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Advanced Nuclear-Cladding and Fuel Materials with Enhanced Accident Tolerance for Current Generation & GEN III+ LWRs

Bradley Williams
Program Manager, Advanced Fuels
Office of Fuel Cycle R&D

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Advanced Fuels Campaign

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!

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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 TO#1 is established (Apr 10)*

FY2011

- *TO1 participants provided feedback on innovative fuel concepts (Nov 11)*
- *Industry TO#5 is established: Increased enrichment*
  INL advisory group is established (Feb 11)
- *FUKUSHIMA Events (Mar 11)*
- *Working Group: topic changed to enhanced accident tolerant 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 Participants

TASK ORDER 1
- *Shaw/Westinghouse*
- *AREVA*
- *Energy Solutions*
- *Enercon*

TASK ORDER 5
- *Shaw/Westinghouse*
- *AREVA*
- *GE-Hitachi*

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

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The advisory committee considered many concepts

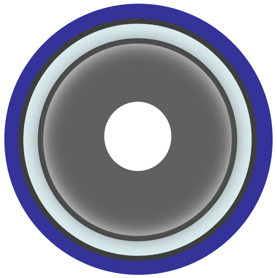
- Accident Tolerant Corrosion and Wear Resistant Coating of MAX Phase Materials on Zirconium Alloy Cladding
- Accident Tolerant High Conductivity LWR Fuel
- Advanced Dispersion Fuel for LWR’s
- Advanced Water Rod Designs for BWR Assemblies
- Annular Fuel Pellet With Getter Core
- Double-Cladding LWR Fuel Rod Design
- Exploring Uranium Nitride Fuel Utilization in LWR
- Fully Ceramic Microencapsulated (FCM) Fuel
- “Freeze-casting” as a Novel Process to Make Light Water Reactor Fuels
- High Power Density Zr-U Fuel for LWRs
- Hydride fuel for BWR and PWR
- MAX Phase Carbides: Enabling Materials for Removal of Zircaloy in LWR Fuels
- Mesoscale Fuel/Cladding Synthetic Control
- Metal Matrix Microencapsulated (M3) Fuel
- Mixed thorium-plutonium oxide fuels for LWRs
- Multi-layered SiC/SiC LWR fuel cladding
- Nitride fuels for LWRs
- SiC-Composite Fuel and Cladding Using Preceramic Precursors
- Silicon Carbide Triplex Cladding for LWRs – Coupled with Advanced Fuel Forms
- Thorium-Based Fuels for PWRs
- U-lined fuel rod
- Uranium Alloy Metal Fuel for Light Water Reactors
- Wire wrapped fuel rods for hexagonal PWR fuel assemblies

The recommendations by the INL Advisory Committee

- Concepts that the IAC recommended for future research included:
  - MAX Phase Materials or other coatings
  - Silicon carbide cladding concepts
  - Fully Ceramic Microencapsulated (FCM) Fuel
- The IAC opinion was divided on uranium nitride fuel
  - Compatibility with water is a key issue that must be solved
  - Large payoff if successful; may warrant further investment to research water compatibility

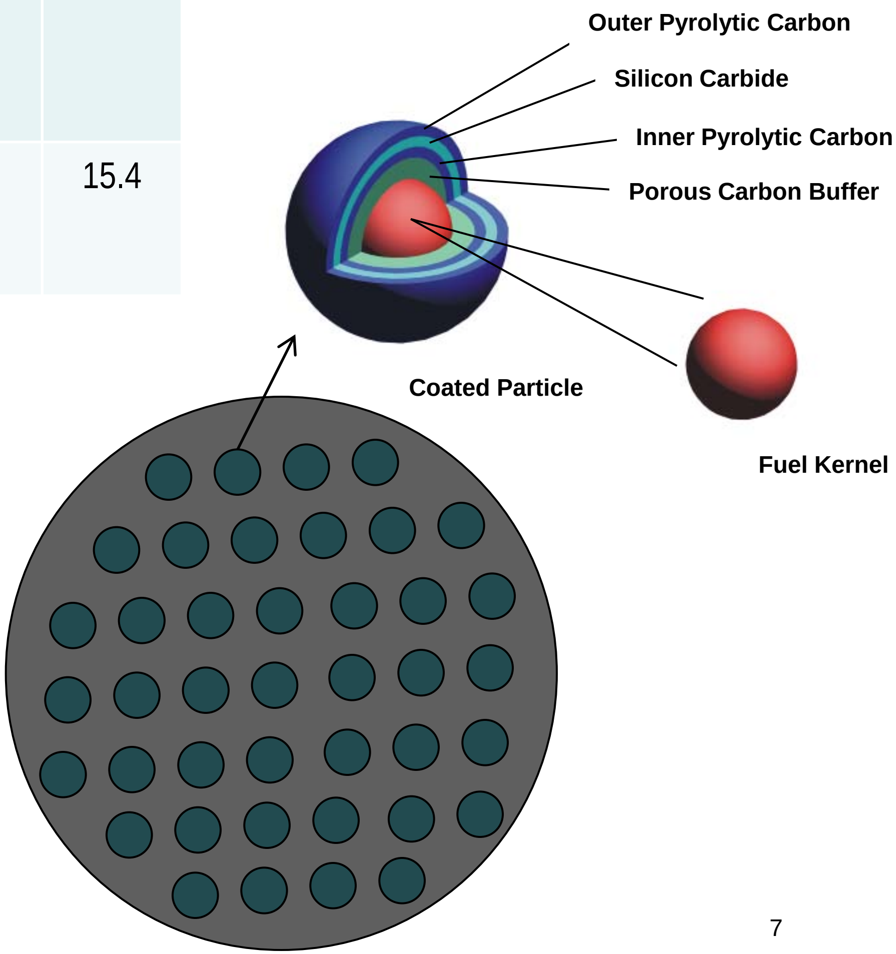
Ongoing feasibility studies within the campaign

- Metallic LWR Fuels

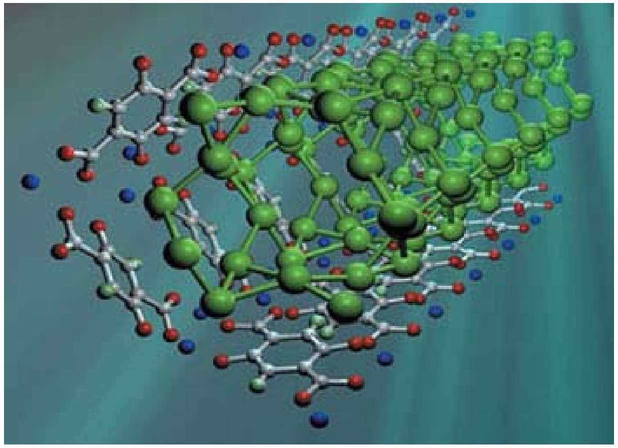


Property	Metal	Oxide
Thermal Conductivity (cal/sec-cm-C)	0.063	0.022
Specific Heat (cal/mole-C)	6.6	15.4

- Microencapsulated Fuels



- Getter concepts for fission gases



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, can tolerate loss of active cooling in the core for a considerably longer time period while maintaining or improving the fuel performance during normal operations

To demonstrate the enhanced accident tolerance of candidate fuel designs, metrics must be developed and evaluated using a combination of design features for a given LWR design, potential improvements and the design of advanced fuel/cladding system.

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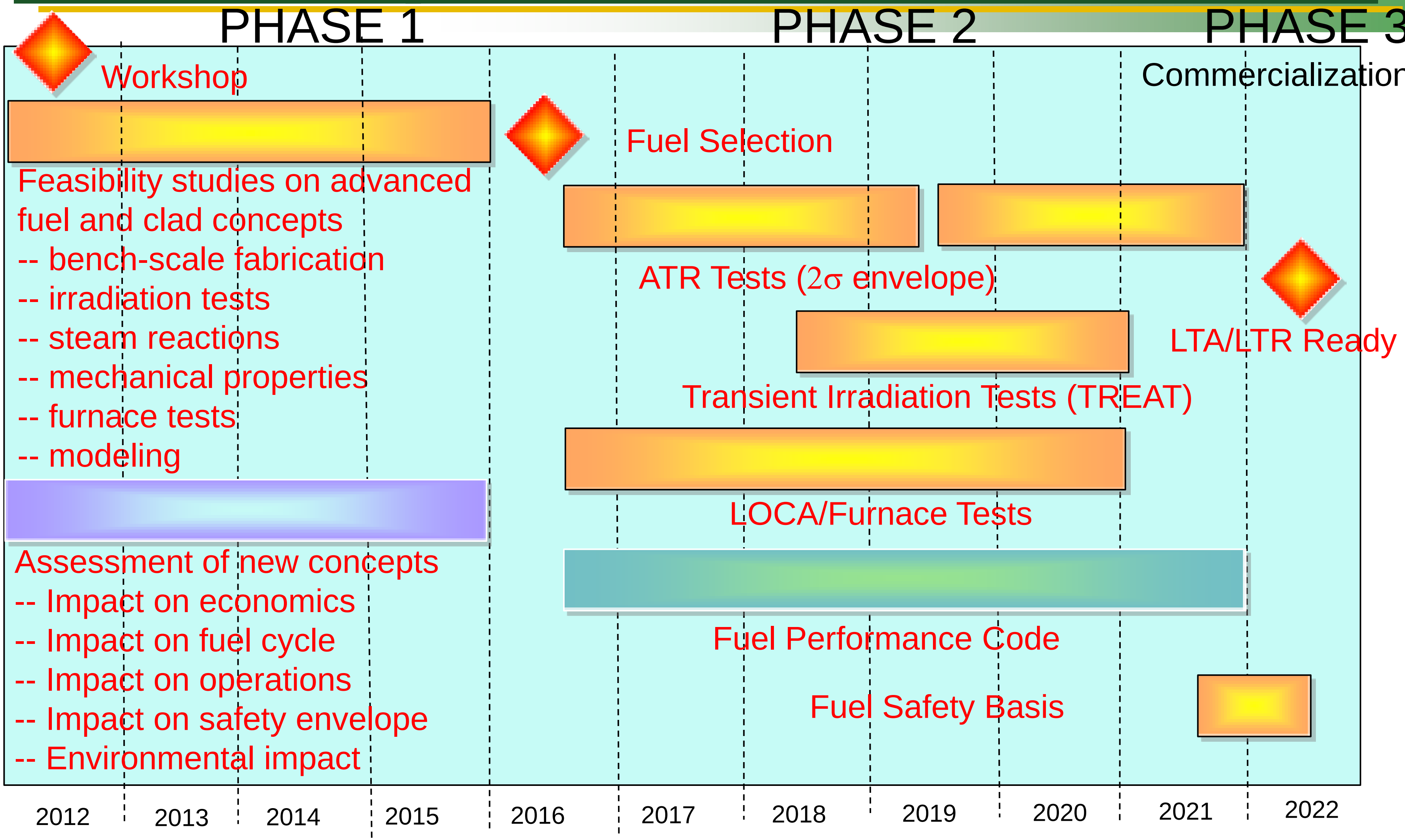
R&D Strategy : National Labs + Universities + Industry



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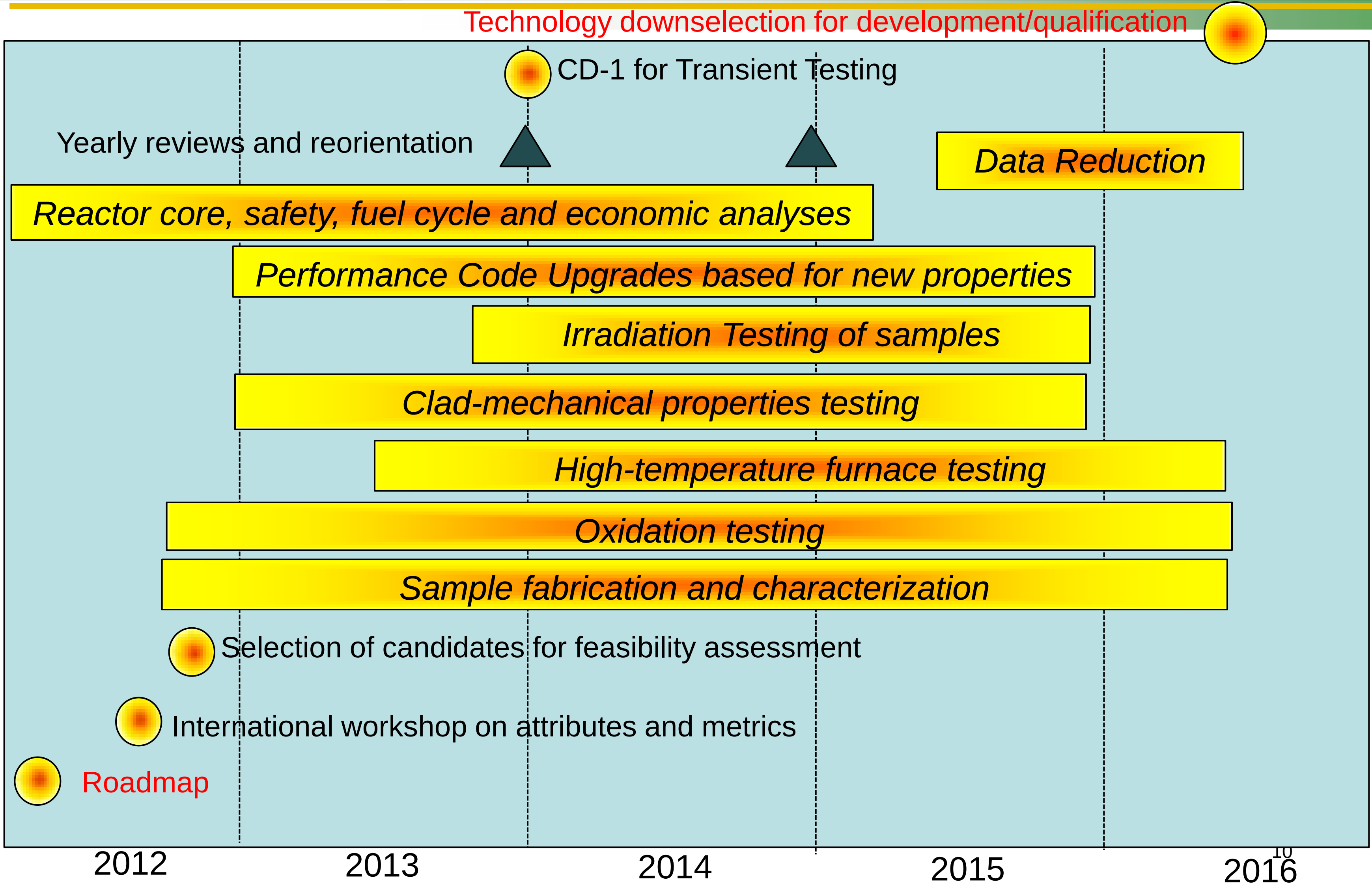
Feasibility phase – Major activities and milestones



What are the major issues to be addressed for the attributes?

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

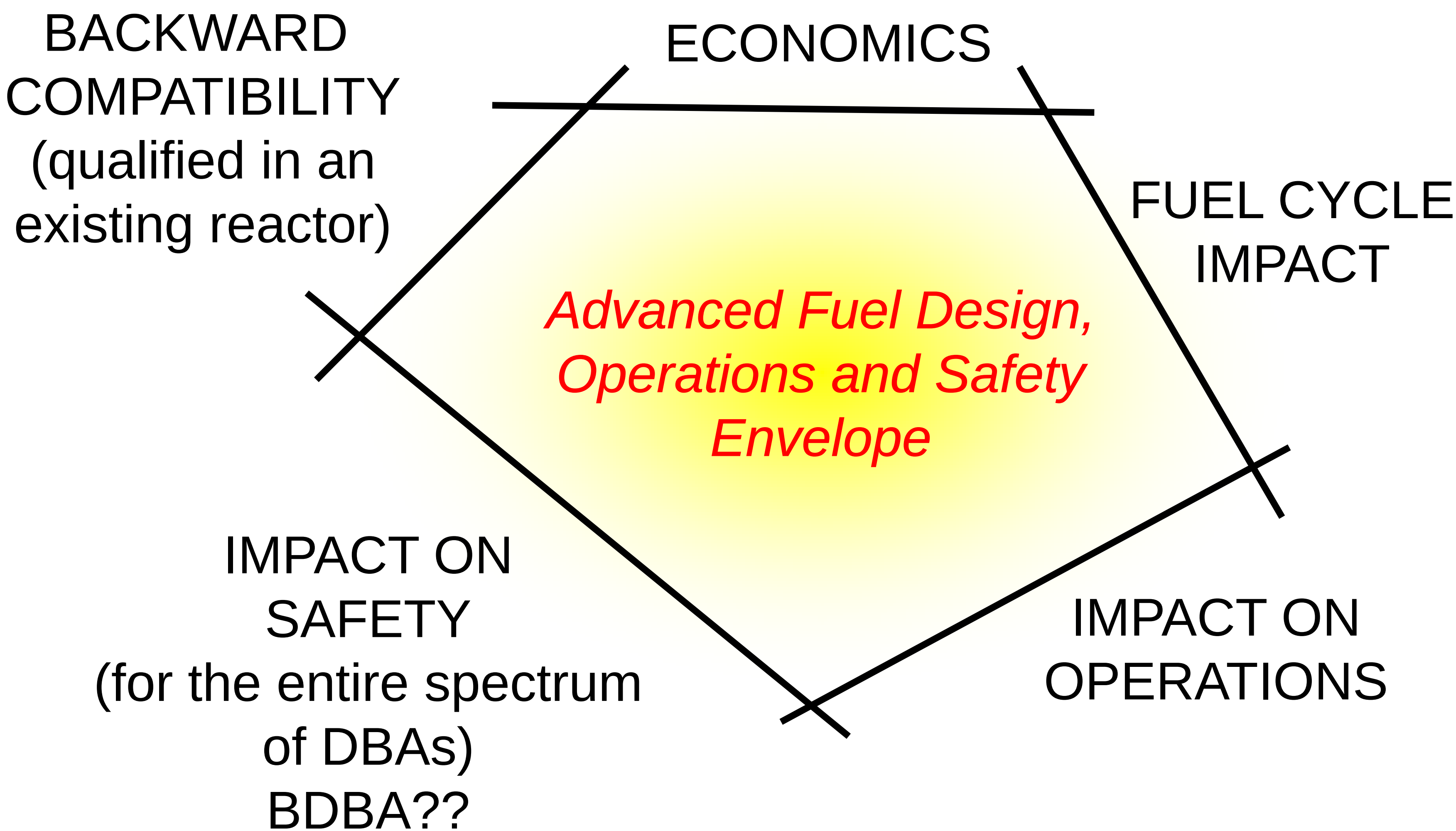
Improved Fuel Properties
- Lower operating temperatures
- Clad internal oxidation
- Fuel relocation / dispersion
- Fuel melting

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.

Constraints on new fuel designs



Economics should be considered within the big picture

- Economic Impacts: It is likely that the "fuels with enhanced accident tolerance" will cost more
- How much additional cost will be tolerable to utilities ?
- Can some of the increase in cost be offset by other cost reduction ?
    - Higher burnup – longer cycle – smaller volume of used fuel?
    - Higher power density – power upgrades?
    - Reduction in reliability requirements on or total elimination of some safety systems?
    - cost reduction during wet and dry storage?

The impact of the new fuel on the overall fuel cycle must be considered.

- Enrichment
  - Small increases beyond 5% (SS cladding with UO_2 fuel)
  - Larger increases in enrichment (up to 20%) (microencapsulated fuels)
- Storage/Transportation/Disposal
  - Storage behavior of new fuels and cladding (wet and dry storage)
  - Impact on repository performance
- Impact on reprocessing if implemented in the next 30 to 40 years

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The new fuel should not shrink the currently established operating envelope.

- Maintain or expand the cycle length
  - Some concepts require new design for burnable poisons
  - Increased enrichment
- Maintain or improve on reactivity coefficients and safety margins
  - Void coefficients, doppler, etc…
- Maintain or improve on DNB margins
  - Fuels that can partially operate past DNB ??
- If a new assembly design is needed, it must operate within the thermal-hydraulic constraints of the primary loop design.
- Compatible with control rod, and safety rod designs

The fuel should not negatively impact the response to design basis accidents (DBAs)

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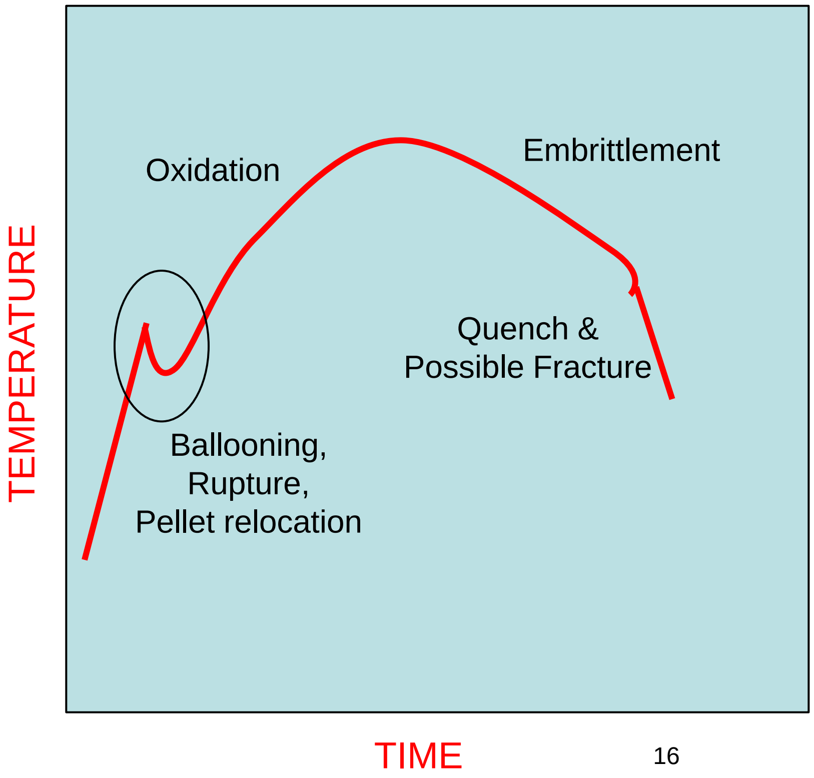
- Consider all accidents
  - Reactivity Insertion Accidents (RIA)
  - Loss-of-coolant accidents (LOCA)
  - Station blackout
  - Anticipated Transients without Scram (ATWS)
  - Others
- Current design-basis LOCA limits
  - Maintain coolable geometry
  - Temperature ≤ 1200 C
  - Oxide layer < 17% clad thickness
  - High burnup fuels?

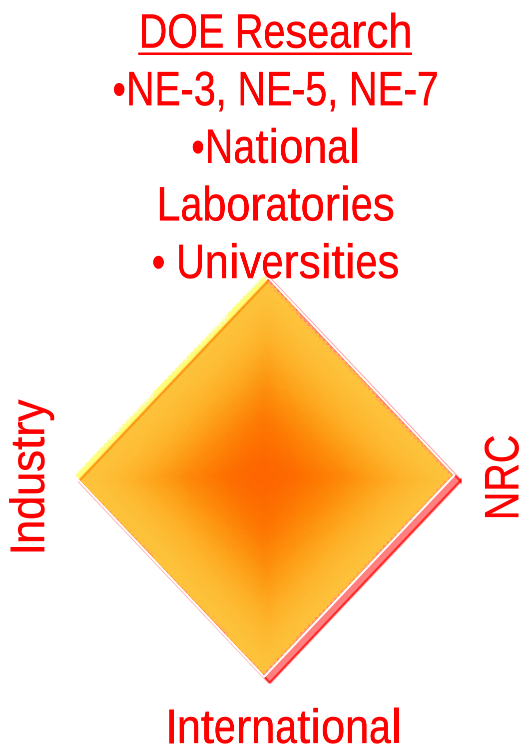


Development and demonstration of new fuels require new infrastructure

- Irradiation testing (steady state, operational transients, design-basis transients, failure thresholds)
- Furnace testing for high temperature conditions with irradiated samples (Hot Cells)
  - Steam reactions
  - Fuel behavior, fission product release
- Mechanical testing of cladding after irradiation and extended exposure to steam while in contact with fuel
- Characterization/PIE of failed fuel or seriously damaged fuel
- Capability to fabricate the new fuels eventually at large quantities for qualification

Interfaces for development of LWR fuels with enhanced accident tolerance

- Integrated program across NE
  - NE-5: fuel development
  - NE-7: supporting technologies (e.g. instrumentation, materials, modeling and simulation, etc…)
  - NE-3: infrastructure
- Strong collaborations with industry is NECESSARY
  - Campaign industry advisory group has been very useful
  - A more formalized working group?
- Working with NRC in defining the enhanced accident tolerance, its attributes and associated metrics will be very USEFUL
  - Working group with NRC-Research
- International engagement in defining accident tolerance, its attributes and associated metrics will be ESSENTIAL



FY12 IRPs on Accident Tolerance

- **Near-Term vs. Longer Term Focus**
  - FCR&D (NE-5) and RC RD&D (NE-7) will each solicit an FY12 IRP related to advanced LWR systems with enhanced accident tolerance.
  - The NE-5 project will focus on advanced fuels for currently operating reactors and those with design certifications (Gen III+).
  - The NE-7 project will focus on advanced LWR concepts (beyond Gen III+) and the associated fuel designs.

- **Near-Term (demonstrated in commercial LWRs within 10 years)**
  - Must fit within dimensional constraints of current reactors (qualified in existing reactors)
  - Must maintain or improve: cycle length, reactivity coefficients and safety margins, DNB margins, and response to design-basis accidents
  - Cannot degrade current performance
  - Potential advances include: clad coatings, advanced claddings, getters, (FCM fuel?)

- **Longer-Term**
  - Advanced reactor systems could be designed to incorporate a wider range of fuel concepts
  - Potential advances include: higher enriched fuels, new fuel compositions, new geometries and assembly/core configurations

NE-5 IRP on Advanced LWR Fuels with Enhanced Accident Tolerance

- **Scope**
  - Develop advanced materials and/or fuel-cladding concepts suitable for use in existing light-water reactors or light-water reactors with design certifications (GEN-III+) that would improve performance and safety, both during reactor service and during long-term storage in spent fuel cooling pools.
  - Improvements to the nuclear fuel and cladding system may be accomplished by many possible methods including: design, materials, or combinations of the two to achieve possibly lower fuel operating temperature, higher temperature capability, higher strength capability, and increased resistance to oxidation.

- **Outcomes**
  - Development, preliminary irradiation and demonstration of technical feasibility
  - Demonstration in commercial LWR within 10 years

- **Cost and Schedule**
  - Three year duration not to exceed $3.5M

Summary

- **The Fuel Cycle R&D Program's Advanced Fuels Campaign has been working on advanced LWR fuels with improved performance and enhanced accident tolerance.**

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

- **The scope of this effort is focused on existing LWR reactors and those with design certifications.**

- **This effort will be coordinated with similar efforts as appropriate and will help lead to a down selection for demonstration.**

- **A Separate FOA related to developing fuels with enhanced accident tolerance has just been released.**
  - https://www.fedconnect.net/Fedconnect/PublicPages/PublicSearch/Public_Opportunities.aspx