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

August 04, 2020

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

SUBJECT: SAFETY EVALUATION, REVISION 2 FOR TOPICAL REPORT, "URANIUM OXYCARBIDE (UCO) TRISTRUCTURAL ISOTROPIC (TRISO) COATED PARTICLE FUEL PERFORMANCE: TOPICAL REPORT EPRI-AR-1(NP)"

Dear Ms. Doane:

During the 675th meeting of the Advisory Committee on Reactor Safeguards, July 8-10, 2020, we reviewed the NRC Staff's Safety Evaluation Report (SER), Revision 2 for topical report, "Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO) Coated Particle Fuel Performance." Our Metallurgy and Reactor Fuels Subcommittee also reviewed this matter on May 6, 2020. During these meetings, we had the benefit of discussions with the Electric Power Research Institute (EPRI), Idaho National Laboratory (INL) and the staff. We also had the benefit of the referenced documents.

CONCLUSIONS AND RECOMMENDATIONS

1. The SER is focused and detailed. The SER identifies appropriate expectations, conditions, and limitations on future use of the topical report by reactor or fuel designers to establish performance of TRISO-coated particles.

2. The topical report provides a valuable starting point and data base for future coated particle fuel designs. However, incorporating coated particles that meet the specifications in the topical report into an overall fuel design should be done with caution to avoid introducing degradation phenomena not accounted for in the irradiation program.

3. The transition from coated particle to overall fuel system will likely require additional coated particle and fuel system irradiation programs to validate the overall design.

4. The SER should be issued.

BACKGROUND

The Department of Energy (DOE) initiated the Advanced Gas Reactor (AGR) fuel development program in 2002 to establish U.S. capability to fabricate high-quality UCO TRISO fuel[1] and demonstrate its performance. TRISO-coated particle fuel is used as part of the overall fuel design for gas-cooled reactor designs as well as fluoride-salt-cooled and potentially other reactor designs. The AGR program initially focused on developing manufacturing processes that yield consistent performance, verified by irradiation and safety testing. Results from the first two coated particle irradiation tests in the AGR program, designated AGR-1 and AGR-2, were designed to demonstrate UCO coated particle performance during irradiation and in post-irradiation high-temperature accident safety tests and are the subject of this topical report. The topical report provides the technical bases for the functional performance of UCO-based TRISO-coated particles. It is intended that the data in the topical report provide a design data base so that these particles can be manufactured with consistent properties that can then be used as the basis for fuel designs in a variety of high-temperature reactor designs.

The topical report identified the following conclusions:

1. Testing of UCO TRISO-coated fuel particles in AGR-1 and AGR-2 constitutes a performance demonstration of these particle designs over a range of normal operating and off-normal accident conditions.

2. The UCO TRISO-coated fuel particles tested in AGR-1 and AGR-2 exhibited property variations and were fabricated under different conditions and different scales, with very similar irradiation and accident safety performance results.

3. The AGR-1 and AGR-2 fission product release data and fuel failure fractions, as summarized in the topical report, can be used to support licensing of reactors employing UCO TRISO-coated particle fuel that satisfy the parameter envelope defined by measured particle layer properties in Table 5-5 from AGR-1 and AGR-2.

The staff review had the following findings:

- The EPRI topical report represents a modified approach for qualifying a novel fuel design. Rather than deterministic limit values, fuel performance is characterized statistically across a population of particles based on test conditions.

- The topical report makes justification and draws conclusions for TRISO-coated particles only, not compacts or other final fuel forms.

- The Quality Assurance Program associated with the data gathered by INL and referenced in the topical report was established as a part of earlier “technology development" activities of the Next Generation Nuclear Plant program and was reviewed by the NRC at that time.

[1] TRISO stands for TRi-structural ISOtropic particle fuel. Each TRISO particle consists of a uranium, carbon and oxygen fuel kernel. The kernel is encapsulated by three layers of carbon- and ceramic-based materials designed to prevent the release of radioactive fission products.

- NRC staff agrees that largely independent of manufacturing process, it is possible to establish a set of measurable criteria to be used to justify predicted performance.

- This predicted performance is based on demonstrated results from testing, and the test conditions represent an envelope bounding performance based on the topical report.

- This topical report may not cover all accident scenarios, i.e., if particles reach conditions that indicate failures may occur, an applicant or licensee referencing this topical report would need to justify how accident conditions were bounded by the data or provide analyses/testing to justify fuel performance in the specific scenario.

DISCUSSION

Certain advanced reactor designs rely on the inherent high temperature and fission product retention performance characteristics of TRISO-coated particle fuel to assure that in all design-basis events radionuclides are retained at their source in the fuel, and regulatory requirements for offsite dose are met at the exclusion area boundary (EAB) and low population zone (LPZ) boundary as per Title 10 of the *Code of Federal Regulations* (10 CFR), Section 50.34(a)(1)(ii)(D). Aspects of this regulatory approach are described in Regulatory Guide 1.232, Revision 0, "Guidance for Developing Principal Design Criteria for Non-Light-Water Reactors," which provides guidance on how the general design criteria (GDC) in Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," may be adapted for non-light-water reactor designs. The regulatory guide works toward establishing design criteria for advanced reactors and containment capability that meet the same functions in the GDC.

The topical report documents the results of the AGR-1 and AGR-2 tests to characterize UCO TRISO-coated particle fuel performance with a specific range of parameters as specified in Table 5-5. The intentions were (1) to demonstrate that the performance meets the objectives for maintaining fuel particle integrity and, therefore, retaining fission products under high temperature and stress during both irradiation and high temperature safety testing conditions; and (2) to establish the ranges of coated particle design and fabrication characteristics that will emulate the performance levels achieved in these experimental programs. Accordingly, the project intent was to establish ranges of TRISO-coated particle design and fabrication parameters that would be capable of achieving acceptable failure rates and levels of fission product retention that satisfy reactor and containment safety performance measures based upon the fuel performance demonstrated within the testing programs.

Given the successful performance of the representative sample of TRISO-coated particles in the AGR-1 and AGR-2 testing matrix, the topical report identified the ranges for particle parameters, which if satisfied, would result in performance and fission product retention behavior similar to the spectrum of results achieved in the AGR test program. Although the topical report references and discusses a wider range of fuel matrix designs and reactor environments that have been operated in other experimental or commercial programs, the data, reactor parameters, and analyses focus on the TRISO-coated particle in the AGR test environment (not on the fuel form or reactor type). The topical report is intended to be used as a qualification document that is limited to the coated fuel particles.

The staff has performed a thorough review of the topical report. Data gathering and assessment within this review included a site audit at the INL, development of Requests for Additional Information, and public meetings.

Based on the above findings the staff identified two limitations and three conditions for approval of the topical report. We agree that the limitations and conditions are appropriate.

However, we note that Table 5-5 captures the physical specifications of the particle layers that conform to the data discussed in the topical report. Some parameters such as the carbon/oxygen ratio (which is dependent on burnup) are not captured within the table and were deemed important to ensure adequate particle fuel performance within the bounds set forth by the topical report.

During our meetings, we explored the stated peak values and uncertainties for temperature measurements during the AGR-1 and AGR-2 irradiations. Temperature measurement capability is extremely important because temperature data, in conjunction with predictions from an analytical model that is tuned based on initially measured data, are used to control the conditions within each test capsule. Drifting thermocouples may provide erroneous information, thereby increasing temperature uncertainty. Although the thermocouples were placed at locations predicted to have lower temperatures, other factors may also contribute uncertainty in estimates for peak calculated temperatures. Uncertainties in the temperatures are provided in the topical report. One of the capsules was irradiated at very high temperatures with little evidence of significant degradation in particle performance. These results suggest that significant margin exists with respect to degradation during accident conditions.

We agree with the staff's overall findings that the conclusions of the topical report are applicable and acceptable subject to the limitations and conditions imposed by the staff as well as to those prescribed in the topical report itself. However, we stress that the topical report represents only a starting point for a fuel design. Fuel particles fabricated to the specifications in the topical report must then be incorporated into an overall fuel system design. Care must be taken that the fuel fabrication process itself does not introduce phenomena such as particle layer cracking beyond that covered in the specifications or other "unknown unknowns" that result in behavior outside of the Table 5-5 parameters.

SUMMARY

The SER is focused and detailed. The SER identifies appropriate expectations, conditions, and limitations on future use of the topical report by reactor or fuel designers to establish performance of TRISO-coated particles.

The topical report provides a valuable starting point and data base for future coated particle fuel designs. However, incorporating coated particles that meet the specifications in the topical report into an overall fuel design should be done with caution to avoid introducing degradation phenomena not accounted for in the irradiation program.

The transition from coated particle to overall fuel system will likely require additional coated particle and fuel system irradiation programs to validate the overall design.

The SER should be issued.

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

Members Rempe and Petti did not participate in the Committee's deliberations regarding this matter.

Sincerely,

Matthew W. Sunseri Digitally signed by Matthew W. Sunseri
Date: 2020.08.04 14:10:07 -04'00'

Matthew W. Sunseri
Chairman

REFERENCES

1. U.S. Nuclear Regulatory Commission, "Electric Power Research Institute – Draft Safety Evaluation, Revision 2 For Topical Report, 'Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO) Coated Particle Fuel Performance: Topical Report EPRI-AR-1(NP)'," June 11, 2020 (ADAMS Accession No. ML20142A365).

2. U.S. Nuclear Regulatory Commission, "Electric Power Research Institute – Draft Safety Evaluation, Revision 1 For Topical Report, 'Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO) Coated Particle Fuel Performance: Topical Report EPRI-AR-1(NP)'," April 29, 2020 (ADAMS Accession No. ML20097D849).

3. Electric Power Research Institute, Transmittal of "Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO) Coated Particle Fuel Performance: Topical Report EPRI-AR-1(NP)," May 31, 2019 (ADAMS Accession No. ML19155A173).

4. U.S. Nuclear Regulatory Commission, Audit Report for the Regulatory Audit of EPRI Topical Report, Uranium Oxycarbide (UCO) Tristructural Isotropic (TRISO) Coated Particle Fuel Performance, November 19, 2019 (ADAMS Accession No. ML19310F085).

5. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.232, Revision 0, "Guidance for Developing Principal Design Criteria for Non-Light-Water Reactors," April 2018 (ADAMS Accession No. ML17325A611).

6. NUREG/CR-6844, "TRISO-Coated Particle Fuel Phenomenon Identification and Ranking Tables (PIRTs) for Fission Product Transport Due to Manufacturing, Operations, and Accidents," July 2004 (ADAMS Accession No. ML042300649).

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