“Commercializing the FHR: From IRP to Kairos Power”

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“ENABLING THE NEXT NUCLEAR: FHRS TO MEGAWATTS” WORKSHOP
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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.
Overview

- FHR Beginning
- Integrated Research Projects
FHR\textsuperscript{1} innovation in the United States started in 2002

- Originally a collaborative effort by Charles W. Forsberg (Oak Ridge National Laboratory), Per F. Peterson (University of California-Berkeley), and Paul S. Pickard (Sandia National Laboratories)

- Concept established new family of high-temperature reactors defined by three fundamental characteristics
  - High-temperature fuel
  - Low-pressure liquid coolant
  - Thin-walled components

\textsuperscript{1}The original concept was referred to as an Advanced High Temperature Reactor (AHTR)
FHR historical timeline

- Original concept: 2000
- Early studies: 2000-2010
  - ORNL (Forsberg)
  - Peterson (UCB)
  - INL
- UW-M salt work initiated: 2006
- Chinese Academy of Science: 2012
- IRP-1 Initiated: 2012
  - MIT/UCB/UM-W
- IRP-2 Initiated: 2015
  - MIT/UCB/UM-W/UNM
  - GT/OSU/TAMU/TAMU-K
- Kairos Power incorporated: 2016
- Kairos Power moves into Alameda HQ: 2018
IRP-2012 structure

Define Status and Path Forward

Technology Development

Integration of Knowledge

Safety / Thermal-Hydraulics (UCB)

Roadmap (MIT)

Workshops (UCB)

Materials out of Reactor (UW)

Commercial Reactor Design (UCB)

Reactors Irradiated Materials (MIT)

Test Reactor Design (MIT)
UC Berkeley studies FHR thermal hydraulics, neutronics, safety and licensing

- Conceptual Design Studies
  - 2014 236 MWt Mk1 PB-FHR
  - X-PREX Pebble Bed Tomography
- Coupled neutronics and thermal hydraulics
- Separate and integral effect tests
- Organize Expert Workshops and White Papers

SINAP TMSR-SF1

Wisconsin emphasis on understanding and testing materials corrosion in salt

- Production, purification and analysis of flibe salt for all experiments all sites
- Static materials corrosion tests in 700C salt
- Selective identical experiments at Wisconsin (no irradiation) and in MIT reactor to understand impacts of irradiation on materials in 700C salt
- Startup of flow loop for corrosion testing

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
MIT Emphasis on Irradiation Testing of Materials in the MIT Reactor In Cooperation with UW
In summary, DOE-led R&D has developed an improved foundation for understanding FHRs.

Multiple FHR Conceptual Design Studies

2008 900 MWt PB-AHTR
2010 125 MWt SmAHTR
2012 3600 MWt ORNL AHTR
2014 236 MWt Mk1 PB-FHR

DOE-NE has invested nearly $40 MUSD directly in the NEUP program to develop FHR technology.
Kairos Power builds off that early DOE investment

- Nuclear energy engineering and design company focused on the \textit{commercialization} of the fluoride salt-cooled high temperature reactor (FHR):
  - Founded in 2016
  - Based in San Francisco Bay Area
  - Builds on UC Berkeley Concept Development and R&D
  - Collaborating with multiple National Labs and Universities
  - 60+ Employees (\textit{and growing})

- Private funding secured for major design, licensing, and technology development programs through 2020 (\textit{and beyond if major milestones are met}).

- Schedule driven by US demonstration by 2030 (\textit{or earlier}) and rapid deployment ramp in 2030s.

- Leverages technology from past advanced reactor designs, coupled together to reduce cost.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
\textbf{Level} & \textbf{Count} \\
\hline
Governance (C + VP) & 5 \\
Director & 7 \\
Lead / Senior & 22 \\
Junior & 19 \\
\hline
\end{tabular}
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Kairos Has Moved Into RAPID-Lab (R-Lab) in Alameda Point

- **R-Lab** is an innovative state-of-the-art facility where engineering design and model and simulation capabilities are *co-located* with experimental capabilities.
R-Lab Covered Lab Space with Test Skids
Corrosion testing with Flibe underway

Designed by UW Madison
Capacity for simultaneous testing of up to 27 corrosion or mechanical properties coupons in both the loop hot leg and cold leg.
Key safety related code development efforts for safety related codes include:

- **SAM**: Dedicated safety related transient systems analysis tool being developed for KP-FHR.
  - Co-development with Argonne National Laboratory.
  - Model Needs and Code Development Plan (CDP) in place and development underway.

- **BISON**: TRISO fuel performance prediction tool.
  - Co-Development with Idaho National Laboratory.
  - Model Needs established, CDP under development.

- **PARCS/AGREE**: Porous media based thermal hydraulics code with coupled neutronics module for core transient analysis.
  - Co-Development with the University of Michigan.
  - Model Needs established. CDP under development.

- **GRIZZLY**: High temperature core structural materials analysis tool.
  - Co-Development with Idaho National Laboratory.
  - Model Needs and CDP still to be created.
Establishing and Leveraging External Paths

KP is leveraging the expertise of the national laboratories and academia to accelerate code development:

• U.S. Department of Energy:
  ◦ FY2018: GAIN voucher with ANL and INL for KP-SAM development and high-fidelity CFD.
  ◦ FY2019-2020: DOE TCF award with ANL for the commercialization of KP-SAM.
  ◦ Engagement through centers (e.g. Thermal Hydraulics Center of Excellence).
  ◦ Current national laboratory collaborators: Argonne National Laboratory, Idaho National Laboratory, Los Alamos National Laboratory.

• Universities:
  ◦ Code development and supplemental validation work.
  ◦ Current collaborators include the University of Michigan, University of Wisconsin, and University of New Mexico, University of Tennessee.

• Consulting Groups:
  ◦ Leveraging experience in commercial grade dedication of safety related codes.
Pre-Conceptual Design

Detailed Design

Mod/Sim Program Developed

Establish Critical External Partnerships

Infrastructure and pipeline

Mod/Sim Code Development Plans

Code Eval. and Gap Analysis

Mod/Sim Code Development

Code Verification

Code Validation & Testing Programs

Documentation of Models, Methods, User Manuals, and UQ

Engineering & Design Team Use of Tools

Use of Tools for Licensing

Pre-PIRTs

PIRTs

KP Design Process Remaining

Mod/Sim Activities

Design Stage and % Remaining

Current status

Time
NRC Proposed Methodology for Code/Development Assessment

- Experimental Assessment Matrix
- Experimental Testing & Data Evaluation
- Model Development
- Code Assessment: Compare Code vs. IET and SET
- Application for Conceptual Design
- Uncertainty Methods
- KP-FHR
- PIRT
- CODE Model Acceptable?

Drives testing needs
Iterative process
Drives Mod/Sim needs
DEFICIENCY
YES
YES
Summary

• FHR technology leverages both technologies and DOE investments in a number of advanced reactor technologies

• Integrated Research Project (IRP) is an extremely successful funding vehicle for cultivating good ideas at the university that have commercialization potential

• Kairos Power has spun out of this initial DOE investment and is currently leveraging these capabilities and talent pool

Kairos Power engineers who worked on DOE-NE NEUP and earlier projects as students