Global Nuclear Energy Partnership

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Research and Development Program

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Presentation to NEAC

Outline

- GNEP R&D Process
- Systems analyses and technical requirements
- Transmutation Fuels
- Separations
- Reactors
- Safeguards
- Regulatory Issues
- Summary

GNEP R&D Process

- **Precursors to the GNEP R&D program were initiated in the late 1990's based on knowledge accumulated internationally since the 1960's.**
- **By the time GNEP was officially started (2006) significant progress had been achieved.**
  - Connection between final disposal options and transmutation scenarios
  - Transmutation potential of the main reactor systems
  - Requirements driven process
  - R&D program has been focused on making Yucca Mountain the single repository needed for the 21st Century

GNEP Program Organizational Structure

PROJECTS

Advanced Burner Reactor
Sal Golub

Consolidated Fuel Treatment Center
Dan Stout

Advanced Fuel Cycle Facility
Andy Griffith (actg)

Design Data Needs

Technology

R & D

Advanced Fuel Cycle R & D
Price (actg)

Technical Integration
Finck (INL)
Cappiello (**LANL**)
Marra (**SRNL**)

Cross Cut Coordination
- Modeling/Simulation (Nowak- **ANL**)
- Safety and Regulatory (Kelly- **SNL**)

Fuels
Pasamehmetoglu (**INL**)
Deputies: Carmack (**INL**)
Maloy (**LANL**)

Separations
Todd (**INL**)
Deputies: Felker (**ORNL**)
Regalbuto (**ANL**)

Systems Analysis
McCarthy (**INL**)
Deputy: Gehin (**ORNL**)

Safeguards
Miller (**LANL**)

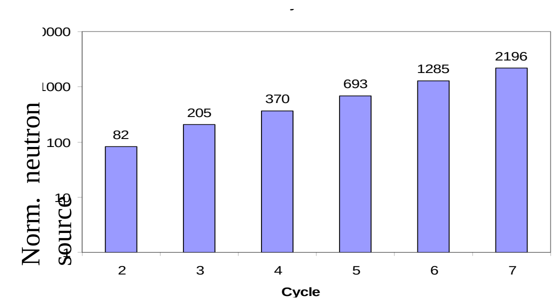
Waste
Peters (**ANL**)

Reactor
Hill (**ANL**)

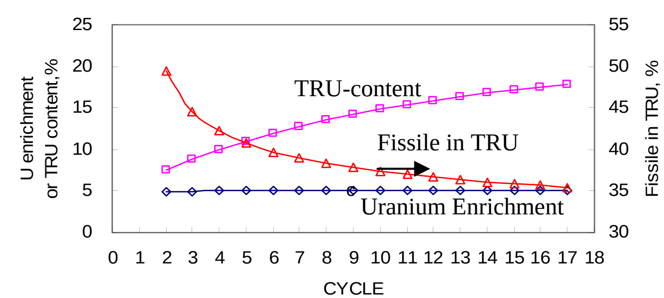
Grid Appropriate Reactors
Ingersoll (**ORNL**)

Systems Analyses: Reactor Performances

- **LWR Performance**
  - Partial burning of Pu is feasible with existing technologies
    - *Enables Pu inventory stabilization*
  - Extensive burning of Pu is achievable with new technologies
    - *Subassembly design*
    - *Higher enrichments*
  - Burning of MA's is not practical
    - *High doses*
- **The Fast Reactor is favored for TRU destruction**
  - Higher fission/absorption
  - Multi-recycle
- **International Integration via OECD Working Groups and Bilateral Collaborations (France)**



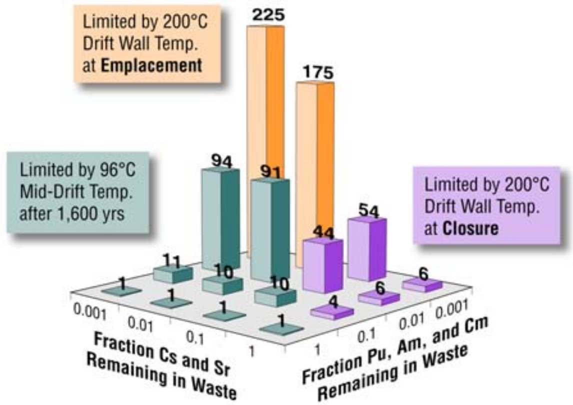
TRU Fuel Handling Indices at Fabrication Stage Compared to CORAIL-Pu Cycle 7



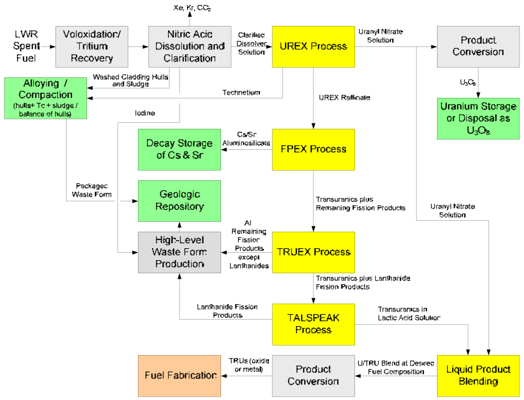
Mass Evolution with TRU Recycling

Systems Analyses: Systems Integration

- **The behavior of a Yucca Mountain like repository is complex with several different limits**
- **Analyses have demonstrated that differentiated thermal management can significantly increase capacity of Yucca Mountain like repositories**
  - Eliminate short term heat by separations and decay
  - Eliminate long term heat by transmutation
- **Specific separations flowsheets have been designed and demonstrated at laboratory scale to achieve these objectives**

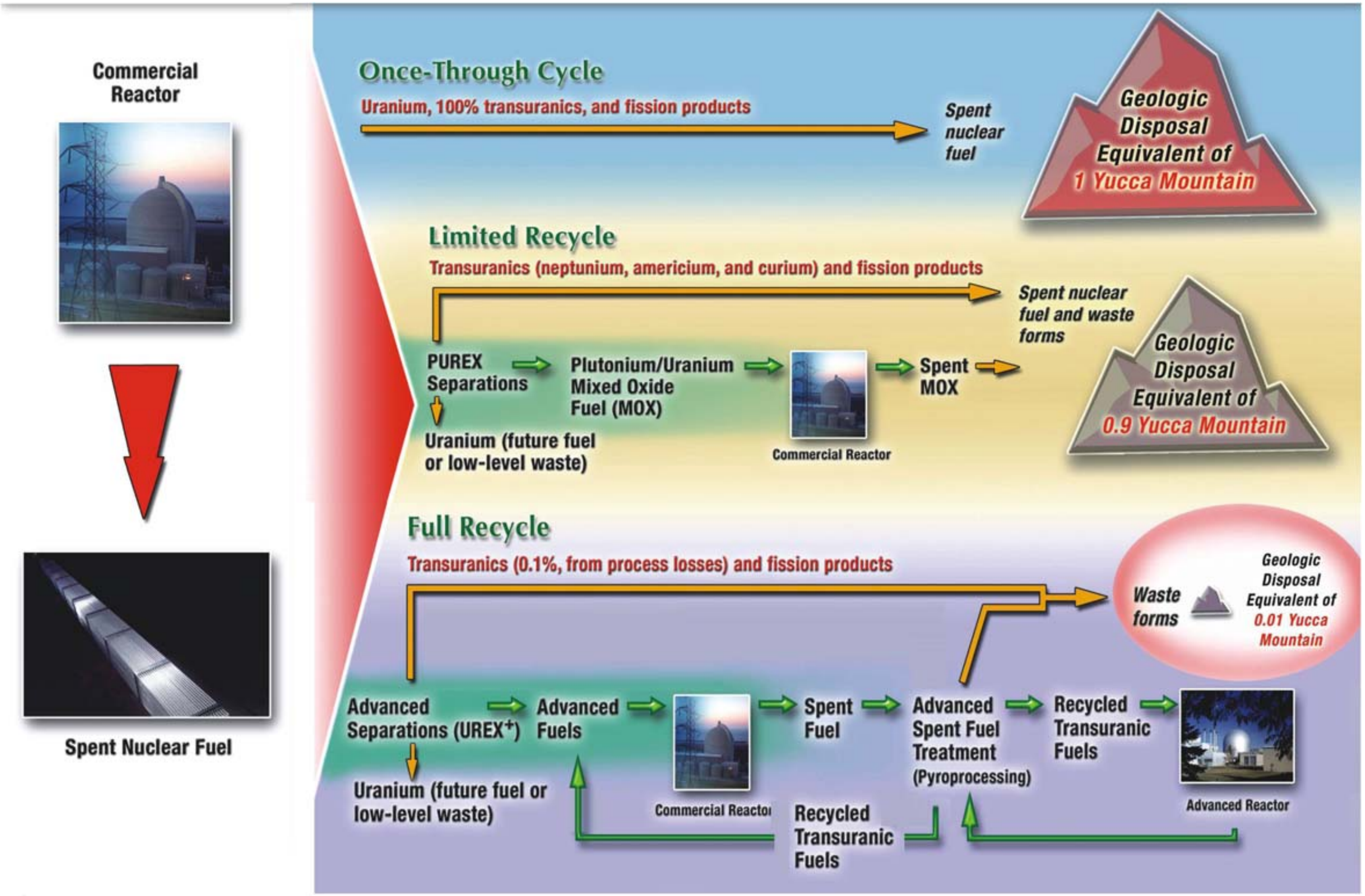


GNEP Thermal Management



Flowsheet Design

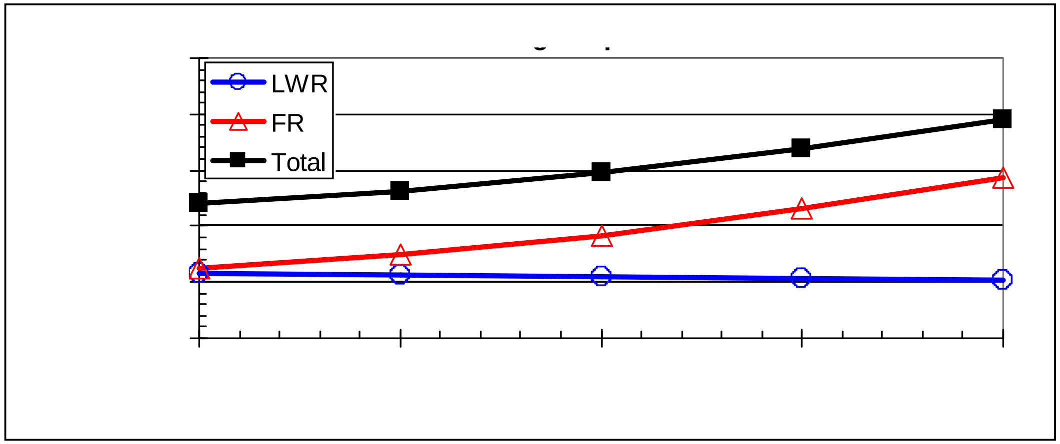
Domestic Used Nuclear Fuel Management Options

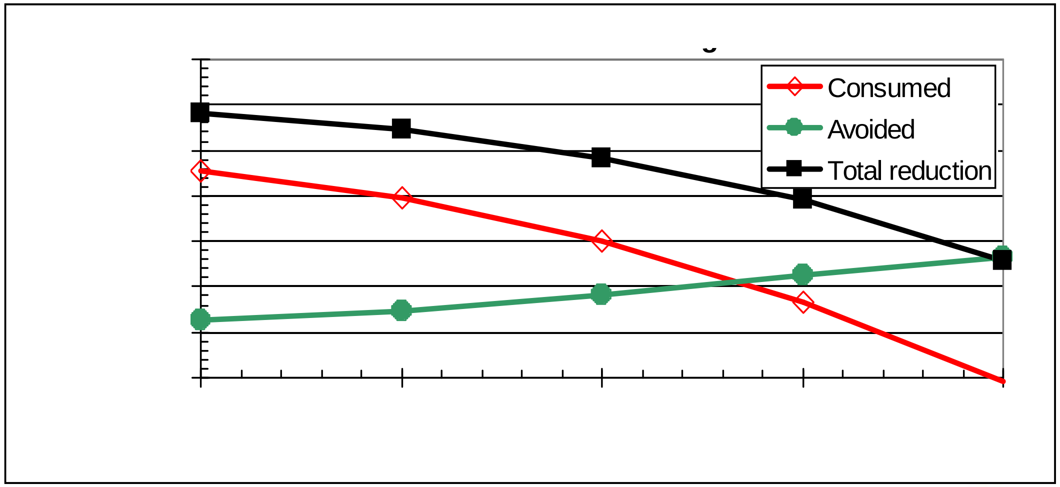


Source: Finck (ANL)

Systems Analysis Technology Criteria

- **Reducing** **process losses** **is important to realize waste management benefits**
  - TRU flow through separations facilities is higher for FR SNF separations than LWR SNF separations
  - Minor actinides dominate long-term decay heat and radiotoxicity
  - Higher burnups are desirable
- **Transuranic reduction (relative to once-through) occurs at all conversion ratios**
- **Technology criteria are strongly linked**

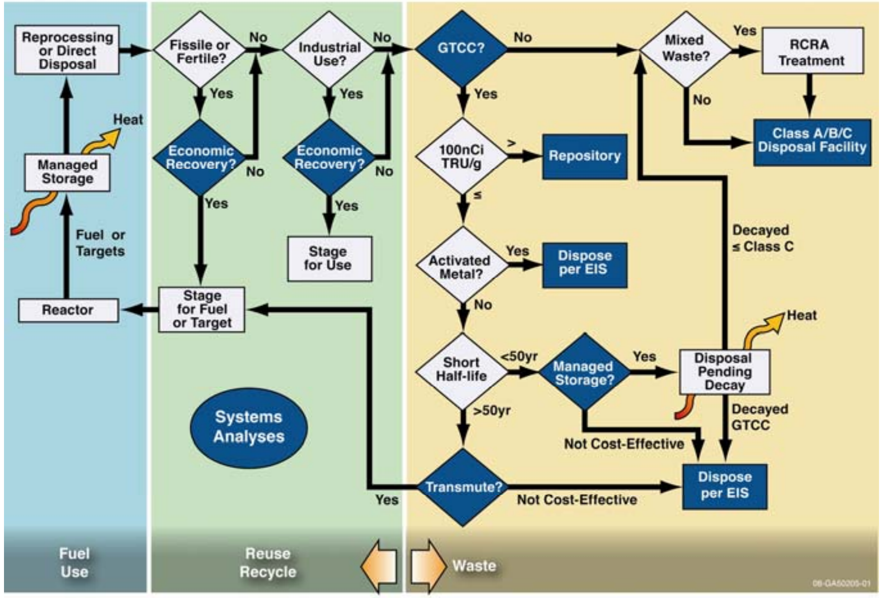




Systems Analyses led to the definition of an Integrated Waste Management Strategy

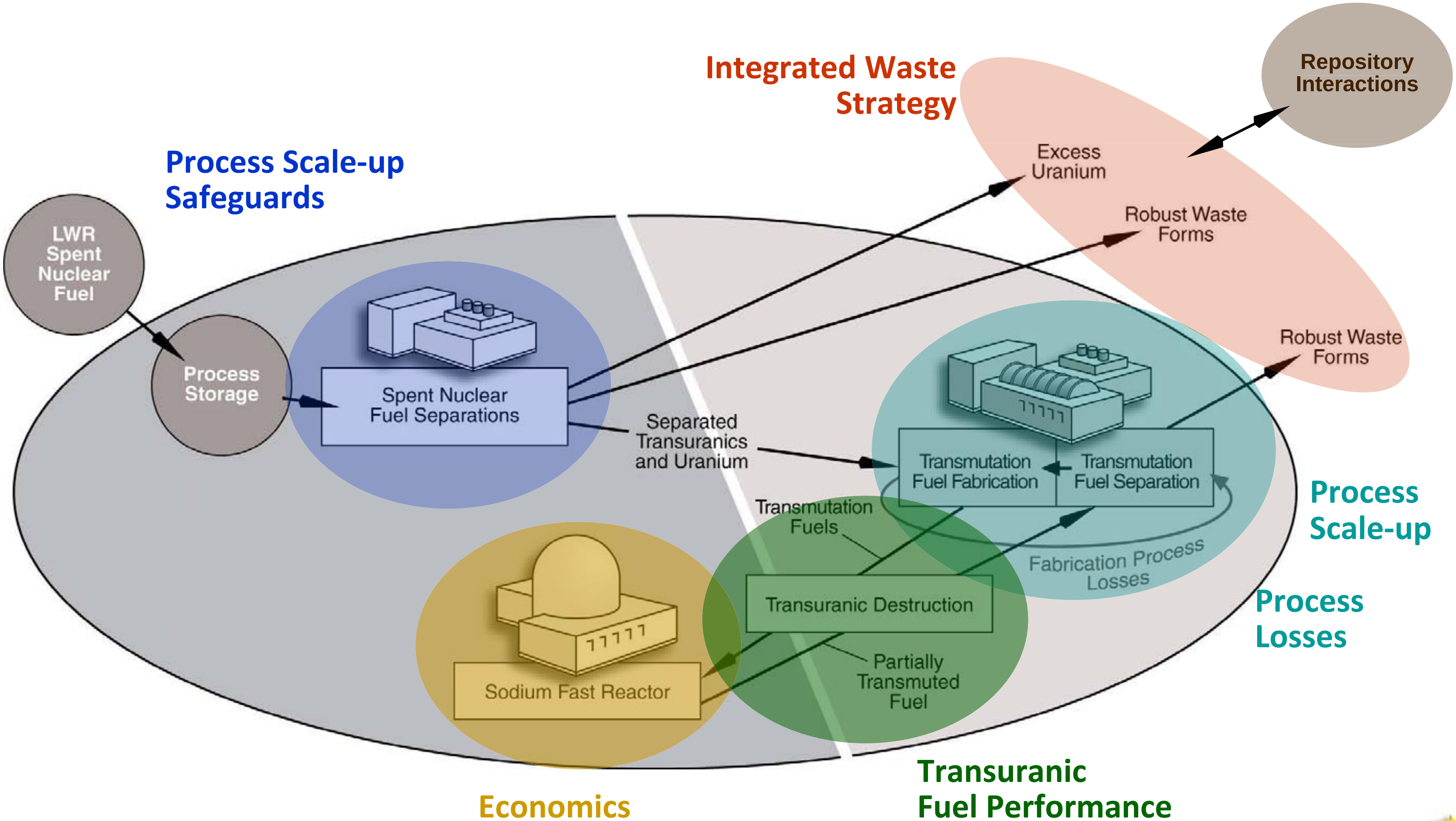
- Risk Based disposal of radioactive waste
  - Waste partitioned by similar chemistry and similar risk
  - Oxidized elements – glass
  - Metallic elements – metal alloy
  - More durable forms in less volume
  - Volume reduction up to 6.5x vs. glass
  - Use provisions similar to 10 CFR 61 with added radionuclides
  - Applicable to all radioactive wastes

Integrated Waste Management Strategy Logic Diagram



- Integrated waste management considers WM in design of fuel cycle
  - Emphasizes recycle and reuse considering value of material and cost avoidance of disposal
  - Integrates current EM GTCC EIS effort
  - Collaborative approach among DOE-NE/EM/RW and NRC/EPA

GNEP: Critical Technology Issues
Need to be informed by scientific knowledge and industrial practices

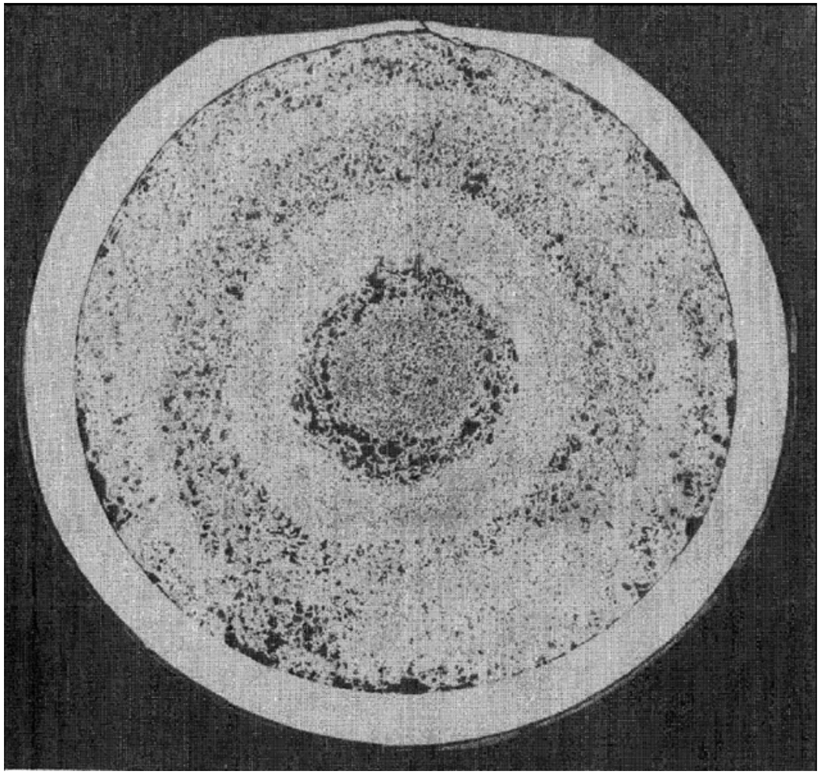


Transmutation Fuel Research and Development Campaign working to achieve fuel qualification of TRU-bearing fuel assemblies using domestic and international capabilities.

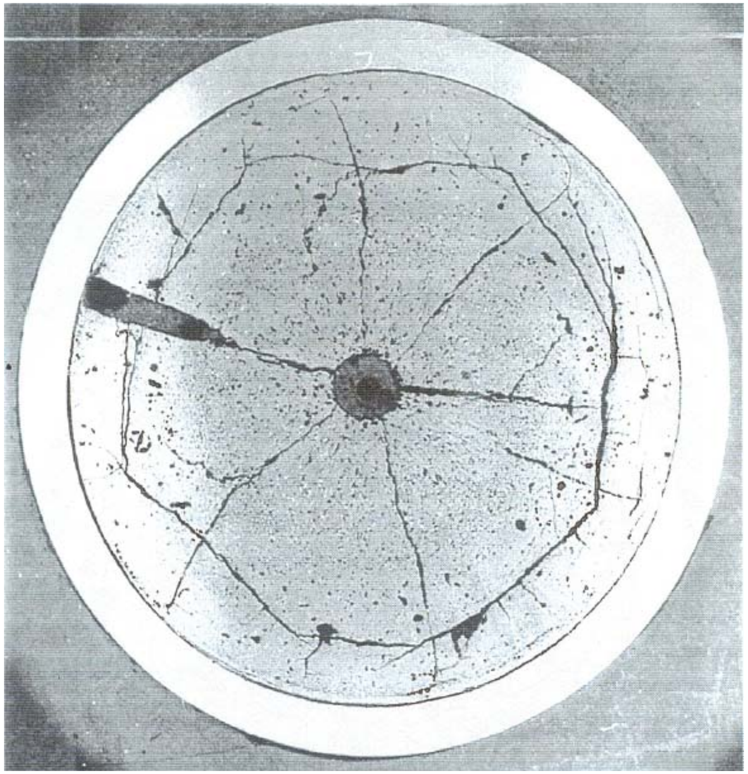
- **Fabrication Development**
  - Bench scale fabrication is currently performed in existing facilities to demonstrate feasibility.
  - Remote fabrication will be developed in existing DOE hot cell facilities to allow the use of real separations material including high specific activity isotopes (ie, Curium) in the next 5 years.
  - Lead-Test-Assembly (LTA) fabrication will require a new domestic facility or an international collaboration facility.
- **Irradiation of TRU bearing fuel**
  - Screening irradiations currently performed in non-prototypic irradiation facilities (ATR and possibly HFIR; MTS in the future).
  - Prototypic steady state irradiation and examination is currently conducted (FUTURIX-FTA) in Phénix (shutting down in 2009) and being pursued in Joyo, Monju, and BOR-60.
  - LTA irradiation and qualification will be needed, new domestic or international fast reactor and TREAT for transient testing.
- **Facilities are critical for the future: AFCF, MTS, ABR**
- **Cross-cutting modeling and simulation effort is being pursued to obtain a revolutionary capability allowing reduced experiments in the future.**

Conventional fast reactor fuels qualified to ~10 at% burnup and demonstrated to ~19.8 at% burnup.

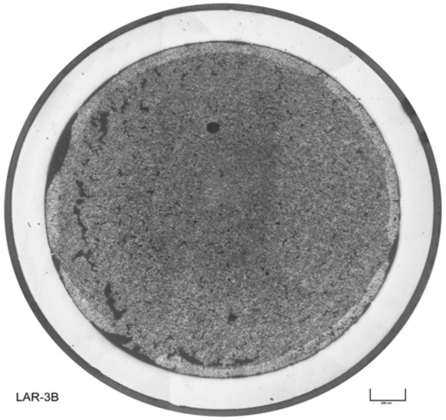
Conventional (U-Pu-Zr) Microstructure (12 at%)



Conventional MOX Microstructure (6.5 at%)



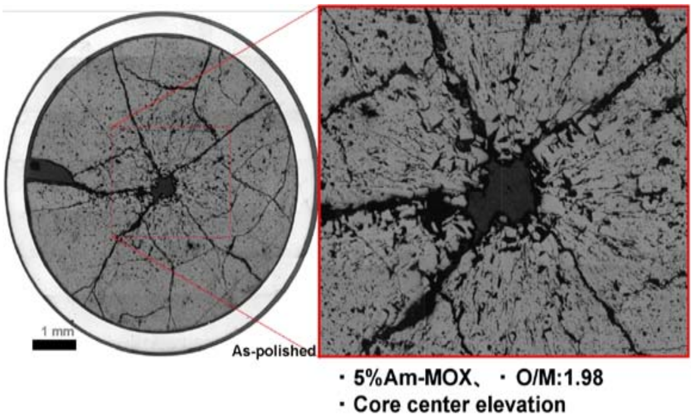
TRU bearing metal and oxide fuels have demonstrated performance and feasibility to ~6 at% and current testing will extend this to ~15 to 20 at%.



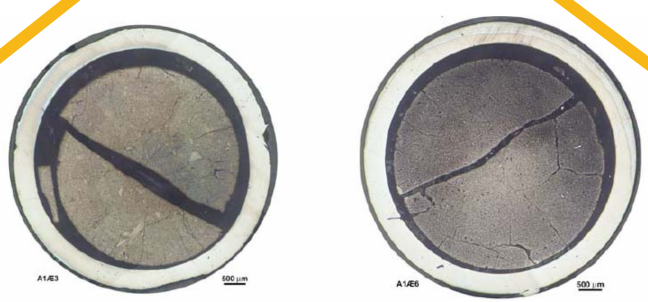
6.0 at.%

6.8×10^{20} f/cm^3

Metals – performance similar to (U, Pu, Zr) and the onset of swelling at higher burnup than conventional (U, Pu, Zr)

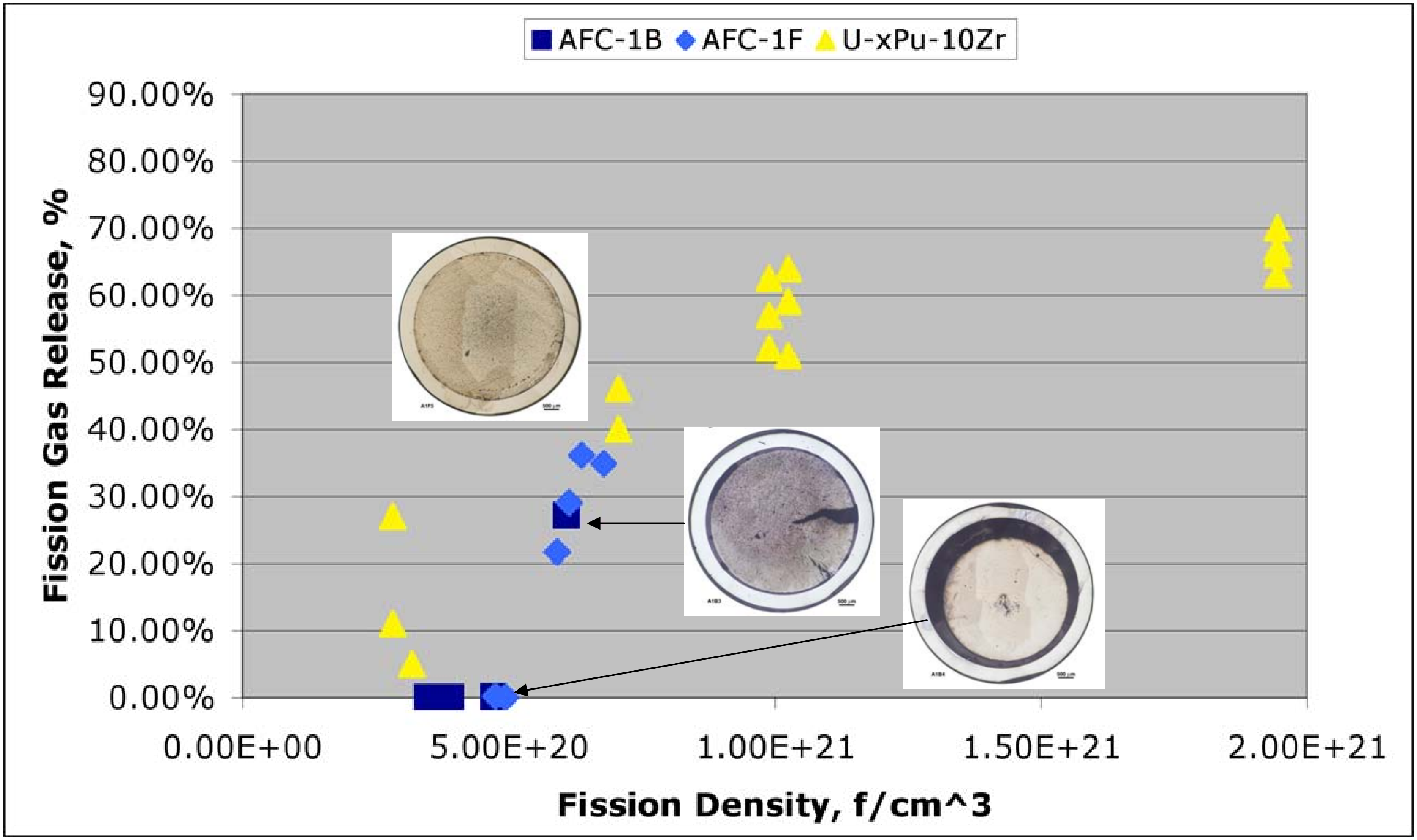


Oxides - performance and microstructure develops similar to conventional MOX.

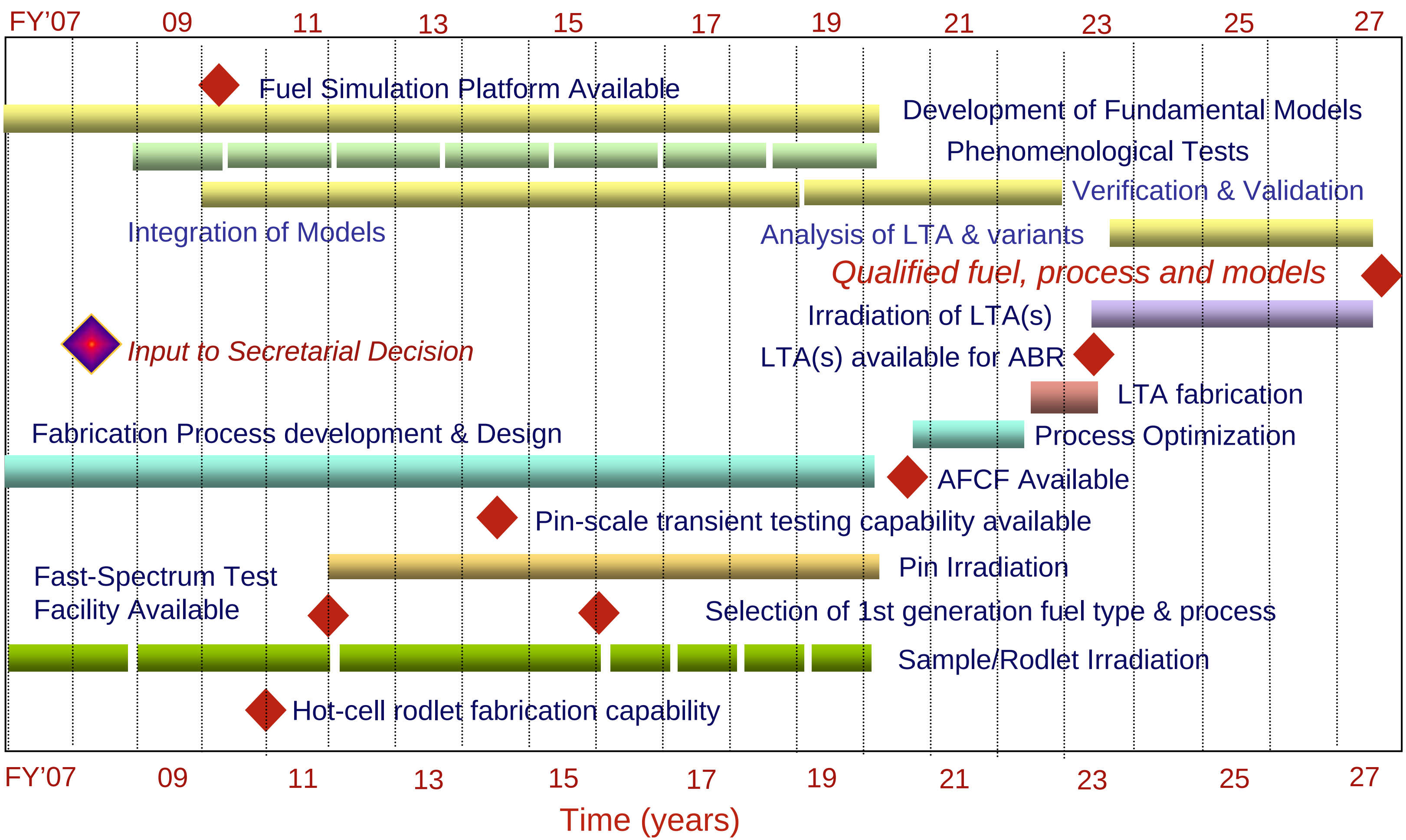


Nitrides - have had difficulty with consistent fabrication but have performed as expected under irradiation.

Recent USDOE transmutation metal irradiation results show that the fuel swelling, fission gas release, and microstructure behaves similar to the the (U-Pu-Zr) system.



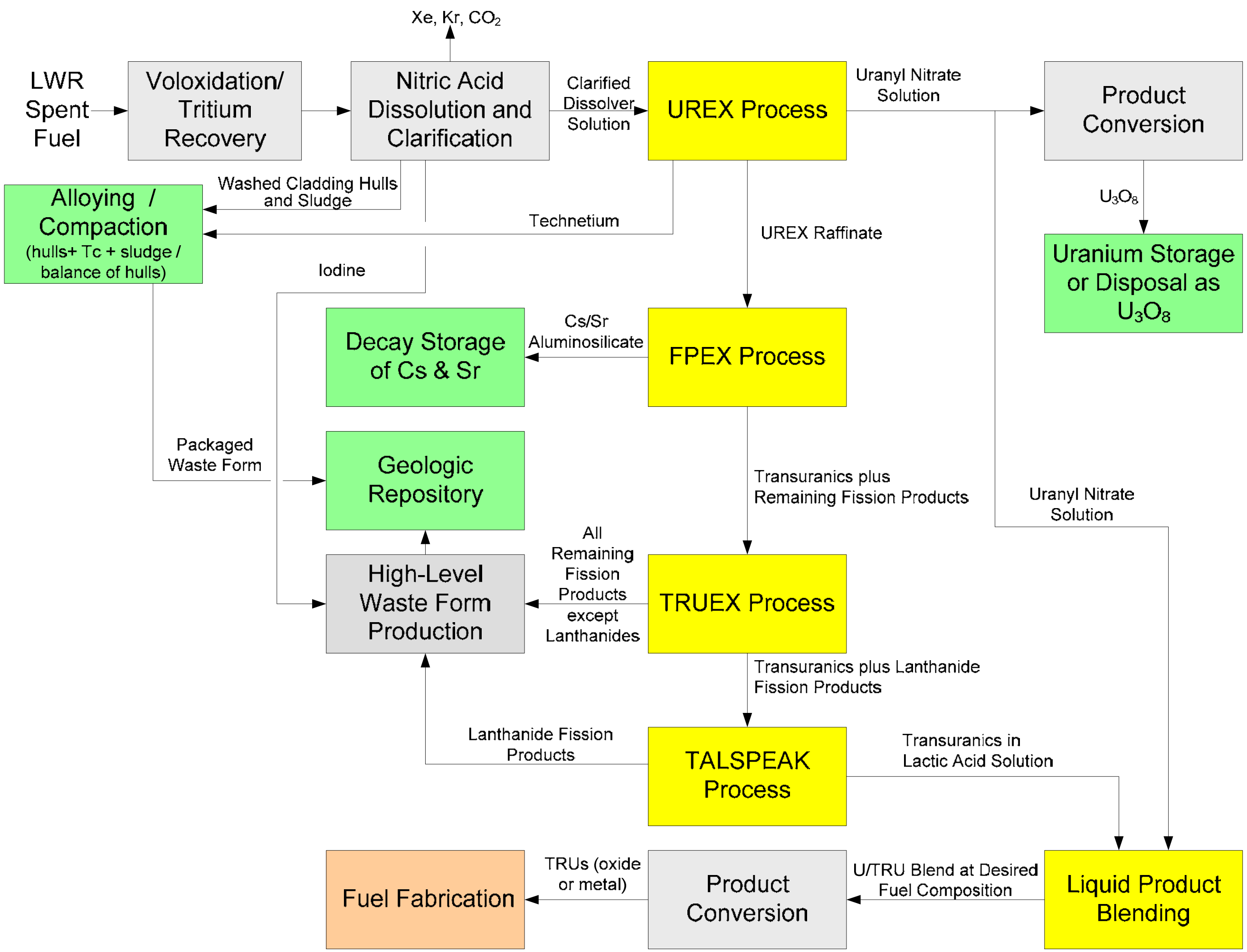
Notional schedule for transmutation fuel qualification
(includes homogeneous & heterogeneous recycling options)



Feasibility of aqueous and electrochemical separations has been demonstrated

- Address LWR and transmutation fuels, driven by repository requirements (e.g. volume, heat load, toxicity)
- Small-scale aqueous flowsheet tests with actual LWR met separation criteria (>99% recovery). ANL tests of UREX; future ORNL coupled tests (CETE)
- Engineering-scale (10-15 MT/yr) aqueous separations equipment testing capability developed for cold testing
- Fast reactor spent fuel processing demonstrated for uranium recovery (97.6% recovery)
- Recovery of uranium and transuranic elements at engineering scale using electrochemical methods
- Initial oxide reduction capability developed at kg scale (surrogates) and 50 g scale (>99% efficiency with actual fuel)

Example of a UREX Flowsheet



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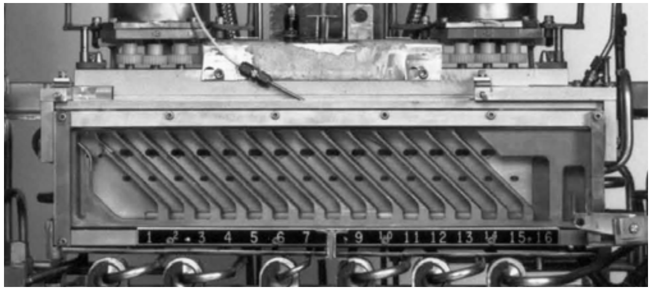
CETE research and development activity at ORNL

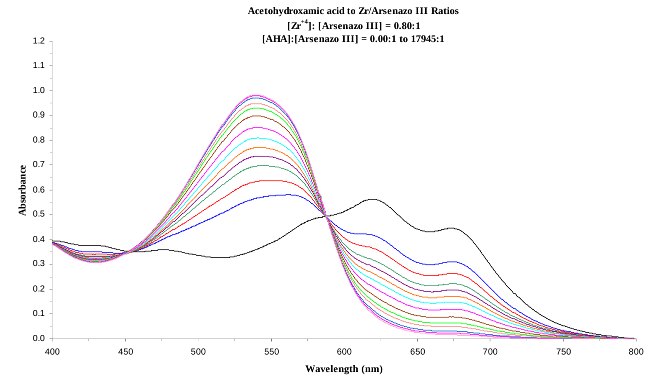


- The ORNL Coupled-End-To-End (CETE) demonstration includes:
  - Volatilization of tritium
  - Fuel dissolution
  - Off-gas characterization and trapping from shearing and dissolution
  - Separation testing of evolutionary “co-extraction” technologies which utilize the same proven solvent as the PUREX process
  - Product solidification

- Provides a testbed in the near-term for the demonstration of GNEP technologies.
  - Flexibility to conduct R&D on a wide range of aqueous separation technologies.
  - Integrate together various steps in the GNEP process (voloxidation, separations, product conversion, fuel/target fabrication, and waste form development) to identify and resolve interfacial issues between these steps.
  - Provide actual SNF separated products to enable GNEP research.

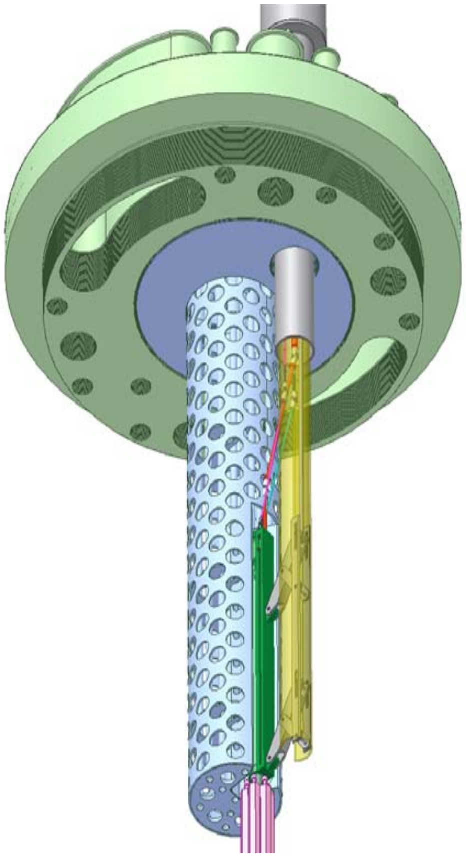
Separations Technology Development Strategy

- Further develop and validate process models and utilize for process optimization and waste minimization
- Understand balance-of-plant issues (acid recycle, solvent losses, solvent wash, noble gas capture, etc)
- Perform integrated testing of separation processes to demonstrate controllability, understand interactions between processes, determine long-term solvent stability, and establish overall process reliability
  - Engineering-scale testing with surrogates and uranium
  - Verification testing with small-scale equipment and spent nuclear fuel to confirm engineering-scale results
- Develop and demonstrate advanced transuranic recovery methods
- Scale-up oxide reduction and electrorefiner capacity
- Stronger interactions between engineering and basic sciences (sigma-teams)
- Strong collaborations with the French CEA have led to fast down selections of options



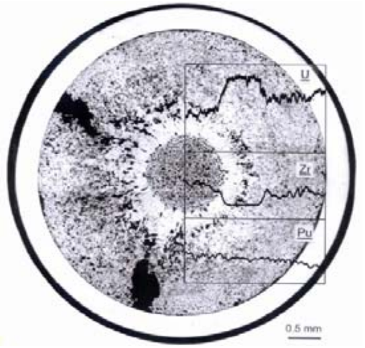
Path Forward to Future Commercial ABR's

- **Improved safety, reliability and economics are needed to achieve long term commercialization of Sodium Cooled Fast Reactors**
- **Pursue cost reduction design features and simplifications:**
  - Compact configurations and components
  - Improved performance, efficiency
  - Advanced materials
  - Improved in-service inspection techniques
  - New modeling and simulation techniques and codes
- **Improve infrastructure to support SFR development**
  - Need to rebuild U.S. infrastructure and leverage capabilities of our international partners
  - Human resources
- **Strong international collaborations are expected with France and Japan**



compact fuel handling system

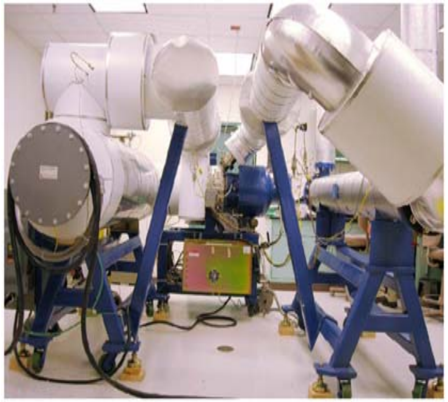
Advanced Fast Reactor Materials



- **Advanced materials for Advanced Burner Reactor**
  - Longevity of components – 60 year life
  - Economics
  - High temperature environment
  - Increased burnup
- **Advanced materials will be irradiated in recycling reactor prototype**
- **ASME codification of materials and design methodology - requires NRC acceptance**
- **Near Term work**
  - Gather highly irradiated material specimens and perform post irradiation examination
  - Establish justification for ABR materials selection
- **Availability of irradiation facility for materials development is an issue**
- **Materials handbook for designers will need to be developed**

Alternative Power Conversion Systems
Supercritical CO_2 Brayton Cycle

- **Brayton Cycle may be an economical alternative to the steam Rankine Cycle**
- **Higher plant efficiency = higher electricity revenue**
  - potential increase from 38 % to 45 % efficiency
- **Lower capital costs from smaller turbomachinery and fewer components**
  - no separator reheaters, condenser, feedwater heaters, deaerator
  - Reduction in turbine generator building size and cost
- **Avoids sodium-water reaction problem**
- **Tests underway at Sandia**

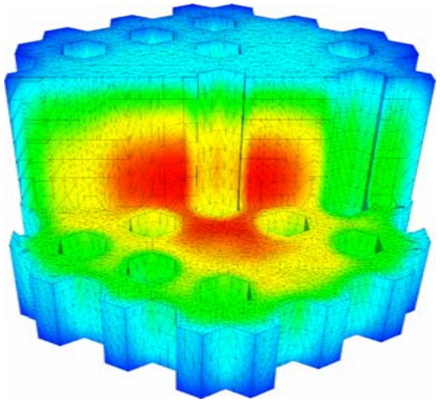


Nuclear Data

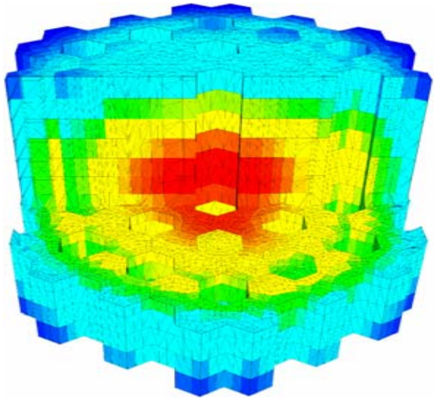
- **Highly precise nuclear data measurements are needed to reduce uncertainties and fully understand phenomena**
  - Fission and capture cross sections for actinides
  - Neutron cross section covariance data
  - High Priority Request List
  - Formalized Data Adjustment
- **Evaluation of an SFR burner requires substantial new data**
  - to optimize system performance and economy
  - Also needed for safeguards and criticality safety
- **Enhanced nuclear data is needed to fully leverage the benefits of advanced computation and simulation**
  - provide designers with improved and validated calculation tools
- **Very mature international collaboration**

Modeling and Simulation

- **Goal: an advanced, fully integrated multi-physics code**
  - Coupled neutronics, thermal-hydraulics and structural mechanics calculations for design, operations, and safety
- **Enable accurate predictions of system performance**
  - Define service conditions for fuels, materials, and components
  - Quantify performance advances and increase assurance of performance gains
    - *prior to system operation*
- **Reliably characterize and reduce modeling uncertainties, which necessitate over-conservatism in design**
- **Enable a more efficient, integrated design process**
- **M&S is the key area for US International Leadership**



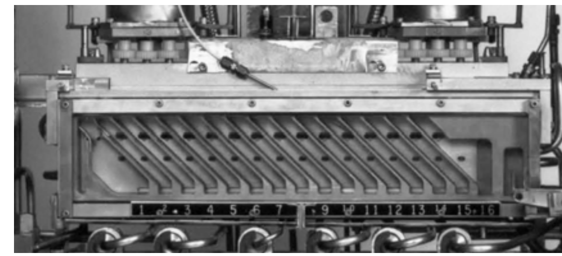
Group 1 Flux

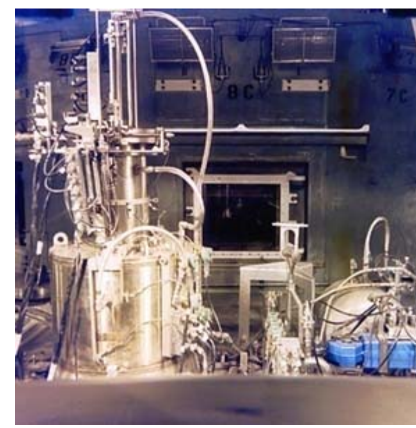


Power Distribution

Safeguards Development Needs

- **Advanced measurement techniques and approaches**
  - Direct measurement of spent fuel, Pu in presence of minor actinides, electrochemical processing, bulk and flowing samples (active and passive)
  - Expansion of neutron balance concept
  - Advanced x-ray, gamma-ray, alpha spectroscopy
- **Nuclear physics and chemical data**
  - Gaps exist, reduce uncertainties/increase confidence, enabling for new measurement approaches
- **Process monitoring**
  - Online chemical analysis, radiation monitoring, other (flows, pH, etc.)
  - Trend, diversion analysis
- **Safeguards analysis and modeling, information technology**
  - Safeguards performance and optimization, data protection and authentication
  - Instrumentation design including basic materials science
  - Facility, site, regional analysis
- **Safeguards envelope**
  - Putting it all together to enable real time knowledge extraction of facility operation





DOE Regulatory Compliance / NRC Engagement

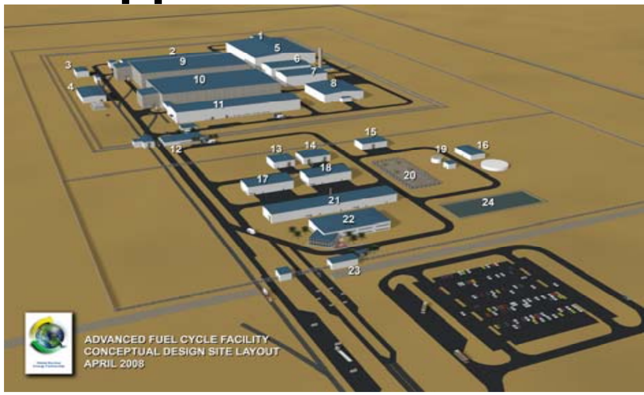
- **Potentially large schedule risk due to uncertain regulatory framework**
  - Regulatory framework for either sodium fast reactors or reprocessing plants has not been exercised for a long time
  - Requirements have evolved over time
  - Historical data is probably useful, but only if it can be qualified for use in license application
- **DOE is placing emphasis on this early in the R&D program because**
  - Licensing requirements will drive data needs
  - DOE owns most of the data and qualifying this is crucial
  - DOE facilities will be needed to generate new data for licensing
- **Regular interface between DOE/NRC liaisons**
  - Memorandum of Understanding / Interagency Agreement
- **DOE/NRC Technical Information Exchanges**
  - Ongoing series of technical exchanges on GNEP program elements

International Collaboration

- **International collaborations have brought significant value to the program:**
  - Nuclear data, integral data, and validation methods
  - Transmutation analyses
  - Systems analyses
  - Flowsheet development
  - Access to irradiation facilities
- **Future priorities:**
  - Continued access to irradiation facilities
  - Flowsheet development
  - Modeling and simulation

Infrastructure Requirements

- **Commercialization of technologies requires demonstration at engineering scale**
  - Minimize technical risk to industry
  - Enable technology transfer
- **Facilities do not now exist to conduct hot engineering-scale demo for separations, FR fuel fabrication, reactor components, fuel irradiation**
- **Facilities also needed to conduct key tests in support of licensing; e.g. transient testing**
  - Critical needs are:
    - *Fuel Fabrication*
    - *Separations*
    - *Fast Flux Irradiations and Transient Testing*
- **Create attractive opportunities to train next generation**



AFCF

Personnel

- **Strengthening universities essential to developing needed expertise for industry, government, regulators and laboratories**
- **In FY09 we are planning to dedicate 20% of our budget to universities**
- **Fellowships**
  - Support masters and doctoral students
- **We are exploring establishing Centers of Excellence**
  - Stabilize funding (5 years)
  - Build capability (labs, equipment, professors)
  - Additional funding through competitive solicitations
  - Competitively selected
  - Key areas
    - *Radiochemistry/Actinide Chemistry*
    - *Safeguards*
    - *Advanced Materials*
    - *Fast Reactors*
    - *Advanced Fuels*

Conclusions

- Advanced fuel cycles and international fuel services are complimentary in addressing global proliferation issues
- Technical challenges have been identified
- The R&D program to address these challenges is:
  - Requirement driven
  - Is incorporating the latest scientific advances
  - Is being informed by input from industrial experience