Westinghouse Accident Tolerant Fuel and Lead Fast Reactor Programs

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Westinghouse Accident Tolerant Fuel Program

- Westinghouse remains fully engaged and committed to the DOE program objectives
  - Consistently participated in the DOE program right from beginning in 2012 (internal ATF program since 2003)
  - Committed to LTA in 2021/2022 with expedited schedule of LTR in 2018/2019 to demonstrate early success
- Fuel: U_3Si_2 – 17% higher U density and 2x to 6x higher thermal conductivity than UO_2. Fuel temperature and FCC benefits
- Cladding options
  - Cr coated Zr: 1300°C capability
  - SiC: ≥1700°C capability

Delayed/reduced H_2 generation and core heatup. Coolable geometry retention by SiC at very high T

Objective is an ATF product that can capitalize enhanced safety to reduce plant capital and operation costs

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Lead Test Rod (LTR) Program

- Objectives
  - Insert U_3Si_2 into a commercial reactor
  - Insert coated Zr cladding into a commercial reactor
- Scope: 17x17 Optimized Fuel Assembly (OFA) rods
  - Coated Zr cladding with U_3Si_2 pellets
  - Uncoated Zr cladding with U_3Si_2 pellets
  - Coated Zr cladding with UO_2 pellets
- Schedule
  - Early 2019 in at least one PWR

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Lead Test Assembly (LTA) Program

- Objectives
  - Insert SiC LTRs into a commercial reactor
  - LTAs will be made up entirely of ATF rods (SiC and coated Zr): the first fully ATF assemblies placed into a commercial reactor
- Scope: 17x17 Robust Fuel Assembly (RFA) containing:
  - SiC rods with U_3Si_2 pellets
  - Coated Zr rods with U_3Si_2 pellets
  - Coated Zr rods with UO_2 pellets
- Schedule
  - Deliver LTAs to PWR in 2021

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A strong team

- **Westinghouse Electric Company LLC** – Technical direction, project management, ATF engineering, licensing; atomistic modeling for fuel performance
- **General Atomics** – SiC cladding development and manufacture
- **INL** - U_3Si_2 manufacture for from U and Si metals; Advance Test Reactor (ATR) & Transient Reactor Test Facility (TREAT) reactor testing; Post Irradiation Examination (PIE); Atomistic modeling
- **National Nuclear Laboratory (NNL, UK)** – U_3Si_2 from UF_6 manufacturing method
- **University of Wisconsin** & **Pennsylvania State University** – Coatings
- **MIT** – Test Reactor and other testing
- **LANL** – Manufacture of U_3Si_2 pellets for Lead Test Rods (LTRs) / Lead Test Assemblies (LTAs); additives for oxidation control and IFBAs; atomistic modeling
- **Halden Project** – In-reactor testing of ATF rods in Pressurized Water Reactor (PWR) conditions; pool-side gamma spectrometry
- **Southern Nuclear Operating Company** & **Exelon** – Utility perspective for economics and licensing

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Also working with other organizations, e.g. ANL, ORNL and CARAT, outside of the DOE contract

Westinghouse ATF program needs (only those related to "fuel safety" shown here)

- Power ramp testing
  - Power pulse testing to simulate RIA:
    - U_3Si_2 melting and PCMI, with both Zr and SiC
    - SiC behavior, with both fresh and pre-irradiated SiC
  - Gradual power increase, to simulate Condition II transients
- LOCA testing
- Run beyond cladding breach
  - U_3Si_2 wash-out (being addressed)
- Separate effect testing:
  - U_3Si_2 high-temperature corrosion with water/steam (being addressed)
  - U_3Si_2 thermal property degradation with irradiation (th. conductivity and melting point)
  - U_3Si_2 annealing testing, for FGR evolution with temperature
  - SiC creep/burst testing
  - SiC corrosion at high temperature (being addressed)
  - SiC CHF measurement and post-DNB operation

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First exp data on U_3Si_2 swelling/FGR will be available through ATF-1 testing PIE (summer 2017)

Proposed baseline (unirradiated) samples for RIA testing in TREAT

Rod ID Phase 2	Pellet	Pellet Supply	Cladding Material	Coating Thickness (microns)	Deposited Energy (cal/gm)
301	5% UO_2	WEC	Zirlo	0.00	max 300
302	5% UO_2	WEC	Zirlo	0.00	max 300
303	5% UO_2	WEC	Zirlo	0.00	300
304	5% UO_2	WEC	Zirlo	0.00	300
305	5% U_3Si_2	INL	Zirlo	0.00	300
306	5% U_3Si_2	INL	Zirlo	0.00	300
307	5% U_3Si_2	INL	SiC	0.00	300
308	5% U_3Si_2	INL	SiC	0.00	300
309	5% U_3Si_2	INL	Coated Zr	30.00	300
310	5% U_3Si_2	INL	Coated Zr	30.00	300
311	5% UO_2	WEC	Zirlo	0.00	300
312	5% UO_2	WEC	Zirlo	0.00	300
313	5% U_3Si_2	INL	Zirlo	0.00	300
314	5% U_3Si_2	INL	Zirlo	0.00	300
315	5% U_3Si_2	INL	SiC	0.00	300
316	5% U_3Si_2	INL	SiC	0.00	300
317	5% U_3Si_2	INL	Coated Zr	30.00	300
318	5% U_3Si_2	INL	Coated Zr	30.00	300

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Upcoming ATF-2 irradiation campaign in ATR: samples subsequently available for TREAT testing

	UO_2 - Zirlo		U_3Si_2 - Coated Zr				U_3Si_2 - SiC	
Rod number		201	210	226	227	203	206	225
Burnup (MWD/kgU)	30	60	20	60	30	60	20	60
Linear power (kw/ft)	6	7	17	17	7	7	17	17
Reactor Days	740	1269	204	612	743	1486	204	612
In Reactor	3/1/2018		3/1/2018				3/1/2018	
Out Reactor	2/4/2023	8/14/2026	7/10/2019	3/29/2022	2/11/2023	1/24/2028	7/10/2019	3/29/2022

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SiC irradiation test program. Samples potentially available for TREAT testing

- MITR-1
  - 2013-2014 (0.8 dpa)
- MITR-2
  - 2015-2016 (0.8 dpa)
- MITR-3
  - 2017 (0.8 dpa)
- Halden IFA-800
  - 2018-2020 (4 dpa)
- ATF-2 in ATR (~230°C)
  - 2018-2023 (20, 60 MWD/kgU)
- ATF-H in Halden (~320°C)
  - 2018-2023 (45 MWD/kgU)
- LTA
  - 2021-2026 (60 MWD/kgU)

Key Westinghouse ATF activities

- U_3Si_2 Kaizen event on U_3Si_2 reactivity with water/steam
  - INL, LANL, Rochester Polytechnic Institute, ANL, National Nuclear Laboratory (UK), Westinghouse Springfield (UK) and Westinghouse Vasteras (Sweden) participated
  - Identified action plan to assess U_3Si_2 reactivity with water/steam (e.g. fuel leaker washout test)
  - Autoclave tests planned at Westinghouse-Churchill to compare U_3Si_2 and UO_2 reactivity
- U_3Si_2 pellets achieved a 20 MWd/kgU burnup in ATR. PIE to be performed in ~summer 2017
- Industrial manufacture: studies on UF_6 to U_3Si_2 conversion (with NNL)

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Future work

- Crud deposition studies (@ Westinghouse-Churchill)
- SiC hermeticity testing with irradiation and temperature gradients (@ ORNL and GA/USC)
- High temperature (>1600°C) testing (@Westinghouse-Churchill and KIT later in 2017)
- Mechanical testing of tubes (@ Westinghouse)
- Continued autoclave corrosion testing (@ Westinghouse-Churchill)
- MITR and Halden testing (unfueled) starting later in 2017
- Coating of SiC and Zr tubes (UW, PSU, ORNL)
- LTR and LTA fabrication planning, design work continuing (Westinghouse)

Testing will continue – sample availability determines test rate

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Lead Fast Reactor program (fuel system aspects)

Westinghouse LFR Roadmap: Prototype and higher-performance LFR

- 1st step: Prototype LFR (PLFR) → "low" temperature to leverage proven materials
  - Technology demonstration mission, targeting commercial competitiveness already
  - $T_{hot} \leq 500°C$
  - UO_2 fuel, 15-15Ti-type steel cladding
- Subsequent "½ step": PLFR uprate with enhanced performance
  - Further enhancement in economic performance
  - Temperature increase up to 700°C to increase efficiency (upper 40s), conditional to materials demonstration
  - Advanced fuel (nitride, metal) and cladding (steel, composite) to support uprate
- Component scalability and prototypicality built into the design, to minimize re-design and re-licensing efforts from PLFR to follow-on units
  - Same vessel size
  - Replaceable components

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Key Westinghouse LFR program needs (related to "fuel safety" and "fuel reliability" only)

- Loss of lead flow testing
  - UO_2 in 15-15Ti-type steel
  - Advanced fuel systems later
- Run beyond cladding breach
  - UO_2/UN/Metal fuel wash-out?
- Comparative RIA testing for advanced fuel systems, e.g. UN, SiC
- Separate effect testing:
  - Corrosion testing in very high-temperature flowing lead (>500°C, up to 750°C), e.g. Al_2O_3-forming steels, Functionally Graded Composites, SiC
  - Assess effect of neutron irradiation on corrosion, and conditions for equivalence with ion irradiation (or relevance)
  - Compatibility testing between UO_2/UN/Metal and lead
  - Lead's fission products retention capability
- Investigation on use of advanced metal fuel for LFR

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Lead-based corrosion loops being assembled at the University of New Mexico and UCB. Westinghouse encourages their support

Conclusions

- Westinghouse is committed to the ATF program, as evident from serious LTR/LTA plans
  - Additional testing needed, especially on SiC and U_3Si_2 under transient prototypical conditions
  - TREAT of great use for assessing ATF behavior
- Westinghouse is committed to LFR technology development
  - Testing needed to assess viability of follow-on, higher-performance LFRs operating at T>550°C: opportunity for innovating Liquid Metal Reactors *status quo*
  - UNM and UCB corrosion testing facilities are a first step in that direction. Need to enhance operating conditions to differentiate from facilities available worldwide

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Thank you.
Questions?