Enhanced Accident Tolerant Fuels for LWRs: Industry Teams

The safe, reliable, and economic operation of the nation's nuclear power reactor fleet has always been a top priority for the United States' nuclear industry. Continual improvement of technology, including advanced materials and nuclear fuels, remains central to the industry's success. One of the missions of the U.S. Department of Energy's (DOE) Office of Nuclear Energy (NE) is to develop nuclear fuels and claddings with enhanced accident tolerance for use in the current fleet of commercial light water reactors (LWRs) or in reactor concepts with design certifications (GEN-III+). A companion information sheet, *Enhanced Accident Tolerant Fuels for Light Water Reactors,* provides additional detail on the overall goals for Accident Tolerant Fuel (ATF) development for LWRs.

ATF Development Activities

With the assistance of the nuclear energy community, the DOE Fuel Cycle Research and Development (FCRD) Advanced Fuels Campaign has embarked on an aggressive schedule for the development of enhanced accident tolerant LWR fuel system concepts. The program is in the early phases of research and development (R&D) and is currently supporting the investigation of a number of candidate technologies that may improve the fuel system. The overall ATF development goal is to demonstrate performance by inserting a lead fuel rod (LFR) or lead fuel assembly (LFA) into a commercial power reactor by 2022 with deployment in the U.S. LWR fleet to follow within 20 years.

ATF development utilizes a three-phase approach to commercialization.

Phase 1: Feasibility Assessment and Down-Selection— Fuel concepts are developed, tested, and evaluated. Feasibility assessments are performed to identify promising concepts, including lab-scale experiments such as fabrication, preliminary irradiation, and material property measurements; fuel performance code updates; and analytical assessments of economic, operational, safety, fuel cycle, and environmental impacts. (FY 2012–FY 2016)

Research teams will begin irradiation of Accident Tolerant Fuel concepts in Idaho National Laboratory's Advanced Test Reactor in 2014.

AREVA

Phase 2: Development and Qualification— Prototypic fuel rodlets are irradiated in a test reactor at LWR conditions to provide the data required for the LFRs/LFAs. The fabrication process expands to industrial scale for LFRs/LFAs. (FY 2016–FY 2022)

Phase 3: Commercialization— Partial-core (region-sized) reloads are tested to verify the performance observed for the LFRs/LFAs and to provide additional data for final licensing of the product. Commercial fabrication capabilities are established. (FY 2022 and beyond)

Each development phase roughly corresponds to the technology readiness levels (TRLs) defined for nuclear fuel development, where TRL 1–3 corresponds to the "proof-of-concept" stage (Phase 1), TRL 4–6 to "proof-of-principle" (Phase 2), and TRL 7–9 to "proof-of-performance" (Phase 3).

Industry-Led ATF Teams

The ATF program is in *Phase 1*, supporting the investigation of several technologies that may improve fuel system response and behavior in accident conditions. DOE is sponsoring multiple teams to develop ATF concepts within national laboratories, universities, and the nuclear industry.These concepts offer both evolutionary and revolutionary changes to the current nuclear fuel system. Industry-led R&D activities are supported by awards made in 2012 under a DOE Funding Opportunity Announcement. The scope and status of each industry team is provided below. Each research team will begin irradiation of ATF concepts in the Idaho National Laboratory (INL) Advanced Test Reactor (ATR). See companion information sheet, *Irradiation Testing of Candidate Accident Tolerant Fuels for LWRs,* for more details.

AREVA

The AREVA R&D team is designing both fuel and cladding concepts for enhanced performance and accident tolerance. AREVA provides team leadership and technical guidance related to fuel manufacture and fuel requirements. Additional team members include the University of Florida, developing fuel pellets; the University of Wisconsin and Savannah River National Laboratory, providing cladding coatings; and Duke Energy and the Tennessee Valley Authority, providing utility consultation.

Concepts being considered by the AREVA team include:

(Continued)

Modified UO_2 Fuel:

- Chromia doping to reduce fission gas generation, improve load-following characteristics, increase uranium density, improve wash-out characteristics in rod failure, and lock-up cesium in the fuel matrix.
- Embedded SiC fibers to improve thermal heat transfer under normal conditions; this will increase fuel efficiency, improve margin in an accident condition, and lock-up iodine in the fuel matrix.

Modified Zr-alloy Cladding:

- Coatings on existing Zr-alloy cladding to reduce hydrogen pickup, mitigate hydride reorientation in the cladding, and increase coping time during accident conditions.

General Electric Global Research

The General Electric (GE) Global Research and Global Nuclear Fuels team includes the University of Michigan and Los Alamos National Laboratory (LANL). The GE team is investigating the replacement of Zr-alloy cladding with advanced steels, such as FeCrAl alloys (APMT), which offer a number of benefits in beyond design-basis accident conditions. Improved properties under normal conditions may provide sufficient benefit to mitigate the increased neutron absorption characteristics of these materials.

Samples of commercial and experimental alloys have been successfully tested for up to 48 h in 100% superheated steam from 600°C to 1475°C. Results to date indicate that the best candidate new alloys, including APMT and Alloy 33, have several orders of magnitude improvement over the current Zr-based alloys in reaction kinetics with steam. These advanced steels have also been tested to demonstrate superior mechanical properties under both normal operating conditions and accident conditions. Ferritic alloys are highly resistant to irradiation damage and to environmentally assisted cracking under normal operating conditions. These materials have been machined into thin walled tubes and end caps have been sealed using orbital weld techniques.

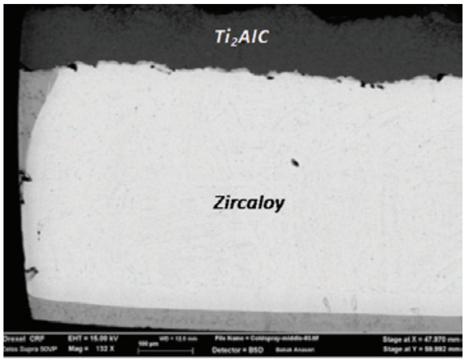
Westinghouse

The Westinghouse Electric Company LLC consortium includes General Atomics (GA), Edison Welding Institute (EWI), the University of Wisconsin (UW), LANL, INL, Texas A&M University (TAMU), the Massachusetts Institute of Technology (MIT) and Southern Nuclear Operating Company (SNOC). Westinghouse has laid out a full development and testing program, and the expected economics of the various options has been determined.

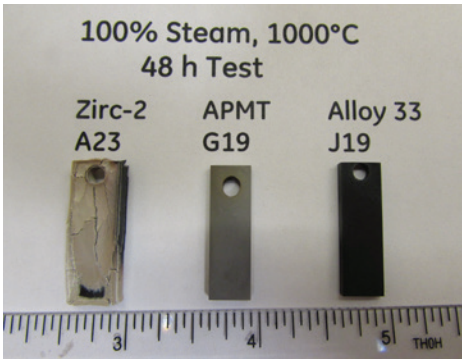
Westinghouse provides team leadership and fuel concept development. Cladding development is provided by GA for SiC-based concepts, while EWI is developing hot-spray coatings for Zr-alloy cladding and UW is developing cold-spray coatings for Zr-alloy cladding (Ti_2AlC and NanoSteel®). Fuel development is conducted by INL for U_3Si_2, LANL for UN, and TAMU for waterproofed UN (using U_3Si_2 additives). MIT provides steam oxidation, quench and preliminary irradiation testing of cladding candidates. A customer perspective on ATF licensing and economics is provided by the utility partner SNOC.

Fuel development results for both U_3Si_2 and waterproofed UN using U_3Si_2 indicate the feasibility of manufacture of both fuel types. U_3Si_2 has been successfully manufactured into pellets at 97.8% theoretical density. This fuel offers a 17% increase in ^{235}U loading (at equivalent enrichment) and a five-fold increase in thermal conductivity relative to standard UO_2 fuel. Waterproofed UN would offer up to 35% increase in ^{235}U loading and 10 times the thermal conductivity of UO_2.

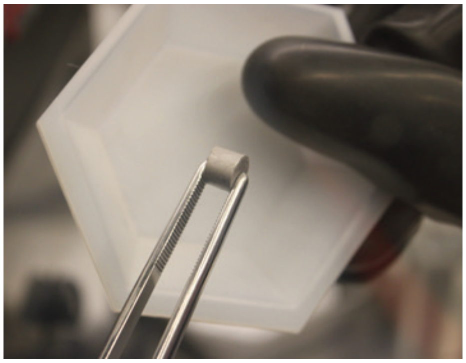
Westinghouse cladding development for coated Zr-based alloys has not produced a significant increase in accident tolerance relative to standard cladding. These trials provide input to potential coating improvements and will guide future research. Samples of SiC-based cladding have been successfully manufactured and tested in an autoclave at accelerated conditions (425°C). High-temperature (greater than 1200°C) steam tests and irradiation in the INL ATR will follow for preferred cladding concepts.



AREVA: Cross section of a Ti_2AlC coated Zircaloy coupon after steam oxidation at LOCA condition



GE: Sample alloys following 48 h exposure to 100% steam at 1000°C



Westinghouse: U_3Si_2 pellet sintered at INL using finely ground powder

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