Feedwater System Reliability Users Group

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Feedwater Heater Shell Degradation

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Presentation Topics

- Introduction
- Background
- History
- Vessel Events
- Inspection Priorities, Guidance and Techniques
- Repair Practices
- Degradation Mechanisms Summary
- Reference Material
- Conclusions
- Overtime

Introduction

- My background is primarily in Engineering Programs, with an emphasis in FAC; Not a FW System engineer – Primary resource is my involvement with the EPRI CHUG community for over 25 years

- This presentation is primarily focused on an awareness of potential degradation of Feedwater Heater Shells in the industry

- It is well known that **Flow-Accelerated Corrosion** (FAC) degrades carbon steel piping and components

- This degradation has led to catastrophic failures of pipes, elbows, etc. (Surry Event 1986)

- FAC is also known to damage shells and the internals of feedwater heaters, Moisture Separator Reheaters (MSR), and Tanks

Background

Flow-Accelerated Corrosion (FAC)

- Sometimes referred to as flow-assisted corrosion or incorrectly as erosion-corrosion— leads to wall thinning (metal loss) of carbon steel piping exposed to flowing water, wet steam, or a combination of both. The rate of metal loss depends on the complex interaction of many parameters such as water chemistry, material composition, and hydrodynamics. Carbon steel piping components that carry wet steam are especially susceptible to FAC and represent an industrywide problem. Experience has shown that FAC damage to piping at fossil and nuclear plants can lead to costly outages or repairs and can affect plant reliability and safety. EPRI and the industry as a whole have worked steadily since 1986 to develop and refine monitoring programs in order to prevent FAC-induced failures.

- Erosion – Mechanical degradation mechanism. **Comes in the form of Cavitation, Liquid Droplet Impingement, Flashing, and Solid Particle Erosion**

Background

- Thinning of feedwater heater shells has been observed and reported in nuclear units in France, Canada and the United States dating back to the 1980's.

- Thinning of heater shells and EDF designs for more FAC resistant heaters are presented in the EPRI FAC Book **(TR-106611-R1).**

- Although, there had been scattered incidents of thinning in feedwater heaters in nuclear plants, this issue was not very prominent up until the beginning of 1999.

Background (Continued)

- Starting in early 1999, a rash of heater failures (ruptures, leaks, severe thinning, and damage to internals) has resulted in a much higher priority being placed on FWH inspections.
- Many of these inspections have uncovered damage often necessitating repairs/replacements.
- Issuance of CHUG Position Paper 4, Rev. 1
  - Recommendations for Inspecting Feedwater Heater Shells for Flow-Accelerated Corrosion Damage

History of Significant Heater Failures - 1999 and later

- Starting in 1999, the United States had three significant failures occur.
- At one unit there was a fish-mouthed failure, at another two holes through the shell wall were found, and at the third one hole was found.
- In each of these cases, the failures were discovered while the stations were online.

Point Beach

- Point Beach is a two-unit PWR, located on Lake Michigan in Wisconsin.
- Details:
  - A fish-mouth rupture (about 27” long and up to 7/8” wide) occurred in the shell of a No. 2 heater.
  - The heater is horizontal and was manufactured by Struthers Wells.
  - The shell has a nominal thickness of 0.5”.
  - Failure occurred where the entering steam (about 88% quality and 347 °F) hit an impingement plate, fanned out and struck the shell.
  - The degradation extended approximately 4 feet along the length of the heater shell.
- Similar wear was found on the parallel heater.

Point Beach (Continued)

INPO O&MR-431, SEN-199 R1, OE-9941, OE-9958

Pilgrim

- Pilgrim is a BWR located near Plymouth, Massachusetts
- Details:
  - Two holes (each about ½”x 1” in size) were found in the shell of a No.3 heater.
  - The heater is horizontal and was manufactured by Yuba.
  - The holes were located in-line with the extraction steam inlet, approximately 45° down the shell from the inlet.

Pilgrim (Continued)

- Details:
  - A band of high wear area ran in the longitudinal direction of the heater shell.
  - The entering steam temperature was 297 °F.
- Shell thinning on both sides of the steam inlet was found on the failed heater, as well as the on the heater of the parallel train.

Pilgrim (Continued)

Susquehanna

- Susquehanna is a two-unit BWR located on the Susquehanna River in northeastern Pennsylvania.

- Details:
  - At Unit 2, a hole (about ½”x1-½” in size) was found in the east side of a No. 3 heater
  - The heater is horizontal and was manufactured by Yuba.
  - UT examination revealed a large area of washout.
  - The thinnest area was located adjacent to the steam impingement plate. Minimum reading of the shell on the west side was 0.388”, compared to the nominal thickness of 0.562”.

Susquehanna (Continued)

Geometry:

- Extraction steam enters the heater about ½ way along its length, at 288 °F with a steam quality of 91%
- Inside, there was a stainless steel liner extending about 45° from the steam inlet (at the 12 o'clock position) down both sides of the inlet
- The hole was in-line with the extraction steam inlet and at the 10 o'clock position. No wear was found in the inlet nozzle, which has an internal stainless steel overlay (Impingement Plate)

Susquehanna (Continued)

Subsequent inspections:

- On the two parallel train heaters - low readings of 0.053” and 0.157” were found. (nominal = 0.562”)
- On one of the No. 2 heaters inspected, the minimum thickness was found 0.337” versus a 0.562” nominal.
- No wear was found on a No. 4 heater inspected

Susquehanna (Continued)

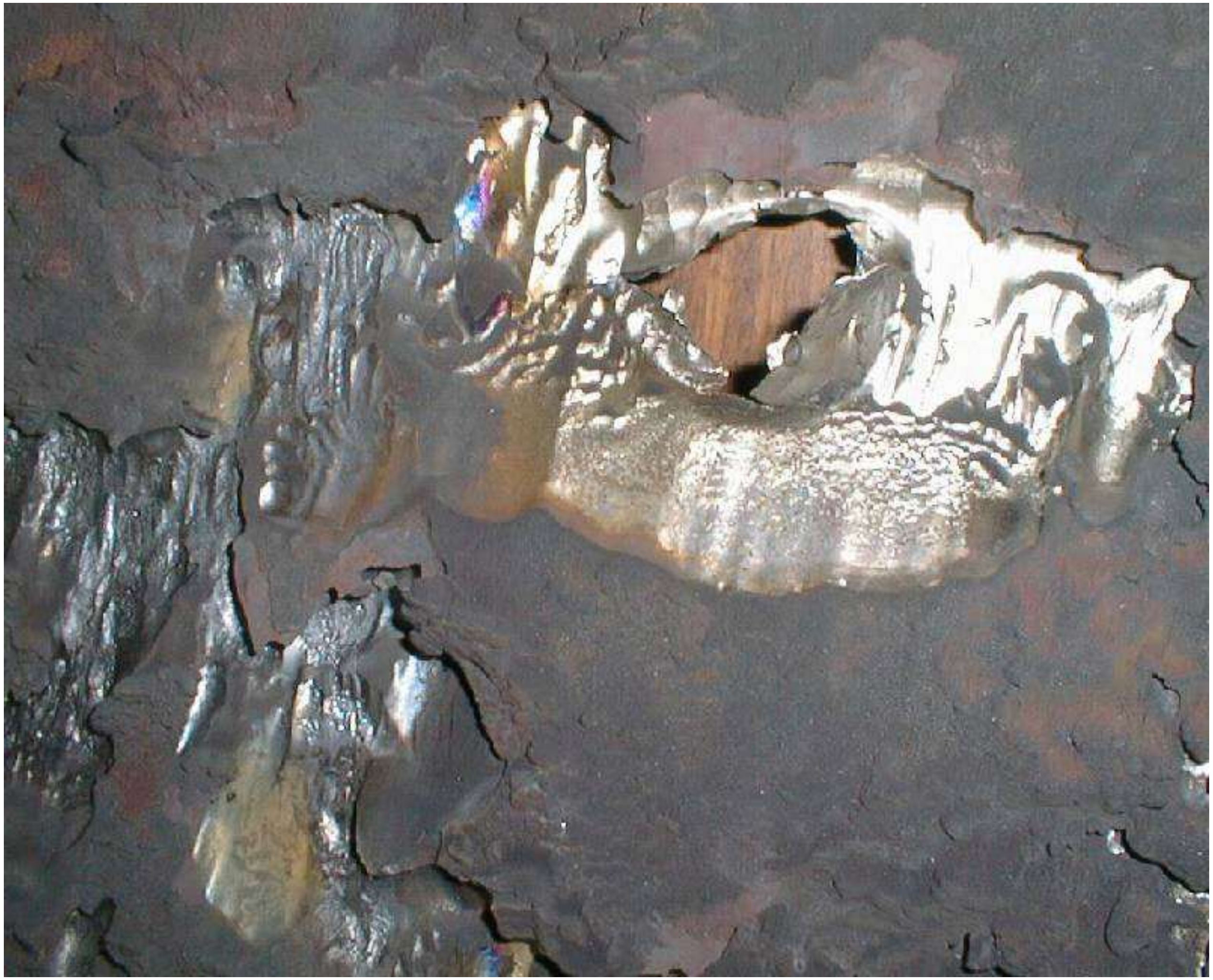
- Upon inspecting the Susquehanna Unit 1 heaters, similar shell damage as to the Unit 2 heaters was found. Unit 1 has also reported considerable damage to the internals of one of the No. 3 heaters
- In making repairs to the shell, considerable damage to the periphery of the tube support plates was found. This damage resulted in a number of unsupported tubes
- Repairs were made by wrapping the tube bundle with stainless steel bands and by inserting cables through the tubes followed by plugging them

Susquehanna Photographs (Continued)

Some Fossil Experience

- Northern States Power has reported that their Riverside Unit 8 fossil plant had experienced thinning of a feedwater heater shell
- The degradation is in a No. 2, low-pressure feedwater heater with an operating temp ~300° F. It is a vertical heater, made by Alco. There was no stainless steel liner. Degradation on both sides, approximately 10:00 and 2:00 positions. Original wall thickness was ~ 7/16"
- Note the hole shown is from handling

Riverside (Continued)



Inspection Selection Priorities

- The following guidance can be used to select which heaters to inspect:
  - Years in service (longer the service the more damage).
  - Operating temperatures above 300° F
  - Wet extraction steam (e.g. steam quality < 96%)
  - Low pH water chemistry (PWRs)
  - High steam velocity
  - Shell material of carbon steel (e.g., SA-285C, SA-515-70, etc.)
  - FAC caused wear in the upstream Extraction Steam piping may be used as an indication of possible wear in a given heater.
- These recommendations may be re-examined based on plant experience.

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Inspection Guidance

- It is ***very important*** to have manufacturers' drawings of the heaters to show where the tube support plates, tube sheet and any protrusions from the bundle (ears on the plates, tie-rods, etc.) are located.
  Experience has indicated that these protrusions may cause accelerated, local shell wear.

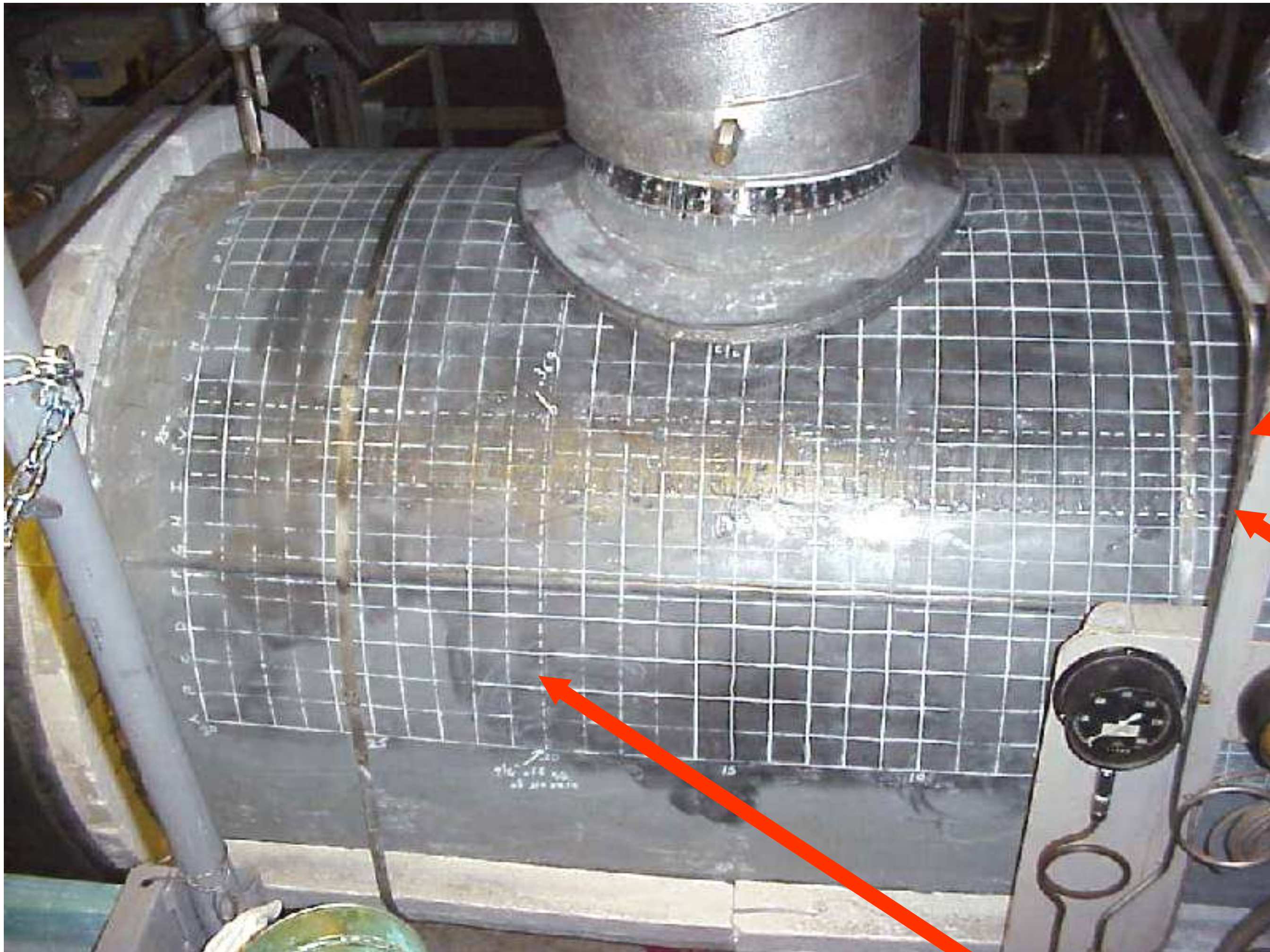
- If you find a shell that has experienced thinning, then you must be aware of the possibility of damage to the heater internals and the upstream Extraction Steam piping.

- Review NSAC-202L for Guidance

Inspection Techniques

- There are several basic inspection approaches
- Before performing any of them do your research. (Drawings, Insulation packages etc.)
- Use pulsed eddy current (PEC) technique through the insulation to get screening information. ***GO-NO-GO ONLY***
- Use pulsed eddy current (PEC) with selected UT “baselines” through holes in the insulation to get more accurate results
- Strip the insulation and use UT. It is good practice to note where the tube sheet and the tube support plates are located. Several utilities have noticed that there may be severe damage locally near these plates (CHUG Position Paper No.4)

Photograph of Good UT Practice



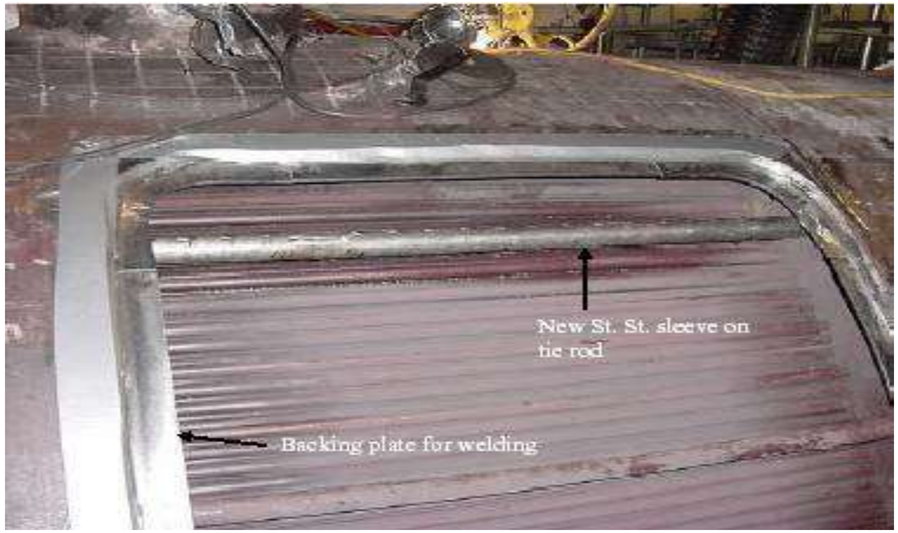
Internal features marked

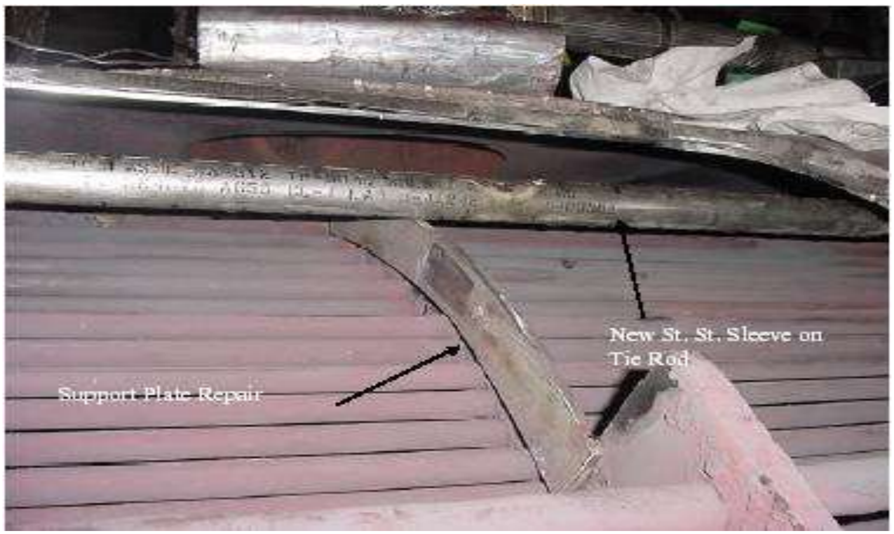
Repair Practices

- A large number of feedwater heaters have been repaired over the last several years
- Most repairs have been made by cutting a “window” out of the shell, and welding in a new piece of plate (i.e. Flush Patch Repair)
- Alternate repair methods are Caps, rolled plate, etc.
- EPRI 1003286, Repair Technology for Degraded Pressure Vessel and Heat Exchanger Shells
- The EPRI CHUG meetings beginning about January 2000 contain many presentations concerning these repairs. These presentations are available on the CHUG website
- The following photographs were presented at the January 2001 meeting

Repairs at Fort Calhoun (Courtesy of OPPD)

Repairs at Oyster Creek (Courtesy Amergen Energy Corp.)





Repairs at McGuire (Courtesy of Duke Power)

"Cap" Repairs

- Weld caps may be used to encapsulate components.
- They may provide a quick and cost effective alternative to flush patch and weld overlay repair methods.
- The cap is welded to the outside surface using a full penetration weld and replaces the encapsulated pressure boundary.
- Code compliance is restored without requiring defect removal. It eliminates removing the pressure boundary, foreign matter intrusion, and exposing internals to the environment.
- Weld caps have been used for heater repairs at several nuclear units. (e.g., see Wolf Creek presentation at the January 2004 CHUG meeting).

“Cap” Repairs (Continued)

Degradation Mechanisms Summary: Is Feedwater Heater Shell Damage FAC?

There are two good answers to this question:

- Materials
  - Stainless steel impingement plates are not damaged, but carbon steel shells are
  - Shells with trace chromium demonstrate immunity while "pure" carbon steel shells are attacked
- Morphology
  - the characteristics of the damaged surface indicate that the damage mechanism is FAC
  - See the photos on the next slide

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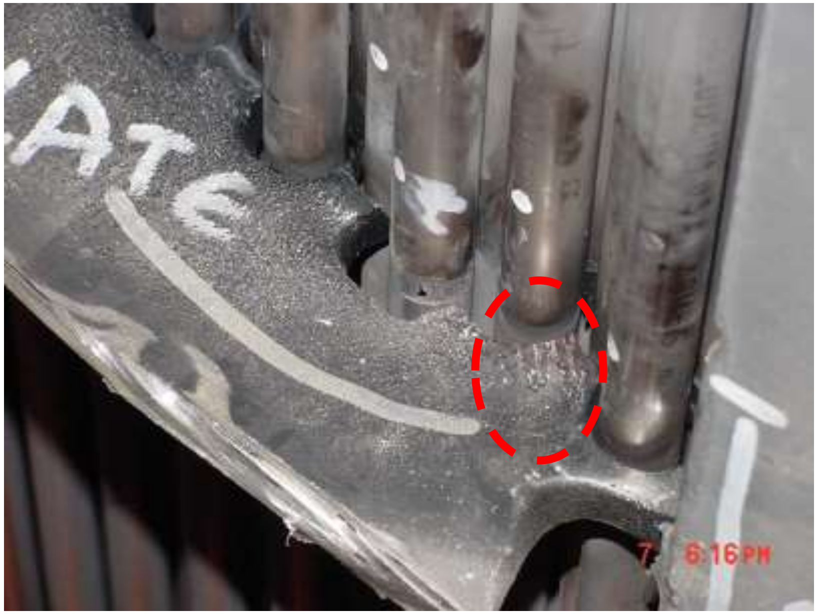
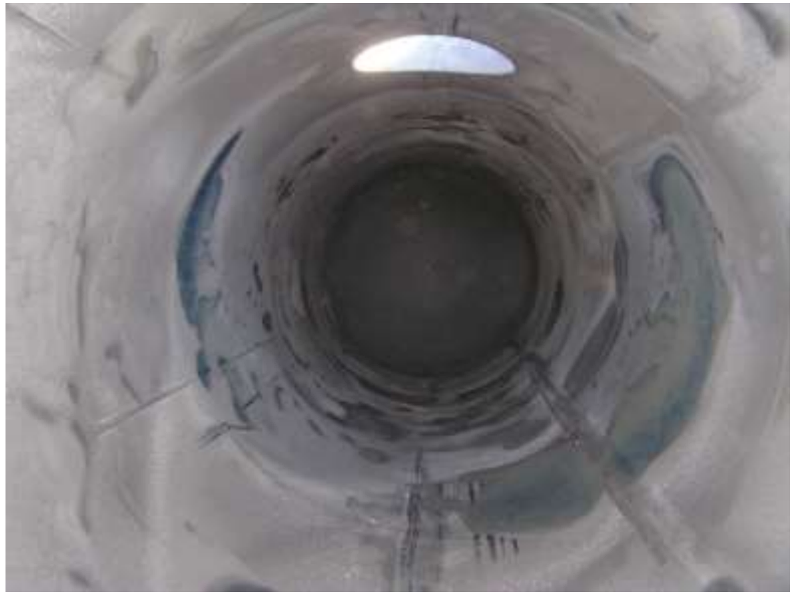
Feedwater Heater Damage

- FAC



FAC appearance on worn
tube support plate



Tiger striping on
worn shell

Degradation Mechanisms Summary

Water Chemistry - Changes in plant water chemistry can reduce the rate of FAC damage. Increasing the pH at operating temperature (the hot pH) for a PWR or increasing the amount of dissolved oxygen for a BWR can reduce the rate of FAC damage significantly.

Temperature – Between 225 deg. and 375 deg. Is the optimal FAC susceptibility temperature range; small operating condition changes and/or configuration changes can impact the component FAC susceptibility (MUR)

Steam Quality - Lower steam quality – Higher FAC Susceptibility

Material – FAC resistant material (CrMo – 0.04 Per.) will significantly reduce FAC damage; CAVEAT – need to completely understand the degradation mechanism to correctly select replacement material.

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Feed-Water System Team

Key Interface Organizations

FW System Engineer – Overall responsibility for System reliability and integrity.

Operations – Provides operating condition parameters and abnormal condition line-ups

Design Engineering- Provides input for plant modifications, configuration changes, etc.

FAC Program Engineer – Overall responsibility for FAC Program implementation and update; typically includes FW Heaters

Reference Material

- EPRI FAC Book **(TR-106611-R1).**
- EPRI NSAC-202L-R4 “Recommendations for an Effective Flow-Accelerated Corrosion Program”
- EPRI Field Guide” FAC and Erosion **(TR-3002008124)**
- Issuance of CHUG Position Paper 4, Rev. 1
- Issuance of INPO SEN-199, 2009
- EPRI Repair Technology for Degraded Pressure Vessel and Heat Exchanger Shells **(TR-1003286)**

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Conclusions

- Ensure you have a good understanding of the parameters that impact FAC Susceptibility
- Ensure you maintain good communications with your key interface organizations – NSAC 202L Key Element
- Work closely with your FAC Program engineer to optimize FW Heater reliability and integrity
- Ensure you validate the degradation mechanism to determine the correct long-term repair and/or replacement decision

Overtime Discussion

- How many utilities here know if all your FW Heaters have been inspected? (INPO Is tracking this)
- Has anyone found any significant shell damage to-date?
- What type of repairs and/or replacements have your utility performed?
- At your utility, who owns the FW Heaters component Health?
- Final FW Low Margin Piping – Excessive Unwarranted Inspections