NRC Regulatory Information Conference

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History of Replacement Steam Generators

- Replacement Steam Generators awarded to Mitsubishi Heavy Industries (MHI) in September 2004
  - Unit 2 RSGs installed in Fall 2009
  - Unit 3 RSGs installed in Fall 2010
- Replacement performed in accordance with NRC requirements
- Two license amendments were submitted and approved

Unit 3
Tube Leak and Tube-to-Tube Wear

- Steam Generator tube leakage occurred on Jan. 31, 2012
- Leakage was small and managed by plant operators using established plant operating procedures
- Approximately 11 months of full power operation following installation of Replacement Steam Generators
- Inspections found unexpected Tube-to-Tube Wear (TTW)

Unit 2
Steam Generator Inspection Results

- Unit 2 Cycle 17 Inspection Results
  - Steam Generator Technical Specification performance criteria were satisfied
  - Per industry guidelines, a single tube pressure test was required for Retainer Bar Wear and performed with satisfactory results
- Tube Wear Locations
  - Wear was detected at:
    - Anti-Vibration Bars (AVBs)
    - Tube Support Plates (TSPs)
    - Retainer Bar locations
    - Free-span Tube-to-Tube Wear (TTW)

Unit 3
Steam Generator Inspection Results

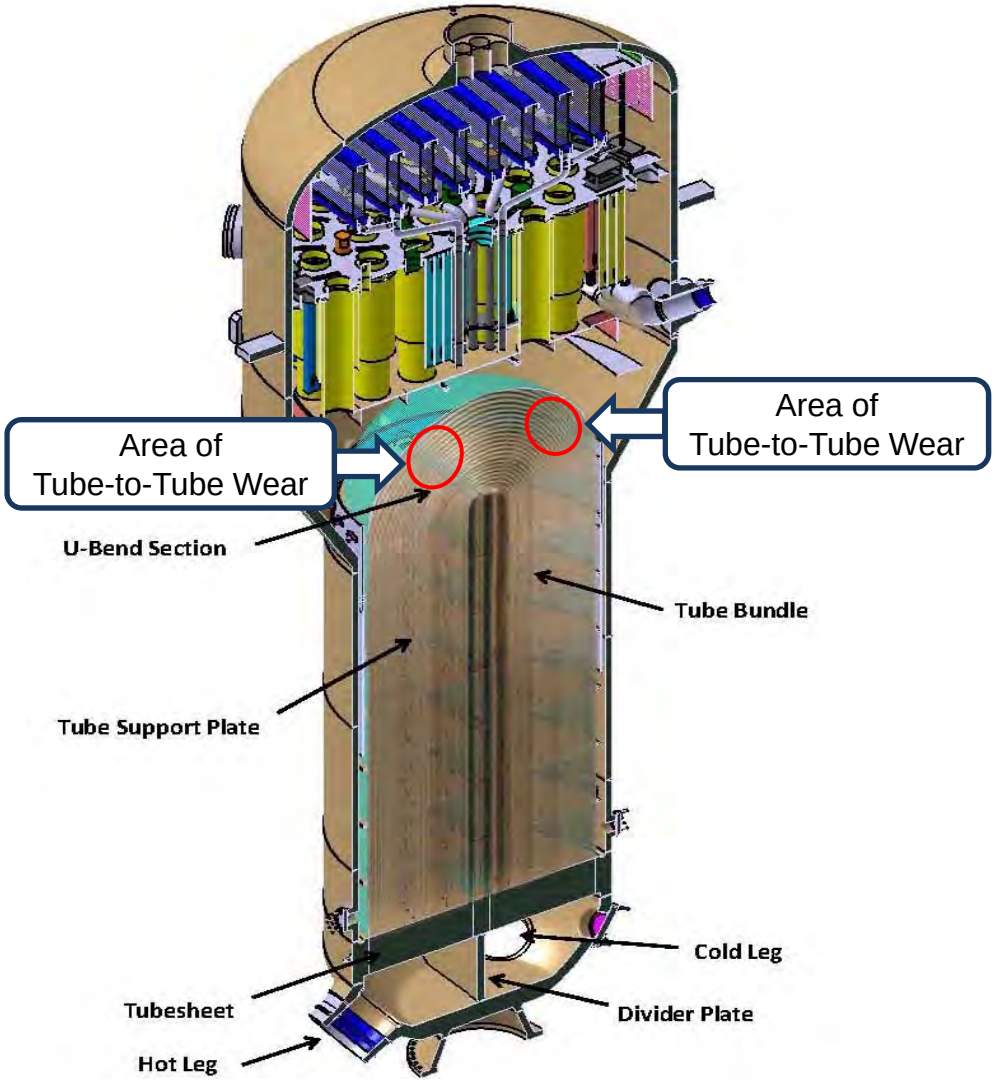
- U3 Mid-Cycle Inspection Results
  - Steam Generator Technical Specification performance criteria were not satisfied
  - Per industry guidelines, 129 tube pressure tests were required due to Tube-to-Tube Wear
  - Eight tubes did not meet performance criteria due to Tube-to-Tube Wear
- Tube Wear Locations
  - Wear was detected at:
    - Anti-Vibration Bars (AVBs)
    - Tube Support Plates (TSPs)
    - Retainer Bar locations
    - Free-span Tube-to-Tube Wear (TTW)

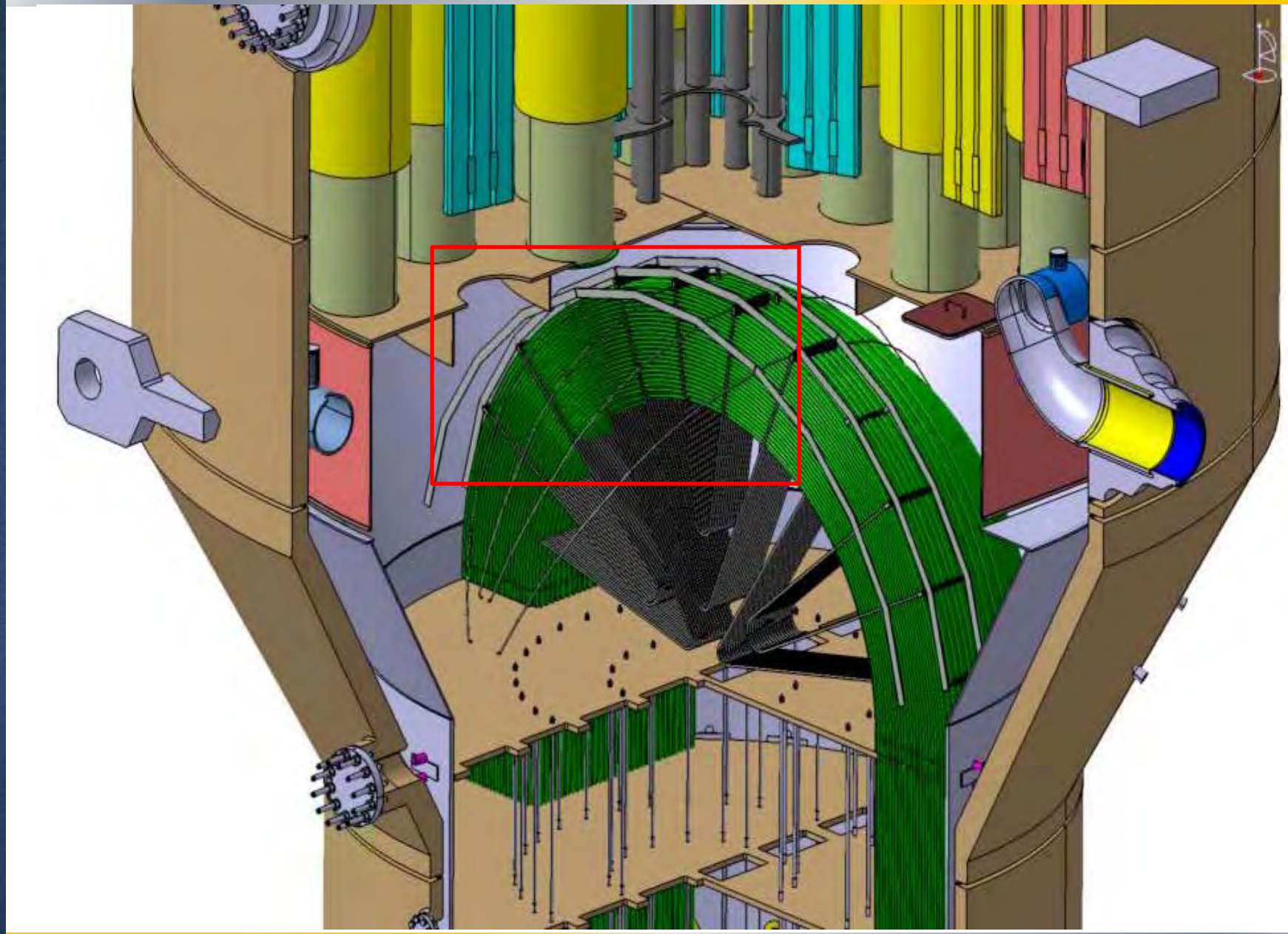
Technical Expertise Supporting SCE

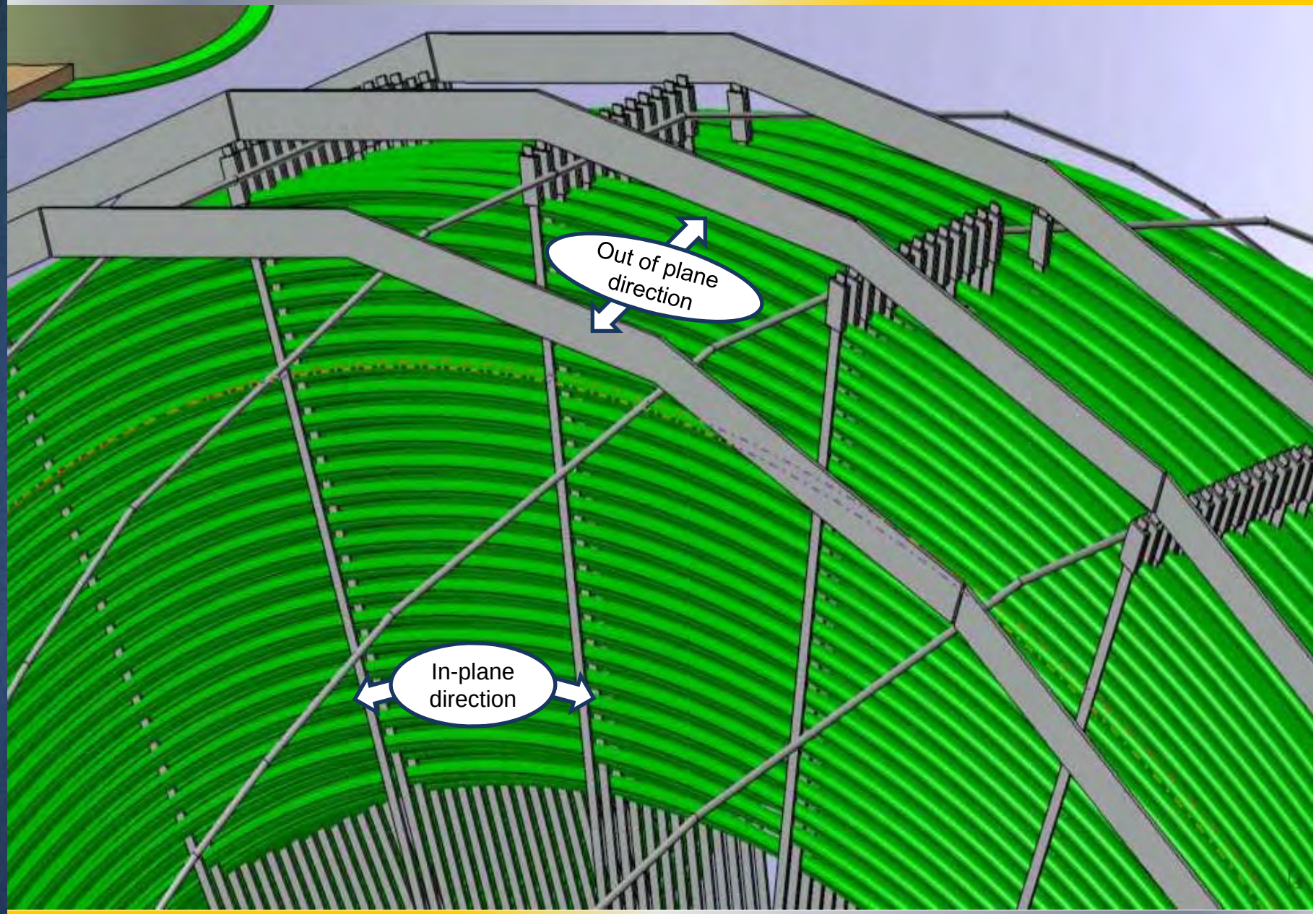
- Mitsubishi Heavy Industries
- AREVA
- Westinghouse
- B&W Canada
- MPR Associates
- EPRI

- Industry personnel, recognized academics and specialized consultants

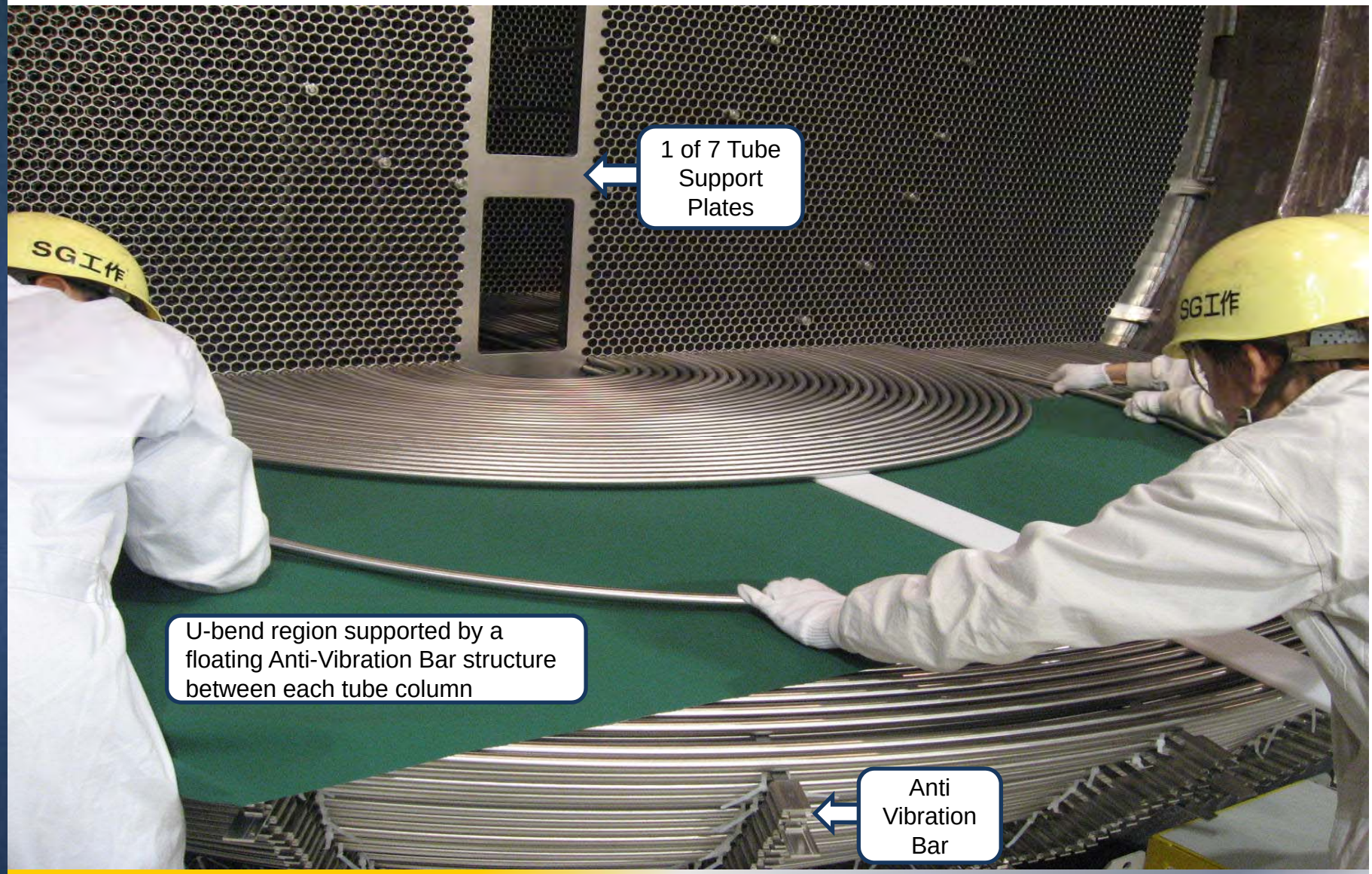
Steam Generator Cut-Away Elevation View





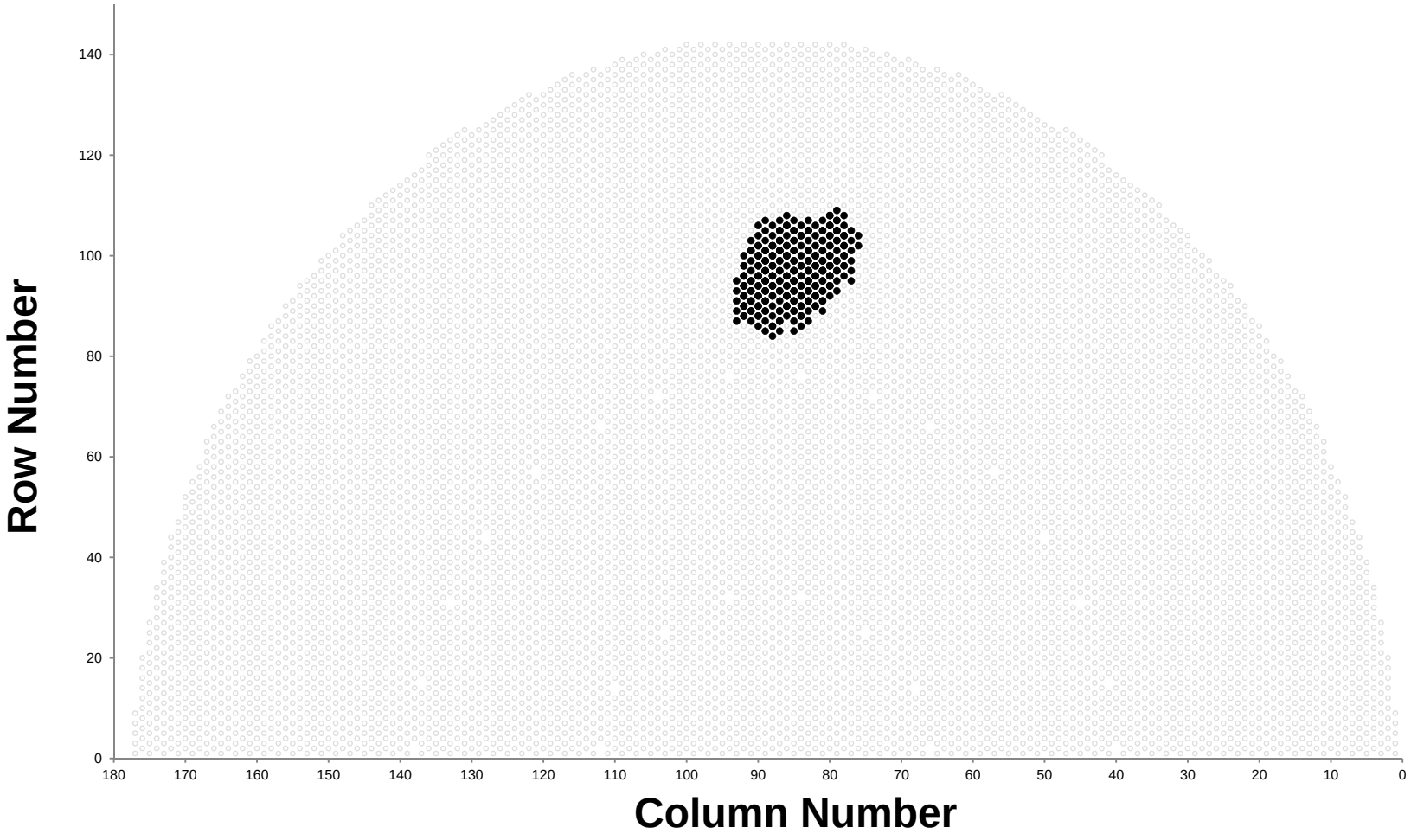

Out of plane direction
In-plane direction

Steam Generator Tubes

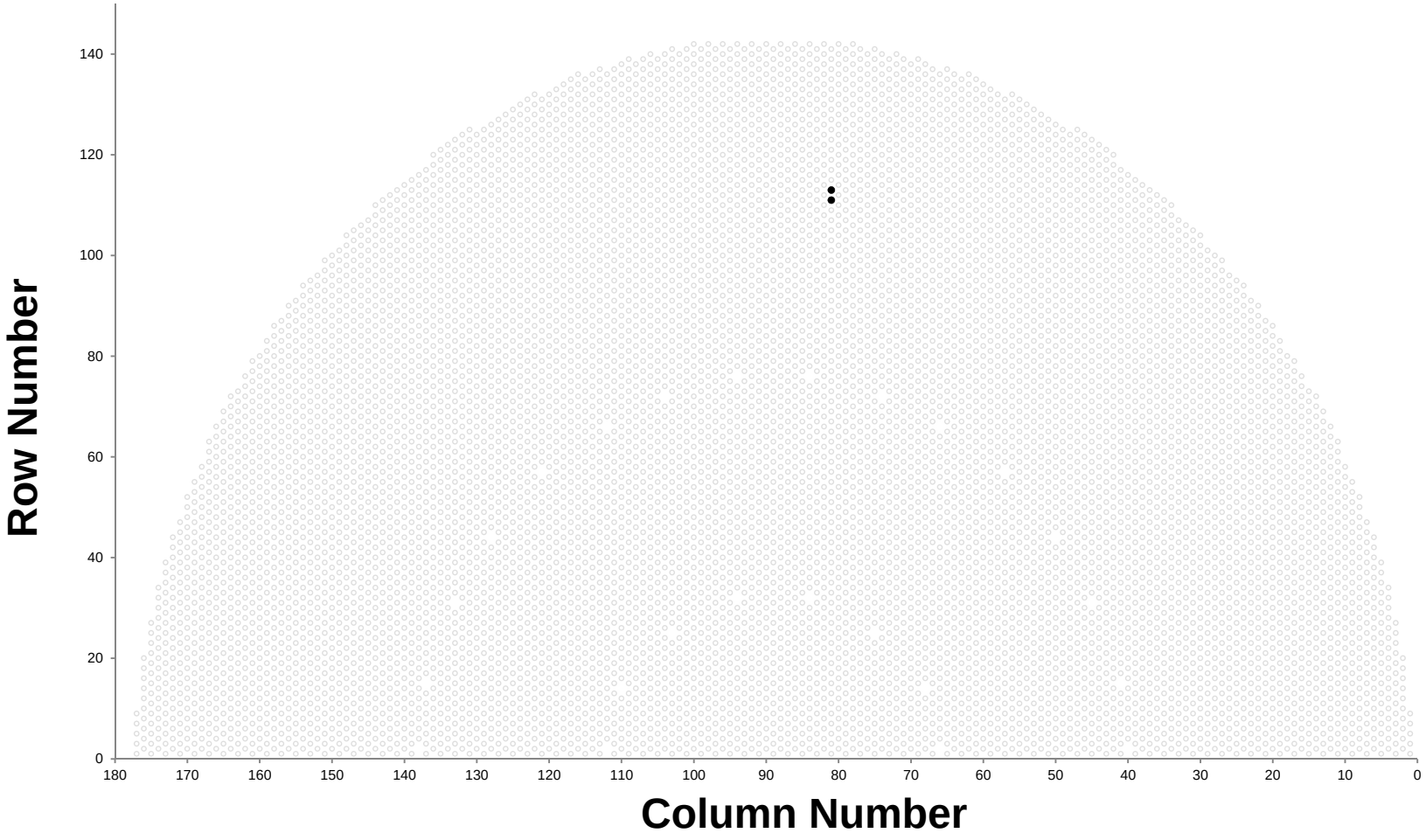


TUBE-TO-TUBE WEAR

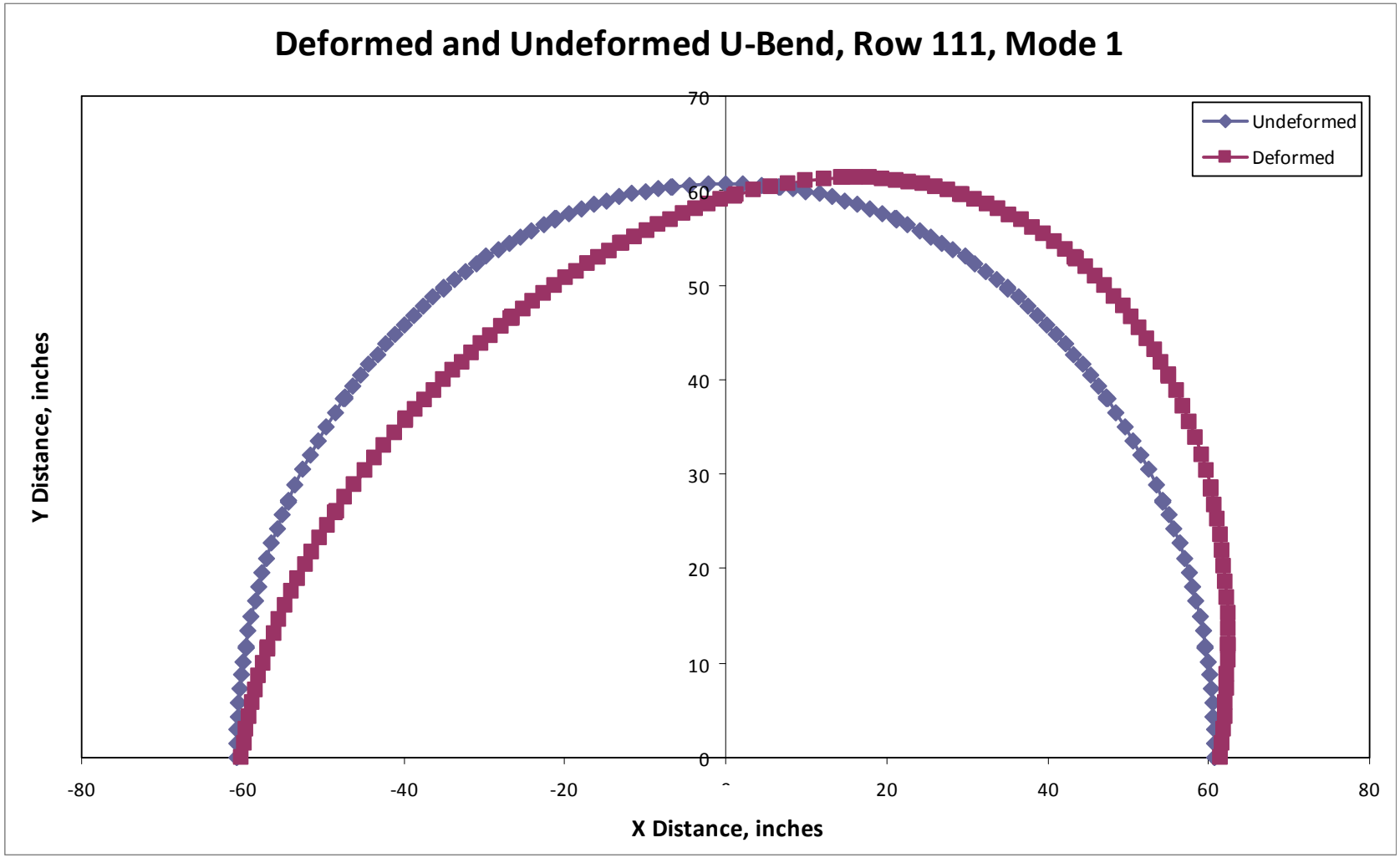
Unit 3 SG E-089 Tube-to-Tube Wear



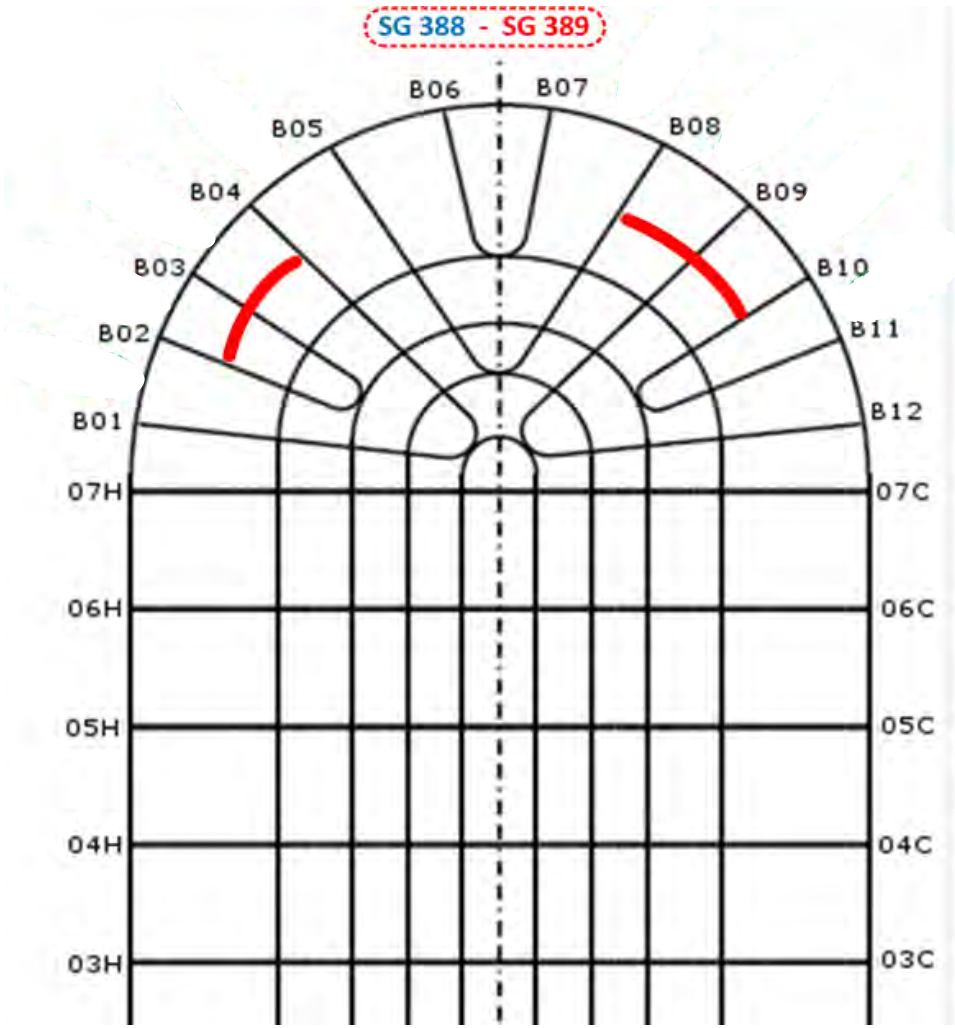
Unit 2 SG E-089 Tube-to-Tube Wear



In Plane Motion and Tube-to-Tube Wear



Unit 3 Steam Generator Tube-to-Tube Wear Indications



Comparison of Tube-to-Tube Wear Between Unit 2 and Unit 3

Description	Unit 2	Unit 3
TTW Indications	2	823
TTW Tubes	2	326
Max Depth (ECT %TW)	14%	100%
Max Length	~6”	~41”
TTW In-Situ Pressure Tests	0	129
TTW In-Situ Pressure Tests (Unsatisfactory)	0	8
Operating Period (Months)	21	11

Tube-to-Tube Wear Cause

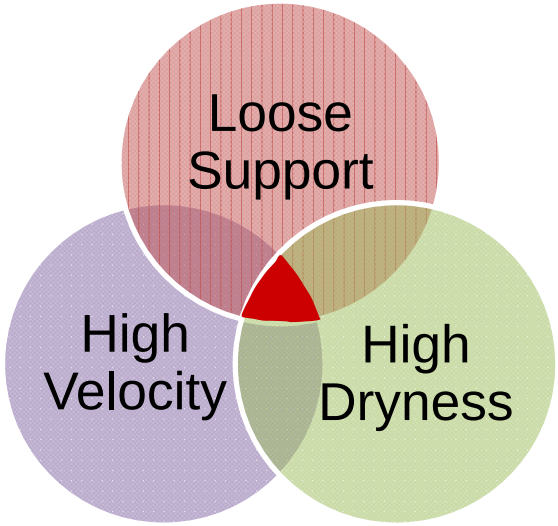
- Fluid Elastic Instability (FEI): excessive tube vibration which occurs when a tube is subject to fluid velocities above a critical value
  - Adverse Thermal-Hydraulic (T/H) Conditions
    - High fluid velocities: transfers energy to the tube
    - High localized void fractions: reduces tube damping
  - Support structure unable to control resulting vibration
    - Anti-Vibration Bars unable to dampen tube vibration at full power
    - Combined with T/H conditions does not provide adequate damping to prevent FEI

Preventing Fluid Elastic Instability

- Reduce fluid velocity
  - Velocity of fluid: transfers energy to the tube
- Improve tube damping
  - Fluid film between tube and supports: function of void fraction/steam quality
  - Fluid interaction with tube: function of void fraction/steam quality
- Reducing power level
  - Reduces velocity
  - Improves void fraction/steam quality
  - Improves tube damping

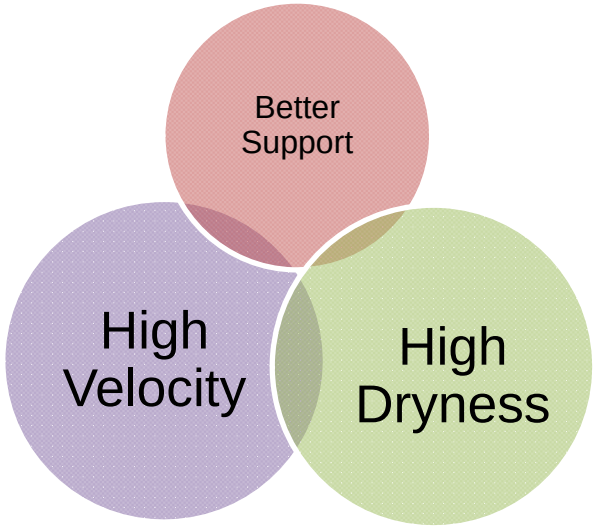
Contributors to In-plane Fluid Elastic Instability

Unit 3



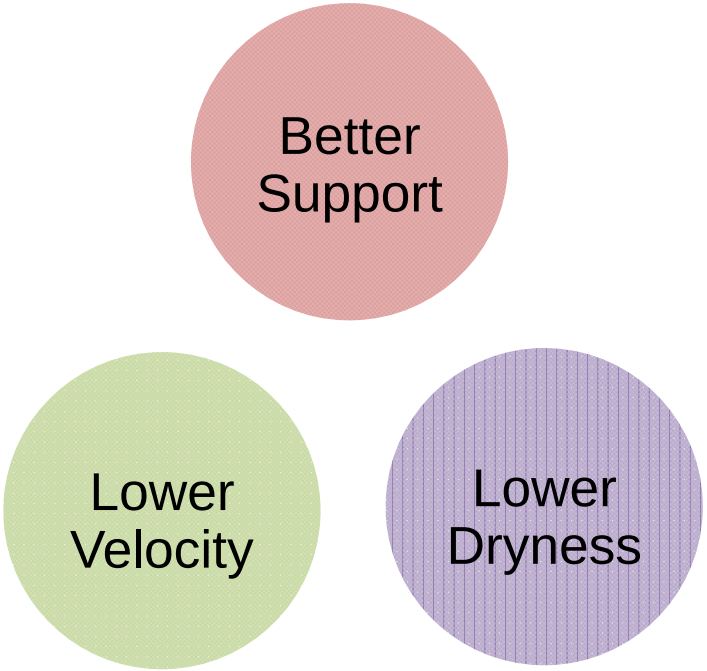
All three conditions required for FEI existed concurrently for many tubes

Unit 2



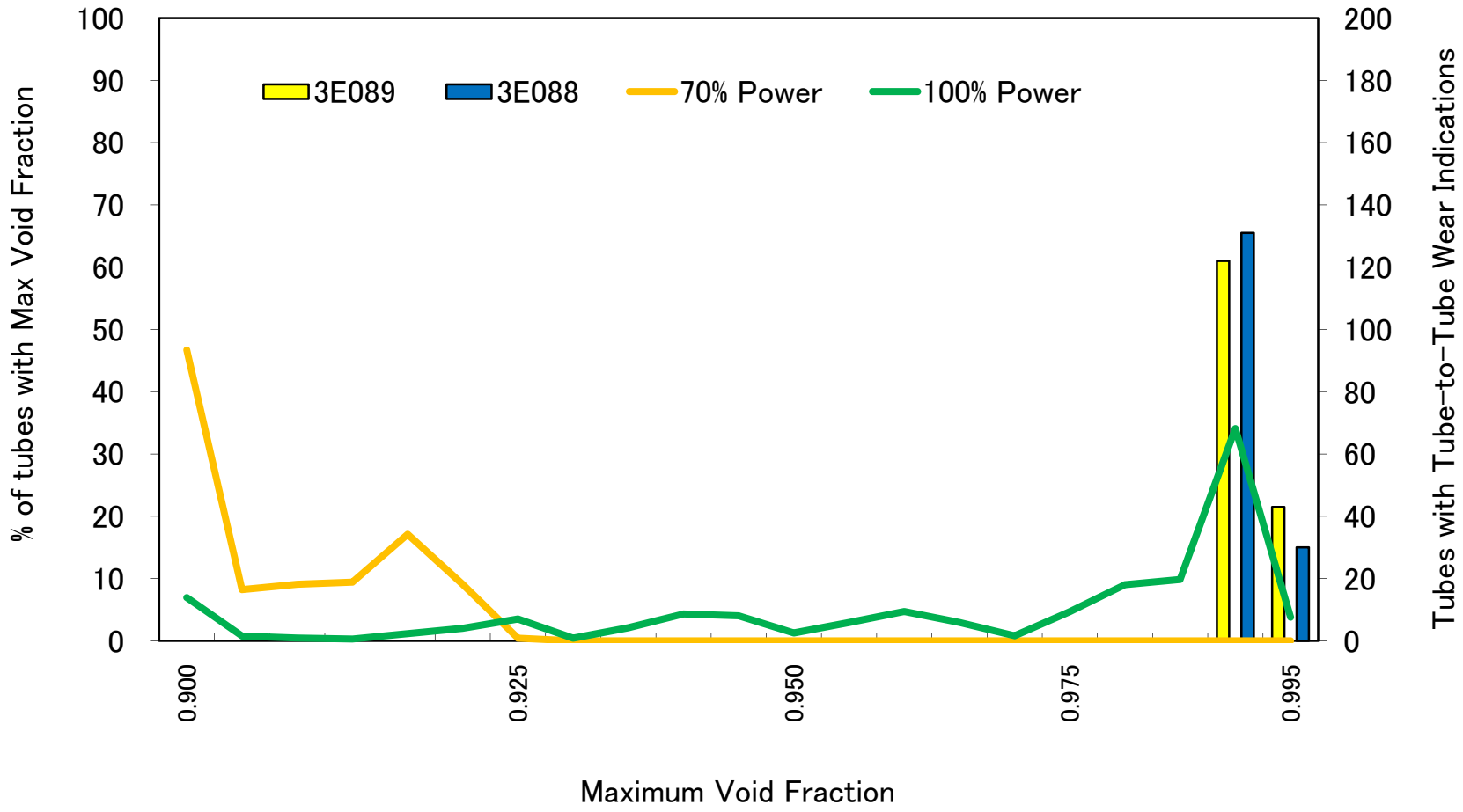
AVB supports are more effective in Unit 2, reducing potential for in-plane FEI

In-plane Fluid Elastic Instability can be Precluded



Eliminating the concurrent combination of high velocities, high dryness and inadequate support can preclude FEI

Maximum Void Fraction as a Function of Power Level



Differences Between Unit 2 and Unit 3

- Deep TTW in multiple tubes only in Unit 3 - after 11 months (approximately 7,000 full power hours); AVB wear also more extensive in Unit 3 than Unit 2

- Fabrication differences during manufacture of SONGS Replacement Steam Generators
  - Unit 3 AVBs have greater flatness due to greater pressing force
    - Confirmed by 20 times more signals indicative of contact in Unit 2 in pre-service inspections
  - Unit 3 tube roundness is more controlled
    - Confirmed by pre-service measurements

Differences Between Unit 2 and Unit 3

- Detailed tube bundle model shows that differences in fabrication resulted in substantially increased contact forces (reduced looseness) between tubes and AVBs for Unit 2

- More effective AVB support conditions allowed Unit 2 to operate at 100% power for 21 months with minimal TTW and less extensive AVB wear

Insights from SONGS Experience

- In-plane FEI was unexpected but industry and plant specific measures worked as designed to detect the resulting tube leak and safely shutdown the plant
- Existing Industry requirements and criteria are strong and have been applied effectively to address tube-to-tube wear and other wear mechanisms
- Significant independent expert participation has been instrumental in developing conclusions
- Operating experience is being shared