Kairos Power

KP-NRC-2004-001

April 1, 2020

Project No. 99902069

US Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Subject: Kairos Power LLC
Presentation Materials for Kairos Power Briefing to the Advisory Committee on Reactor Safeguards on Reactor Coolant and Scaling Methodology Topical Reports

This letter transmits presentation materials for the April 9, 2020, briefing for the Advisory Committee for Reactor Safeguards (ACRS) full committee meeting. At the meeting, participants will discuss two topical reports that were submitted to the Nuclear Regulatory Commission staff for review and approval: (1) Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-TR-005-P); and (2) Scaling Methodology for the Kairos Power Testing Program (KP-TR-006-P).

Enclosure 1 provides the non-proprietary presentation materials for the open session.

If you have any questions or need any additional information, please contact Drew Peebles at peebles@kairospower.com or (704) 275-5388 or Darrell Gardner at gardner@kairospower.com or (704) 769-1226.

Sincerely,

Peter Hastings, PE
Vice President, Regulatory Affairs and Quality

Enclosures:

1) Open Session Presentation Materials for the April 9, 2020, ACRS Briefing (Non-Proprietary)

xc (w/enclosure):

Benjamin Beasley, Chief, Advanced Reactor and Licensing Branch
Stewart Magruder, Project Manager, Advanced Reactor and Licensing Branch
Weidong Wang, Senior Staff Engineer, Advisory Committee for Reactor Safeguards

Enclosure 1

Open Session Presentation Materials for the April 9, 2020, ACRS Briefing (Non-Proprietary)

OVERVIEW OF SCALING METHODOLOGY TOPICAL REPORT

ACRS FULL COMMITTEE MEETING, APRIL 8, 2020

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.

Outline

- Purpose of the Scaling Methodology Topical Report
- Hierarchical Two-Tiered Scaling (H2TS) Methodology
- Use of Surrogate Fluids in Scaled Experiments
- Application of Scaling Methodology to Integral Effects Tests (IETs)
- Application of Scaling Methodology to Separate Effects Tests (SETs)
- Conclusions

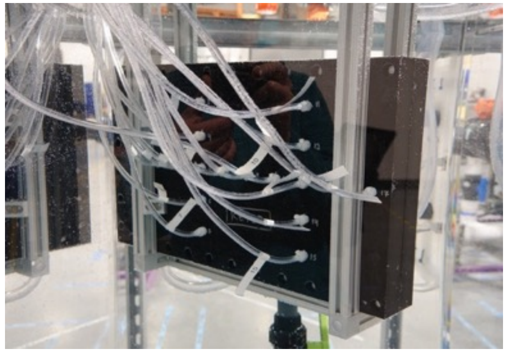
Purpose of the Scaling Methodology Topical Report

- The methodology is used to scale integral effects tests (IETs) and separate effects tests (SETs) supporting the KP-FHR evaluation model assessment base
- The methodology is limited to single-phase Flibe systems and phenomena
- Surrogate fluids enable direct and comprehensive, local measurements of the phenomena under investigation due to higher compatibility of high-accuracy instrumentation (e.g., temperature and flow velocity)
- Kairos Power is requesting NRC review and approval to:
    - Use the scaling methodology with surrogate fluids described in the report (heat transfer oil and water) for testing included in the assessment base of evaluation models supporting KP-FHR safety analysis

Scaling Methods Support Acceleration of Kairos Power's Validation Testing Roadmap

KP-SETs

R-Lab
2020



Fluid dynamics tests
Room-temperature water
40% geometric scale

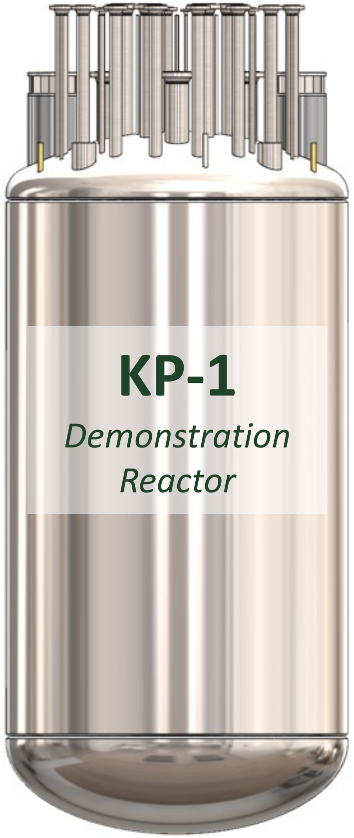
Heat transfer tests
Heat transfer oil (72°C)
Reduced geometric scale

+

KP-IETs

R-Lab
2020
½ Height

Validation of KP-FHR Evaluation Models



Reduced scale (size, power, temperature)
Surrogate fluids
Surrogate materials

Full scale
Flibe coolant (550-650°C)
TRISO fuel pebbles

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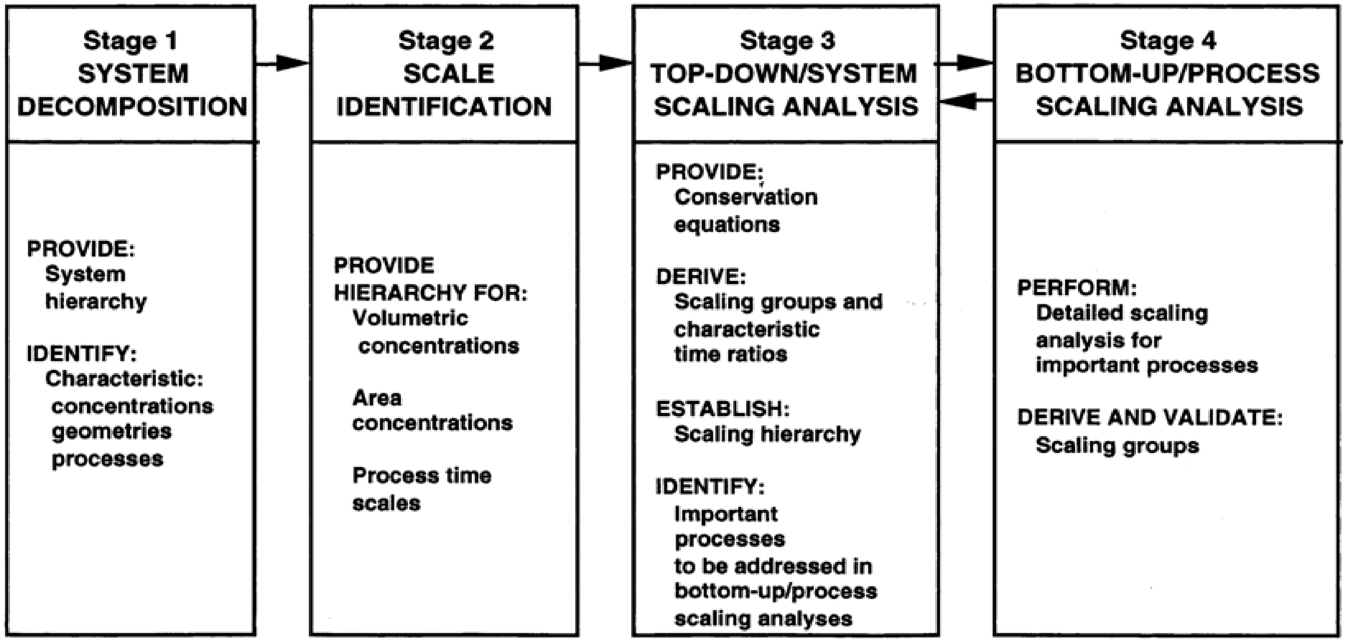
Hierarchical Two-Tiered Scaling (H2TS) Methodology

- Generic scaling method previously developed for and approved by the NRC
- Used for development of previous and current experimental programs for LWRs and non-LWRs
- Selected by Kairos Power for scaling of thermal fluids IETs and SETs as part of the Evaluation Model Development and Assessment Process described in Regulatory Guide 1.203



Source: Zuber, N. et al. (1998). An Integrated Structure and Scaling Methodology for Severe Accident Technical Issue Resolution: Development of Methodology. Nuclear Engineering and Design, 186 (1), 1-21.

Use of Surrogate Fluids in Scaled Experiments

- Surrogate fluids allow the investigation of fluid flow and heat transfer phenomena relevant to the KP-FHR design at significantly smaller scale and required resources (e.g., power and temperature)
  - Heat transfer oil at room temperature may simultaneously match Reynolds, Prandtl, Grashof and Froude numbers for Flibe at average operating temperatures in the KP-FHR primary heat transport system
  - Water may be used for simultaneous matching of Reynolds and Froude numbers
- Surrogate fluids enable direct and comprehensive, local measurements of the phenomena under investigation due to higher compatibility of high-accuracy instrumentation (e.g., temperature and flow velocity) with low-temperature environment
- As a result, extensive, high-accuracy local data may be collected from scaled IETs and SETs to support the assessment base of KP-FHR safety analysis evaluation models, and transparent surfaces may be used for direct visual access
- Surrogate fluids have been used extensively in past and current experimental efforts for nuclear reactor development in both single- and multi-phase flow systems

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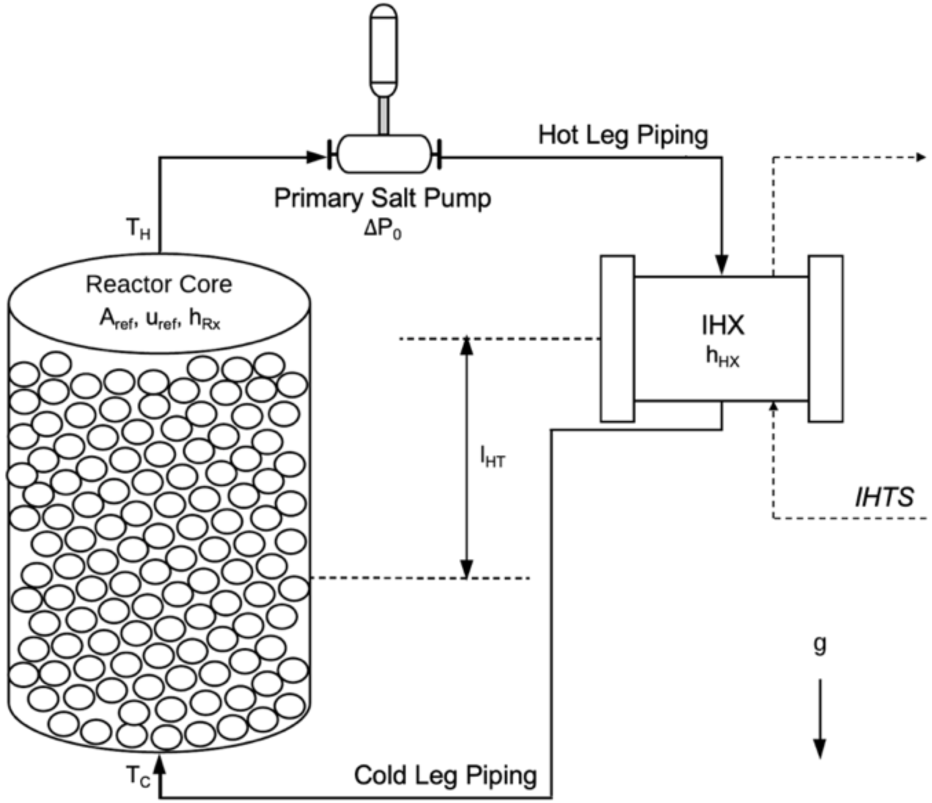
Application of Scaling Methodology to IETs

- Scaling analysis for a surrogate fluid (heat transfer oil) IET of the KP-FHR primary heat transport system
- Classes of licensing basis events illustrated in the topical report:
  - Steady-state, normal forced-circulation operations
  - Transients involving loss of forced flow and transition to natural circulation (e.g., pump trip, loss of heat sink)
- Illustrated using an idealized model of the KP-FHR primary heat transport system and scaled IET



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Application of Scaling Methodology to SETs

- SETs are used to develop closure models and correlations for module/component-level phenomena
- Topical report covers generic fluid dynamics and heat transfer phenomena, and KP-FHR design specific phenomena:
  - Forced circulation fluid dynamics
  - Convective heat transfer
  - Conjugate heat transfer with solid structures
  - Twisted elliptical tube experiments
  - Pebble bed granular flow dynamics experiments
  - Porous media and packed bed heat transfer experiments

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Conclusions

- Kairos Power has adopted the H2TS methodology for scaling of IET and SET experiments in support of KP-FHR evaluation models
- The report details the scaling methodology used for thermal fluid IETs that will model the KP-FHR primary heat transport system under normal operations and transients that involve transition to natural circulation
- The report details the scaling methodology used for thermal fluid SETs relevant to specific KP-FHR components and phenomena
- The report describes the motivations and rationales for using specific classes of surrogate fluids in scaled KP-FHR IET and SET experiments
- **Kairos Power is requesting NRC review and approval to:**
    - Use the scaling methodology with surrogate fluids (heat transfer oil and water) described in the report for testing included in the assessment base of evaluation models supporting KP-FHR safety analysis

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Questions

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OVERVIEW OF REACTOR COOLANT TOPICAL REPORT

ACRS FULL COMMITTEE MEETING, APRIL 8, 2020

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.

Outline

- Purpose of Reactor Coolant Topical Report
- Coolant Selection Criterion for MSRE
- KP-FHR Flibe Specification
  - Corrosion allowances
  - Neutronic Considerations

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Purpose of the Reactor Coolant Topical Report

Kairos Power requested the NRC review and approval of the reactor coolant design specification limits and thermophysical properties for the Kairos Power Fluoride Salt-Cooled, High Temperature Reactor (KP-FHR).

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Compilation of Coolant Data and Information

Williams ORNL-2006

ORNL/TM-2006/12

Assessment of Candidate Molten Salt Coolants for the Advanced High-Temperature Reactor (AHTR)

March 2006

Prepared by

D. F. Williams
L. M. Toth
K. T. Clarno

Reference leveraged heavily for basis of Flibe due to excellent compilation of broad information.

CONTENTS

Coolant Selection Criterion for MSRE

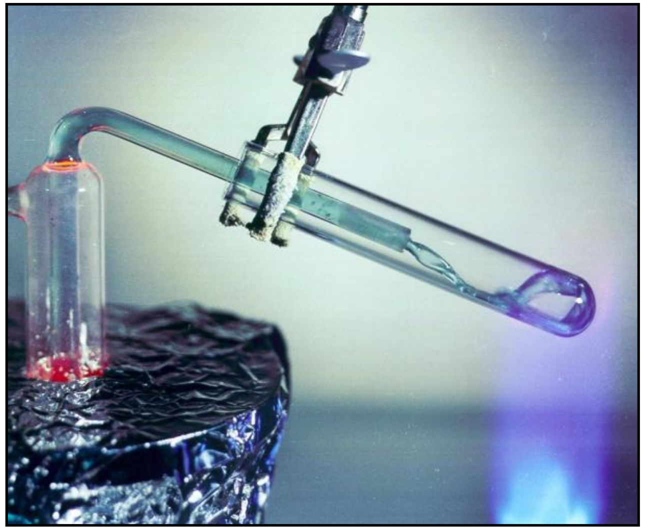
Criteria	Flibe Information
1. Stability at high temperatures (>800°C)	Vapor pressure is low over operational temperatures
2. Stability under radiation	Minimal degradation if using ^{7}Li
3. Melting point below 500°C	The melting point of Flibe is 459°C
4. Materials compatible	Clean Flibe has low corrosion rates. Additions of elemental beryllium control corrosion to less than 30 micron/year
5. Effective solvent for fissile material and fission products	Flibe was solvent for MSRE fuel salt; able to dissolve fuel and most fission products
6. Negative coolant reactivity	Coolant density Coefficient: -$0.01 per 100°C Coolant Void Ratio: -$0.11*
7. Low short-term activation and no long-life activation	Short-term activation is small.
8. Low relative neutron capture	8x neutron capture relative to graphite.
9. Thermophysical properties	

* Analysis performed using prismatic VHTR geometry.

From Williams ORNL-2006

KP-FHR uses Flibe ($2LiF:BeF_2$) as a coolant

- Flibe coolant provides enhanced safety features relative to LWR designs.
  - Large thermal inertia minimizes rapid temperature transients
  - Negative temperature coefficient of reactivity supports reactivity control
  - Minimal short-term and long-term activation
- Flibe is an optimization for nuclear reactor operation
  - High density and heat capacity (i.e. thermal inertia)
  - Viscosity comparable to water
  - Stable under radiation and at high temperatures
- Flibe supports safety basis as a barrier to fission product release.
  - Absorbs fission products that escape the TRISO protective layer, providing additional functional containment protection.



LiF-BeF_2 mixture (Flibe)

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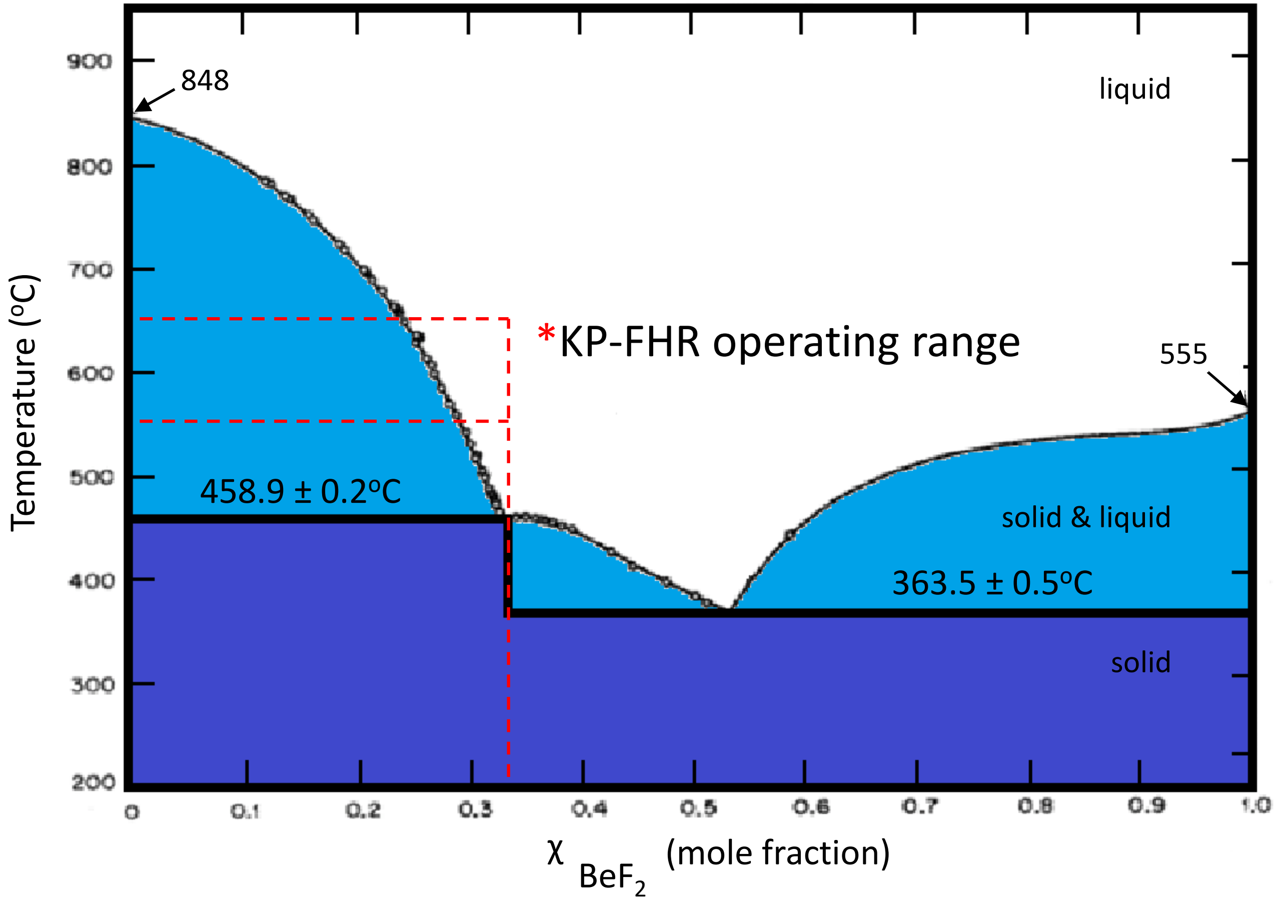
Lithium Fluoride, Beryllium Fluoride Phase Diagram



Simplified from ORNL-DWG71-527OR2

Grimes, W.R., Bohlmann, E.G., Meyer, A.S., and Dale, J.M.,"Fuel and Coolant Chemistry," Chapter 5 in Rosenthal, M.W., Haubenreich, P.N., and Briggs, R.B., The Development Status of Molten-Salt Breeder Reactors, Oak Ridge National Laboratory Report ORNL-4812 (1972).

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Reactor Coolant Topical Report Scope

Reactor Coolant Topical Report Defines

- Thermophysical properties of Flibe
  - Density, viscosity, heat capacity, thermal conductivity, melting temperature, etc.
- Chemical Specification used in KP-FHR
  - Corrosion allowances; impurities known to cause corrosion have limits on concentration
  - Neutronics considerations; impurities important for neutronics have limits on concentration


Questions