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Transformational Advanced Fuels Development

USNRC 5th Annual Fuel Cycle Information Exchange

John Herczeg
Acting Director, Office of Fuel Cycle
Research and Development

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Outline

- Fuel Cycle R&D Advanced Fuels Campaign – Scope and Strategy
- FCR&D Fuel Cycle Options
- Advanced Fuel Cycle R&D Campaign – Mission & Objectives
- AFC R&D – Grand Challenges
- Deep Burn and Other Concepts in the AFC R&D Campaign
- Summary Observations

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Technical Areas (Campaigns)

- Separations and Waste Forms
- **Advanced Fuels** (focus of this presentation)
- Modeling and Simulation
- Materials Protection, Accounting, and Control for Transmutation
- Used Nuclear Fuel Disposition

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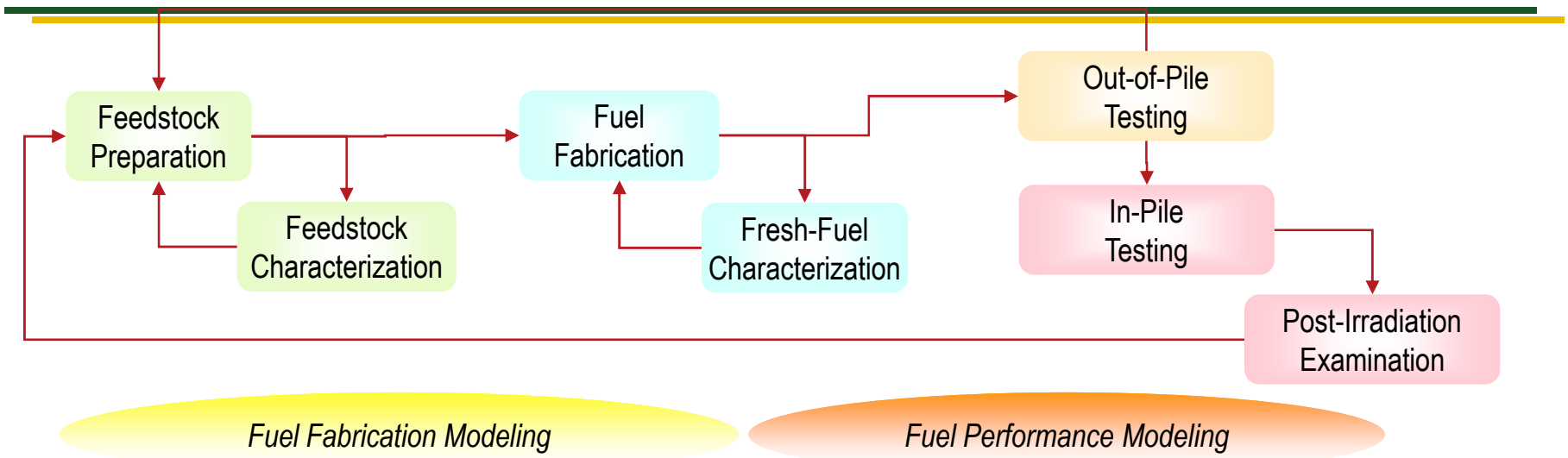
AFC Scope



- Advanced cladding and core materials in contact with various coolant types used in the reactors and transmuters
- Metallic, ceramic, and composite (dispersion in the form of CERCER and CERMET) fuels
- Pelletized, powder-loaded (Vibropac), sphere-pac, and particle fuel
- Fuels containing fissile and fertile materials and fertile-free fuels and targets with inert matrices
- Targets used for heterogeneous transmutation of minor actinides (MAs)
- Fabrication process development and in-pile fuel performance assessment
- Fuel types that can be used both in thermal- and fast-spectrum systems
- Fuels that contain fertile thorium
- Fuels and targets for modified open cycle that initially contain considerable impurities (e.g. fission products).

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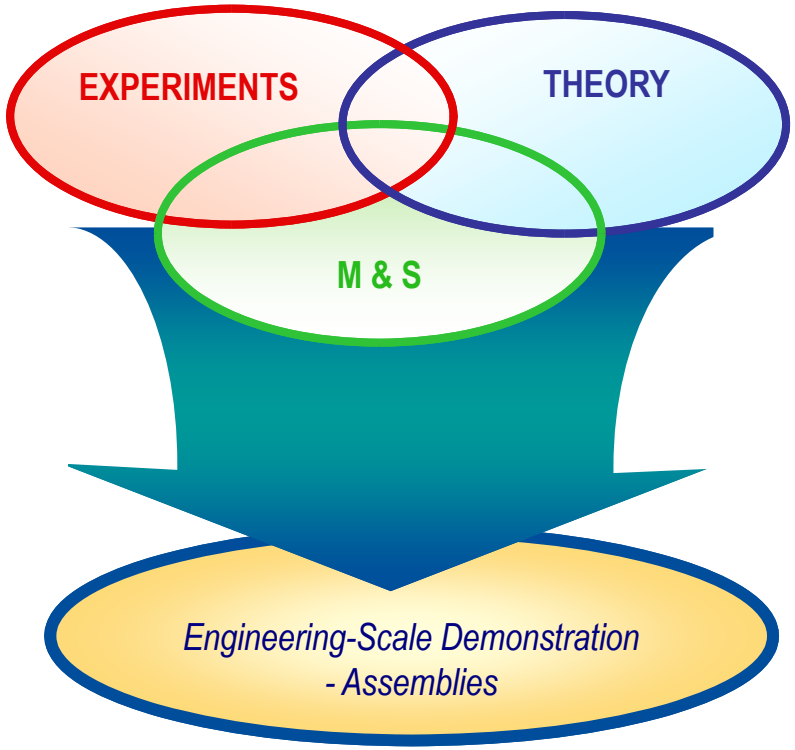
Campaign Implementation Strategy

- **Dual-Track Approach**
  - Evolutionary approach
  - Revolutionary approach
- **Goal-Oriented Science-Based Approach**
  - Experiments
  - Theory
  - Modeling & Simulation
- **Transformational Solutions**
  - Seek innovation
  - Evaluate transformational impact - collaboration with systems analysis campaign
  - Define screening processes
- **Technology Readiness Levels**
  - Used as a tool to gauge progress



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Fuel Cycle Options - Details

- **Once-Through**
  - No recycling or conditioning of used fuel
  - Low uranium utilization
  - Appropriate for a low price uranium future
  - Appropriate when repository capacity and/or actinide loadings are not show stoppers
- **Modified Open Cycle**
  - Limited used fuel conditioning or reprocessing (e.g., recladding)
  - Higher uranium utilization and burnup (i.e., used fuel is spent fuel)
  - Appropriate for a high price uranium future
  - Appropriate when major constraint is on repository capacity (e.g., heat loading, geologic media)
  - Appropriate when actinide loading is not a show stopper
- **Full Recycle**
  - Multiple reprocessing and recycle steps resulting in transmutation of most actinides
  - “Complete” uranium utilization (with breeder)
  - Appropriate for a high price uranium future
  - Appropriate when repository capacity and/or actinide loadings are show stoppers

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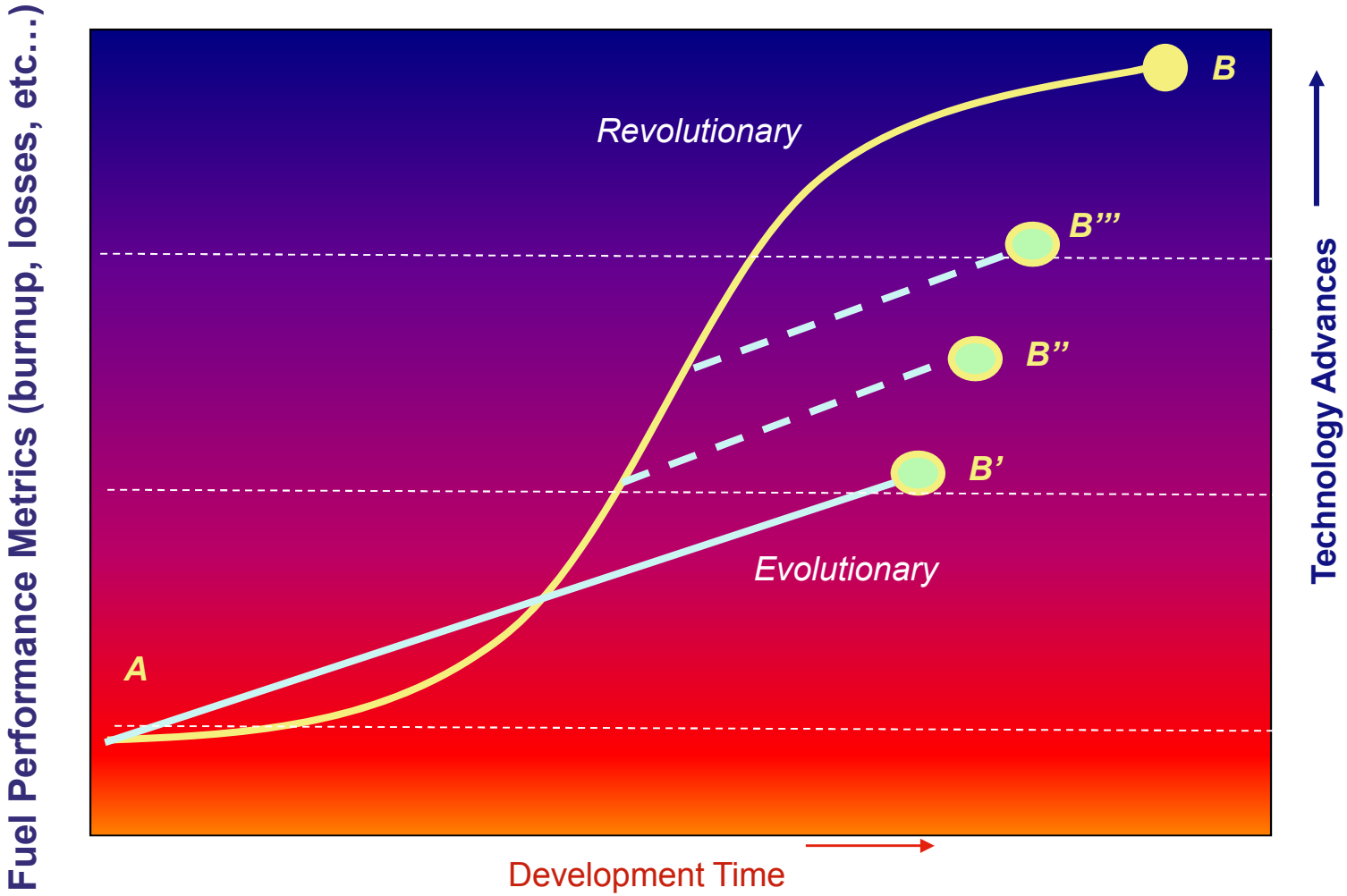
A dual-track approach is adopted for the advanced fuel development



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Advanced Fuels Campaign Mission & Objectives

- **Mission**

  Develop and demonstrate fabrication processes and in-pile performance of advanced fuels/targets (including the cladding) to support the different fuel cycle options defined in the NE roadmap.

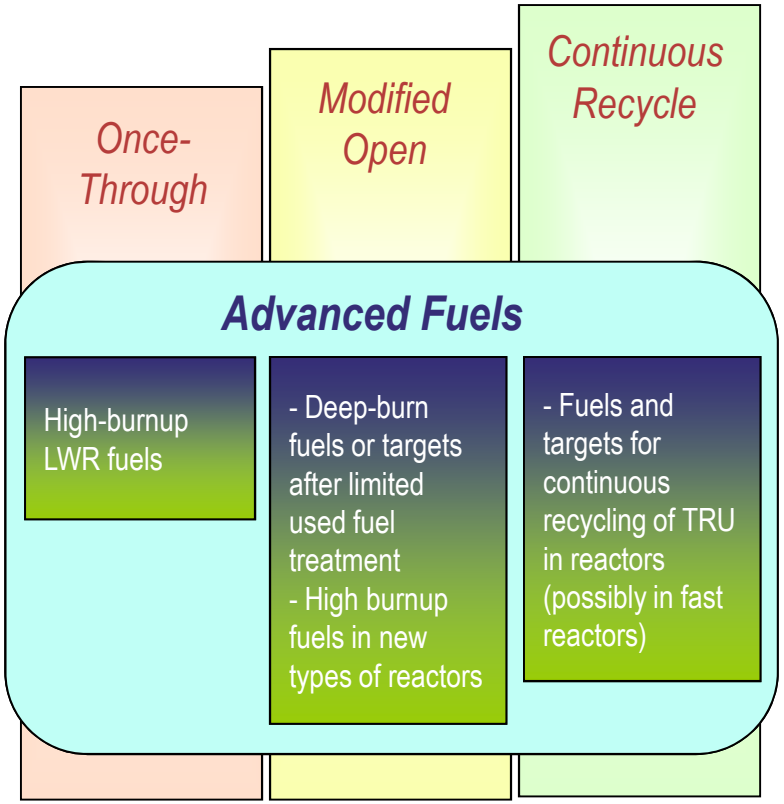
- **Objectives**

  Development of the fuels/targets that

  - Increases the efficiency of nuclear energy production
  - Maximize the utilization of natural resources (Uranium, Thorium)
  - Minimizes generation of high-level nuclear waste (spent fuel)
  - Minimize the risk of nuclear proliferation

- **Grand Challenges**

  - Major increase in fuel burnup and performance over the currently known technologies
  - Significant decrease in fabrication losses with highly efficient predictable and repeatable processes



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Grand Challenges

What

- **Difficult R&D goal with a significant chance of failure for which the means to achieve it have not yet been defined.**
  - Significant benefits if successful but even failure would still represent dramatic improvement.

We are continually faced by great opportunities brilliantly disguised as insoluble problems

Lee Iacocca

Why

- **Stimulus for creativity and innovation**
- **Focuses efforts on desired end-states**
- **Easier to communicate the why of the program**
- **Inspire the imagination and understanding of key stakeholders**
- **Position program to span multiple Administrations and Congresses**

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Advanced Fuels

Today's Technology Challenges

- Fuels with variable compositions
- Understanding and predicting fuel behavior and performance
- Reliably fabricating fuel with zero defects and with minimal process losses

Grand Challenge

- Light water reactor fuels with significant performance improvements related to uranium utilization
- Fast reactor fuels with multi-fold increases in performance over previous generation fuels, with very low fabrication losses, and that permit high transmutation of radiotoxic elements

Development Path

- Develop a microstructural understanding of fuels and materials
- Closure of combined transport and phase-field equations
- Separate effect testing and properties measurement at sub-grain scale to support modeling development
- Advanced irradiation techniques
- Innovative clean and reliable fabrication techniques with tightly controlled microstructures tailored to desired performance

Transformational Result

- Predictive capability for fuel process and in-pile behavior for a variety of initial and boundary conditions
- Novel fuel forms qualified for commercial use

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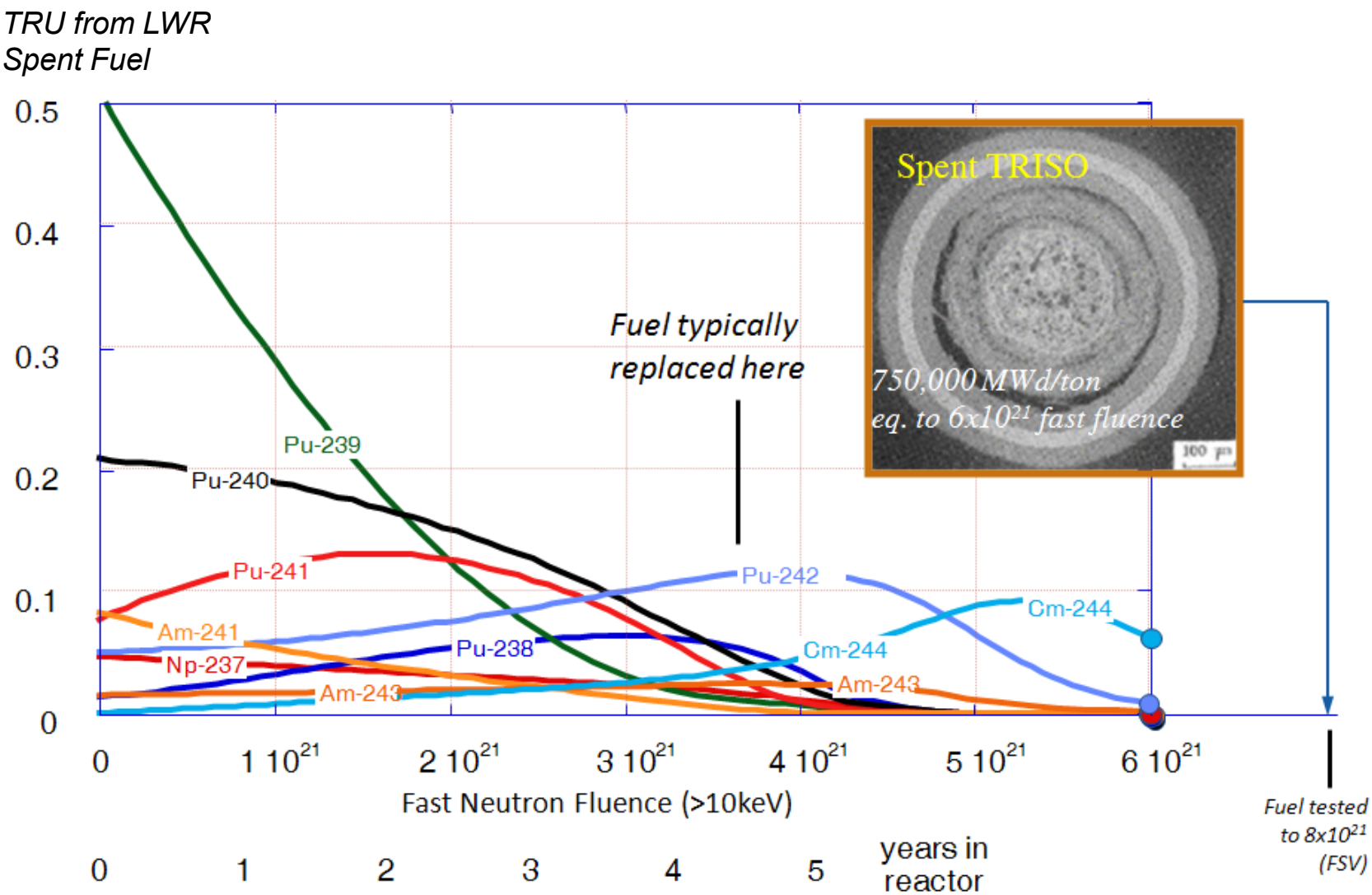
The General Concept of Deep Burn in TRU-TRISO Fuels in an HTGR – An Example of a Modified Open Cycle Concept



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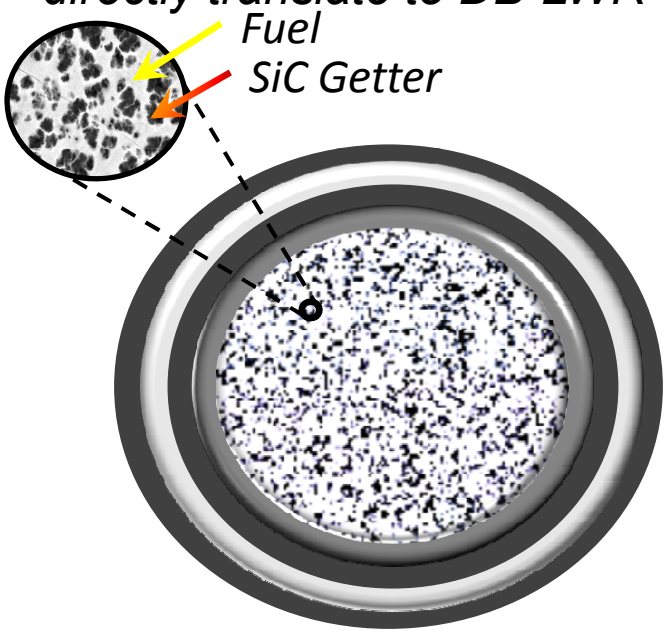
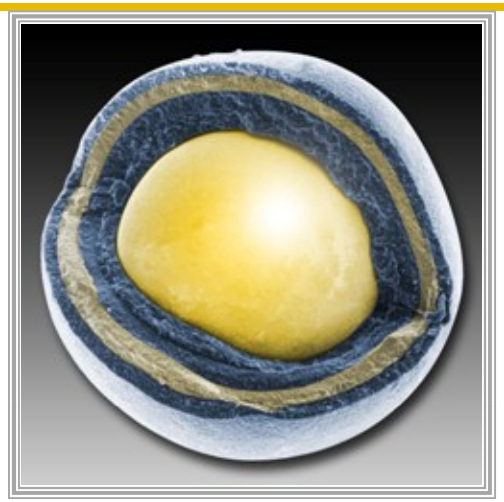
Deep Burn TRISO Fuel for Potential LWR Use- *a Possible Advanced Fuel Cycle R & D Concept*

Use of TRISO AGR Fuels:

•ZERO fuel failures for ~ 19% fertile fuel burnup

•Assumption is AGR and DB-HTR technology will directly translate to DB-LWR





Deep Burn Kernel

• Assumption of use of DB-gettered kernel for LWR application. Kernel development carried under DB programs.

Clad and Compact

• The DB-LWR specific fuels development will focus on compacting and compact-clad interaction. With the goal of irradiation of a Deep Burn fuel form within a standard zircaloy clad as a LTA in a commercial reactor

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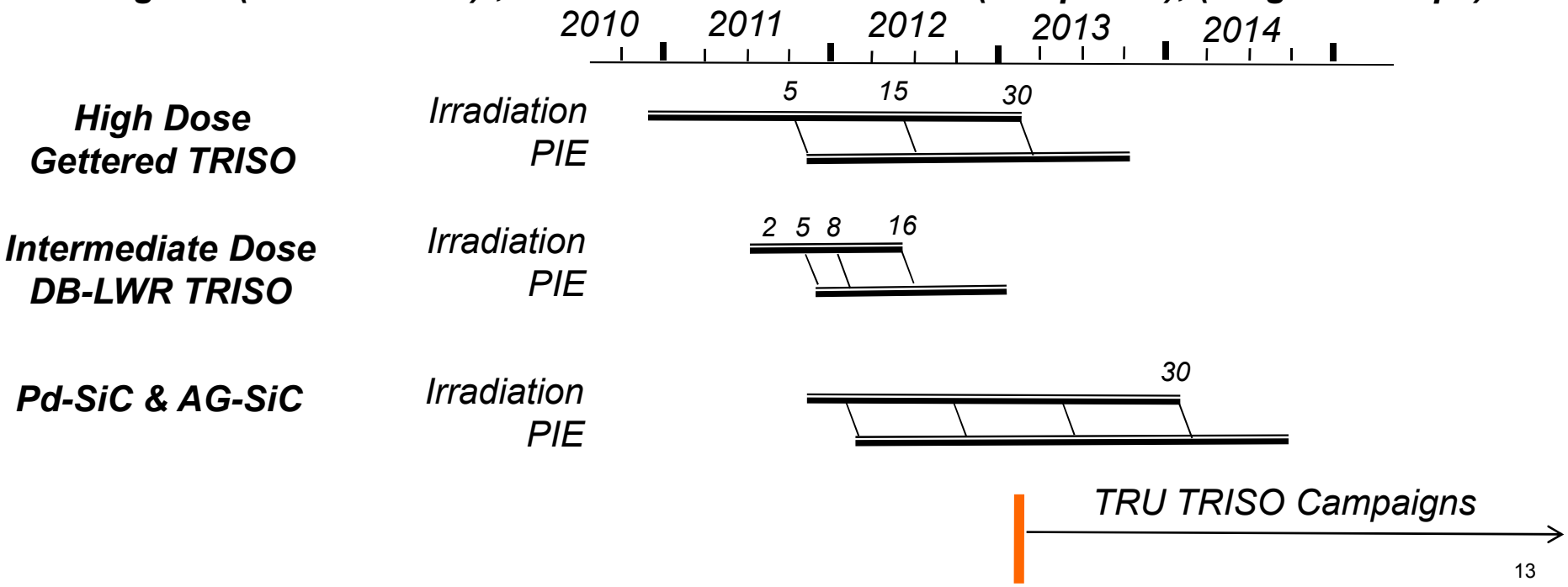
Surrogate TRISO Irradiation

In support of advanced fuel development

- ***A parallel program of HFIR rabbit irradiation will be carried in parallel to the TRU-TRISO development. It will directed by, and intended to verify aspects of the modeling efforts, and provide performance and properties of TRISO at high dpa.***
- ***Planned irradiation campaigns:***
  - ***High Dose Gettered HTR Surrogate; (1000°C, 1300°C), (5,15, & 30 dpa)***
  - ***Intermediate Dose Gettered, DB-LWR Surrogate; (350°), (2,5,8, & 16 dpa)***
  - ***Pd-SiC (HTR-relevant) ; (Temp TBD), (range to 30 dpa)***
  - ***Ag-SiC (HTR-relevant) ; (Temp TBD), (range to 30 dpa)***



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Some Other Transformational Concepts Being Considered For Development in the Fuel Cycle R&D Fuels Program

- Advanced Metallic Fuel For Reliable Fast Reactor Performance to very high Burnup
- The Use of Gettering materials in LWR Fuel Pins for Higher Burnup Performance
- Uranium-Alloy Metal Fuel For Light Water Reactor Use
- Thorium Based Fuel Options For Thermal and Fast Reactors
- Enhanced Means of Increasing Thermal Conductivity of Oxide Fuels
- Exploring the Possibilities of Nano-structured Materials for Innovative Fuel Designs

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Summary Observations

- Under the guidance of "Science-Based" Research and Development, we are considering numerous innovative transformational advanced fuels concepts that have the potential to benefit both thermal and fast spectrum reactors

- Doing Transformational R&D we have to accept increased risks in our R&D program efforts as we encourage thinking outside-of-the-box.

- Even with the increased transformation orientation of our program, we recognize the need to seek regular contacts with industry representatives and other Government entities, such as the NRC