Chemistry and Materials Experiments at Seaborg Technologies

1. Introduction to Seaborg Technologies

2. Introduction to the “Compact Molten Salt Reactor”

3. Experimental Programme

4. InnoBooster experiments
Introduction to Seaborg

- Founded in basement in Copenhagen
- Commended in UK feasibility study
- Included in IAEA SMR Handbook
- Doubled in size
- First ever public grant in nuclear in Denmark
- Doubled in size
- Raised pre-seed funding
- EU SEALION project
- MoU with Asian partners
- Documented Customer Interest
- Doubled in size
Current Status

- 16 employees
  - from four continents
  - technical focused
- Largest reactor start-up outside of North America
- Protected IP, gaining more
- Obtained private and public funding
- Documented customer interest
- MoU with Asian research institutions
- Started our first practical experiments
- In the conceptual design phase
Compact Molten Salt Reactor

Main features:
• Small, modular, thermal MSR
• $250 \text{ MW}_{\text{th}}/100 \text{ MW}_e$
• Up to 8x smaller critical core than graphite moderated MSRs
• Modular core unit concept
• Focus on inherent safety and proliferation resistance
Core Design

Liquid moderator:
- Compact core
- Greater lifetime
- Reactivity control features
Salt Purification

- Ability to produce clean, dry salt underpins all chemistry experiments
- Need to set-up our own lab facilities or work with others who are experienced
- Hydrofluorination is standard method – mixture of HF and H₂ gas
- Remove moisture and oxygen, electrochemistry to remove metallic impurities
- Hydrogen bifluorides (e.g. NH₄HF₂, KHF₂, NaHF₂, etc.) may suffice for smaller scale experiments

\[ [F - H - F]^- \rightarrow HF + F^- \]
Physical Chemistry

• Key priority is obtaining thermophysical properties of salt
• Considering using different fuel salt composition to other projects
  • Avoid lithium-7 – tritium production and availability
  • Avoid beryllium – chemical toxicity concerns
  • But, data lacking
• Two approaches: theoretical and experimental
• Intend to collaborate with experts in this area to obtain more accurate values for:
  • Heat capacity
  • Thermal conductivity
  • Viscosity
  • Vapour Pressure
  • Boiling Point
Reprocessing, Decommissioning, Waste Disposal

- Not using in-situ reprocessing, therefore a lower priority for us
- Many existing methods available
- However, can’t propose to build a reactor without all these issues resolved
- Will test and use existing methods, and develop improved methods whilst prototype, etc. are running

Most important for us is controlling the reactor chemistry, including removing volatile and noble metal fission products
Volatile Fission Products

• Eager to investigate speciation of volatile fission products
• Cs and I in particular
• Important for understanding reactor operation and accident scenarios
• Also important to understand chemical speciation
• Numerous techniques:
  • modelling
  • differential scanning calorimetry
  • Knudsen effusion mass spectrometry
  • solubility measurements
  • spectroscopy (UV-vis, Raman, etc.)
  • electrochemistry

Capelli et al., 2018, “Thermodynamics of soluble fission products cesium and iodine in the molten salt reactor”.
Caesium Volatility Apparatus

Sill, 1988; Adamson et al., 2016; Kamizono et al., 1989; Banerjee et al., 2012.
Thermal Scattering Library

- Thermal neutrons interact with melt structure, not just atomic nuclei
- Need to account for these effects to ensure neutronics calculations are precise
- Thermal scattering libraries (kernels) available for many materials, e.g. heavy water, graphite, beryllium
- Data is lacking for low-Z atoms in molten salts
- Require neutron spectrometry on molten salts at a range of temperature
- Purification and containment of salts is essential
- Alternative approach is molecular dynamics calculations, but experiments necessary for verification
Materials Testing

- Materials concerns:
  - molten halide corrosion
  - irradiation damage and helium bubble formation
  - tellurium embrittlement
  - high temperature creep

- Start with simple testing: e.g. static exposure, helium ion bombardment, creep testing
- Increase complexity to as close to reactor conditions as possible
- Key concern for us is irradiation damage – neutron spectrum is relatively hard before reaching first fuel tube
- Can we just use Hastelloy N? Short term (e.g. prototype) – probably, long term – no
Materials Qualification

- Hastelloy N not qualified for high temperature use, despite previous experience
- Series of commercial-scale forgings and mechanical testing required
- Testing takes a long time (dependent on desired lifetime)
- Hastelloy N has known issue – tellurium embrittlement and helium bubble accumulation

**Materials are complex.** The effects of processing on the microstructure, and the effects of microstructure on performance must be characterised.

- The use of any drastically different material from earlier generations of molten salt reactors should come with significant benefits
InnoBooster Project

- Testing material with very low neutron absorption
- “Scratch the surface” testing only – limited time and budget
- Funding from Danish government
- Experiments at DTU Risø campus
Lab Equipment
Experimental Matrix

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<tr>
<th>Temperature</th>
<th>Duration</th>
<th>Temperature</th>
<th>Duration</th>
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</table>

\[ \ln k_r = \ln A - \frac{E_a}{RT} \]
Thank you for your attention

Please contact me at:

dco@seaborg.co

with any further questions or comments
### History of Alloy Development

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## Alloying elements

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<td>Cr, Mo</td>
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<td><strong>FCC Matrix Stabilizers</strong></td>
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<td><strong>Carbides</strong></td>
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<td>MC</td>
<td>Ti</td>
<td>W, Ta, Ti, Mo, Nb, Hf</td>
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<tr>
<td>$M_7C_3$</td>
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<td>$M_{23}C_6$</td>
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<td>$M_6C$</td>
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<td><strong>Carbonitrides</strong></td>
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<td><strong>Promotes General Precipitation of Carbides</strong></td>
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