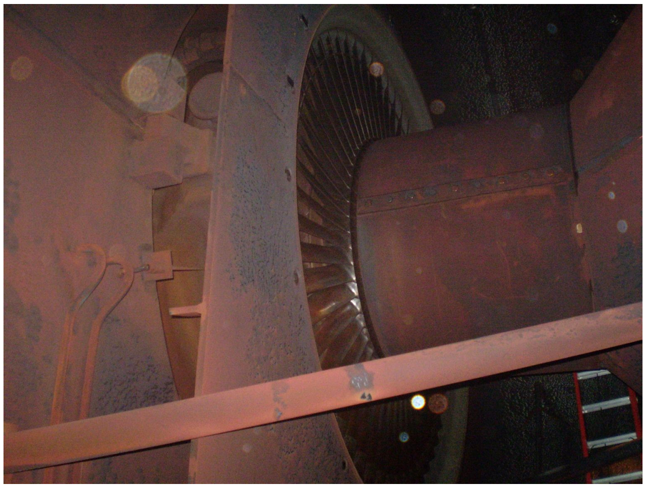

Photo 13: LP turbine exhaust

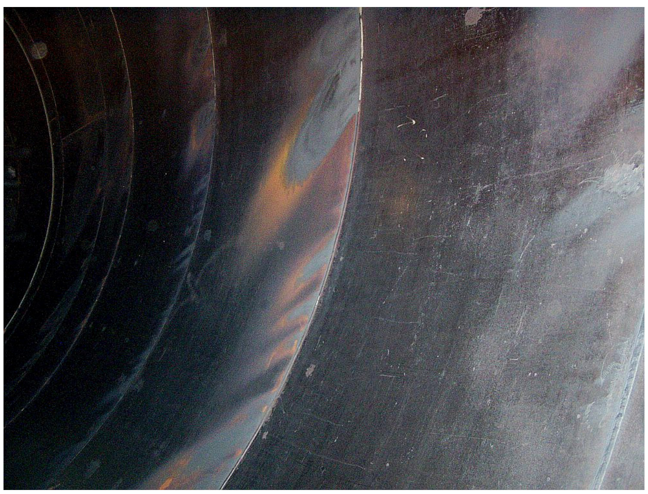

Photo 14: LP exhaust to lower distribution section; minor active corrosion, DHACI rating A

Photo 15: Lower distribution duct section, including risers

Photo 16: Upper distribution duct; DHACI rating 3 at tube inlets

Photo 17: Tube inlets in upper duct; DHACI rating 1 at tube inlets

Photo 18: Crack in lower duct turning vane extending from support weld

Definitions

A-frame: The A-shaped structure defined by a set of finned heat exchange tubes attached to an upper duct.

air cooled condenser (ACC): A steam condensing device that employs air as the steam coolant.

air inleakage: Air drawn into the process flow of steam by the vacuum (lower absolute pressure) caused by condensing steam; occurs when a point of entry exists into the vacuum.

backpressure: Absolute pressure at the exhaust of the steam turbine, driven by the vacuum created by condensing steam in the condenser.

condensate: Liquid water formed from condensed steam.

condensate filter: A particle filter positioned in the flow path of condensate that is being pumped towards a steam generator.

condensate polisher: An ion exchange system positioned in the flow path of condensate being pumped towards a steam generator.

confined space: An area in which free flow of ambient air may not occur.

deaerator: A device that removes gases from water by the use of heat, vacuum or sparging with steam.

dephlegmator: The section in an ACC that is designed to remove non-condensable gases from condensing steam.

DHACI: Dooley Howell Air cooled Condenser Index, a numbering / lettering system that describes the status of corrosion on the steamside of ACCs.

feedwater: Water that is pumped towards a steam generator as part of the steam cycle.

finned tubing: Heat exchange tubes for ACCs that have external fins to enhance cooling capacity.

Flow-accelerated Corrosion (FAC): A corrosion mechanism in high purity water by which iron is gradually dissolved under specific conditions of water chemistry, temperature, and flow rate.

iron oxide: The common corrosion product of iron in high purity aqueous systems.

iron transport: Iron that is released into the steam cycle flow path, most often transported in particulate iron oxide form.

lockout-tagout: A safety arrangement in which equipment is locked, labeled and documented in order to avoid its operation when personnel might be endangered.

lower duct: The primary duct through which low pressure turbine exhaust steam passes before it is distributed into risers.

magnetite: The primary form of transported iron oxide in steam cycles.

pH: The common measure of acidity in water; control of pH in the steam cycle of power plants is critical to minimizing corrosion.

riser: A vertical duct extending from the lower duct to the upper duct, which may or may not have valves to restrict or block flow.

tubesheet: A metal plate on the bottom of the upper duct to which finned heat exchange tubes are attached by welding.

turning vanes (louvers): A series of baffles throughout the ACC ducts that are designed to direct steam flow.

upper duct: The duct at the top of an A-frame to which finned tubes are attached.

ACC Visual Inspection Worksheet

LOCATION	NOTES
LP turbine blades, last stage(s)	
LP turbine exhaust, direct impact and vicinity	
Large steam exhaust duct	
• general surface	
• flow-related corrosion areas	
Lower distribution duct	
• flow-related corrosion areas	
• riser entries	
• other comments	
Lower Duct DHACI rating: A, B or C	
Upper distribution duct (which one?)	
• entry louvers	
• entry duct region	
• general duct	
• tubesheet and cross-supports	
• tube entries	
• first few inches (cm) into condensing tubes	
Upper Duct DHACI rating: 1,2,3,4 or 5	
External tube condition	
Deposits	
Additional Comments	

ACC Inspection Worksheet: Background Information

	NOTES
Unit name	
Date inspected	
Inspector	
Plant contact	
Unit design (general / MW capacity)	
Tubes (dimensions, materials)	
ACC manufacturer & startup year	
Condensate Temperature (seasonal)	
Design steam flow (klbs/hr or kg/s)	
Condensate polishing? (describe)	
Condensate filtration? (describe)	
Condensate Fe levels: startup	
Condensate Fe levels: routine	
Condensate pH control range / chemical(s)	
Reducing chemical addition?	
Feedwater / condensate dissolved oxygen, typical	
Typical air inleakage rate (SCFM)	
Air inleakage reduction efforts?	
Known problems with Fe transport? (describe)	
Other steam cycle chemistry problems?	
Backpressure setpoints: alarm – trip	
Typical backpressure (BP) (seasonal)	
MW limitations due to BP?	
ACC shutdown actions?	

Unit operating mode: baseload / load cycling / unit cycling?	
Operating hours	
Number of fans	
Fan problems? (describe)	
Number of A frames	
Through-wall leaks in tubes?	
External tube cleaning system?	
Other comments	