Fuel Cycle Research and Development

Overview of Accident Tolerant Fuel Development

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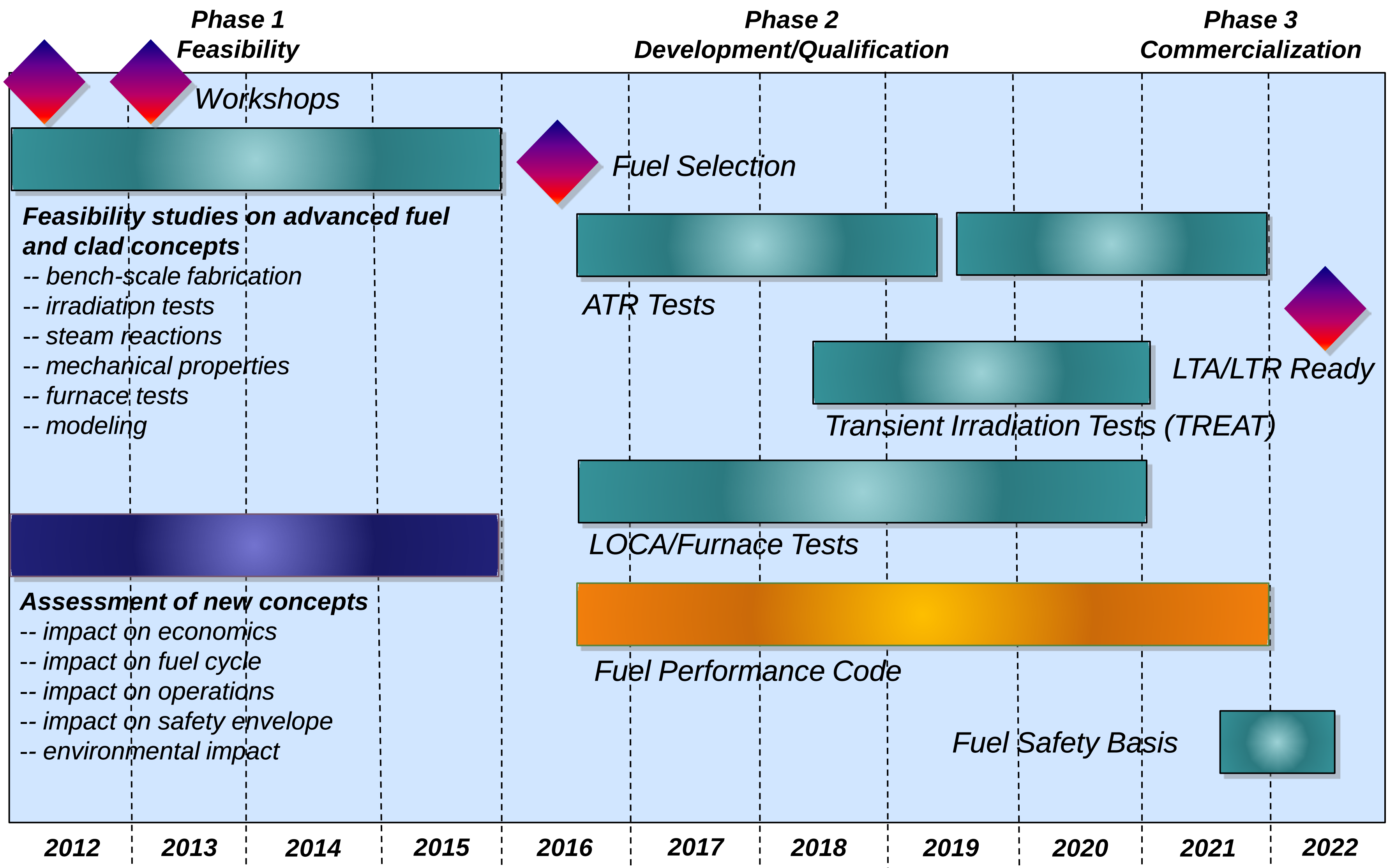
OECD/NEA workshop on Accident Tolerant Fuels
December 10-12, 2012 (Paris, FRANCE)

Accident Tolerant Fuel became a major focus area after Fukushima

- U.S. DOE fuel development program was exploring the development of next generation of LWR fuels enhanced performance.
  - Increased burnup – reduced waste volume
  - Increased reliability – reduced failures
  - Higher power density – power upgrades
- After the unfortunate events in Fukushima (March 2011) , the U.S. congress directed the DOE to focus efforts on development of fuels with enhanced accident tolerance.
- Accident Tolerant Fuel development program is being implemented as a collaborative effort among National Laboratories, Industry and Universities within the U.S.
- Due to the nature of the problem, International collaborations would be very beneficial.

RD&D Strategy For Enhanced Accident Tolerant Fuels



Major attributes of accident tolerant fuels are associated with the behavior of fuel and cladding at high temperatures.

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 (depending on the LWR system and accident scenario) 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.

High temperature during loss of active cooling

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

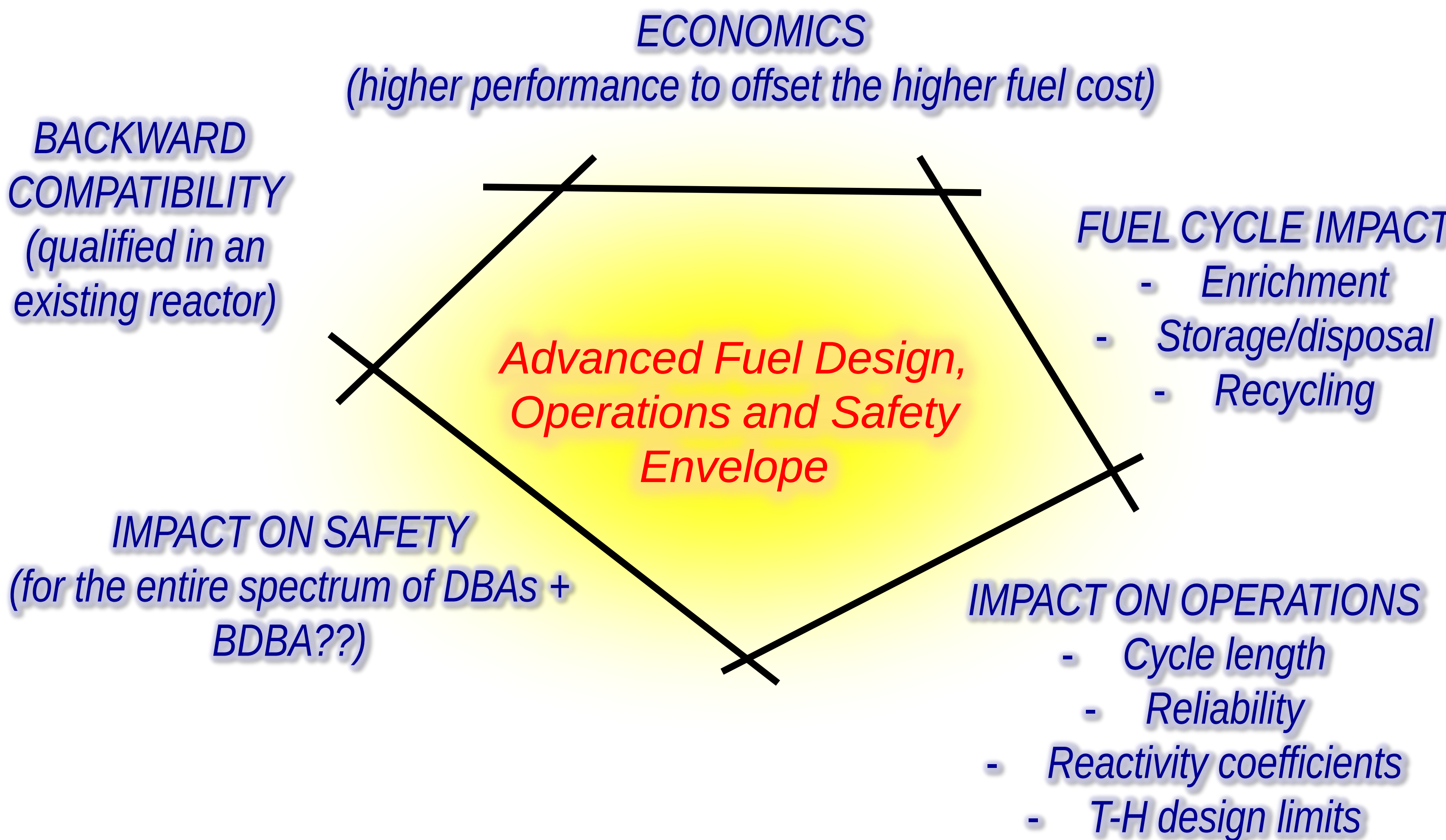
Slower Hydrogen Generation Rate
- Hydrogen bubble
- Hydrogen explosion
- Hydrogen embrittlement of the clad

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

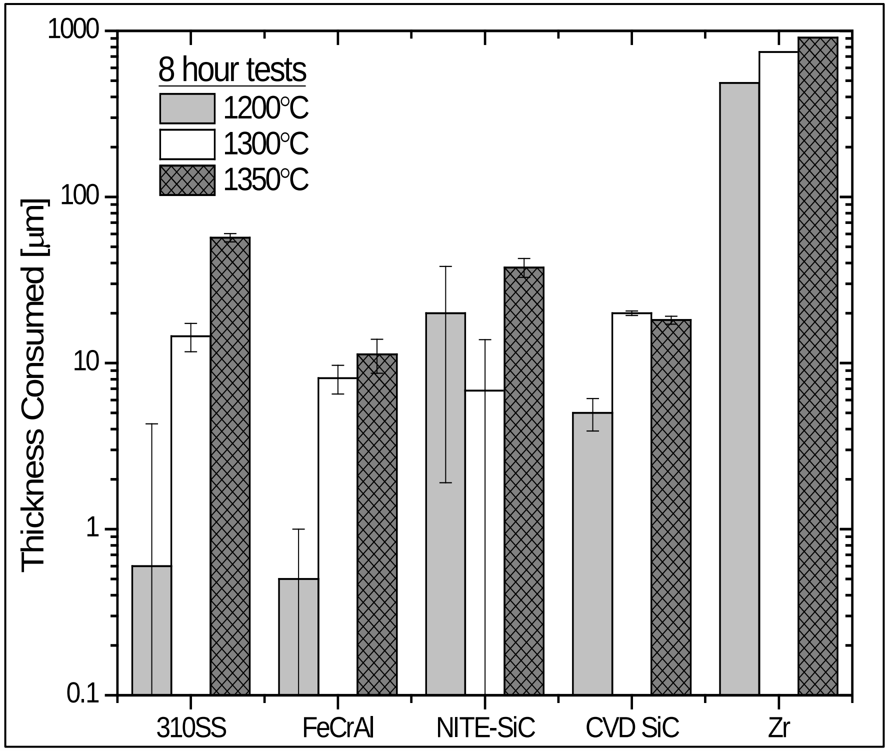
Enhanced Retention of Fission Products
-Gaseous fission products
-Solid/liquid fission products

The new fuel design must meet the LWR operations, safety and fuel cycle constraints



The primary focus is on cladding materials with more benign steam reaction

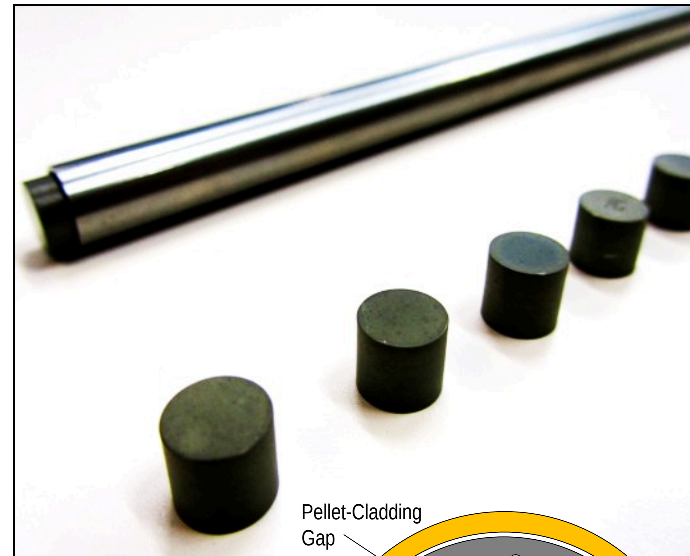
- Advanced steels (e.g. FeCrAl)
- Refractory metals (e.g. Mo)
- Ceramic cladding (SiC)
- Innovative alloys with dopants
- Zircalloy with coating
  - SiC
  - MAX-phase ceramics

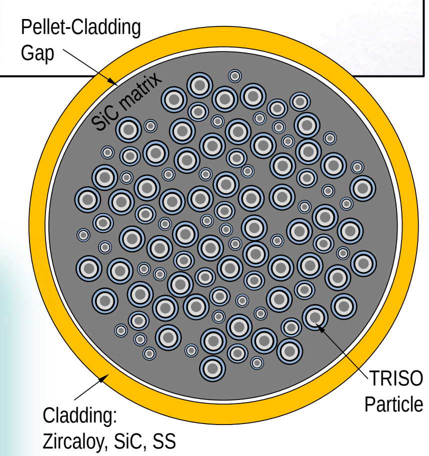


Each concept has some pros and cons across the spectrum of operating and transient conditions of interest. A systematic analytical and experimental evaluation is being performed during the feasibility studies.

Some new fuel concepts also are being considered

- Higher density fuels (metal, nitride, silicite)
  - Higher thermal conductivity
  - Higher fissile density to compensate for neutronic inefficiency of some new clad concepts without increasing enrichment limits
- Oxide fuels with additives.
- Microencapsulated fuels
  - TRISO or BISO fuel dispersed in a ceramic or metallic matrix





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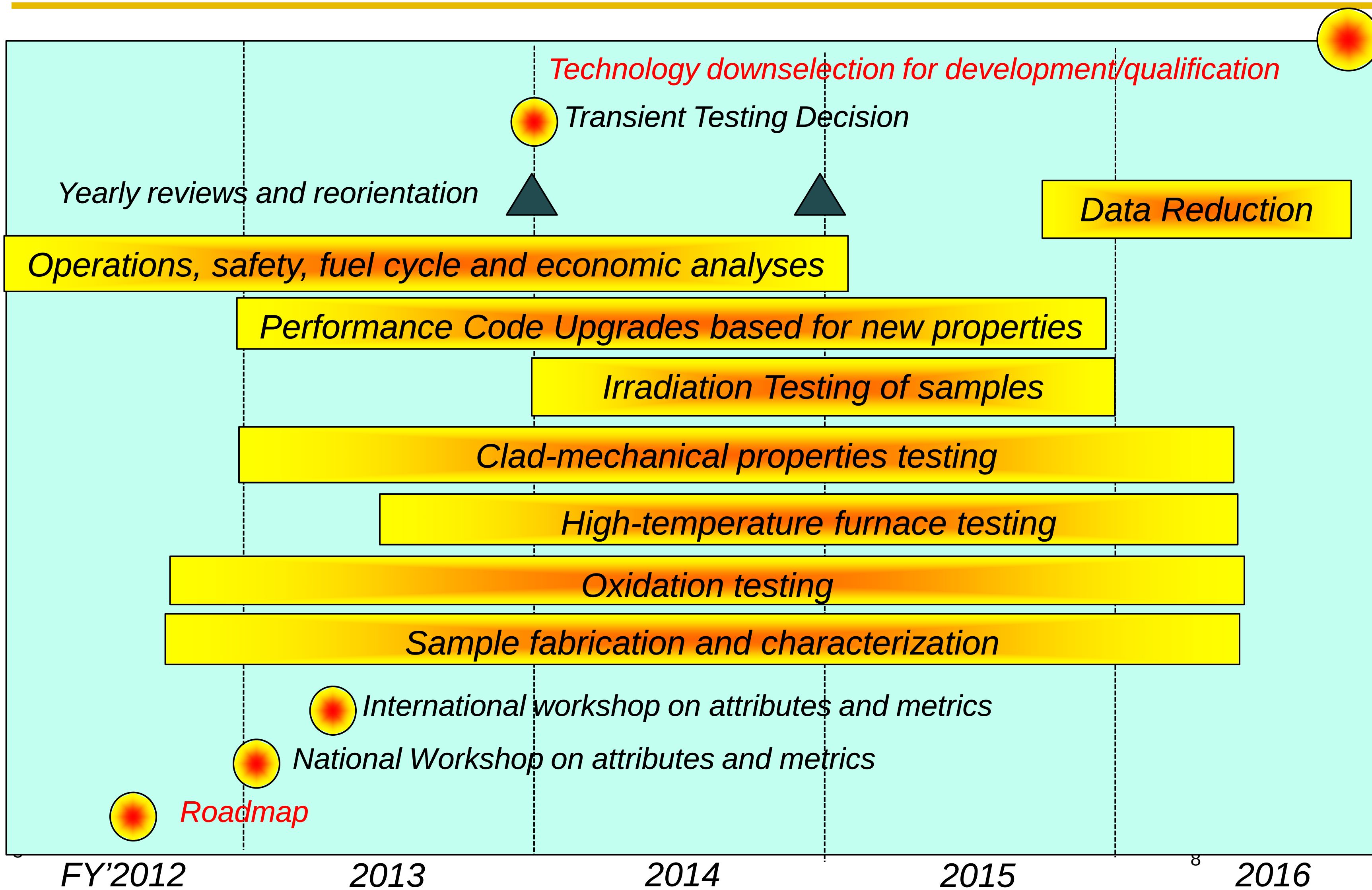
U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Near-term activities for ATF are aimed at completing the feasibility assessment



Background Information on Lead Industry and University Participants in the Accident Tolerant Fuels Development Program

Industry Teams Awarded 2 Year Feasibility Assessment s

- **Westinghouse: Develop and test cladding concepts, such as SiC and SiC ceramic matrix composites, and high density / high thermal conductivity fuel pellets, such as Uranium nitride-uranium silisides.**

  Partners include: General Atomics, Massachusetts Institute of Technology, Idaho National Laboratory, Texas A&M University, Edison Welding Institute, Los Alamos National Laboratory, and the Southern Nuclear Operating Company

- **General Electric Global Research : Proposes ferritic/martensitic alloys to demonstrate accident tolerance in fuel cladding materials for current light water reactors; in addition the use of these materials will maintain or improve the fuel cycle length and will improve the behavior of the fuel bundle under severe accident scenarios such as in the case of the loss-of-coolant accident (LOCA). Partners include: University of Michigan, Los Alamos National Laboratory, Global Nuclear Fuels.**

- **AREVA Federal Services, LLC : Concepts being developed and tested include fuel with chromium dopant in the UO-2, the addition of SiC fibers to the doped pellets, and several coatings on the Zirconium-alloy fuel claddings. Partners include: Duke Energy, TVA, Savannah River National Laboratory, University of Florida, University of Wisconsin.**

Integrated Research Proposals: Accident Tolerant Fuels

***University of Illinois, Urbana Champaign* PI:** **Brent Heuser**

Engineered Zircaloy Cladding Modifications for Improved Accident Tolerance of LWR Nuclear Fuel

Collaborators: University of Florida, University of Michigan, University of Manchester , ATI Wah Chang, Idaho National Laboratory

***University of Tennessee* PI: Kurt Sikafus**

Advanced Accident-Tolerant Ceramic Coatings for Zr-Alloy Cladding

Collaborators: Pennsylvania State University, University of Colorado- Boulder, University of Michigan, Oxford, U Manchester, U Huddersfield, U Sheffield, Australian Nuclear Science and Technology Organization), Westinghouse Electric, Los Alamos National Laboratory

***Georgia Institute of Technology* PI: Bojan Petrovic**

Integral Inherently Safe Light Water Reactor

Collaborators: University of Michigan, Virginia Tech, University of Tennessee, University of Idaho, Morehouse College, Polytechnic University of Milan, University of Cambridge, Westinghouse Electric, Southern Nuclear, Idaho National Laboratory

Summary and Conclusions

- Accident Tolerant Fuel feasibility studies are on-going in the U.S where multiple fuel and cladding concepts are being evaluated.
  - Collaboration among national laboratories, industry and universities
  - Examples of the efforts will be discussed in multiple presentations during this workshop.
- Two major facilities are being pursued as part of this initiative
  - Severe accident test station with fresh and irradiated fuels (target date: 2013)
  - Transient testing of fuels using TREAT (target date: 2018)
- The experimental efforts are complemented by analyses
  - Fuel performance under transients
  - Core analyses
  - Reactor systems analyses including severe accidents
- The topic is amenable for strong international collaborations