Steam Generator Tube Degradation

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February 7, 2013
Agenda

• Opening Remarks
  – Bill Borchardt, Eric Leeds

• Accident Analysis
  – Chris Jackson

• Operating Experience/Oversight
  – Ken Karwoski
Accident Analysis

Chris Jackson
Branch Chief
Reactor Systems Branch, NRR
Safety Analyses

- Final Safety Analysis Report
- Anticipated Operational Occurrences and Accidents

- Objectives for Design Basis Accidents
  - Fuel Design Limits
  - RCS Pressure Boundary
  - Containment Design
  - Dose Consequences
Safety Analyses

- Steam generator tubes transfer heat from the reactor to the turbine
- Steam generators form a barrier between the reactor coolant and steam system
Safety Analyses

• Steam generators provide an input to many important accident analyses
  – RCS flow, heat removal, steam pressure, core inlet and exit temperature, power

• Failure of steam generator tube is an accident (SGTR)
Steam Generator Tube Rupture is a Design Basis Accident

- SRP Section 15.6.3
  - Dose Perspective
- Not limiting
  - Fuel Design
  - Containment
Steam Generator Tube Rupture is a Design Basis Accident

• Reactor Operators Play an Important Role in plant Recovery
• Operators are Trained and Tested on this event
Ginna Event

• In 1982 a tube rupture occurred at Ginna
  – Steam side of steam generators filled with water
  – Water entered the steam lines
  – Water was discharged through steam relief valves into atmosphere
Ginna Event

- NRC issued GLs 1982-07, 08, 11
- Licensees took action through Owners Group initiative to improve SGTR recovery capability
  - WCAP-10698-P-A (ML071430455)
Safety Analyses - Conclusion

• SGTR is not a limiting event from a fuel damage or containment pressure perspective
• SGTR accident analysis demonstrates that dose consequence are within the regulatory limit
Steam Generator Operating Experience and Oversight

Ken Karwoski
Senior Level Advisor Division of Engineering, NRR
Steam Generator Designs

• 2 major types of steam generators
  – Recirculating: “U-shaped” tubes
  – Once-through: Straight tubes

• Steam generator tube materials
  – Mill Annealed Alloy 600 (600MA)
  – Thermally treated Alloy 600 (600TT)
  – Thermally treated Alloy 690 (690TT)
Recirculating and Once Through Steam Generators

Recirculating  Recirculating  Once Through
Types of Tube Degradation
Managing Tube Degradation

- Degradation has led to industry proposals to implement various tube repair criteria and methods
- Operating conditions and maintenance can affect steam generator lifetime
- Staff’s focus is on tube integrity
Steam Generator Replacements

• 57 of 69 units have replaced
• Incorporated design enhancements to address degradation
• Replaced using 10 CFR 50.59 process since 1989
  – Regional Inspections
Cracking in Alloy 600TT Tubing

- First instance of cracking detected in 2002 (2\textsuperscript{nd} generation tube material)
- Since 2002, cracks detected at several locations along tube length
- Number and severity of cracks, to date, has been minor
Steam Generator Tube Wear

• Detected in both original and replacement steam generators

• Number of indications of detected wear varies from none to thousands

• Severity of wear determines the safety significance not the number of indications
Tube-to-Tube Wear - Replacement Once Through Steam Generators

- Indications attributed to tube-to-tube contact in Fall 2011
- Wear is shallow and slow growing
- Root cause evaluation underway
Tube-to-Tube Wear – Once Through Steam Generators
San Onofre Tube Wear

• Mitsubishi replacement recirculating steam generators

• Unit 2 wear
  – Loose parts/foreign objects
  – Tube supports and retainer bar
  – Tube-to-tube wear

• Unit 2 operated full cycle and maintained tube integrity
San Onofre Tube Wear (cont.)

- Unit 3 shut down half way through cycle due to primary-to-secondary leakage
- Unit 3 wear
  - Tube supports and Retainer bar
  - Tube-to-tube wear
- 8 tubes did not have adequate tube integrity in Unit 3
Regulatory Framework

• Inspection/Repair of tubes governed by plant technical specifications
• Original technical specifications developed in 1970s
• Improved specifications are risk informed, performance based
• All plants have adopted
NRC Oversight/Monitoring

- **Multi-Tiered approach**
  - Regional activities
  - Headquarters activities
  - Industry interactions

- **Public Transparency**
NRC Research Activities

• Steam generator research performed since 1970s
  – Inspection
  – Integrity
  – Corrosion

• International Steam Generator Tube Integrity Program
Industry Program

• Industry responded to emerging degradation

• Industry standardized programs for addressing steam generator issues
  – Water Chemistry Guidelines
  – Inspection and Integrity Guidelines
  – Primary-to-Secondary Leakage Guidelines
Steam Generator Performance

• Performance has improved since 1970s
• Prior to 2012 last time a plant did not have adequate tube integrity was 2003
Steam Generator Tube Rupture Frequency
Defense-in-Depth

- Design
- Design Basis Accident
- Operator Training
- Tube Inspections and Assessments
- Operational Programs
- Risk Significance
Summary

- Steam generator tubes may degrade
- Degradation can be managed
- Staff monitors steam generator operating experience
- Staff’s focus is on tube integrity
- Performance has improved
Acronyms

• avg. - average
• CFR – Code of Federal Regulations
• cont. - continued
• GL – generic letter
• IGA - intergranular attack
• MA - mill annealed
• NRC - Nuclear Regulatory Commission
• NRR – Office of Nuclear Reactor Regulation
• ODSCC - outside diameter stress corrosion cracking
• PWR - pressurized water reactor
Acronyms (cont.)

- PWSCC – primary water stress corrosion cracking
- RCS – reactor coolant system
- SG – steam generator
- SGTR – steam generator tube rupture
- SRP – standard review plan
- SS – stainless steel
- TT – thermally treated
- yr - year