UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

June 19, 2020

Mr. Peter Hastings
Vice President, Regulatory Affairs
and Quality
Kairos Power LLC
707 W Tower Ave
Alameda, CA 94501

SUBJECT: SAFETY EVALUATION FOR KAIROS POWER LLC TOPICAL REPORT "SCALING METHODOLOGY FOR THE KAIROS POWER TESTING PROGRAM" (REVISION 1) (EPID NO. L-2019-TOP-0011 AND CAC NO. 000431)

Dear Mr. Hastings:

By letter dated March 6, 2019 (Agencywide Documents Access and Management System (ADAMS) Package Accession No. ML19065A309), Kairos Power, LLC (Kairos Power) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review, "Scaling Methodology for the Kairos Power Testing Program." The NRC staff sent a preliminary set of questions to Kairos Power on October 15, 2019 (ADAMS Accession No. ML19290E570). By letter dated December 23, 2019 (ADAMS Accession No. ML19357A252), Kairos Power submitted "Scaling Methodology for the Kairos Power Testing Program" (Revision 1).

The NRC staff documented its review in the enclosed safety evaluation (SE), which was previously provided to you for the identification of proprietary information and factual errors on February 7, 2020 (ADAMS Accession No. ML20034E109, non-public). You provided comments to the NRC staff on March 9, 2020 (ADAMS Accession No. ML20134J077). The NRC staff has incorporated your comments, as appropriate, in the enclosed SE. In addition, the Advisory Committee for Reactor Safeguards (ACRS) was briefed on this topical report on February 21, 2020, and April 9, 2020. The ACRS endorsed the publication of this SE in a letter dated May 21, 2020 (ADAMS Accession No. ML20142A301).

The enclosed SE is final, and a redacted version will be made publicly available as specified in your comments.

The Enclosure to this letter contains Proprietary information. When separated from the Enclosure, this document is DECONTROLLED.

If you have any questions, please contact Stewart Magruder at 301-348-5766 or by e-mail at Stewart.Magruder@nrc.com.

Sincerely,

/RA/

Benjamin Beasley, Chief
Advanced Reactor Licensing Branch
Division of Advanced Reactors and Non-Power Production and Utilization Facilities
Office of Nuclear Reactor Regulation

Project No. 99902069

Enclosure:
Final SE

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gardner@kairospower.com
peebles@kairospower.com

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UNITED STATES
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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT KP-TR-006, REVISION 1,

"SCALING METHODOLOGY FOR THE KAIROS POWER TESTING PROGRAM,"

KAIROS POWER, LLC

PROJECT NO. 99902069

1.0 INTRODUCTION AND BACKGROUND

By letter dated March 6, 2019 (Reference 1), as updated by letter dated December 23, 2019 (Reference 2), Kairos Power, LLC (Kairos Power), requested U.S. Nuclear Regulatory Commission (NRC) review and approval of Topical Report (TR) KP-TR-006, "Scaling Methodology for the Kairos Power Testing Program." The updates to the TR reflected discussions between Kairos Power and NRC staff during a public call on November 15, 2019 (Reference 3), which included changes to address the questions on the TR from the NRC staff (Reference 4). This TR describes the Kairos Power methodology to perform scaling analyses with surrogate fluids for Flibe ($2LiF{:}BeF_2$) as part of the Evaluation Model Development and Assessment Process (EMDAP) described in Regulatory Guide 1.203, "Transient and Accident Analysis Methods," (Reference 5).

2.0 REGULATORY EVALUATION

Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.34, 10 CFR 52.47, 10 CFR 52.137, "Contents of Applications; Technical Information," 10 CFR 52.79, and 10 CFR 52.157, "Contents of Applications; Technical Information in Final Safety Analysis Report," require a safety analysis report to analyze the design and performance of structures, systems, and components (SSCs). The analysis for the design and performance of the integrated system of SSCs relies upon the use of evaluation models (i.e., an analytical tool or set of analytical tools). An applicant may employ approved evaluation models to demonstrate compliance with applicable regulatory requirements, including several principal design criteria. The adequacy of an evaluation model may be demonstrated through an assessment which includes comparison to test data.

Additionally, 10 CFR 50.43(e) provides requirements for applications for a design certification, combined license, manufacturing license, operating license, or standard design approval that propose nuclear reactor designs which differ significantly from light-water reactor designs that were licensed before 1997, or use simplified, inherent, passive, or other innovate means to accomplish their safety functions. In the absence of prototype plant testing, 10 CFR 50.43(e) requires that sufficient data exist on the safety features of the design to assess the analytical tools used for safety analyses over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences.

Enclosure

The data needed for the assessment of analytical tools, specified by the EMDAP process and 10 CFR 50.43(e), is provided by physical experiments. The physical experiments are typically performed at facilities built on a different scale (e.g., reduced physical dimensions, reduced pressure and temperature). The appropriate test facility parameters (e.g., dimensions, materials, thermodynamic conditions) are derived from the prototypical plant using a scaling methodology. This TR provides the scaling methodology used in developing the assessment data specified by the EMDAP process and 10 CFR 50.43(e). The scope of the NRC staff's review includes the suitability of the scaling methodology, which includes the use of surrogate fluids, to the Kairos Power fluoride-salt-cooled, high temperature reactor (KP-FHR) primary heat transport system (PHTS) under normal operations and transient conditions.

3.0 TECHNICAL EVALUATION

The NRC staff reviewed KP-TR-006 as described in the following sections of this safety evaluation (SE):

- Section 3.2 of this SE assesses the scaling methodology approach to integral effects tests (IETs).
- Section 3.3 of this SE assesses the scaling methodology approach to separate effects tests (SETs).
- Section 3.4 of this SE assesses the use of surrogate fluids in scaled tests.
- Section 4.0 of this SE summarizes the conditions and limitations imposed by NRC staff on the use of the TR. The bases for these conditions and limitations are provided in the technical evaluations in Sections 3.2 through 3.4 of this SE.

3.1 Introduction and Outline

The KP-TR-006 is divided into eight sections and two appendices that the NRC staff evaluated as follows:

- Section 1 of the TR provides an introduction to the report, discusses the regulatory background, and clarifies the specific items for which NRC approval is requested. The NRC staff considered this information in the regulatory evaluation in Section 2.0 of this SE.
- Section 2 of the TR provides background information on the hierarchical two-tiered scaling methodology. The NRC staff considered this information in its evaluations in Section 3.2 through Section 3.4 of this SE.
- Section 3 of the TR describes the application of the scaling methodology to IETs. The NRC staff considers this information in its evaluations in Section 3.2 of this SE.
- Section 4 of the TR describes the application of the scaling methodology to SETs. The NRC staff considers this information in its evaluations in Section 3.3 of this SE.
- Section 5 of the TR describes the use of surrogate fluids in scaled experiments for the KP-FHR design. The NRC staff considers the use of surrogate fluids in its evaluations in

Section 3.2 and Section 3.3 of this SE, and evaluates the use of surrogate fluids in Section 3.4 of this SE.

- Section 6 of the TR provides a brief summary and conclusion. The NRC has no regulatory findings associated with Section 6 of the TR.

- Section 7 contains nomenclature. The NRC has no regulatory findings associated with Section 7 the TR.

- Section 8 contains the list of references. The NRC has no regulatory findings associated with Section 8 the TR.

- The TR contains two appendices that contain information relevant to the body of the TR. The NRC staff considers this information in its evaluations in Section 3.2 through 3.4 of this SE.

3.2 Scaling Methodology Approach to IETs

Section 3 of the TR describes the applicant's scaling methodology approach to scaling IETs, and specifically addresses the scenarios of (1) forced circulation under steady-state normal operation, (2) natural circulation transient evolution, and (3) quasi-steady natural circulation. The overall approach, as presented in Section 3 of the TR, includes first performing a top-down scaling by performing a control volume analysis on the PHTS as a whole (which uses conservation equations), and then conducting a bottom-up scaling to focus on and capture all important phenomena and associated processes within individual modules/components. The NRC staff finds the overall approach to scaling IETs acceptable because it is consistent with the well-established hierarchical two-tiered scaling methodology (Reference 6), and the use of non-dimensionalized equations to develop similarity/scaling parameters is standard practice (Reference 7).

Additional issues considered by the NRC staff during the review of the IET include the generality of the method and the evaluation of scaling distortions. Section 3.1 of the TR clarifies that even though the report covers an idealized version of the PHTS, the TR presents the full methodology needed to perform system scaling for high-fidelity models for the KP-FHR, which will resolve transient response at the level of all individual module/components in future analyses. Similarly, Section 3.2.1 of the TR clarifies that the scaling methodology applied within the TR focuses on a single loop PHTS for simplicity, but that the methodology may be extended to flow networks with branches and allow for investigation of bypass flows. As stated in the preceding paragraph, the NRC staff finds the overall approach of the methodology acceptable, however, the staff recognizes that the analyses for the three scenarios presented in the TR include assumptions that may not be appropriate under other scenarios or design configurations. Accordingly, the NRC staff imposed Limitation 1 to limit approval on the scaling groups identified in the TR to the scenarios and configuration presented in the TR.

Section 2.4 of the TR provides a description of the types of as-built scaling distortions that may be expected to occur in the scaled facility. Additionally, past NRC experience with scaled thermal-hydraulic facilities has revealed that unplanned sources of scaling distortion can occur (e.g., test configuration at time of testing) (Reference 8).

Accordingly, the NRC staff imposed Condition 1 to require a distortion analysis be performed for the as-built facility and completed tests, and to evaluate the impact of those distortions on the associated evaluation model assessment.

Sections 3.2.1 through 3.2.2 of this SE evaluate the scaling analyses performed for the three scenarios described in the TR.

3.2.1 Normal Operation Scaling Analysis

Section 3.2 of the TR describes the IET scaling for normal operation and is performed by utilizing one-dimensional forms of the steady-state conservation of momentum and energy equations. Included in the assumptions is that the parasitic heat losses are negligible. The NRC staff notes that the expected Flibe coolant temperatures for the KP-FHR is 550 degrees Celsius (℃) to 650℃, which scales to approximately 58 ℃ to 88 ℃ for the heat transfer oil in the scaled IET facility. Due to the large temperature differences, the NRC staff expects parasitic heat losses may be significantly different between the prototype KP-FHR and the scaled IET facility. Accordingly, the NRC staff imposed Condition 2 on the TR to require an evaluation of the parasitic heat losses in the distortion report. Based on the information contained in Section 3.2 of the TR, and subjection to Condition 2, the NRC staff finds the one-dimensional approach with the Boussinesq approximation acceptable because it is consistent with similar analyses that have been performed for pressurized water reactors (Reference 9).

Section 3.2.2 of the TR contains the top-down scaling analysis for normal steady-state operation, which resulted in the identification of the five scaling groups presented in Table 1 of the TR (3 from the momentum equation and two from the energy equation). The NRC staff performed a non-dimensional analysis on the steady-state conservation of momentum and energy equations and obtained the same scaling groups. The NRC staff finds the results of the top-down scaling analysis for normal steady-state operation acceptable because it used the well-accepted approach of non-dimensionalizing conservation equations and the staff was able to independently verify the results.

Section 3.2.3 of the TR contains the bottom-up scaling analysis for normal steady-steady operation, which results in the identification of the two additional scaling groups presented in Table 1 of the TR. Specifically, Section 3.2.3 of the TR identified additional scaling groups associated with the loop frictional and form losses, and modified Stanton numbers from the top-down scaling analysis. The TR identified the preservation of the Reynolds number between the scaled facility and prototype for individual modules/components in order to preserve the frictional and form losses, and also identified alternatives for preserving the overall frictional and form losses in cases where geometric similarity cannot be maintained. Additionally, the TR identified the preservation of the Reynolds and Prandtl numbers in order to preserve the heat transfer characteristics to preserve the modified Stanton number. The NRC staff notes that the preservation of the Reynolds and Prandtl numbers is consistent with the results obtained by non-dimensionalizing the fluid conservation of momentum and energy equations (Reference 7). The TR clarifies that such bottom-up scaling is applied when geometric scaling is feasible, and the specific heat structure behavior may be matched, but that an alternative method must be used when geometric scaling is not feasible. Based on the information presented in Section 3.2.3 of the TR, the NRC staff finds the results of the bottom-up scaling for the normal steady-state operation acceptable because it describes a method for preserving the higher-level characteristics identified in the top-down analysis.

3.2.2 Natural Circulation Scaling Analysis

Section 3.3 of the TR describes the IET scaling for natural circulation and is performed by utilizing one-dimensional, time-dependent forms of the conservation of momentum and energy equations. The equations are similar to the equations discussed in Section 3.2.1 of this SE, but the time-dependent derivatives are included. The assumptions from the normal operation scaling analysis, presented in Section 3.2 of the TR, are included with two additional assumptions of (1) the temperature rise across the core, once the system reaches quasi-steady natural circulation, is similar to the normal operation temperature rise, and (2) **[[** [redacted] **]]**. Section 3.3 of the TR clarifies that the scaling analysis will still result in the correct temperature differences occurring in natural circulation, even if the temperature rise assumption is not correct. The NRC staff agrees that the scaling will result in the correct temperature differences during natural circulation, even if the temperature rise assumption is not correct, because the scaling methodology preserves the loop Richardson number, which drives the temperature difference. Additionally, the NRC staff finds the **[[** [redacted] **]]** assumption acceptable because the methodology preserves the remaining aspects of fluid momentum. However, to identify the absence of **[[** [redacted] **]]** behavior in this scaling methodology, the NRC staff imposed Limitation 2 on the TR. The scaling analysis provided in Section 3.3 of the TR identifies the need to preserve the energy balance at the solid/fluid interface as a result of including time-dependent terms with the potential need to scale for heat conduction within the solid structures.

Section 3.3.2.1 of the TR contains the top-down scaling analysis for natural circulation transient evolution, which resulted in the identification of the eight scaling groups presented in Table 2 of the TR (three from the fluid momentum equation, three from the fluid energy equation, the Biot number for energy balance at the solid/liquid interface, and one from the solid conduction equation). The NRC staff performed a non-dimensional analysis on the transient conservation of momentum and energy equations and obtained the same scaling groups. The NRC staff finds the results of the top-down scaling analysis for natural circulation transient evolution acceptable because it used the well-accepted approach of non-dimensionalizing conservation equations, and the staff was able to independently verify the results.

Section 3.3.2.2 of the TR contains the bottom-up scaling analysis for natural circulation transient evolution, which resulted in the identification of the two additional scaling groups presented in Table 2 of the TR. Specifically, Section 3.3.2.2 identified the same additional scaling groups as was identified for normal operation. Additionally, Section 3.3.3 identifies the Grashof number as another scaling group to be preserved under natural circulation scenarios. The NRC staff notes that the preservation of the Grashof number, in addition to the Reynolds and Prandtl numbers, is consistent with the results obtained by non-dimensionalizing the fluid conservation of momentum and energy equations under the Boussinesq approximation (Reference 7). Like the scaling analysis for normal operation, the TR clarifies that such bottom-up scaling is applied when geometric scaling is feasible, and the specific heat structure behavior may be matched, but that alternative methods must be used when geometric scaling is not feasible. Based on the information presented in Section 3.3.2.2 of the TR, the NRC staff finds the results of the bottom-up scaling for the natural circulation evolution acceptable because it describes a method for preserving the higher-level characteristics identified in the top-down analysis.

Section 3.3.3 of the TR clarifies that scaling under the quasi-steady natural circulation phase of the natural circulation scenario is covered by the natural circulation transient evolution scaling analysis performed in Section 3.3.2 of the TR. Additionally, Section 3.3 of the TR states that the difference between the scenarios presented in Section 3.3.2 and Section 3.3.3 is the Nusselt number dependency (Grashof vs Prandtl) for the lower flow rates expected for quasi-steady natural circulation scenarios The NRC staff finds these statements regarding quasi-steady natural circulation acceptable because the scaling analysis performed for the natural circulation evolution was performed for conservation equations that included all of the terms for quasi-steady natural circulation, plus additional terms to address the transient behavior.

3.2.3 Design Specification and Quantification of Scaling Distortions

Section 3.4 of the TR provides a system and component level scaling implementation to replicate normal operation, initial onset of natural circulation, and long-term quasi-steady natural circulation scenarios in the KP-FHR PHTS using a single scaled test facility. Specifically, Sections 3.4.1 through 3.4.4 provide an illustrative example by which a single facility could be designed to preserve the scaling groups derived in Sections 3.2 and 3.3 of the TR. Tables 3 through 8 of the TR contain the results of the illustrative scaling application. The NRC staff performed sample calculations using the process outlined in Section 3.4 of the TR and was able to verify the results presented in Tables 3 through 8. Based on the information provided in Section 3.4 of the TR, the NRC staff agrees that a single test facility can be designed to replicate normal operation, initial onset of natural circulation, and long-term quasi-steady natural circulation scenarios in the KP-FHR PHTS with the use of surrogate fluids because the results provided in the TR demonstrate that key scaling parameters can be preserved at reduced temperatures with little scaling distortion. The NRC staff addresses additional considerations regarding the use of surrogate fluids in scaled facilities in Section 3.4 of this SE. Additionally, the NRC staff recognizes that the results presented in the TR are for illustrative purposes of the scaling methodology and that the final facility design parameters may be different.

3.3 Application of Scaling Methodology to SETs

Section 4 of the TR describes the application of scaling to SETs. Sections 4.1 through 4.4 of the TR discuss the treatment for forced circulation fluid dynamics, convective heat transfer, conjugate heat transfer with solid structures, and channel flow experiments. These discussions include the use of scaling parameters and values obtained from non-dimensionalized transport equations that are well-established for single phase fluid flow and heat transfer (Reference 7 and Reference 10). The NRC staff finds the scaling approaches discussed in Sections 4.1 through 4.4 of the TR acceptable because they are consistent with standard practice for single-phase fluid flow and heat transfer.

Section 4.5 of the TR describes a methodology for scaling twisted tube heat exchangers that are relevant to the design of the KP-FHR intermediate heat exchanger (IHX). Specifically, Section 4.5 of the TR states that Kairos Power can confirm performance for specific thermal-fluid conditions where literature-reported correlations are widely varying by performing their own experiments, and that the use of surrogate fluids enables Kairos Power to perform these experiments at reduced cost with higher fidelity instrumentation (i.e,, the use of a surrogate fluid allows for testing at significantly reduced temperatures where accurate instrumentation is readily available). Section 4.5 of the TR further states that the twisted elliptical tube experiments can be scaled by preserving the (1) Reynolds numbers on the tube and shell sides of the IHX, (2) the Prandtl numbers for the fluids on the tube and shell sides of the IHX, (3) geometric similarity on the tube side of the elliptical tubes by preserving the cross section aspect ratio and tube twist pitch ratio, and (4) geometric similarity on the shell side by preserving the cross section aspect ratio and modified Froude number. The NRC staff agrees that the approach described in Section 4.5 of the TR is reasonable because it preserves the non-dimensional groups that are obtained through a non-dimensional analysis of the momentum and heat transfer equations (i.e., Reynolds and Prandtl numbers), and the geometric scaling appears reasonable. However, the NRC staff questioned the experience base of the scaling approach for the design of heat exchangers and inquired about the issue on a public call on November 15, 2019 (Reference 3 and Reference 4). Specifically, the NRC staff was concerned that the geometric scaling approach presented in Section 4.5 of the TR could introduce unidentified scaling distortions and was seeking evidence to determine that the geometric scaling approach, in combination with the preservation of the Reynolds and Prandtl numbers, was sufficient to ensure boundary layer similarity. Kairos Power provided a list of relevant references to the NRC staff to support the use of surrogate fluids for twisted tube heat exchanger experiments (Reference 11). The NRC staff examined the reference list but was unable to identify tests that successfully demonstrated that preserving the geometric parameters for twisted tubes identified in Section 4.5 of the TR (cross section aspect ratio and tube twist) resulted in preservation of momentum and heat transfer phenomena with acceptable distortions. Accordingly, the NRC staff imposed Condition 3 to require an evaluation model referencing this TR to address the potential for unidentified scaling distortions, due to uncertainties in the adequacy of the geometric scaling presented for twisted tube heat exchangers, in the evaluation model assessment and uncertainty quantification.

Section 4.6 of the TR describes the scaling approach for pebble bed flow and fuel element dynamics experiments. Specifically, Section 4.6 describes the preservation of the force balance on a pebble in equilibrium and the preservation of the Reynolds and Froude numbers to appropriately scale the inertial, viscous, and buoyance forces on a pebble. The NRC staff finds this scaling approach acceptable because it describes an approach that preserves the appropriate parameters associated with inertial, viscous, and buoyance forces on a pebble.

Section 4.7 of the TR describes the scaling approach for porous media or packed bed experiments. The TR clarifies that new heat transfer correlations need to be developed for different flow regimes and Reynolds number ranges applicable to the KP-FHR to address heat transfer from the fuel to the coolant, and that these correlations will be obtained using scaled SET experiments. The scaling approach described in Section 4.7 preserves (1) the Prandtl number for the prototypical coolant in the surrogate fluid, (2) the Reynolds number of the prototypical coolant in the surrogate fluid, and (3) the porous media porosity from the prototype in the experiment. The TR also identified the additional considerations of preserving the pebble to volume diameter ratio between prototype and experiment and selecting a model pebble material with high thermal-conductivity to minimize conductive heat transfer effects. The NRC staff agrees that the scaling approach described in Section 4.7 of the TR is reasonable because it preserves the Reynolds and Prandtl numbers that are known to be significant parameters for heat transfer phenomena, and it preserves important geometrical aspects of the packed bed. However, similar to the issue with the scaling approach for twisted tube heat exchangers, the NRC staff questioned the experience base of the scaling approach for the packed bed heat transfer experiments on a public call on November 15, 2019 (Reference 3 and Reference 4). Kairos Power provided a list of relevant references to the NRC staff to support the use of surrogate fluids for packed bed heat transfer experiments (Reference 11). The NRC staff examined the reference list but was unable to identify tests that successfully demonstrated that preserving the Reynolds number as defined in Section 4.7 of the TR, and preserving the porous media porosity resulted in preservation of momentum and heat transfer phenomena with acceptable distortions. Accordingly, the NRC staff imposed Condition 4 to require an evaluation model referencing this TR to address the potential for unidentified scaling distortions, due to uncertainties in the adequacy of the geometric scaling presented for porous media or backed beds, in the evaluation model assessment and uncertainty quantification. In addition to the SETs identified in Section 4 of the TR, Section 1.3 of the TR clarifies that, if the phenomena and process identification step of the EMDAP process reveals phenomena that requires testing, and that test is not captured by the types of SETs covered in this report, the methodology used to scale that SET will be reconciled in a future submittal.

3.4 Use of Surrogate Fluids in Scaled Experiments

Section 5 of the TR describes the use of surrogate fluids in scaled experimental activities for the KP-FHR. Additionally, the use of surrogate fluids is assumed throughout the TR. Section 5 of the TR clarifies that the motivation for the use of surrogate fluids is to allow for the investigation of relevant fluid and heat transfer phenomena at significantly smaller scale, reduced temperatures, fewer required resources, and to enable the use of available and accurate instrumentation. The NRC staff also recognizes the added safety benefit of eliminating a Beryllium containing coolant from the associated tests. Section 5 of the TR also references Table 12 and Figure 12, which provide illustrations for how a heat transfer oil can be used in place of prototypical Flibe in scaled experiments. The NRC staff performed calculations, using the thermophysical properties of the heat transfer from Table 13 of the TR and the thermophysical properties for Flibe from the Kairos Power reactor coolant TR (Reference 12), and was able to obtain the results presented in Table 12 and Figure 12 of the TR.

Section 5 of the TR also addressed additional considerations when using a surrogate fluid. Specifically, Section 5.3 of the TR clarifies that radiative heat transfer in the KP-HFR will introduce distortion when scaling down to a surrogate fluid using heat transfer oil or water due to lower temperature conditions as compared to the conditions under prototypical operation. Section 3.2.1 of this SE discussed the need to address the potential disparity associated with parasitic heat losses between the prototype and experimental facility, which is neglected in the IET scaling analyses presented in the TR. Section 5.3 of the TR further clarifies that heat transfer scaling distortions due to radiation heat transfer are expected to be greater when convection heat transfer is lower (e.g., laminar flow) and that these distortions will be quantified when designing scaled IETs. The NRC staff imposed Condition 5 on this TR in order to clearly capture the condition stated by Kairos Power in Section 5.3 of the TR.

In addition to the consideration of distortions associated with radiative heat transfer, the NRC staff considered the potential for phase change (e.g., freezing). Literature on scaling indicates that the use of refrigerants to scale processes involving changes of phase has seldom produced meaningful quantitative correlations, and that it is preferable to employ the same fluids, properties, and initial conditions when changes of phase or non-equilibrium conditions occur in a complex system (Reference 13). The NRC staff notes that Section 3.3.1 of the TR identifies freezing of the primary salt during long-term natural circulation is a figure of merit for IET scaling, but the TR did not address the applicability of the scaling methodology or associated scaling distortions should any change of phase occur. Accordingly, the NRC staff imposed Limitation 3 to clarify that the use of surrogate fluids, as described in the TR, cannot be used for scenarios involving a change of phase. Based on the information presented in Section 5 of the TR, the scaling analyses presented for the IETs and SETs presented in Sections 3 and 4 of the TR, and subject to Limitations 1 through 3 and Conditions 1 through 5, the NRC staff finds the use of surrogate fluids acceptable because the use of surrogate fluids has a history of use in single-phase fluid flow and heat transfer and the analyses presented in the TR demonstrate that the use of surrogate fluids results in experimental facilities that exhibit little scaling distortions.

4.0 LIMITATIONS AND CONDITIONS

The NRC staff's conclusions about KP-TR-006 are subject to the following limitations and conditions:

Limitation 1	The NRC staff's approval on the identified scaling groups is limited to the KP-FHR PHTS for one-dimensional flow under the following scenarios: - Forced circulation under steady-state normal operation - Natural circulation transient evolution, and - Quasi-steady natural circulation Identification of scaling groups for other scenarios and/or design configurations will require additional analysis in accordance with the methodology. Section 3.2 of this SE describes the basis for this limitation.
Limitation 2	This TR does not attempt to scale **[[**[redacted]**]]** behavior. Modeling of **[[**[redacted]**]]** behavior during associated transients would require justification outside the scope of this TR. Section 3.2.3 of this SE describes the basis for this limitation.
Limitation 3	The use of surrogate fluids cannot be used for scenarios involving a change of phase. Section 3.4 of this SE describes the basis for this limitation.
Condition 1	An evaluation model that references this TR will include a summary of a distortion analysis that evaluates the as-built and completed test distortions. The associated evaluation model needs to evaluate the impact of these distortions on evaluation model assessment. Section 3.2 of this SE describes the basis for this condition.
Condition 2	An evaluation model that references this TR needs to assess the impact of the distortion attributed to the parasitic heat loss differences between the KP-FHR prototype and the scaled facility. Section 3.2.1 of this SE describes the basis for this condition.
Condition 3	An evaluation model that references this TR for the scaling of twisted tube heat exchangers needs to assess the potential for unidentified scaling distortions, due to uncertainties in the adequacy of the geometric scaling presented for twisted tube heat exchangers, in the evaluation model assessment and uncertainty quantification. Section 3.3 of this SE describes the basis for this condition.
Condition 4	An evaluation model that references this TR for the scaling of heat transfer phenomena in packed beds, and the associated development of heat transfer correlations, needs to assess the potential for unidentified scaling distortions, due to uncertainties in the adequacy of the geometric scaling presented for porous media or packed beds, in the evaluation model assessment and uncertainty quantification. Section 3.3 of this SE describes the basis for this condition.
Condition 5	The distortion report will quantify the impact of thermal radiation heat transfer. Section 3.4 of this SE describes the basis for this condition.

5.0 CONCLUSIONS

The NRC staff approves the use of KP-TR-006, “Scaling Methodology for the Kairos Power Testing Program,” Revision 1, subject to the limitations and conditions identified in Section 4.0 of this SE, for scaling momentum and heat transfer phenomena for the KP-FHR PHTS under normal operations and transient conditions to develop assessment data as specified by EMDAP and consistent with the applicable requirements of 10 CFR 50.43(e). In particular, the NRC staff finds that (1) the application of the scaling methodology to IETs and SETs identifies the appropriate scaling groups to capture the relevant physical phenomena, and (2) the use of surrogate fluids as described in KP-TR-006 is capable of preserving the appropriate scaling groups, with acceptable distortions, under more favorable experimental conditions. These findings are based on the following:

1. KP-TR-006 presents an acceptable methodology for scaling IETs (see Section 3.2 of this SE).

2. KP-TR-006 presents an acceptable methodology for scaling SETs (see Section 3.3 of this SE).

3. KP-TR-006 presents adequate justification for the use of surrogate fluids (see Section 3.4 of this SE).

Principal Contributor: Timothy Drzewiecki, NRR

Date: June 19, 2020

6.0 REFERENCES

1. KP-NRC-1903-001, “Kairos Power LLC, Topical Repot Submittal, Scaling Methodology for the Kairos Power Testing Program,” March 6, 2019 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML19066A047)

2. KP-NRC-1912-002, “Kairos Power LLC, Topical Report Submittal, Scaling Methodology for the Kairos Power Testing Program Topical Report, “Revision 1, December 23, 2019 (ADAMS Accession No. ML19357A252)

3. Summary of November 15, 2019, Public Meeting to Discuss Kairos Power LLC’s Scaling Methodology Topical Report, January 30, 2020 (ADAMS Accession No. ML20030A254)

4. E-mail from L. Candelario to Kairos Power LLC – RE Scaling Methodology Topical Report – Clarification questions and comments, October 15, 2019 (ADAMS Accession No. ML19290E570)

5. Regulatory Guide 1.203, “Transient and Accident Analysis Methods,” December 2005 (ADAMS Accession No. ML053500170)

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