Industry Update

PWROG Farley Zinc Program

Rich Jacko – Westinghouse
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PWROG Farley Zinc Program

- Farley 2 Pilot Plant for Zinc Addition
  - Laboratory and test reactor experiments indicated reduced general corrosion and PWSCC mitigation benefits of zinc addition
  - EPRI sponsored demonstration plant
  - Zinc injection began June 12, 1994
  - RCS zinc concentration
    - 30 ppb Cycles 10, 12 - 14
    - 15 ppb Cycles 15 – 17 (post SG replacement)
  - Integrated zinc exposure 1551 ppb-months at last inspection
  - Integrated zinc exposure 1791 ppb-months at RV head replacement

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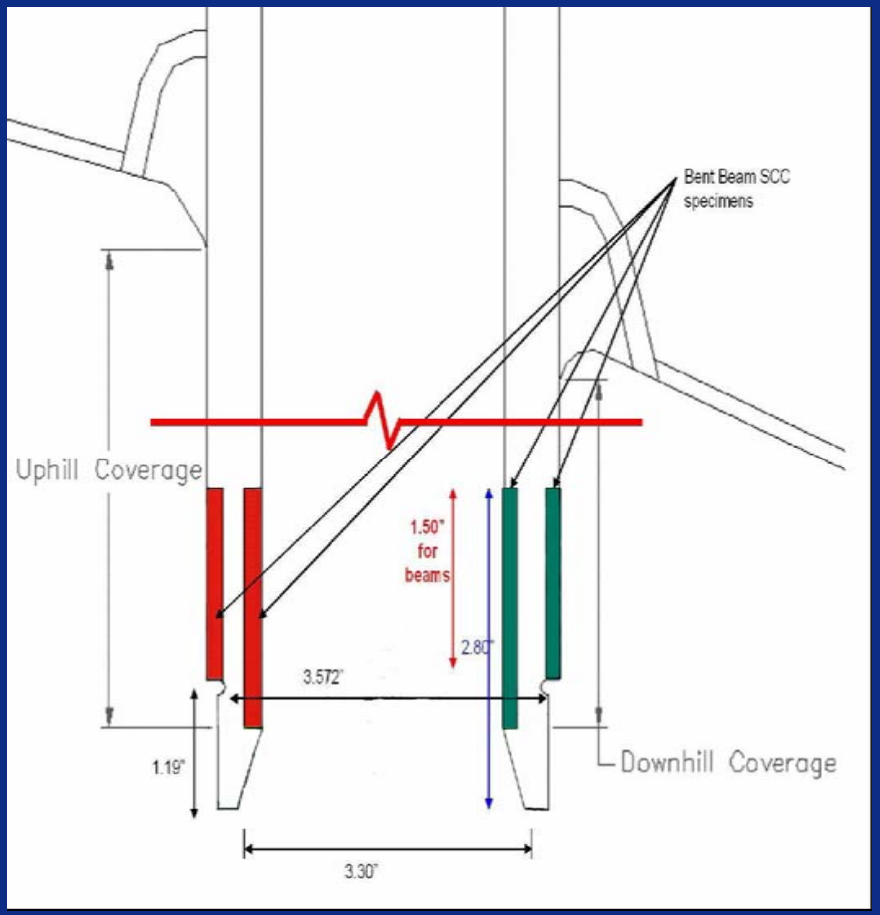
PWROG Farley Zinc Program

Heat M3935 at Farley

- 62 of 69 Farley 2 RV head penetrations were manufactured from Alloy 600 Heat M3935.
- Heat M3935 have shown PWSCC in ***all other plants without Zn injection***
- Replacement of the RV head at Farley 2 during the Fall 2005 outage provided a unique opportunity to obtain Alloy 600 CRDM material that operated for an extended period with Zn additions to the primary coolant.

PWROG Farley Zinc Program
Farley Heat 3935

- Farley CRDM provided inservice exposed material to show the benefit of zinc as a PWSCC chemical mitigation
- Plan to fabricate test specimens keeping as-is surface films intact
- Divide specimens into two groups
- Carefully remove zinc from the surface films of one group
- Perform comparison crack initiation testing



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PWROG Farley Zinc Program

- EPRI and the PWR Owners Group (PWROG) have approved programs to study the effects of zinc addition on PWSCC
- Ultimate Industry Goal – Acceptance of Zinc as a chemical mitigation method to support inspection relief.
- PWROG PA-MSC-0257 “PWSCC Crack Initiation Testing of Farley Unit 2 Alloy 600 CRDM Material” approved in February 2006
  - 5 year program with 5 distinct phases including “hold points”.
  - Verify the enhanced PWSCC resistance of Ht M3935 at Farley is due to zinc
  - Exposure of Alloy 600, Alloy 690, 82/182, and 52/152 materials to demonstrate that the benefits of soluble zinc extend to other primary side Alloy 600/Alloy 690 components and their associated welds.
  - Develop strategies to support utility technical evaluations.

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PWROG Farley Zinc Program
Task Description

- Task 1 - Development of the Industry Road Map and Creation of the Utility Core Team – Completed
- Task 2 - Material Characterization and Validation of Accelerated PWSCC Testing Methods for Sub-sized Specimens in 752°F Steam – Completed
- Task 3 - Baseline 680°F Autoclave Testing of Heat M3935 Material from the Davis-Besse and Farley 2 CRDM Penetrations (without zinc additions) - underway
- Task 4 - 680°F Autoclave Testing of Zn-Exposed Farley Unit 2 Heat M3935 Head Penetration Material (with zinc additions)
- Task 5 - Data Analysis and Comprehensive Final Report

PWROG Farley Zinc Program
Task 2 – Overview

- Test material and surface film characterization of Farley and Davis-Besse materials.
- Design of sub-sized four point bent-beam specimens with convex and concave stressed surfaces.
- Development of strain hardening method and verification of surface film integrity.
- Crack initiation testing in 752°F steam using surrogate Alloy 600 and Davis-Besse material
- Estimate time to crack initiation in primary water

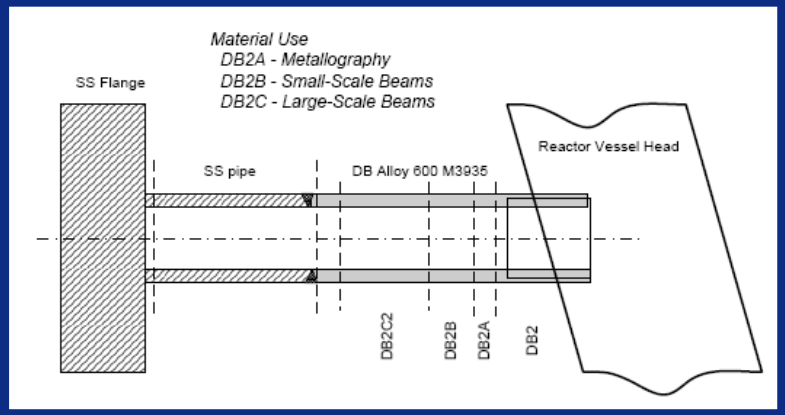
PWROG Farley Zinc Program

Task 2 – Test Materials

- Davis Besse Penetration #2 from US-NRC
  - Heat 3935 – SCC test samples
  - Material from above reactor head – limited oxide on ID
  - Air formed oxide on the OD
- Farley Penetration #14 and #16
  - Heat 3935
  - Threaded end from inside head used for material characterization efforts
- Surrogate Heat #1 – B&W 91117 – SCC test samples
- Surrogate Heat #2 – C2649 – SCC test samples

PWROG Farley Zinc Program

Task 2 – Heat 3935 Materials



- Davis Besse Penetration #2 from US-NRC Heat 3935
- Material from above reactor head
- Air formed oxide on the OD and limited oxide on ID

- Farley 2 material from Nozzles #14 & #16
- Replicas taken from ID & OD
- No obvious SCC initiation cracks detected
- Surface generally in good condition
- Some scratches to deal with – generally axial so limited effect

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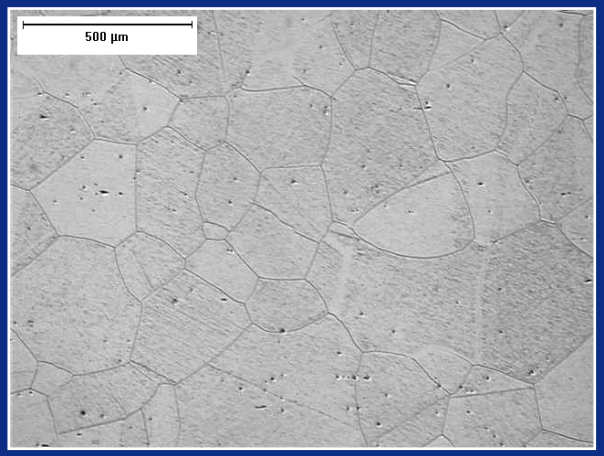
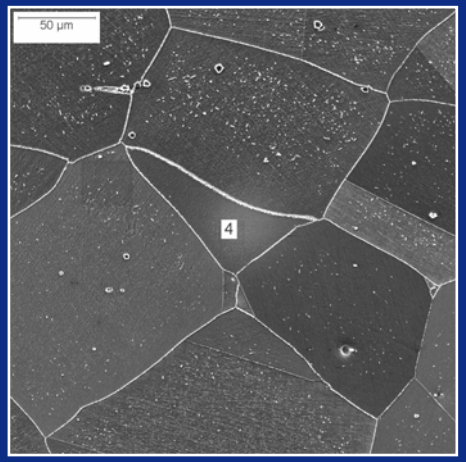
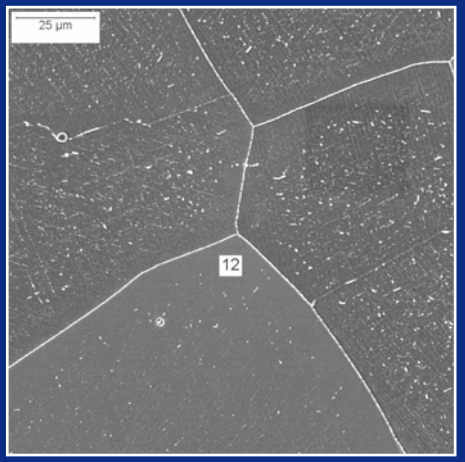
PWROG Farley Zinc Program

Task 2 – Heat 3935 Microstructure

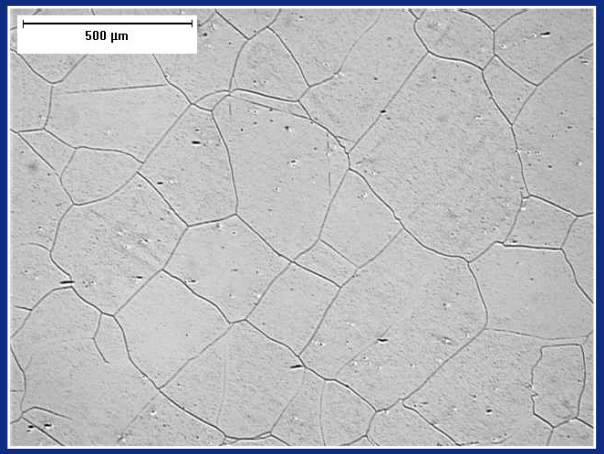
Davis-Besse #2

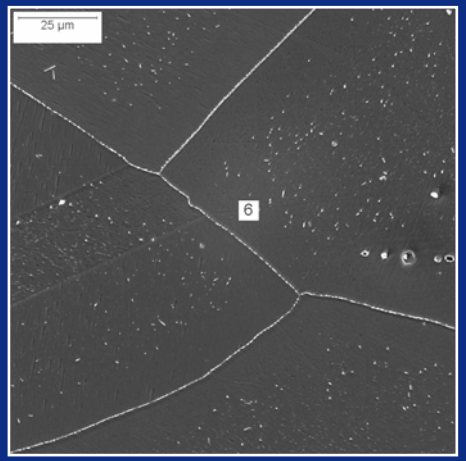


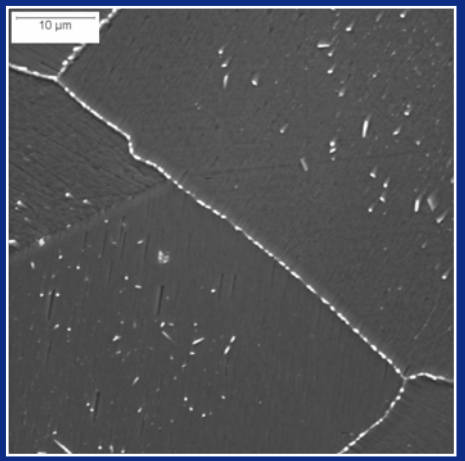




Farley #14







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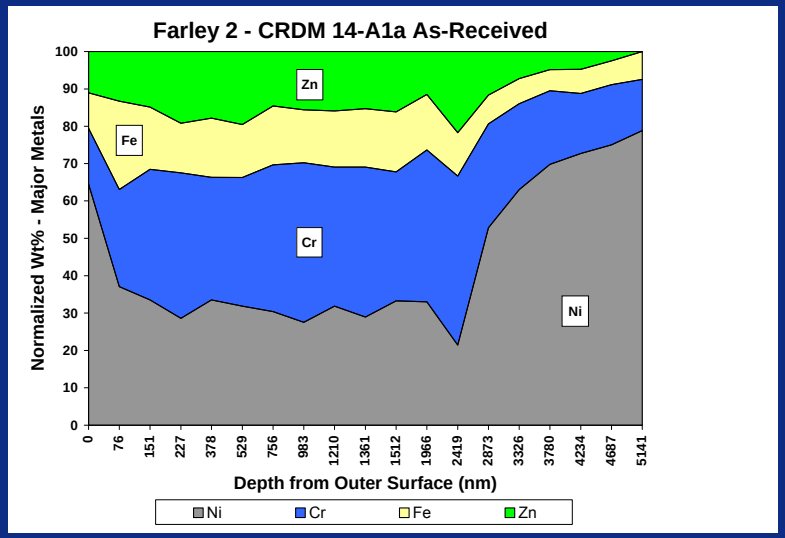
PWROG Farley Zinc Program

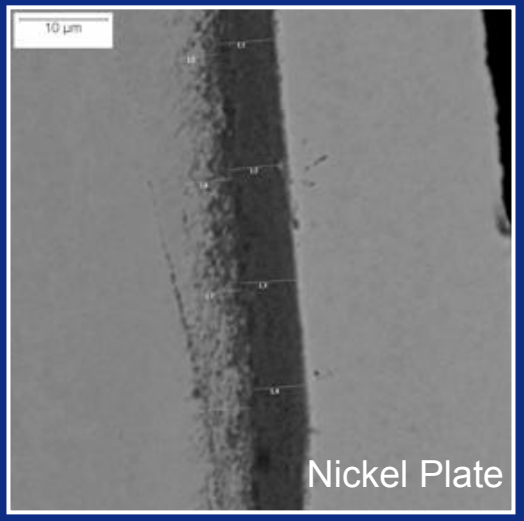
Task 2 – Heat 3935 Microstructure Comparison

- Heat M3935 from both Davis Besse and Farley 2 are similar
- Same grain size and grain structure indicate similar processing and annealing treatments
  - ASTM 2 grain size
- Carbide structure similar in both materials
  - Little evidence of intragranular carbides
  - With 0.028% C, the Alloy 600 would need to have seen ~1800°F to fully solutionize all carbides
  - Appears to be a distinct carbide free zone near the grain boundary in M3935 from both plants

PWROG Farley Zinc Program
Material Characterization – Zinc Incorporation



- After ~1800 ppb-mo of Zinc exposure, Zinc has fully penetrated the oxide film
- Auger & EDS analysis indicates zinc represents about 10 wt% of the metals in the oxide film



- Moderate thickness ID oxide/deposit visible
- Porous metal layer visible below original oxide-metal interface; mostly on OD
- Cr and Fe depleted from the base metal to form oxide
- Average thicknesses
  - Oxide/deposit = 3.2 µm
  - Porous A600 layer = 2.2 µm

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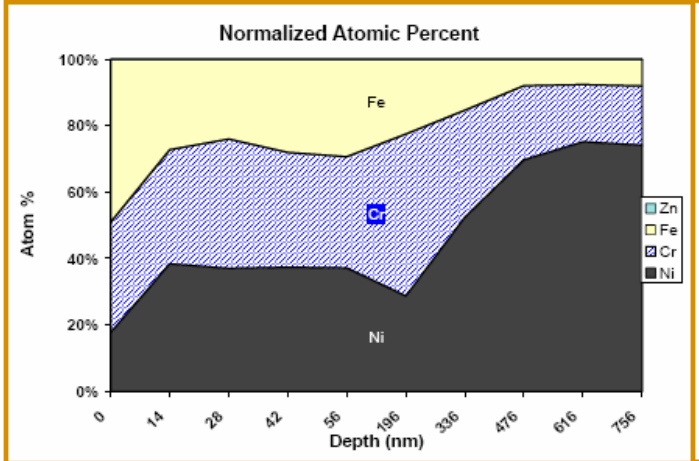
Zinc incorporation
1996 Observations by comparison

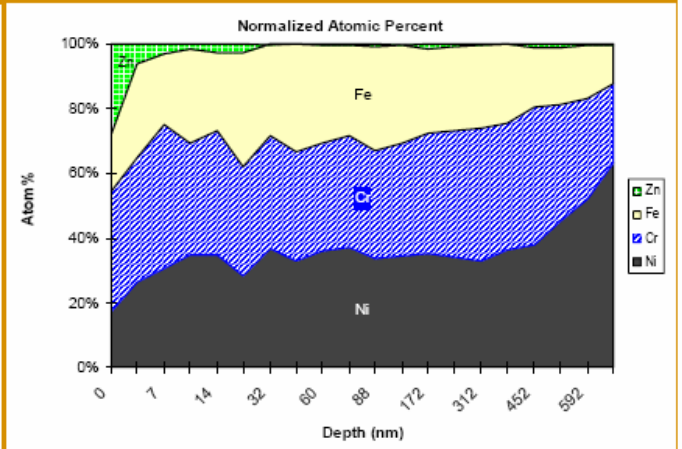
Farley Unit 2 Oxide Film – Incorporation of Zinc
(TR-106358-V1, Aug 1996)

Pulled SG tube film characterization



Cycle 9

No Zinc



Cycle 10

310 ppb-mo (~40 ppb for 239 days)

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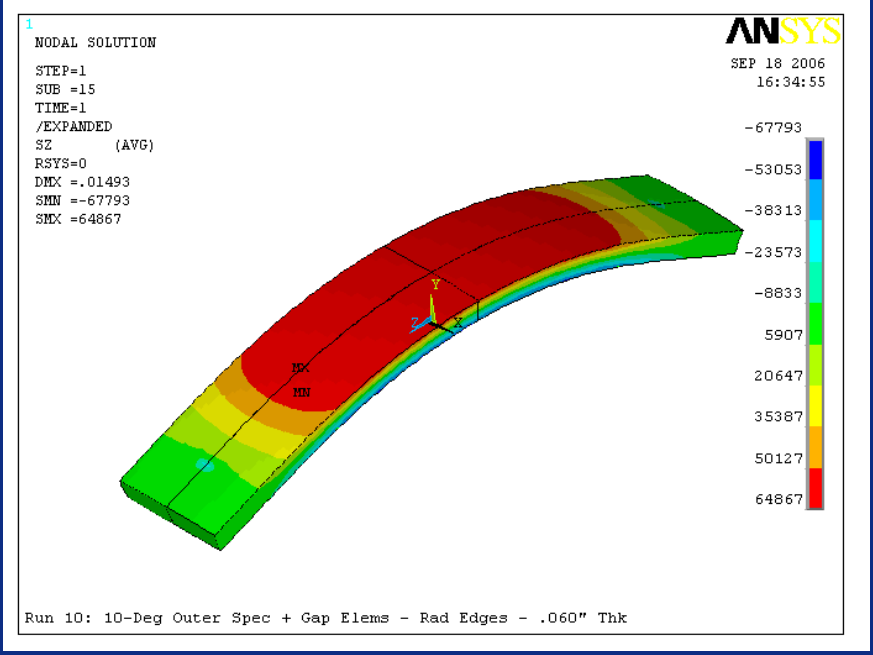
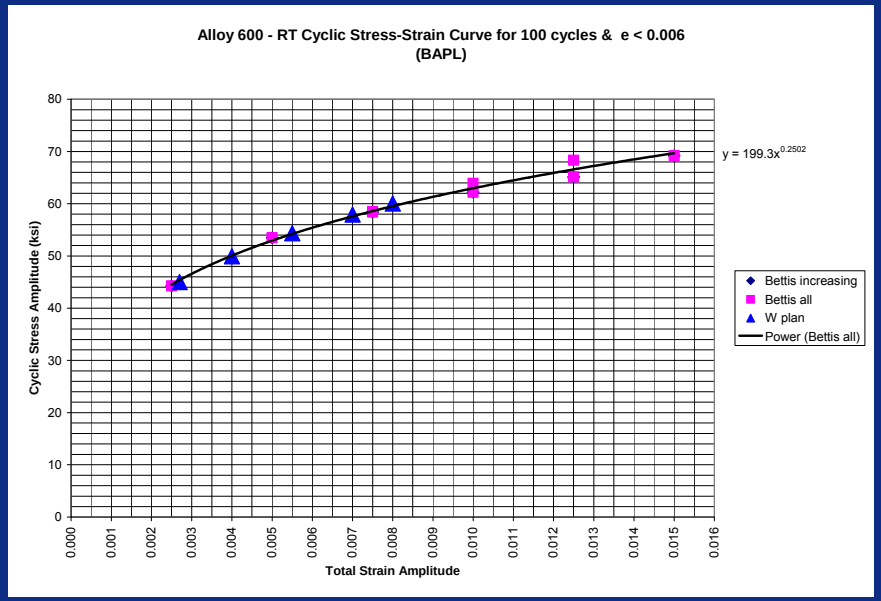
Specimen and Cyclic Hardening Process





Finite element models were utilized to determine strain gradients across sub sized specimens as a function of specimen width and thickness

Cyclic hardening process developed to strain-harden the surfaces of the Alloy 600 to the level required to achieve the desired test results in reasonable times. Final strain: 0.7% to 0.8%

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PWROG Farley Zinc Program
Task 2 - SCC Initiation Test Matrix

- 80 specimens tested in high temperature steam at 752°F (400°C) - 44 small scale and 36 large scale
- Combination of M3935 and two surrogate Alloy 600 heats

		SCC specimen size					
size/heat=		***large M-3935***	***small M-3935***	***large 91117***	***small 91117***	***small C-2649***	
Stress (ksi)							***Strain***
78°F	**752°F**						***(u-strain)***
63.2	**56.6**	- -	- -	7	8	- -	***2000***
56.9	**51.0**	5	5	6	8	4	***1800***
50.5	**45.3**	- -	- -	6	6	- -	***1600***
45.8	**41.1**	5	5	7	8	- -	***1450***
		Total number of specimens =				**80**	

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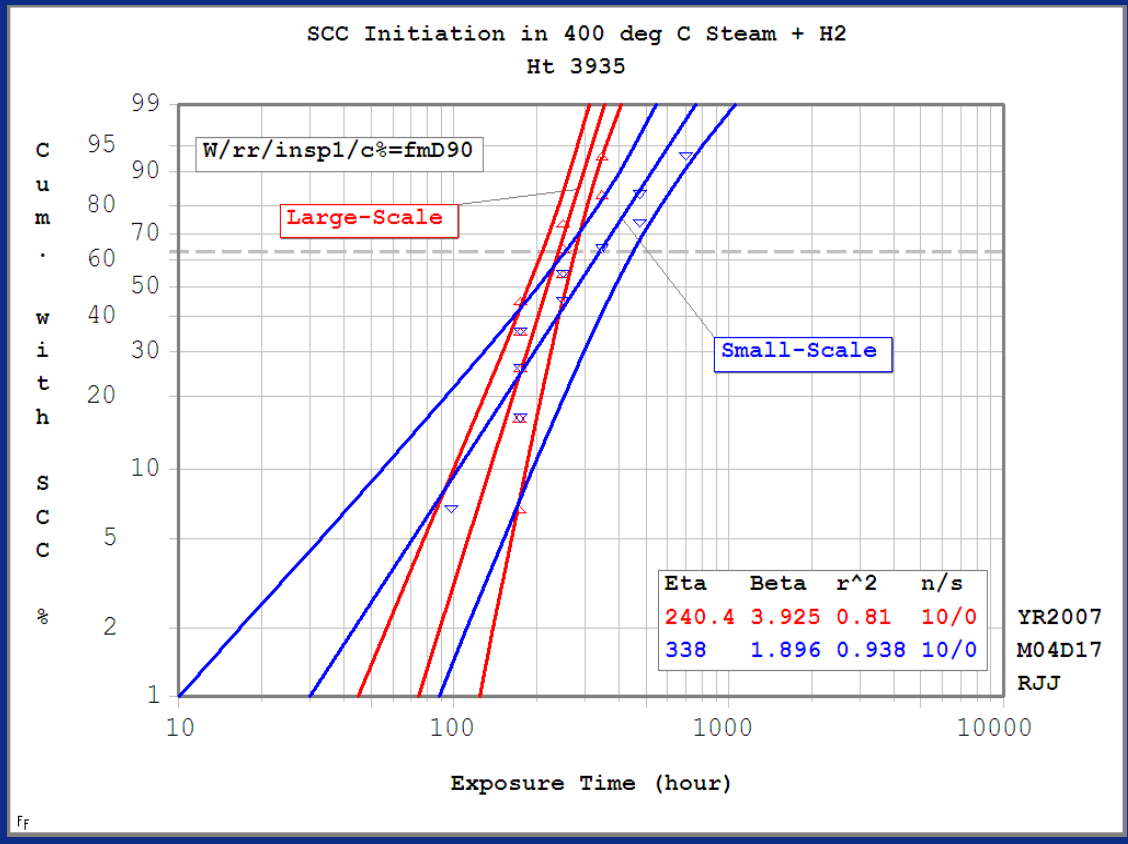
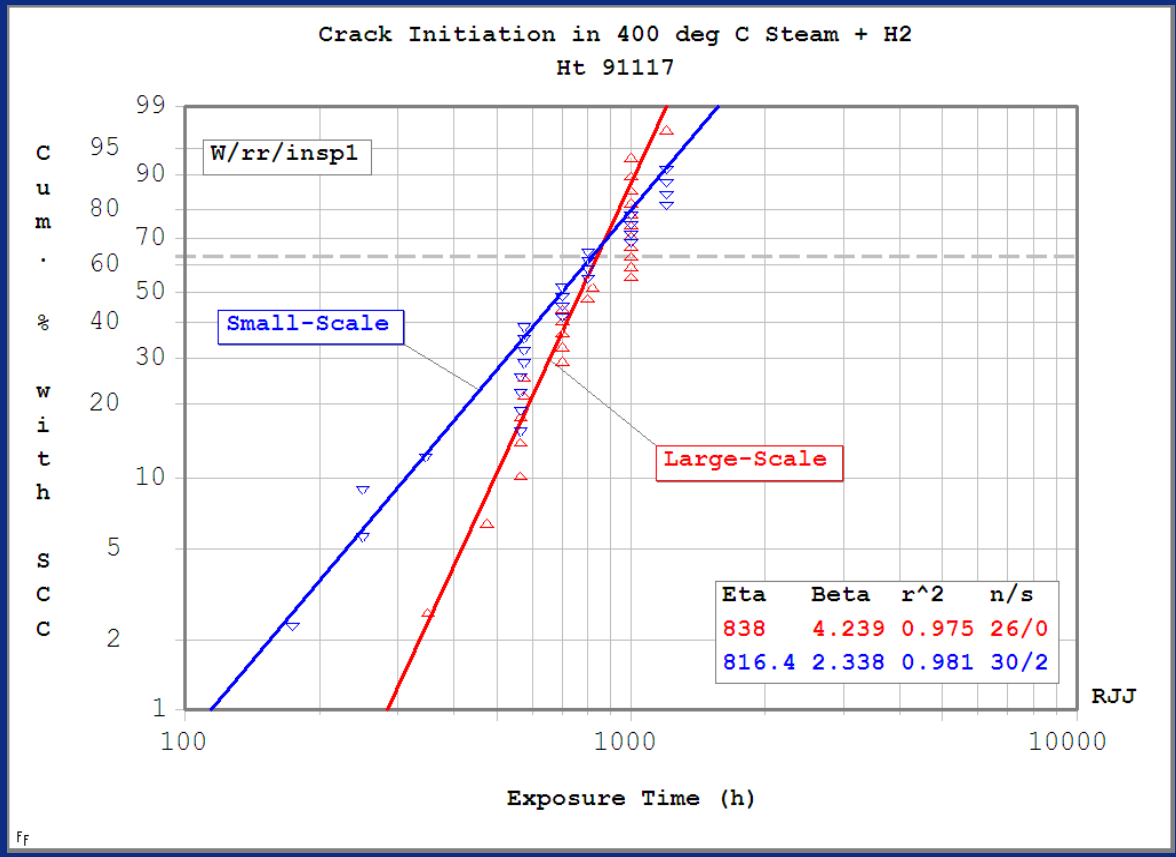
Task 2 Results - Davis Besse Ht M3935

- Results indicate similar characteristic lives for the two specimen sizes
- Weibull slope or shape factor slightly lower for the small size specimens
- 90% Confidence bands are drawn on the failure distributions
- Overlap indicates similar behavior (large / small)



PWROG Farley Zinc Program
Task 2 Results – Surrogate Heat 91117

- Results indicate similar characteristic lives for the two specimen sizes
- Weibull slope or shape factor slightly lower for the small size specimens
- Weibull slopes consistent with S/G experience
- SCC in 54 of 56



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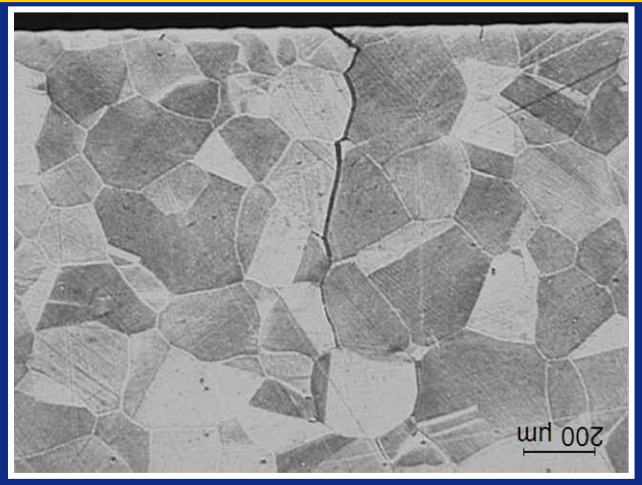
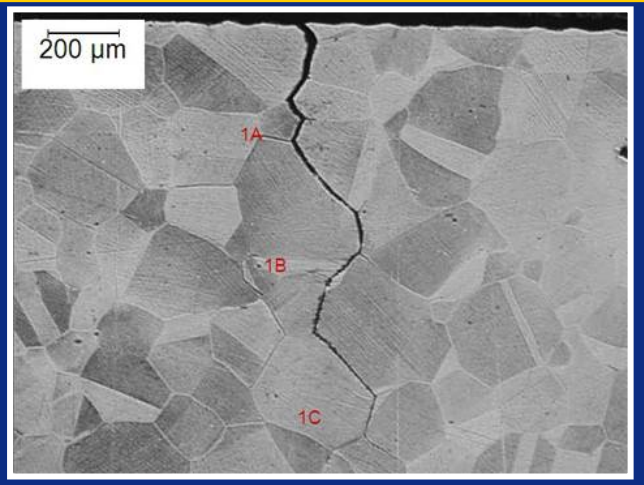
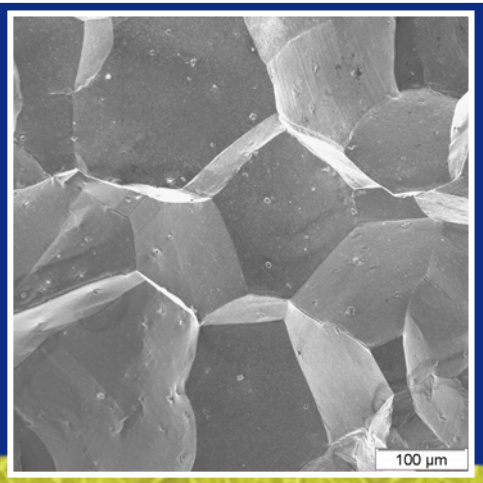
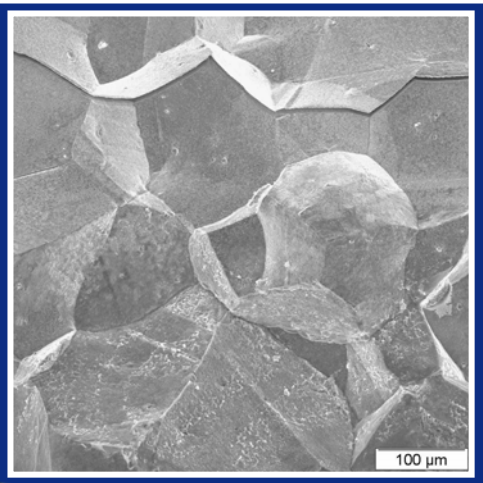
SCC in Davis Besse Heat M3935

Large-Scale Beams









Small-Scale Beams

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PWROG Farley Zinc Program
Task 2 Conclusion

- Farley CRDM: Zinc has incorporated deep into the oxide & deposits
- Small scale test specimen design validated
- Work hardening process validated
- Weibull characteristic crack initiation times similar for conventional, “large-scale” bent beam specimens and the “small-scale” beams designed for use with the Farley material
- Based on Westinghouse experience, the doped steam & hydrogen testing results would indicate that:
  - Baseline specimens of Ht M3935 would expect to initiate SCC in simulated 680°F primary water (no zinc) in ~3000 - 6000 hours
  - If SCC behavior meets expectations, should be able to demonstrate a significant zinc benefit when comparison tests run with Zinc

PWROG Farley Zinc Program
Task 2 – Goals not met

- Ability to remove zinc from Farley “baseline” specimens
  - Additional decon studies planned for June
- Demonstrate that the cyclic hardening operation does not introduce considerable “damage” to the oxide films
  - Cyclic hardening of material removed from North Anna penetrations

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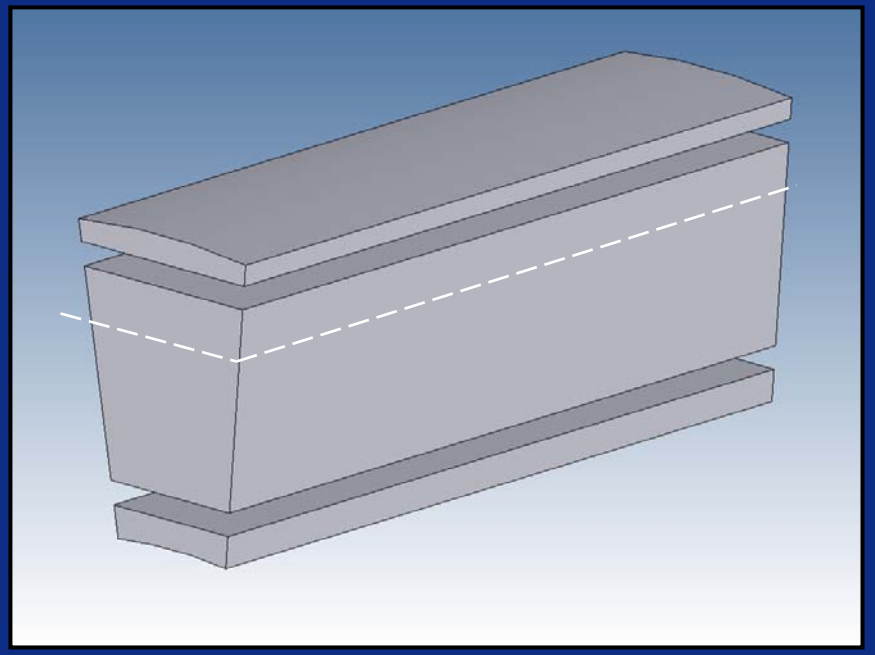
Contingency Plan for Farley – Davis Besse Comparisons

- Plans are complete for OD material from Farley 2 and Davis Besse
- FEM suggests that ID specimens may not be well suited for SCC studies
- Comparisons can be made for fresh specimens removed below outer layer



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PWROG Farley Zinc Program
Task 3 and Task 4 Overview

- Task 3 preparation is underway for baseline crack initiation testing in 680˚F primary water (with no zinc additions) scheduled to start July 07
  - Test specimens to include Davis-Besse, Farley 2 (zinc enriched surface film removed), surrogate Alloy 600, Alloy 82/182, Alloy 52/152, and Alloy 690.
  - Interim inspections after every 400 to 700 hours of testing until 8400 hours total exposure (equivalent to ~19 EDY at 600°F using a Q = 50 kcal/mole).
- Task 4 testing will consist of crack initiation testing in 680°F primary water (with 15 ppb zinc additions)
  - Test specimens to include Farley 2 M3935 with zinc enriched surface film, Davis-Besse M3935, Alloy 82/182 and 52/152 welds, and Alloy 690.
  - Interim inspections at approximately 1000 hours intervals up to 18000 hours total (equivalent to ~ 41 EDY at 600°F).

Task 3 – Baseline SCC performance of Heat M3935 & materials of interest

Objective

- Demonstrate that the excellent PWSCC performance observed by the Farley 2 M3935 material was due to Zinc addition
- When Zinc is removed from the Farley Material, SCC performance is expected to be similar to the Davis Besse Material
  - Complications may arise due to the presence porous layer below oxide
  - Planning on removing some specimens below surface layer
  - Baseline testing of 690/52/152/182/82 for surface characterization

Task 3 – Baseline SCC performance of Heat M3935 and other Alloy 600

- The deep Zinc penetration observed in the Farley 2 material may prove difficult to remove
- Testing of 2nd layer specimens Farley & Davis Besse

	E at T (ksi) 31.59	E at T (ksi) 28.73		small Far#14 M-3935	small Far#16 M-3935	small DB#2 M-3935	small C-2649
Strain (u-strain)	ksi 77°F	ksi 680°F	MPa 360°C				
2100	66.3	60.3	416	5	5	10	7
1800	56.9	51.7	357	5	5		7
1800	56.9	51.7	357	5	5	10	- -
1600	50.5	46.0	317	2	3	5	- -
1450	45.8	41.7	287	- -	- -	- -	- -
						Total No. of Alloy 600 Beams =	74

Lomi decon

Flat beams

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Task 3 – Baseline SCC performance of Alloy 690 and weld metals

- Alloy 690 and the associated weld metals will be tested as stressed beams
- Regions on these specimens will be prepared for future surface film analysis (Auger / FEG SEM)

	E at T (ksi) 31.59	E at T (ksi) 28.73	Flat beams				
Strain (u-strain)	ksi 77°F	ksi 680°F	MPa 360°C	*Alloy 690 cw 7A21*	*52M archive*	*152 archive*	*182/82 large VCSum*
2100	66.3	60.3	416	5	5	4	9
1800	56.9	51.7	357	- -	- -	- -	- -
1800	56.9	51.7	357	- -	- -	- -	- -
1600	50.5	46.0	317	- -	- -	- -	- -
1450	45.8	41.7	287	- -	- -	- -	- -

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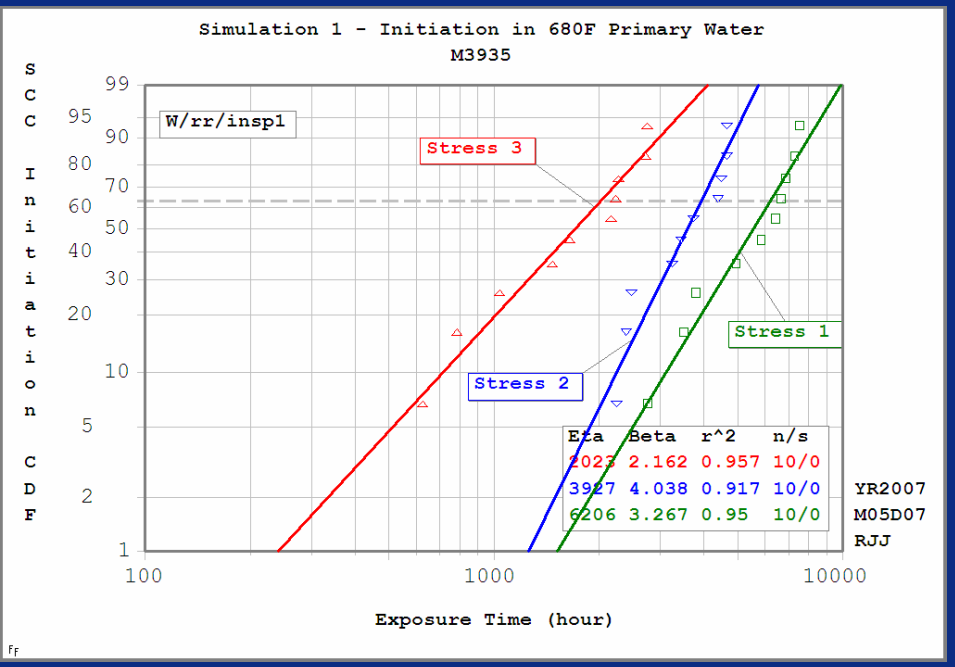
Task 3 - Baseline Testing

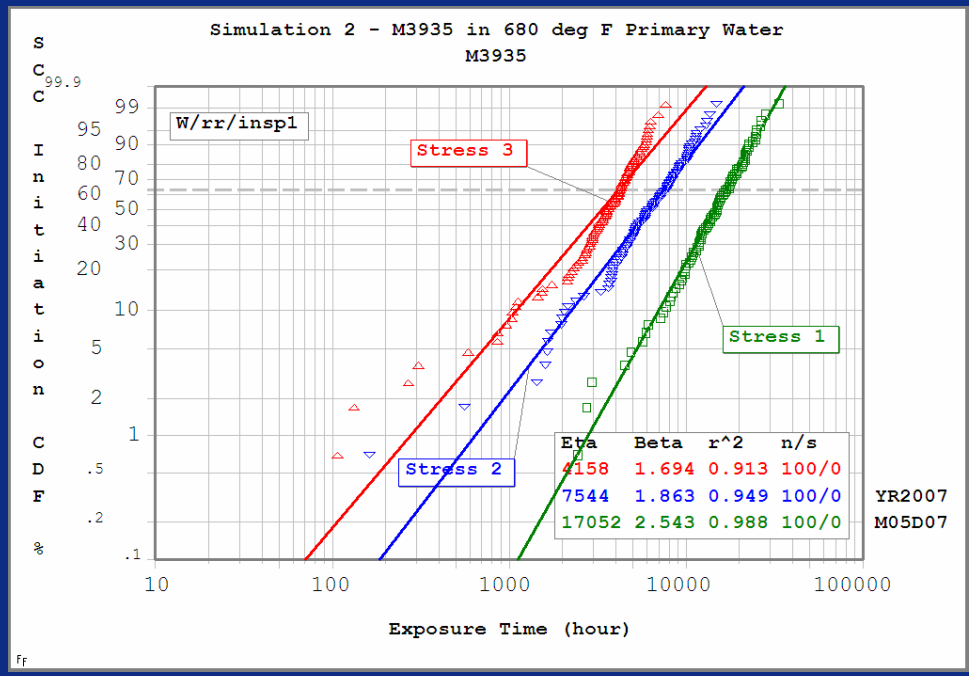
- Original plan to test Alloy 690/52/152 as coupons
- Only plan to examine similarity of Zn incorporation
- Easier to examine these materials in the same test fixtures
- There are technical reasons to examine stressed specimens; role of T and stress on Zn effects
- Plan to test Alloy 690/52/152 as polished and electropolished stressed beams

Simulations of Task 3 Initiation Tests



Expected

Conservative

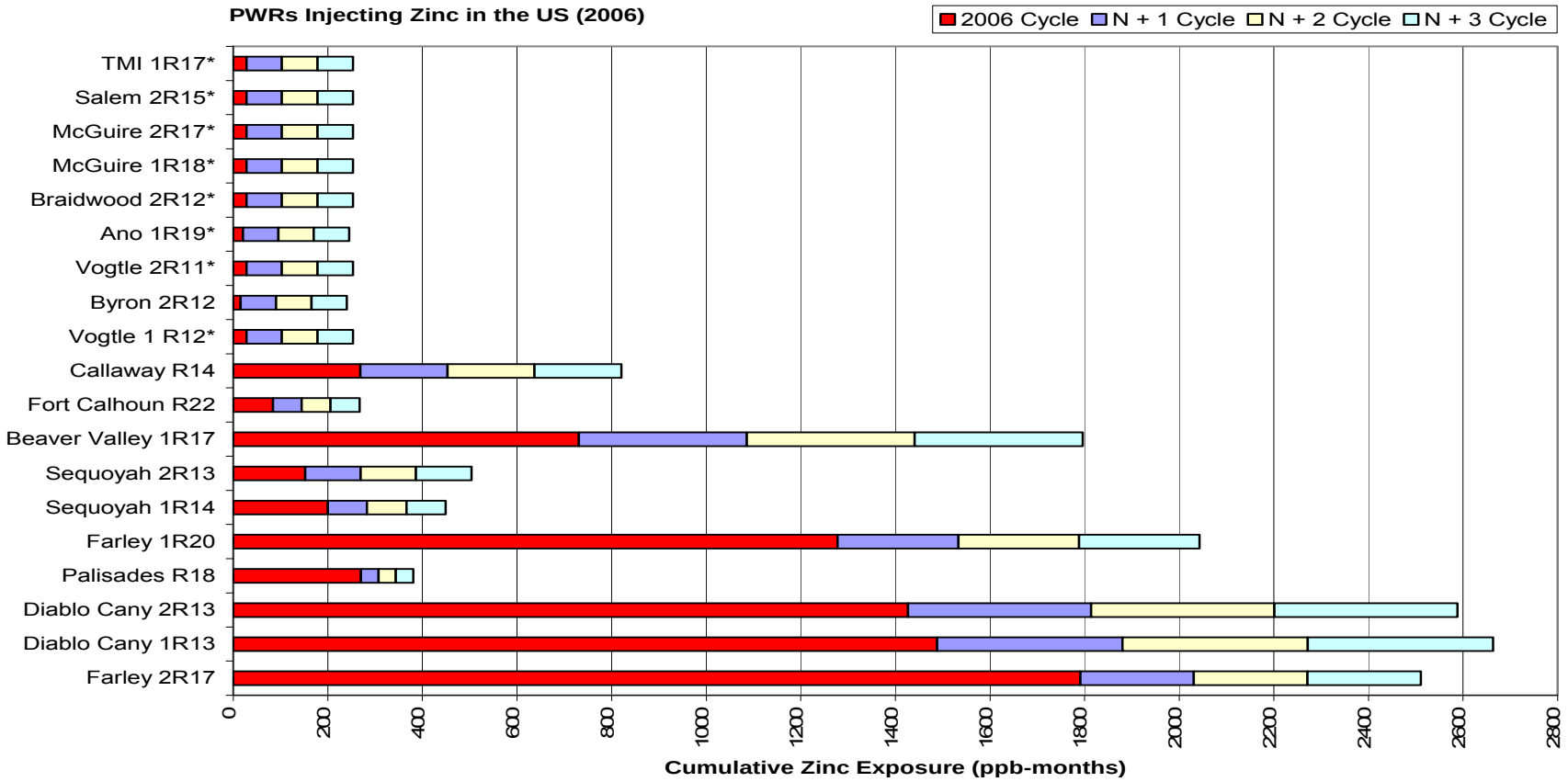


Task 3 Testing with Zinc Injection

Current status

- All Farley materials are cut into segments
- Cutting of thin beam specimens has started
- Hardening of surrogate Alloy 600 specimens complete
- Starting to cut Alloy 690 specimens
- Cyclic hardening of radioactive specimens planned for June
- Testing scheduled for July 07 thru Aug 08

PWROG Farley Zinc Program
US PWRs – Cumulative Zinc Exposure



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Task 4 – Testing SCC performance of Heat M3935 and other Alloy 600 with Zn

- Farley 2 OD specimens pre-exposure ~1800 ppb – mo of zinc exposure
- Davis-Besse OD specimen have 0 ppb - mo pre-exposure
- Selected flat beam specimens will be pre-exposed to either 200, 400 or 800 ppb-mo of zinc prior to the start of SCC testing

	E at T (ksi) 31.59	E at T (ksi) 28.73					
Strain (u-strain)	ksi 77°F	ksi 680°F	MPa 360°C	*small Far#14 M-3935*	*small Far#16 M-3935*	*small DB#2 M-3935*	*small C-2649*
2100	66.3	60.3	416	10	10	10	8
1800	56.9	51.7	357	8	8	- -	- -
1800	56.9	51.7	357	15	15	15	- -
1600	50.5	46.0	317	- -	- -	- -	- -
1450	45.8	41.7	287	- -	- -	- -	- -
				Total No. of Alloy 600 Beams =			99

Lomi decon

Flat beams

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Task 4 – Testing SCC performance of Alloy 690/52/152 with Zn

Alloy 690 and the weld metals will be pre-exposed to Zinc containing primary water prior to the start of SCC testing

small Far#14 M-3935	*small Far#16 M-3935*	*small DB#2 M-3935*	Flat beams with no oxide preconditioned to:		
5	5	5	200	ppb-mo =	50 ppb x 4 mo
5	5	5	400	ppb-mo =	100 ppb x 4 mo
5	5	5	800	ppb-mo =	200 ppb x 4 mo
15	15	15			

	E at T (ksi) 31.59	E at T (ksi) 28.73	Flat beams				
Strain (u-strain)	ksi 77°F	ksi 680°F	MPa 360°C	*Alloy 690 cw 7A21*	*52M archive*	*152 archive*	*182/82 large VCSum*
2100	66.3	60.3	416	5	5	5	9
1800	56.9	51.7	357	- -	- -	- -	- -

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Task 4 – SCC Testing with Zinc

- Current plans are to initiate Zn testing in late 2008
- If baseline Task 3 testing shows anticipated SCC initiation trends, would anticipate asking PWROG to move the start of Task 4 testing with zinc to 2008
- 18000 hours of crack initiation testing planned (equivalent to ~ 41 EDY at 600°F)
  - Approximately 2.5 years to complete after starting

Summary

- Farley CRDM showed Zinc has incorporated deep into the oxide films & deposits
- Small scale test specimen design validated
- Work hardening process validated
- Baseline testing of Farley & D-B material starting
- Baseline testing of Alloy 690/52/152/182 also starting
- Plans for Task 4 with zinc exposure will finalize after SCC initiation observed in baseline tests
- Part of the Task 4 test matrix will be fresh specimens with different starting integrated ppb-mo of zinc exposure simulating conditions at various plants