INL/CON-24-81334-Revision-1

Fracture Behavior Considerations for the TRISO Particle Matrix

December 2024

Changing the World's Energy Future

Tanner Jason Mauseth, Fei Teng, Lu Cai, John D Stempien

INL/CON-24-81334-Revision-1

Fracture Behavior Considerations for the TRISO Particle Matrix

Tanner Jason Mauseth, Fei Teng, Lu Cai, John D Stempien

December 2024

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract n/a

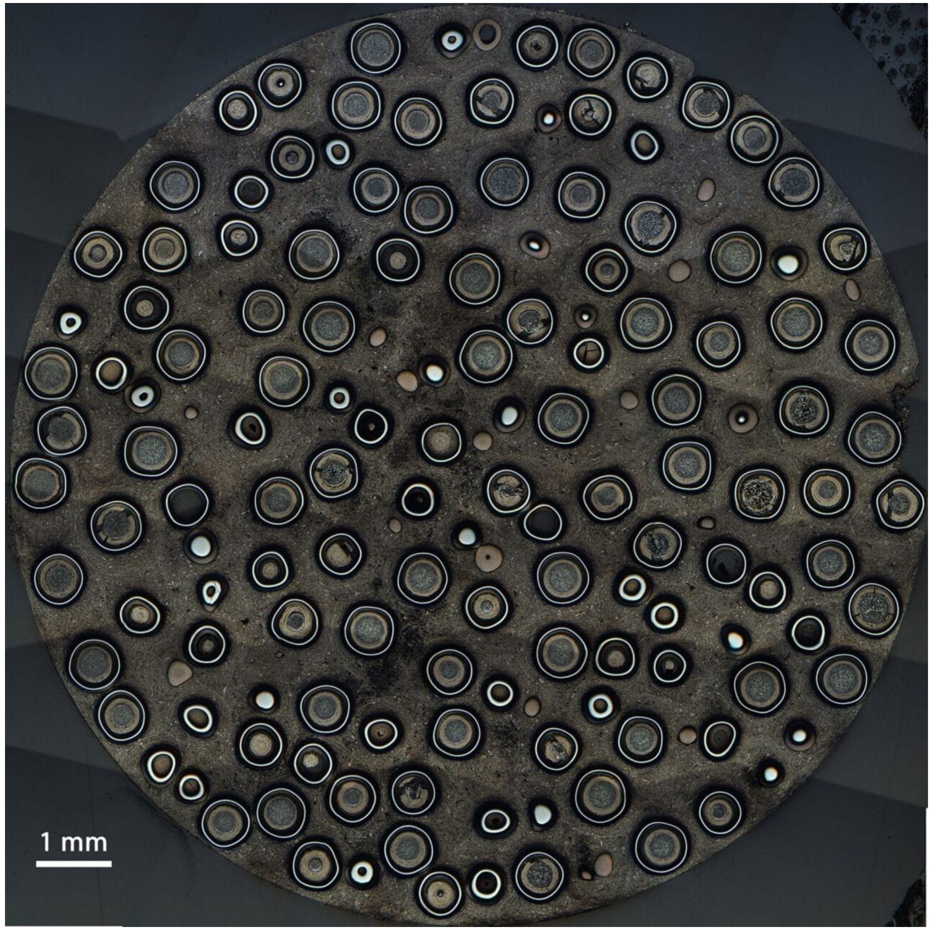
2024 Workshop on Storage and Transportation of TRISO and Metal Spent Nuclear Fuels, December 3-5

Tanner Mauseth
Post-Irradiation Examination (PIE) Research Scientist

Fracture Behavior Considerations for the TRISO Particle Matrix

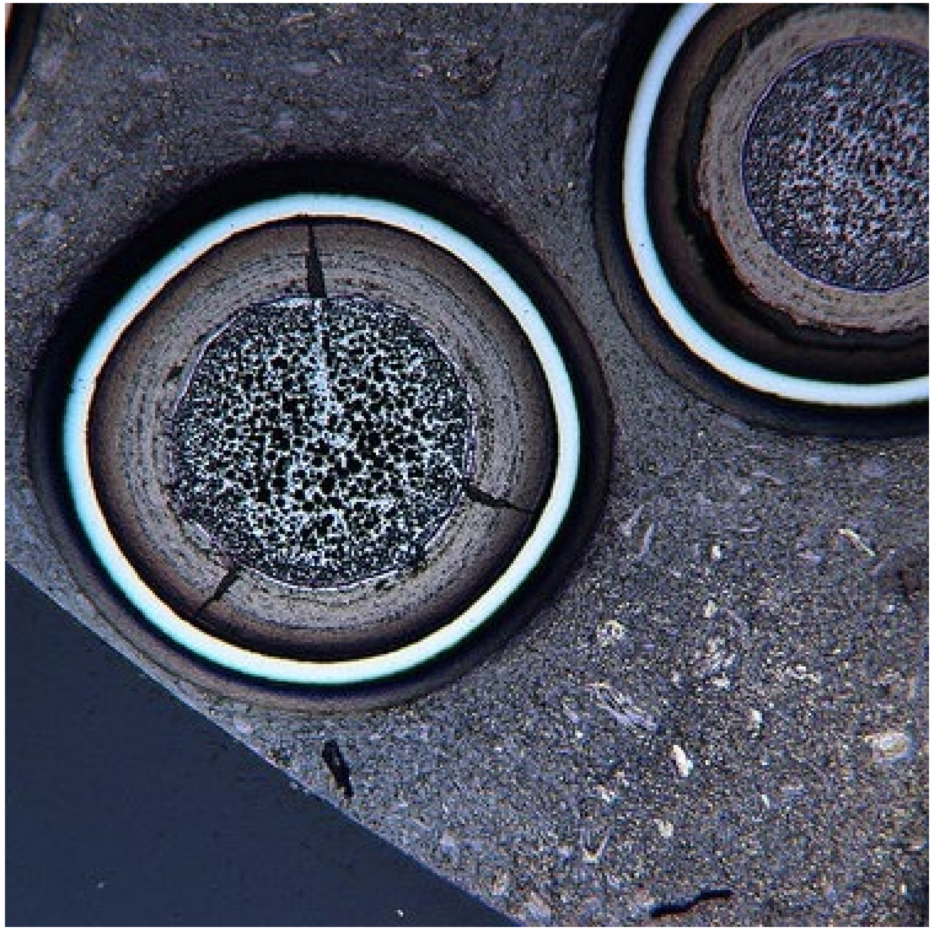
Introduction to Matrix Fracture Concerns

- **Matrix Role in TRISO Particles:**
  - The graphite or carbon composite matrix provides mechanical support and stability to TRISO particles, preventing interaction and damage, and maintaining the integrity of the fuel assembly under high temperatures and mechanical stresses.
  - The matrix acts as an additional barrier, capturing escaped fission products and reducing the risk of their release, ensuring the safe operation of the reactor and minimizing radioactive contamination.
- **Fracture Behavior:**
  - Matrix fracture refers to the cracking or breaking of the graphite or carbon composite matrix embedding TRISO particles, compromising mechanical integrity due to thermal stresses, irradiation-induced damage, or mechanical impacts.
  - Matrix fractures can lead to radiological releases, loss of containment, and compromised fuel integrity due to the release and migration of fission products and the physical displacement of TRISO particles.
- **Gaps in Understanding:**
  - While the matrix provides structural support and withstands mechanical stresses and irradiation, further research is needed to understand the long-term effects of these conditions and the detailed mechanisms leading to matrix fracture.
  - The matrix captures escaped fission products and aids in heat distribution, but additional studies are required to explore its interactions with fission products and the potential for alternative materials to enhance its performance and durability.



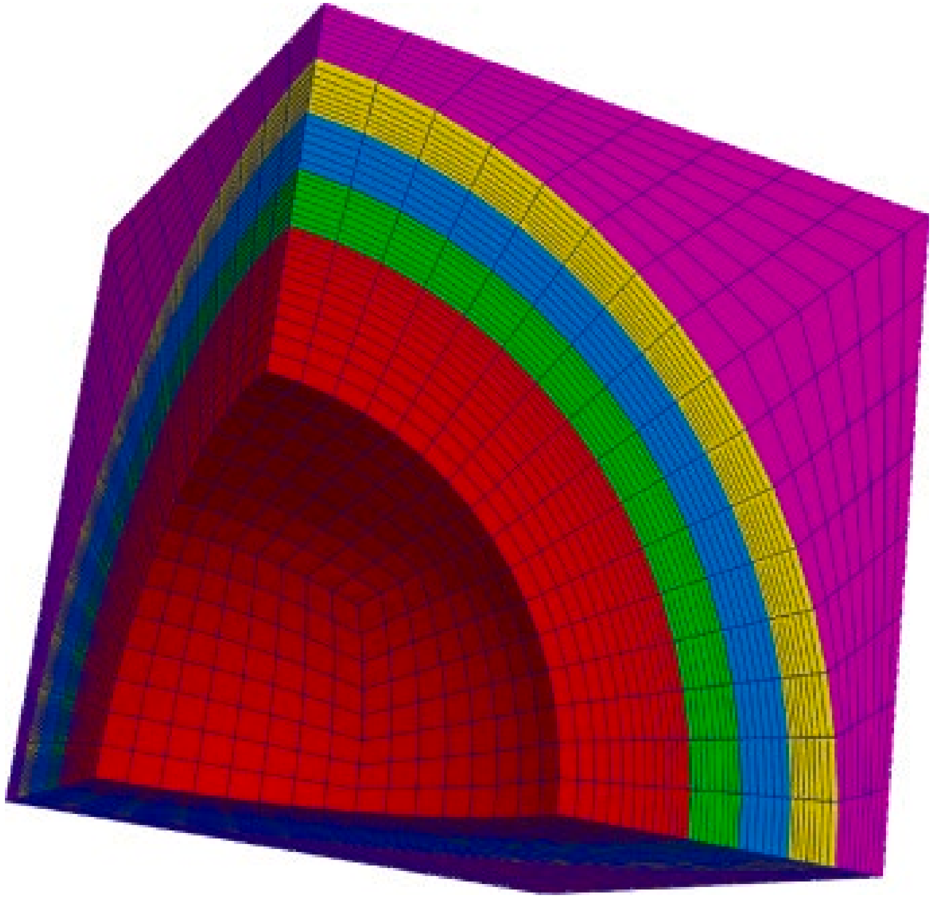
Key Considerations for Matrix Fracture Assessment

- **Micro-Tensile Strength:**
  - Evaluating the micro-tensile strength of the matrix is crucial for predicting fracture behavior and mechanical integrity, ensuring continued support and containment for TRISO particles under reactor conditions.
  - The micrometer-scale tensile strength characterization techniques developed by Mauseth (2023) for TRISO particle layers and interfaces can be applied to the TRISO particle matrix.
- **Fracture Toughness:**
  - Fracture toughness is essential for the TRISO particle matrix's ability to resist cracking under operational stresses, maintaining structural integrity and ensuring the stability and containment of TRISO particles.
  - Material composition, irradiation effects, thermal stresses, and mechanical stresses significantly impact the fracture toughness of the TRISO particle matrix, affecting its ability to resist crack propagation and remain durable under reactor conditions.
- **Irradiation Effects:**
  - Neutron irradiation significantly affects the mechanical properties of the TRISO particle matrix, causing defects, swelling, embrittlement, and changes in thermal conductivity and strength, which can compromise structural integrity.
  - Further research is needed to understand and mitigate irradiation impacts on matrix materials, focusing on long-term effects, microstructural changes, radiation-induced creep, material optimization, and interactions with fission products.



Current Data and Modeling Capabilities

- **Existing Data:**
  - The properties of graphite and carbonaceous matrix materials embedding TRISO particles, including density, porosity, thermal conductivity, and tensile strength (20-40 MPa), are well-documented. These materials exhibit increased brittleness and reduced tensile strength under stress due to irradiation effects.
  - Further research is needed to understand long-term irradiation effects, microstructural changes, radiation-induced creep, material optimization, and interactions with fission products in TRISO matrices, including mechanisms of degradation and defect evolution.
- **Modeling Fractures:**
  - Modeling fractures under both normal and off-normal conditions is crucial for ensuring the safety, reliability, and containment integrity of TRISO fuel, aiding in predictive maintenance and accident assessment.
  - Challenges in modeling fractures in TRISO matrices include incomplete long-term data on cumulative damage, limited understanding of irradiation-induced microstructural changes, scarce studies on radiation-induced creep, variability in advanced materials, and insufficient data on interactions with fission products, all adding uncertainties to predictive models.
- **Validation Needs:**
  - Comprehensive and validated data are essential for accurate predictive models to ensure TRISO fuel's safety, reliability, and performance, meet regulatory standards, mitigate risks, and support material optimization and innovation.
  - Data validation for TRISO matrices requires long-term irradiation experiments, microstructural analysis, benchmarking, inter-laboratory studies, advanced simulations, standardized protocols, data sharing, and mechanical and thermal testing.



Discussion Points and Questions

- Research Needs:
  - What additional research is needed to better understand matrix fracture behavior?

- Data Sufficiency:
  - Is current data sufficient to model matrix fracture under various conditions?

- Design Optimization:
  - How can design features be optimized to mitigate matrix fracture?

- Collaboration:
  - How can industry and regulators collaborate to ensure safety and compliance?