U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

Steam Generator Tube Degradation

Bill Borchardt

Executive Director For Operations

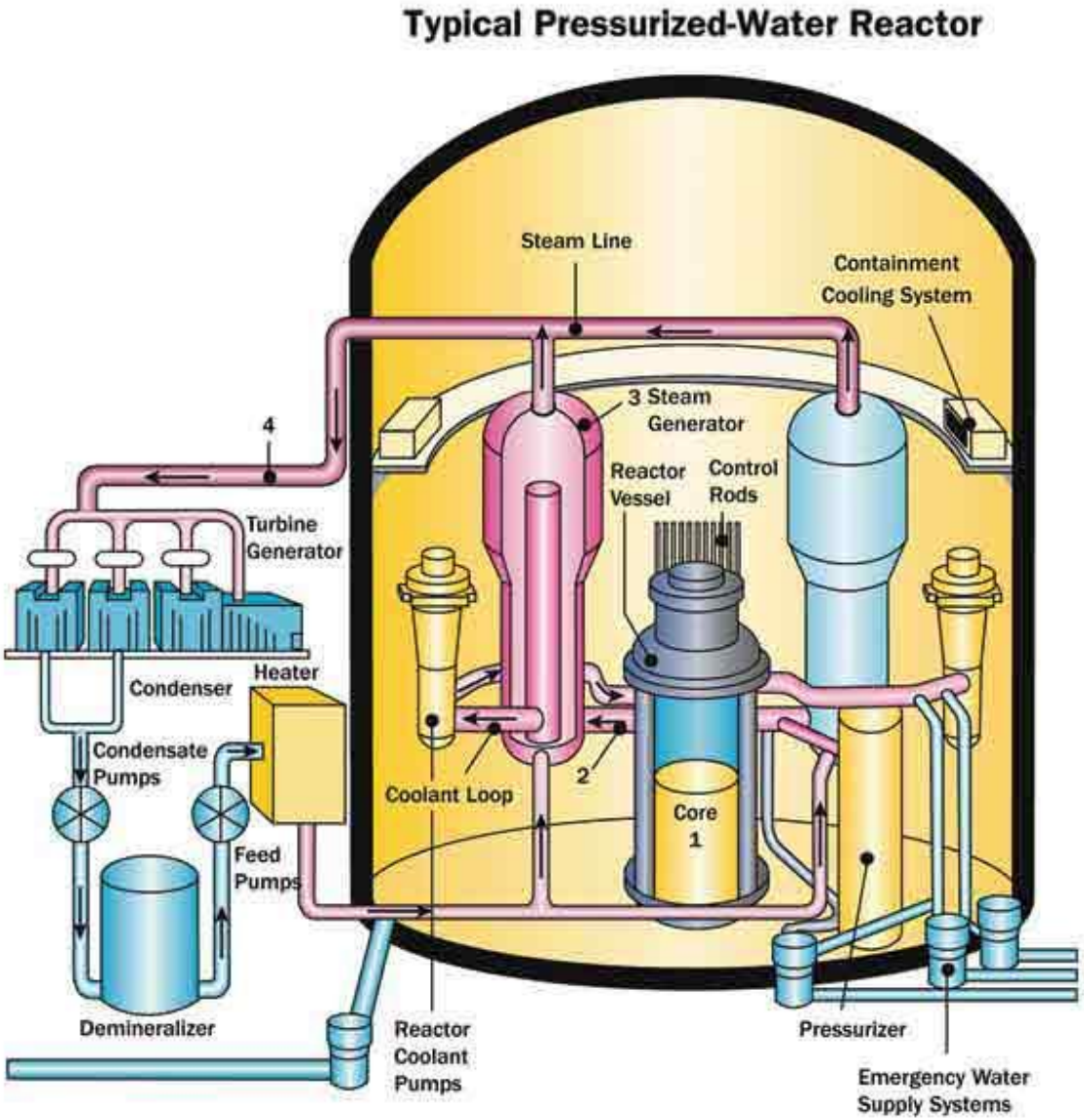
February 7, 2013

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


Typical Pressurized-Water Reactor
Steam Line
Containment
Cooling System
3 Steam
Generator
4
Reactor
Vessel
Control
Rods
Turbine
Generator
Condenser
Heater
Condensate
Pumps
Coolant Loop
2
Core
1
Feed
Pumps
Demineralizer
Reactor
Coolant
Pumps
Pressurizer
Emergency Water
Supply Systems

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**

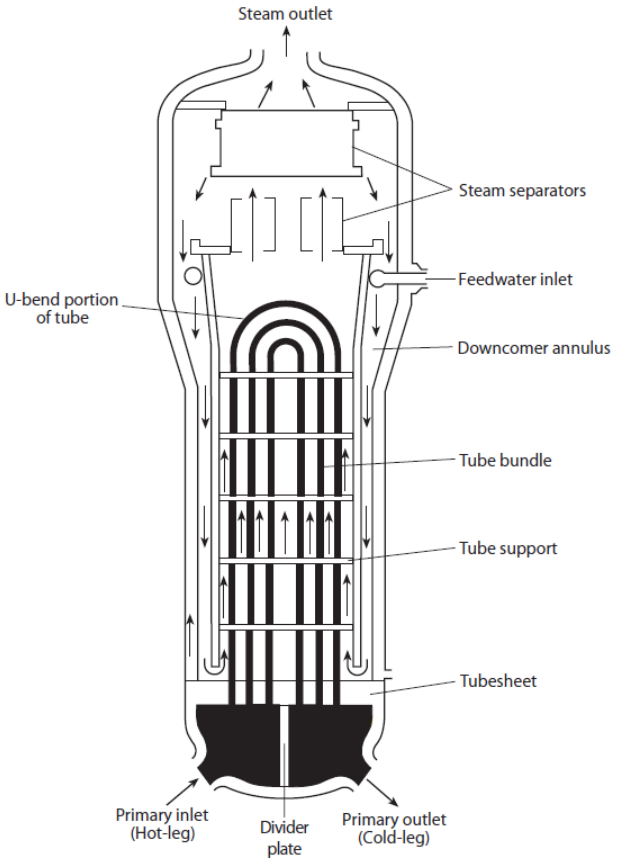
Steam Generator Operating Experience and Oversight

Ken Karwoski
Senior Level Advisor
Division of Engineering, NRR

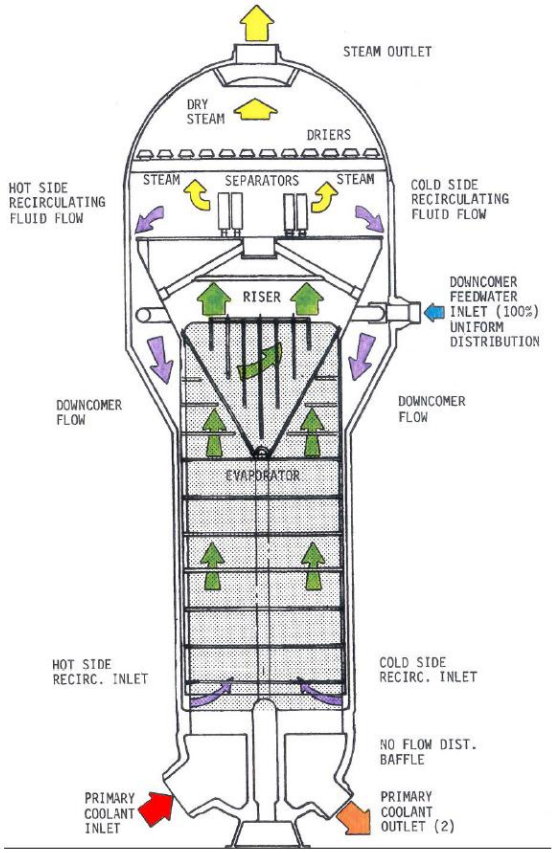
Steam Generator Designs

- **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)**

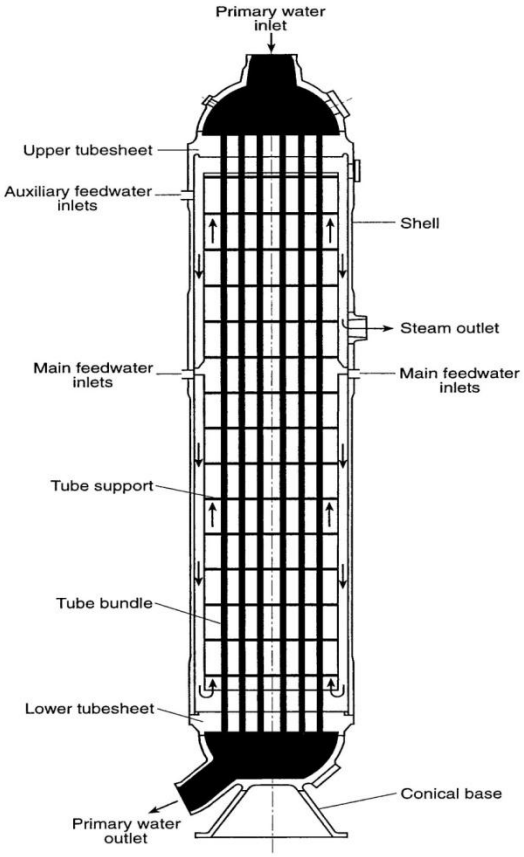
Recirculating and Once Through Steam Generators



Recirculating

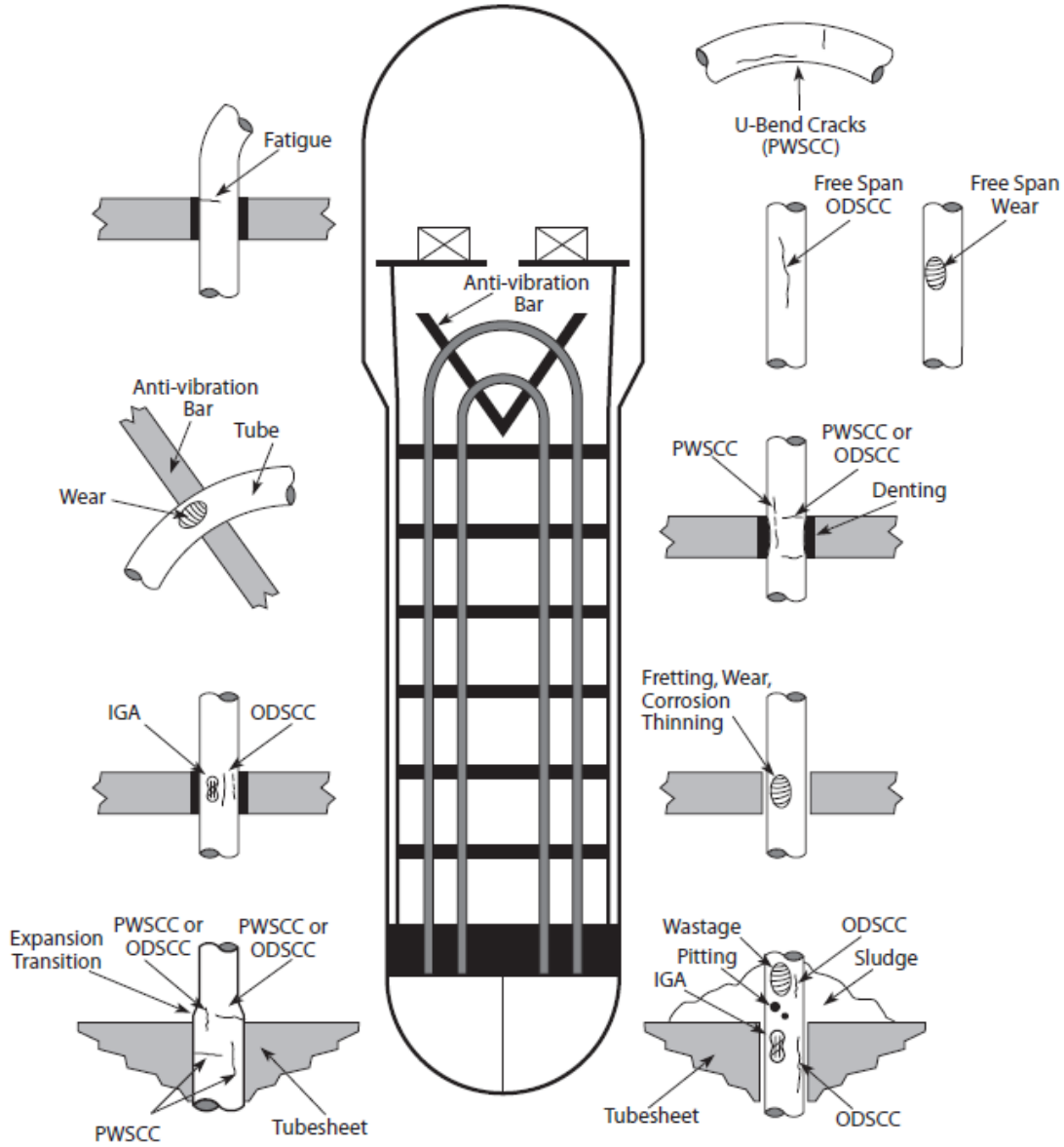


Recirculating



Once Through

Types of Tube Degradation



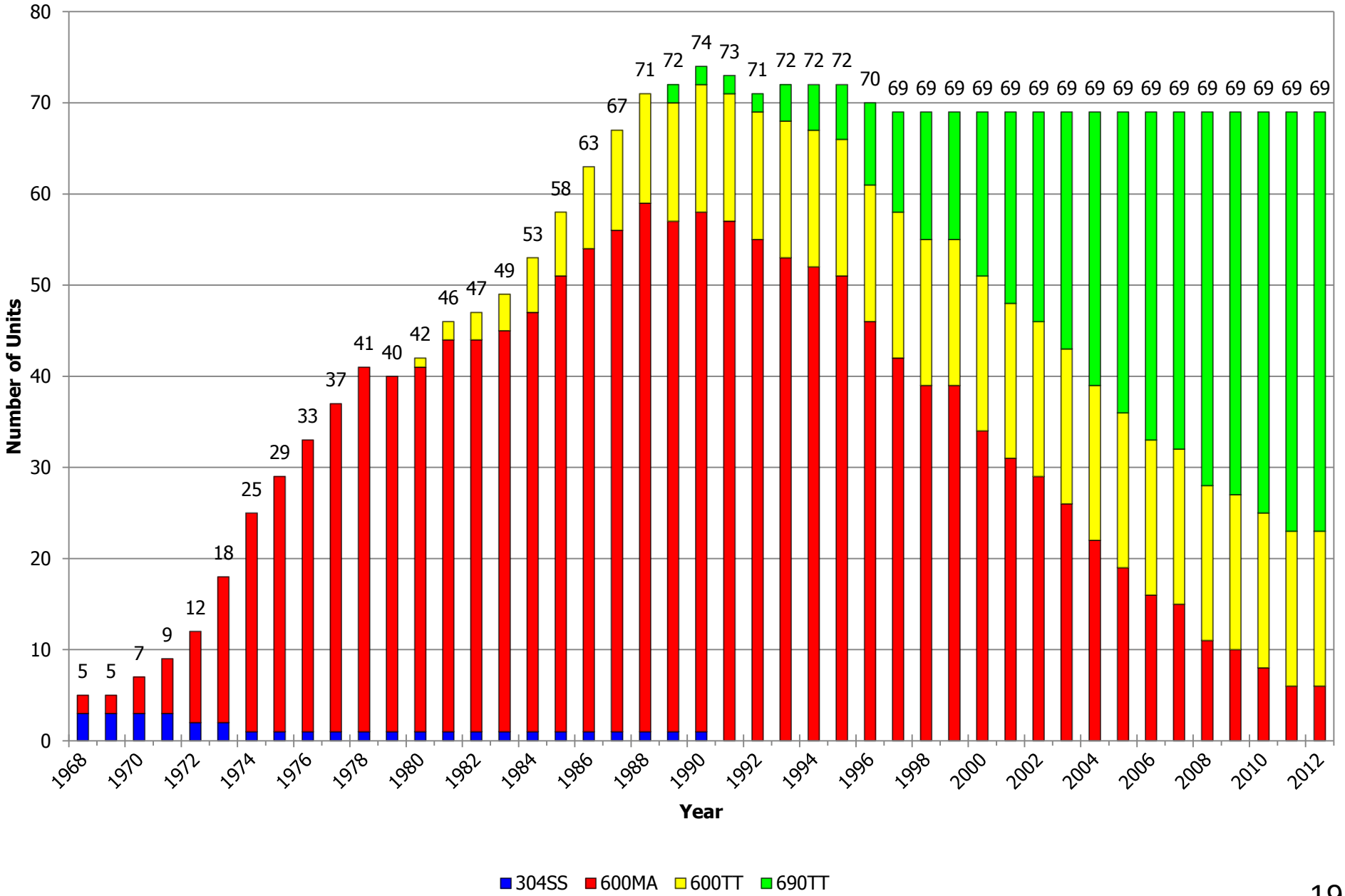
Managing Tube Degradation

- **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

Units in Operation: 1968-2012



Cracking in Alloy 600TT Tubing

- First instance of cracking detected in 2002 (2nd generation tube material)
- Since 2002, cracks detected at several locations along tube length
- Number and severity of cracks, to date, has been minor

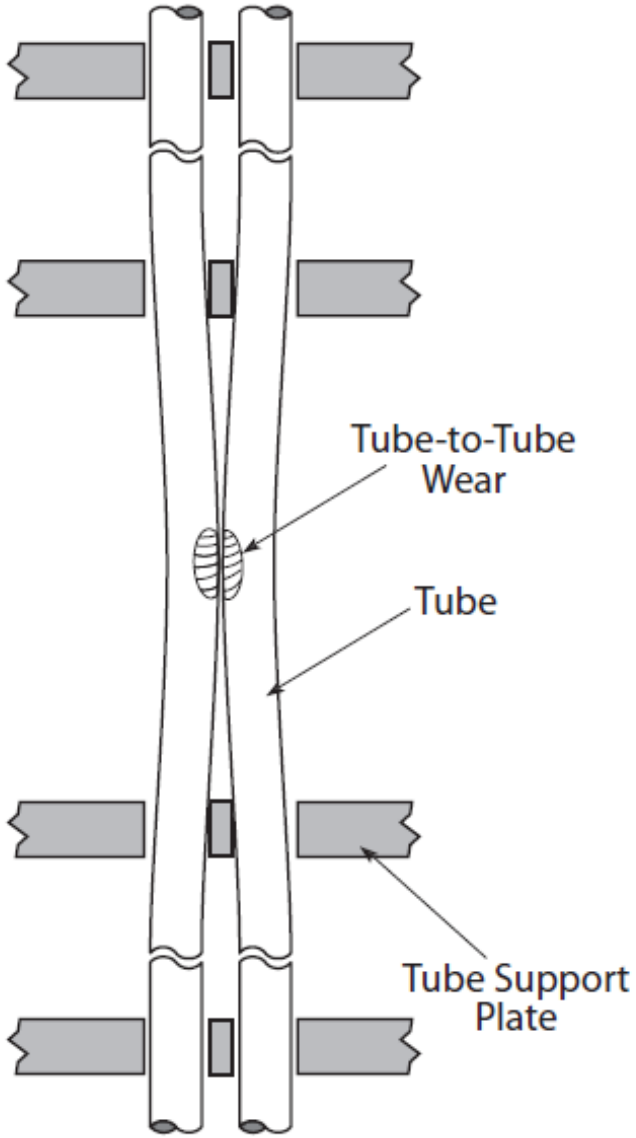
Steam Generator Tube Wear

- **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**

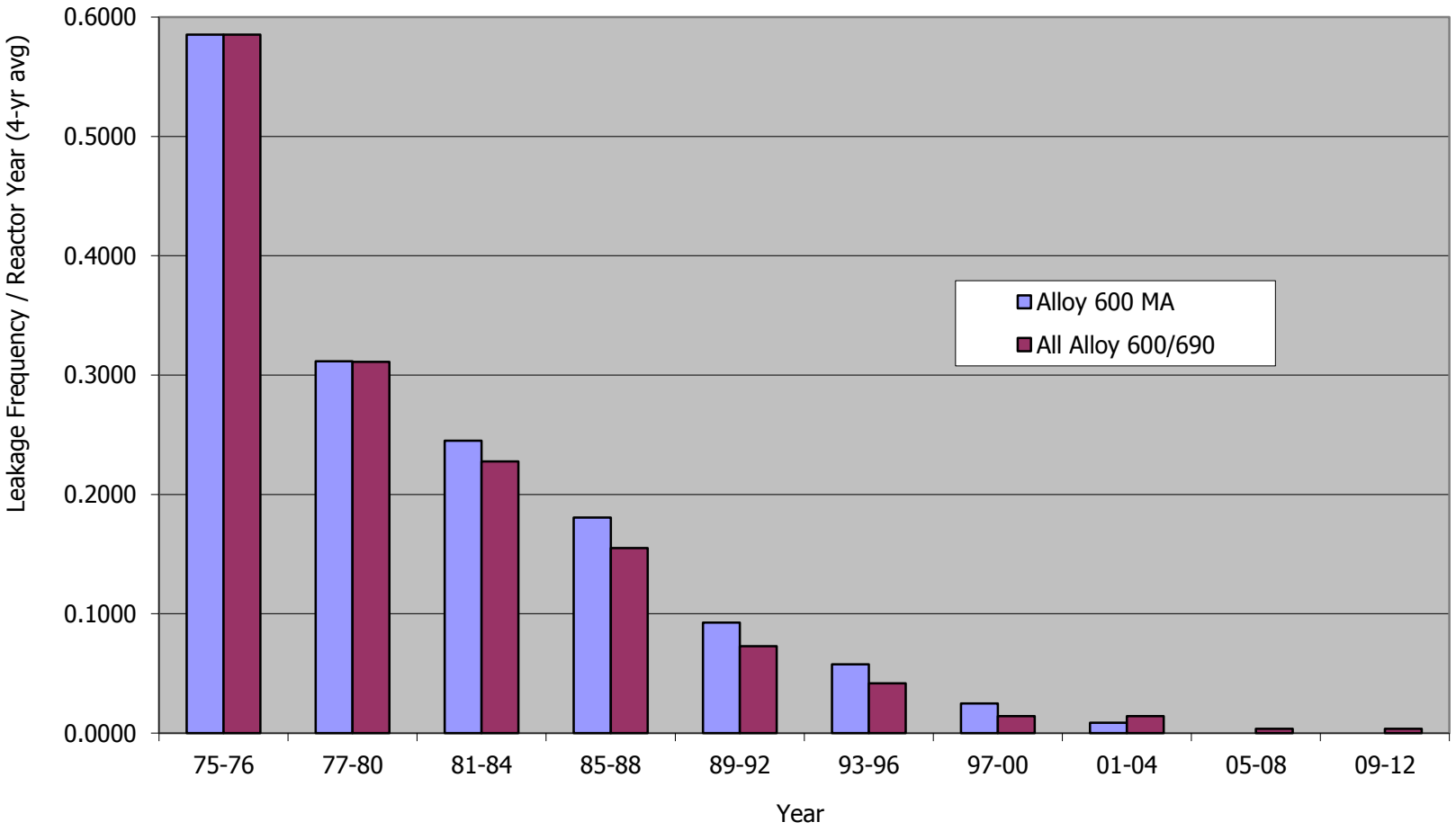
Industry Program

- **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**

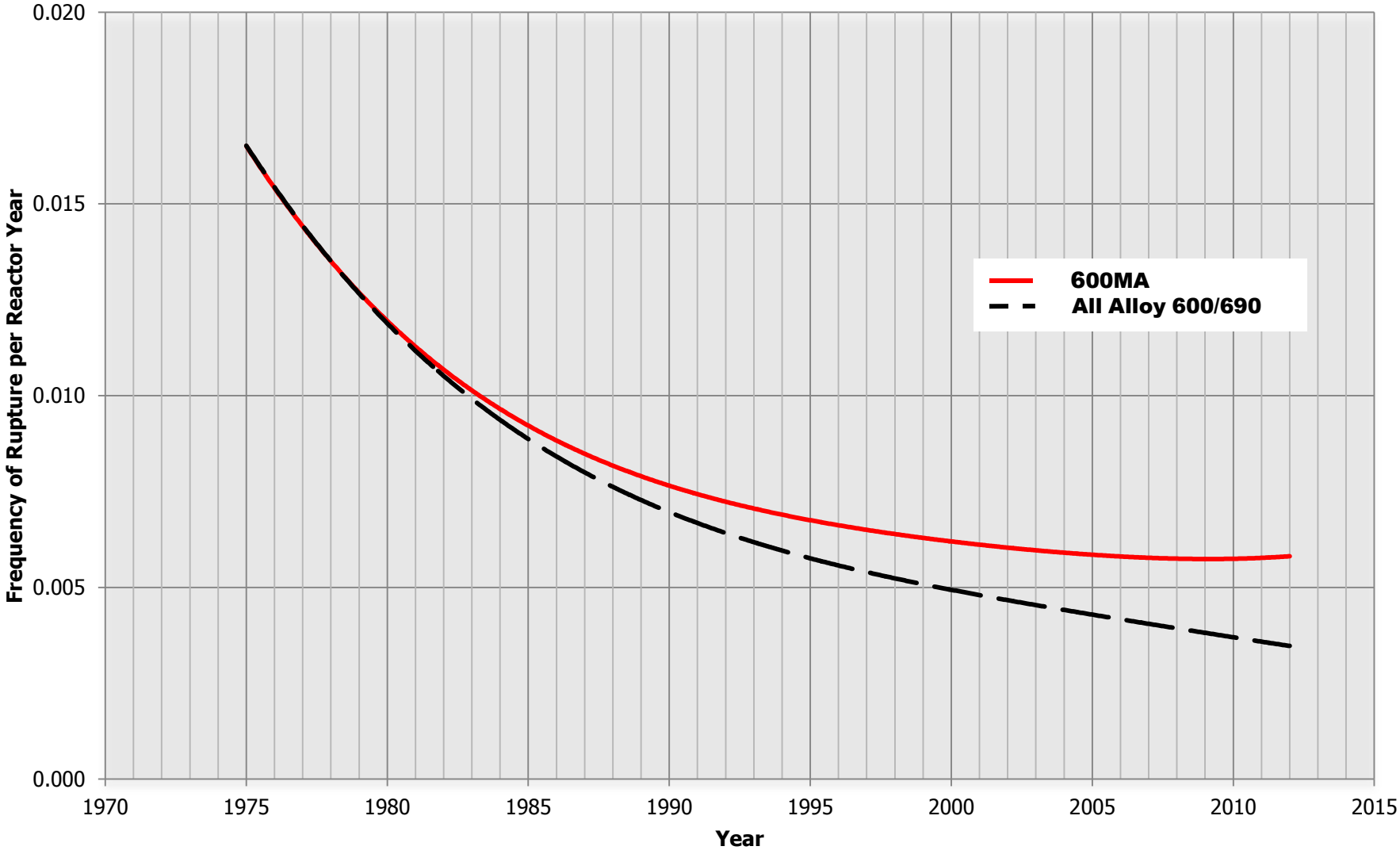
Steam Generator Performance

- **Performance has improved since 1970s**
- **Prior to 2012 last time a plant did not have adequate tube integrity was 2003**

Forced Outage Frequency: Primary-to-Secondary Leakage



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**