



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

December 20, 2019

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

FROM: Stewart L. Magruder, Senior Project Manager */RA/*
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SUBJECT: REPORT FOR THE REGULATORY AUDIT OF KAIROS POWER
LLC FUEL AND THERMAL/FLUIDS PHENOMENA
IDENTIFICATION AND RANKING TABLES, CORE DESIGN AND
SOURCE TERM

Kairos Power LLC (Kairos) began pre-application discussions with the NRC staff on their Kairos Power Fluoride-Salt-Cooled, High-Temperature Reactor (KP-FHR) in October 2018. Over the past year, Kairos has submitted several topical and technical reports and has met with the NRC staff on numerous occasions. During these meetings, Kairos informed the NRC about their plans to submit topical reports in the areas of fuel performance evaluation methodology and fuel qualification (ML19156A242), and transient and accident analysis methodologies including accident source term. Additionally, Kairos discussed the phenomena identification, and ranking tables (PIRTs) which were developed in support of these topical reports. This audit allowed the NRC staff to perform a preliminary review of the PIRTs performed by Kairos to support an efficient review of these licensing topical reports.

The audit took place at Kairos' offices in Alameda, CA on December 3-4, 2019.

Enclosure:
Audit Report

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SUBJECT: REPORT FOR THE REGULATORY AUDIT OF KAIROS POWER LLC FUEL AND
THERMAL/FLUIDS PHENOMENA IDENTIFICATION AND RANKING TABLES,
CORE DESIGN AND SOURCE TERM DATED: DECEMBER 20, 2019

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***via email**

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| NAME | SMagruder | BBeasley | MHayes |
| DATE | 12/18/2019 | 12/20/2019 | 1/4/2020 |

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KAIROS POWER, LLC
SUMMARY REPORT FOR THE REGULATORY AUDIT OF KAIROS
POWER LLC FUEL AND THERMAL/FLUIDS PHENOMENA
IDENTIFICATION AND RANKING TABLES, CORE DESIGN AND
SOURCE TERM
December 3 - 4, 2019

1.0 BACKGROUND AND PURPOSE

Kairos Power LLC (Kairos) began pre-application discussions with the NRC staff on their Kairos Power Fluoride-Salt-Cooled, High-Temperature Reactor (KP-FHR) in October 2018. Over the past year, Kairos has submitted several topical and technical reports and has met with the NRC staff on numerous occasions. During these meetings, Kairos informed the NRC about their plans to submit topical reports in the areas of fuel performance evaluation methodology and fuel qualification (ML19156A242), and transient and accident analysis methodologies including accident source term. Additionally, Kairos discussed the phenomena identification, and ranking tables (PIRTs) which were developed in support of these topical reports. This audit allowed the NRC staff to perform a preliminary review of the PIRTs performed by Kairos to support an efficient review of these licensing topical reports.

2.0 AUDIT REGULATORY BASES

Title 10 of the *Code of Federal Regulations* (10 CFR) 50.34(a)(4), 10 CFR 50.34(b)(4), 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). The development of these evaluation models has commonly been performed in accordance with the Evaluation Model Development and Assessment Process (EMDAP) which is described in Regulatory Guide 1.203, "Transient and Accident Analysis Methods," (ML053500170). One of the major steps included in the EMDAP process is the development of PIRTs to identify important relevant phenomena and gain expert opinion regarding the knowledge level of those phenomena.

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 innovative 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. The PIRT process is typically used to assess the available data on the safety features of the design, and to identify testing needs.

3.0 AUDIT OBJECTIVES

A review of the PIRTs will support the NRC staff in understanding the process Kairos used to assess the available data on the safety features of the design and in conducting an efficient review of topical reports in the areas of fuel performance evaluation methodology and fuel qualification and transient and accident analysis methodologies. This early engagement with Kairos provides for a safety-focused, risk-informed and an efficient staff review process.

4.0 SCOPE OF THE AUDIT AND AUDIT ACTIVITIES

The audit was conducted on December 3 through December 4, 2019 at Kairos' offices in Alameda, CA. The NRC staff conducted the audit in accordance with the Office of Nuclear Reactor Regulation (NRR) Office Instruction NRR-LIC-111, Revision 1 "Regulatory Audits". Members of the audit team, listed below, were selected based on their detailed knowledge on fuel and thermal/fluids; their experience supporting previous design reviews; and their knowledge of the regulatory framework regarding new approaches to fuel and thermal/fluids reviews. Audit team members included:

1. Jeffrey Schmidt, Senior Reactor Systems Engineer (NRC)
2. Michelle Hart, Senior Reactor Engineer (NRC)
3. Antonio Barrett, Reactor Systems Engineer (NRC)
4. Chris Van Wert, Senior Reactor Systems Engineer (NRC)
5. Stephen Bajorek, Senior Level Advisor Thermal Hydraulics (NRC)
6. Joseph Kelly, Senior Reactor Systems Engineer (NRC)
7. James Corson, Reactor Engineer (NRC)
8. Stewart Magruder, Senior Project Manager (NRC), Audit lead
9. Luisette Candelario, Project Manager (NRC)

Kairos staff who participated in substantial discussions with the NRC staff included:

1. Nicolas Zweibaum, Manager, Engineering Testing
2. Brandon Haugh, Director, Modeling and Simulation
3. Per Peterson, Chief Nuclear Officer
4. Ryan Latta, Fuel Qualification Engineer
5. Blaise Collin, Fuel Performance Engineer
6. Micah Hackett, Director, Fuels and Materials
7. Jim Tomkins, Senior Licensing Engineer
8. Drew Peebles, Senior Licensing Engineer
9. Darrell Gardner, Director, License Application

The first day of the audit began with introductions and an overview of the KP-FHR design. Next the Kairos engineering team provided a series of presentations on the following topics:

- KP-FHR Testing Program Overview
- KP-FHR Fuel Element Phenomenological Identification and Ranking Tables (PIRT) Overview
- KP-FHR Thermal/Fluids PIRT Overview

After the presentations, the NRC staff reviewed the PIRT and provided feedback to Kairos. On December 4, 2019, Kairos provided a core design overview presentation followed by a tour of Kairos' facilities and testing laboratory. Next, Kairos provided a mechanistic source term

overview. Following the mechanistic source term overview presentation, an audit exit meeting was conducted.

5.0 SUMMARY OF OBSERVATIONS

The NRC staff's summary of observations listed below is based on the notes taken by the staff during the audit. The NRC staff did not acquire any documents during the audit.

Testing Program Overview

Kairos Power staff presented a high-level description of its testing program. The presentation comprised its component technology development, validation testing process, and qualification testing. Kairos Power indicated that its testing program plans to address knowledge gaps for high importance phenomena identified in the PIRTs.

Fuel Element PIRT Overview

Kairos Power staff gave a presentation on a PIRT exercise for fuel performance. The PIRT panel included both internal and external experts on TRISO fuel manufacturing and performance during normal operations, anticipated operational occurrences, and accident scenarios. The PIRT included phenomena for both the TRISO particles and for the pebble containing the particles. NRC staff had time to review the PIRT report and provide comments to Kairos Power staff. Staff commented that the PIRT was generally well done. Staff asked several questions about how Kairos Power will incorporate results of Idaho National Laboratory's Advanced Gas Reactor program – including ongoing tests AGR 5/6/7 – into their fuel qualification program. Staff expressed interest in seeing Kairos Power's test plans to address knowledge gaps for high importance phenomena identified in the PIRT, particularly phenomena related to pebble manufacturing and behavior under normal and accident conditions, as well as the impact of the molten salt coolant on fuel performance.

Thermal/Fluids PIRT Overview

Kairos Power staff presented a description of their design and of their thermal/fluids PIRT for normal operation and several accident scenarios. The PIRT identified numerous phenomena of importance, as well as a characterization of the knowledge level for those phenomena. These phenomena importance / knowledge level rankings are being used by Kairos to define requirements and capabilities for their analysis codes, and as a basis for several experimental projects. NRC and Kairos Power staff discussed the PIRT and design, providing the NRC staff with an improved understanding of the design and its safety features. NRC staff reviewed the thermal/fluids PIRT and provided Kairos with comments on several of the importance knowledge level rankings and suggestions to improve clarity. In general, the NRC staff review found the Kairos Power PIRT to be comprehensive, well-written, and technically accurate. The NRC staff expressed an interest in additional design information, and in timely access to results from Kairos Power testing programs.

Core Design Overview

Kairos Power staff discussed the core design and physics of the KP-FHR, presented design tools, discussions of verification and validation; and uncertainty quantification. The NRC staff found that this early engagement supports an efficient review of overall licensing topical reports.

Laboratory Facility Tour

Kairos Power staff provided the NRC staff with a tour of their testing laboratory facilities. The NRC staff observed several ongoing tests and noted that the tour provided a helpful visual perspective of the Kairos Power design.

Mechanistic Source Term Overview

Kairos Power staff gave a high-level presentation of their plans to develop radiological source terms for normal operation, anticipated operational occurrences and design basis events to be submitted in a topical report for NRC staff review. Mechanistic source terms for beyond design basis events would be described in a separate document. The NRC staff commented on the interaction between the mechanistic source term and event selection, considering the discussion of credit for barriers to radionuclide release for the different event classes. NRC and Kairos Power staff had a lengthy discussion about providing justification for aerosol production, transport and removal modeling. The NRC staff asked about plans for describing uncertainty in the radiological source terms. The NRC staff noted that in general, more explanation is better for the topical reports, considering that this is a non-LWR design. NRC and Kairos Power staff also discussed regulatory requirements relevant to source term, including the relationship to functional containment. The NRC staff looks forward to additional interactions on this topic.