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Development Strategy for Advanced LWR Fuels with Enhanced Accident Tolerance

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Presentation

- **The presentation will discuss the following topics:**
  - Review the history and evolution of the Accident Tolerant Fuel Program
  - Review the proposed activities involved in effecting an Industry, Government, University collaboration to achieve a defined goal

- **Outline**
  - Description of the history from a pre-Fukushima LWR enhanced fuel performance development activity to a post-Fukushima enhanced accident tolerance fuel development activity
  - Three Phased Strategy
  - The Big Challenges
    - *Define a goal that is technically reasonable*
    - *Plan a strategy that effectively utilizes industrial, laboratory and university talent to support reaching the goal*
    - *Develop a stable program*

Fuels Campaign Mission

Focus of this presentation

Next generation LWR fuels with enhanced performance and safety and reduced waste generation

Metallic transmutation fuels with enhanced proliferation resistance and resource utilization

Capabilities Development for Science-Based Approach to Fuel Development

- Advanced characterization and PIE techniques
- Advanced in-pile instrumentation
- Separate effects testing
- Transient testing infrastructure

The program must address all three major elements of the campaign in a balanced way!

Advanced LWR Fuels with Enhanced Accident Tolerance

Vision

LWR fleet using fuels with enhanced accident tolerance to provide a substantial fraction of the nation's clean energy

Mission

Develop the next generation of LWR fuels with improved performance, reliability and safety characteristics during normal operations and accident conditions while minimizing waste generation

Must be acceptable to vendors/utilities

- ***Better safety performance (e.g. during normal, design-basis accidents and beyond design-basis accidents)***
- ***Reliability and fuel configurations similar to current fleet***
- ***Acceptable economics***
- ***Favorable neutronics and licensing characteristics***

10-year Goal

Insert a LTA/LTR into an operating commercial reactor

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Progression of Advanced LWR Fuel Development Activities

FY2010

- *Innovative fuels call for the national labs*
- *Innovative fuels review: 10 concepts selected, 3 concepts funded (Feb 10)*
- *Industry Task (TO1) supporting the Fuels Working Group established (Apr 10)*

FY2011

- *TO1 participants provided feedback on innovative fuel concepts (Nov 11)*
- *Industry TO5 established: advanced concepts & increased enrichment INL advisory group is established (Feb 11)*
- *FUKUSHIMA Events (Mar 11)*
- *Working Group: focus changed from enhanced performance to enhanced accident tolerance fuels (Mar 11)*

FY2012

- *Advisory group recommendations for fuel/clad concepts (Oct 11)*
- *Senate language on accident tolerant fuels*

ENHANCED PERFORMANCE

ENHANCED ACCIDENT TOLERANCE

Industry Engagement With Fuels R&D - since 2010

Working Group Support
- *Shaw/Westinghouse*
- *AREVA*
- *Energy Solutions*
- *Enercon*

LWR Fuel Concept Support
- *Shaw/Westinghouse*
- *AREVA*
- *GE-Hitachi*

INL Advisory Group
- *Duke*
- *Dominion*
- *TVA*
- *Constellation*
- *Westinghouse*
- *AREVA*
- *Global Nuclear Fuels*
- *EPRI*
- *Babcock & Wilcox*

Senate Guidance Regarding Accident Tolerant Fuel

- **In the Consolidated Appropriations Act, 2012, Conference Report 112-75, the Department of Energy, Office of Nuclear Energy was:**
  - Directed "to give priority to developing enhanced fuels and cladding for light water reactors to improve safety in the event of accidents in the reactor or spent fuel pools,"
  - Urged " that special technical emphasis and funding priority be given to activities aimed at the development and near-term qualification of meltdown-resistant, accident-tolerant nuclear fuels that would enhance the safety of present and future generations of Light Water Reactors,
  - And requested "to report to the Committee, within 90 days of enactment of this act, on its plan for development of meltdown resistant fuels leading to reactor testing and utilization by 2020."

Definition and Challenge

Definition of Fuels with Enhanced Accident Tolerance

Fuels with enhanced accident tolerance are those that, in comparison with the standard UO_2 – Zircaloy system currently used by the nuclear industry, can tolerate loss of active cooling in the reactor 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, operational transients, as well as design-basis and beyond design-basis events.

Major Attributes to Address

Improved Reaction Kinetics with Steam
- Heat of oxidation
- Oxidation rate

Slower Hydrogen Generation Rate
- Hydrogen bubble
- Hydrogen explosion
- Hydrogen embrittlement of the clad

High temperature during loss of active cooling

Improved Fuel Properties
- Lower operating temperatures
- Clad internal oxidation
- Fuel relocation / dispersion
- Fuel melting

Improved Cladding Properties
- Clad fracture
- Geometric stability
- Thermal shock resistance
- Melting of the cladding

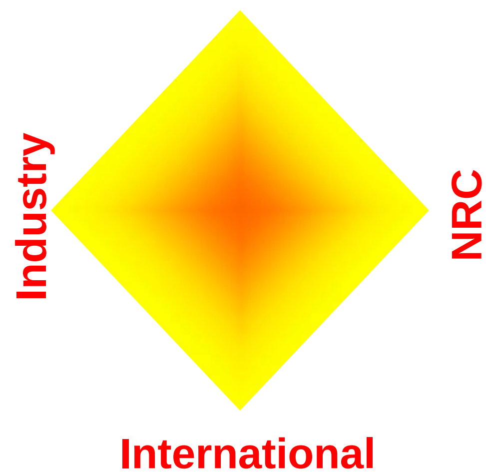
Enhanced Retention of Fission Products
- Gaseous fission products
- Solid/liquid fission products

Based on these safety-related issues, metrics for quantifying the enhancements in accident tolerance must be developed in conjunction with the safety features of a given LWR design and based on specific accident scenarios.

Programmatic Interfaces

- **Integrated program across NE**
  - NE-3: infrastructure (e.g. test facilities)
  - NE-5: fuel development , coordination with university support
  - NE-7: supporting reactor related technologies (e.g. instrumentation, materials, modeling and simulation, etc.)
- **Strong collaborations with industry is NECESSARY**
  - Campaign industry advisory group has been very useful
  - Formal technical coordination group?
- **Working with NRC in defining the accident tolerance, its attributes and associated metrics will be very USEFUL**
- **International engagement in defining accident tolerance, its attributes and associated metrics will be ESSENTIAL**

DOE Research
- **NE-3, NE-5, NE-7**
- **National Laboratories**
- **Universities**



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Further Actions Engaging Industry & Universities

- **Funding Opportunity Announcement :**

Development of LWR Fuels with Enhanced Accident Tolerance, (DE-FOA-0000712)

Fund up to 3 two-year projects ($10M total) focused on early phase analysis and data collection

  - https://www.fedconnect.net/Fedconnect/PublicPages/PublicSearch/Public_Opportunities.aspx searching under key word "accident"

- **NEUP Integrated Research Project:**

Advanced Nuclear-Cladding and Fuel Materials with Enhanced Accident Tolerance for Current Generation & Gen III+ Light Water Reactors

  - Fund a single three-year project ($3.5M total) to develop materials and fuel concepts.
  - www.neup.gov searching under IRP

- **NEUP Program Supporting R&D Awards in FY12 related to accident tolerant fuel:**
  - *Testing of Sapphire Optical Fiber and Sensors in Intense Radiation Fields, when Subjected to Very High Temperatures* (Ohio State Univ.)
  - *Improved Accident Tolerance of Austenitic Stainless Steel Cladding through Colossal Supersaturation with Interstitial Solutes* (Case Western Reserve Univ.)
  - *Development of Innovative Accident Tolerant High Thermal Conductivity UO2 Fuel Pellets with a Diamond Dopant* (Univ. of Florida)
  - *Better Radiation Response and Accident Tolerance of Nanostructure Ceramic Fuel Materials?* (Univ. of Tennessee)

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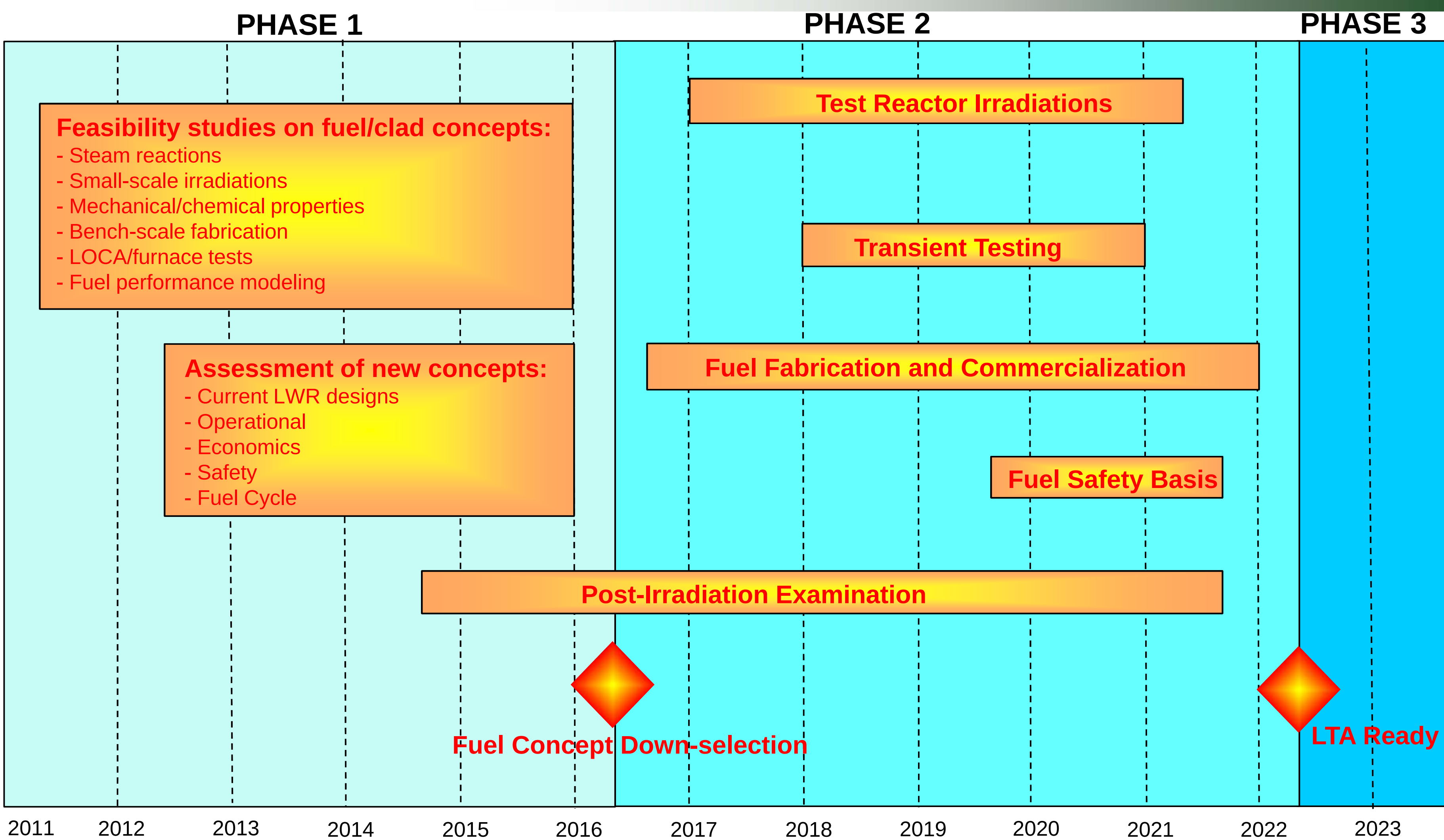
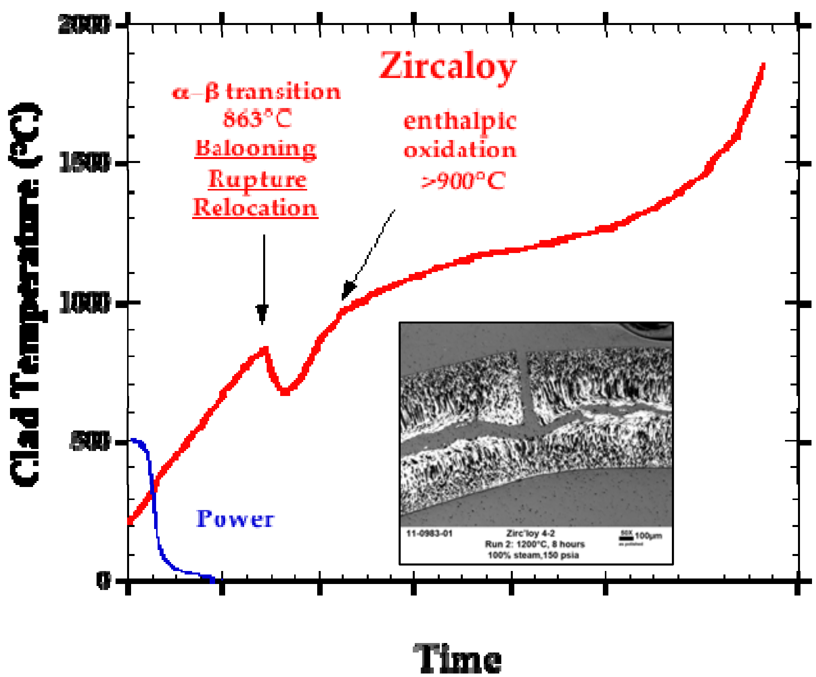
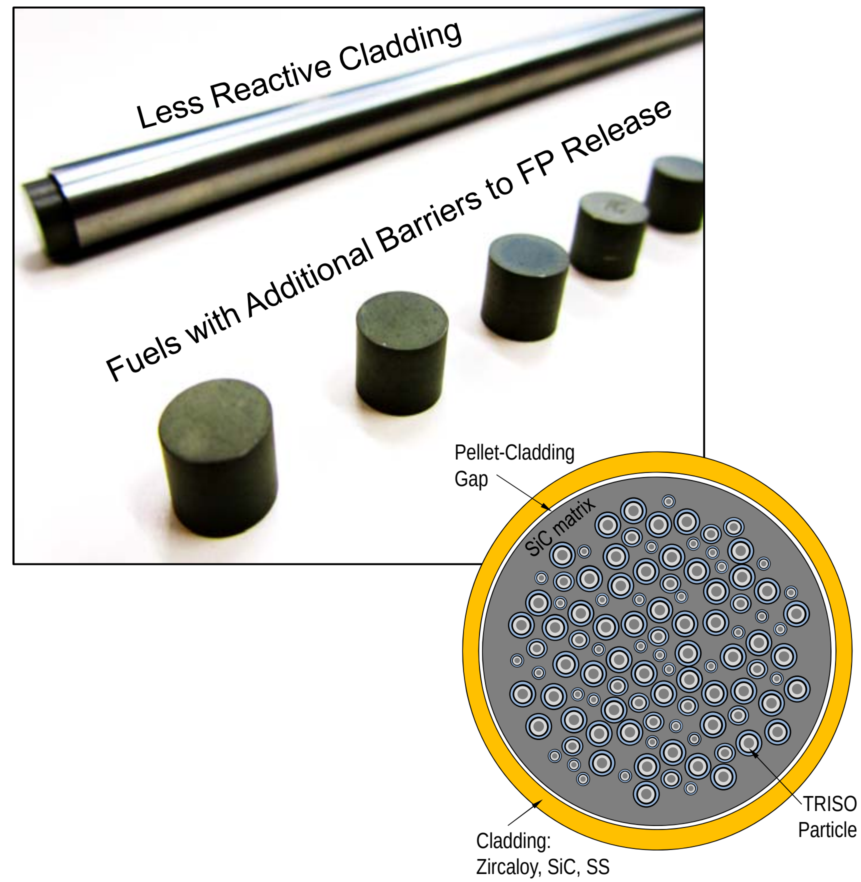
R&D Strategy:
National Labs + Universities + Industry



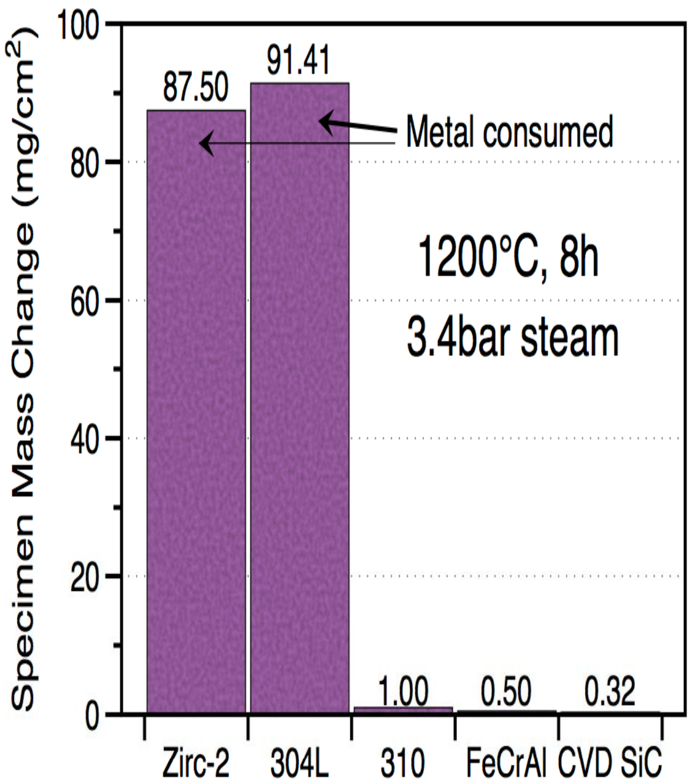
Enhancing Safety Margin with Advanced Fuels (example courtesy of L.Snead, ORNL)

Reactor safety margin can be improved through new fuel forms with much reduced exothermic reaction, suppressed hydrogen production, and greater time to fission product release.

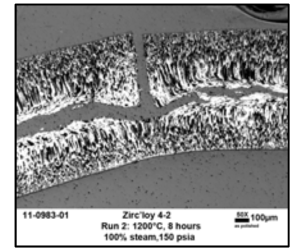




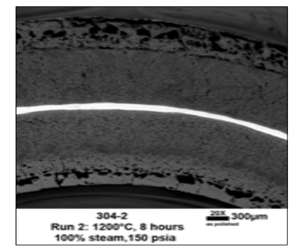
Comparison of Fuel Clad Options
1200°C - 8 hours Accident Condition



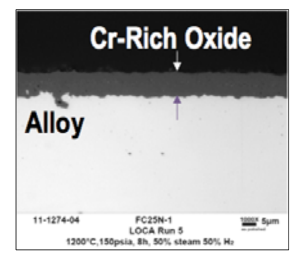
Zircaloy Clad – UO_2			
Thickness Consumed	Clad Heat Generation	Clad Hydrogen Generation	Fission Product Release
Complete (650 μm)	10^{11} J	740 kg	Complete



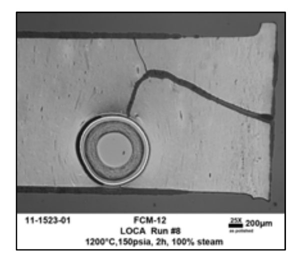
Connecticut Yankee 304 L Stainless – UO_2			
Thickness Consumed	Clad Heat Generation	Clad Hydrogen Generation	Fission Product Release
600 of 650 μm	10^{10} J	350 kg	Significant



FeCrAl Steel– UO_2			
Thickness Consumed	Clad Heat Generation	Clad Hydrogen Generation	Fission Product Release
1 micron	1E7	1 kg	None



Zircaloy Clad - SiC Matrix TRISO Fuel			
Thickness Consumed	Clad Heat Generation	Clad/Fuel H Generation	Fission Product Release
Complete (650 μm)	10^{11} J	740/50 kg	None



Summary

- **A three-phase approach for commercialization of the LWR fuels with enhanced accident tolerance is defined:**
  - Feasibility (industry participation with limited cost share)
  - Development and qualification (industry participation with cost share)
  - Commercialization (industry)

- **The scope is focused on operating reactors and reactors with design certifications (GEN II thru GEN III+)**

- **The technologies developed during the process can be applicable to more advanced designs**