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Revision 0

Fission Accelerated Steady-state Testing (FAST)

Changing the World's Energy Future

Geoffrey Beausoleil
Principal Investigator

Nate Oldham
Bryon Curnutt
Kyle Gagnon
Chris Murdock
Randy Fielding
Team Members and Collaborators

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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INTRODUCTION

In an effort to accelerate the irradiation time for advanced reactor fuels, a revised capsule design has been analyzed and developed for the Advanced Fuels Campaign (AFC). This design incorporates a highly enriched, reduced diameter fuel pin that is doubly encapsulated by two steel capsules. This design alloys accelerated irradiations and reduced sensitivity to fabrication variances and eccentricities. The capsule designs utilize existing experiment baskets from the AFC capsules in the Advanced Test Reactor (ATR) outer A position (FAST-OA) and the ATF-1 capsules in the small I position (FAST-SI).

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ACRONYMS

AFC	Advanced Fuels Campaign
AFQ	Accelerated Fuel Qualification
ATR	Advanced Test Reactor
DISECT	Disc Irradiation for Separate Effects Testing with Control of Temperature
DOE	Department of Energy
EM^2	Energy Multiplier Module
FAST	Fission Accelerated Steady-state Testing
FAST-OA	Fission Accelerated Steady-state Testing-outer A position
FAST-SI	Fission Accelerated Steady-state Testing-small I position
FCCI	fuel-cladding chemical interaction
FIMA	fissions per initial metal atom
GA	General Atomics
INL	Idaho National Laboratory
LDRD	Laboratory Directed Research and Development
NEAMS	Nuclear Energy Advanced Modeling and Simulation
NSUF	Nuclear Science User Facility
ORNL	Oak Ridge National Laboratory
PIRT	Phenomena Identification and Ranking Table
R&D	Research and Development
TREAT	Transient Reactor Test (facility)
UC	uranium carbide

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Fission Accelerated Steady-state Testing (FAST)

1. PROJECT DESCRIPTION

Previous advanced reactor fuels, namely fast reactor fuels, have been successfully irradiated within the Idaho National Laboratory (INL) Advanced Test Reactor (ATR). However, these tests have had challenges in that they require adjustments to the experiment design to make the power profiles more prototypic (introduction of a cadmium shroud), a tight-tolerance helium bond between the cladding and the capsule wall (a low heat flux zone for increasing the cladding temperature to prototypic temperatures), high sensitivity to fabrication variances and eccentricities (lower limit of fabrication tolerances significantly affect the outcome of the experiments), and, ultimately, very long irradiation times in order to achieve high burnup targets (10-12 years for >20 %FIMA). These challenges have been addressed by the Fission Accelerated Steady-state Testing (FAST) experiment design.

Phase 1 of the FAST experiments is focused on alloy fuels for sodium fast reactors that are assembled for insertion into the ATR during the 169A cycle (November 2020). In total, there are 28 experiments being inserted:

- Control specimens that compare to historical irradiation tests will be used to understand the impact of accelerated irradiation to fuel performance. These pins are uranium with 10 wt% Zr (U-10Zr), 75% smear density, and sodium-bonded solid pins in HT9 cladding.
- Fuel Additives that contain antimony, tin, or palladium in order to mitigate lanthanide fission product attack on the cladding (fuel-cladding chemical interaction [FCCI]). These are similar to the palladium bearing Advanced Fuels Campaign (AFC)-3A and AFC-3B tests but will be irradiated to higher burnups.
- Sodium-free annular fuel pins that are thermally bonded with helium. These are comparable to the helium-bonded annular fuel tests from AFC-3A and AFC-3B but will be irradiated to higher burnups.
- HT9 cladding with zirconium liners to prevent FCCI will be used with U-10Zr, sodium-bonded solid pins.

This project will provide INL an accelerated irradiation platform that can be easily adopted to multiple fuel forms and reactor designs. The benefits will enable the Laboratory and Department of Energy (DOE) to meet industry needs for quickly investigating advanced fuel concepts and to achieve the objectives of deploying safe, reliable, and economic operation of next generation reactors.

2. ACCOMPLISHMENTS

The FAST project has completed the final fabrication and assembly of the experiments listed above and is awaiting the 169A outage for inserting them into the reactor. The project overcame numerous challenges, especially those associated with work shutdown during the initial COVID-19 response. FAST is also being incorporated into multiple research projects beyond its initial scope in AFC.

- Mockup weld processes were not successful in actual execution of the pressurized outer capsules. This was determined to be due to excessive local heating and pressurization of the head space in the capsule. The assembly team managed to respond within a week with a new weld process that reduced the time and load of the weld spark and enabled adequate closure of the weep hole. The capsules were then able to pass final inspections.
- FAST experiments were built into BISON models to begin predictive fuel performance assessments of the experiments. These models are currently being evaluated and compared to match the design

analysis results (i.e., finite element thermal analysis) before turning on more extensive material models for the predictive analysis (e.g., fuel swelling, fission product distribution, or fission gas release).

- Bryon Curnutt presented the combinatorial design process of FAST at NuFuel 2019, an INL sponsored fuels conference held at the Paul Scherrer Institute in Switzerland. The presentation highlighted the methods used for designing the FAST experiments, including the scripting of experiment parameters for thermal analysis tools and neutronics analysis.
- The FAST team led a working group on accelerated qualification of advanced metal fuel for fast reactor concepts. This group included involvement from AFC and Nuclear Energy Advanced Modeling and Simulation (NEAMS) from multiple laboratories and universities. The meetings resulted in a Phenomena Identification and Ranking Table (PIRT) analysis of key fuel phenomena and properties (Figure 1). The PIRT was then used to outline a modernized approach to the qualification presented by Crawford et al [1] where stages 1-3 could be reduced from a 15-20 year process to 5-8 years (Figure 2). This PIRT and methodology for qualification is the subject of a paper submitted to *Nuclear Technology*.
- FAST is being utilized by a Laboratory Directed Research and Development (LDRD) project that is partnering with General Atomics (GA) and to irradiated uranium carbide (UC) fuel. GA is intending UC fuel compacts to be the used in their high temperature gas cooled fast reactor design (Figure 3), Energy Multiplier Module (EM^2). The LDRD is testing accelerated fuel irradiation of ceramic fuels as well as multiple fuel designs (Figure 4). UC fuel is also the subject of the Accelerated Fuel Qualification (AFQ) effort that GA has with Oak Ridge National Laboratory (ORNL) and a semi-integral irradiation test, such as with FAST, is a necessary component of qualification.

3. PUBLICATIONS

Beausoleil et al, Integrating Advanced Modeling and Accelerated Testing for a Modernized Fuel Qualification Paradigm, submitted to *Nuclear Technology*

4. REFERENCES

1. Crawford, D.C., et al., *An approach to fuel development and qualification.* Journal of Nuclear Materials, 2007. **371**(1): p. 232-242.

5. WHY THIS PROJECT IS IMPORTANT

FAST is positioning INL and the DOE complex to be able to meet the modern demands of technology research and development (R&D) for nuclear fuel by reducing irradiation times for fuel up to ten times faster.

6. PHOTOS, FIGURES, AND GRAPHICS

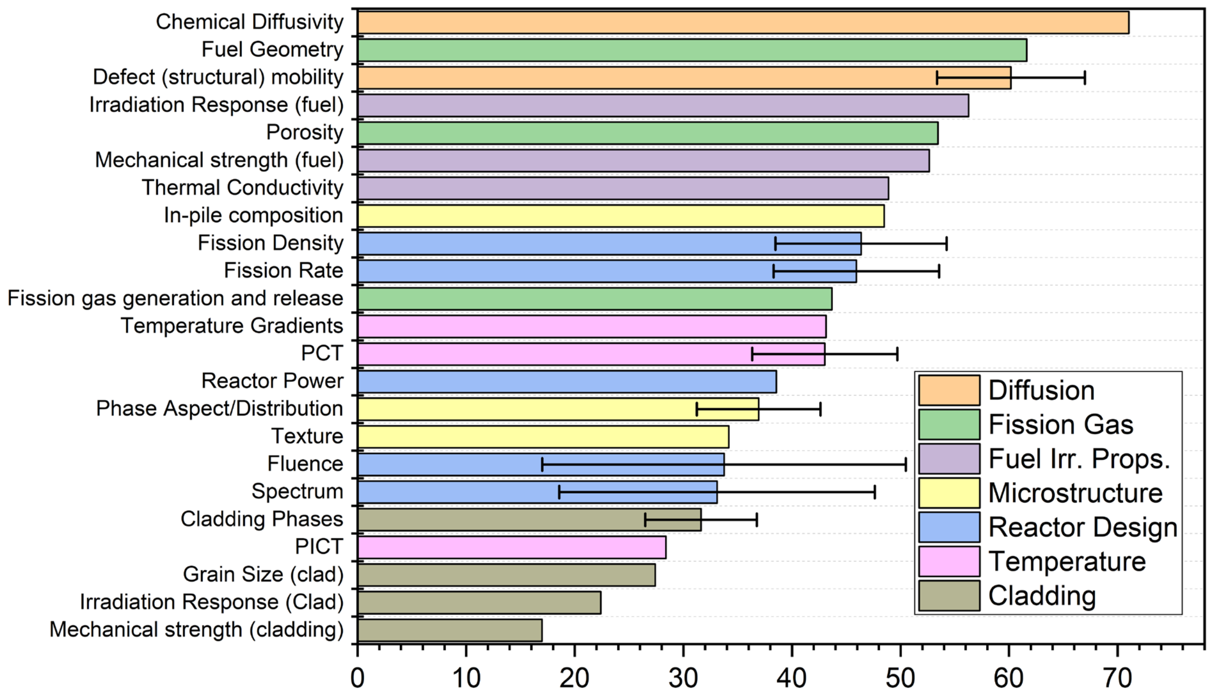

Figure 1. A listing of fuel behaviors and properties in order of research priority based upon the PIRT analysis done by the accelerated testing team in AFC. These priorities are being used to guide model development within BISON and post-irradiation examination of FAST test specimens. Future experiment designs will be guided by those results and these property relationships.

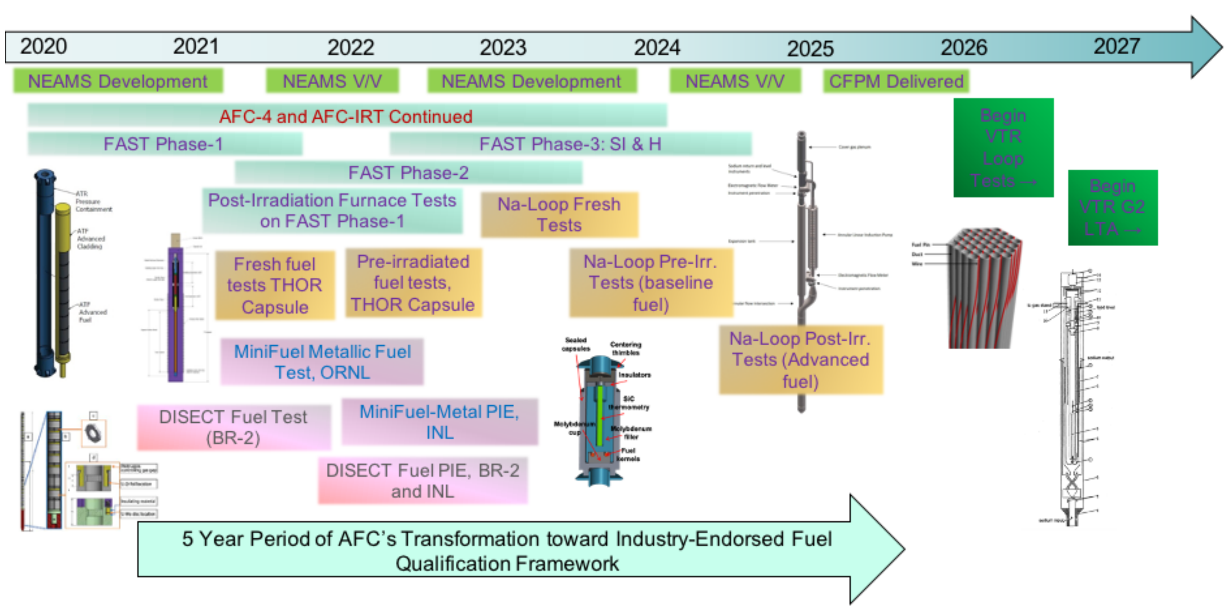

Figure 2. Integrated six-year plan for development of metal fuel for both commercial interests and the versatile test reactor driver fuel. This plan integrated both separate effects testing in the Oak Ridge MiniFuel and the Nuclear Science User Facility (NSUF) DISECT experiments along with the semi-integral testing of FAST and transient conditions in TREAT.

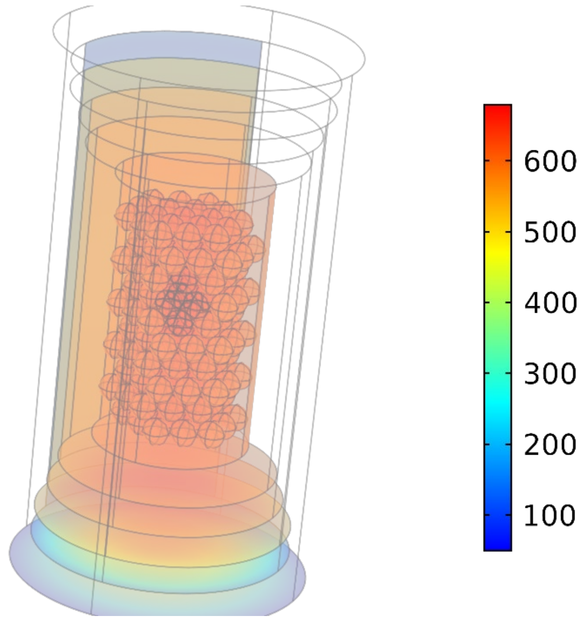

Figure 3. A thermal analysis model of uranium carbide kernel compacts to be used in a FAST experiment in support of General Atomics EM2 reactor concept. The analysis was used to determine how kernel size may affect the bulk behavior of the compact as it is scaled down for FAST dimensions.

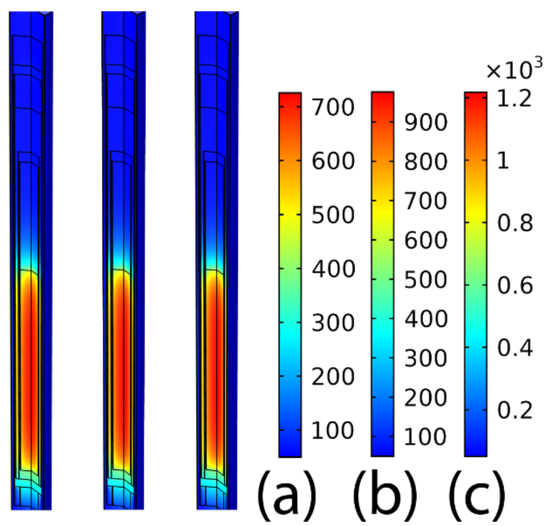

Figure 4. Three different thermal analyses of the uranium carbide FAST experiments used to determine the necessary enrichments and power generation rates needed to achieve the desired temperatures. The UC experiments will push FAST to much higher cladding and capsule temperatures than previously explored with the metal fuel, opening it up to support other very high temperature applications.