Nuclear Energy University Program (NEUP)
Fiscal Year 2020 Annual Planning Webinar
Molten Salt Reactor Materials
(Subtopic RC-1)
Examples of Molten Salt Reactor (MSR) Designs being Developed by Industry

TerraPower
MCFR

Terrestrial Energy
IMSR

Kairos Power
PB-FHR

Reactor Vessel
Cross Section

Elysium USA, MCSFR

Flibe Energy

ThorCon Power
## MSR Operating Conditions

- Relative to PWR, MSR’s operate at lower pressure, higher temperature, and in very different coolant (Max dose is approximate)

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Coolants</th>
<th>Pressure (MPa)</th>
<th>Estimated Max. Dose (dpa)</th>
<th>Estimated Lifetime (years)</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td>FLiBe</td>
<td>0.1</td>
<td>&lt;10</td>
<td>&gt;10</td>
<td>Kairos FHR</td>
</tr>
<tr>
<td>Liquid (not pumped)</td>
<td>FLiBe, Nitrate</td>
<td>0.1</td>
<td>200</td>
<td></td>
<td>Moltex</td>
</tr>
<tr>
<td>Liquid</td>
<td>FLiBe, FLiBe</td>
<td>595-450°C</td>
<td>565-270°C</td>
<td></td>
<td>MSRE (∼1.5 years full power)</td>
</tr>
<tr>
<td>Liquid</td>
<td>NaNO₃, KNO₃</td>
<td>598-344°C</td>
<td></td>
<td></td>
<td>ThorCon</td>
</tr>
<tr>
<td>Liquid</td>
<td>U,Cl</td>
<td>0.1</td>
<td>200</td>
<td></td>
<td>TerraPower</td>
</tr>
<tr>
<td>Solid</td>
<td>Water</td>
<td>16</td>
<td>100</td>
<td>60+</td>
<td>Commercial PWR</td>
</tr>
</tbody>
</table>

* To be determined, KF-ZrF₄, FLiNaK, KCl-MgCl₂, etc.

MSR Systems Have Many Different Design Characteristics Leading to Different Materials Challenges

- **Fast Spectrum**
  - Higher point defect generation rate

- **Thermal Spectrum**
  - Lower point defect generation rate

- **Liquid fuel**
  - Fuel salt, fission products
  - Coolant salt

- **Solid fuel**
  - Primary coolant salts
  - Secondary coolant salts

- **Different salt chemistries and their reactions with metals**
  - Chloride salts
  - Fluoride salts

- **Drastically different design lives**
  - 5 yrs
  - 30 to 60 yrs
Corrosion rates are highly varying because of the variety of conditions, methods, and salt chemistries used.
Corrosion in Molten Chloride Salts Differs from Other Reactor Coolants

- Oxide layers can form on metal surface in molten chloride salts but mostly porous and non-protective
- Formation of a stable passivating oxide layer is much more challenging
- Corrosion is due to depletion of Cr in alloy matrix underneath oxide layer and the intergranular corrosion
- Need to control potential below Cr/CrCl₂ to mitigate corrosion
- Oxidizing impurities must be minimized
- Want materials noble to Cr corrosion potential
- Generally, nickel-based alloys have better corrosion resistance than stainless steels
- Very few studies on effects of actinides and fission products on the materials corrosion

(Guo, Zhang et al. 2018) updated by the Authors to include Nb, Ta, and V
MSR Component Doses Can Range From Less Than One to 25 DPA

Potential for irradiation damage of MSR materials must be assessed
Limited ASME Nuclear Code Approved Materials for MSRs

• ASME Section III, Division 5, Class A structural materials
  • 304H and 316H (stainless steels, 815C, 300,000 h)
  • Alloy 800H (high alloy, 760C, 300,000 h)
  • 2.25Cr-1Mo (ferritic, 300,000 h)
  • Modified 9Cr-1Mo (ferritic-martensitic, 650C, 300,000 h)

• Extensions of these 5 materials to 500,000-hour design lives are being pursued by ASME code committees
  • One to two years to complete

• New Division 5, Class A Code Case for Alloy 617 (954C, 100,000 h)

• These Class A materials are not optimum for MSR structural applications due to the extreme environments of high temperatures, corrosive salts, and neutron irradiation (including fission products)
Technical Gap Assessment

Technical Gap Assessment For Materials And Component Integrity Issues For Molten Salt Reactors

US NRC ADAMS Public Documents
Accession Number: ML19077A137
• Supports long-term needs for MSR structural materials
• Awards on developing the next generation MSR structural materials for applications in fluoride-based MSRs were made in FY18 and FY19
Proposals are sought to develop high performance new metallic alloy(s) that can be used for welded construction of structural components of molten chloride salt fast reactors using liquid fuel.

Non-metallic materials are not within the scope of this call.

Characteristics of the new metallic alloy(s) to be considered include, but are not limited to:
- High temperature strength up to 900 to 950C
- Long-term thermal stability
- Chloride-based salt/fuel salt compatibility
- Irradiation damage resistance
- Resistance to possible fission or transmutation product embrittlement
- Tensile and creep ductility
- Fabricability and weldability
Innovative concepts are highly encouraged, for example,

- Exploiting nano-scale interfaces within the alloy to trap defects and possible transmutation products
- Applying novel, high-value experiments with integrated computation materials engineering (ICME) for the development and testing of new metallic alloy(s)

While not required, interaction with MSR designers on their system requirements is highly encouraged
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