U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Fuel Cycle Research and Development

FCRD Overview

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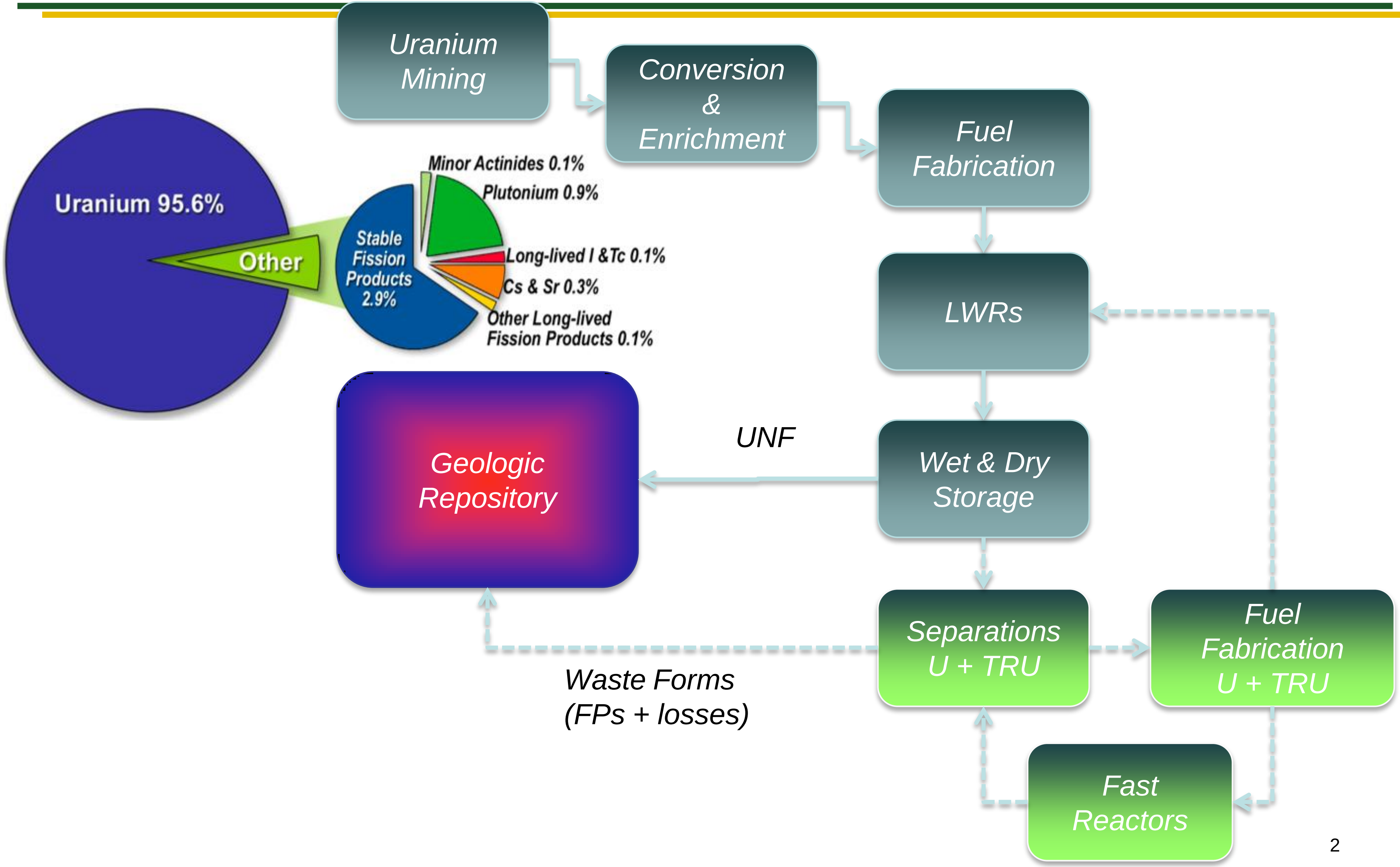
FCRD includes a variety of technologies looking at different fuel cycle options



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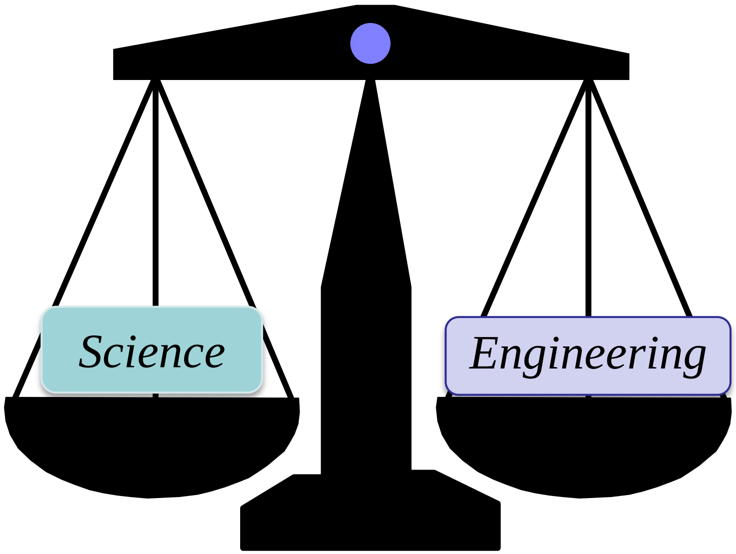
Separations and Waste Form Campaign Objectives

- **Develop the next generation of fuel cycle separation and waste management technologies that enable a sustainable fuel cycle, with minimal processing, waste generation, and potential for material diversion.**
  - The campaign strategy is based a sound balance between science and engineering



Campaign Overview

Where we were, where we are and where we are going –

Past (history)	Present (options)		Future (needs)
Pu for weapons	UO_X burning only	Pu MOX	Recycle TRU
PUREX	Once through	PUREX	Advanced separations
Waste stored in tanks	Local SNF storage	Immediate waste treatment	Consolidated processing/storage
Vent fission gasses	n/a	Vent or release fission gasses	Capture and immobilize fission gasses
Deferred vitrification	Deferred Fuel disposal	Glass for future disposal	High performance waste forms/ geologic disposal

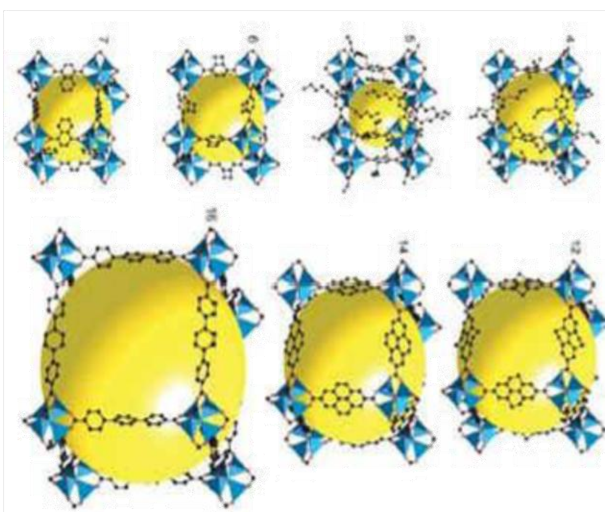
Focused Objectives

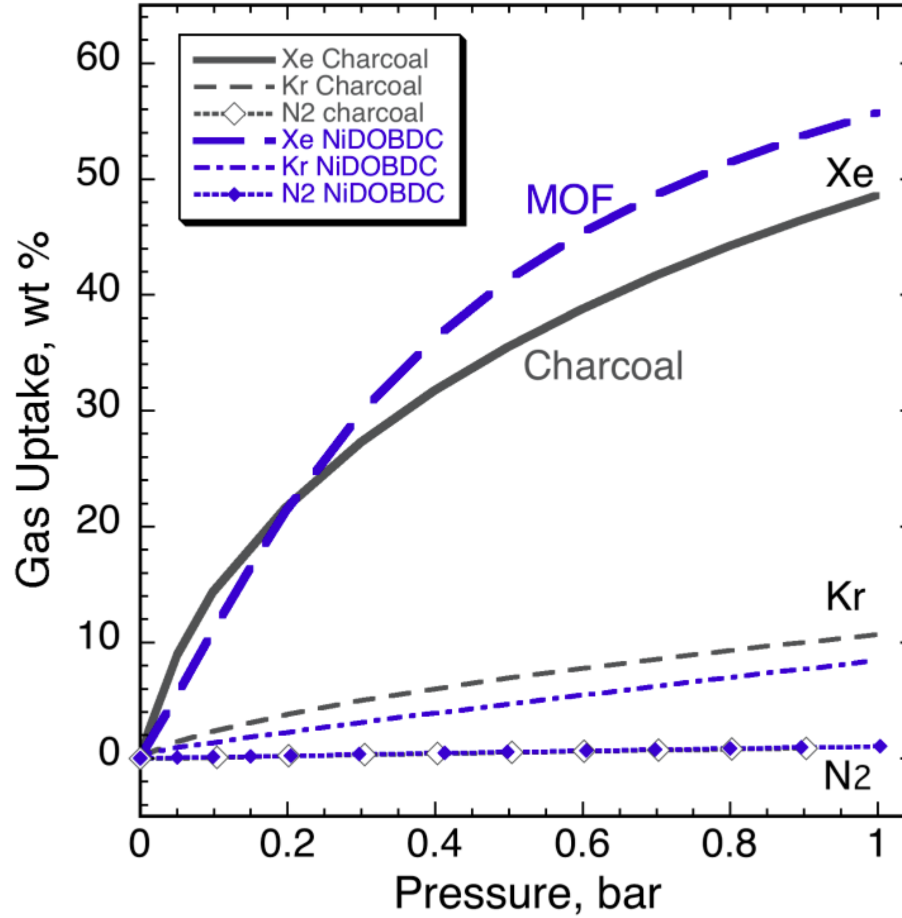
Fundamental Science & Mod/Sim	• Develop the next generation methods and tools for separations, waste form development, and waste form performance- fundamental science related to applied research
Minor Actinide Sigma Team	• Enabling technology for TRU recycle options from LWR fuel • Develop cost effective technology ready for deployment
Off-gas Sigma Team	• Enabling technology for any recycle option (Tritium, Iodine, Krypton) • Develop cost effective technology ready for deployment
Advanced Waste Forms & Processes	• Open disposal options with higher performance waste forms • Develop cost effective technology ready for deployment
Electrochemical Processing	• Develop and demonstrate deployable and sustainable technology for fast reactor fuel reprocessing
Fuel Resources	• Develop cost effective method for passive sea water extraction • Establish bounding cost for uranium resource

Noble Gas Separations at Room Temperature

- **Novel metal organic frameworks (MOF's) are being developed with the correct size and functionality to selectively capture Kr and Xe from air at near room temperature.**
- **These materials are being developed for use in used nuclear fuel reprocessing plants.**
- **There are obvious commercial applications for noble gas separation and sale.**

Metal-organic framework's tuned to molecule size and chemistry, Eddaoudi, et al.,2002, Science, 295, 469. →

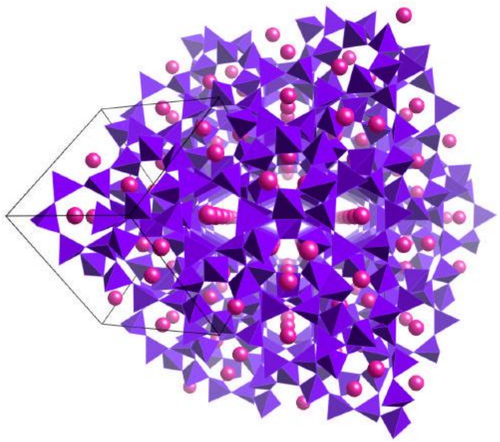




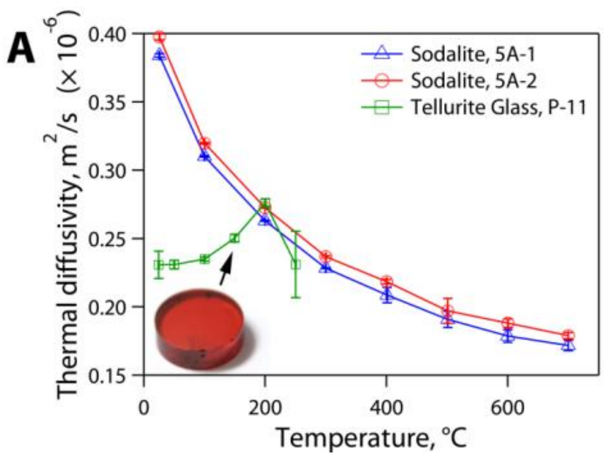
↑ *Strachan, D.M., et al. 2011, Summary Report on the Volatile Radionuclide and Immobilization Research for FY2011 at PNNL. FCRD-SWF-2011-000378, PNNL-20807.*

Waste Forms Applicable to Fukushima

- **The Fuel Cycle Research and Development Program has been developing waste forms for streams important to advanced fuel cycles:**
  - Alkali-alumino-silicate ceramics for high heat materials such as Cs
  - Ceramics and glass ceramics for high halide streams
  - These may be applicable to the Cs capture media and heavy brine wastes being collected as part of the Fukushima site cleanup



Model structure of ($^{137}Ba^{137}Cs^{133}Cs)AlSi_2O_6$
J Fortner and M Kaminski. 2008. Annual Report on Characterization of Aged Radioactive Pollucite, ANL, Argonne, IL.



Thermal diffusivity for a tellurite glass and sodalite samples for high chloride wastes: BJ Riley et al. 2010. Alternative Electrochemical Salt Waste Forms, Summary of FY2010 Results, FCRD-WAST-2010-000129

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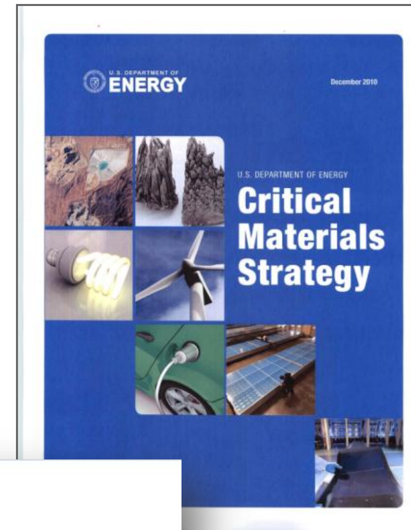
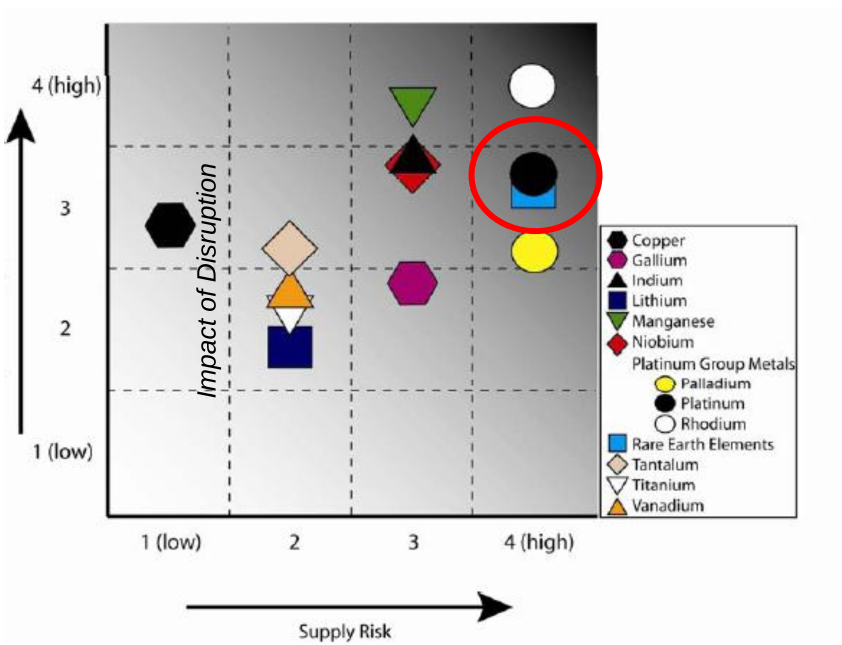
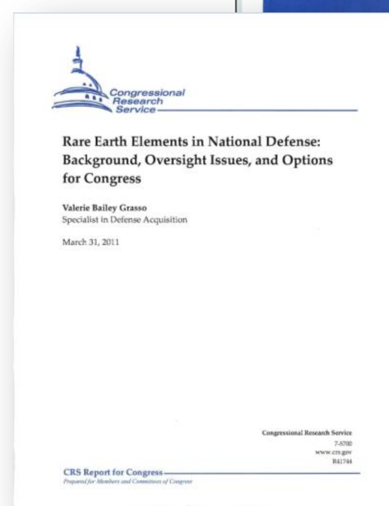
Separation/Purification of Rare Earth Elements

- *Rare earth elements are used in electronics, magnets, catalysts, glass, metal alloys and ceramics – many of these uses have strategic and defense applications*
- *Currently about 95% of the world supply of rare earth elements comes from China*
- *The FCR&D minor actinide sigma team has extensive experience with 4f element separation and many of the technologies being developed could have application to separate or purify rare earth elements more effectively*







The program must address all three major elements of the campaign in a balanced way!

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

Vision, Mission and Near-Term Goals

Vision:
LWR fleet with enhanced accident tolerance providing a substantial fraction of the national clean energy needs

Mission:
Develop advanced fuels and non-design intrusive reactor system technologies(e.g. instruments, auxiliary power sources) with improved performance, reliability and safety characteristics during normal operations and accident conditions

10-year Goals
- *Insert a LTA into a operating commercial reactor*
- *Demonstrate non-intrusive technologies that enhance safety (e.g. instrumentation with enhanced accident tolerance)*

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

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

High temperature during loss of active cooling

Improved Cladding Properties
- -Clad fracture
- -Geometric stability
- -Thermal shock resistance
- -Melting of the cladding

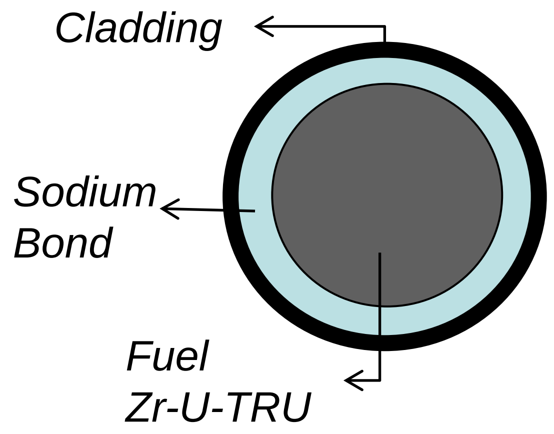
Enhanced Retention of Fission Products
- -Gaseous fission products
- -Solid/liquid fission products

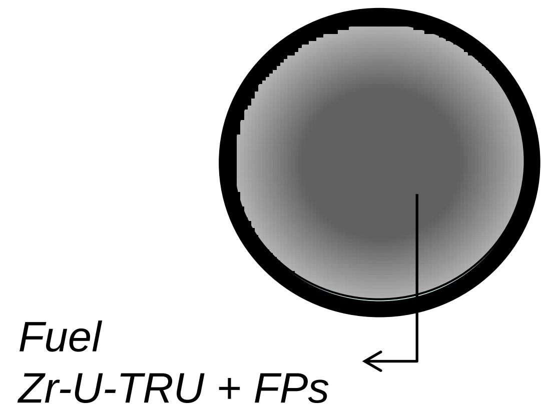
Fuels with enhanced accident tolerance are those that, in comparison with the standard UO_2 – Zircaloy system, can tolerate loss of active cooling in the core for a considerably longer time period (depending on the LWR system and accident scenario) while maintaining or improving the fuel performance 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.

Major issues for metallic fuel

- *Cladding –*
  - *HT-9 possibly good up to 200 dpa*
  - *Radiation tolerance above 200 dpa*
- *Fuel-Clad Chemical Interactions*
  - *Diffusion barrier between the fuel and cladding*
  - *Ln getters within the fuels*
- *Fission gas getters in the plenum*





Major issues for storage/disposition

- *Disposition*
  - *Container/cask materials resistant to environmental degradation in hundred thousand-year time frame*
- *Dry storage*
  - *Container/casks materials resistant to environmental degradation in hudred-year time frame*
  - *Remote/non-destructive monitoring technologies*