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

November 17, 2021

Matthew Sunseri, Chairman
Advisory Committee on Reactor Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555

SUBJECT: SAFETY EVALUATION OF THE KAIROS POWER LLC TOPICAL REPORT KP-TR-010, REVISION 3, "KP-FHR FUEL PERFORMANCE METHODOLOGY"

Dear Chairman Sunseri,

In your letter dated September 21, 2021 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML21256A221), the Advisory Committee for Reactor Safeguards (ACRS) reported on its review of the U.S. Nuclear Regulatory Commission (NRC) staff's safety evaluation (SE) of the Kairos Power LLC (Kairos Power) Topical Report KP-TR-010, Revision 3, "KP-FHR Fuel Performance Methodology."

Your letter contained the following conclusions and recommendations:

1. The topic of fuel performance is highly interrelated with fuel qualification and mechanistic source term. An overall road map on the planned topical reports and sequencing for this multi-stage review approach should be provided.

2. To effectively facilitate this new staged process with Kairos and future design developers, staff should develop guidance clarifying the level of information required for staff review at each stage.

3. The limitations and conditions identified by the staff adequately addressed the lack of verification, validation, and a quantitative uncertainty analysis in the "KP-FHR Fuel Performance Methodology" topical report. The SE should be issued.

4. Given the staged nature of this review process, the staff should ensure that subsequent Kairos licensing documentation addresses the following:

    a. Failure Mechanism Concerns
    b. Fission Product Modeling Concerns
    c. Fuel Qualification Performance Envelope Concerns
    d. Potential Non-conservative Failure Rate Calculations

The NRC staff appreciates the ACRS review and recommendations. Regarding Recommendations 1 and 2, the NRC encourages advanced reactor developers to engage in robust early interactions with the NRC staff. The NRC provides information to prospective

applicants in documents such as "A Regulatory Review Roadmap for Non-Light Water Reactors" (ADAMS Accession No. ML17312B567) and “Pre-application Engagement to Optimize Advanced Reactors Application Reviews” (ADAMS Accession No. ML21145A106). These documents outline a flexible approach for staged licensing activities, however, preapplication engagement is optional. During preapplication, a developer may submit documents of varying scope and detail for information, informal review, and formal review. A developer often provides a high-level regulatory engagement plan that will identify when the developer expects to submit documents on specific topics. However, the engagement plans do not provide details on the content of submissions or on the interactions between submissions. The NRC staff should not specify how a developer organizes and submits information during preapplication activities. Because preapplication engagement is optional, the NRC staff does not plan to provide an overall road map on the planned Kairos topical reports or develop guidance clarifying the level of information required for staff review at different stages of preapplication. Regarding Recommendation 3, to ensure public health and safety, the NRC staff placed specific limitations and conditions in its SE report for the Kairos KP-FHR Fuel Performance Methodology topical report which will need to be met before an application can be approved. The NRC staff appreciates that the ACRS agrees with the limitations and conditions.

The NRC staff notes that the goals of the first phase of the Kairos Power fuel performance methodology topical report, as stated in the SE conclusion are: (1) incorporation of the relevant Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO) failure mechanisms; (2) incorporation of the relevant uncertainties which affect the in-service failure fractions and the overall particle releases; (3) the methodology used to determine the sampled individual uncertainties over a range of variation; and (4) a statistical framework which combines individual uncertainties into conservative upper tolerance limits for the failed fuel fractions and on product release, subject to the limitations and conditions described in the SE. Although Kairos has not identified any specific phases, NRC staff anticipates that future topical reports or applications will provide information to address the limitations and conditions.

In Recommendation 4, the ACRS requested the NRC staff to ensure the following concerns are addressed in subsequent Kairos Power licensing actions.

Failure Mechanism Concerns

The ACRS noted that only a subset of TRISO failure mechanisms is evaluated in the Fuel Performance Methodology Topical Report (ADAMS Accession No. ML21162A349). The NRC staff agrees that the methodology includes the appropriate failure mechanisms. The NRC staff and applicant agreed that some failure modes could be eliminated based on the use of UCO fuel kernels and the expected operating conditions given in Table 2-6, “KP-FHR Expected Normal Operating Conditions,” of the topical report. Specifically, the NRC staff did not consider some Uranium Dioxide (UO_2) failure mechanisms relevant to UCO fuel kernels, such as carbon monoxide production causing kernel migration, the debonding between the Inner Pyrolytic Carbon (IPyC) and Silicon Carbide (SiC), which has not been observed in recently manufactured particles, and SiC decomposition, which only occurs at very high temperatures considered outside the expected operating conditions. Limitation and Condition 3 of the NRC staff’s SE (ADAMS Accession No. ML21161A213) limits the operating range to the NRC staff’s approved Electric Power Research Institute (EPRI) EPRI-AR-1-A, “Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO) Coated Particle Fuel Performance,” topical report (ADAMS Accession No. ML20336A052). The NRC staff’s SE states, “For conditions which lie outside the operating range of EPRI-AR-1-A, the failure modes in Sections 2.2.2 and 6.2 must be reevaluated and the topical report updated as necessary.” The NRC staff agrees with the

ACRS that if operating conditions, including design basis transient conditions, fall outside the EPRI-AR-1-A ranges (e.g., SiC temperature, peak particle powers, etc.), the applicant must reevaluate the failure mechanisms and revise the affected range by either revising the fuel performance topical report or including the revised information in a license application (e.g., construction permit or COL application).

As noted by the ACRS, the applicant currently intends to validate the KP-BISON fuel performance code using both UCO and UO_2 comparisons. The NRC staff's review will focus on KP-BISON's ability to accurately predict UCO behavior, which is the stated particle type. Therefore, the NRC staff's review of the validation, which is beyond the scope of the first phase of the review, which covers only the methodology's calculational framework, will focus on UCO particle validation with a likely emphasis on the comparison of KP-BISON to the advanced gas reactor (AGR) test program data.

Finally, the ACRS noted that a low-frequency failure mechanism of buffer/IPyC cracking and subsequent palladium (Pd) failure of the SiC layer is not explicitly evaluated as a failure mechanism in the fuel performance topical report. The NRC staff agrees that this mechanism is not explicitly evaluated but notes that Section 6.2, "Particle Failure," of the topical report addresses this concern. The NRC staff notes that a SiC failure due to Pd attack is an evaluated failure mechanism and is independent of the IPyC layer state. Therefore, Pd is readily available at the SiC layer and every particle is subject to a Pd failure (i.e., not only those with a cracked IPyC). The NRC staff agrees that this failure mode likely bounds the low frequency failure mode of buffer/IPyC cracking and Pd induced SiC failure observed in the AGR program. The NRC staff's final determination of this bounding assumption will be considered during the future KP-BISON validation review and evaluation of the methodology's overall failed particle fission product release.

Fission Product Modeling Concerns

The NRC staff agrees with the ACRS that europium release was observed in the AGR test program. Section 3.2.9, "Fission Product Transport," of the topical report states, "The diffusivities of other radioelements (barium, cerium, europium, and ruthenium) have been measured in some of the components of TRISO particles (kernel or coating layers), resulting in either incomplete datasets or in diffusion times larger than the in-reactor residency time of the fuel." The applicant determined that the incomplete nature of the specific diffusivities, precludes explicitly modeling europium release as part of the fuel performance methodology. The AGR program integral tests do not provide sufficient information to determine the specific layer diffusivities. Instead, the europium release is addressed as part of Topical Report KP-TR-012, "Mechanistic Source Term," which will be presented at an upcoming ACRS meeting. As stated in the NRC staff's SE, topical report Section 3.2.9 titled "Fission Product Transport," was not part of the first phase review scope and hence the NRC staff made no finding regarding europium modeling in the fuel performance methodology topical report.

With regard to iodine modeling, Section 3.2.9, "Fission Product Transport," of the topical report states that iodine and xenon have a similar behavior to krypton. Table 3-8, "Diffusion Coefficients for Key Fission Productions Modeled in KP-BISON," lists iodine and xenon under the krypton heading for the diffusion coefficients. Therefore, the applicant assumes iodine behaves the same as krypton. As noted by the ACRS, tellurium is not discussed in the fuel performance topical report but is mentioned in Table 7-1, "KP-FHR Radionuclide Groups and Representative Elements and Compounds for Gas Space Transport," of the KP-FHR Mechanistic Source Term topical report. As stated in the NRC staff's SE, Section 3.2.9 and

Table 3-8 of the topical report were not part of the first phase review scope and hence the NRC staff made no findings regarding the modeling of iodine or tellurium in the fuel performance methodology topical report.

Fuel Performance Qualification Envelope Concerns

As noted by the ACRS, the commercial power reactor (KP-X) will very likely have particle powers higher than those given in Figure 4-6, "Radar plot of key parameters for TRISO-coated fuel performance," of the EPRI-AR-1-A topical report. The NRC staff's SE Limitation and Condition 3 deals directly with this issue. Limitation and Condition 3 states, "The approval of this TR is limited to operation of the non-power or power KP-FHR reactors, within the bounds supported by the AGR program, as reflected in Table 4-6 in EPRI-AR-1-A." It is currently estimated that the non-power reactor, Hermes, will stay within the EPRI topical report bounds. The applicant is addressing the expansion of the particle power range beyond the EPRI topical report for the KP-X reactor (and, if necessary, for Hermes) as part of Topical Report KP-TR-011, "Fuel Qualification Methodology," which will be presented to the ACRS at a later date.

Potential Non-conservative Calculation of Failure Rates

The NRC staff appreciates the ACRS's insight regarding the potential for non-conservative failure fractions while using KP-BISON (the proposed fuel performance code). The robust nature of the TRISO fuel and likely benign operating conditions may not produce enough failures to accurately estimate failure fractions and thus complicate validation of the KP-BISON code. As noted during the ACRS presentation, if the NRC staff cannot validate the code because of a low number of failures, Kairos could use experimental data as input to bound fuel failure fractions. The validation of KP-BISON will be addressed in a subsequent preapplication or application review, as noted by Limitation and Condition 2. The NRC staff made no findings regarding the illustrative failure fractions, based on the lack of validation, and made no findings regarding the use of other input to determine the failed particle fractions as part of the first phase of the review.

The NRC staff appreciates the ACRS's review. The NRC staff plans to issue the SE report in November 2021 and looks forward to future interactions with the ACRS regarding the Kairos Power Fuel Qualification Methodology and Mechanistic Source Term Methodology Topical Reports.

Sincerely,

Taylor, Robert signing on behalf
of Veil, Andrea
on 11/17/21

Andrea D. Veil, Director
Office of Nuclear Reactor Regulation

Project No. 99902069

cc: Chairman Hanson
Commissioner Baran
Commissioner Wright
SECY

SUBJECT: SAFETY EVALUATION OF THE KAIROS POWER TOPICAL REPORT KP-TR-10, REVISION 3, "KP-FHR FUEL PERFORMANCE METHODOLOGY" DATED: NOVEMBER 17, 2021

DISTRIBUTION: OEDO-21-00414-NRR
PUBLIC
JSchmidt, NRR
BBeasley, NRR
RidsNrrOd
RidsNrrDanu
RidsNrrDanuUARL
RidsNrrDnrl
RidsOpaMail
RidsOcaMailCenter
RidsOgcMailCenter
RidsNrrMailCenter
RidsAcrsAcnwMailCtr
RidsNrrLACSmith

ADAMS Accession No.: ML21302A220 **NRR-106**

OFFICE	NRR/DANU/UARL/PM*	NRR/DANU/UARL/LA*	NRR/DANU/UARL/BC*
NAME	BBeasley	CSmith	WKennedy
DATE	11/01/2021	11/03/2021	11/04/2021
OFFICE	NRR/DANU/DD	NRR	
NAME	MShams	RTaylor *for* AVeil	
DATE	11/09/2021	11/17/2021	

OFFICIAL RECORD COPY