



U.S. DEPARTMENT OF  
**ENERGY**

**Nuclear Energy**

## **FC 2: Advanced Fuels**

**Frank Goldner**

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**DOE-NEUP FY2021 Webinar**

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# Advanced Fuels Campaign: Structure and Mission

## ■ Mission:

- 1) Support development of **near-term Accident Tolerant Fuel (LWR)** technologies
- 2) Perform research and development on **longer-term Advanced Reactor Fuel** technologies



### Accident Tolerant Fuels

LWR fuels with improved performance and enhanced accident tolerance

### Advanced Reactor Fuels

Advanced reactor fuels with enhanced resource utilization for once-through and recycle

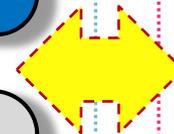
### Capability Development to Support Fuel Development and Qualification

Advanced characterization and PIE techniques  
Advanced in-pile instrumentation  
Separate effects testing for model development/validation  
*Steady-state and transient irradiation* testing infrastructure



### Fuels Product Line

Multi-scale, multi-physics, fuel performance modeling and simulation





### FY 2019 Nuclear Energy University Program R&D Awards

Title	Workscope	PI Last Name	Lead University	Total Budget
<b>Fuel Cycle Research and Development</b>				
Remote laser based nondestructive evaluation for post irradiation examination of ATF cladding	FC-2.1: Post Irradiation Examination (PIE)/Non-Destructive Examination (NDE) Techniques for Corrosion Thickness Measurements on ATF Claddings (Coated Zr, FeCrAl, SiC)	Yu	University of South Carolina	\$ 800,000
Radiation-Induced Swelling in Advanced Nuclear Fuel	FC-2.3: Investigations into Non-Traditional Solid Fuels for Advanced Non-Light Water Reactors	Lang	University of Tennessee at Knoxville	\$ 799,989
High throughput assessment of creep behavior of advanced nuclear reactor structural alloys by nano/microindentation	FC-2.4: Advanced Creep Testing of Ferritic Steels for Reactor Cladding Applications	Mara	University of Minnesota, Twin Cities	\$ 800,000
Novel miniature creep tester for virgin and neutron irradiated clad alloys with benchmarked multiscale modeling and simulations	FC-2.4: Advanced Creep Testing of Ferritic Steels for Reactor Cladding Applications	Murty	North Carolina State University	\$ 800,000
Thermal Conductivity Measurement of Irradiated Metallic Fuel Using TREAT	FC-2.5: Separate Effects Testing in TREAT using Standard Test Capsules	Ban	University of Pittsburgh	\$ 500,000
Neutron Radiation Effect on Diffusion between Zr (and Zircaloy) and Cr for Accurate Lifetime Prediction of ATF	FC-2.5: Separate Effects Testing in TREAT using Standard Test Capsules	Zhao	The Ohio State University	\$ 499,997



# FY 2020 NEUP Awards

## Nuclear Energy

Linear and nonlinear guided ultrasonic waves to characterize cladding of accident tolerant fuel (ATF)	CFA-20-19660	FC-2.1: NDE Techniques for Assessing Integrity of Coated Cladding Tubes	Laurence	Jacobs	Georgia Institute of Technology	\$800,000
Chemical Interaction and Compatibility of Uranium Nitride with Liquid Pb and Alumina-forming Austenitic Alloys	CFA-20-19627	FC-2.2: Investigations of Carbide and Nitride Fuel Systems for Advanced Fast Reactors	Jie	Lian	Rensselaer Polytechnic Institute	\$800,000
Femtosecond Laser Ablation Machining & Examination - Center for Active Materials Processing (FLAME-CAMP)	CFA-20-19545	FC-2.3: High-Throughput and/or Micro-Scale Post-Irradiation Examination Techniques to Support Accelerated Fuel Testing	Peter	Hosemann	University of California, Berkeley	\$800,000
Maintaining and building upon the Halden legacy of In-situ diagnostics	CFA-20-19374	FC-2.4: Maintaining and Building upon the Halden Legacy of In Situ Diagnostics	Michael	Corradini	University of Wisconsin-Madison	\$800,000
Investigation of Degradation Mechanisms of Cr-coated Zirconium Alloy Cladding in Reactivity Initiated Accidents (RIA)	CFA-20-19076	FC-2.5: NSUF Separate Effects Testing in TREAT using Standard Test Capsules	Hwasung	Yeom	University of Wisconsin-Madison	\$500,000

# FC 2.1 – Fuel-to-Coolant Thermomechanical Transport Behaviors Under Transient Conditions

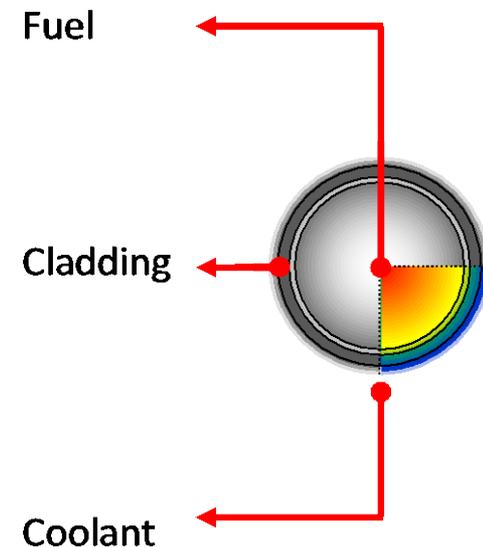
**Federal Manager: Frank Goldner**

**Technical POC: Colby Jensen, INL**

- **DOE is working with industry to perform R&D to enable licensing Accident Tolerant Fuels and extending burnup licensing limits beyond 62 GWd/MTU.**
- **Fuel performance during operational and accident transient conditions is an important R&D opportunity area to support fuel qualification and extend licensable limits.**
  - Inadequate characterization of transient Fuel-to-Coolant (F2C) transport behaviors (both qualitatively and analytically) often poses a challenge to predicting and/or explaining the associated material response.
  - Integral experiments for fuel performance during transients are being developed and performed at the Transient Reactor Test (TREAT) facility for testing irradiated fuels
- **Improved understanding and predictive capabilities for a variety key phenomena relevant to LWR transients will provide expand opportunities for achieving maximum performance and expanded fuel utilization.**

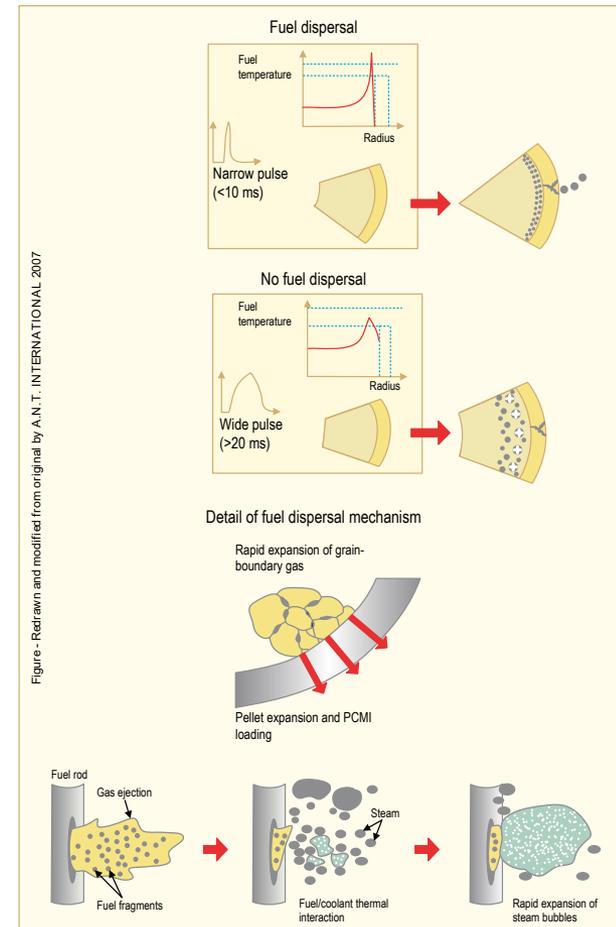
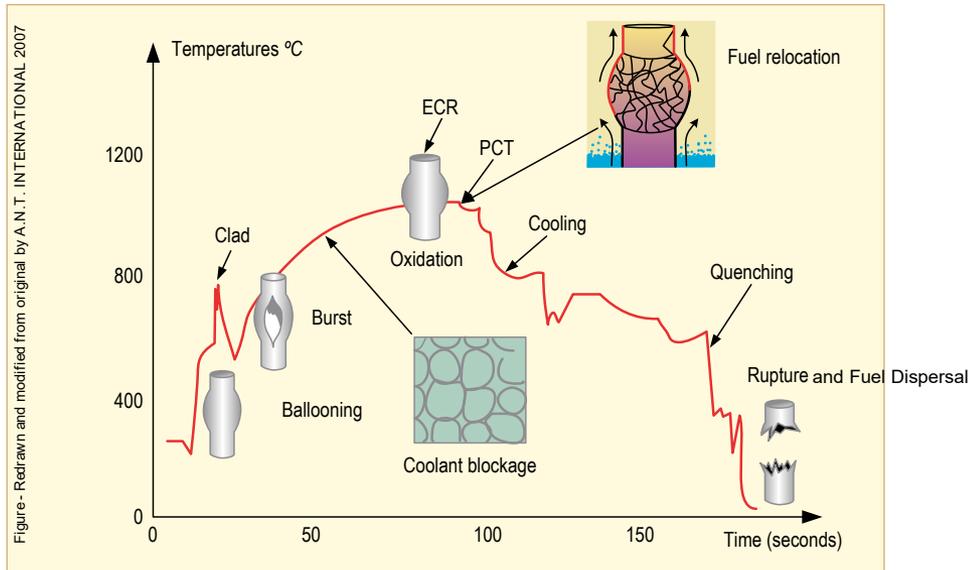
# FC 2.1 – Fuel-to-Coolant Thermomechanical Transport Behaviors Under Transient Conditions

- **Fuel-to-Coolant (F2C) thermomechanical transport behaviors include a variety of mechanisms for thermal or mechanical energy transport between the fuel/cladding/coolant**
  - Oftentimes requiring multiphysics coupling of fuel performance and thermohydraulic modeling & simulation tools
  - Phenomena of interest typically span multiple reactor transients from operational to design basis accidents.
  - In all cases, it boils down to understanding and developing models to describe energy transfer from the fuel through the cladding to the coolant and, in some extreme cases, directly from fuel to coolant
  - RIA and LOCA examples shown on next slide



# FC 2.1 – Fuel-to-Coolant Thermomechanical Transport Behaviors Under Transient Conditions

- Examples of phenomenological evolution for design basis accident transient conditions (could include operational events as well)





# FC 2.1 – Fuel-to-Coolant Thermomechanical Transport Behaviors Under Transient Conditions

- **This call seeks proposals including experimental and/or modeling scopes that will extend current understanding and prediction of F2C transport behaviors, thermal and/or mechanical, *during transient conditions relevant to nuclear fuel operations and safety.***
  - Transient conditions and corresponding phenomena selected for study must show clear connectivity to meaningful impacts to industry through opportunities for qualifying expanded fuel performance limits.
- **Proposals should focus on clear applications to near-term Accident Tolerant Fuels (ATF) concepts and high burnup fuel (>62 GWd/MTU).**
- **Proposals should show clear connectivity of separate effects experimental studies and modeling to integral behaviors (preferably in-pile integral experiments, planned or historical where applicable).**
  - Planned experiments at TREAT include AOO (short duration DNB/dryout type), RIA, and LOCA experiments.
  - Historical data could be used where available
  - A clear explanation should be provided if this is not possible and outcomes should include the description of an in-pile integral experiment that would )
- **Proposals are encouraged to consider coordinating findings with the NEAMS program so that models can be incorporated into relevant tools.**

## FC 2.2 – High Burnup LWR Fuel Rod Behavior under Normal and Transient Conditions

**Federal Manager: Frank Goldner**

**Technical POC: Nathan Capps, ORNL**

- **Nuclear Industry is looking to extend peak rod average burnup limits above the current regulatory burnup limit, 62 GWd/MTU, with increased enrichment**
  - Current LWR fuel ( $Zr/^{235}UO_2$ ) and ATF concepts are under consideration for burnup and enrichment extension
  
- **LWR fuel ( $Zr/^{235}UO_2$ ) and ATF concepts are expected to meet all the current safety criteria for burnup extension**
  
- **ATF concepts are expected to provide safety enhancements that lead to additional economic benefits**

## FC 2.2 – High Burnup LWR Fuel Rod Behavior under Normal and Transient Conditions

- The objective of this call is to encourage proposals aimed to improve our ability to predict and model high burnup (i.e. >62 GWd/MTU) fuel rod response and behavior under normal and transient conditions.
- The primary focus should be to investigate those conditions that might be most limiting under normal and transient conditions, e.g. rod internal pressure and fission gas release, and evaluate potential test irradiation conditions that would eventually be conducted to provide data to fill the most critical gaps in predicting fuel performance.
- Accident Tolerant Fuels should be investigated in order to evaluate the additional safety margin in comparison to current Light Water Reactor fuels.
- It is anticipated that novel experimental measurements and/or modeling approaches will be necessary to address this challenge.
- Proposals should consider how these methods and datasets accelerate and inform the safety case. It is anticipated that proposals will not require test irradiations. However, characterization of irradiated materials may be considered.
- Proposed experimental investigations may consider using surrogate materials, but the proposal must make a strong case as to why the information collected through use of surrogate material is applicable to the mechanisms governing the fuel response.

## FC 2.2 – High Burnup LWR Fuel Rod Behavior under Normal and Transient Conditions

### ■ Proposals Goals:

- Improve our ability to predict and model high burnup (>62 GWd/MTU) fuel rod response and behavior under normal and transient conditions
- Identify fuel rod conditions that might be most limiting (e.g. fission gas release, rod internal pressure, fuel temperatures, etc.)
- Identify safety margin afforded by ATF concepts

### ■ Applicants should consider:

- Novel experimental measurements and/or modeling approaches (i.e. mechanistic modeling) to inform analyses
  - *Material characterization of irradiated materials may be considered*
- Discuss how these methods and datasets will accelerate and inform the safety case and margin identification

### ■ Applicants should not consider:

- Developing new safety/licensing criteria
- Experiments requiring test irradiations

### ■ Expected Deliverables:

- Journal Publications



### ■ AFC National Technical Director:

- Steve Hayes(INL), [steven.hayes@inl.gov](mailto:steven.hayes@inl.gov)

### ■ Federal Program Managers:

- Frank Goldner, [frank.goldner@nuclear.energy.gov](mailto:frank.goldner@nuclear.energy.gov)

### ■ Technical Leads:

- Colby Jensen (INL), [colby.jensen@inl.gov](mailto:colby.jensen@inl.gov)
- Nathan Capps (ORNL), [cappsna@ornl.gov](mailto:cappsna@ornl.gov)

- Please review previous fuel related awards at [www.neup.gov](http://www.neup.gov).



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# Background Information

Nuclear Energy

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**Advanced Nuclear Fuel Technologies**

Home

Advanced Nuclear Fuel Technologies | Advanced Fuels Program | Accident Tolerant Fuels

The Department of Energy directs programs that conduct research and development (R&D) activities for advanced nuclear fuels that will continue to improve the operation of the current fleet of light water reactors and will be used in the next generation of reactors. The safe, reliable and economic operation of the nation's nuclear power reactor fleet has always been a top priority for the nuclear industry. Continual improvement of technology, including advanced materials and nuclear fuels, remains central to industry's success.

Advanced Fuels Program | Accident Tolerant Fuels | Light Water Reactor Sustainability | Transient Reactor Test Facility | Department of Energy Office of Nuclear Energy

## Accident Tolerant LWR Fuel Information Sheet

**U.S. DEPARTMENT OF ENERGY** Nuclear Energy | **Advanced Nuclear Fuels**

### Enhanced Accident Tolerant Fuels for Light Water Reactors

**Development Goal:** Demonstrate performance by inserting a lead test rod or lead test assembly into a commercial power reactor by 2022 with deployment in the U.S. light water reactor fleet to follow within 20 years.

**ATF Program Goals**  
The overall goal of ATF development is to identify alternative fuel system technologies to enhance the safety, competitiveness, and economics of commercial nuclear power. The development of an enhanced fuel system supports the sustainability of nuclear power, allowing it to continue to generate clean, low-CO<sub>2</sub> emitting electrical power in the United States. Enhanced accident tolerant fuels would reduce loss of active cooling in the reactor core for a considerably longer period of time than the current fuel system. (Continued)

**Current LWR Fuel**  
Today's U.S. commercial LWR fleet uses uranium dioxide (UO<sub>2</sub>) ceramic alloy fuel systems to provide 70 percent of the nation's clean energy. Decades of industry research and operational experience have produced an extensive database supporting the performance of LWR fuel during normal power operations and during postulated accident conditions. The nuclear power industry is focused on continuous improvement and reliable operation, and subsequent damage to the Fukushima Daiichi nuclear power plant complex, enhancing the accident tolerance of LWRs became a topic of serious discussion. As a result of discussion from Congress, DOE-NE initiated the Enhanced Accident Tolerant Fuel (ATF) Development program.

**Enhanced Reaction Kinetics with Steam**

- Increased heat of oxidation
- Lower oxidation rate
- Reduced hydrogen production (or other combustible gases)
- Reduced hydrogen embrittlement of cladding

**Enhanced Fuel Properties**

- Lower fuel operating temperatures
- Minimized cladding internal oxidation
- Minimized fuel relocation/dispersion
- Higher fuel melt temperature

**Enhanced Cladding Properties**

- Resistance to clad fracture
- Robust geometric stability
- Thermal shock resistance
- Higher cladding melt temperature
- Minimized fuel-cladding interactions

**Enhanced Retention of Fission Products**

- Gaseous fission products
- Solid/liquid fission products

**Enhanced Tolerance to Loss of Active Core Cooling**

Key considerations in establishing accident tolerant fuel attributes

U.S. Department of Energy - Nuclear Energy



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# Recent Advanced Fuels Campaign Documents – Available on OSTI

## ***OSTI Document Links of Interest:***

*Overview of Accident Tolerant Fuel Program*

<http://www.osti.gov/scitech/servlets/purl/1130553>

*Accident Tolerant Fuel Performance Metrics*

<http://www.osti.gov/scitech/servlets/purl/1129113>

*Advanced Fuel Cycle Web Site:*

<https://nuclearfuel.inl.gov/afp/SitePages/Home.aspx>

*2019 Accomplishments Report*

<https://nuclearfuel.inl.gov/afp/2019%20Accomplishments%20Report/index.aspx?page=1>

