NEUP Nuclear Energy University Programs

U.S. Department of Energy

July 27-28, 2010

FY2011 NEUP Workshop Nuclear Fuels (NF) Breakout Session

Rockville, Maryland

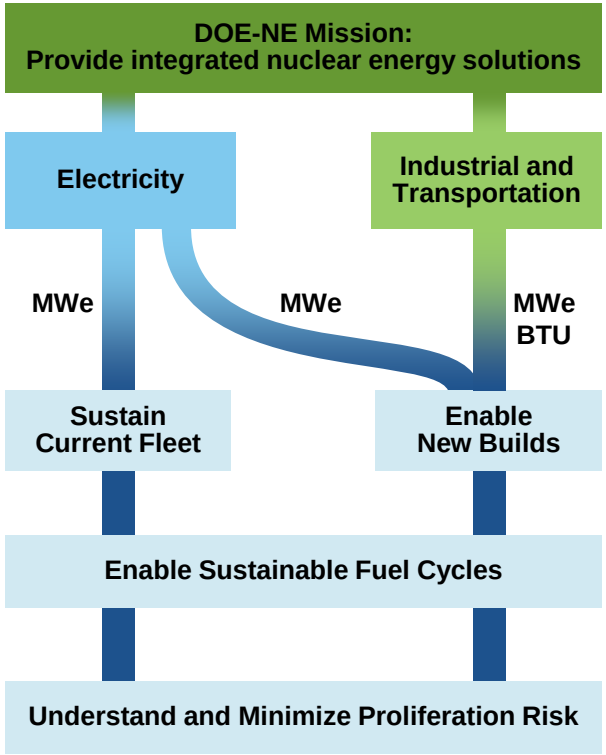
NE Roadmap Introduces Four Research Objectives

Objective 1: Develop technology and other solutions that can improve the reliability, sustain the safety, and extend the life of current reactors.

Objective 2: Develop improvements in the affordability of the new reactors to enable nuclear energy to help meet the Administrations energy security and climate change goals

Objective 3: Develop sustainable nuclear fuel cycles

Objective 4: Understand and minimize the risk of nuclear proliferation and terrorism

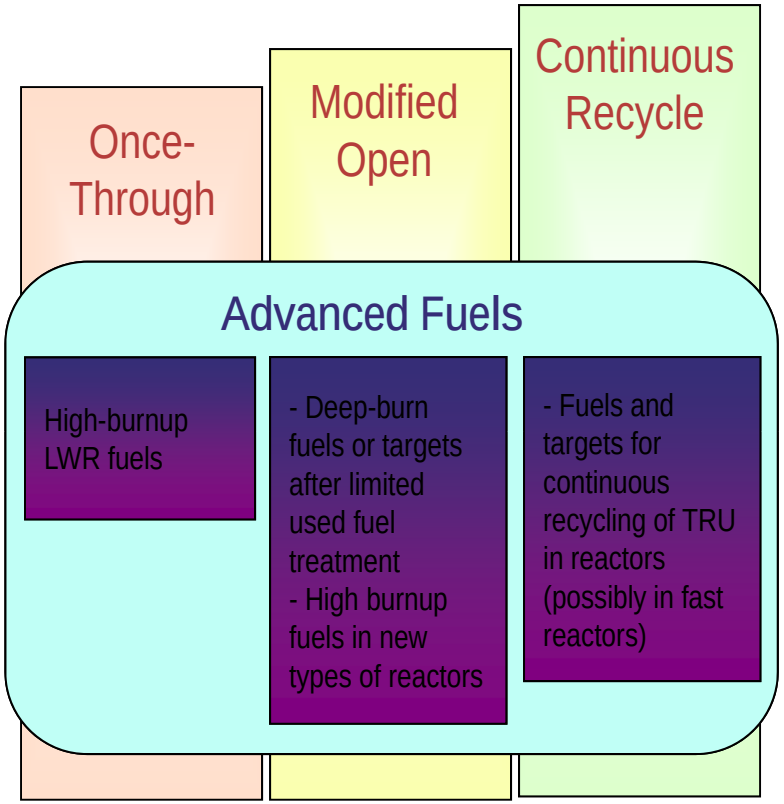


Advanced Fuels Campaign Mission & Objectives

- Mission

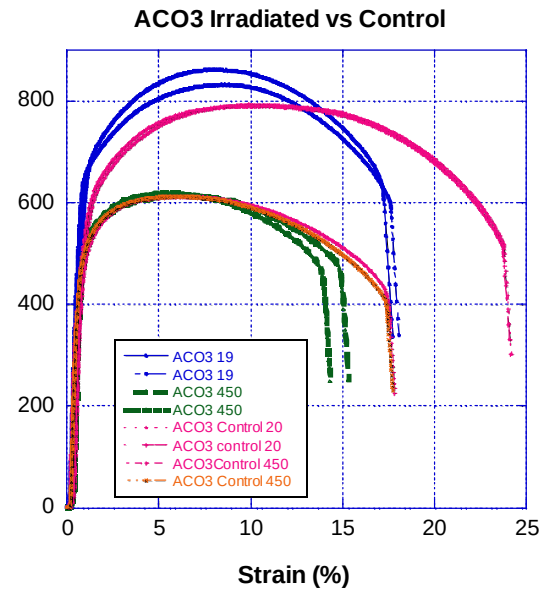
  Develop and demonstrate fabrication processes and in-pile performance of advanced fuels/targets (including the cladding) to support the different fuel cycle options defined in the NE roadmap.
- Objectives

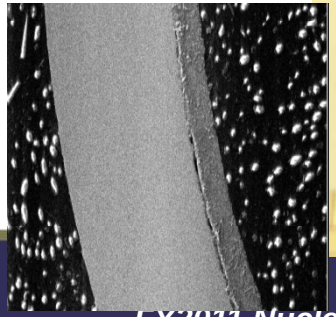
  Development of the fuels/targets that
  - Increases the efficiency of nuclear energy production
  - Maximize the utilization of natural resources (Uranium, Thorium)
  - Minimizes generation of high-level nuclear waste (spent fuel)
  - Minimize the risk of nuclear proliferation
- Grand Challenges
  - Multi-fold increase in fuel burnup over the currently known technologies
  - Multi-fold decrease in fabrication losses with highly efficient predictable and repeatable processes



Research to Support the Grand Challenges-Core Materials Development

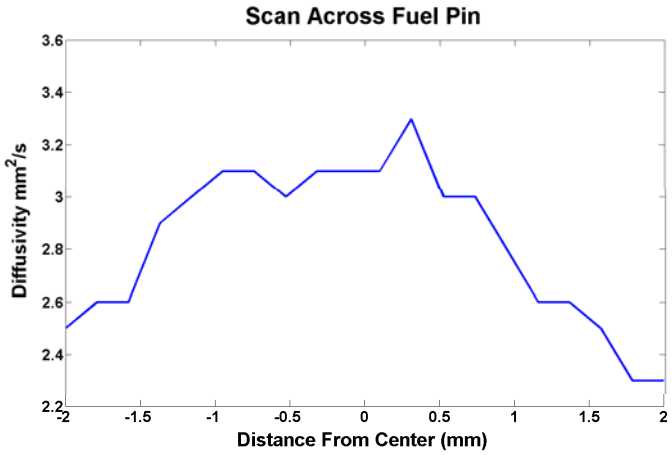
- Knowledge base up to 200 dpa high-dose core materials irradiation data
  - ACO-3 duct testing
    - Fracture toughness testing
    - Charpy testing
    - Tensile testing
    - Tensile testing SANS measurements
  - FFTF/MOTA Specimens and Testing
- Advanced Materials Development
  - Coating/liners to mitigate FCCI
  - Develop and test advanced cladding materials
    - Ion irradiations
    - Testing MA-957 after high-dose irradiations
    - Improved processing of Advanced ODS alloys

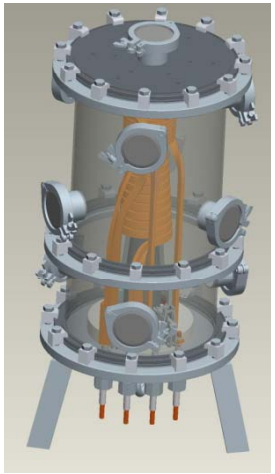




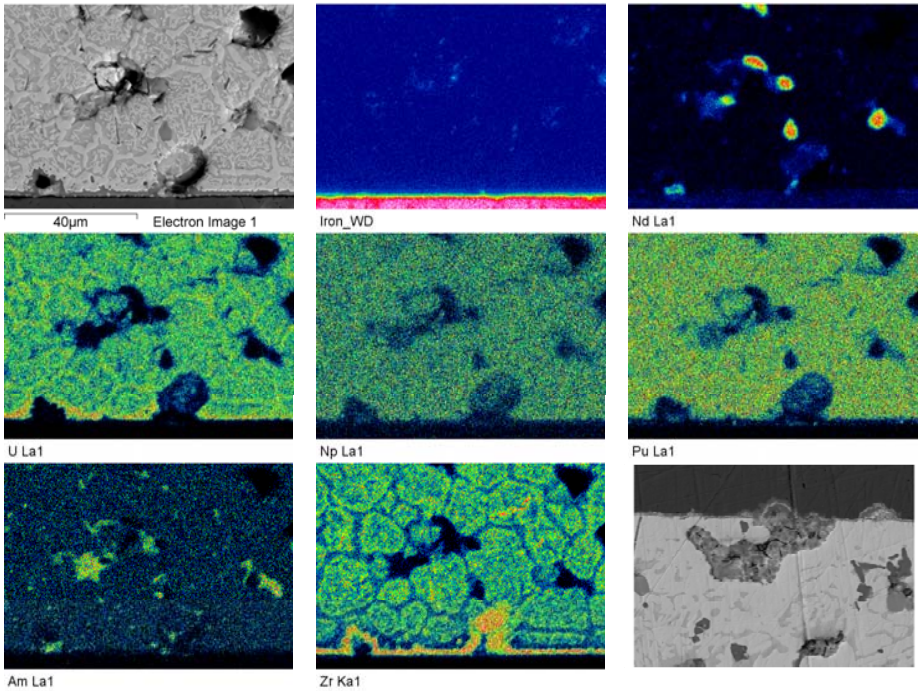
Research to Support the Grand Challenges-Metallic Fuels

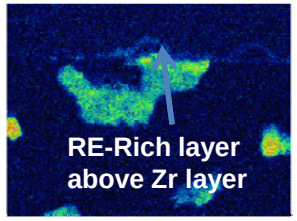
- Feedstock Preparation
  - Am purification
  - AmO_2 reduction
  - NpO_2 reduction
- Casting Process Development
  - Metal fuel fabrication
    - Bench-scale casting furnace is being installed in a glovebox
    - Continuous casting system being investigated
    - Microwave casting system being investigated
    - Fabrication of sample for characterization and FCCI testing
  - Advanced fuel characterization
- Characterization/Properties
  - Thermal and phase analysis
  - Microstructure
  - FCCI
  - Advanced Measurement Techniques (STDM)
  - Laser-based resonant ultrasound (LRUS) (microstructure mediated mechanical properties)

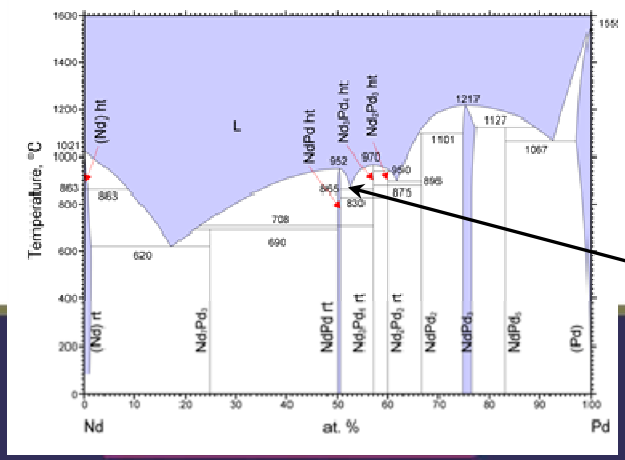




Metallic Fuel Development - FCCI Studies





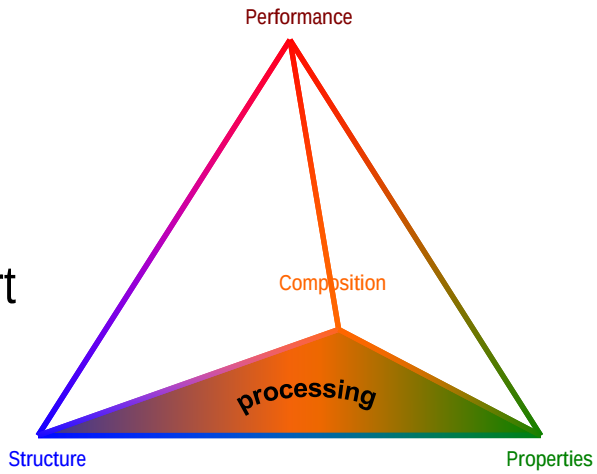


Example: Pd-rich : Nd composition has solidus of 865°C.

- Even at relatively low temperatures (450°C, 600 hrs) fcci appears to occur.
  - ~25 µm of Fe diffusion into the fuel but
  - No measurable fuel constituents found in cladding
- Zirconium appears to enrich at surface (interface) and inhibits Fe diffusion into fuel.
  - Zr layer thickness proportional to fuel Zr content.
- RE enhancement of FCCI possible at higher temperatures.
  - At lower temperatures, locations where Am and RE rich precipitates intersect fuel surface show no enhanced interaction.
  - Zr layer forms around precipitates, but not where precipitates contact cladding.
- Current effort: Indium and Thallium have been suggested as fresh fuel dopants to pin Ln's (Hofmann et al.) but binary systems of In or Tl with U and Ln's are little known or unknown.
- Pd, Ti, and Ag appear best for stabilizing Ln's in fuel matrix.

Research to Support the Grand Challenges – Ceramic Fuels

- Feedstock: powder synthesis and optimization for processing and performance testing
  - feedstock powder/particle synthesis, powder/particle characterization
  - fabrication processes and characterization
- Feedstock/processing: sol-gel and resin particle R&D in support of advanced processing and particle fuel development
  - Relatively dust-free, free flowing, remote handling and versatile process
  - Some evidence of reduced FCCI, FCMI, higher gap conductance
- Processing: powder conditioning and process control are fundamental to ceramics fuels R&D
  - Better green processing: better milling, better compaction, lower sintering temperature, near net shaping
  - Increased control of processing increases pellet quality and microstructure control.

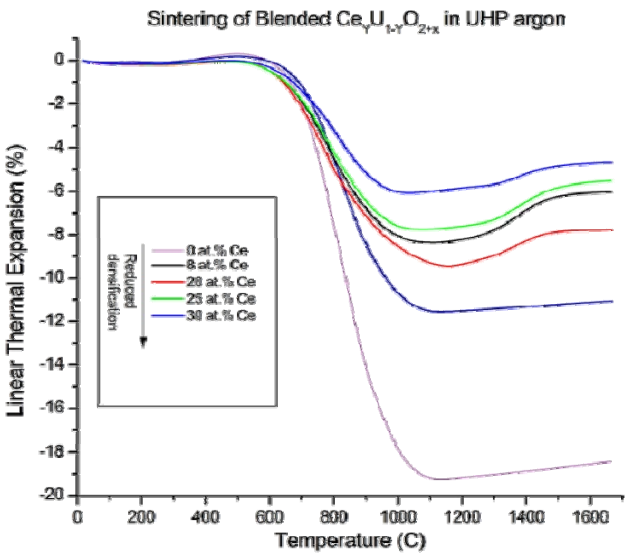


MOX and MA-MOX, ϕ~5 mm

Focus on developing understanding and subsequent control of ceramic fuel properties and performance with an emphasis on integration with modeling and simulation.

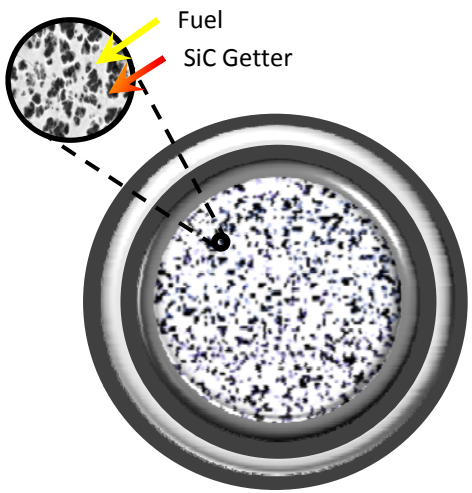
Ceramic Fuel Development (cont.)

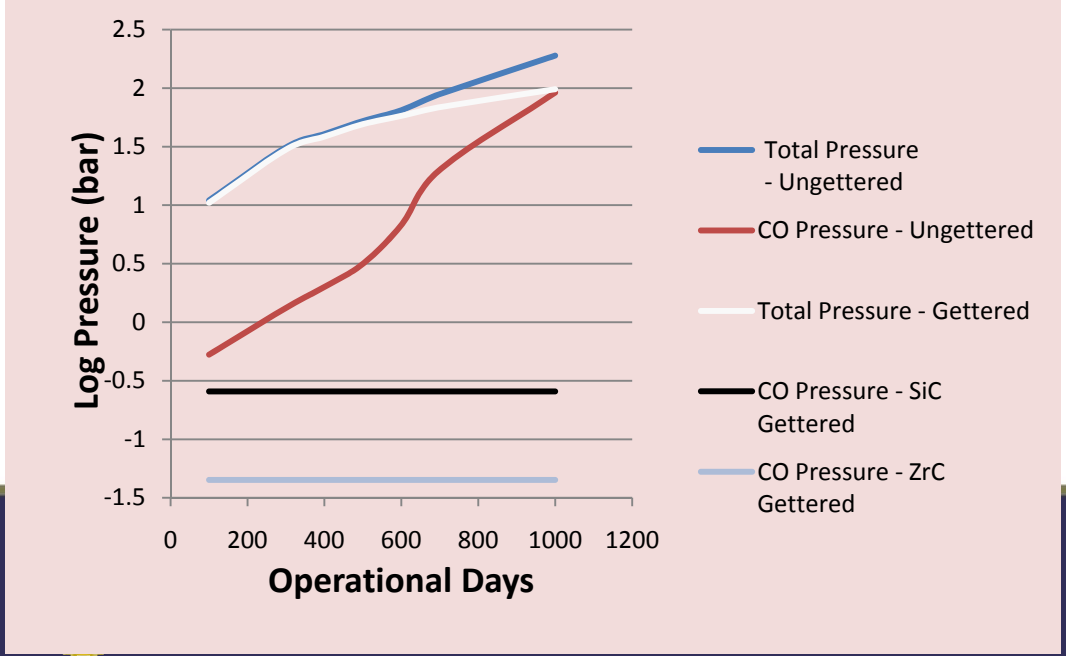
- Processing/Properties: Thermo-chemical understanding and model development
  - Processing: control of O/M for optimized sintering, final desired O/M
  - In-Reactor Behavior: Behavior of O/M during burnup, secondary phase formation, oxygen pressure, chemical activities for transport modeling, chemical interactions with cladding
  - Thermogravimetric studies define the protocol for dynamically controlling O/M during fabrication and testing, and provide esssential data for development and refinement of thermochemical models.
- Sintering Kinetics: Lanthanides are being used as model systems to understand the effects of complex chemistry on sintering kinetics
- Properties: Melt point determination, 2 methods being developed
  - Bulk measurement - RF heating
  - Local Measurement - Laser Heating



Research to Support the Grand Challenges – Coated Particle Fuels

- Based on TRISO fuel technology
- Kernel to include TRU & SiC getter
- TRU Kernel and Coating facilities being built
- Irradiation target: 2012 - 2013
- Gettering significantly reduces total pressure at high burnup
- Modeling indicates reduction in CO (and oxygen) pressure through use of internal getter
- Both SiC and ZrC are good oxygen getter
- Modeling further suggests reduced kernel migration (amoeba)

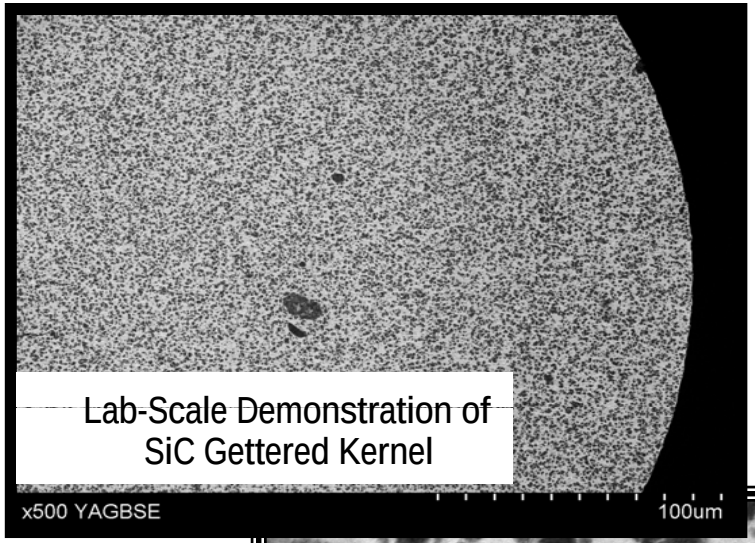




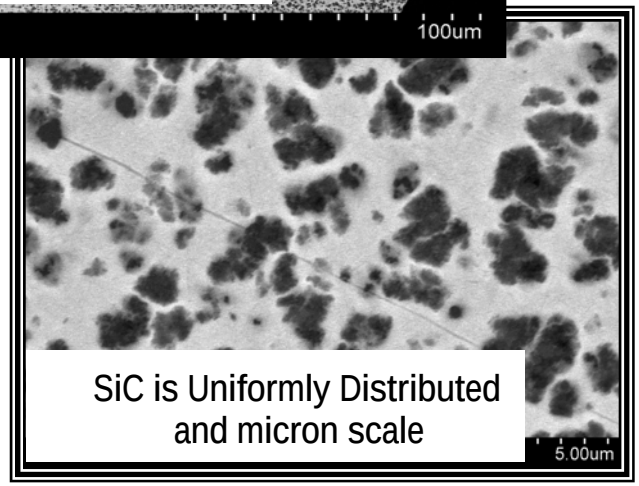
Kernel and Coating Development

- Small or getter containing kernels
- Process development for installation into TRU gloveboxes underway
- Parallel design and installation of coating furnace is being carried out

- ZrC is being evaluated as a substitute to SiC
- Fine equiaxed grains have been demonstrated
- Initial neutron irradiations show general radiation tolerance
  - Dimensional stability
  - Stable thermal conductivity
  - Stable mechanical properties
- A ZrC handbook (similar to SiC handbook) is being assembled.



Lab-Scale Demonstration of SiC Gettered Kernel



SiC is Uniformly Distributed and micron scale

Fuel Irradiations-HFIR Hydraulic Rabbit Testing: Low Fluence Fuel Irradiations

- Purpose
  - Plan systematic, low-fluence irradiation experiments using the hydraulic rabbit facility
    - Explore early stages of the microstructural evolution of metallic fuel materials as a function of elemental composition, temperature and fluence.
    - Obtain fundamental data to support fuel modeling and simulation code development
  - Design rabbits and perform thermal and neutronics analyses required to ensure acceptable in-core performance and to satisfy HFIR Experiment Requirements
  - Perform low power reactivity insertion testing to establish bounding conditions on the rabbit test article payload.
- Status
  - 31Mar10: Complete computational analysis of low power rabbit reactivity insertion test cases: **Completed on time**
  - 29Sep10: Submit rabbit irradiation experiment safety basis analysis documentation to HFIR: **On Schedule**

Results and Status

•Nuclear Review Panel experiment approval obtained

•Two Conceptual Rabbit Designs produced for TEM samples using thermal neutron shield to control linear heat generation rate

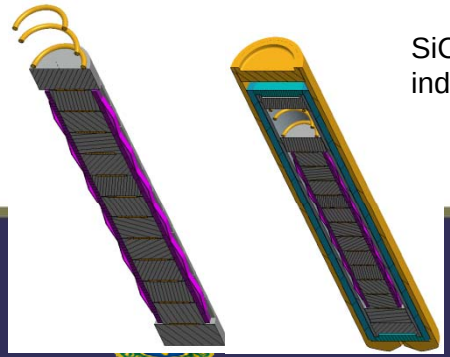
•Neutronics/thermal models generated - analyses on track

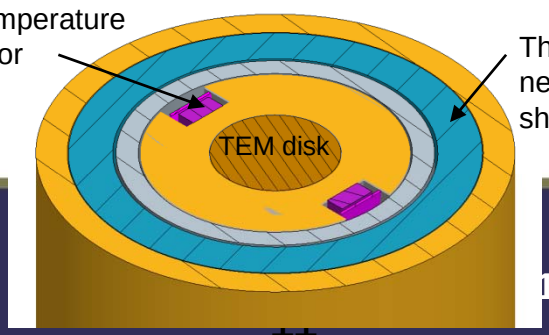
•Since large reactivity insertion/ejection has potential to shut down the reactor, tests are required before using the hydraulic tube for neutron-shielded rabbits to characterize the facility

•Point kinetics model developed to provide qualitative understanding of system response to “black” rabbit insertion/ejection

•Dry Run to test data acquisition system planned for next startup (~5May10)

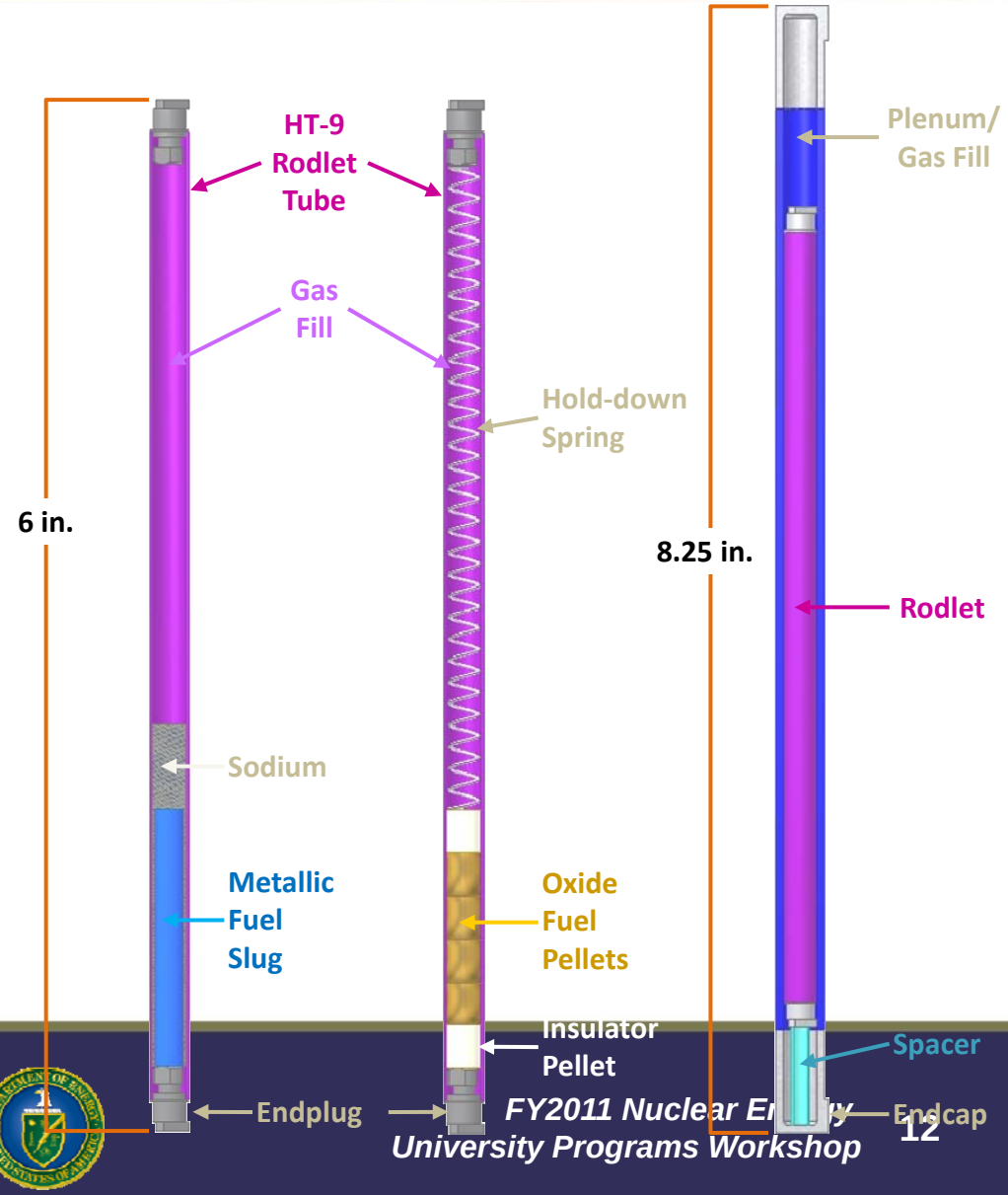
•Black rabbit insertion/ejection testing planned for ~16Jun10





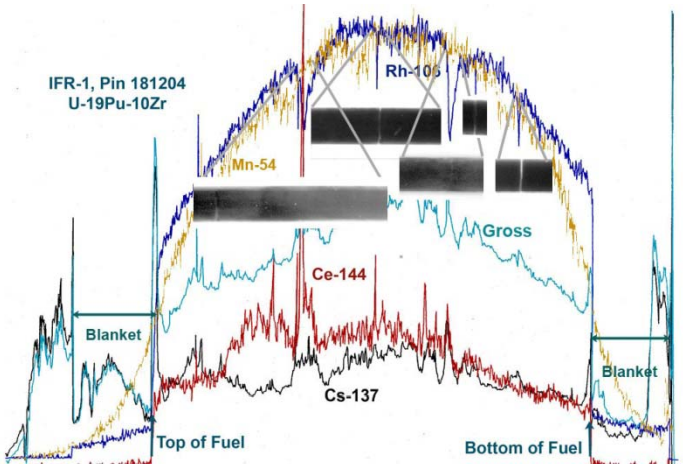
ATR Irradiations : AFC-3 Drop-In Capsule Design

- Design change: individual capsules for each rodlet
  - Maintain same rodlet design
  - Up to 5 capsules per position
- Fuel columns (1½") span 34½" of ATR core height
  - 31½" in AFC-1,2
  - Still within "flat" flux zone
- AFC-3 design offers simplifications in capsule fabrication
- First irradiation expected summer of 2011



Post Irradiation Examination of ATR-Irradiated Fuels

- Non-Destructive Examination of 14 AFC-1 and 6 AFC-2 Rodlets
  - Draft Report due Jun 2010 on schedule
  - Improved neutronics calculation methods for PIE benchmark comparisons in progress
- Baseline Destructive Examination of 14 AFC-1 and 6 AFC-2 Rodlets
  - Install and qualify MAT 271 gas mass spectrometer for fission gas analysis in progress
  - Install and qualify improvements on GASR system
  - Remaining examinations pending refurbishment of hot cell sample preparation station

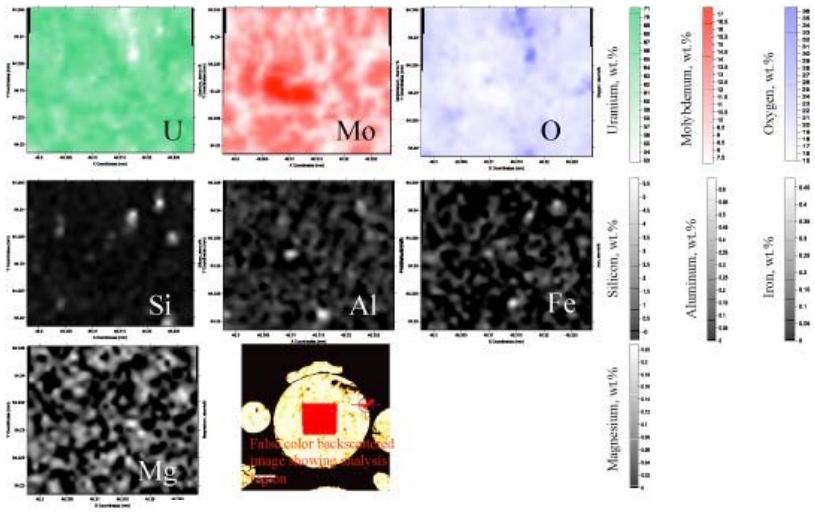


Gamma Scanning Results with Corresponding Neutron Radiographs for Typical IFR-1 U-19Pu-10Zr Pin

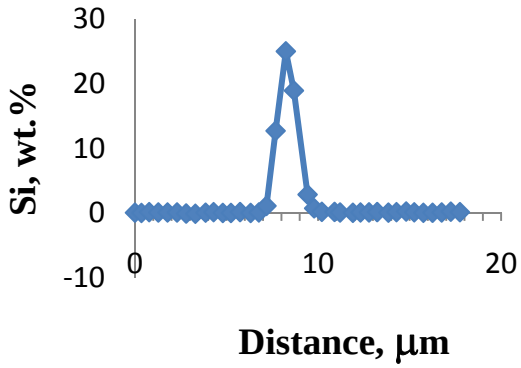
Finnigan MAT 271 Gas Mass Spectrometer

PIE Update (continued)

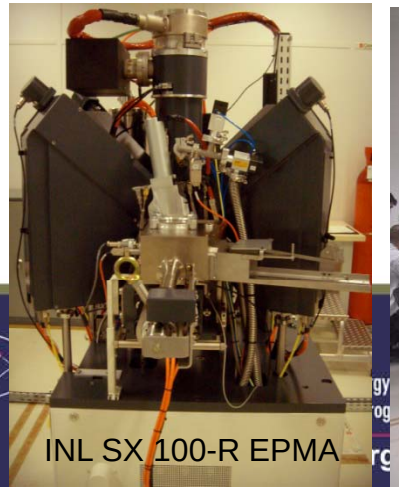
- Electron Probe MicroAnalyzer (EPMA) Technique Development (K. Wright)
  - Technical Exchange Visit to JRC Institute of Transuranium Elements (ITU)
  - Fuel analysis techniques on INL JEOL 8900
  - Status report by 7/31/10 on schedule
- Shielded EPMA Cameca SX 100-R
  - Factory Acceptance Test in Jan 2010
  - Instrument delivered to INL Feb 2010
  - Assembly and installation by Sep 2010



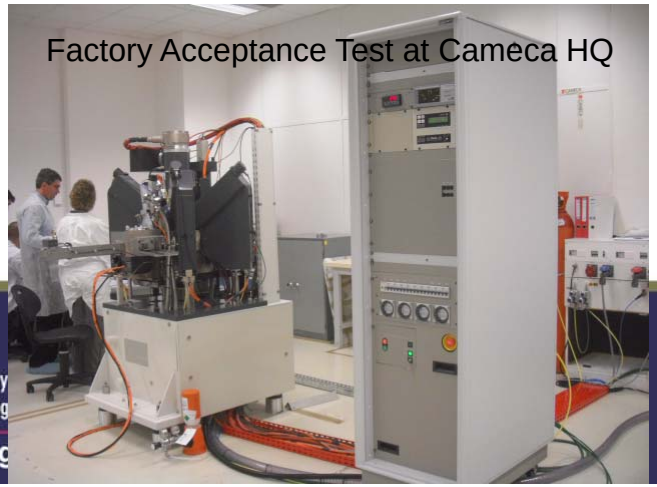
Quantitative map of light elements and minor elements in U-Mo fuel alloy (INL IRC JEOL 8900)



Quantitative Si traverse at fuel-matrix interface



INL SX 100-R EPMA

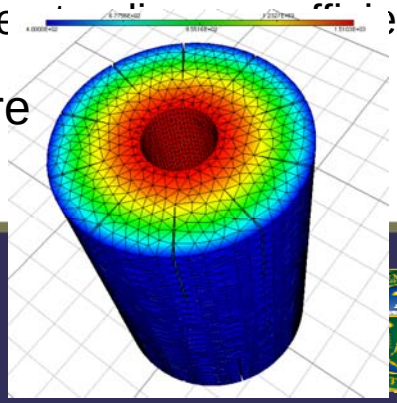


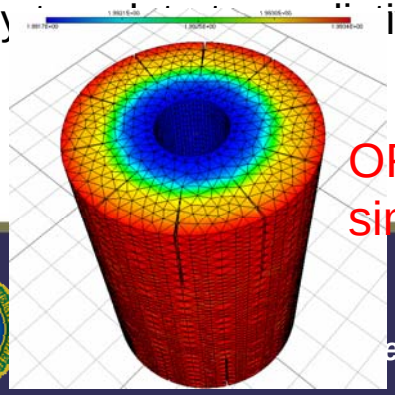
Factory Acceptance Test at Cameca HQ

Challenges for "New and Improved" Oxide Fuels

- Objective is higher power, deep burn and ability to close the fuel cycle
  - Involves optimizing existing fuels, designing new systems and establishing the ability to incorporate minor actinides (MAs)
  - Increase thermal conductivity, contain fission products and MAs, predictable FG behavior
- Requires capability to understand, predict and control key aspects of fuel performance as a function of composition, form and burn-up
  - Fission gas release, e.g. LWR UO_2 rim structure
  - Fission product accommodation
  - Thermal margin
  - Mechanical integrity, e.g. FCMI
  - Chemical stability (FCCI, redistribution, buffering of O:M, additional phase formation)
- Close coordination of experiment with modeling and simulation so that improved fundamental unde ently ive capability

Temperature





Oxygen/Metal Ratio

ORNL simulation

Workscope Description

Nuclear Fuels

Defining fuel designs and fabrication techniques that produce fuels with very low failure rates, as demonstrated by irradiation and accident safety testing programs.

Fuels Design, Characterization & PIE (F-9)

FCR&D-AF: R&D of innovative fuel and target concepts, for both thermal and fast spectrum nuclear reactors.

•Goal to achieve significantly higher fuel and plant performance requirements, including major increases in burn-up than yet achieved.

- R&D in the areas of fabrication, characterization, and performance of advanced fuel, materials, and target systems
- Fuel types of interest are high burnup-high performance metallic, ceramic, and coated particle fuels.

•As examples, specific areas of research and development are:

- Advanced fabrication technology and research with potential for decreasing fabrication process losses while increasing fuel quality and consistency.
- Fabrication process models, such as compaction and sintering models, that support advanced fabrication process development.
- Research and development that increases fuel performance, such as increased power and extended burnup, via increased understanding and control of diffusion, species migration, and enhanced thermal transport.
- Fundamental fuel materials studies and associated technology development that supports increased understanding of fuels performance, while simultaneously supporting the development of predictive, physics-based fuels performance models.

NOTE: All fuels work not directly related to standard NGNP TRISO should be submitted under the FCR&D bin.