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Changing the World's Energy Future

TRISO Fuel Performance Modeling with PARFUME

July 2022

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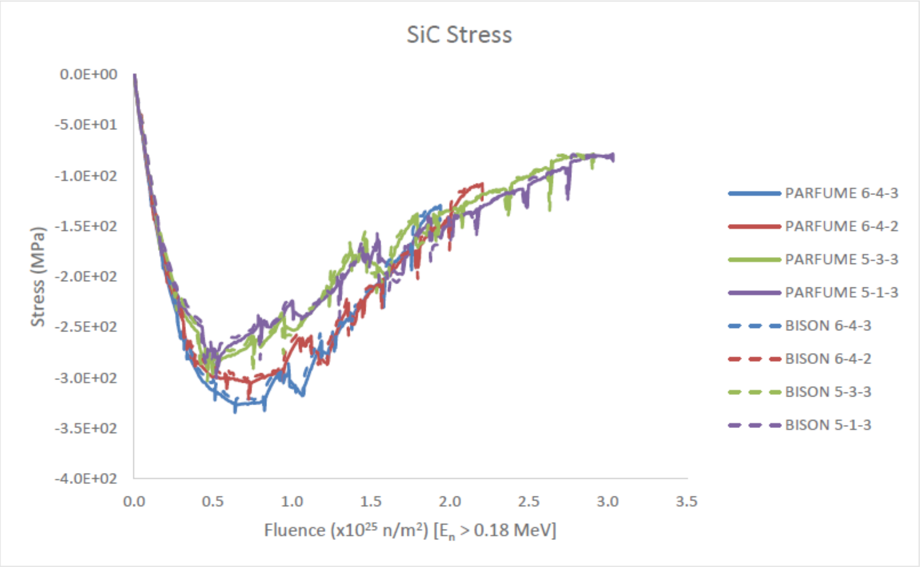
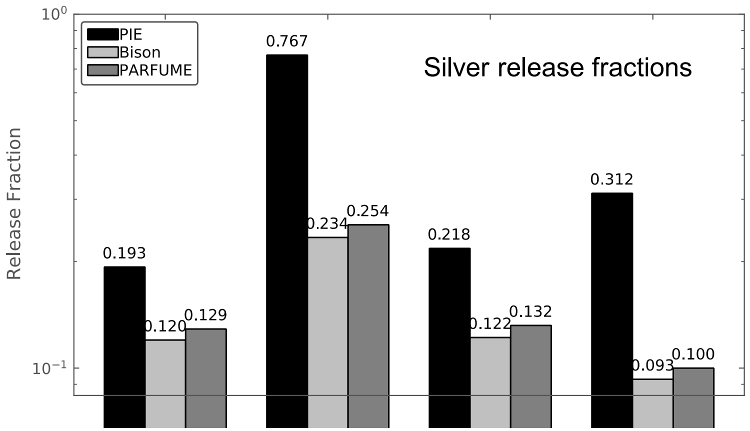
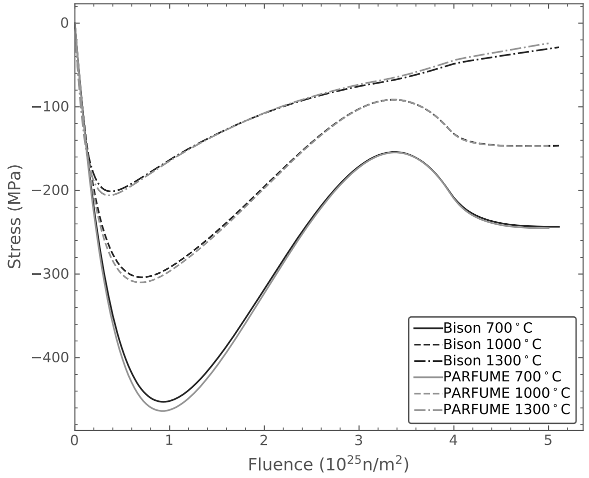
ART Advanced Reactor Technologies
GAS-COOLED REACTORS

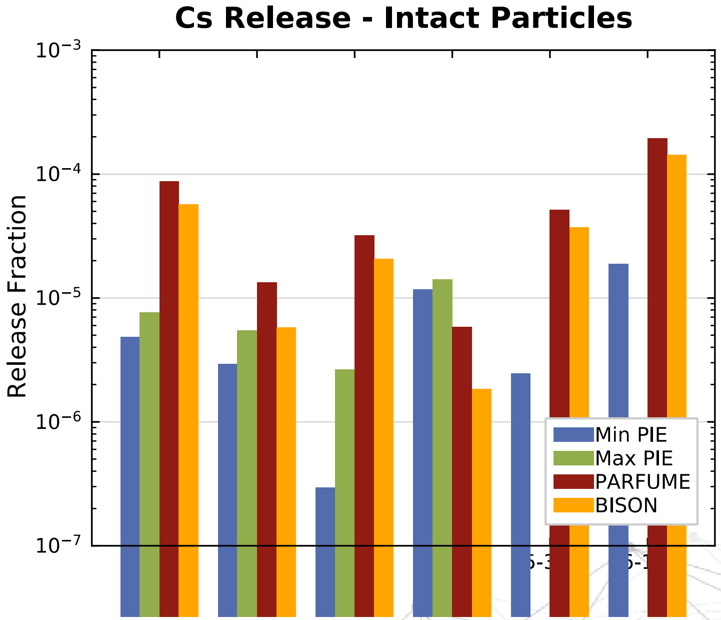
Outline

- Introduction
- Overview of TRISO Fuel Performance Modeling
- TRISO fuel performance code PARFUME
- PARFUME application to support the AGR program
- Current Status and Future Work

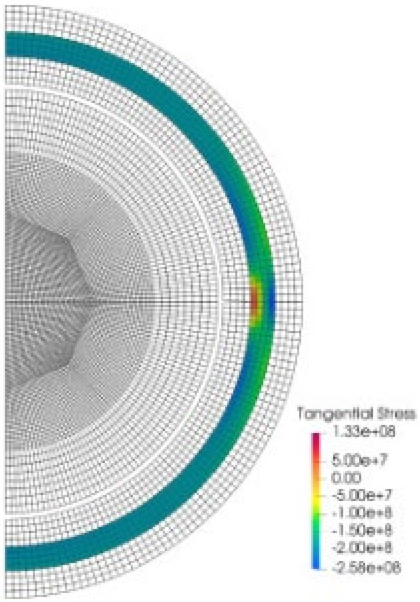




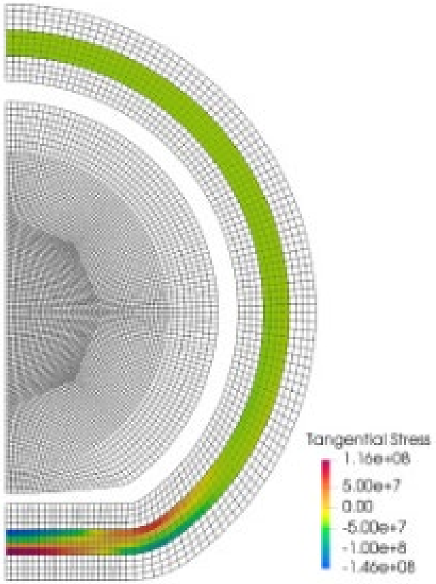




Introduction

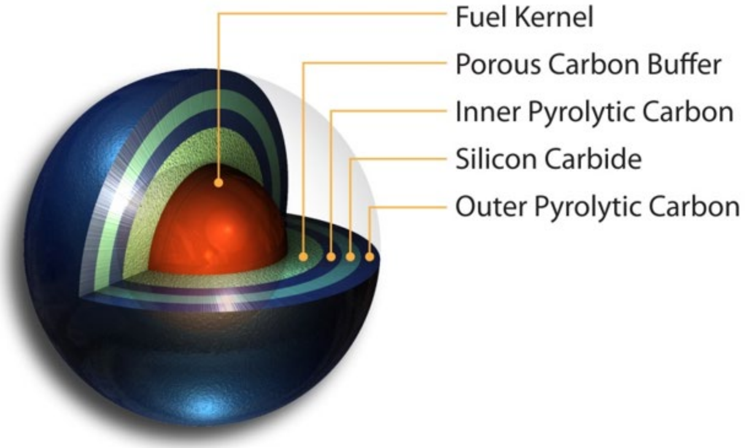


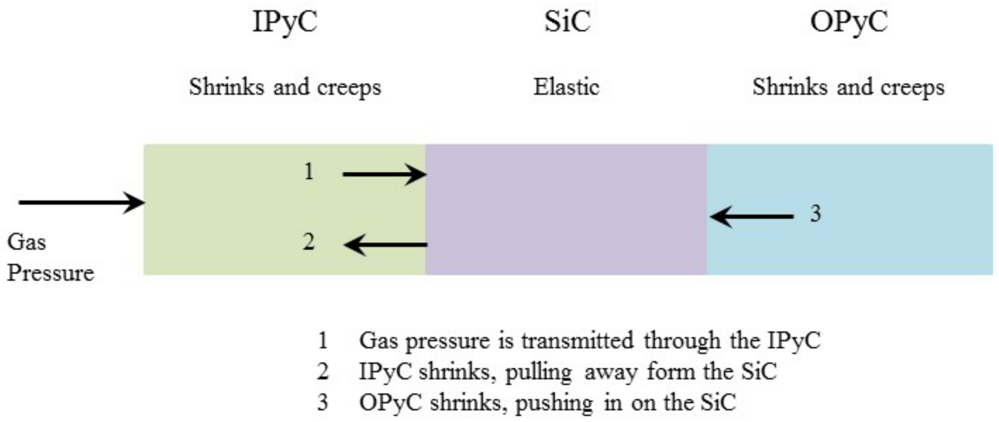
- Why fuel performance modeling?
  - Addresses:
    - Fuel particle failure
      - Structural
      - Thermal
      - Chemical
    - Fission product transport
      - fuel-compact matrix
      - fuel-element graphite
  - Assists in the:
    - Fuel design
    - Fabrication
    - Optimization
    - Experiment design
    - Fuel behavior
- Objective
  - Enhance the understanding of fuel behavior and fission product transport
  - Improve the fuel performance and fission product models
  - Develop advanced models using new methods
  - Provide validated tools to industry



TRISO Fuel Performance Modeling

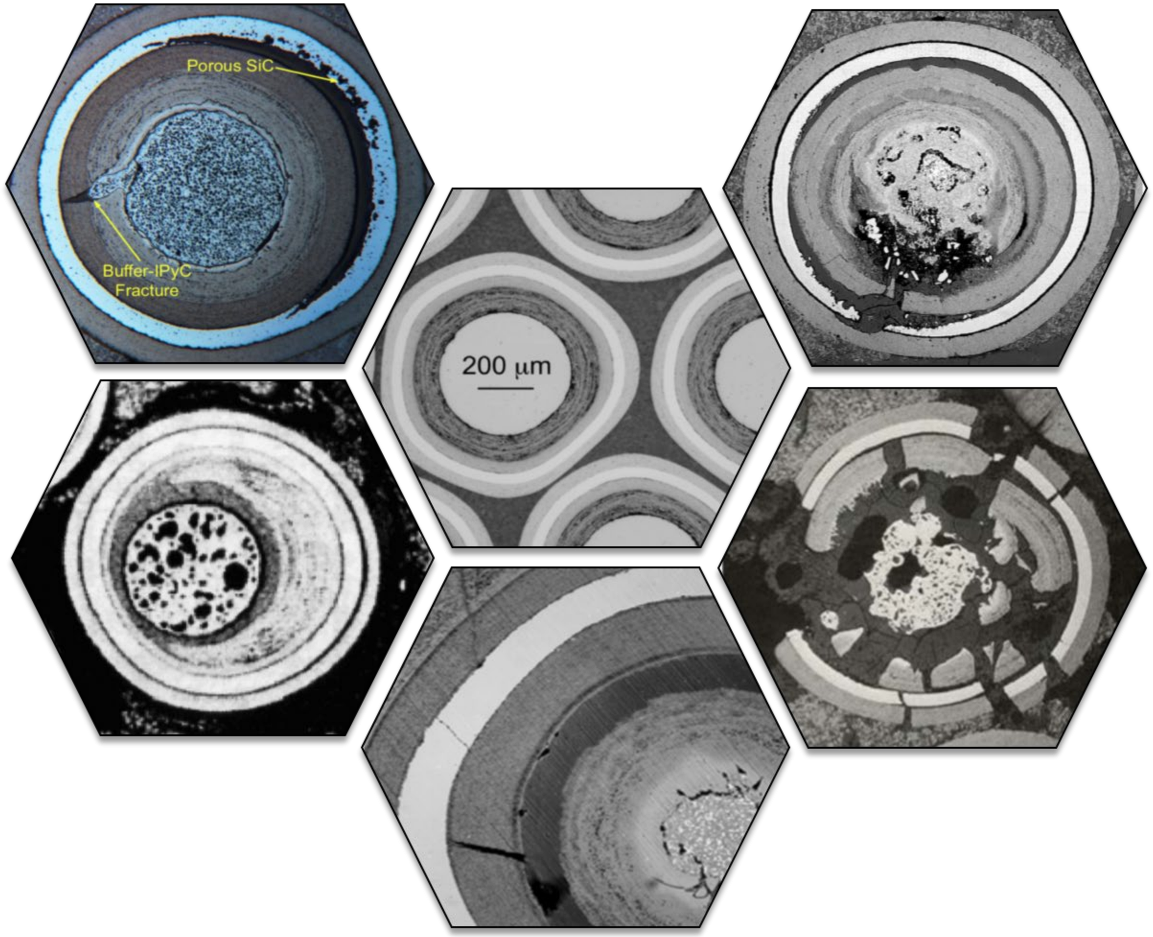
- Basic fuel particle behavior
  - Several physical phenomena influence the behavior of the particles including fission gas production and irradiation effects
- Applications of fuel performance modeling
  - Optimize particle design
  - Plan irradiation experiments
  - Identify tolerances of specifications
  - Estimate reactor fuel performance
- Existing TRISO fuel performance codes
  - PARFUME: Spherical symmetry to reduce the particle response to a 1D model and uses closed-form analytical solution for the stress-strain-displacement relationship.
  - Bison: uses finite element method to solve the basic thermo-mechanics and mass diffusion equations. This avoids the simplifications necessary for a closed form solution.





TRISO Failure Modes

- Mechanical
  - Pressure vessel failure
  - Cracking of the IPyC layer
  - Partial debonding of IPyC/SiC and Buffer/IPyC
  - Pressure vessel failure of an aspherical particle
- Thermochemical
  - Amoeba effect
  - Palladium attack of the SiC layer
  - Corrosion of SiC by CO
  - SiC thermal decomposition



PARFUME – PARticle Fuel ModEl

- Fuel Performance Code PARFUME
  - An integrated mechanistic code that evaluates the thermal, mechanical, and physico-chemical behavior of TRISO fuel particles
  - Capable of evaluating fuel particle failure under both irradiation and accident conditions
  - Tracks the probability of fuel particle failure given the particle-to-particle statistical variations in physical dimensions and material properties.

Early particle fuel performance codes were 1-D and considered only pressure vessel failure

- Various irradiation experiments had greater levels of failure than could be predicted by pressure vessel failure alone
- PIE results from NP-MHTGR and other experiments have revealed that other multi-dimensional effects may have contributed to the observed fuel failures
- To investigate these failure mechanisms, INL started development of an integrated mechanistic fuel performance modeling code called PARFUME

By 2000, the main components of PARFUME consisted of

- Closed form stress solution for a three-layer particle
- Monte Carlo sampling of particle attributes
- Failure probabilities calculated with Weibull distributions in coating layer strengths

By 2005, major code enhancements were in place which included

- Particle sampling performed by a multiple integration technique allowing for very small failure probabilities to be calculated
- Kernel migration and Pd penetration failure mechanisms considered
- Consistent set of material properties

By 2007, safety test conditions could be modeled within PARFUME where

- Particle layer failures are synchronized with fission product diffusion
- Correlations from TMAP (Tritium Migration Analysis Program) are used to calculate fission product diffusion

Fuel Performance Modeling to Support the AGR Experiments

AGR-1

- Pre-irradiation prediction (**EDF-5741**)
- Fission product release comparison to in-pile PIE (**INL/EXT-14-31975**)
- Fission product release comparison to safety test PIE (**INL/EXT-14-31976**)

AGR-2

- Pre-irradiation prediction (**ECAR-1020**)
- Safety test predictions (**INL/EXT-14-33082**)
- Fission product release comparison to in-pile and safety test PIE (**INL/EXT-20-59448**)
- Comparison between PARFUME and Bison (**INL/EXT-20-59890**)

AGR-3/4

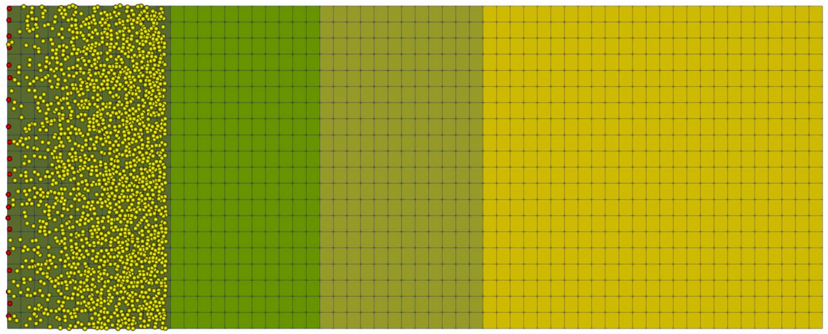
- Pre-irradiation prediction (**INL/EXT-16-38280**)
- Irradiation as-run predictions (**INL/EXT-21-65160 Bison**)
- Fission product release comparison to in-pile and safety test PIE (**FY-22 Bison**)

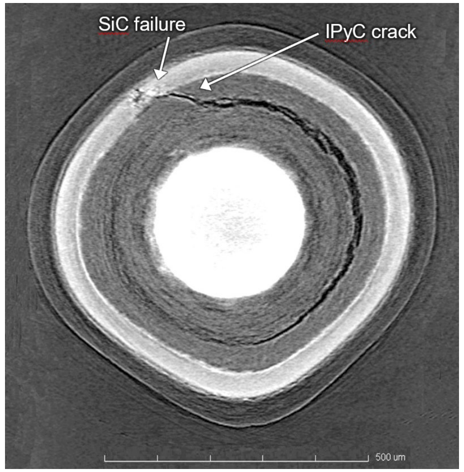
AGR-5/6/7

- Pre-irradiation prediction (**INL/EXT-17-43189**)
- Fuel performance basis for fuel specification (**ECAR-2341**)
- Irradiation as-run predictions (**INL/EXT-21-64576**)
- Safety test predictions (**FY-23 PARFUME/Bison**)
- Fission product release comparison to in-pile and safety test PIE (**FY-26 PARFUME/Bison**)

Fuel Performance Modeling to Support the AGR Program

- Additional activities
  - IAEA normal and accident benchmarks (**ECAR-728**)
  - Assessment of material properties for TRISO fuel particles (**INL/EXT-18-44631**)
  - Kernel/buffer volume fraction margin (**FY-23)**
- Modeling improvements
  - Fission product transport model (**FY-23 Bison**)
  - Thermomechanical buffer layer modeling (**TBD Bison**)
  - Pyrocarbon creep rate (**TBD PARFUME/Bison**)

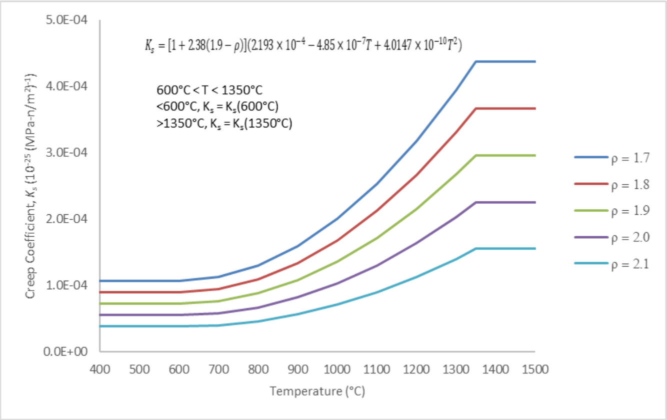




AGR-5/6/7 predicted fuel particle failure using PARFUME.

Capsule	5	4
Average compact temperature (°C)	741	839
Average compact predicted failure fraction	2.60E-04	1.14E-04
Total number of TRISO particles	81432	52728
Predicted number of TRISO particle failures	21	6
Observed number of TRISO particle failures[1]	0	0

1. Per AGR-5/67 irradiation as-run report based on the data currently available.



Questions?