Allegheny Energy

Accident Review
Hatfield’s Ferry Power Station

November 4, 2007
Salem Harbor Unit 3 Boiler Event – Technical Description

Event Date: Nov. 6, 2007
Station/Unit: Salem Harbor Unit 3
Manufacturer: B&W
Design: Natural circulation boiler, front wall fired
Year Constructed: 1958
Nominal MW Output: 150 MW
Fuel Type: Pulverized Coal
Rated Boiler Conditions:
- Superheat: 1965 psi/1000 °F
- Reheat: 467 psi/1000 °F
- 1,000,000 lbs/hr steam

General Failure Event Description:
The failure involved three division wall tubes off the front division wall header located inside the lower dead air space. One tube contained a number of small, localized areas of through-wall damage in and immediately above the header stub tube. Two adjacent tubes experienced complete double-ended ruptures of the stub tubes just above the stub-to-header shop weld and just below the stub to division wall tube field weld. The unit was at full load steady-state operation at the time of failure.

Component Description:
The front division wall header was specified to be 14” OD x 1-7/8” wall, SA 106 Grade B. There are a total of 33 division wall tubes coming off of this header. The tubes are specified to be 2-31/32” OD x 0.240” MWT, SA210-A1 material.

Root Cause Analysis:
The metallurgical analysis, performed by Structural Integrity Associates, Inc., concluded that the failure initiated at a weld-root defect in the stub-to-division wall tube field butt weld. This weld likely dated to the time of boiler construction. The defect consisted of entrapped slag and lack of fusion that was nearly through-wall in extent. The defect broke to the surface of the tube from minor in-service growth that had occurred over the last 50 years and a small steam leak initiated. The location of this leak was oriented in the direction that faced two adjacent tubes. Steam erosion from the initial leak caused steam cutting of one or both of these adjacent tubes until a second consequential leak developed, at which point a complex pattern of ricocheting steam was created, causing further erosion damage. The spacing of these tubes relative to one another allowed erosion damage to occur over a wide band, culminating in the complete double-ended rupture of two of the three tubes. It is suspected that the sudden release of large quantities of steam quickly pressurized the enclosed lower dead air space.
Pipe Failure at KCPL latex Plant on May 9, 2007

and Lessons Learned

Prepared by: KCPL and PII
February 21, 2008
Injuries & OHSA

- 2 People killed
- 1 Seriously Injured
- 3 Serious citations from OHSA
Desuperheater Supply Piping Failure
Failure occurred between gate valve & elbow
**THIS IS NOT A CONTROL VALVE, IT IS OPEN OR CLOSED**

Before

After
Iatan Station

- 670 MW (net) Station
- B&W Drum unit firing PRB coal
- Operating pressure 2975 psi at 1005F / 1005F
- In service for 27 years (1980 in service)
- Recently had run almost 3 years without accident
- Clean & reliable plant
Facts Leading Up To Event

- Unit was on line but in startup
- Feeders were plugging due to wet coal
- Operators were on feeder deck
- Main steam desuperheating station is located on feeder deck
- 4” Schedule 160 A106 Gr. C desuperheater pipe ruptured
- Desuperheater piping design 500F, 3200 psi; Operating conditions 485F, 2954 psi
Failure Mechanisms

- FAC induced by “Throttling Valve” defined as:
  - Low Ao/Ap
  - Abrupt step changes on outlet

- Localized high velocity due to downstream elbow
Valve Replacement Chronological Events

- Originally sent valve for repair 2/28/85
- Decided to buy new valve 4/22/86
- Higher pressure class valve received 9/26/86
- Replacement 9/28-29/86
FW01 1032

Original Design

Tee Reducer
8” to 4”

Flow

4” OD ~ 7’ 4” OD

Flow

FW01 1025

8” OD
Figure 2.9

Illustration of Wall Thickness Pattern at the Time of Rupture
Possible Origin of Fracture
(Thinnest Wall Thickness)

~ 7"

~ 4.5"

Overload Fracture Origin & Propogation

Figure 2.10
Figure 2.12
FW01-1032 Replacement Valve

Figure 2.11
Typical Separation and Re-Attachment After a Sudden Expansion ($V_R$ = Relative Velocity)

Figure 2
Figure 3

Illustration of Free-Vortex Flow Velocity Distribution
Factors Impacting FAC

- Velocities of flow: Increased velocity increased wear
- Temperature: 200-500°F
- Geometries of piping: Elbows, Reducers, Valves, etc.
- Piping materials: <0.1% alloy content, <0.5% 2 phase flow
- Water chemistry: Table
### Comparison of Normal Feedwater Cycle Chemistry Limits for AVT And OT as a Function of Feedwater Metallurgy

<table>
<thead>
<tr>
<th>Parameter</th>
<th>AVT(R) Mixed-Metallurgy</th>
<th>AVT(R) All-Ferrous</th>
<th>AVT(O) All-Ferrous</th>
<th>OT All-Ferrous</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>9 – 9.3</td>
<td>9.2 – 9.6</td>
<td>9.2 – 9.6</td>
<td>D. 9 – 9.4 O. 8 – 8.5</td>
</tr>
<tr>
<td>Cation Conductivity (μS/cm)</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.15</td>
</tr>
<tr>
<td>Fe (ppb) at EI</td>
<td>&lt;5 &lt;2</td>
<td>&lt;2</td>
<td>&lt;2 (&lt;1)</td>
<td>&lt;2 (&lt;0.5)</td>
</tr>
<tr>
<td>Cu (ppb) at EI</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
<tr>
<td>O₂ (ppb) at EI</td>
<td>&lt;5 (&lt;2)</td>
<td>&lt;5 (&lt;2)</td>
<td>&lt;10</td>
<td>D. 30 – 50 O. 30 – 150</td>
</tr>
<tr>
<td>O₂ (ppb) at CPD</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Reducing Agent</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>ORP (mV) at DAI</td>
<td>-300 to -350</td>
<td>-300 to -350</td>
<td>Oxidizing</td>
<td>Oxidizing</td>
</tr>
</tbody>
</table>

**Notes:**
- EI - economizer inlet, CPD - condensate pump discharge, DAI - deaerator inlet, D - drum unit, O - once-through unit
- * - Copper alloys may be present in condenser.
- + - These ORP values are meant to be indicative of a reducing treatment where a reducing agent is added to the feedwater, after the CPD, and oxygen levels are less than 10 ppb at the CPD. However, ORP is a sensitive function of many variables and may under these conditions be as high as -80 mV.

*From: EPRI Report #1008082*
Figure 1

Designation of Items Analyzed by PII Investigation Team (Item 3 = Failed Pipe)
## Alloy Content of Pieces

<table>
<thead>
<tr>
<th>Item Number</th>
<th>% Cr +% Mo</th>
<th>Wear Rate – Thinnest Area (Mils/Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 1 (Part of Valve FW01-1032)</td>
<td>3.03%</td>
<td>Negligible (Machine Marks are Still Visible)</td>
</tr>
<tr>
<td>Item 2 (Vertical Section of the Elbow, Downstream of the Failed Pipe, Item 3)</td>
<td>0.14%</td>
<td>3.4 mils/Year</td>
</tr>
<tr>
<td>Item 2 (Round Section of the Elbow)</td>
<td>0.03%</td>
<td>3.2 mils/Year</td>
</tr>
<tr>
<td>Item 3 (Failed Pipe, Downstream of FW01-1032)</td>
<td>0.03%</td>
<td>17.6 mils/Year</td>
</tr>
<tr>
<td>Item 4 (Downstream of FW01-1025)</td>
<td>0.14%</td>
<td>4.3 mils/Year</td>
</tr>
<tr>
<td>Item 5 (Downstream of Item 4)</td>
<td>0.13%</td>
<td>1.1 mils/Year</td>
</tr>
<tr>
<td>Item 6 (Downstream of Item 2)</td>
<td>0.03%</td>
<td>4.3 mils/Year</td>
</tr>
<tr>
<td>Item 7 (Part of FW01-1025)</td>
<td>0.20%</td>
<td>N/A</td>
</tr>
<tr>
<td>Item 8 (Downstream of Reducer)</td>
<td>0.21%</td>
<td>10.0 mils/Year</td>
</tr>
</tbody>
</table>
# Comparison of Calculation Results

<table>
<thead>
<tr>
<th></th>
<th>EPRI</th>
<th>Connected Flow Modeling</th>
<th>Actual Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failed Pipe</td>
<td>7.9 mils per year</td>
<td>19.1 mils per year after 1986</td>
<td>17.6 mil/year (average)</td>
</tr>
<tr>
<td>Elbow</td>
<td>17.6 mils per year</td>
<td>4.3 mils per year</td>
<td>3.2 mils per year</td>
</tr>
<tr>
<td>Downstream of 1025</td>
<td>7.9 mils per year</td>
<td>4.2 mils per year</td>
<td>4.3 mils per year</td>
</tr>
</tbody>
</table>
10 Lessons Learned

- Actively participate in industry FAC forums and benchmark against high performers
- Define a corporate policy and organizational responsibilities
- Develop FAC Procedures
- Utilize predictive computer models such as checkworks or checkup in conjunction with engineering judgment
10 Lessons Learned

- Ensure inspections are made downstream/upstream of components and arrangements likely to cause FAC (This includes valves with step changes on outlet)
- Select piping and geometries originally and in modifications to limit velocities < 15 fps. Consider internal geometries on wall erosion
- Ensure feedwater chemistry is optimized to limit FAC
- Utilize chromium piping where high wear is expected
- Maintain configuration documentation
- Root cause analysis of any failure
FAC Policy Decisions

- Piping below 75% of design minimum wall thickness (factor of safety of 3) will be replaced at next forced outage if parts are available (Design minimum wall is a calculated # based on hoop stresses, while nominal wall is the thickness as specified in original specifications).
- Piping below 50% design minimum wall thickness will be replaced immediately.
- V.P. approval will be required to operate beyond these time frames.
Engineering Details

- Design
  - Valves:
    - Bigger is not always better particularly with higher pressure class valves
    - Low Ao (valve exit)/Ap (pipe ID) ratios adversely impact FAC
    - Specify “C” dimension on valve outlet to match pipe
    - Eliminate sudden dimension changes on valve outlets (<15 degrees will not have flow separation)

- Piping
  - Two phase flow best addressed with =>1.25% chromium material
  - Higher than expected spray flow rates on units burning PRB make desuperheater spray supply lines susceptible to FAC
Engineering Details

- Design (continued)
  - Material
    - A106 piping alloy content varies and is crucial to resisting FAC
    - Be aware of localized erosion from “entrance-effects” (alloy piping followed by carbon steel piping)
    - Input all valves as carbon steel in CHECWORKS, regardless of actual material
    - Carbon steel downstream of stainless FWH is susceptible to entrance effect

- Training
  - Train everyone to recognize FAC
Thinning
Engineering Details

- A Structured FAC Program (continued)
  - Check high energy piping in high traffic areas, regardless of indicated susceptibility
  - Control alloy content of A106 pipe or location that it is installed in new plants
  - Checking high wear areas as indication of status of other areas is not guarantee
  - Be aware that similar geometries and process conditions can have widely different wear rates
  - Once you changed to an all ferrous system, chemical clean ASAP so you can move to higher PH
Vendors Providing Support to KCPL

- Aptech – Eddy Current Testing on line (Marvin Cohn 408/636-5360)
- CSI – CHECWORKS support and written program (Robert Aleksick 847/836-3000)
- EPRI – Report # 1008082, Training Programs
- Performance Improvement International (PII)– Root Cause Analysis and Lessons Learned from Past Industry Events (Dr. Chiu 760/722-0202)
Conclusion

- Have a formal FAC program with executive support
- Configuration Management and Root Cause Analysis are proactive approaches to identifying issues and do not rely on vendor to determine what is equivalent or acceptable
- Industry standards need to be raised and maintained
- You do not want to have an FAC incident!
Serious Injuries from Falls Through Grating
Four Duke Energy employees and contractors have been seriously injured or killed in the last 20 months as a result of falling through or from floor grating.
Falls Through Grating
Falls Through Grating
Falls Through Grating
Falls Through Grating

3 feet from the position of Employee #2 to grating opening
Falls Through Grating
Falls Through Grating

• Common themes:
  – Not assessing the workplace to identify fall hazards.
  – Temporarily removing grating and failing to take the precautions necessary to remove the fall hazards.
  – Failure to follow procedure.
Falls Through Grating

• Duke’s Safe Work Practice Manual:
  – Prior to beginning each job, an assessment must be performed to determine if fall hazards are present and if protective measures are needed. Workers must be informed of the fall hazards and protective measures.
  – For work around holes more than 6 feet above lower levels, including holes created by temporarily removing grating, a personal fall arrest system, covers, or guardrails shall be erected around the holes.
Falls Through Grating

• Actions taken:
  – Published a Safety Alert to all business units identifying the trend.
  – More emphasis at generating plants on controlling removal of grating.
  – More emphasis on assessing the workplace and identifying potential fall hazards.
  – Increased emphasis on compliance with requirements to wear fall protection.
Team Recommendations

- Upgrade communications.
- Upgrade heavy equipment cab safety.
- Install beacons to designate coal feeder in operation.
- Install video system to monitor coal feeder areas.
- Marking of coal feeders.
- Coal pile lighting.
- Review training manuals.