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Accident Tolerant LWR Fuels - Update and Status

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NEAC Meeting

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Presentation Overview

- **Background: Where does ATF fit in NE?**
- **Status: Where is the ATF Program and where is it going?**
- **Collaborations: University and International Partners**
- **Funding**
- **Questions**

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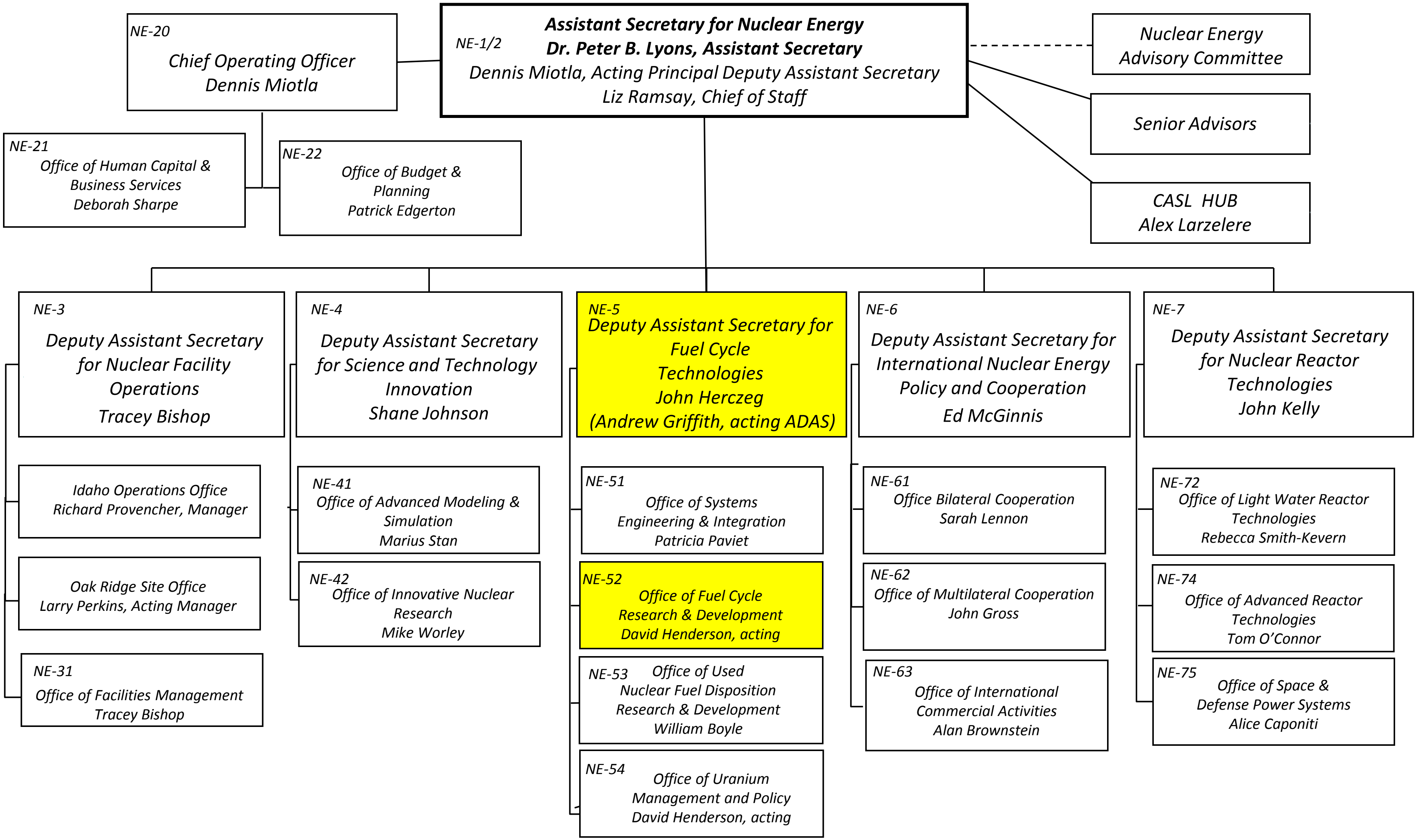
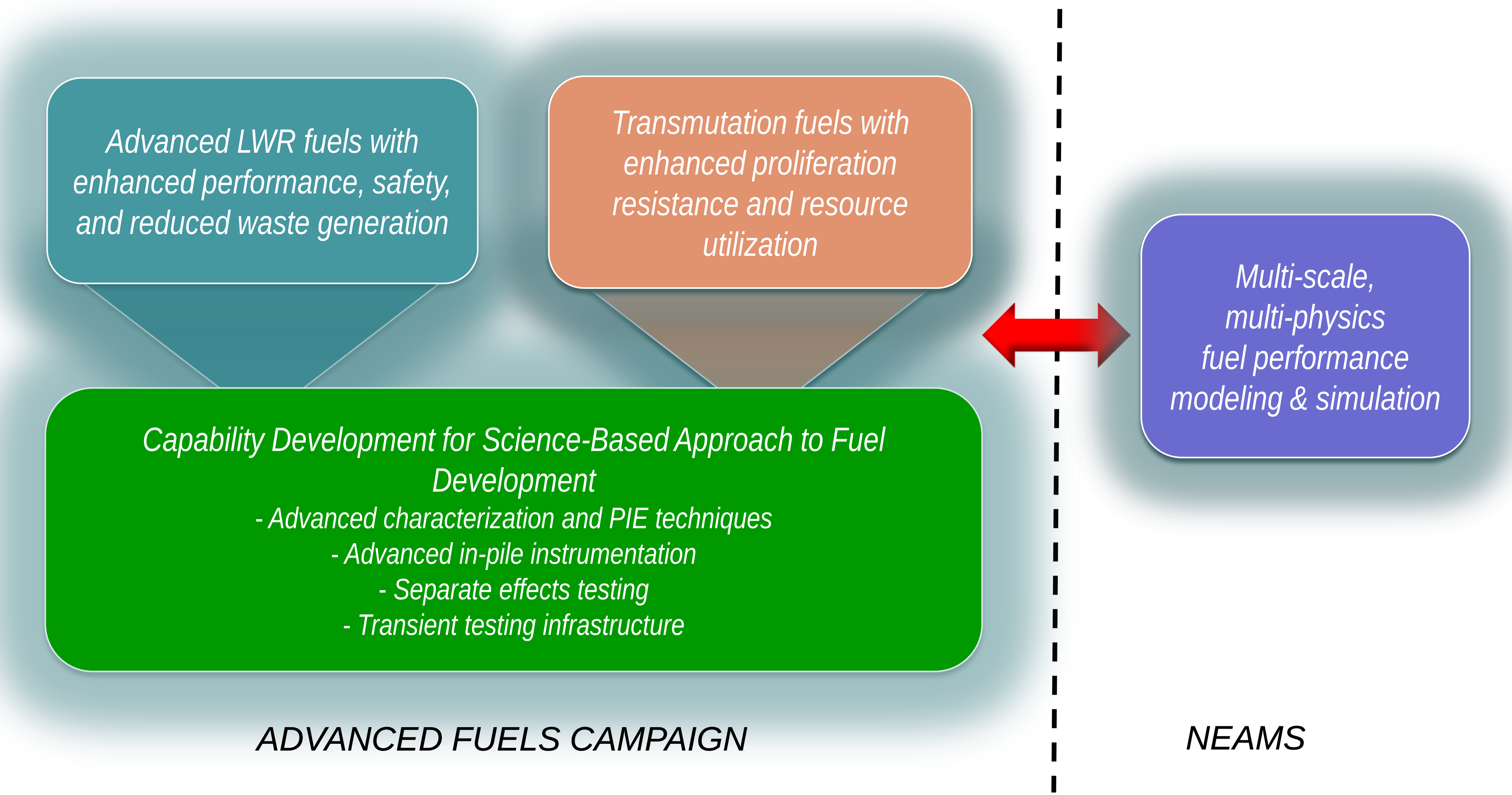


FCRD Advanced Fuel Campaign



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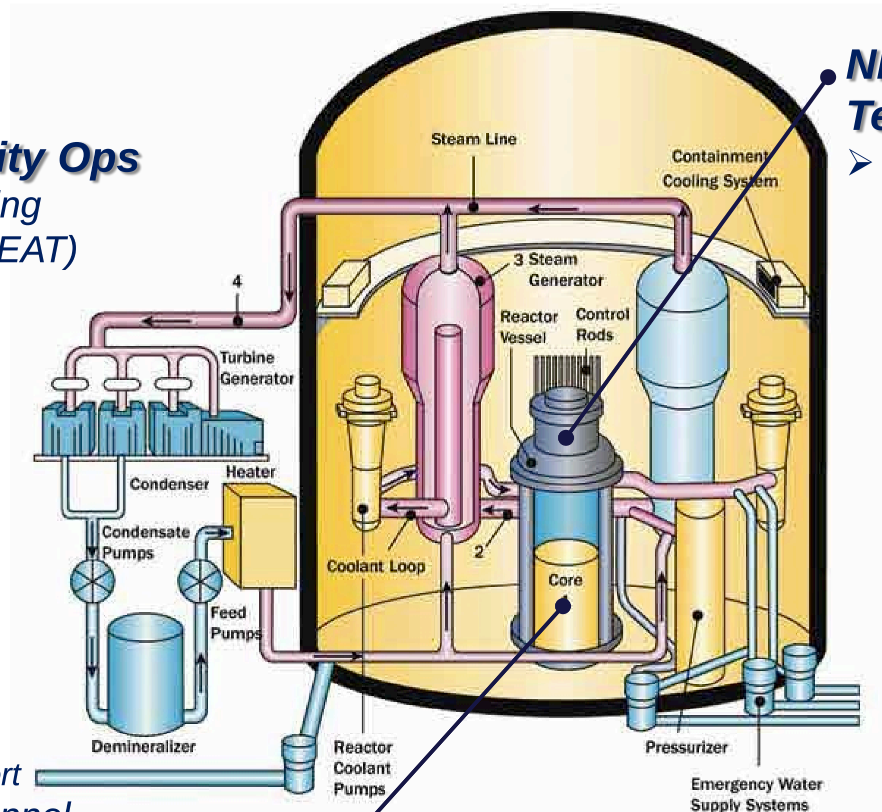
DOE-NE RD&D Activities for Enhanced Accident Tolerance in LWRs



NE-3: Nuclear Facility Ops
- Steady State Rx Testing
- Transient Testing (TREAT)
- PIE Upgrades

NE-4: S&T Innovation
- NEAMS Fuel Performance Code Development
- NEUPs, **IRPs**, NEET
  - Adv Instrumentation
  - High Temperature Materials
  - Transient Experiment Support
- EPRI/DOE (BWR) SiC Channel Box R&D

NE-7: Nuclear Reactor Technologies
- LWR Sustainability Program
  - Accident Tolerant Equipment and Instrumentation
  - RISMC Simulation of ATF impacts using advanced tools
  - Adv Materials Development
  - Accident Tolerant Reactor IRP (GA Tech)

NE-6: International Cooperation
- Collaborations on ATF

NE-5: Fuel Cycle Technologies
- ATF and Core Materials Industry, lab, university collaborations (FOAs/IRPs)
- Bilateral Collaborations – Japan, EU, France, China, UK
- Infrastructure Development, Oxidation testing, ATR and TREAT Experiments, PIE

Rx Graphic for Illustration Purposes only – Activities have PWR and BWR applicability

Maximizing Overall Performance Benefits

Multi-variable evaluation approach is designed to maximize improvement in several interrelated areas while identifying instances in which improvement in one area could negatively impact another area.

Improved Reaction Kinetics with Steam
- Decreased heat of oxidation
- Lower oxidation rate
- Reduced hydrogen production (or other combustible gases)
- Reduced hydrogen embrittlement of cladding

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

Enhanced Tolerance to Loss of Active Core Cooling

Improved Cladding Properties
- Resilience to clad fracture
- Robust geometric stability
- Thermal shock resistance
- Higher cladding melt temperature
- Minimized fuel - cladding interactions

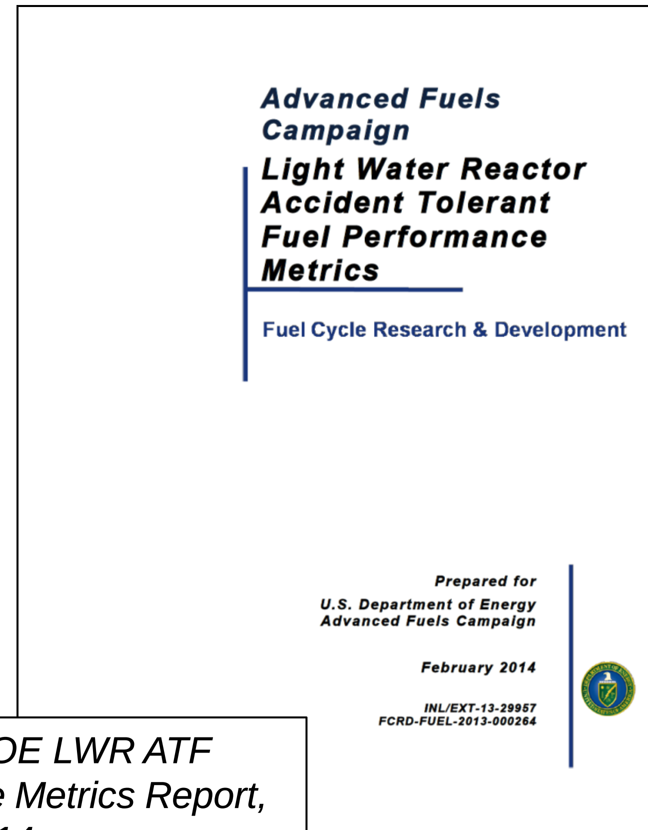
Enhanced Retention of Fission Products
- Gaseous fission products
- Solid/liquid fission products

Fuels with enhanced accident tolerance are those that, in comparison with the standard UO_2 – Zr system, can tolerate loss of active cooling in the core for a considerably longer time period (depending on the LWR system and accident scenario) while maintaining or improving the fuel performance during normal operations.

ATF Designs Must Meet Operations, Safety and Fuel Cycle Constraints

ATF will be evaluated over all potential “performance regimes”

- Fabrication/Manufacturability (to include Licensibility)
- Normal operations and anticipated operational occurrences (AOOs)
- Postulated accidents (Design Basis)
- Severe accidents (Beyond Design Basis)
- Used fuel storage / transport / disposition (to include potential for future reprocessing)



Advanced Fuels Campaign

Light Water Reactor Accident Tolerant Fuel Performance Metrics

Fuel Cycle Research & Development

Prepared for
U.S. Department of Energy
Advanced Fuels Campaign

February 2014

INL/EXT-13-29957
FCRD-FUEL-2013-000264

See: U.S. DOE LWR ATF Performance Metrics Report, February 2014

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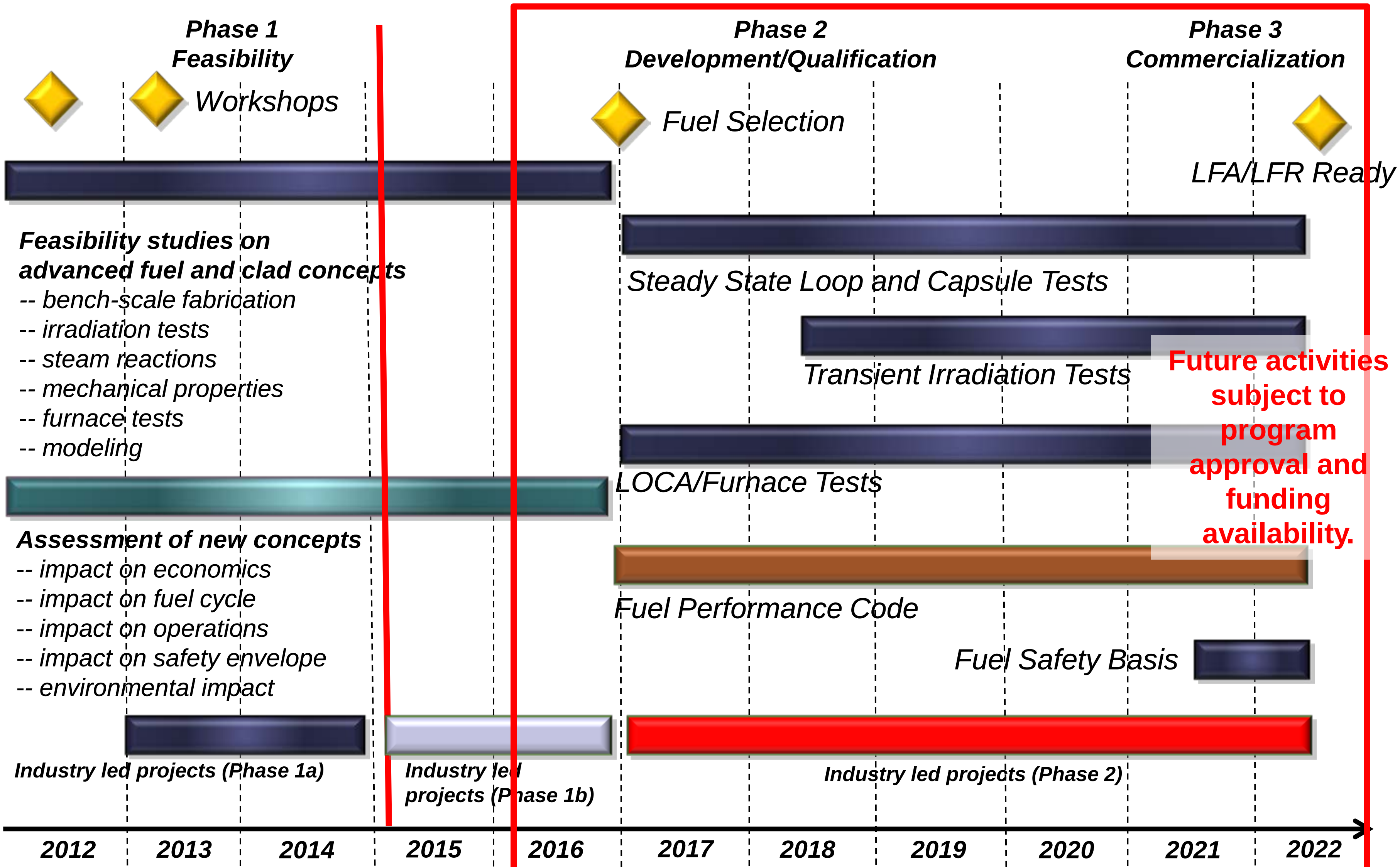
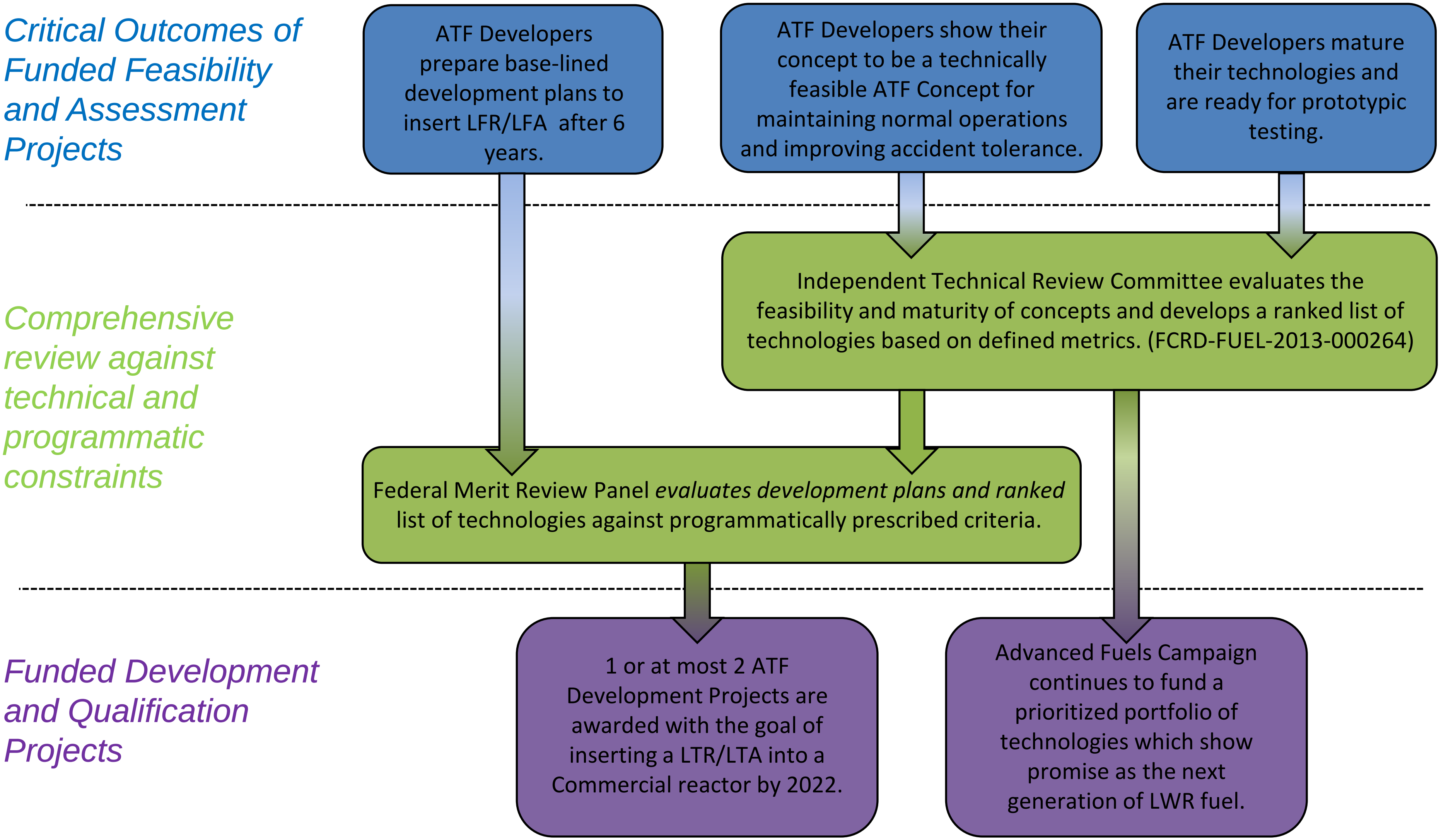
RD&D Strategy For Enhanced Accident Tolerant Fuels – 10 Year Goal



Path from Feasibility and Assessment to Development & Qualification



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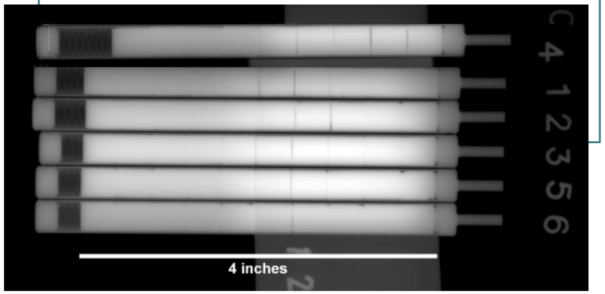
Industry Teams completed Phase 1a of initial ATF projects. (Phase 1b authorized for FY2015 - FY2016)

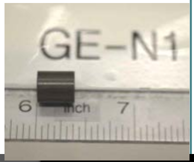
AREVA

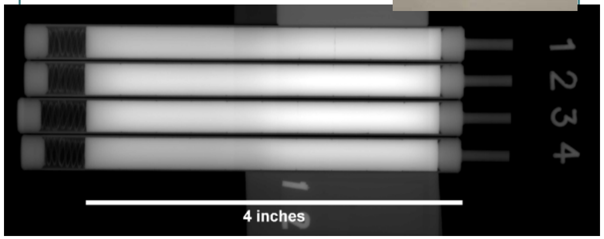
- *Develop **coated Zr-alloy cladding** for improved accident performance*
- ***Increased fuel pellet conductivity**: Fuel with reduced stored energy that must be accommodated during DBE*
- *Additives achieved:*
  - *SiC powder or whiskers*
  - *Diamond*
  - *Chromia dopant*



GE

- *Develop advanced **ferritic/martensitic steel alloys (e.g., Fe-Cr-Al) for fuel cladding** to improve behavior under severe accident scenarios*
- *Objectives:*
  - *Characterize candidate steels*
  - *Study tube fabrication methods, neutronics, fuel economy, thermo-hydraulic calculations, regulatory approval path*
  - *Initiate ATR testing with UO_2 and two cladding materials.*

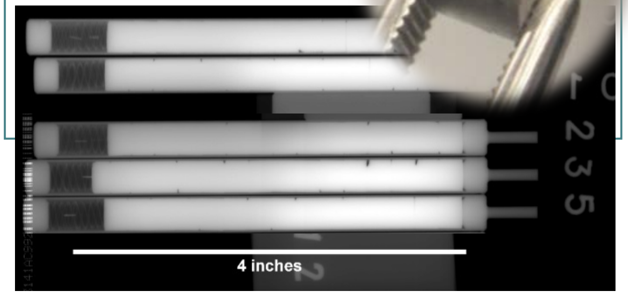




Westinghouse

- ***Cladding** concepts:*
  - ***SiC** and SiC ceramic matrix composites;*
  - ***coated Zr alloys***
- ***High density/high thermal conductivity fuel pellets***
- *First batch of U_3Si_2 pellets were sintered using finely ground powder*
- *Pellets were pressed using pressures of 6,000-10,000 psi and sintered at temperatures of 1400 ° C*

U_3Si_2 Pellet



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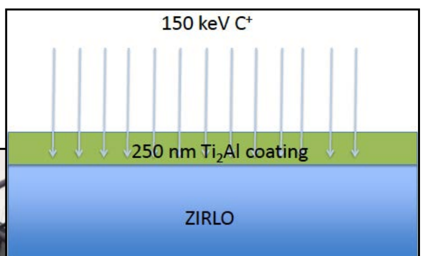
Integrated Research Projects (IRPs) on ATF and Advanced Reactor Design

University of Tennessee

- Ceramic coatings for cladding: MAX phase and multi-layer ceramics
- Team: Penn State, U. Michigan, UC Boulder, LANL, Westinghouse, Oxford, U. Manchester, U. Sheffield, U. Huddersfield, ANSTO

Approach:
(i) MAX phase ceramic coatings and
(ii) graded interface architecture (multilayer) ceramic coatings, using yttria-stabilized zirconia (YSZ) as the outer protective layer



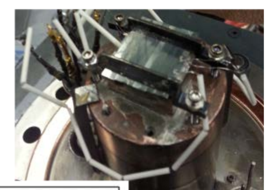
Autoclave Tree

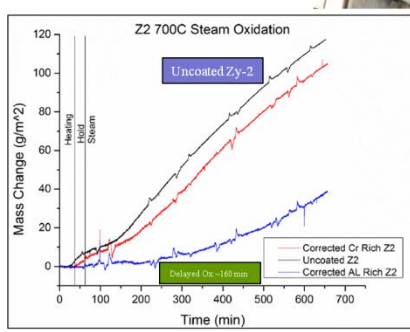
THE UNIVERSITY of TENNESSEE
KNOXVILLE, CHATTANOOGA, MARTIN, TULLAHOMA, MEMPHIS

University of Illinois

- Engineered Zr alloy cladding
- Team: U. Michigan, U. Florida, INL, U. Manchester, ATI Wah Chang

Approach:
(i) application of a coating layer to Zr base
or
(ii) modification of the bulk Zr cladding composition to promote precipitation of minor phase(s) during fabrication





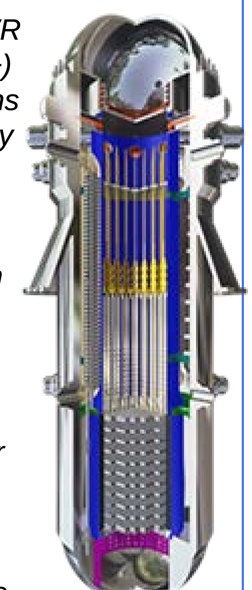
UNIVERSITY OF ILLINOIS
URBANA-CHAMPAIGN • CHICAGO • SPRINGFIELD

Georgia Institute of Technology

- *Integral Inherently Safe Light Water Reactor (I2S-LWR)*

Team: U. Michigan, Virginia Tech, U. Tennessee, U. Idaho, Florida Tech, Morehouse College, INL, Westinghouse Electric, Southern Nuclear, Polytechnic of Milan, U. Cambridge, U. Zagreb

Approach:
(i) Focus on advanced LWR concepts (beyond Gen III+) and associated fuel designs
(ii) Extend enhanced safety of SMRs to GWe-class PWR through integral primary configuration and high-performance fuel with enhanced accident tolerance (silicide fuel with FeCrAl cladding)
(iii) Holistic/synergistic design to make the reactor inherently safe, while promoting economics
(iv) Improvements to all GEN IV performance goals



Georgia Tech

Bilateral International Collaboration Includes Significant ATF Development

France

Currently defining bilateral activities with specific agreement to support international activities related to ATF, with joint development of attributes and metrics and coordination of facilities.

CEA pursues ATF R&D through a tri-party agreement with AREVA and EDF.

Japan

- *Definition of attributes and metrics*
- *Coordination of technology research and development*
- *Coordination of facilities used for R&D*

Russian Federation (currently on hold)

- ***Advanced LWR fuels and ATF***
- *Exchange of attributes and metrics*

China

- *Attributes and metrics*
- *Information exchange on R&D facilities*

European Union

- *2 New INERI projects*
- *Horizon 2020*

UK –

Bilateral activities currently under discussion
(active partners in ATF FOAs and IRPs)

Others

- ***OECD/NEA Expert Group***
- ***IAEA Expert Group***

FY 2014-15 Budget Summary

(dollars in thousands)

Subprogram	FY 2014 Current	FY 2015 Request	FY 2015 House Mark	FY 2015 Senate Mark
Material Recovery & Waste Form Development	34,170	35,300	b	b
Advanced Fuels	58,177	43,100	60,100	60,100
Systems Analysis and Integration	18,977	18,500	b	b
MPACT	7,358	7,600	b	b
Used Nuclear Fuel Disposition				
Used Nuclear Fuel R&D	29,520	49,000	55,000	30,000
Integrated Waste Mgmt. System	29,520	30,000	0	89,000
Fuel Resources	3,485	5,600	b	b
Balance (b)		67,000	66,900	50,900
Total	**181,207***	**189,100**	**182,000**	**230,000**

** Total is post SBIR-STTR which is approximately $5M.*

FY 2015 House Mark

- *$12,000 for additional support of feasibility studies for accident tolerant light water reactor fuels and $5,000 for additional support of capability development of transient testing.*
- *$6,000 is to support activities to design and certify a rail car or cars for use with licensed and anticipated transportation casks.*
- *There is $150M for Nuclear Waste Disposal "to continue the Department of Energy's statutorily required activities for the Yucca Mountain license application." There is also $55M for the NRC "to continue adjudication of the Yucca Mountain license application." The House directs the NRC to report "not later than January 1, 2015, on its plan to complete the license application and its additional funding needs as necessary."*

FY 2015 Senate Mark:

- *$3,000 is to design, procure, and test industry-standard compliant rail rolling stock; $30,000 is for activities on behavior of spent fuel in long-term storage, under transportation conditions, and in various geologic media. Priority should be placed on the on-going study of high-burnup fuel in dry storage.*
- *$10,000 is for the development and qualification of meltdown-resistant fuels based on ceramic-compacted coated particles. $3,000 is recommended to advance promising and innovative research, including ceramic cladding from qualified and competitively selected small business research task awards that complement industry and university projects and are focused on the development and testing of accident tolerant fuels.*

Summary

- Very challenging goal and timeline
- Excellent support, interaction, and collaboration across the board
- Fully committed and making good progress

QUESTIONS?