

# **Experience with Flow-Induced Vibration**

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# Design

- **Westinghouse has designed and manufactured steam generators (SGs) for 40+ years**
- **Potential for flow-induced vibration (FIV) is routinely analyzed in every SG design**
  - **Tubes**
  - **Moisture Separators/Dryers**

# Design

- **Input parameters and methodologies used in FIV analysis are documented in the technical literature**
  - **Extensive testing performed to support analytical methodology**

# Design

- **Improvements in analytical methods have been made as operating experience and test data have evolved**
  - **Replacement steam generator (RSG) U-bend assemblies have incorporated design enhancements**

# Manufacturing

- **Field modifications have been effective in resolving original SG FIV issues**
  - **Complete anti-vibration bar (AVB) assembly replacement**
  - **Pre-heater modifications**

# **Manufacturing**

- **Westinghouse manufacturing processes have improved for RSGs and new SGs**
- **Advanced AVB design since 1990s**
  - **Tighter dimensional controls on components**
  - **Improved assembly, oversight and documentation**

# **Operating Experience**

- **Original SGs**

- **Good performance with few issues observed**

- **A limited amount of AVB wear has been observed in different models**
    - **Some short-term rapid wear in early life due to manufacturing issues has been observed**
    - **Over the long term, with a few exceptions, AVB wear has not challenged pressure boundary integrity**

# Operating Experience

- **AVB replacements in 19 original SGs, implemented 1985 – 1993**
  - **Effectively minimized AVB wear in Model 51 and one Model F plant by incorporating an expandable design**
  - **Other Westinghouse model SGs did not have wear issues**



# Operating Experience

- **Model D3 - FIV issues resulted in tube leak in a Westinghouse pre-heater SG design**
  - **Field modifications to divert flow in pre-heater**
- **Model D4/D5 – Pre-heater wear not as severe as Model D3 (no tube leaks)**
  - **Tube expansion**
  - **Split feedwater flow**

# Operating Experience

- **Replacement SGs**
  - **No significant operational issues have been observed**
  - **A fraction of 1% of tubes have experienced AVB wear**
  - **Many Westinghouse RSGs have no AVB wear indications after one or more cycles of operation**

# **Chronology of Significant FIV Issues**

- **AVB Wear Resulted in Tube Leak (1983, Model 33)**
  - **Related to manufacturing issue**
- **Pre-heater Wear (1983, Model D3)**
  - **Caused by turbulence and out-of-plane fluidelastic instability**
  - **Resolved by flow control modification and improved tube support**

# **Chronology of Significant FIV Issues**

- **Tube Rupture due to High Cycle Fatigue (1987, Model 51)**
  - **Caused by denting at top tube support and variation in AVB insertion depth**
  - **Addressed by analysis, the installation of sentinel plugs and stabilizers in a few tubes at some plants in response to NRC Bulletin 88-02**

# **Chronology of Significant FIV Issues**

- **Rapid AVB Wear (1992, Model F)**
  - **Related to manufacturing issue in one SG**
  - **Resolved by AVB replacement (improved gap control)**

# **Recent SONGS RSG Experience**

- **Westinghouse performed an evaluation for SONGS Unit 2 addressing tube wear at AVBs, tube-to-tube wear (TTW) and the potential for in-plane instability in the U-bend**
  - **Westinghouse concludes that TTW observed in two tubes in Unit 2 results from proximity of the tubes and out-of-plane vibration and/or in-plane turbulence and not from in-plane instability**

# Recent SONGS RSG Experience

- **Eddy current data shows:**
  - **No extension of wear scars beyond the width of the AVB, not only in these tubes, but other tubes in Unit 2 as well**
  - **Vibration due to in-plane instability will cause extension of the wear scars beyond the width of the AVB, as observed in Unit 3**
- **The two Unit 2 tubes with TTW have no indications of top tube support plate wear as found with tubes with in-plane instability in Unit 3**

# **Recent SONGS RSG Experience**

- Westinghouse evaluation was documented in an operational assessment for the three degradation mechanisms**



# Summary

- **Westinghouse has observed issues related to FIV in the past in original SGs**
- **As a result of our experience with tube wear and fatigue over the past two decades, we have incorporated enhanced design, manufacturing, and oversight into our RSGs and recent new SGs**

# Summary

- **Westinghouse strives for zero wear through our design and manufacturing; as a result, minimum wear has been observed**
- **Tube wear in original SGs in service is managed in accordance with NEI 97-06 SG performance criteria**
- **SGs satisfy performance criteria and are safe to operate**