

Westinghouse Non-Proprietary Class 3

LTR-NRC-16-80 NP-Attachment

Westinghouse Accident Tolerant Fuel (ATF) Program (Non-Proprietary)

December 2016

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Westinghouse Accident Tolerant Fuel (ATF) Program

December 15, 2016



Outline

- Purpose of the meeting
- Background – DOE ATF program
- Westinghouse technologies for ATF
 - Coated cladding
 - U_3Si_2 pellets
 - SiC cladding
- Licensing approach
 - Lead Test Rods (LTR) []^{a,c}
 - Lead Test Assemblies (LTA) []^{a,c}
- Data acquisition and methods
 - Out-of-pile testing
 - In-pile testing []^{a,c}
 - Multi-scale modeling
- Next steps and plan for licensing interactions



Purpose of the Meeting

- Provide an overview of Westinghouse's technologies for ATF
- Present licensing approach for ATF technologies
- Obtain feedback from NRC on licensing approach
- Plan next steps for licensing interactions

**This meeting is the first step to advance
licensing of ATF technologies**



DOE ATF Program



Development of Light Water Reactor Fuels with Enhanced Accident Tolerance

Report to Congress
June 2015

United States Department of Energy
Washington, DC 20585

- After Fukushima, enhancing accident tolerance became a priority topic
- US Congress approved funding to DOE to start developing nuclear fuel with enhanced accident tolerance
- Aggressive 10 year schedule starting in 2012
 - Feasibility (Phase 1) complete
 - Development and Qualification (Phase 2) started in October 2016
- Insertion of Lead Test Rods/Assemblies in commercial reactor by 2022
 - Industry is working to further accelerate the schedule



ATF – Performance Benefits

- Tolerate loss of active cooling for a longer period of time
 - Cladding properties
 - Reaction kinetics with steam (reduced oxidation and hydrogen)
 - Cladding higher melting temperature and geometric stability
 - Thermal properties of fuel pellets (higher thermal conductivity)
 - Enhanced retention of fission products in fuel pellets
- Enhanced performance under normal conditions and severe accident scenarios
- Increased safety margins under severe accident conditions
- Improved public trust and support for nuclear

**ATF enhances performance under severe
accident conditions**



Westinghouse ATF Technologies

Coated Cladding

U_3Si_2 Pellets

SiC Cladding



Westinghouse Technologies for ATF

- Westinghouse ATF technologies improve:
 - Oxidation resistance with new cladding materials
 - Thermal conductivity with new pellet materials
- Six cladding/pellet combinations considered
 - Based on multi-year research (started in 2003)
 - Two combinations currently being pursued

		Cladding		
		Zr _{coated}	100% SiC Composite	Zr _{coated} + SiC _{wrapped}
Pellet	UN/U ₃ Si ₂			
	U ₃ Si ₂	Currently Pursued		



Coated Cladding

a,b,c



Coated Cladding – Performance and Development

a,b,c



U₃Si₂ Pellets

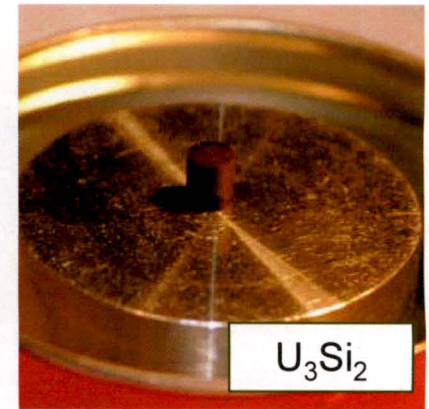
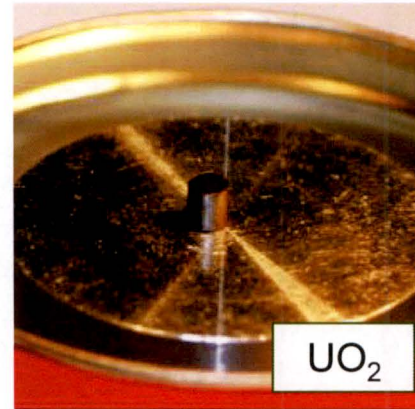
Increased uranium density and higher thermal conductivity

	UO ₂	U ₃ Si ₂
Uranium density (g/cm ³)	9.68	11.3
Thermal conductivity (W/m K)	5-2 (300-2000°C)	9-20 (300-1200°C)

Fabrication



Testing



Corrosion testing in water at 300°C (50 hours)
No measurable weight change or evolution in appearance

U_3Si_2 Pellets – Performance and Development

a,b,c



SiC Cladding

- Retention of tensile strength up to 2500°C
 - No ballooning and bursting
- Slow reaction with steam at >1700°C
 - Eliminate oxidation driven temperature spikes
 - Oxidation kinetics orders of magnitude lower than Zr
- Melting point >2500°C
 - Integrity under most severe beyond design basis accident conditions
- Reasonably small cross section for thermal neutrons
- Good irradiation behavior
 - Swelling is small and predictable



SiC Cladding – Performance and Development

a,b,c



Licensing Approach

Lead Test Rods (LTR) [

Lead Test Assemblies (LTA) [

Region Implementation of ATF Technologies

]a,b,c

]a,b,c



LTR/LTA Licensing Approach - Coated Cladding



LTR/LTA Licensing Approach – U_3Si_2 Pellets

a,c



LTR/LTA Licensing Evaluation Plan

a,c



LTR/LTA Licensing Approach – SiC Cladding

a,c



LTR/LTA Licensing – Manufacturing and Transport

a,c



Region Implementation of ATF Technologies

- Changes to existing plant safety analysis (10 CFR 50.34)
 - Fuel failure criteria
 - Onset of gap release of fission products
 - Behavior of fission product release
 - Thermal hydraulic response of reactor coolant systems
 - Core melt progression and relocation
 - Impact of core melt on containment integrity
 - Spent fuel pool
- []^{a,b,c}
- LAR and Technical Specification changes

Quantification of Benefit of ATF Technologies

- Severe accident testing ($\gg 1200^{\circ}\text{C}$) provides:
 - Maximum cladding temperature
 - Maximum time at maximum temperature
- High temperature corrosion models revised to account for temperature and corrosion benefit of ATF cladding
- Insertion of revised corrosion models to severe accident codes for evaluation of ATF region implementation

Development of objective metrics for accident tolerance is an industry effort

Data Acquisition and Methods

Out-of-pile Testing

In-pile Testing [

Multi-scale Modeling

]a,c

Out-of-Pile Testing

a,b,c



In-pile Testing – Data Needs for Fuel Rod Design

- Un-irradiated material properties
 - Coefficient of thermal expansion
 - Heat capacity
 - Density
 - Melting point
 - Hardness
- Fuel performance measurements
 - Fission gas release
 - Thermal conductivity of fuel
 - Fuel swelling
 - Pellet/cladding mechanical and chemical interaction
 - Fission product/cladding chemical interactions

Focusing on the relatively short list of irradiated properties needed

In-pile Testing – Coatings

a,b,c



In-pile Testing – U_3Si_2 Pellets

a,b,c



In-pile Testing – Innovation on Data Acquisition

a,b,c

**Technologies now being developed and tested by
Westinghouse**



Multi-Scale Modeling

- First principles atomic scale modeling
 - Determine physical properties of irradiated materials
 - Thermal conductivity
 - Fission gas release
 - Swelling
- Collaboration with NEAMS – DOE program
- CASL – Virtual reactor design
- MedeA and Thermo-Calc software

**Modeling has the potential to provide evolution
of properties with irradiation**



Next Steps - Plan for Licensing Interactions

a,b,c

**Initiating coordinated work with the NRC is
crucial for success**



Summary

- An overview of Westinghouse's technologies for ATF was provided
 - Coated cladding
 - U_3Si_2 pellets
 - SiC cladding
- Licensing approach for ATF technologies was presented
 - LTR/LTAs
 - Region implementation
- Next steps for licensing interactions proposed

a,b,c
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Discussion