



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

October 26, 2021

The Honorable Christopher T. Hanson,
Chairman
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

**SUBJECT: SUMMARY REPORT – 688th MEETING OF THE ADVISORY
 COMMITTEE ON REACTOR SAFEGUARDS, SEPTEMBER 8-9, 2021**

Dear Chairman Hanson:

During its 688th meeting, September 8-9, 2021, which was conducted virtually due to the Agency's expanded telework capacities employed in response to the COVID-19 pandemic, the Advisory Committee on Reactor Safeguards (ACRS) discussed several matters. The ACRS completed the following correspondence:

LETTER

Letter to Margaret M. Doane, Executive Director for Operations (EDO), NRC, from Matthew W. Sunseri, Chairman, ACRS

- Safety Evaluation of the Kairos Topical Report, KP-TR-010, Revision 3, "KP-FHR Fuel Performance Methodology," dated September 21, 2021, ADAMS Accession No. ML21256A221

MEMORANDA

Memoranda to Margaret M. Doane, EDO, NRC, from Scott W. Moore, Executive Director (ED), ACRS:

- Documentation of Receipt of Applicable Official NRC Notices to the Advisory Committee on Reactor Safeguards for September 2021, dated September 16, 2021, ADAMS Accession No. ML21256A020
- Regulatory Guides, dated September 16, 2021, ADAMS Accession No. ML21256A021

HIGHLIGHTS OF KEY ISSUES

1. Safety Evaluation (SE) of the Kairos Topical Report, KP-TR-010, Revision 3, "KP-FHR Fuel Performance Methodology"

The Kairos topical report presents a calculational framework for fuel performance and fission product release and an associated uncertainty analysis to determine the upper tolerance confidence limits associated with fission product release from intact and failed Tri-structural Isotropic (TRISO)-coated particle fuel. The methodology depends on the use of the KP-BISON code. Because of limited information on the code and its verification and validation (V&V) status, the staff explicitly did not review the code and focused instead on the calculational methodology. The calculational framework in the topical report is intended to support the Kairos test reactor, Hermes, and the power reactor, Kairos Power Fluoride High Temperature Reactor (KP-FHR).

The Committee's technical concerns are identified in the remainder of this letter. Some of these issues may be related to fuel qualification and mechanistic source term which the Committee has not yet had the opportunity to review. Given the staged nature of the review process, the staff should ensure that these concerns are addressed in subsequent Kairos licensing documentation.

Failure Mechanism Concerns

The in-service failure mechanisms considered in the Kairos methodology are based on historical experience of TRISO fuel. For Uranium Oxycarbide (UCO) TRISO-coated particles, three relevant mechanisms are: (a) pressure vessel failure leading to failure of all coating layers, (b) fission product palladium attack/corrosion of the Silicon Carbide (SiC) layer leading to a SiC failure, and (c) Inner Pyrolytic Carbon (IPyC) cracking under irradiation causing the crack to propagate into the SiC layer leading to a failure of both the IPyC and SiC layers. In addition, the following phenomena can be important in some instances: (a) carbon monoxide (CO) production, a concern for Uranium Dioxide (UO₂) and not UCO, (b) kernel migration, a concern for UO₂ and not UCO, (c) debonding between the IPyC and SiC, a concern in older TRISO fuels but not observed in current TRISO fuel, and (d) SiC thermal decomposition that occurs only at very high temperature (> 2000° C). The methodology has implemented a subset of these failure mechanisms. It is recommended that the models that were not considered in the methodology be re-evaluated because some of these models could be important to incorporate for postulated reactivity events where high temperatures might occur (e.g., SiC decomposition) or for UO₂ TRISO fuels that were tested in Germany and China (e.g., CO attack of SiC) and are currently part of the applicant's validation plans.

These failure models have been well established in the open literature on coated particle fuels. However, it is unclear how these failure mechanisms capture the low-frequency failure mechanism observed in the advanced gas reactor (AGR) test program, namely fracture of the buffer leading to a crack in the IPyC and SiC layers followed by palladium penetration along the crack leading to cesium release measured during post-irradiation examination (PIE) of the AGR program. This failure mechanism is a quasi-hybrid of the historic TRISO failure mechanisms. Some clarification of how the failure mechanisms in the model account for the observed failure mechanism discussed in the NRC-approved TRISO particle performance Electric Power Research Institute (EPRI) report is recommended.

Fission Product Modeling Concerns

The fission product diffusivity database for TRISO fuel is largely based on long-lived fission products (Kr-85, Cs-134 and Cs-137, Sr-90, Eu-154, and Eu-155) and simple diffusion models can be used to calculate their release from the fuel during normal operation. Fission product groups in the methodology include noble gases, iodine, cesium, strontium, and silver.

No mention of europium is provided in the Kairos topical report, yet europium release has been observed under irradiation and in high temperature safety testing of UCO TRISO fuel and should be added.

The topical report also does not clearly address how the methodology will consider the release of shorter-lived metallic fission product isotopes of iodine (e.g., I-131, I-132, and I-134) and tellurium that are expected to be released from the fuel and accumulate as circulating activity in the coolant. Some of these isotopes are important for public safety and others for estimating worker dose. The release of these short-lived isotopes has historically been calculated based on release-to-birth ratios because they establish equilibrium in the fuel particles very quickly.

Fuel Performance Qualification Envelope Concerns

The staff noted in the SE that the predicted performance of TRISO particles must stay within the design service operating envelope described by the NRC-approved EPRI report on TRISO particle fuel performance. While most of the operating conditions are well within that operating envelope, particle power is not. An evaluation of the effect of higher particle power on TRISO particle fuel performance is needed to assure the framework approach remains valid for both the test reactor Hermes and the KP-FHR.

Potential Non-conservative Calculation of Failure Rates

The topical report provides an illustrative example of the fuel failure rate calculational methodology. Some of these failure rates are very low, and hence will be very difficult to validate given the large particle population necessary to statistically establish the validity of the calculated failure rates. Furthermore, the calculated failure rates could be non-conservative relative to the experimentally derived failure rates presented in the NRC-approved EPRI report on UCO TRISO fuel particle performance. That report established 95% confidence bounds on both full particle and IPyC and SiC layer failure fractions based on the number of particles tested in the AGR program and failures observed during irradiation or measured in PIE. These experimentally established limits should serve as a minimum failure rate in any reactor safety analysis to capture the statistical limitation of testing from the AGR program.

Committee Action

The Committee issued a letter on September 21, 2021, with 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

2. Discussions at the Planning and Procedures (P&P) Session

The Committee discussed the Full Committee and Subcommittee schedules through January 2022 as well as the planned agenda items for Full Committee meetings.

The ACRS Executive Director also led a discussion of significant notices issued by the Agency since the last Full Committee meeting in July 2021 (this activity is documented in the memorandum dated September 16, 2021).

The Committee discussed recommendations on review of several draft and final regulatory guides, as documented in the memorandum mentioned above, dated September 16, 2021.

The Committee approved Member Ballinger’s attendance at the EPRI Extended Storage Collaboration Program Winter Meeting in Charlotte, NC, November 6-8, 2021. [Note that since the September FC meeting, this event has become a virtual event only.]

The ACRS ED and Chairman led a discussion of the planned re-entry of the Agency on November 7, 2021. The ACRS plans to hold an in-person (hybrid) Full Committee meeting in December. All Subcommittee meetings through the end of the 2021 calendar year will be virtual.

Member Ballinger led a discussion about the review of DG-1377 (RG 1.21, Revision 3), “Measuring, Evaluating, and Reporting Radioactive Material in Liquid and Gaseous Effluent and Solid Waste.” The Subcommittee recommended not to write a letter on this guide. The Committee agreed to not write a letter on this issue.

Member Ballinger also led a discussion of the status of the SHINE construction permit amendment and operating license application. The NRC staff is still working with the applicant on this issue and there are no interactions with the ACRS planned at this time.

3. Scheduled Topics for the 689th ACRS Meeting

The following topics are on the agenda for the 688th ACRS meeting scheduled for October 5-8, 2021:

- Framatome's Topical Report (TR) on GALILEO Implementation of LOCA methods
- Regulatory Guide Endorsing Non-LWR PRA Standard
- Discussions surrounding the Biennial Report on NRC's Research Program
- Commission meeting preparations

Sincerely,

Handwritten signature of Matthew W. Sunseri in black ink.

Signed by Sunseri, Matthew
on 10/26/21

Matthew W. Sunseri
Chairman

October 26, 2021

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