Nuclear data for Kairos Power’s Fluoride-salt cooled High Temperature Reactor (KP-FHR)
Kairos Power’s mission is to enable the world’s transition to clean energy, with the ultimate goal of dramatically improving people’s quality of life while protecting the environment.

In order to achieve this mission, we must prioritize our efforts to focus on a clean energy technology that is affordable and safe.
Kairos Power is Uniquely Suited to Supply the Technology to Replace U.S. Natural Gas Capacity

**ROBUST INHERENT SAFETY**
- Uniquely large fuel temperature margins
- Absorption of fission products in primary coolant
- Low-pressure system
- Effective passive decay heat removal

**LOWER CAPITAL COSTS**
- Reduce requirements for high-cost nuclear grade components and structures
- Leverage conventional materials, existing industrial equipment, and conventional fabrication and construction methods

**IMPROVED OPERATING ECONOMICS**
- High efficiency
- Flexible deployment of low-cost nuclear heat
Kairos Power Fluoride Salt-Cooled High-Temperature Reactor (KP-FHR)

Coated Particle Fuel [from HTGRs]

Liquid Fluoride Salt Coolants [from MSRs]

Low-Pressure Pool Vessel [from SFRs]
Basic System Configuration with Steam Cycle
Kairos Test Program Enables Component Development by Narrowing the Design Space

Repeated test cycles enable component development by narrowing design space
Development Strategy - Iterative Development Approach

- Engineering Test Unit (non-nuclear, fibra)
- Hermes Reactor
- U-Facility Reactor Demonstration Unit (non-nuclear)
- Commercial Plant 140 MWe/Unit

Reducing cost risk 
Reducing cost risk 
Reducing cost risk 
Test experience 
Test experience 
Test experience
Kairos Power’s RAPID-Lab for Iterative Testing for Design, Safety, Validation
Kairos Power Recent Progress

**S-Lab**
Flibe Chemistry and Materials Testing Lab
Operational Sep 2020

**New Mexico Expansion**
T-Facility and Manufacturing Development Facility
Purchased Jan 2020

**K-33 Hermes Site**
Test reactor site in Tennessee
Nov 2020
KP-FHR Core

• 280-320MW\textsubscript{th}
• Packed-bed: PF ~60%
• Pebbles inserted from the bottom and are removed at the top
• Control system is combination of in-bed and in-reflector
KP-FHR Fuel

- Fuel Kernel
- Buffer Layer
- Inner Pyrocarbon
- Silicon Carbide
- Outer Pyrocarbon

~0.4 mm
KP-FHR Coolant

- Flibe is both absorber and moderator
- Li-7 enrichment is important for operation (coolant reactivity coefficient)
- Carbon-to-heavy metal (CHM) ratio
  - Coolant reactivity coefficient
  - Discharge burnup
  - Time to Li-6 equilibrium

Coolant Temperature Reactivity Coefficient
Negative (-)  Positive (+)

Optimum CHM
Core Design Tools

Serpent 2
Star-CCM+
KP-AGREE

KP-FHR Design Tools

Temperature Distribution
Thermophysical Properties
Thermal-Hydraulics
Nuclear Data
Neutron and Gamma Transport

Criticality
Power Distribution
Burnup

Materials Properties

Discrete Element Model (DEM)

Velocity Profile
Porosity Profile

Nodal Solver Neutronics/TH

Multigroup Library

kp-xsec

Studsvik
Nuclear data important to KP-FHR

- Thermal scattering data
  - Graphite
  - Flibe
- Cross sections of $^{19}$F, $^{9}$Be, $^{6}$Li, $^{7}$Li
Sources of uncertainty to multiplication factor

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Uncertainty, pcm</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^7$Li capture</td>
<td>1,240</td>
</tr>
<tr>
<td>$^{235}$U nu</td>
<td>379</td>
</tr>
<tr>
<td>$^{238}$U capture</td>
<td>214</td>
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<tr>
<td>$^{19}$F capture</td>
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<tr>
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<tr>
<td>$^{12}$C capture</td>
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<tr>
<td>$^{12}$C elastic</td>
<td>121</td>
</tr>
<tr>
<td>Total</td>
<td>1,380</td>
</tr>
</tbody>
</table>

The major source of uncertainty in Flibe is $^7$Li capture cross section.

FHRs feature relatively small coolant density reactivity coefficients

- Coolant density (temperature) reactivity feedback in FHRs is a fine balance between flibe absorption and moderation
  - Positive feedback from reduced absorption
  - Negative feedback from reduced moderation (spectrum hardening)
- Coolant temperature feedbacks can only be achieved if flibe has a significant contribution to moderation

![Coolant temperature reactivity feedback (pcm/K) as a function of carbon-to-heavy metal ratio](image-url)
Uncertainty in the coolant density feedback is also dominated by $^7\text{Li}$ capture.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Relative uncertainty, %</th>
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<tbody>
<tr>
<td>$^7\text{Li}$ capture</td>
<td>31.30</td>
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<tr>
<td>$^{19}\text{F}$ capture</td>
<td>4.33</td>
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<td>$^{19}\text{F}$ elastic</td>
<td>2.10</td>
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<td>$^7\text{Li}$ elastic</td>
<td>1.67</td>
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<tr>
<td>$^{9}\text{Be}$ capture</td>
<td>0.99</td>
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</tbody>
</table>
FHR and fluoride molten salt reactors share similar data needs

Uncertainty from nuclear data for the effective multiplication factor of the Molten Salt Reactor Experiment

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</tr>
<tr>
<td>$^{238}\text{U} \text{ capture}$</td>
<td>257</td>
</tr>
<tr>
<td>$^{7}\text{Li} \text{ capture}$</td>
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<td>$^{235}\text{U} \text{ fission}$</td>
<td>120</td>
</tr>
</tbody>
</table>

D. Shen and et al. “ZERO-POWER CRITICALITY BENCHMARK EVALUATION OF THE MOLTEN SALT REACTOR EXPERIMENT”
Conclusion

- Nuclear data needs for FHRs are not unique, well known and widely used isotopes

- Liquid Flibe TSLs:
  - Zhifeng Li, et al “On the improvements in neutronics analysis of the unit cell for the pebble-bed fluoride-salt-cooled high-temperature reactor” – showing 100-500pcm change in k-eff

- Uncertainties can be bounded for important figures of merit for safety

- Hermes will be used to validate computational tools and predicted uncertainties
Questions?