Fluoride-salt-cooled High-Temperature Reactor (FHR) Integrated Research Project (IRP)

MIT / UC-Berkeley / U. of Wisconsin & U. Of New Mexico

C. W. Forsberg\textsuperscript{1}, L. W. Hu\textsuperscript{1}, P. F. Peterson\textsuperscript{2}, M. Fratoni\textsuperscript{2}, K. Sridharan\textsuperscript{3}, and Anil Prinja\textsuperscript{4}

\textsuperscript{1}Massachusetts Institute of Technology
\textsuperscript{2}University of California at Berkeley
\textsuperscript{3}University of Wisconsin at Madison
\textsuperscript{4}University of New Mexico

Enabling the Next Nuclear: FHRs to Megawatts Workshop
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Base-line Pebble-Bed FHR

- Pebble fuel
  - Graphite-matrix coated-particle fuel
  - Pebbles float in the salt
- Clean liquid $^7\text{Li}_2\text{BeF}_4$ salt coolant
- Continuous refueling
  - 10 to 12 cycles through the core
  - Full burn-up in one year
- Inlet temperature 600°C
- Exit temperature 700°C
- 200 to 400 MWt
Development of Experimental Facilities and Methods to Address Questions and Enable Commercial Development
U.C. Berkeley Low-Temperature Simulant for 700°C Salt Enables Large-scale Testing

- Dowtherm A (organic) near 70°C has thermophysical properties very close to liquid salts at 700°C
- Enables low-cost large-scale thermal hydraulic tests using simulants to be performed for operational and safety system performance
- Compact Integral Effects Test facility (CIET) built at UCB and conducting simulations of FHR system—various smaller facilities also built
- **Dramatic reduction in cost and time to understand system performance.**
U.C. Berkeley Thermohydraulic Neutronic Modelling of FHR Core

- Coupled high-fidelity neutronics and thermal-hydraulics for transient scenarios
  - Serpent for neutronics
  - OpenFOAM for thermal-hydraulics (porous media) and pebble motion (discrete element modeling)
- For rapid scoping calculations
  - COMSOL Multiphysics software
  - Finite element method for spatial discretization to solve systems of PDEs or ODEs

UC Berkeley IRP coupled full-core neutronics/TH simulations of TMSR-SF1

fhr.nuc.berkeley.edu/
UW FLiBe Salt Production and Purification
Providing Materials for the FHR Community

Comparison of the quality of salts produced by various methods.

UW Madison’s salt purification system
• Removes moisture, sulfur, and several corrosive metal impurities.
• Can produce 40 kg of FLiBe per batch
• Salt purification enables repeatable, high quality salt chemistry and corrosion experiments
Wisconsin Static Corrosion Testing
316 SS Viable with Proper Chemistry Control

- Static corrosion tests carried out at 700°C for 2000 hours.
- Measured the influence of the salt redox potential on corrosion.
- Materials: 316 stainless steel, graphite, W-Zr-C, Mo-Hf-C.
- 316 stainless steel shows moderate corrosion resistance.
- Beryllium reduction leads to lower depth of attack in stainless steel.
- Graphite can accelerate corrosion of stainless steel.

Weight change performance of various materials.

Beryllium reduced salts lead lower depth of attack and less void formation in 316 L Stainless Steel.
Wisconsin Natural Circulation Flibe Flow Loop For Corrosion Testing in 700°C Salt
MIT Irradiation Testing of Materials in 700°C Salt in the MIT Reactor: Cooperation with UW

Identical Testing Except UW Out of Reactor and MIT in Reactor

MIT Irradiation Capsule Schematic
MIT Established Capabilities For Materials Testing in 700°C Flibe Salt

- **Experimental capabilities**
  - In flibe salt. 1000 hour tests
  - 95 materials samples in last capsule test
  - Flux 2.4E14 n/cm²
  - Electrically heated capsule to assure no freezing

- **Materials testing included**
  - Tritium generation and migration testing
  - Carbon and graphite
  - Surrogate coated-particle fuels
  - SiC
  - Metals

- Providing the data base for a demo/test reactor
MIT Irradiation System Developed for Tritium Permeation Measurements (FS-4 Exp.: 3GV Port)
First Test: Factor 14 Reduction in Permeation with NiCr/Alumina on 316SS

Reactor Top Shielding

Gas inlets(1,2,3)

3GV port

Neutron Flux

Tritium Generation

Bubbler and absorber

Bubbler and absorber

Bubbler and absorber

Quartz tube,
Capsules with coating

Tube furnace

Gas inlet (4)

High temp. tritium permeation through alloy and coating barrier

Bubbler and absorber
MIT Tritium Experimental Studies: Behavior and Control

- Irradiated many materials in 700°C salt that generates tritium
  - Heat irradiated materials up to 1000°C in helium/hydrogen to drive off tritium
  - Determine quantities tritium adsorbed and temperature of desorption
- May be able to efficiently remove tritium from salt with carbon bed
  - Activated carbons have much higher tritium capture capabilities than nuclear grade graphite
  - Experiments indicate high tritium uptake; May enable use of carbon bed to remove tritium from salt out-of-core
Tritium and other impurities can be removed from salt by gas sparging.

Use ultrasonics to increase gas sparging mass transfer.

Surrogate fluids used in experiments:
- flibe - glycerol/water
- He/Ar - oxygen

**UNM: Improved Tritium Removal with Sono-Mechanical Enhanced Gas Stripping**
MIT FHR Economic Case Based on Higher Average Temperature of Delivered Heat

<table>
<thead>
<tr>
<th>Coolant</th>
<th>Average Core Inlet Temp. (°C)</th>
<th>Average Core Exit Temp. (°C)</th>
<th>Average Temp. Heat (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>270</td>
<td>290</td>
<td>280</td>
</tr>
<tr>
<td>Sodium</td>
<td>450</td>
<td>550</td>
<td>500</td>
</tr>
<tr>
<td>Helium</td>
<td>350</td>
<td>750</td>
<td>550</td>
</tr>
<tr>
<td>Salt</td>
<td>600</td>
<td>700</td>
<td>650</td>
</tr>
</tbody>
</table>

- Enables higher-efficiency power cycles and industrial heat
- Enables coupling to heat storage systems with base-load reactor operations and variable electricity to the grid to minimize costs and maximize revenue
  - Double hot-to-cold sensible heat storage temperature range, heat storage cost drops in half
  - Higher efficiency of stored heat-to-electricity

Kairos Power

Startup Company 2017
60 People and Hiring
The Kairos RAPID-Lab Co-locates Engineering Design, Experimental Testing, and Mod/Sim in Alameda, California

https://kairospower.com/
Conclusions

- University projects converted FHR from concept into credible reactor option with economic case
- Major experimental facilities have been build and collecting data required for a test/prototype reactor
- Defined commercial path forward
- Much progress but long path to commercialization
- Thank DOE/NE and ORNL for their support

https://www.dropbox.com/s/7qgz3cse5nqya3i/ANP-TR-180.pdf?dl=0