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Overlays for Improved Corrosion Resistance During MSR Operation

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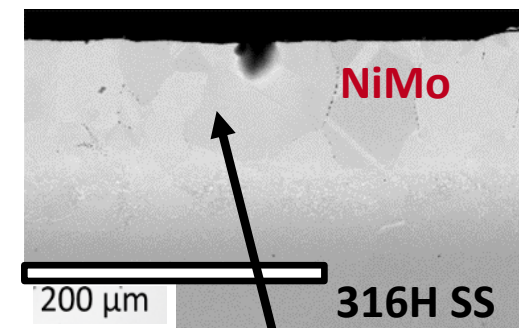
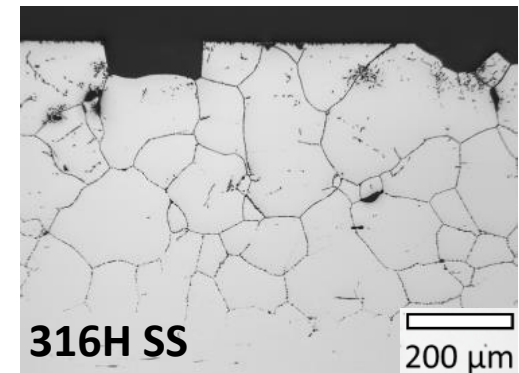
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2024 Molten Salt Reactor Workshop

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Bottom Line Up Front

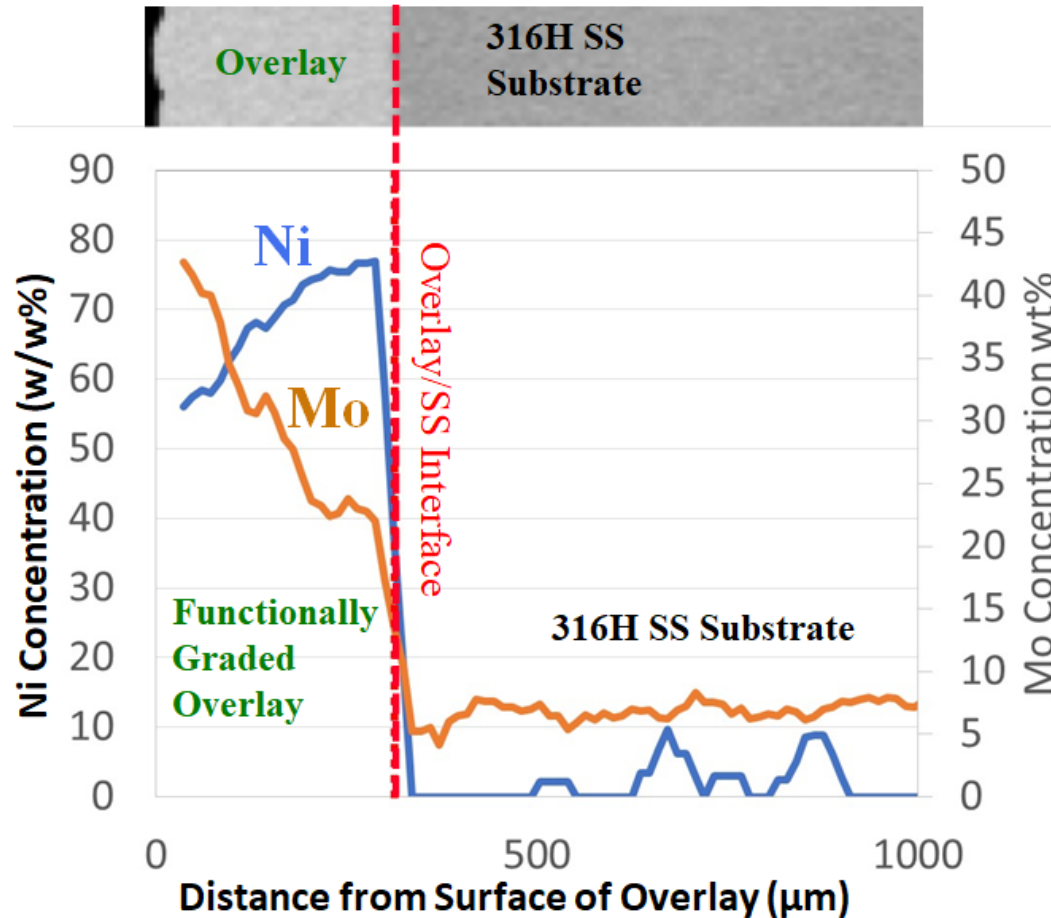
- Motivation to enable higher temperature nuclear reactor operation and use of molten salts
- Electrodeposition of functionally graded NiMo overlay for corrosion protection of 316H SS in molten salts
 - Scalable for MSR components including internal surfaces
 - Enables lower cost, ASME-certified boiler materials
- Post-deposition Hot Isostatic Pressing (HIP) creates a diffusion bond between overlay and substrate
- Significant improvement in corrosion resistance of 316H SS substrate after exposure to FLiNaK up to 750°C / 1,000 hr (static corrosion tests)
- Functionally graded NiMo overlays deposited on 8" pipe segments for flowing loop test
- Preliminary estimates show significant cost savings for NiMo overlays on 316H SS (vs Hastelloy N)



Functionally graded, diffusion bonded NiMo overlay

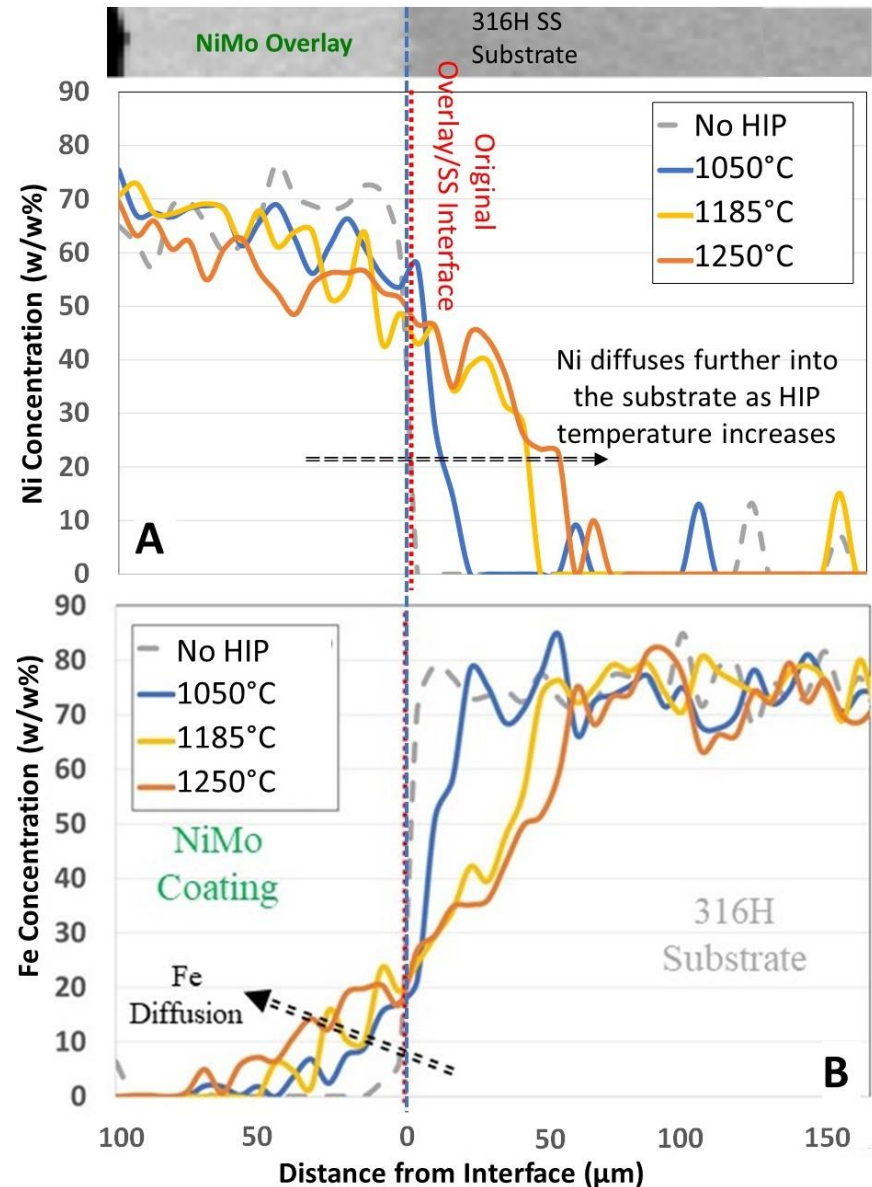
Electrodeposited Functionally Graded Overlay

- Functional grading of composition
 - Reduces CTE mismatch between substrate and overlay
 - Ni-rich at the 316H SS (or Ni alloy) substrate and Mo-rich at the surface



Diffusion Bonded Functionally Graded Overlays

- Diffusion bonding creates a metallurgical bond
 - Diffusion of species in and out of substrate is evidence of diffusion bonding
 - Ni and Mo diffuse into the 316H SS
 - Fe and Cr diffuse out of 316H into NiMo
- Effect of Variables
 - Higher temperatures increases diffusion of species (1050 to 1250°C) (next slide)
 - Longer soak time increases diffusion of species (1.75 to 7 hours)
 - HIP pressure (14,500 vs. 22,000) has minimal effect

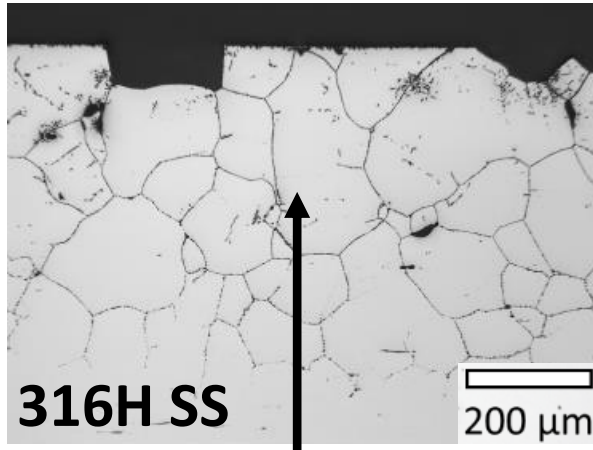


Static Pipe Test Setup

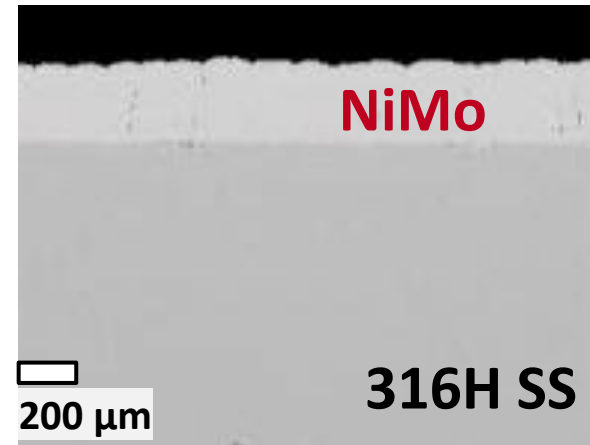
- Static testing prior to flowing loop test
- Performance of overlays on 316H SS pipe
 - Compared to coupons: 700°C/500 h in FLiNaK
 - Several thicknesses
 - At maximum flowing test conditions: 750°C/1000 h
- Demonstrate butt-weld performance
 - Coated pipe to coated pipe
 - Coated pipe to uncoated pipe



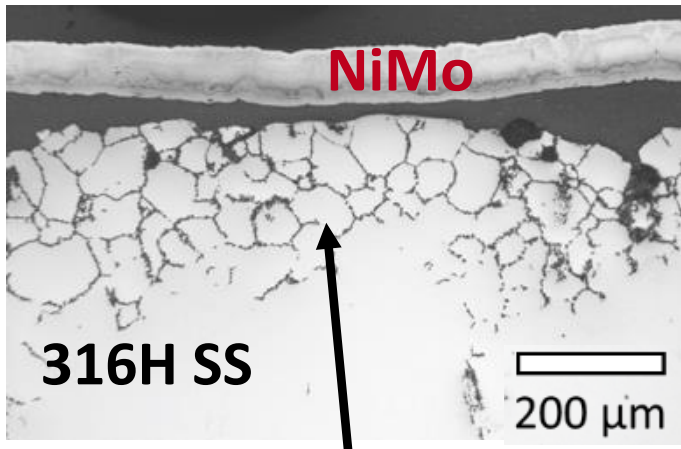
Exposure to FLiNaK at 700°C for 500 hours (ORNL)



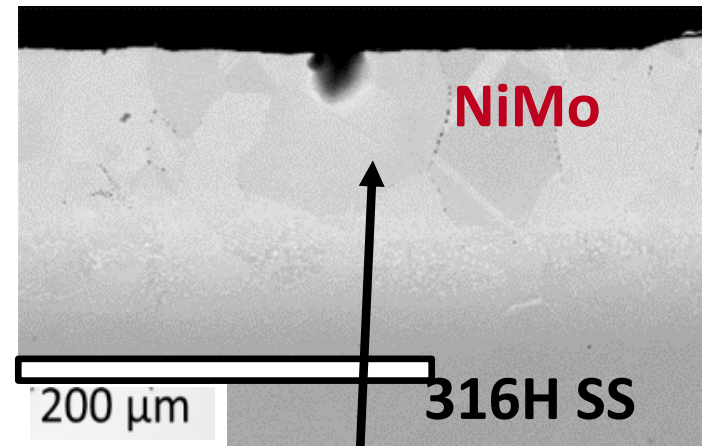
Substrate attack on bare 316H SS



Electrodeposited overlay, before diffusion bonding – no corrosion test



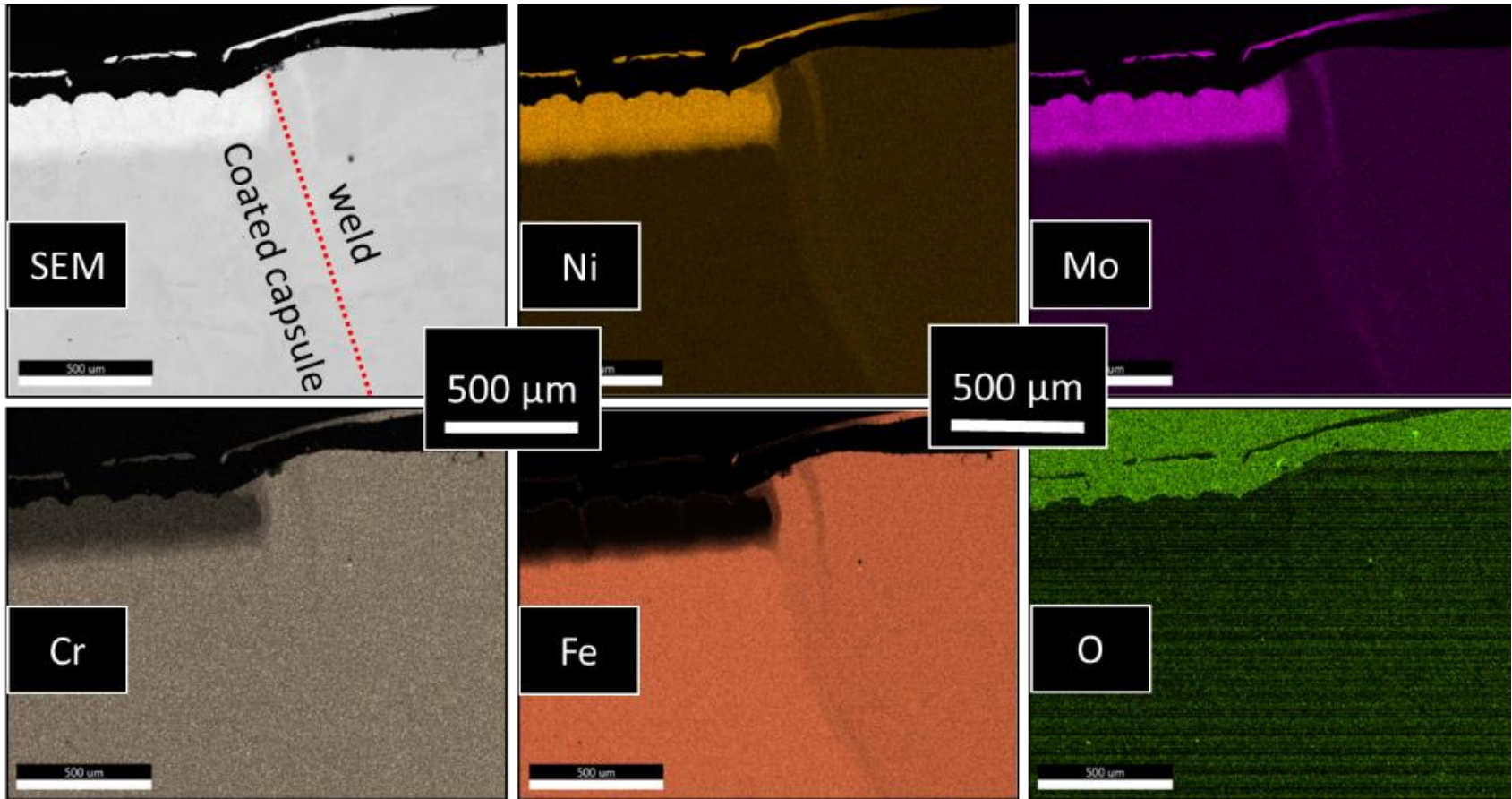
Substrate attack on 316H SS with functionally graded overlay



No substrate attack on 316H SS with functionally graded, diffusion bonded NiMo overlay

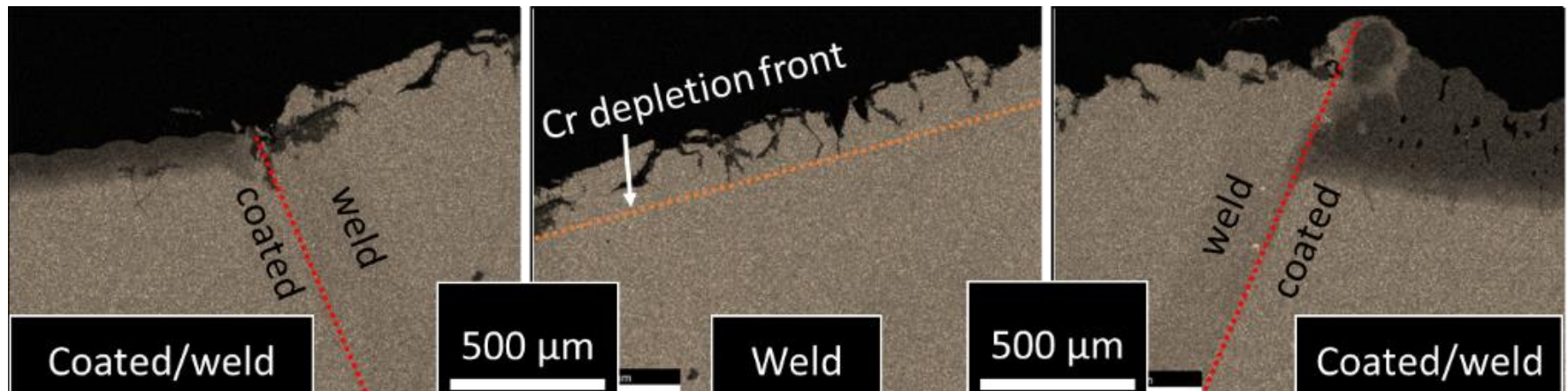
Overlay Adhesion Post-Welding

- After welding coated pipe-uncoated pipe, diffusion-bonded NiMo overlay remains intact



Overlay Adhesion Post-Welding/Corrosion Testing

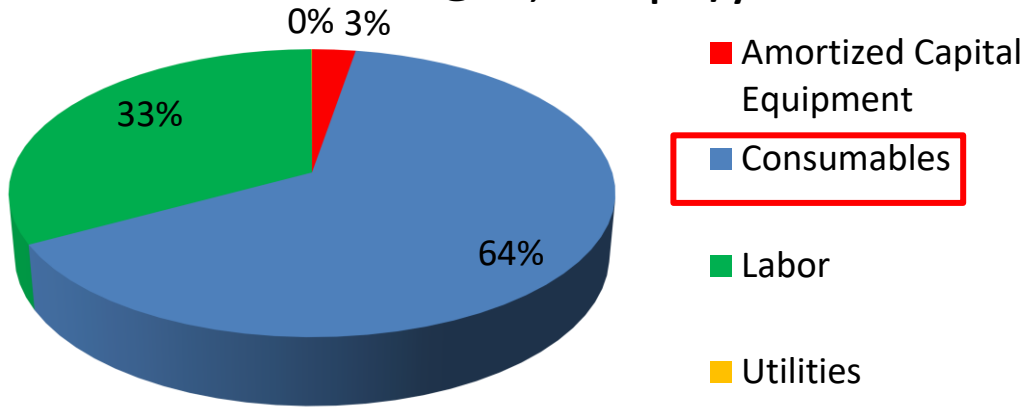
- After static pipe corrosion test (700 hrs, 500°C, FLiNaK)
 - Cr depletion front observed in weld section of coated pipe--
coated pipe
 - 316H SS is being etched away



- May be able to “heal” the weld seam
 - Brush overlay deposition

Preliminary Electrodeposition-Based Economic Analysis

@ 25,000 Pipes/yr

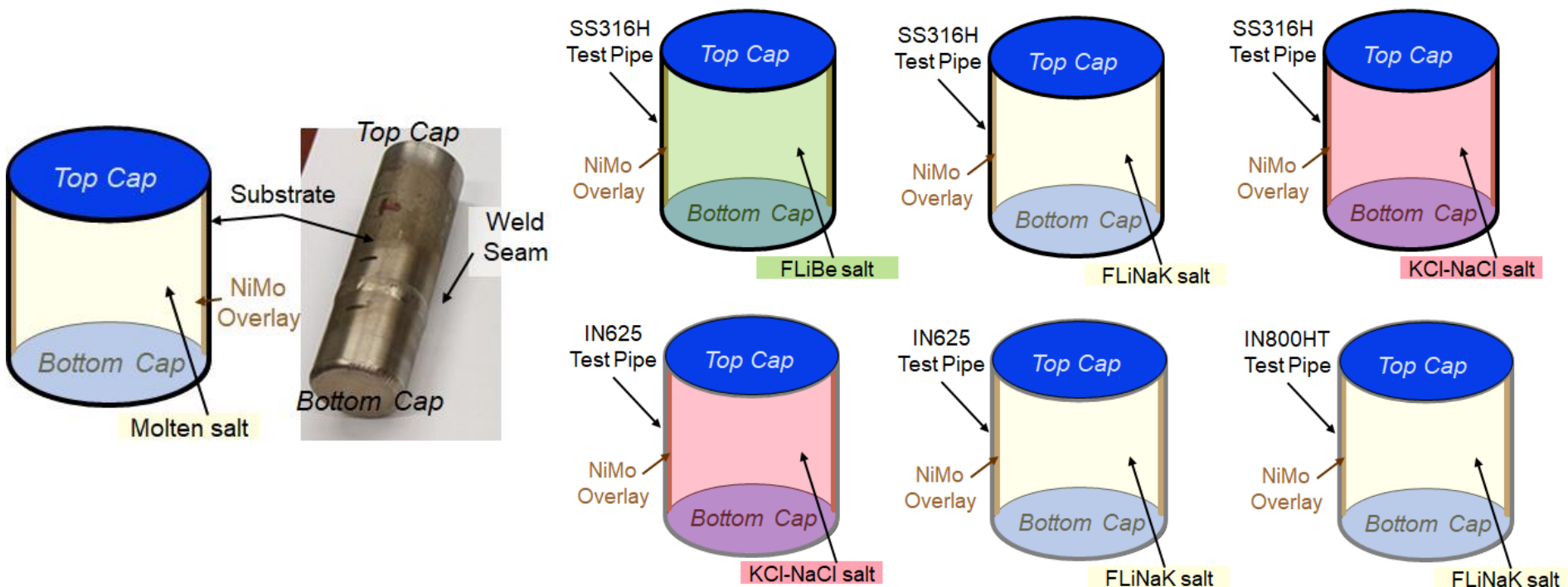


- 200 μm overlay cost estimate based on a 3 m x 2.5 cm pipe
 - \$230 for 316H SS pipe
 - \$940 for Hastelloy N pipe
- Diffusion bonding not included in cost estimate

Line No.	Plant Parameters	5,000 Pipes	10,000 Units	25,000 Units
1	Cylinder Size	4751 cm ²	4751 cm ²	4751 cm ²
2	Run Time (h)	18	18	18
3	Total Pipes/Hr	1	1	3
4	Total Hours worked per day	24	24	24
5	Pipes/Day (24 hr.)	16	32	72
6	Days worked per year	348	348	348
7	Units/Yr. (348 days)	5,568	11,136	25,056
8	Plating Line Cost (\$/pipe)	\$6.07	\$3.04	\$2.02
9	Material Cost (\$/pipe)	\$56.51	\$50.87	\$49.00
10	Labor Cost (\$/pipe)	\$112.50	\$56.25	\$25.00
11	Total Cost (\$/3m pipe)	\$175.08	\$110.16	\$76.02

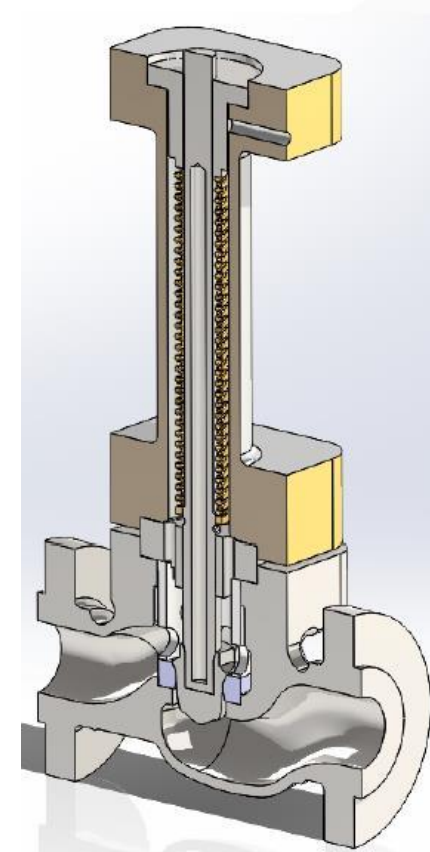
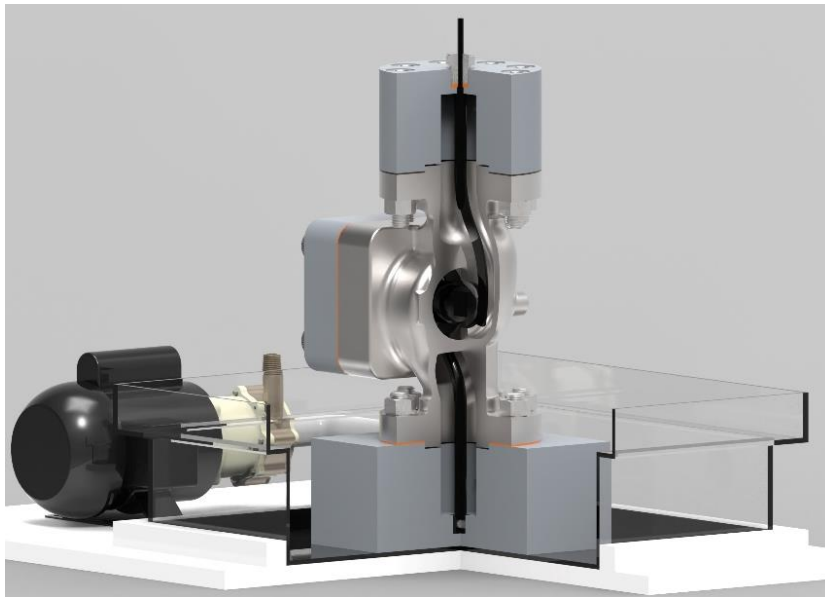
Next Steps

- Investigate other substrates: IN625 and IN800HT
- Explore corrosion resistance in FLiBe, FLiNaU, KCl-NaCl-MgCl₂, and/or FLiNaTh
- Investigate higher operation temperatures (1000°C) in FLiNaK
- Assess capabilities under thermal cycling



Next Steps

- Design tooling to apply overlays onto components of interest to our partners
- Ready technology for manufacturing transition:
 - Develop standards, technical data sheets and preferred operating procedures
 - Develop bath maintenance procedures



2" Flowserve valve for controlling flow of molten salts from Gen3 CSP



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**THANK YOU FOR YOUR ATTENTION!
QUESTIONS?**

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