Improving Economics of Generation 3 CSP System Components Through Fabrication and Application of High Temperature Nickel-Based Alloys

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CSP Gen 3 (Pre-Award) Kickoff Meeting
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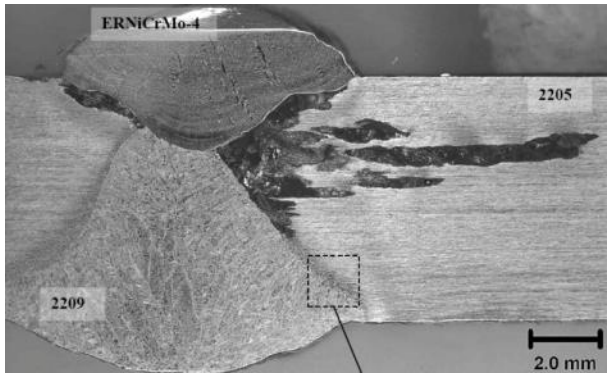
Team Members:

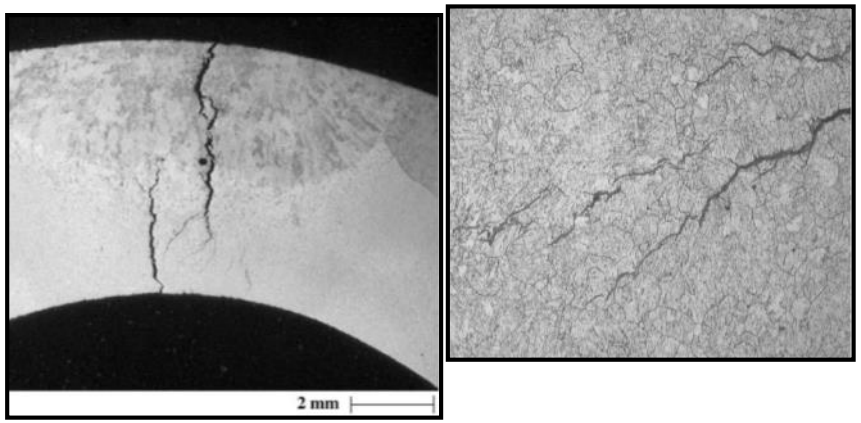
Special Metals, Oak Ridge National Laboratory

Background – Team Experiences

- Unanticipated materials challenges in first-of-a-kind applications and demonstrations in power generation



Metallic Wet FGD Corrosion – Over 70 effected units in U.S. (Materials Selection & Fabrication)



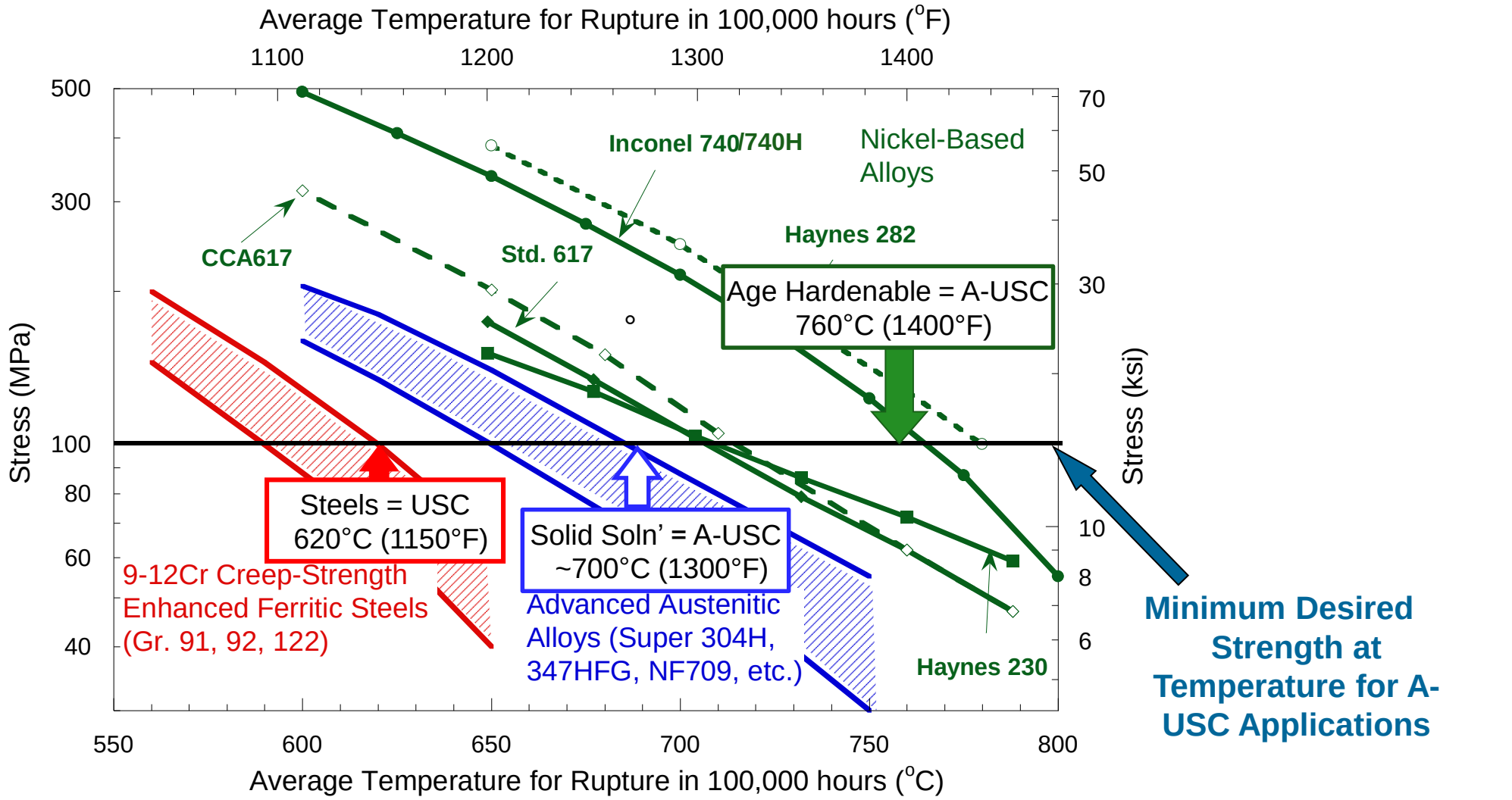
Stress Corrosion Cracking (SCC) in waterwall panels – Extensive Issues in Europe, U.S., and Asia (fabrication, erection, heat-treatment, environment, etc.)

Exfoliation Blockage & Damage in New SC Coal and Combined Cycle HRSGs (Design & Materials)

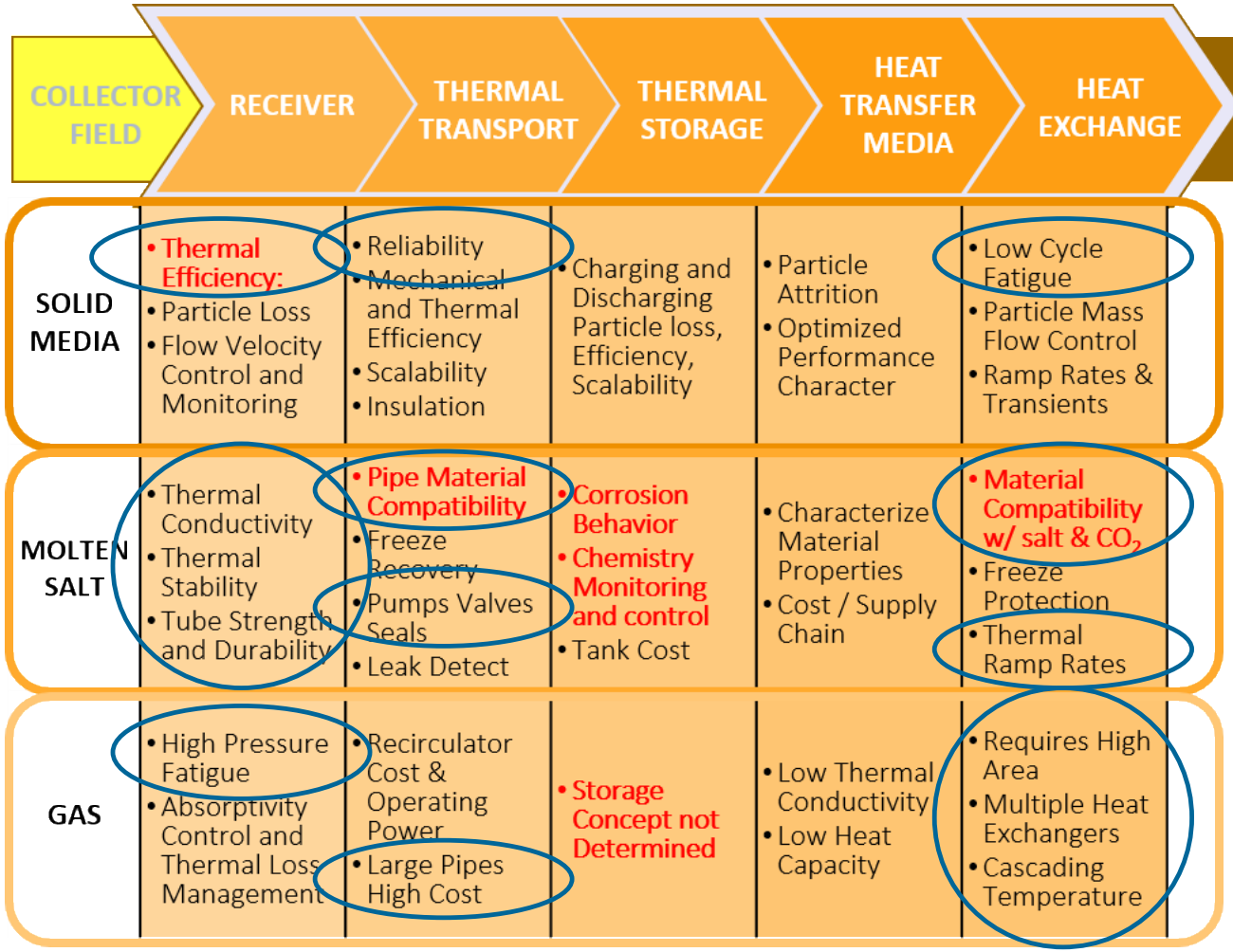
Project Needs: Research to minimize these risks in a cost-effective manner for Gen 3 CSP must start in Design and continue through Demonstration

Materials Selection for Gen 3 CSP Goal: >715ºC

High Temperature Strength, Corrosion Resistance, Ductility, etc. = Age-Hardenable Nickel-Based Alloys will be Required



Nickel-Based Materials will be needed for all pathways



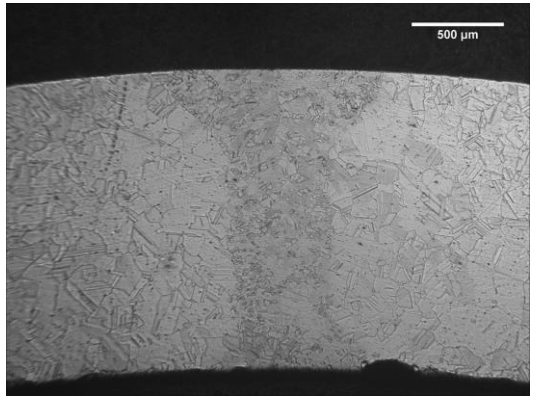
R&D GAPS Specific to CSP Components

- Low-cost manufacture
- Data for Codes and Standards
- Fabrication/Welding Trials
- Gen 3 Environments
- Potential damage interactions: Creep-fatigue, TMF, etc.

Materials Needs and Economics

- Reduced cost through:
  - Use of higher-strength alloys to minimize overall material usage
    - 740H up to 50% less expensive than 230 for pressure boundary components
  - Innovative manufacturing
    - Rolled & welded tubing up to 30% less expensive

Feasibility Trials for Thin-Wall 740H Welded Tubing



Project Organization & Team

- **Task 1**: Project Management - EPRI
- **Task 2**: Collaboration with Gen 3 CSP Teams & Code Interactions – EPRI
  - Interaction early and often with all pathway developers: materials for testing, test conditions, specific design and component requirements
  - Engage codes and standards to ensure testing will address current deficiencies
- **Task 3**: Manufacturing – Special Metals (and partners)
  - Baseline materials
  - **Welded tube (thin wall)**
  - **Welded pipe (Large diameter)**
  - **Subcomponent manufacture (bending, welding)**
  - Techno-economics (enable cost estimates and savings for design teams)
- **Task 4**: High-Temperature Mechanical Testing & Data Analysis – EPRI
  - Tensile/Fatigue (time independent)
  - Creep (time dependent)
  - Pressurized creep of welded tubing – *Unique to CSP receivers to gain code acceptance*
- **Task 5**: Materials Compatibility and TMF - ORNL
  - Molten Salt – will be conducted through current lab activities on materials produced
  - Thermal-Mechanical Fatigue (TMF) for cyclic service

Key Team Members

- EPRI:
  - John Shingledecker: Overall Lead, Task 1 & 2 Lead
  - Daniel Purdy: Task 4 Lead
  - Cara Libby: Coordination with Gen 3 Pathway teams
- Special Metals:
  - John (Jack) deBarbadillo: Task 3 Lead
  - Brian Baker: Processing Support
  - Ronnie Gollihue: Welding and Fabrication Support
- Oak Ridge National Laboratory
  - Bruce Pint: Parallel Laboratory Studies
  - Amit Shyam: TMF and combined damage mechanism testing

Questions / Assistance

- Laboratory testing conditions selection
  - Temperature(s) for components
  - Cyclic experience and design basis
- Product forms of Interest: welded tube (small diameter thin wall), welded pipe (large diameter), and subcomponents
  - What subcomponents or other components should we be considering?
- Techno-economics: will need general sizes/amounts of materials needed, informed by design
- Other materials?
- Other materials concerns not being addressed?

Summary

- Proper research, selection and application of materials in the design stage *reduces technology development risks* for pilot demonstrations
  - Nickel-based alloys will be needed for Gen 3 CSP
  - A successful project will enable Gen 3 CSP in a cost-effective manner
  - The project will address unique attributes for materials and components for all three Gen 3 CSP Pathways including modifications to code rules to enable high efficiency, low cost, and cyclic operation
- The assembled team has the experience, support of pathway developers, and commercialization path to ensure project success

Back-up Slides

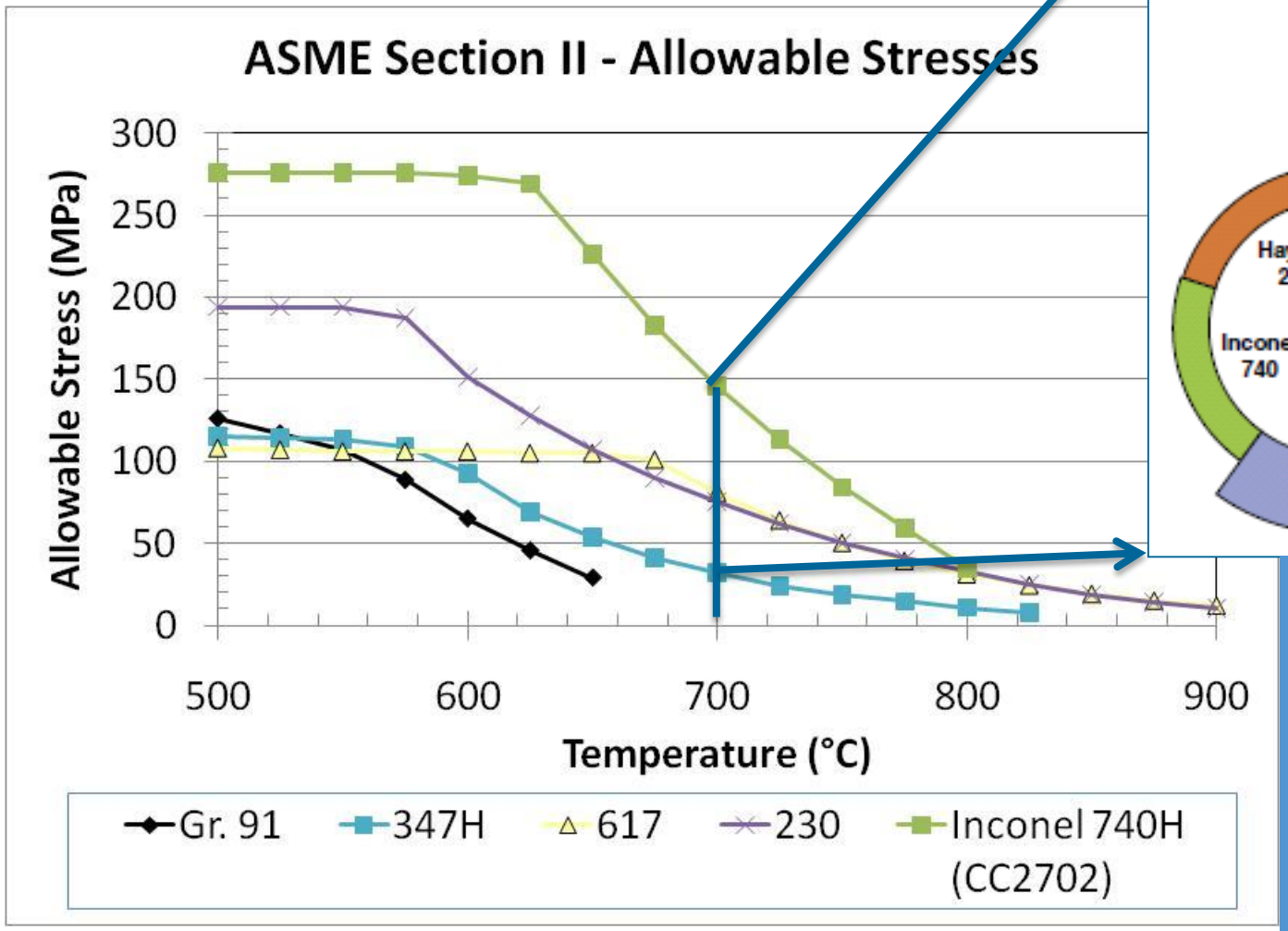
Together…Shaping the Future of Electricity

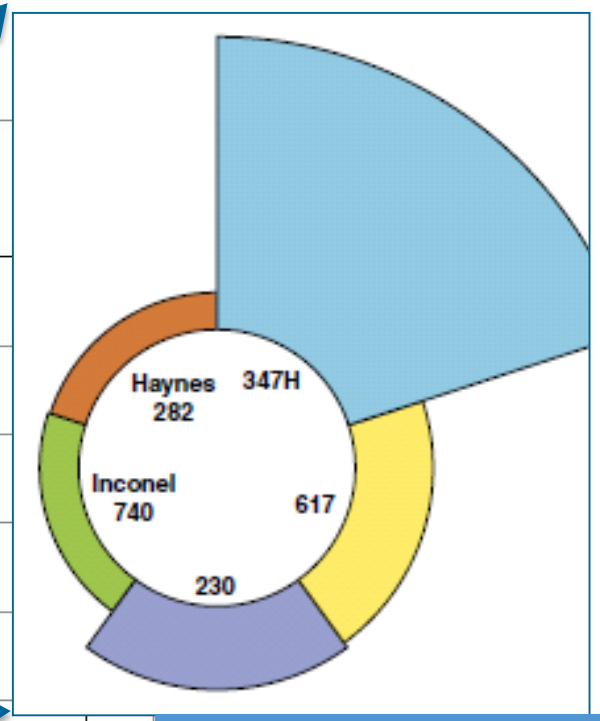
Project Goal

This overall goal of this project is the reduction of plant cost for high temperature components through applied R&D on alloy 740H.

- ***This will be accomplished by the demonstration of alternate manufacturing routes, quantifying the performance, and evaluating the economic benefits in comparison to other candidate nickel-based alloys through fabrication trials, high-temperature mechanical property studies (fatigue, creep, thermal mechanical fatigue, metallurgical examinations of tested samples), corrosion evaluation, and interactions with Gen 3 technology pathway developers.***

Materials Selection for Gen 3 CSP Plants – Economics of Using Higher-Strength Alloys





Higher allowable stress enables thinner walls = lower cost, more cyclic flexibility

Economic Comparisons: Why do we need to use Inconel 740H or Similar Age-Hardenable Alloy?

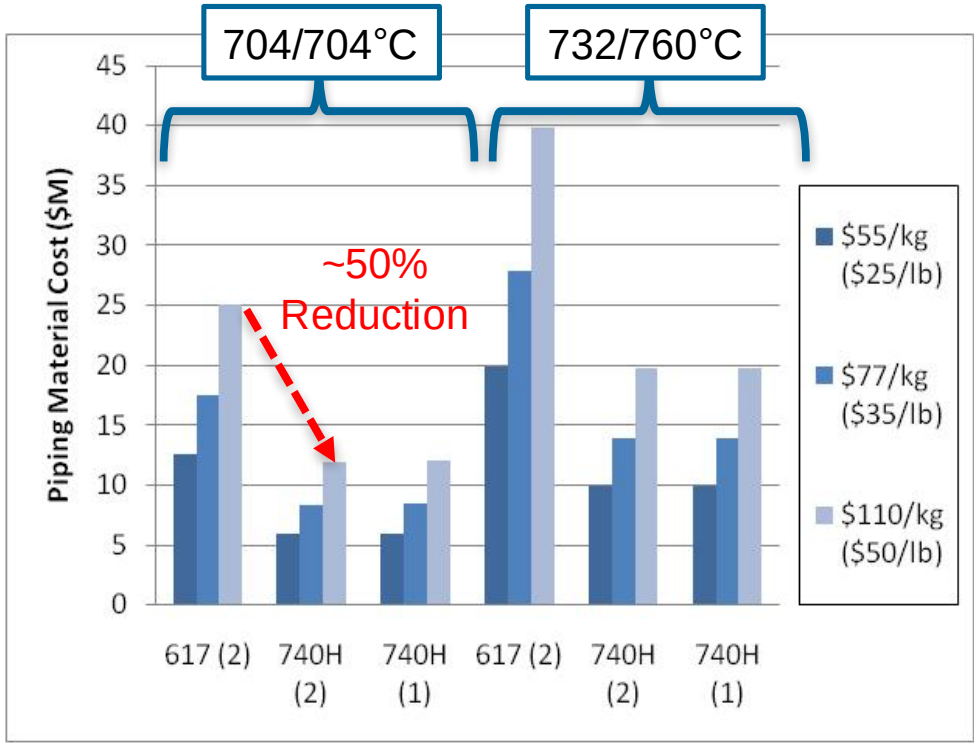
Comparison of relative wall thickness to alloy 230 at 600°C (**bold**) for a given tube/pipe** inner diameter with a pressure of 30MPa for various materials and temperatures.

Alloy Class	Alloy	600°C (Gen 2)	700°C (Gen 3)	Application
Stainless steel	347H/ 316	1.8	7.1	Current Gen 2 Piping/Balance of Plant
Solid Solution Nickel-based	**230**	**1.0**	2.2	Current Gen 2 Receiver
Age-Hardenable Nickel-based	740H	0.53	1.04	Potential Candidate Material
Age-Hardenable Nickel-based	282*	0.48	0.98	Potential Candidate Material

**Not ASME Approved, Estimated Stress Allowables from Available Creep Rupture Data*

***Additional penalties for welded tubing/pipe have not been applied, assumed full wrought properties*

Cost Savings for A-USC Power Plant Piping at 704C – Sold. Sol. versus Age Hardenable Alloy



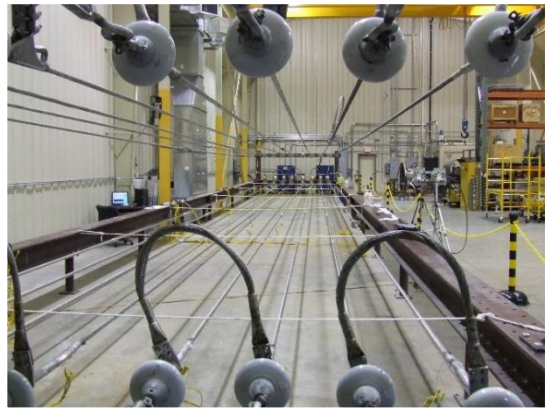
Major Milestones – Yearly Decision Points

1. *The decision point to move forward to BP2 will be successful production and demonstration of short-term (high-temperature tensile, fatigue) properties for welded 740H tubing which exceed the current ASTM criteria of 85% of the base metal strength.*
2. *The decision point to proceed to BP3 will be that the economic analysis justifies the use of lower-cost 740H fabrication methods for Gen 3 designs. 740H should show a minimum 20% reduction in cost to 230 for Gen 3 application.*
3. *The decision point to proceed to BP4 will be written and documented feedback from ASME code committee and ongoing Gen 3 technologists to approve development of a data package to improve, change, or add additional needed code rules for pilot/demo scale development*
4. *The end project goal for BP4 will be approval of code changes by the code committees.*

Preliminary Test Plan for Task 4 (minimum level of testing anticipated to meet project objectives)

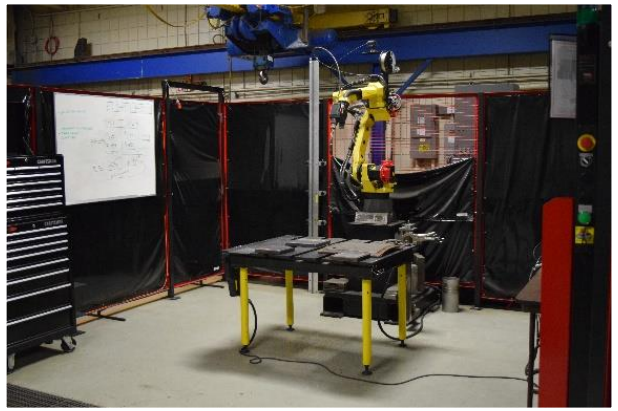
Material	4.1 Short-Term Testing				4.2 & 4.3 Intermediate & Long-Term Testing						Notes
	Tensile		Fatigue		Hold -Time Fatigue (creep-fatigue)		Uniaxial Creep		Pressurized Creep		
	# Tests	Temp (C)	# Tests	Temp (C) / Strain Range	# Tests	Temp (C) /Conditions (strain range+hold time)	# Tests	Temp (C): Est. Duration (hrs)	# Tests	Temp (C), Est. Duration (hrs)	
Alloy 230			6	600,750 / 2.0-0.4					3	600,750: 300, 1,000, 4,000	Baseline & Confirmation
740H			14	750 / 2.0-0.4	6	750 / 1.0-0.4+1-6min hold			3	750C: 300, 1,000, 4,000	Baseline, Fill in Data Gaps, Set Welded Conditions
740H Welded Tube	21	25-900	7	750 / 2.0-0.4	2	750 / 1.0-0.4+1-6min hold			18	700, 750, 800, 850: 300, 1000, 3000, 5000, 10,000	Two Process Variations Evaluated in Short-term
740H Welded Pipe	7	25, 550-800	7	750 / 2.0-0.4	2	750 / 1.0-0.4+1-6min hold	8	700-800: 300, 1000, 3000, 5000, 10,000+			Cross-weld samples
740H Fabricated Components	14	25, 550-800					16	700-800: 300, 1000, 3000, 5000, 10,000+			Assume testing of multiple fabricated components
Totals for Min. # of Tests	42		34		10		24	>50,000hrs	21	>80,000hrs	
750C Selected for Most Cyclic Testing, Will be confirmed/modified after discussion with Gen 3 Pathway Teams											

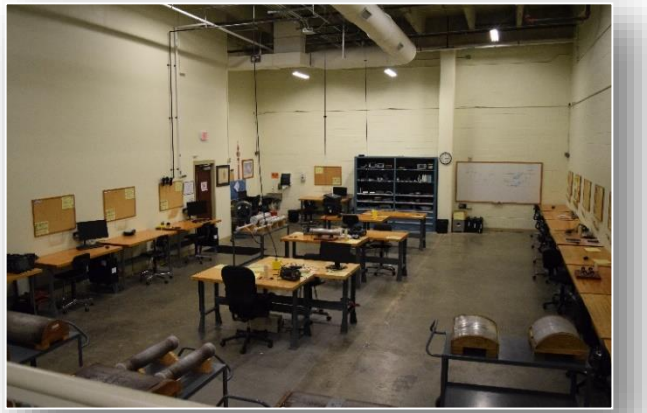
EPRI Charlotte Laboratory



72,000 sq. ft. of interior research laboratories

- Welding Laboratory
- Machine Shop
- Metallurgical/Microscopy Laboratories
- Nondestructive Evaluation (NDE) Lab
- Transmission
- Corrosion
- High-Bay/Configurable Space





EPRI High Temperature Mechanical Test Lab

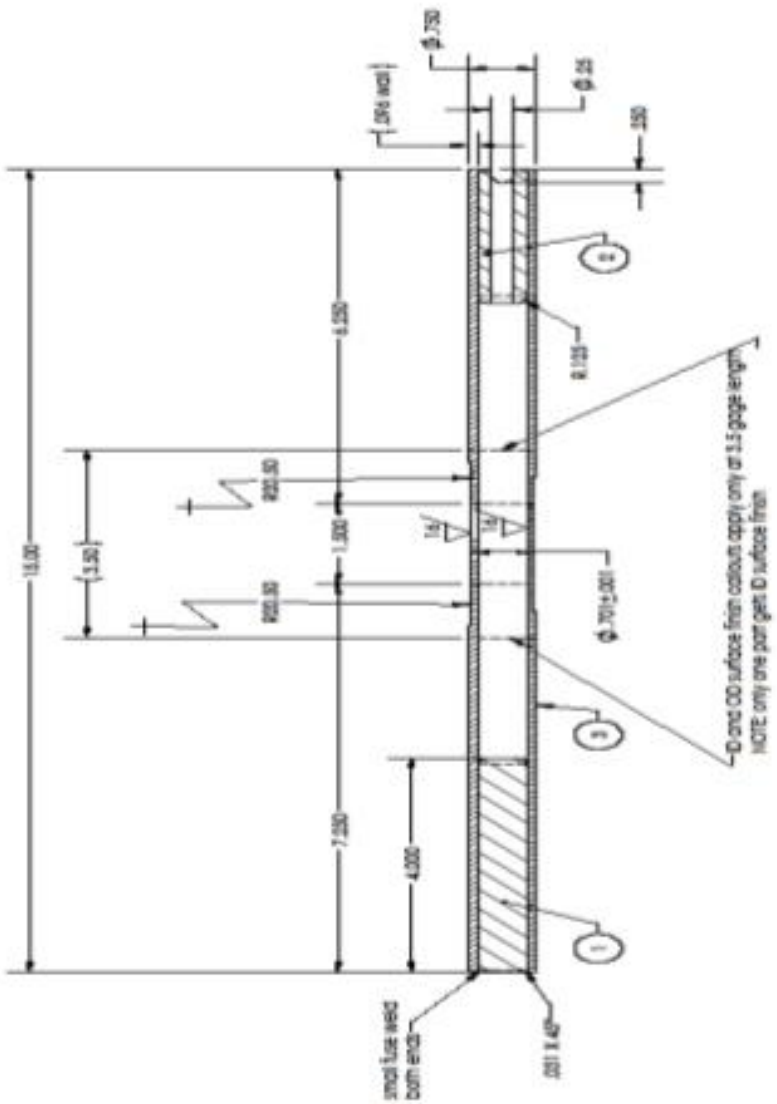
Unique testing capabilities to support materials performance and lifing R&D

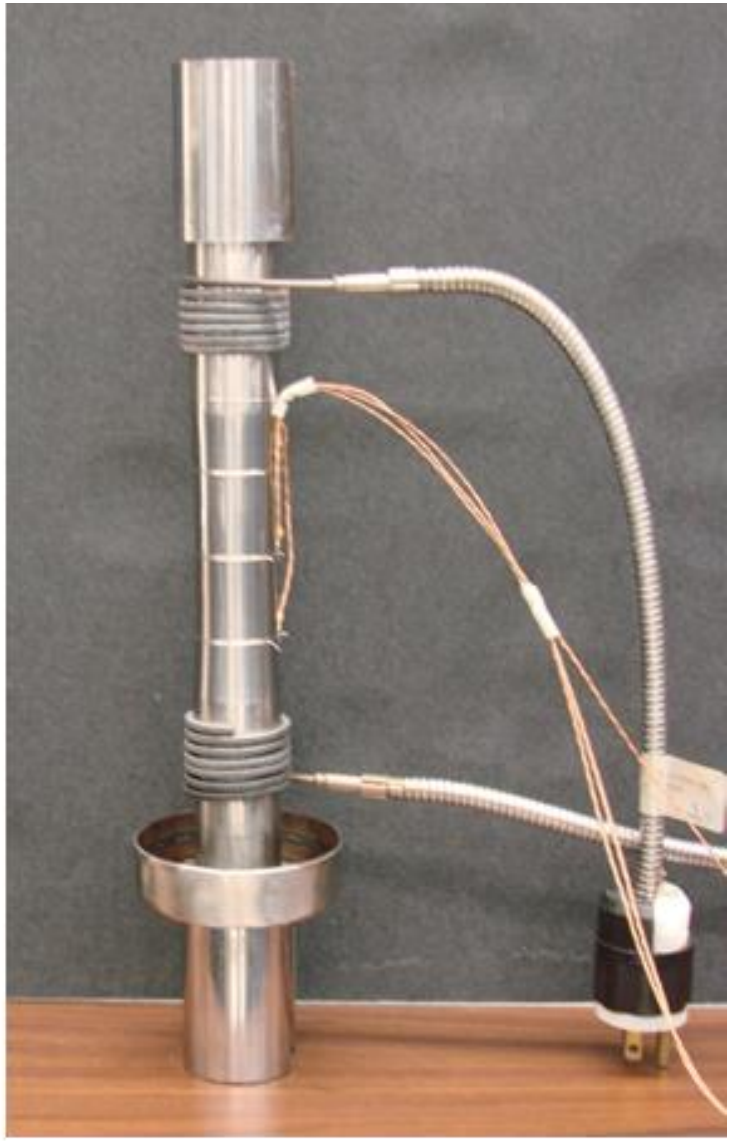
- Creep Testing:
  - Standard Frames
  - High Load Frames
- Data Acquisition, Custom Extensometers, Specialty Samples

Recent/Ongoing EPRI Projects

- Notched Bar Creep Testing
- Large Weldments
- Full-size tube weldments
- Advanced Stainless Steels
- NDE Sample Generation

ORNL Combined TMF and Corrosion Testing





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