NRC PWSCC Crack Initiation Research Project

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Protecting People and the Environment

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Objectives

- Conduct confirmatory research to develop PWSCC initiation data for Alloy 182 to support xLPR.
  - Understand uncertainties and accuracy of PWSCC initiation models
- Develop PWSCC initiation data for Alloys 600/690/52/52M/152 to help develop inspection requirements for components made from these alloys.
  - Support reviews of potential submittals requesting credit for the use of more resistant materials.

Note: Our aim is not necessarily to simulate the conditions of components in service, but rather develop data to evaluate the initiation models using parameter levels (i.e. temperature, % cold work, applied stress) known to cause/accelerate cracking in susceptible alloys (within the applicable ranges of the models) and to obtain data in a time frame that supports our objectives.

Approach
MOU Addendum

- The NRC and EPRI have entered into a memorandum of understanding (MOU) to conduct cooperative research on PWSCC initiation testing at PNNL.
- The program is planned to test A600/182 and A690/152/52(M) for a total estimated project duration of five years:
  - Support xLPR validation
  - Provide data to support inspection requirements for Alloy 690/152/52(M)

Approach
Experimental Test Plan Summary

- Two SCC initiation systems will be used.
  - One system for Alloy 600/182 tests (multiple loadings each 6-9 months)
  - One system for Alloy 690/152/52 tests (anticipated single loading, 5 yrs)
- 3-9 specimens per material/condition to provide statistical information.
- All specimens will be tested in a polished condition to facilitate observations of cracking.
- Majority of specimens will be at the yield stress.
  - Service experience suggests that majority of initiation events have occurred in components with cold-worked surface layers at their yield stress.
- Simulated PWR primary water at 360°C and dissolved hydrogen equivalent to the Ni/NiO stability line for accelerated testing.
- Post-test specimen evaluation

Approach

PWSCC Initiation Specimen Types

- (Reverse) U-bend
  - Advantages: Ease of fabrication, easy to apply different surface finishes, simple loading method, ability to simultaneously expose a large number of specimens
  - Disadvantages: Stress level and stress state vary strongly and accurate estimation requires FEM, cannot test as-received material, limited control over applied strains and stresses, no in-situ detection
- Blunt notch CT
  - Advantages: In-situ detection
  - Disadvantages: Stress level and stress state vary strongly and accurate estimation requires FEM, limited exposed surface, difficult to apply surface finishes
- 3-pt bend
  - Advantages: Ease of fabrication, easy to apply different surface finishes, can be bolt-loaded or actively loaded, ability to simultaneously expose a large number of specimens, any material condition can be tested, in-situ detection
  - Disadvantages: Stress level and stress state vary strongly and accurate estimation requires FEM.

Approach

PWSCC Initiation Specimen

- Tensile geometry has many appealing features
  - Simple, uniaxial stress, directly measured
  - Can test material in as-received or CW condition
  - Exposes a large number of grain boundaries
  - Can apply different surface finishes
  - Can be static or actively loaded
  - Amenable to in-situ crack detection using DCPD
- Disadvantages
  - Challenging to simultaneously test a large number of actively loaded specimens.

1.2" tall
(30.5 mm)

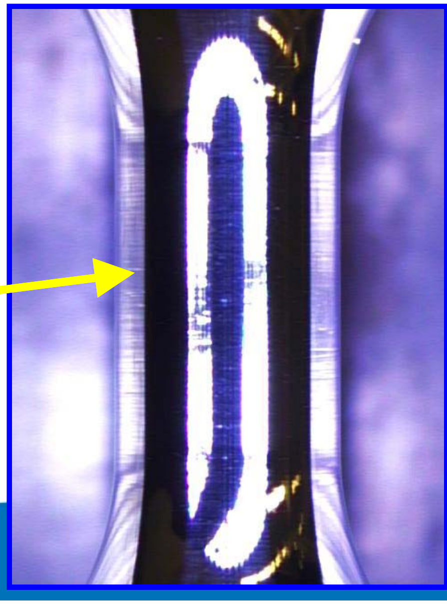
Approach
Tensile Specimen Selected

- Tensile geometry adopted to facilitate understanding the stress state and allow for active loading.
- Optimized geometry for DCPD-based detection of SCC initiation.
  - Short gauge length and small diameter accentuates DCPD initiation signal.
  - Large diameter region adjacent to the gauge section acts as a resistivity reference analogous to a reference coupon for SCC CGR testing.
- A range of surface finishes or notches can readily be applied.

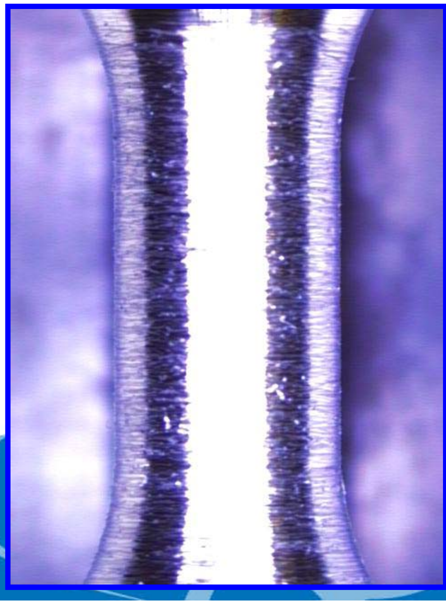
1.2" Tall SCC Initiation Specimen

Examples of Surface Finishes

1 µm finish



60 grit finish

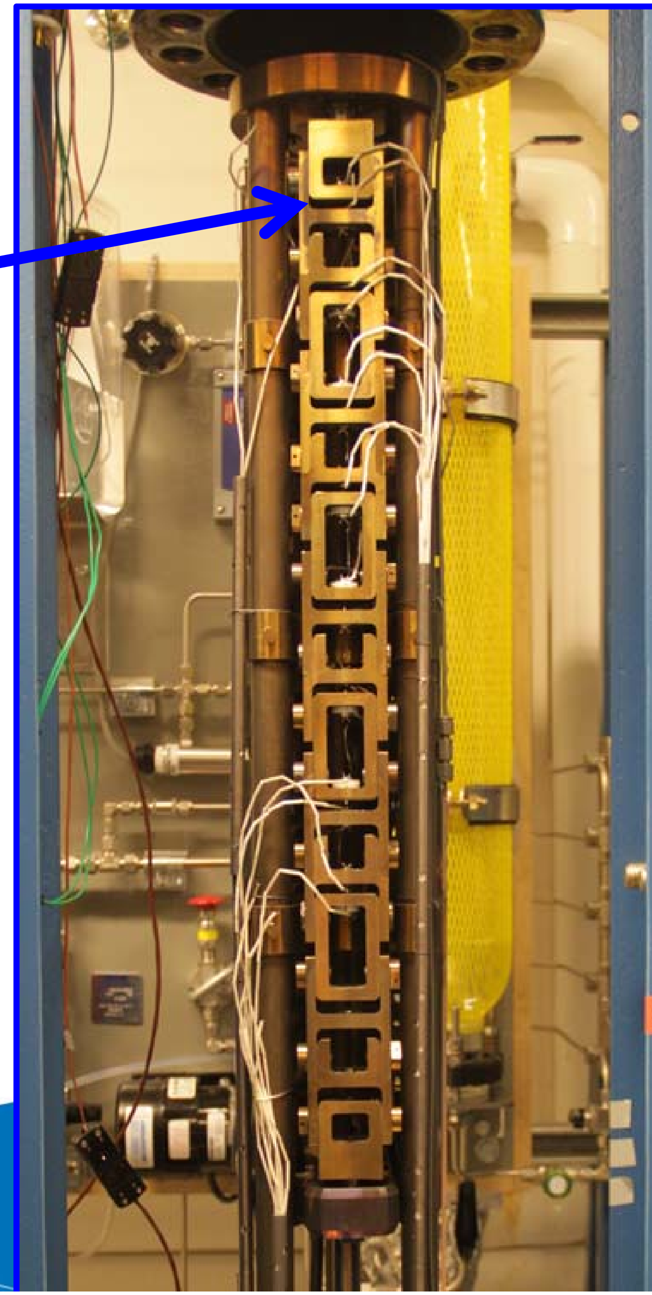


Approach

PNNL Test Facility

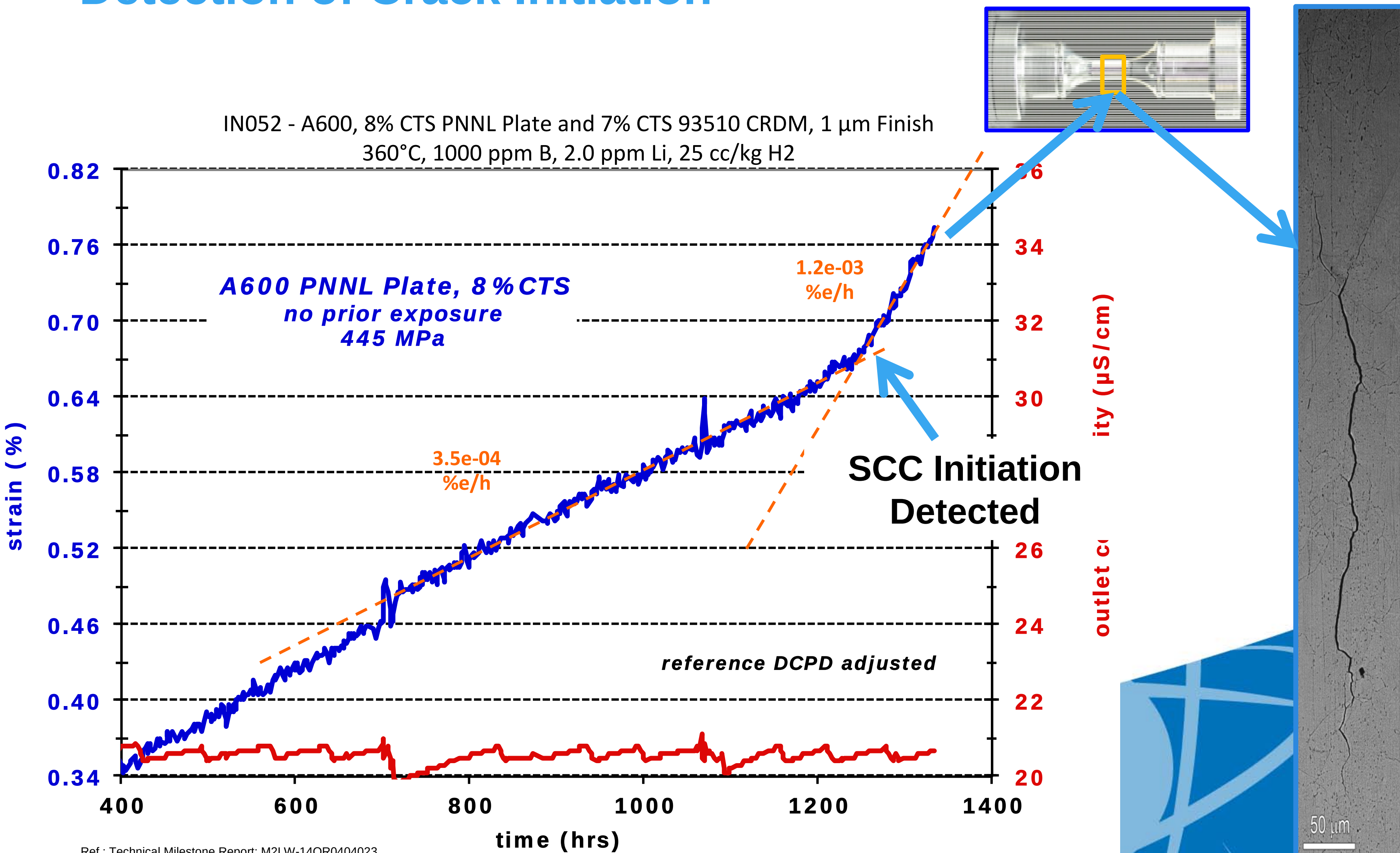
- Fabricating two 36-specimen testing systems
  - Based on similar test system developed for DOE-NE LWRS program
- All specimens at the same load; stress controlled by adjusting gauge diameter
- Crack initiation detected using DCPD

PNNL 36 Specimen Load Train



Approach

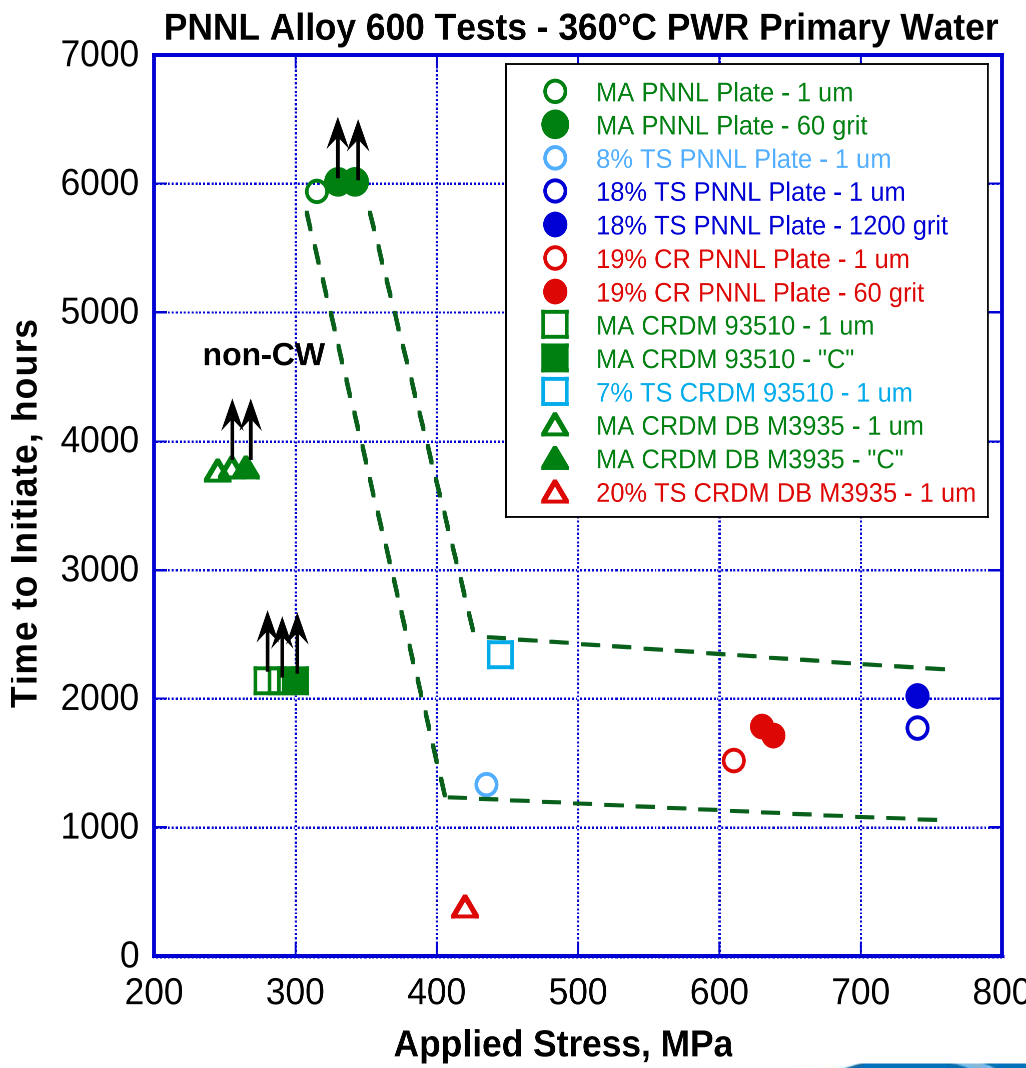
PNNL Test Facility – DCPD Based Detection of Crack Initiation



Ref.: Technical Milestone Report: M2LW-14OR0404023
PNNL-23712 September 2014

Approach
Material Condition

- Cold worked condition is the top candidate for two reasons:
  - French research has shown that initiation in service materials has primarily occurred in components with a highly cold worked surface layer.
  - CW will allow for more reasonable SCC initiation times of ~1500-2000 h.
- xLPR has interest in as-welded alloy 182. Added to the test matrix.



PNNL testing shows non-CW alloy 600 trending towards 4000-6000+ hours.

Ref.: Technical Milestone Report: M2LW-14OR0404023
PNNL-23712 September 2014

Approach

Test Matrix

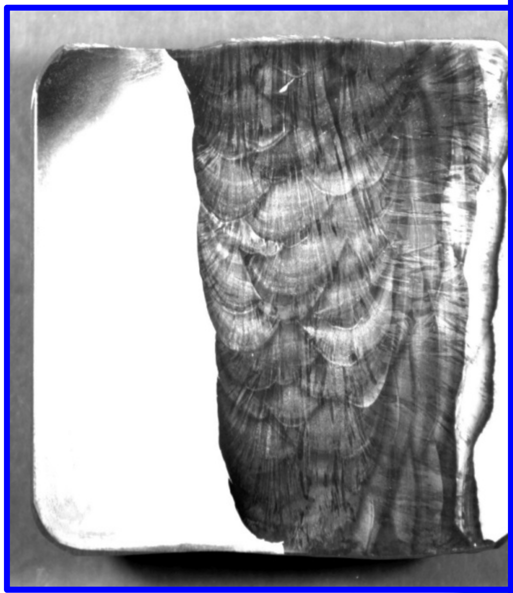
- 4 Different Alloy 182 Welds
  - Testing of as-welded for xLPR
  - Testing of 15% CW condition for xLPR and comparison to 152/52(M)
  - 3 specimens as-welded per weld; 6 specimens in CW condition per weld
- 4 Different Alloy 600 Heats
  - All tests performed on 15% CW material to compare to Alloy 690
  - 9 specimens in CW condition per heat
- 4 Different Alloy 152/52/52M Welds
  - All tests performed on 15% CW material
  - 6 specimens per weld
- 4 Different Alloy 690 Heats
  - All tests performed on 15% CW material
  - 3 specimens per heat
- 15% cold-work selected based on prior initiation time experience with Alloy 600 and range of damage layer strength in service Alloy 600 components.

Approach

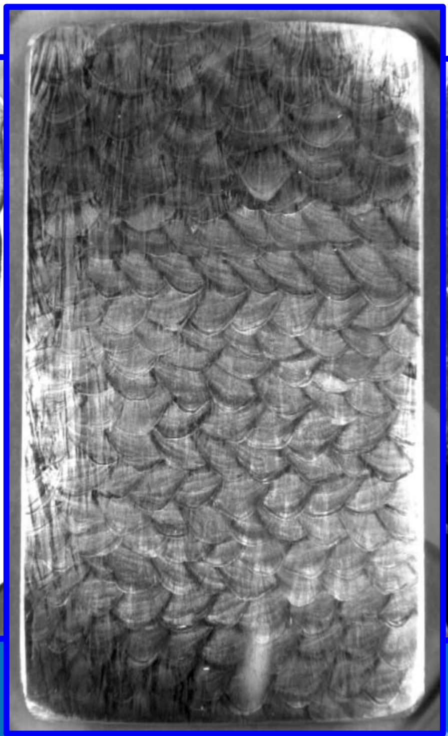
Material Characterizations

- General microstructure, hardness, EBSD for strain, and SEM-EDS for compositional variations are underway.
- Most all materials have been or will be SCC crack growth rate tested.
  - Characterize range of SCC crack growth susceptibility of the selected materials.
  - Allow comparisons between SCC initiation time and SCC CGR response.

Flawtech alloy 182 dissimilar metal nozzle weld

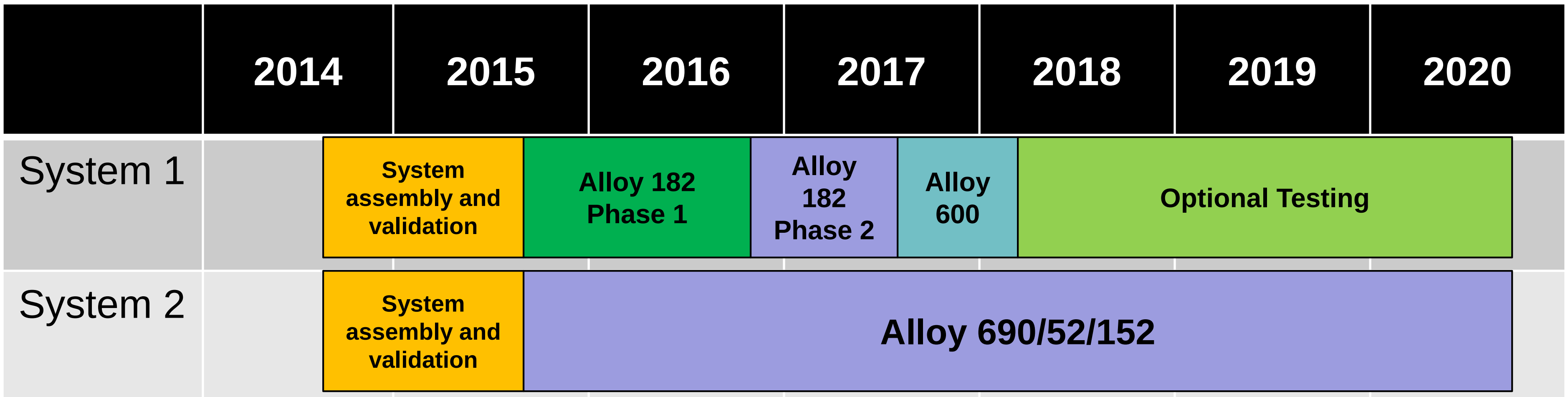


Studsvik alloy 182 linear weld



Phase 2B alloy 182 dissimilar metal nozzle weld

Approach
Testing Timeline



- Alloy 182 Phase 1
  - Heat-to-heat variability
- Alloy 182 Phase 2
  - Applied stress effects
- A third NRC test system may become available for use during this project.

Approach

Test Plan Expert Review

- PNNL developed initial draft test plan which was distributed to selected experts for review and comments.
- Process to address comments from the reviewers:
  - Each comment was recorded in a spreadsheet
  - NRC and EPRI reviewed comments
  - Each comment was addressed individually by PNNL
    - NRC and EPRI also reviewed and commented on PNNL responses
- Most comments fell into three major categories:
  - Test Acceleration
    - Use of cold work
    - Stress ratio ($S_{applied}/S_y$)
    - Temperature
  - Specimen Design
    - Tensile vs others (i.e. U-bend, bent beam)
  - Surface Finish
    - Polished vs ground

Approach
Test Plan Expert Review

- PNNL developed a second draft of the test plan that addresses the expert reviewers’ comments.
  - Latest draft test plan is being reviewed by NRC and EPRI
- EPRI and NRC are working on a plan to disseminate the test plan, comments and the response to each comment.

Project Status

Materials: Acquisition

- Alloy 182 Welds:
  - Two dissimilar metal nozzle welds and two linear welds have been obtained.
- Alloy 600 Heats
  - Three plate heats and one CRDM heat have been obtained.
  - SCC initiation test experience for one of the plate heats from DOE-NE LWRS SCC initiation program.
- Alloy 152/52/52M Welds
  - Have obtained one each of alloy 152, 52, 152M, and 52M welds.
- Alloy 690 Heats:
  - Two CRDM heats and two plate heats have been obtained.

Project Status

Materials: Forging

- Two of three forging rounds completed:
  - Alloy 182
    - 3 of 4 welds forged to date.
  - Alloy 600
    - 3 of 4 heats forged to date
  - Alloy 152/52/52M
    - 3 of 4 welds forged to date
  - Alloy 690
    - 4 of 4 heats forged to date
- Completion date for forging is July 2015

Project Status

Test System

- Systems designed and built at PNNL from scratch.
- NRC-EPRI systems benefit from design and operational experience gained on DOE-NE LWRS system.
- All component purchases are complete.
- Construction of two systems underway.
- Completion expected in July 2015.

Project Status

Test System

Two test systems under construction for NRC-EPRI Program

Example of completed and operational 36 specimen system for DOE-NE LWRS Program at PNNL

Summary

- NRC and EPRI are conducting cooperative research under an MOU to develop PWSCC initiation data for Alloys 600/182 and Alloys 690/52/152 to support xLPR validation efforts and inform inspection requirements for Alloy 690/52/152.
- NRC and EPRI are contracting with PNNL to:
  - Develop test plan
  - Purchase components and assemble two new testing systems for this work
  - Obtain and process materials and make specimens
  - Perform testing and post-testing evaluations
- PNNL test plan was reviewed by experts in the field.
- Status:
  - Anticipated five-year project ending in 2020
  - Almost all materials obtained and most have been processed
  - Testing systems to be completed in August 2015
  - First tests to begin in September 2015

Acknowledgements

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Acronyms

- CGR – crack growth rate
- CT – compact tension
- CW – cold work
- DCPD – direct current potential drop
- DOE - NE LWRS – Department of Energy Nuclear Engineering Light Water Reactor Sustainability
- EBSD – electron backscatter diffraction
- EDS – energy dispersive spectroscopy
- EPRI – Electric Power Research Institute
- FEM – finite element method
- NRC – Nuclear Regulatory Commission
- PNNL – Pacific Northwest National Laboratory
- PWSCC – primary water stress corrosion cracking
- SCC – stress corrosion cracking
- SEM – scanning electron microscope
- xLPR – extremely Low Probability of Rupture