Reactor Coolant Leakage from a Safety Injection Nozzle Weld at the Oconee Nuclear Generating Station

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March 11, 2014

General Overview of the Event

- November 8, 2013:
  - Oconee Units 1 and 3 are operating at full power
  - Oconee Unit 2 is in a refueling outage (defueled)
- Oconee Unit 1 developed a 0.08 gpm Reactor Coolant System (RCS) leak
- The leak is identified in the 1B2 High Pressure Injection (HPI) nozzle safe end to piping stainless steel (SS) weld.
- The Unit is shutdown, and the Failure Investigation Process is entered to investigate the cause of the leak.
- The weld is replaced, extent of condition on the other units completed, and the unit returned to service.

Background

- Generic Letter 85-20, "Resolution of Generic Issue 69, High Pressure Injection/Make-up Nozzle Cracking"
- NRC Bulletin IE 88-08, "Thermal Stresses in Piping Connected to Reactor Coolant Systems"
- 1997 Oconee Nuclear Station (ONS) Unit 2 RCS Leak at 2A1 HPI pipe to safe end weld caused by thermal fatigue (subsequent shutdown of Units 1 and 3 as part of extent of condition)
- NRC Information Notice 97-46, "Un-isolable Crack in High Pressure Injection Piping"
- 1997: NDE-960, Rev 0, "Ultrasonic Examination of High Pressure Injection System Welds and Base Material at Oconee Nuclear Station" issued
  - 60 degree angle probe for primary axial scanning
  - Specified to flat top the weld crown if not accessible from both sides
  - 60 degree angle probe for austenitic welds with single sided access
- 2004: NDE-995, Rev 0 "Ultrasonic Examination of Small Diameter Piping Butt Welds and Components for Thermal Fatigue" issued
  - Does not require weld flat topping
  - Primary use of 45 degree probe, 60 degree for confirmation
  - Does not require coverage quantification for limitations

Background

- 1B2 Safe-end to Pipe Weld History
  - 1997: Weld replaced as part of valve replacement mod
    - RT Indications
    - Weld repaired
  - 2000: UT Indications found during augmented inspection
    - RT Unacceptable
    - Weld ground out and replaced
  - 2013: Self revealing through wall crack

General Arrangement

Investigation – Fault Table

- Weld Defect
  - Original Weld
  - 1997 Repair
  - **2000 Weld Repair**
- Fit-up Configuration Issues
- Vibration Fatigue
  - Vortex Shedding
  - **RCP Induced**
  - **HPI Full Flow Test**
  - Acoustic Resonance
  - Various modes
- Material Degradation
  - Thermal Aging
  - Stress Corrosion Cracking
  - Chemical Attack
  - Erosion
- Overload
  - Overpressure
  - Failed snubber or restraints
  - Direct Impact
  - Waterhammer
- Thermal Fatigue

Testing to Support or Refute Fault Table Items

- Chemistry Patch Test for contaminants
- 1B2 Pipe and Hangers inspected for conformance to design
- Radiographic Test (RT) 1B2 Thermal Sleeve
- Metallurgical analysis of crack
- Backflow testing
- Collected vibration data (HPI Flow Test, RCP starts)
- Extent of Condition
  - Ultrasonic Test (UT) and Penetrant Test (PT) all 4 U1 HPI nozzles (UT not done on 1B2)
    - Augmented Inspection Procedure (NDE-995)
    - PDI-UT-2
    - UT with encoded phased array
  - UT using PDI-UT-2 on all welds previously inspected with NDE-995
  - Reviewed historical RT on all 4 HPI nozzles
    - Weld installation RT
    - Augmented Inspection RT of Thermal Sleeves
    - Greater than 50% thru-wall crack evident on 1B2 in 2011

Extent of Condition

- Unit 2 (Refueling)
  - Limitations identified in prior HPI weld inspections
  - All HPI welds inspected
    - Dye Penetration Test (PT)
    - Ultrasonic Test (UT)
      - PDI-UT-2
      - Encoded phased array
    - One weld rejected
      - Radiographic Test (RT)
  - Four additional welds inspected
- Unit 3 (Operating)
  - Prompt Determination of Operability performed
    - No limitations in HPI safe end weld UT exams
    - Four valve-to-valve welds with limited coverage were RT'd

Cause of the Event

- What initiated the crack?
- What caused the crack to propagate?
- Why didn't we find the crack?

Cause of the Event

- What caused the crack?
  - Geometry
    - Significant corner on the pipe weld ID
    - Slight piping misalignment
    - Weld position on the safe end
    - Natural frequency
  - Operating conditions
    - 2003 1B2 RCP High Vibrations
    - 2008 1B2 RCP Seal Failure and High Vibrations during shutdown

Cause of the Event

- What caused the crack to propagate?
  - Periodic High Pressure Injection flow tests
  - Supporting Analysis
    - Metallographic exam
    - Fracture Mechanics
    - Vibration Testing

Cause of the Event

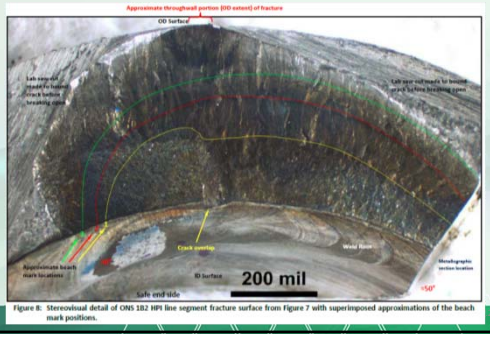

Figure 8: Stereovisual detail of ONS 1B2 HPI line segment fracture surface from Figure 7 with superimposed approximations of the beach mark positions.

Cause of the Event

- Fracture mechanics

10 Hz Loading Frequency		50 Hz Loading Frequency	
Peak-to-Peak Stress (Ksi)	Time to Reach Thru-Wall	Peak-to-Peak Stress (Ksi)	Time to Reach Thru-Wall
1	438 Days	1	88 Days
5	52 Hours	5	10 Hours
10	5.3 Hours	10	1.1 Hours

1Ksi stress producing 1E-10 to 1E-08 inches/cycle
5 Ksi stress producing 1E-08 to 3E-06 inches/cycle
10 Ksi stress producing 1E-07 to 3E-05 inches/cycle
Met Lab reported sub-micron sized striations (less than 4E-05 inches)

- HPI Full Flow Testing
  - Vibration Analysis
  - Prior leak during flow testing
  - 10.6 hours cumulative test duration on 1B2 line

Cause of the Event

- Why didn't we find the crack?
  - NDE-960, Rev 0, "Ultrasonic examination of High Pressure Injection System Welds and Base Material at Oconee Nuclear Station"
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    - Does not require weld flat topping
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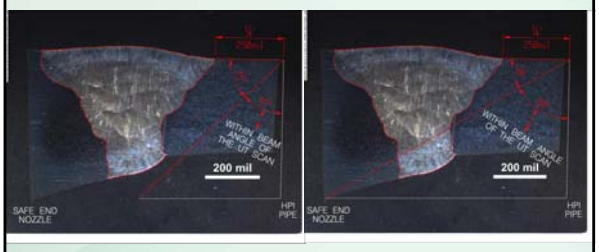
    - Does not require coverage quantification for limitations
  - ISI Section XI Functional Area Manual (FAM)
    - Inadequate guidance for the conduct of Augmented Examinations
    - Unclear expectations to disposition Augmented Examinations with limitations
    - Inconsistent or cumbersome documentation of acceptance criteria and weld volume coverage
    - Unclear expectations to enter Augmented Examination limitations into the Corrective Action Program

45 and 60 Degree Scan Differences



Cause of the Event

- Mechanical, high cycle fatigue
  - Initiating crack cause unknown, likely 2008 high 1B2 Reactor Coolant Pump vibration during seal failure
  - Crack growth likely resulted from periodic HPI system Full Flow Test
- Inadequate technical procedure guidance
  - Inadequate disposition of results when conditions limited examination of the weld volume
- Inadequate administrative guidance in ISI Section XI Functional Area Manual
  - Conduct of Augmented Examinations
  - Disposition of UT results when conditions limited examination of the weld volume

Questions?