DOE AND INDUSTRY TESTING OF ACCIDENT TOLERANT FUELS

Steven L. Hayes, PhD

Idaho National Laboratory

National Technical Director, DOE Advanced Fuels Campaign

Outline of Presentation

- Objectives of Accident Tolerant Fuels (ATF)
- Industry Led Development of ATF Concepts
- DOE Supported Testing of ATF Concepts
  - Steady-state Testing in the Advanced Test Reactor (ATR)
  - Transient Testing in TREAT
  - LOCA Testing at ORNL
- Near-term Plans

"Fuels with **enhanced accident tolerance** are defined as fuels that can **tolerate a severe loss of active cooling** in the reactor core **for a considerably longer time period** than the current UO_2 – zirconium alloy fuel system, while maintaining or improving the fuel performance during normal operations, operational transients, and DBAs."

Shannon M. Bragg-Sitton, et al., "Metrics for the Technical Performance Evaluation of Light Water Reactor Accident-Tolerant Fuel," *Nuclear Technology*, **195** (2016) 111-123.

Industry Led Development of ATF Concepts

- **AREVA**
  - Cr-coated $M5_5$ cladding
  - Doped UO_2 for improved thermal conductivity and performance

- **GE**
  - Iron-based cladding
  - ODS variants for improved strength

GE imagination at work

- **Westinghouse**
  - Cr-coated Zirlo cladding
  - SiC cladding
  - Alternative fuel with improved thermal conductivity and high density

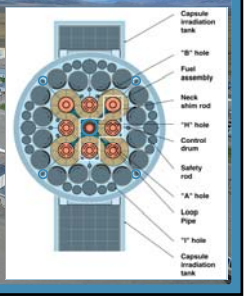
DOE Irradiation Test Plan to Support ATF Development

Test Series	ATF-1	ATF-2	ATF-3	ATF-H-x	CM-ATF-x	ATF-y
Test Reactor	ATR	ATR	TREAT	Halden	Commercial Reactors	TREAT
Test Type	Drop-in	Loop	Static/Loop	Loop	LTR/LTA	Loop
Test Strategy	Scoping Many Compositions	Prototypic Cladding and Integral Fuel Concepts	Focused	Focused	Mature concepts	Mature concepts
	Nominal conditions	Nominal conditions	Off-normal conditions	Nominal conditions	Nominal conditions	Off-normal conditions
Fuel	UO_2*, U_3Si_2, UN	Promising concepts	Rodlets conditioned in ATF-1 and ATF-2 irradiations	Promising concepts	Promising near-term concepts	Rods conditioned in LTR/LTA irradiations
Cladding	Zr w/coatings, Fe-based alloys, advanced alloys, SiC					
Key Features	Fuel and fuel-cladding interactions	PWR conditions	Integral testing	BWR conditions	Prototypic testing	Integral testing
Timeframe	FY15 – FY20+	FY18 – FY22+	FY18 – FY25+	FY19 – FY22+	FY19 – ?	FY22 – ?

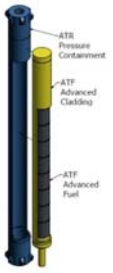
Testing ATF Concepts in the Advanced Test Reactor

ATF-1 Test Series
- Drop-in capsules in (4) small-I positions
- Scoping tests of fuels and fuel-cladding interactions

ATF-2 Test Series
- Instrumented test train in center flux trap
- Pressurized loop with prototypic PWR conditions
- Tests of cladding and integral fuel concepts
- Conditioning of fuel rodlets for subsequent transient testing



ATF-1 Early Concepts Test Matrix

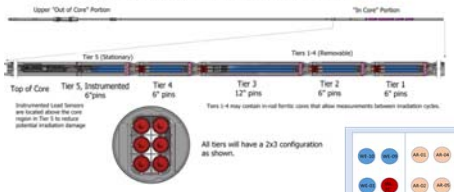


Development Lead	Fuel	Cladding	No. of Rodlets
Westinghouse	U_3Si_2	Zirlo	5
AREVA	UO_2	Zircaloy-4	2
	UO_2 + SiC whiskers	Zircaloy-4	2
	UO_2 + diamond particles	Zircaloy-4	2
GE	UO_2	APMT	2
	UO_2	Alloy 33	2
ORNL	UO_2	FeCrAl	2
Total			17

Irradiation in ATR began in 2015

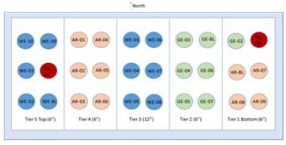
ATF-2 Testing in Pressurized Water Loop

ATF Water Loop Configuration for Safety Analysis Purposes



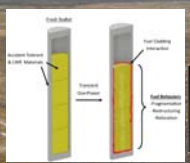
ATF-2 startup will begin in ATR Cycle 164A (May 2018)

Teir 5 instrumentation: LVDTs, TCs, and optical pressure sensors



Transient Reactor Test (TREAT) Facility

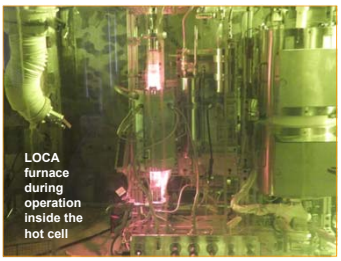
- 100 kW steady-state power with 19 GW peak transient power
- Core: 1.2 m tall x ~2 m. diameter; surrounded by 0.25 m graphite reflector
- 19 x 19 array of 10 x 10 cm fuel and reflector assemblies
- Fuel: 0.2 wt.% highly enriched UO_2 dispersed in graphite
- 12 steady-state and 8 transient control rods
- Instantaneous, large negative temperature coefficient (self protecting driver core)



Operating limits for LWR fuel designs are defined by the threshold for cladding rupture and fuel relocation under upset conditions. Transient tests in TREAT will be performed on ATF concepts to evaluate life-limiting fuel-cladding mechanical interactions and fuel melt behavior.

TREAT Reactor transient operations restarted in January 2018.

Loss of Coolant Accident (LOCA) Test Facility established in hot cell at ORNL



LOCA furnace during operation inside the hot cell

- Internally pressurized, irradiated fuel rods
- Flowing steam environment
- Heating rate 5°C/sec
- Temperature up to 1200°C
- Capable of water quench

Post-burst Zircaloy-4 tubes after LOCA sequence to 1200◦C with internal pressurization.

Near Term Plans

FY18
- Continue ATF-1 testing of fuel concepts (ATR)
- Initiate ATF-2 testing of cladding/integral fuel concepts in PWR Loop (ATR)
- Initiate transient experiments in TREAT in preparation for ATF testing
- GE: initiate testing of FeCrAl cladding in (Hatch)
- Westinghouse: establish LFR fabrication line for U_3Si_2 fuel
- AREVA: perform pool-side exams of chromia-doped UO_2 fuel (LaSalle)

FY19
- Continue ATF-1 and ATF-2 testing (ATR)
- Initiate transient testing of un-irradiated ATF rodlets (TREAT)
- GE: initiate LTA testing of IronClad and ARMOR fueled rods (Clinton)
- Westinghouse: initiate LTR testing of Cr-coated Zirlo and U_3Si_2 fuel (Byron)
- AREVA: initiate testing of Cr-coated M5 cladding (Vogtle)

FY20
- Continue ATF-1 and ATF-2 testing (ATR)
- Initiate transient testing of irradiated ATF rodlets (TREAT)
- Initiate LOCA testing of irradiated ATF concepts (ORNL)