Advisory Committee on Reactor Safeguards
Full Committee Meeting
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Palisades Steam Generator Update - Operational Assessment

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NRR/DNRL/NCSG

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Acronyms

- 1RXX – refueling outage number
- AILPC – accident induced leakage performance criterion
- BOC – beginning of cycle
- CIRC - circumferential
- CM – condition monitoring
- DBH – diagonal bar hot
- Eggcrate – horizontal lattice tube support
- EOC – end of cycle
- EPRI – Electric Power Research Institute
- FSAR – final safety analysis report
- ID – inside diameter
- NDE – nondestructive evaluation
- NOPD – normal operating pressure differential
- OA – operational assessment
- OD – outside diameter
- PW – primary water
- SCC – stress corrosion cracking
- SG – steam generator
- SGOG – Steam Generator Owners Group
- SIPC – structural integrity performance criterion
- TEH – tube end hot
- TSH – top of tubesheet hot
- TTS – top of the tubesheet

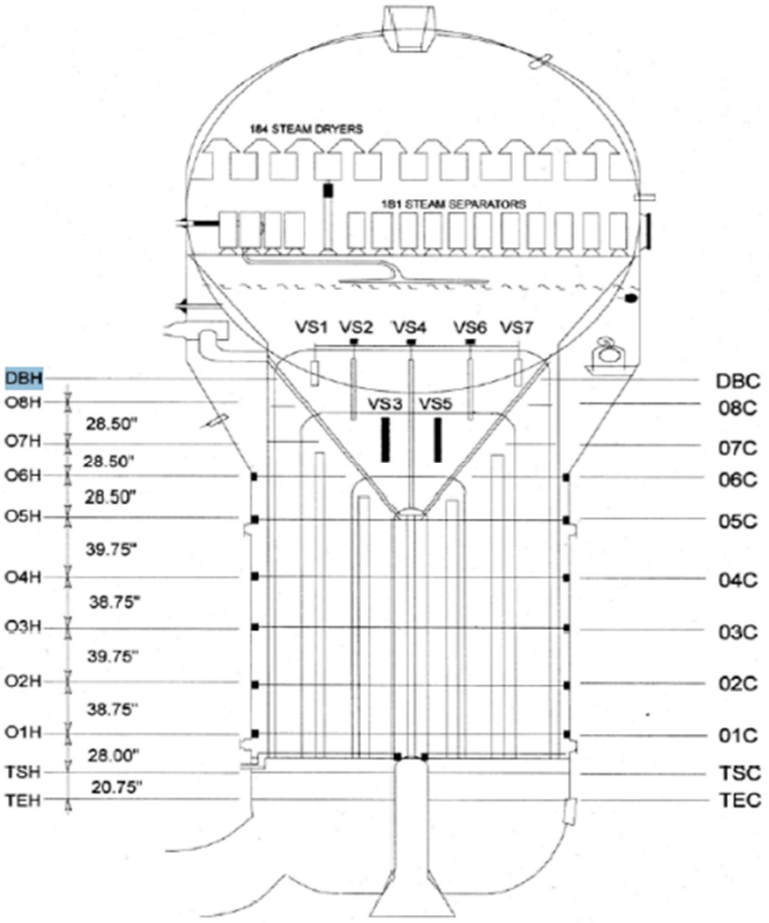
Agenda

- Summary Up Front
- Palisades SG Design
- SG Inspection (1D28) Results
- CM OA Process
- 1D28 CM Summary
- Cycle 29 OA Review
- SG Chemical Cleaning
- Concluding Remarks

Summary - Palisades SG Tube Degradation

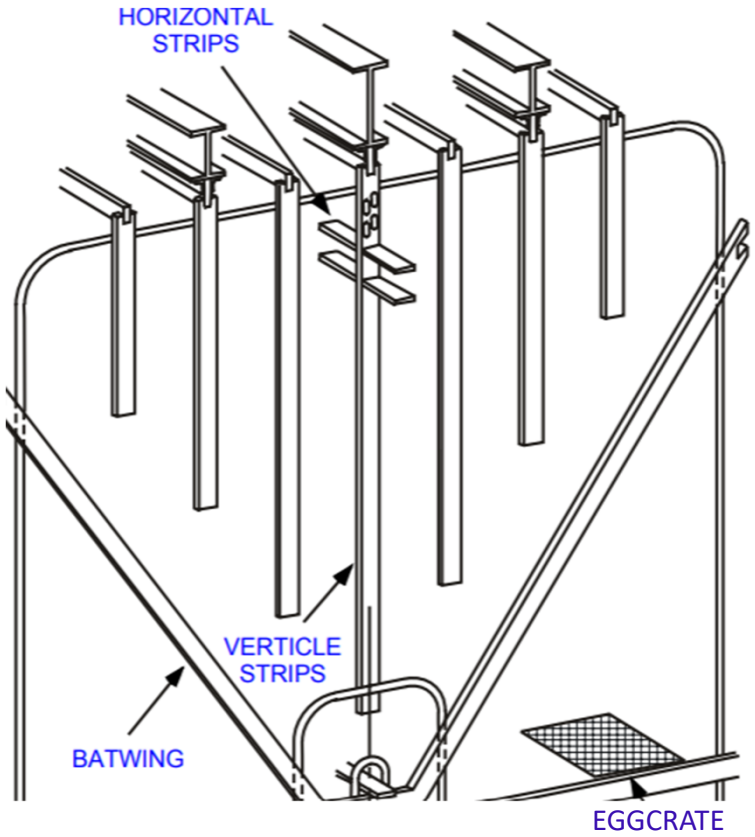
- 1D28 SG inspection: Over 1200 axial ODSCC indications at eggcrate supports
  - Plugging would exceed 15% SG A design limit; licensee submitted LAR to install sleeves
- A total of 2971 SG sleeves will be placed in service to preserve plugging margin
  - 906 corrective sleeves (SCC present), 2065 preventative sleeves (no SCC present)
- Condition Monitoring (CM) showed tube integrity was maintained, 23 tubes passed insitu pressure tested as part of CM (no burst or leakage)
- Cycle 29 Operational Assessment, Rev. 2 - 1.5 Effective Full Power Years
  - Analysis results meet all performance criteria, little margin for eggcrate SIPC
  - key conservative assumptions: (1) crack growth rates for ODSCC at eggcrates based on assuming all cracking at 1D28 was just below detection threshold at 1R27
    (2) assuming no improvements from EPRI SGOG chemical cleaning of both SGs
  - Based on NRC-licensee clarification call, OA revision is in progress

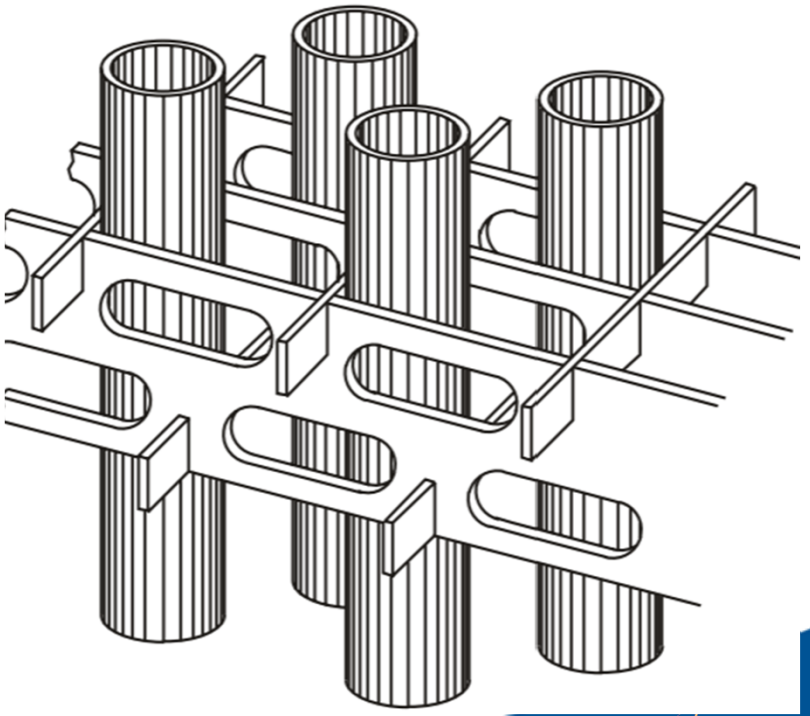
Palisades Combustion Engineering Model 2530 SGs



- Installed in 1990, each SG has 8,219 tubes
- Alloy 600 mill annealed tubing
- Nominal 0.75 inch diameter, 0.042 inch wall thickness
- Rows 1-18 U-bend, Rows 19-138 square bend design
- Horizontal stainless steel lattice type “eggcrate” support plates
- Sleeves installed 01H to 05H

Vertical and Horizontal (Eggcrate) Supports





1D28 SG Inspection – Final Results

SG	Location	Type	Indications	Tubes
A	TSH	Axial ODSCC	17	16
A	TSH	Circ PWSCC	29	10
A	TSH	Circ ODSCC	73	60
A	Tube Supports	Axial ODSCC	900	608
A	TEH to TEC	Wear > 40%	5	5
A		EFFECTIVE PLUGGING PERCENT		11.1%
B	TSH	Axial ODSCC	10	9
B	TSH	Circ PWSCC	10	10
B	TSH	Circ ODSCC	1	1
B	Tube Supports	Axial ODSCC	313	220
B	TEH to TEC	Wear > 40%	3	3
B		EFFECTIVE PLUGGING PERCENT		6.4%

1D28 Condition Monitoring

- CM uses inspection results to assess whether tube integrity (SIPC, AILPC) was maintained until the inspection
- CM limits pre-determined for each degradation mechanism/location for rapid evaluation:
  - Flaw clearly meets CM limit with initial NDE sizing
  - Flaw needs enhanced eddy current flaw sizing (profiling) to determine if CM is met
  - Insitu pressure testing (ISPT), if NDE alone cannot confirm CM is met
- All tubes met CM during 1D28, ISPT needed for 23 indications
  - 8 eggcrates, 2 axial TTS, 11 circumferential TTS, 1 DBH, 1 obstructed tube
  - No leakage or tube burst during ISPT

CM – Axial ODSCC at Eggcrates SG B

Figure 9-12: SGB – CM for Axial ODSCC at TSP Locations (Before LxL Sizing)

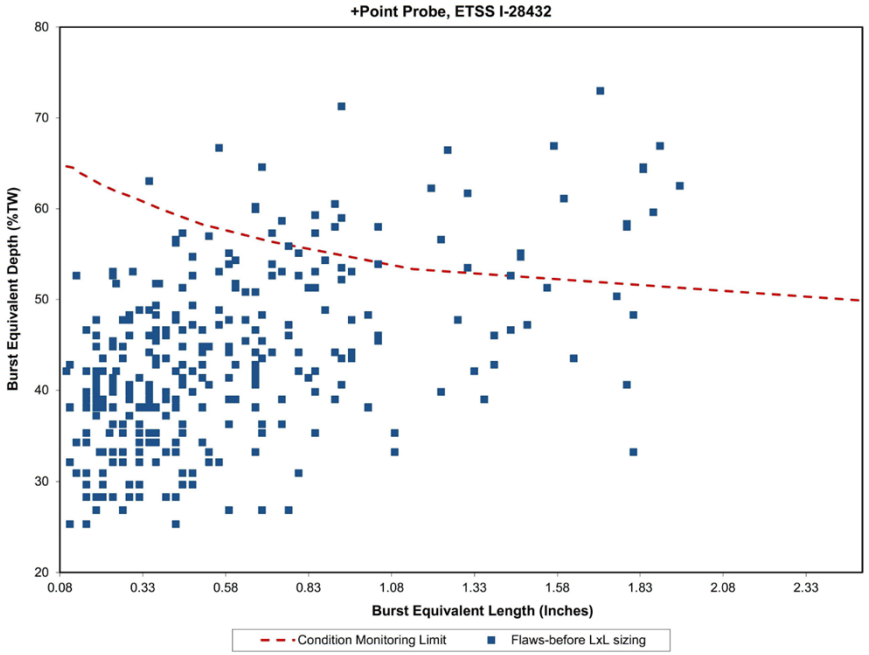
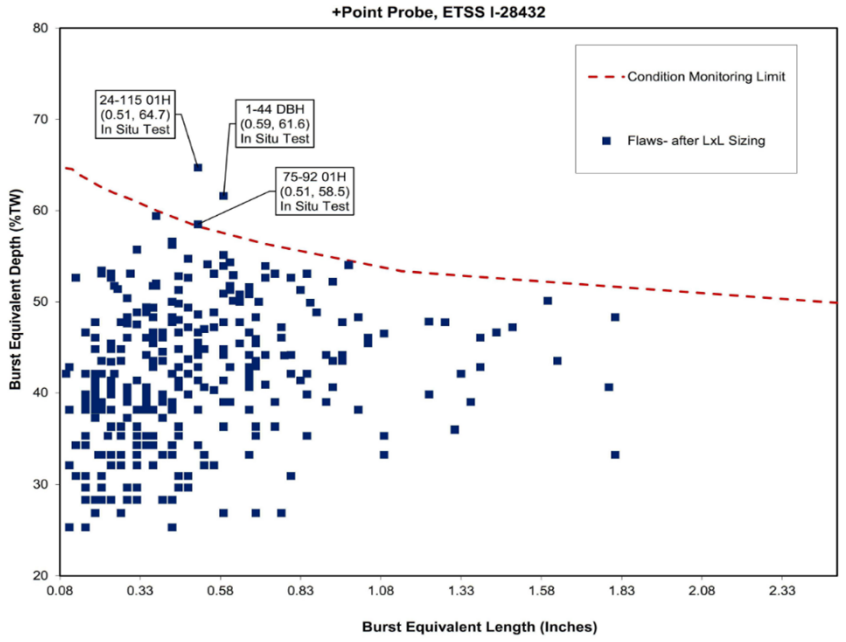


Figure 9-13: SGB – CM for Axial ODSCC at TSP Locations (After LxL Sizing)



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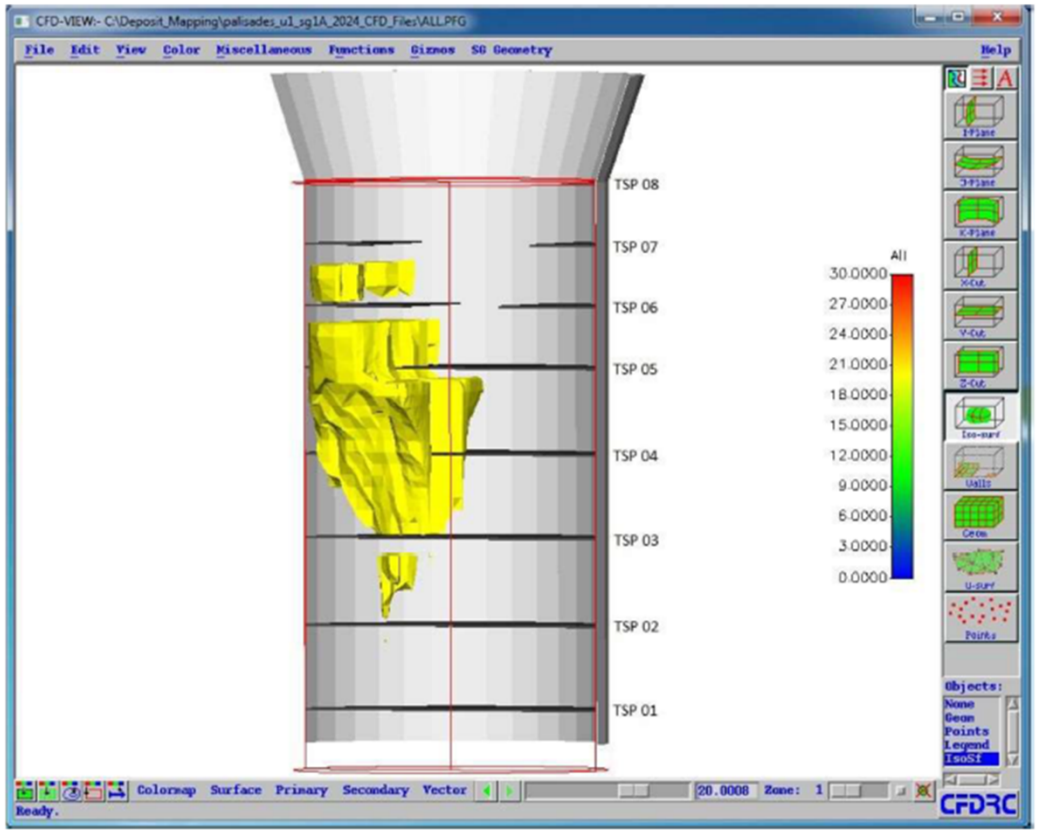
Eggcrate Support Cracking SG A

Figure 8-4: Palisades SG A Tube OD Deposit Loading 20.0 mils and thicker



Support Number	Eggcrate Cracks
05H	7%
04H	10%
03H	8%
02H	24%
01H	37%

~ 70%

ODSCC Distribution at Eggcrates is Consistent With a Temperature Driven Mechanism

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Operational Assessment (OA)

- Forward-looking projection of SG tube degradation, OA provides the technical basis for meeting tube integrity until the next SG tube inspection
- Addresses all tube degradation mechanisms such as wear at support structures, SCC at the lattice supports, SCC at the top of tubesheet
- The OA process is addressed in EPRI SG Integrity Assessment Guidelines
- Degradation can be projected using deterministic (worst case tube), mixed, or fully probabilistic methods

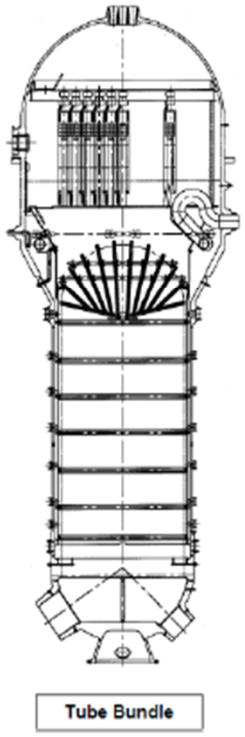
OA Options

- Two general approaches

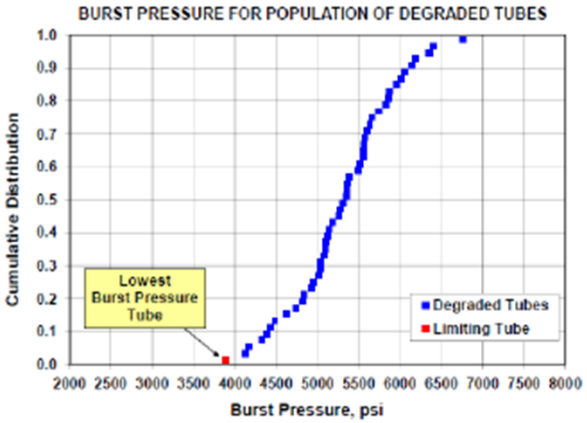
  Full bundle probabilistic
  - Monte Carlo simulation methods are used to predict the future distribution of the structural integrity parameters at the end of the next inspection cycle (EOC), so that the lower 95th percentile of the worst case burst pressure values may be obtained. Similarly, the upper 95/50 total bundle leakage is also calculated.

  –Simplified techniques, including:
  - Arithmetic
  - Simplified Statistical
  - Monte Carlo
  - Mixed techniques – a combination of the above.

OA - Full Bundle Probabilistic Process

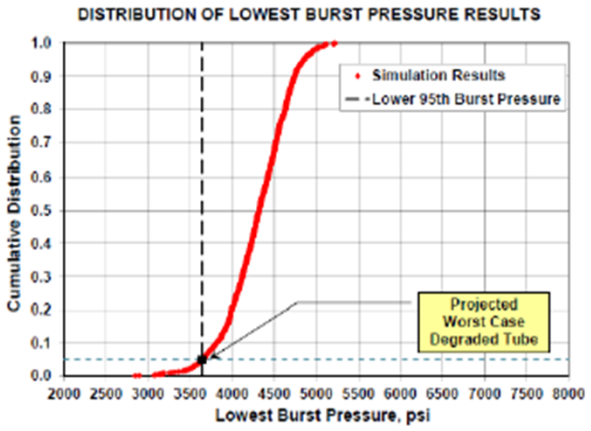


Tube Bundle



After Many Simulations for All Degraded Tubes in the Bundle

One MC Simulation For All Degraded Tubes in the Bundle



95/50 Criterion vs 95/95

- 95/50 Probability/Confidence is the industry consensus for OA:
  - EPRI Technical Basis for SG Tube Integrity Performance Acceptance Standards, 2006
  - EPRI SG Program Guidelines – Integrity Assessment Guidelines
- Some uses of 95/95 acceptance criteria, typically related to leakage and dose, not the structural integrity performance criterion
  - H* amendments for tube cracking deep within tubesheet, Alloy 600 TT fleet
  - Individual unit examples before consensus approach developed
- Note the 95/50 criterion is used in conjunction with deterministic safety factors, (3 x NOPD burst normal operation, 1.4 design basis accidents) providing multiple layers of protection

Palisades OA for Operating Cycle 29

- Full tube bundle probabilistic OA model used for:
  - Axial Outside Diameter Stress Corrosion Cracking (ODSCC) at Eggcrates, Vertical Straps, and in the Freespan
  - Axial ODSCC and PWSCC at Top of Tubesheet (TTS)
  - Freespan Axial Intergranular Attack (IGA)
  - Circumferential (Circ) ODSCC at TTS
  - Tube Support Wear
- Mixed Arithmetic/Monte Carlo method used for:
  - Circ PWSCC at Expansion Transitions and Expanded Tubesheet Locations
  - Axial ODSCC at Dents/Dings
  - Axial PWSCC at Dents/Dings and Small Radius U-bends
  - Tube-to-Tube Wear

Palisades Cycle 29 OA, Rev. 2 (1.5 EFPY)

- Probabilistic full tube bundle method used for most degradation mechanisms, including ODSCC at eggcrate supports
- A lower 95th worst case tube calculated burst pressure that is greater than 3 times NOPD meets structural tube integrity

Mechanism	Lower 95th Burst (psi)	3 times NOPD (psi)	Comments
ODSCC at Eggcrates	3978	3960	Simulated outages 1R20 to 1R29 50,000 times
Axial ODSCC at TTS	4340	3960	50,000 trials
Circ ODSCC at TTS	7499	3960	50, 000 trials
Axial PWSCC U-bends	BOC structural depth from 95th POD, upper 95th growth	EOC Lower 95th Flaw Burst pressure is 4180 psi (3960 psi 3DP)	Mixed Arithmetic/Monte Carlo approach

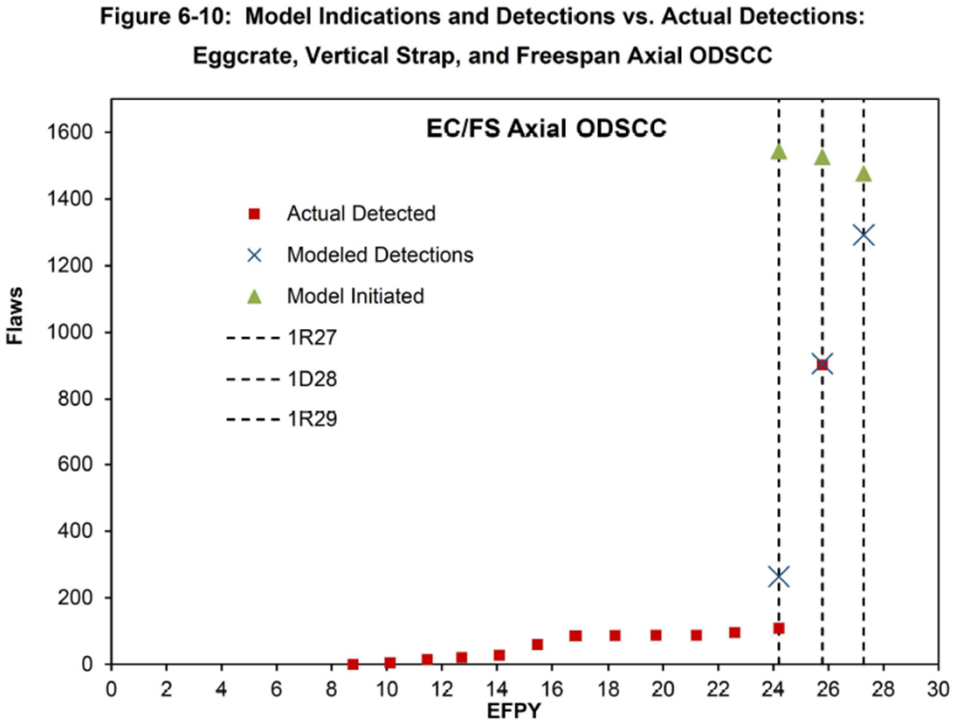
OA Indication Prediction Comparison

Damage Mechanism	Projections for 1D28	Projections for 1R29
Axial ODSCC at Supports (Evaluated Probabilistically)	22 indications/SG	1292 indications (SG A bounding; used for SG B)
Axial ODSCC at Top of Tubesheet (Evaluated Probabilistically)	16 indications/SG	21 indications/SG
Axial PWSCC within Tubesheet (Evaluated Probabilistically)	NOT PERFORMED	68 indications/SG
Circumferential ODSCC at Top of Tubesheet (Evaluated Probabilistically)	23 indications/SG	35 indications/SG
Wear at Supports (Evaluated Probabilistically)	3372 indications (both SGs)	3408 indications (both SGs)

Modeling of ODSCC at Eggcrate Supports

- Crack initiation modeled with a Weibull function starting with 1R27, model parameters adjusted until 1D28 results were benchmarked
- To fit the large increase in detected indications in 1D28, outages prior to 1R27 were treated as having perfect ODSCC detection
- OA input for SCC growth rates assumed all flaws detected during 1D28 were at the threshold of detection at 1R27
  - Results in average growth 9% TW/EFPY
  - Conservative to both the EPRI Guidelines default average growth adjusted to Palisades operating temperature (2.15% TW/EFPY), and the EPRI average growth rate meant to conservatively bound any Alloy 600 unit/temperature
  - Cycle 29 upper limit growth of 19.23% TW/EFPY

OA Model Results



- Probabilistic model of SG A bounds SG B
- Wiebull distribution with parameters adjusted to benchmark 1D28 (~26 EFPY)
- Assumes perfect detection prior to 1R27 (~24 EFPY)

NRC Staff Comments, Cycle 29 OA

- Cycle 29 OA meets all acceptance criteria
- Small margin for meeting SIPC – ODSCC at eggcrate supports
- OA conservatively calculated average SCC growth rates by assuming all cracks were present at detection threshold and only grew during the last operating cycle (assuming cracking also occurred during the extended shutdown period decreases crack growth rate)
- OA assumes no benefits from chemical cleaning
- Clarification call with licensee on October 14, 2025
  - Obtain clarification on portions of Cycle 29 OA modeling
  - Upper tail growth and sensitivity analysis discussion
- Licensee's vendor is performing additional Cycle 29 OA sensitivity analyses; a new OA (Revision 3) will be issued

Palisades SGs Chemical Cleaning

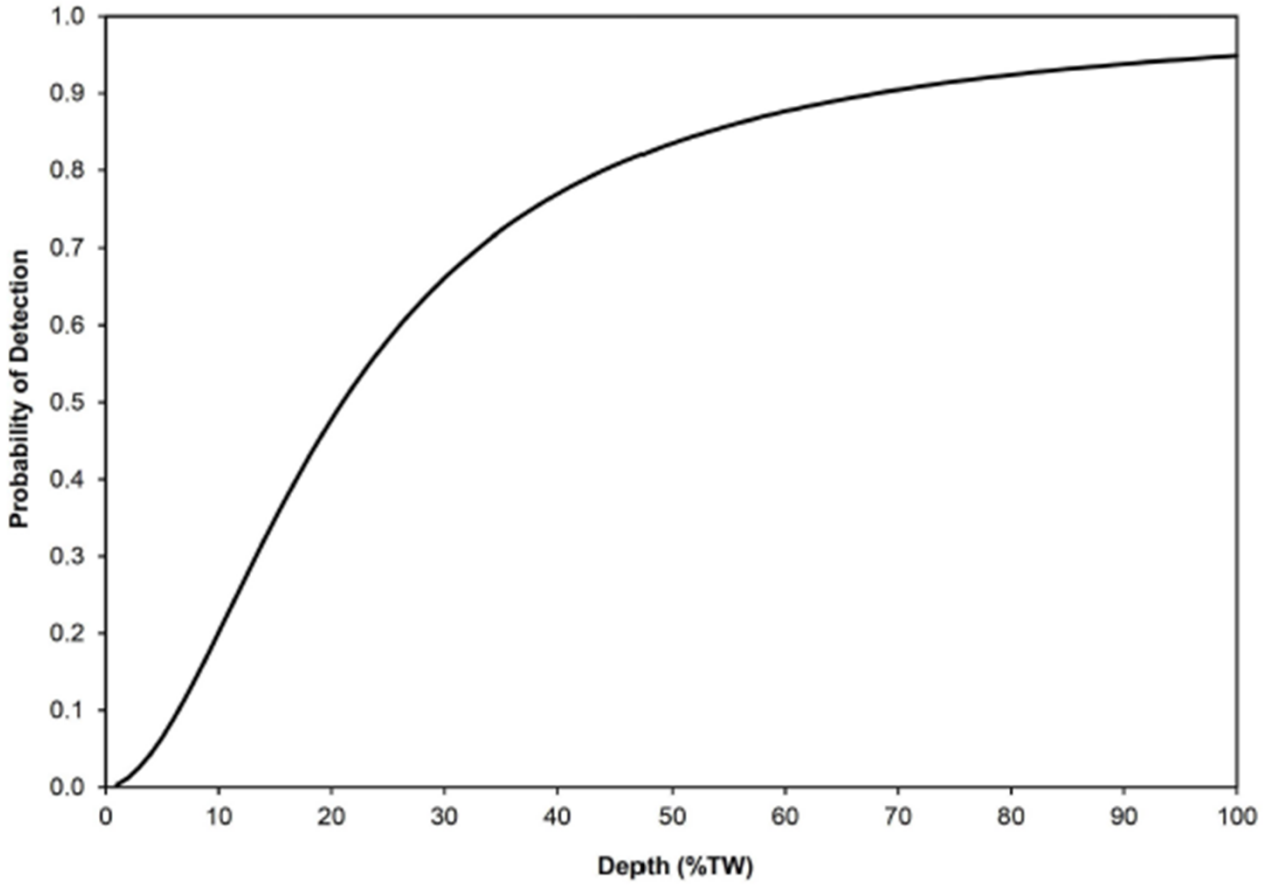
- EPRI SGOG (Hard) chemical cleaning performed in October 2025
  - Separate cleaning steps for copper and magnetite deposits
- Preliminary amount of material removed:
  - SG A: approximately 3000 pounds total deposits
    - 88 pounds elemental copper, 2000 pounds of elemental iron
  - SG B: approximately 3100 pounds total deposits
    - 85 pounds of copper, 2100 pounds of elemental iron
- Alloy 600 MA tubing fleet operating experience shows a variable but clear improvement in tube cracking from hard chemical cleaning

Concluding Remarks – Path Forward

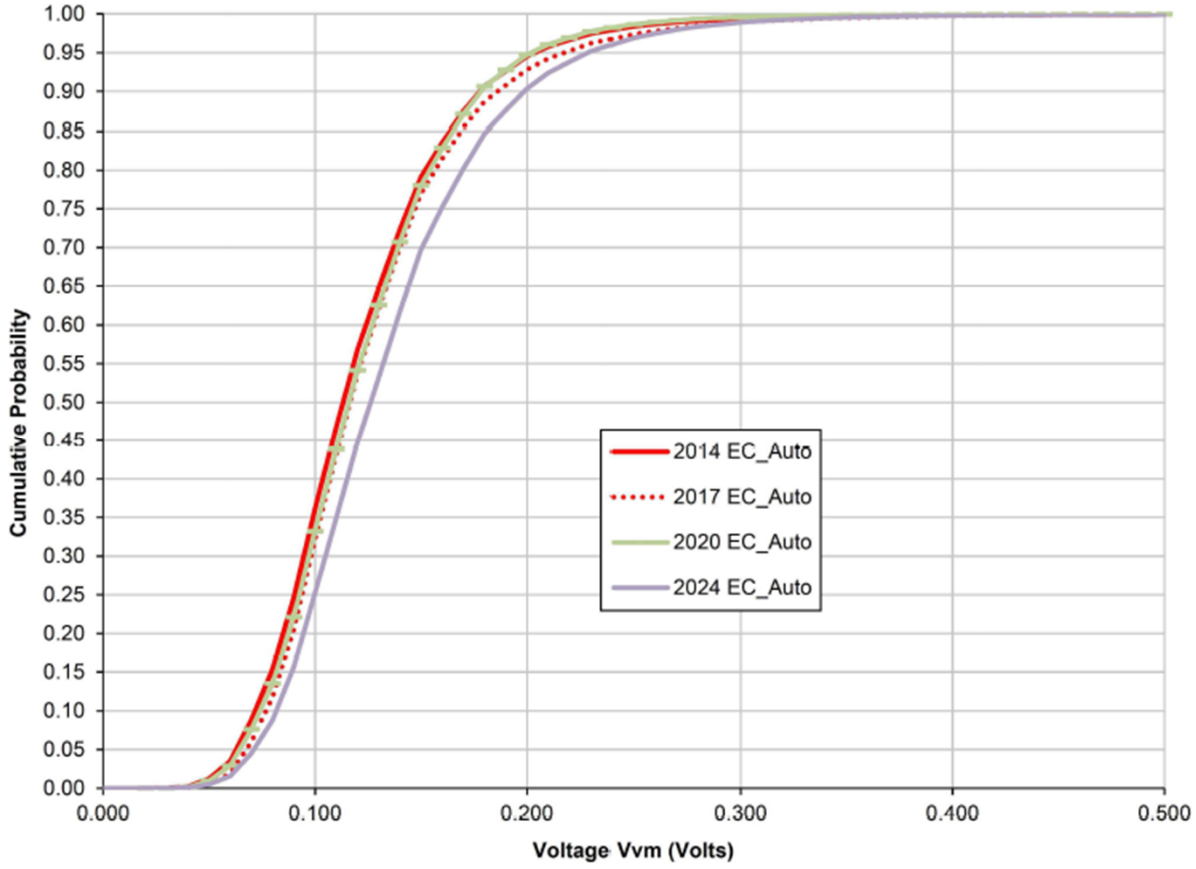
- NRC SG Sleeve Amendment issued October 30, 2025 (ML25303A280)
- NRC staff have no safety issues related to Palisades start-up and initial SG tube integrity, however, staff has questions related to OA modeling of cracking at the eggcrate supports
- Palisades is performing additional OA analysis based on NRC staff questions about the OA
- NRC staff evaluation of Palisades Cycle 29 OA continues, OA revision (Rev. 3) will be submitted to NRC after licensee review

Back-up slides

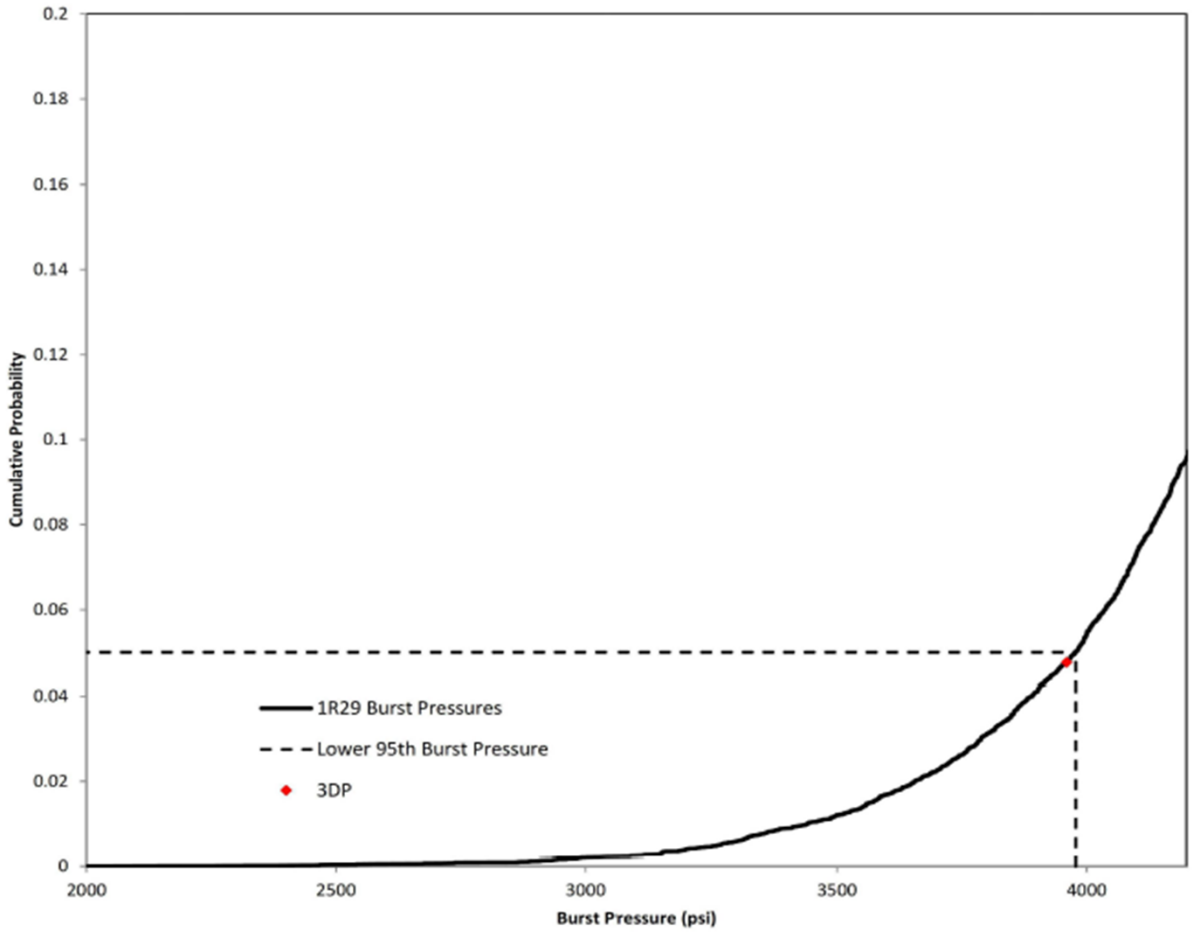
Bobbin POD Curve: Eggcrate, Vertical Strap, and Freespan Axial ODSCC



Eggcrate Support Bobbin Noise Comparison



Burst pressure Evaluation - Eggcrate



Palisades SG Tube Sleeving Amendment

- Issued October 30, 2025, ML25303A280
- Sleeve life is limited to 10 years
- Sleeve installation limited to hot leg only
- License Condition (LC) related to sleeve inspection:
  - LC establishes a minimum sleeve inspection scope, the actual scope will be determined by the degradation assessment and OA
  - 100 percent of in-service sleeve/tube assemblies by the end of 1R29
  - 50 percent sleeve/tube assembly inspection by the end of each RFO thereafter, with scope expansion per EPRI Integrity Guidelines if flaw detected in pressure boundary portion of sleeve or parent tube
  - LC intended to maintain high probability of detecting structurally significant parent tube flaws should they initiate