UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

May 27, 2020

Ms. Margaret M. Doane
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: SAFETY EVALUATION FOR TOPICAL REPORT KP-TR-006-P, REVISION 1, "SCALING METHODOLOGY FOR THE KAIROS POWER TESTING PROGRAM"

Dear Ms. Doane:

During the 672nd and 673rd meetings of the Advisory Committee on Reactor Safeguards, April 8-10, 2020 and May 6-8, 2020, we conducted our review of the staff's safety evaluation (SE) report of Topical Report KP-TR-006-P, Revision 1, "Scaling Methodology for the Kairos Power Testing Program." Our Kairos Subcommittee also reviewed this SE report on February 21, 2020. We met with the staff and representatives from Kairos Power LLC. We also had the benefit of the referenced documents.

CONCLUSION AND RECOMMENDATION

1. Topical report KP-TR-006-P, with the limitations and conditions imposed by the staff SE report, provides an acceptable methodology to scale momentum and heat transfer phenomena for the Kairos reactor under normal operations and transient conditions.

2. The SE report should be issued.

BACKGROUND

The Kairos topical report (TR) summarizes the scaling methodology used in their testing program to design scaled experiments that predict behavior in the prototypical Kairos fluoride-salt-cooled high-temperature reactor. This methodology will be used to perform scaling analyses as part of the evaluation model development and assessment process described in Regulatory Guide 1.203, "Transient and Accident Analysis Methods."

The hierarchical two-tiered scaling (H2TS) methodology from NUREG/CR-5809, "An Integrated Structure and Scaling Methodology for Severe Accident Technical Issue Resolution," was selected for Kairos scaling efforts. The scaling methodology is used for thermal-fluids integral effects tests that will model the Kairos primary heat transport system under normal operations and transient conditions. The methodology is also used to develop a comprehensive set of separate effects tests for phenomena and component level tests. This report details the application of the scaling methodology to the Kairos testing.

The TR provides a basis for obtaining experimental data using surrogate fluids instead of a lithium fluoride (LiF), beryllium fluoride (BeF_2) salt, FLiBe (2LiF:BeF_2). The high operating temperatures, power requirements, and toxicity hazards of working with FLiBe make the use of surrogate fluids beneficial for testing. The use of surrogate fluids enables direct and comprehensive measurements of the phenomena under investigation due to the higher compatibility of available, more accurate instrumentation (e.g., temperature, flow velocity, and pressure) in surrogate fluids versus prototypical molten salts at high temperatures. Kairos intends to use heat transfer oil and water as surrogate fluids for FLiBe in specific thermal-fluids tests. This report demonstrates that these surrogate fluids provide acceptable substitutes for FLiBe for certain types of scaled integral effects tests and separate effects tests, and that the important thermal-fluids characteristics can be properly scaled. This enables Kairos to perform scaled experiments with these surrogate fluids before final testing with FLiBe.

DISCUSSION

The staff has evaluated the scaling methodology approach for:

- integral effects tests,
- separate effects tests,
- and the use of surrogate fluids in scaled tests.

For integral effects tests, Kairos addresses the scenarios of: forced circulation under steady-state normal operation, natural circulation transient evolution, and quasi-steady natural circulation. The overall approach includes: performing a top-down scaling by performing a control volume analysis on the reactor using conservation of energy and momentum equations; afterwards, conducting a bottom-up scaling to focus on and capture all important phenomena and associated processes within individual modules and components. The staff review has found this approach to be acceptable because it is consistent with the well-established H2TS scaling methodology of NUREG/CR-5809, and it uses non-dimensional equations to develop similarity/scaling parameters using the methodology of NUREG/CR-3267, "Similarity Analysis and Scaling Criteria for LWR's Under Single-Phase and Two-Phase Natural Circulation."

For separate effects tests, Kairos addresses the treatment of: forced circulation fluid dynamics, convective heat transfer, conjugate heat transfer with solid structures, channel flow experiments, and the scaling of twisted-elliptical-tube heat exchangers. The staff finds this treatment acceptable because it includes the use of scaling parameters and values obtained from non-dimensional transport equations that are well established for single-phase fluid flow and heat transfer.

Kairos also addresses the use of surrogate fluids in Section 5 of the report. The staff finds this approach acceptable because the use of surrogate fluids is known to result in small scaling distortions in single-phase fluid flow and heat transfer.

The staff review finds the scaling TR acceptable for referencing with three limitations and five conditions. Limitation 1 restricts the approval of the scaling groups identified in the TR to the scenarios and configuration presented in the TR. Limitation 2 restricts the applicability during some flow transients and requires transient-specific justification. Limitation 3 restricts application of surrogate fluids to events without phase change (boiling or solidification). Conditions 1 through 5 specify how evaluation models that reference this TR need to document specific features on a case specific basis.

The proposed integral effects tests have been scaled based on one-dimension (1D) bulk coolant flow. Because the main goal of these experiments is to identify the impact on the integrity of support materials, we are concerned that three-dimension (3D) effects may be relevant, and they may not be covered by these tests. For example, the 3D power distribution in the core may induce 3D flow and core-exit redistributions that may result in streaming that could impact some of the support structures in a way that a 1D analysis may underestimate.

The integral effect tests have not considered overcooling events or overheating events for the scaling of thermal-hydraulic phenomena. The overcooling events comprise an important set of conditions that can lead to coolant freezing phenomena (plate out, tube plugging, and slurry flows) that could be significant during transients and accidents. Such operational conditions will almost certainly require FLiBe experiments, not surrogate fluids. The overheating events would not necessarily affect coolant composition but would need to be considered for how an overheating event may affect materials degradation (e.g., corrosion, impurity control, and local heating in the core due to coolant flow affecting structural strength). The approach needed to address these operational conditions is likely to require experiments with FLiBe at a reasonable scale to address key phenomena.

We also note that acceptance of data from tests using this scaling methodology assumes that properties of the surrogate fluid and FLiBe are well-known and accepted by the staff. In the case of FLiBe, this will require that all the limitations and conditions imposed by the staff on the Kairos coolant properties topical report (KP-TR-005-P) are met, including staff review and approval of confirmatory data obtained under an approved quality assurance program, to reduce uncertainties related to FLiBe thermophysical properties.

SUMMARY

Topical report KP-TR-006-P, with the limitations and conditions imposed by the staff SE report, provides an acceptable methodology to scale momentum and heat transfer phenomena for the Kairos reactor under normal operations and transient conditions. The SE report should be issued.

We are not requesting a formal response from the staff to this letter report.

Sincerely,

Scott W. Moore
Digitally signed by Scott W. Moore
Date: 2020.05.27 12:32:04 -04'00'

Matthew W. Sunseri
Chairman

REFERENCES

1. Kairos Power LLC, letter KP-NRC-1903-001, Topical Repot KP-TR-006-P Submittal, "Scaling Methodology for the Kairos Power Testing Program," March 6, 2019 (ADAMS Accession No. ML19066A047 Non-Proprietary, ML19065A311 Proprietary).

2. Kairos Power LLC, letter KP-NRC-1912-002, Topical Report KP-TR-006-P Submittal, "Scaling Methodology for the Kairos Power Testing Program," Revision 1, December 23, 2019 (ADAMS Accession No. ML19357A252 Non-Proprietary, ML19357A253 Proprietary).

3. U.S. Nuclear Regulatory Commission, Safety Evaluation for Kairos Topical Report "Scaling Methodology for the Kairos Power Testing Program," Revision 1, January 2020 (ADAMS Accession No. ML20034E109).

4. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.203, "Transient and Accident Analysis Methods," December 2005 (ADAMS Accession No. ML053500170).

5. NUREG/CR-5809, "An Integrated Structure and Scaling Methodology for Severe Accident Technical Issue Resolution," Appendix D, "Hierarchical, Two-Tiered Scaling Analysis," November 1991 (ADAMS Accession No. ML063400263).

6. M. Ishii and I. Kataoka, NUREG/CR-3267 (ANL-83-32), "Similarity Analysis and Scaling Criteria for LWR's Under Single-Phase and Two-Phase Natural Circulation," March 1983. (https://inis.iaea.org/collection/NCLCollectionStore/_Public/14/779/14779008.pdf).

7. Kairos Power LLC, letter KP-NRC-1903-002, Topical Report KP-TR-005-P Submittal, "Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor," March 8, 2019 (ADAMS Accession No. ML19079A325 Non-Proprietary and ML19079A326 Proprietary).

8. Kairos Power LLC, letter KP-NRC-2001-001, Topical Report KP-TR-005-P Submittal, "Reactor Coolant for the Kairos Power Fluoride Salt-Cooled High Temperature Reactor," Revision 1, January 16, 2020 (ADAMS Accession No. ML20016A486 Non-Proprietary and ML20016A487 Proprietary).

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