HTGR/VHTR Technology Maturation: A DOE Success Story

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Dave’s view of advanced reactors

• In terms of what limits each reactor system:
  – LWRs are thermal hydraulic machines
  – SFRs are physics machines
  – HTGRs are materials machines
  – MSRs are chemistry machines
Objectives of VHTR/NGNP R&D

• Key needs: Fuels, Graphite, High Temperature Materials Qualification

• Structure: Focus on needs of the technology
  – Established TDO for focus and integration with the project/vendors
  – NQA-1 (Quality Engineer embedded into R&D)
  – Stayed away from politics

• Fuel program is 15 years old; graphite is ~10 years old and high temperature materials work was mostly completed about 3 years ago – original objectives remain valid today!

• Such longevity in a DOE program is rare.

Success breeds success!
TRISO Fuel Program Objectives (program started in 2003)

• Make fuel as good as the Germans
  – Had never been done in the US

• Demonstrate UCO fuel performance under normal operation (1250°C; 19% FIMA)
  – Bold performance envelope; many concerned about high temperature and high burnup

• Demonstrate UCO fuel performance under accident conditions (1600-1800°C in high temperature furnaces)
  – Never had fuel good enough in the past to do this type of testing

• Provide data to improve and validate models on fuel performance and fission product transport

Sounds easy but it was a lot of hard work by the team (INL, ORNL, BWXT and GA)!
Irradiation: AGR-1 had no particle failures and AGR-2 had 0-1 failure (hard to tell). Statistically inferred failure rates 10 to 20x better than designer requirements

Safety testing: Outstanding performance of UCO TRISO at high temperatures. Results a factor of 5 to 8x better than designer requirements

Tremendous amount of detailed PIE: meticulous work on fission product mass balance to show that the fuel retains key fission products
Overview of Approach for Particle Fuel Performance Modeling in PARFUME

Past Failure Mechanisms Observed in PIE

Reactor Service Conditions:
- Neutron Flux
- Power Density
- Fast Neutron Fluence/Damage Temperature

Fuel Attributes

Dimensionality, failure modes to be considered, key material properties

Pieces of the Model: the engine

Boundary Conditions and Geometry: the road

Constitutive Relations: the gasoline

Thermal Response → Structural Behavior Module → Failure Evaluation (Weibull) → Fission Product Release

Overview of Approach for Particle Fuel Performance Modeling in PARFUME

Transitioning models to BISON soon
Graphite Program

1500 °C
HTV

1200 °C
AGC - 5
AGC - 6

900 °C
AGC - 3
AGC - 4

600 °C
AGC - 2
AGC - 1

Database for previous nuclear graphite grades

Dose (dpa)
1 3 4.5 6

Replaced by HDG-1 and -2: high dose graphite irradiations

- Structural Graphite R&D
- Material Properties
- Irradiation Behavior
- Behavior Models

Graphite Behavior Modeling
Nuclear Graphite
Baseline Properties
Testing and Mechanisms
Irradiated Properties
Graphite Accomplishments

• Established analytical measurement laboratories at INL and ORNL to perform extensive material characterization of graphite. INL lab is being upgraded to handle irradiated graphite

• Characterized thousands of graphite samples for AGC irradiations

• Detailed characterization of graphite billets from different vendors is complete

• AGC-1 and 2 are complete. AGC-3 PIE is 90% complete

• AGC-4 irradiation is underway until next Fall. HDG-1 will follow and span CIC

• Lots of data to make strong statistical inferences about variations in material performance and properties lot-to-lot and within a billet
Dimensional Change Data and Creep  
→ Establishes graphite lifetime a key unknown for designers!
High Temperature Materials Accomplishments

• Completed initial material screening tests to determine acceptability of candidate alloys for large metallic components in VHTR
• Established test loop to measure impact of impurities on IHX alloys and extended models for predicting He impurity interaction with IHX alloys up to 1000°C
• Developed data to demonstrate that LWR pressure vessel steel (A503/533) can be used in VHTR environment
• Extended code case for Alloy 800H from 760°C to 850°C
• Developed data to codify Inconel 617 for use in VHTR up to 950°C. Draft code case submitted to ASME