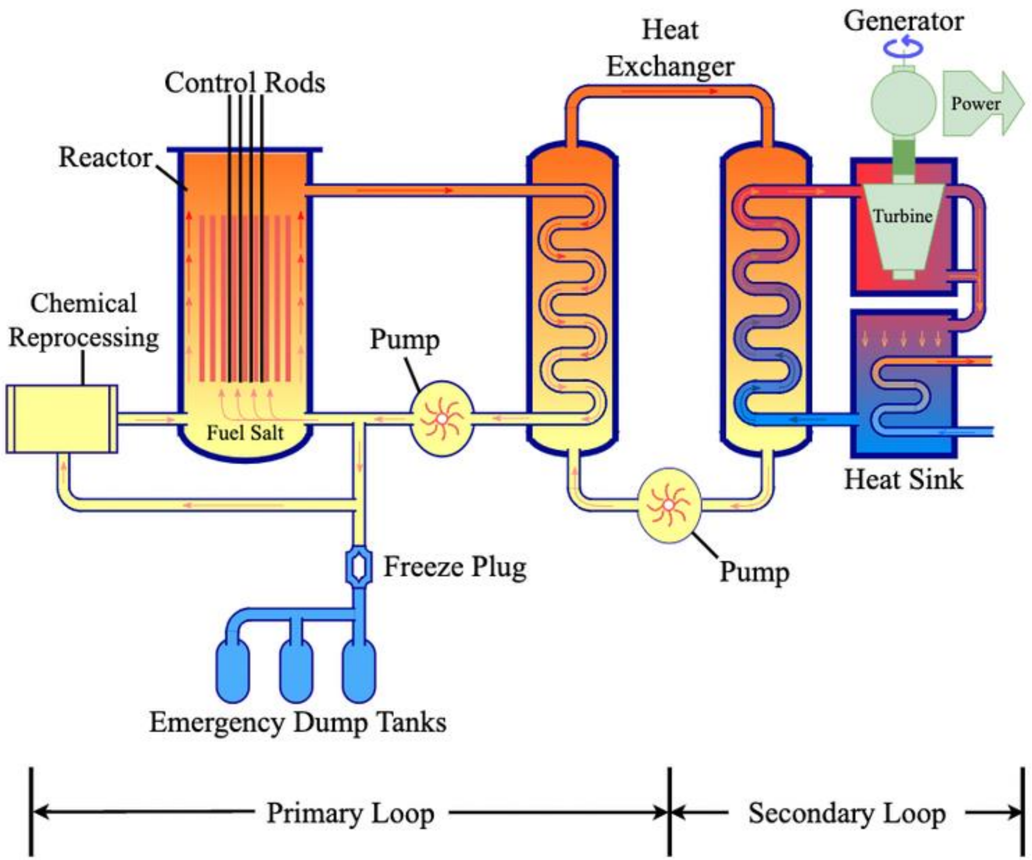
Amphoteric Compounds Decreasing Corrosion Potential in MSRs

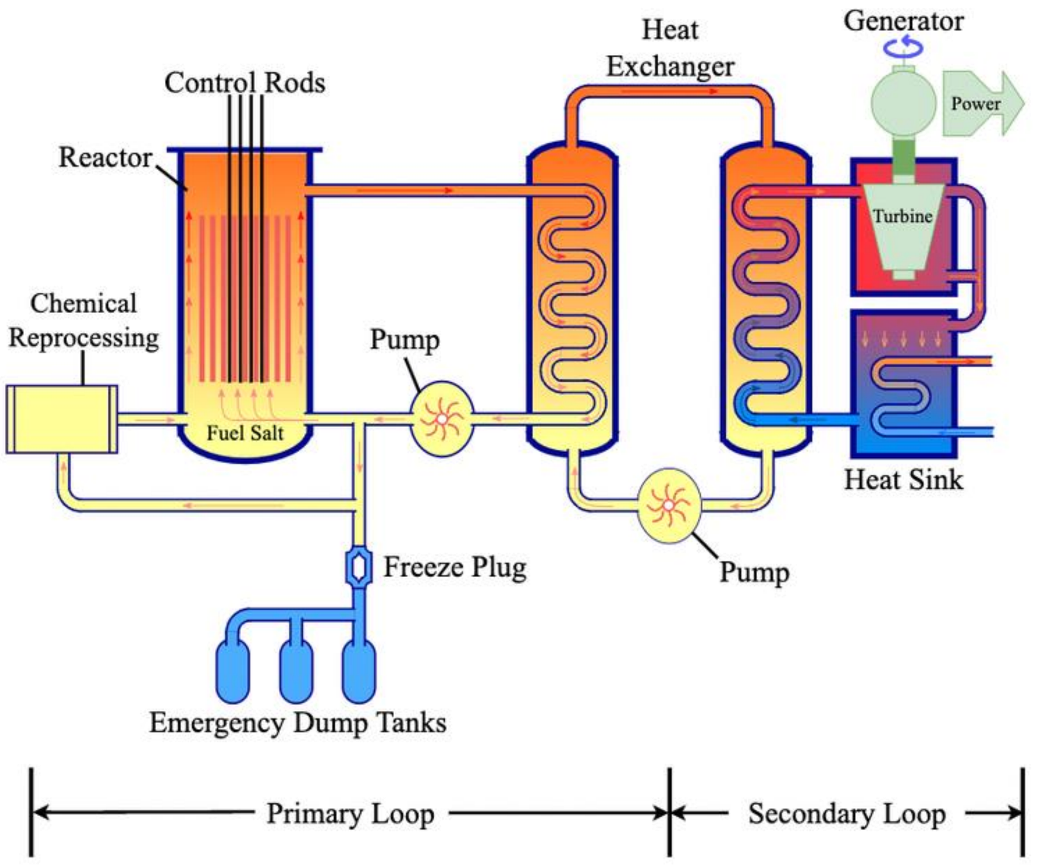
Aiden Zurcher



Small Modular Reactors: An Overview of Modeling, Control, Simulation, and Applications - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/A-conceptualized-Molten-Salt-Reactor_fig4_377250195 [accessed 3 May 2025]

Molten Salt Reactor (MSR) Justification

- Key advantages over traditional reactor designs
  - Liquid fuel – brittleness is a non-issue.
  - Operates at atmospheric pressure
  - Far higher thermal conductivity
  - Freeze plug and thermal expansion
  - Chemical reprocessing removes fission products



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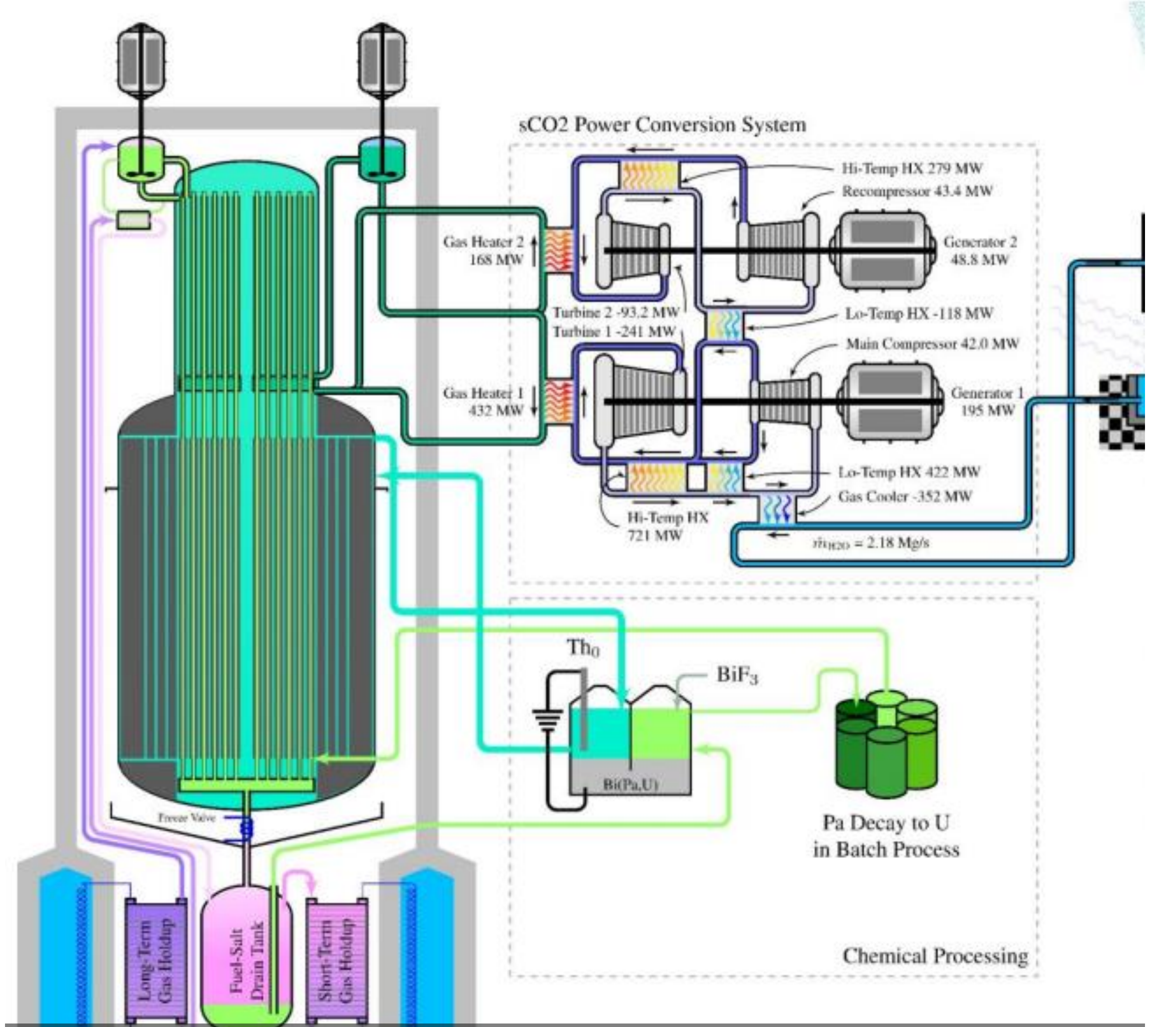
Molten Salt Reactor Problems

- High corrosion
  - Oxidizing species
  - Passivation layers thermodynamically unfavorable
  - High temperatures
- Novel technology
  - No existing online chemical reprocessing
- Expensive corrosion resistant materials

MSR Case Study: Flibe Energy LFTR

- Two region (feed/breed) core
  - Thorium breeding layer outside of scope
- U233 in molten fluoride salt solution
- Lithium 7 Fluoride and Beryllium Fluoride
- ~600˚C fuel temperature
- High corrosion environment
  - Relies on Hastelloy-N, nickel alloy



International Atomic Energy Agency, Small Modular Reactors Catalogue 2024, pg. 278

Advantages of decreasing corrosion potential

- Less need for Hastelloy-N
  - Nickel susceptibility to neutron degradation
  - Hastelloy-N is more expensive than Stainless steel
    - ~$50 per kg compared to ~$3 per kg
    - Makes MSRs more economically viable
  - Can rely on more-studied structural materials

Nominal Composition of Hastelloy N (%)

	Standard	Modified
Ni	bal	bal
Mo	16	12
Cr	7	7
Fe	4	0.5
Mn	0.5	0.2
Si	0.5	0.1
C	0.05	0.05
Ti+Nb	—	2
Re	—	0.01

Materials considerations for molten salt accelerator-based plutonium conversion systems - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Nominal-Composition-of-Standard-and-Modified-Hastelloy-N_tbl3_234994599 [accessed 3 May 2025]

How can corrosion potential in MSRs be decreased?

My suggestion: Amphoteric Compounds

- React with both acids and bases
  - Stabilize oxidation state
- Can neutralize corrosive ions
  - Bond with high valence species
- Passivation layer formation
- Forms stable molecules
- Shift in redox potential

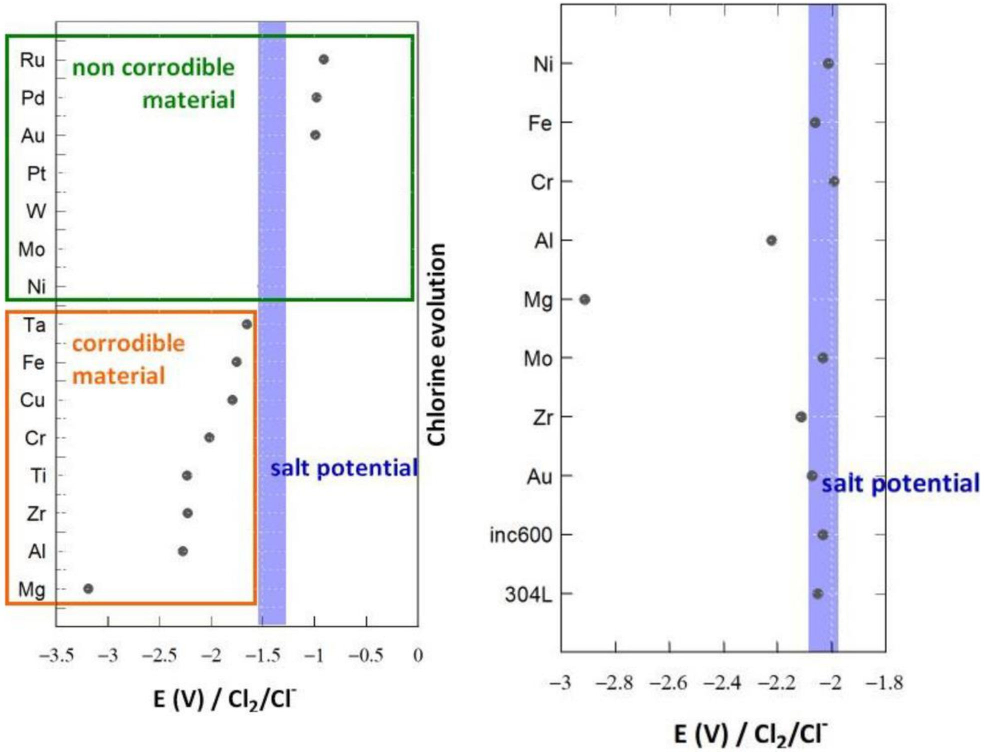
Chloride Examples in Literature

- 2024 Carriere et al.
  - $TiCl_2$ in LiCl-KCl

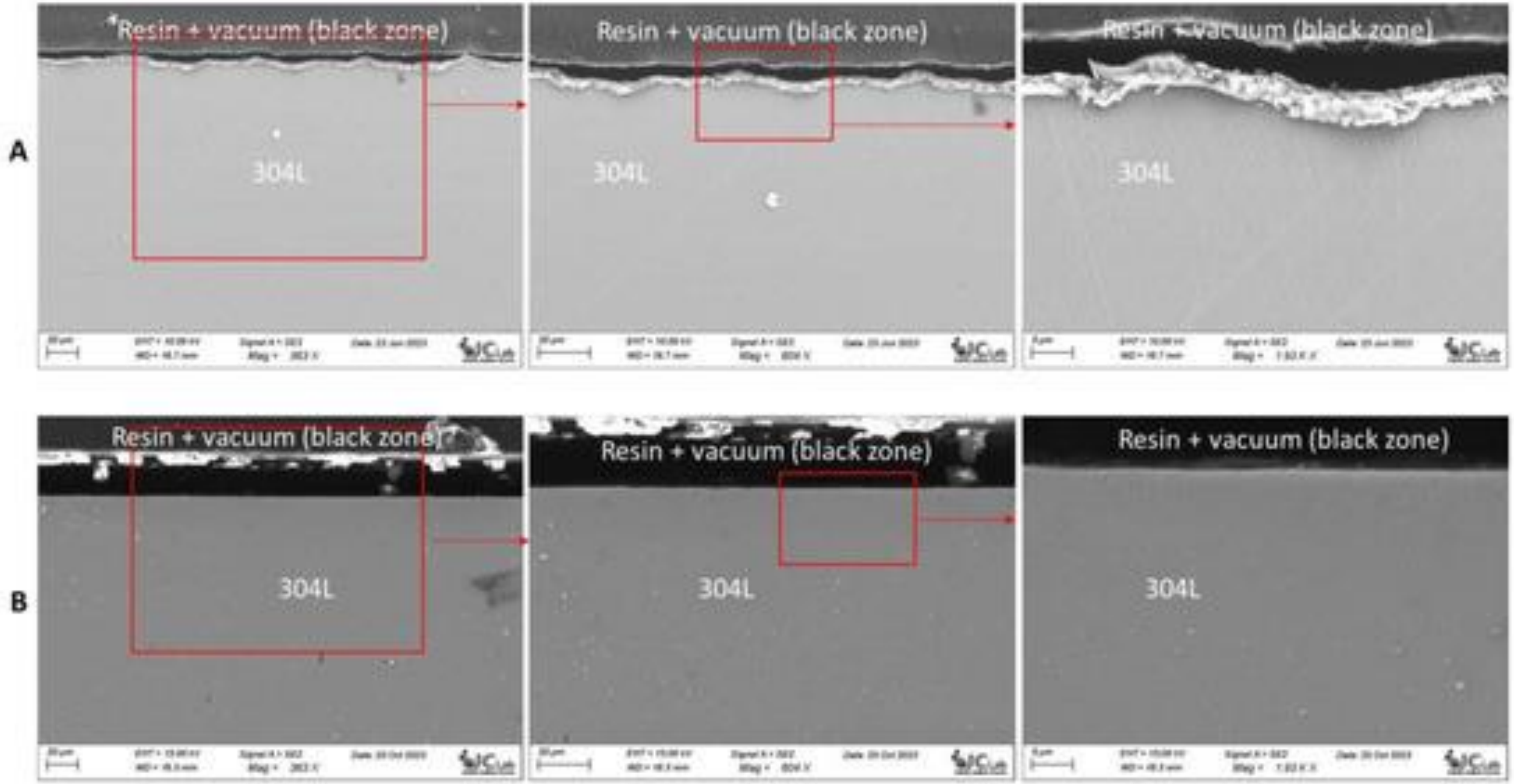
  Decreased potential to -1.0V from -0.35V
  - Below oxidation potential of Cr, Fe, Ni, 304 L and Inc600
  - .1 mol Cl/kg salt and .15 mol Ti /kg salt

Chloride Examples in Literature

- 2024 Delpech et al.
  - Identified Ti as best additive
  - Ti in Cl salt solution
  - Ti prevents corrosion of all but Mg, Al, Zr



Result reproduced from Delpech et al. comparing metals without (left) and with (right) TiCl2 in a



Reproduced from Delpech et al. Cross-sectional SEM-SE images of 304L immersed for 1 week in LiCl-KCl at 500 °C (successive zooms from left to right): (**A**) Without addition of Ti. (**B**) With addition of Ti.

Titanium in Molten Salt Comparison

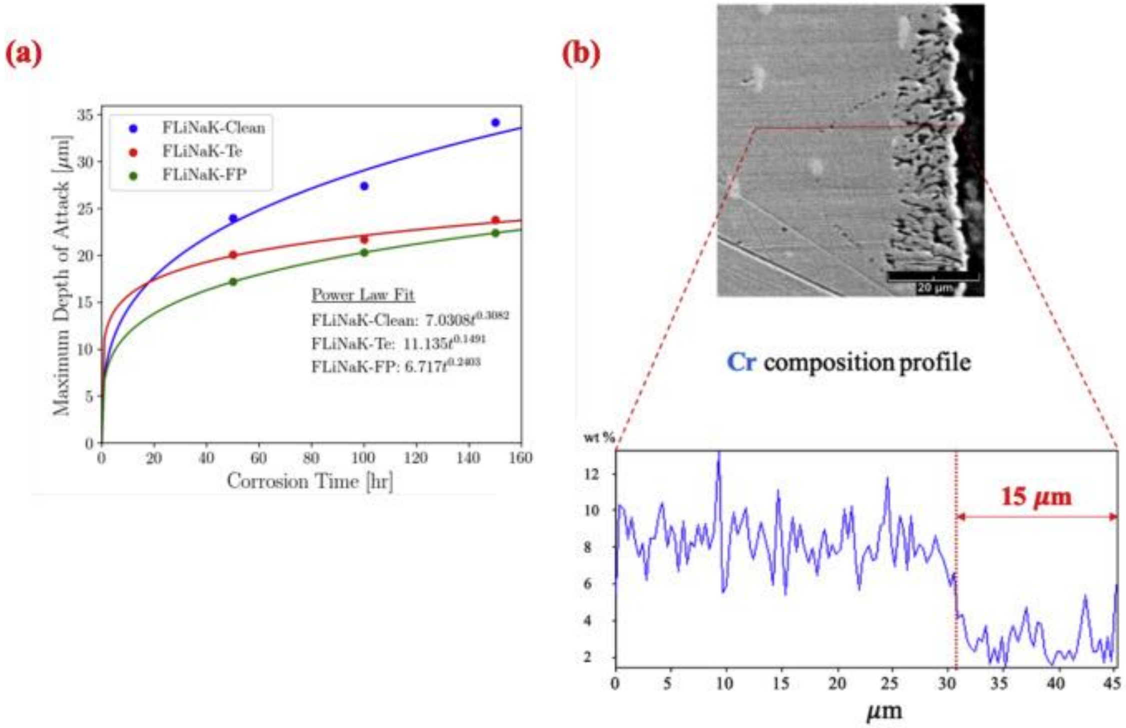
Chlorides

- Well studied
- Far more volatile and corrosive
- Low getter product stability
- Requires vapor containment

Fluorides

- More limited study
  - Traditionally other additives were researched
- Less volatile and corrosive
- Higher getter product stability

Discussion: What about changing conditions?

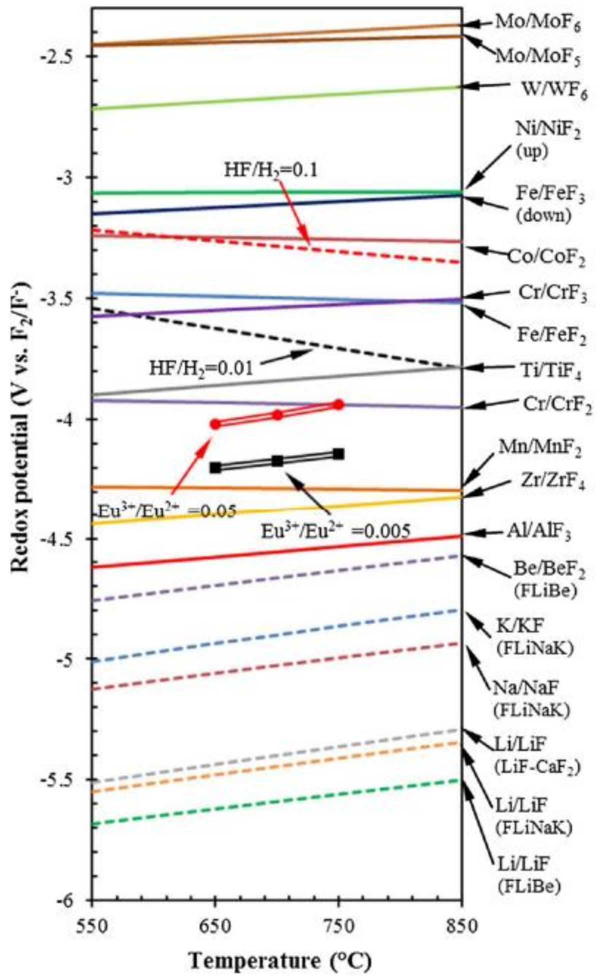


The graphs demonstrate the corrosive ability of a molten salt environment on Hastelloy-N, with and without fission products. Reproduced from https://doi.org/10.1016/j.jnucmat.2020.151994

- Increasing fission products
  - MSR design filters fission products
    - In chemical reprocessing – though not yet built
  - Increases corrosion (Limited study)
    - Redox destabilization – more oxidizing than base salt
    - Formation of volatile compounds
    - Amphoteric compounds could be consumed/overwhelmed
    - Impurity formation

Discussion continued

- Increasing temperature
  - Faster leaching of alloying elements
    - Passivation layer breakdown
  - Amphoteric oxides could dissolve
  - Ternary salt formation
  - Improved buffering kinetics
- Corrosion potential related to redox potential
- Amphoteric compounds must have:
  - High thermal stability
  - Low volatility



Relationship of redox potential with temperature of common redox reactions.
Reproduced from https://doi.org/10.1016/j.corsci.2018.08.035

Complications

- Lower redox potential complicates FP control
  - Increase deposition risk of noble metals and actinides
  - Monitor reactor conditions essential
- Sludge formation and fouling mitigation
  - Sacrificial deposition surfaces
  - Flow management

Amphoteric Additives in the Long Term

- Forming tellurides are generally stable
  - Limited solubility
- Risk of plating or precipitating out
  - Monitor Concentrations to avoid exceeding solubility
  - Surface coatings to protect components
  - Minimize stagnant flow
- Regular replenishment necessary

Conclusion

- MSRs have advantages over LWRs
- High corrosive environment of MSRs
  - Current designs use expensive nickel alloys
- Titanium can control corrosion in chloride salt solutions
- Interaction with fission products and temperature is complex
  - Nuclear has a high bar, must be well understood
- FliBe Energy should consider testing titanium as an additive

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Thank You