Closing the Nuclear Fuel Cycle

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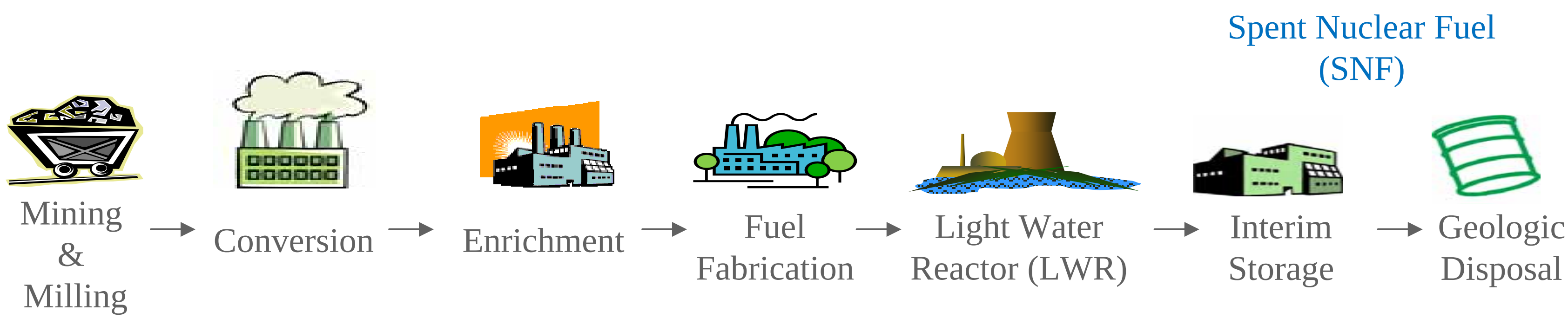
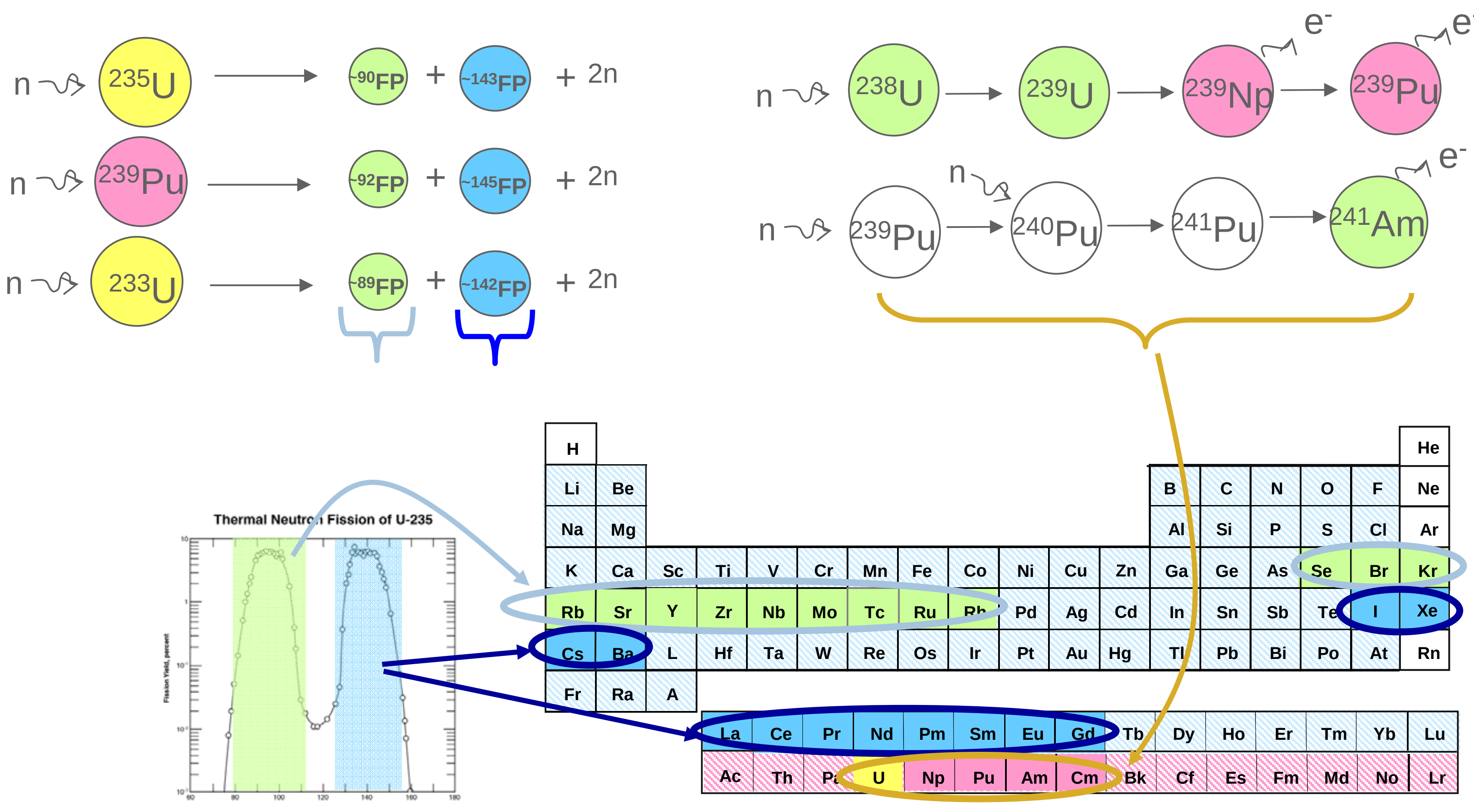
Open (or Once-Through) Nuclear Fuel Cycle



Currently, all spent nuclear fuel (or high-level wastes) from commercial reactor operations is slated for eventual geologic disposal

Background: Nuclear Reactions in Light Water Reactors (LWRs)

- Fission: Fissile isotopes split producing energy and fission products
- Neutron Absorption: Isotopes absorb neutrons forming higher actinides



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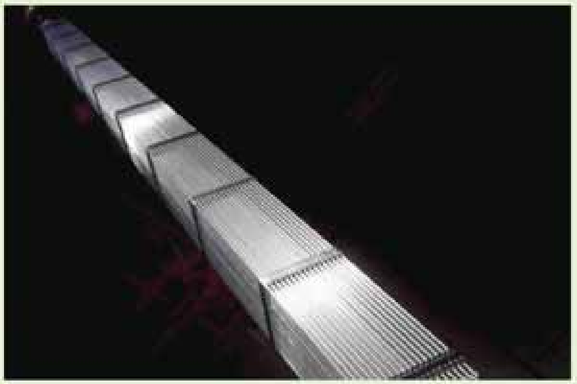
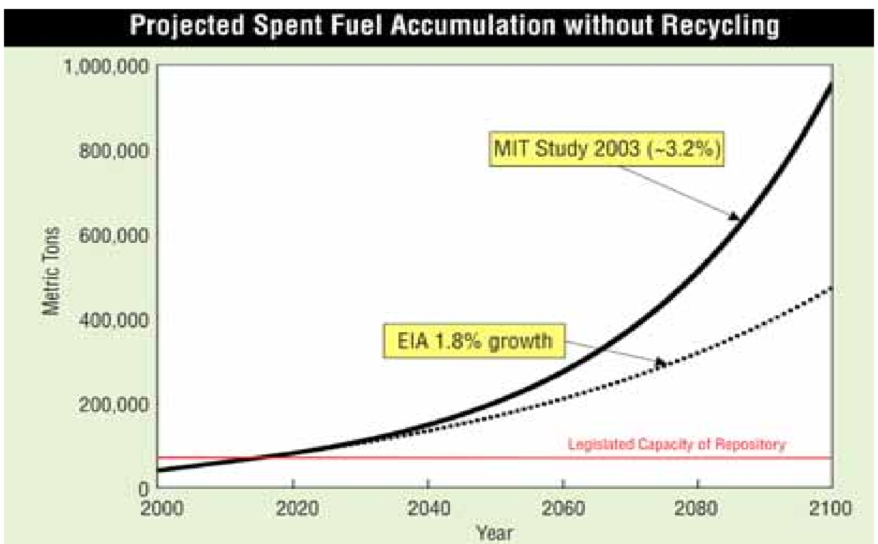
Spent Nuclear Fuel (SNF)



Spent nuclear fuel is generated when nuclear fuel rods are removed from nuclear reactors. In the U.S., this amounts to 2,000 metric tons per year.



SNF Composition and Challenges*

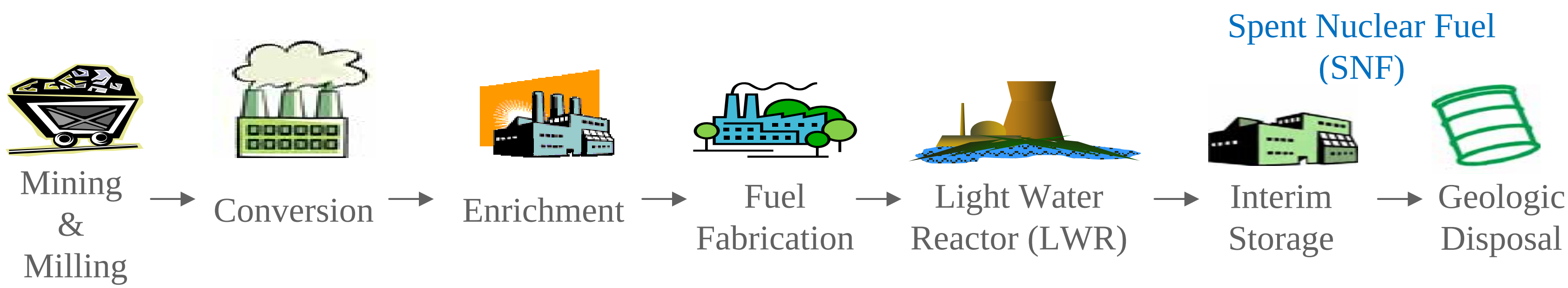
- ~1 to 2% Transuranics (Pu, Np, Am, Cm) – long-term dose and heat generation, and proliferation concerns
- ~3 to 5% Fission Products – short-term heat-generation, long-term dose
- Remainder Uranium – waste volume and recoverable resource

* Burnup dependent

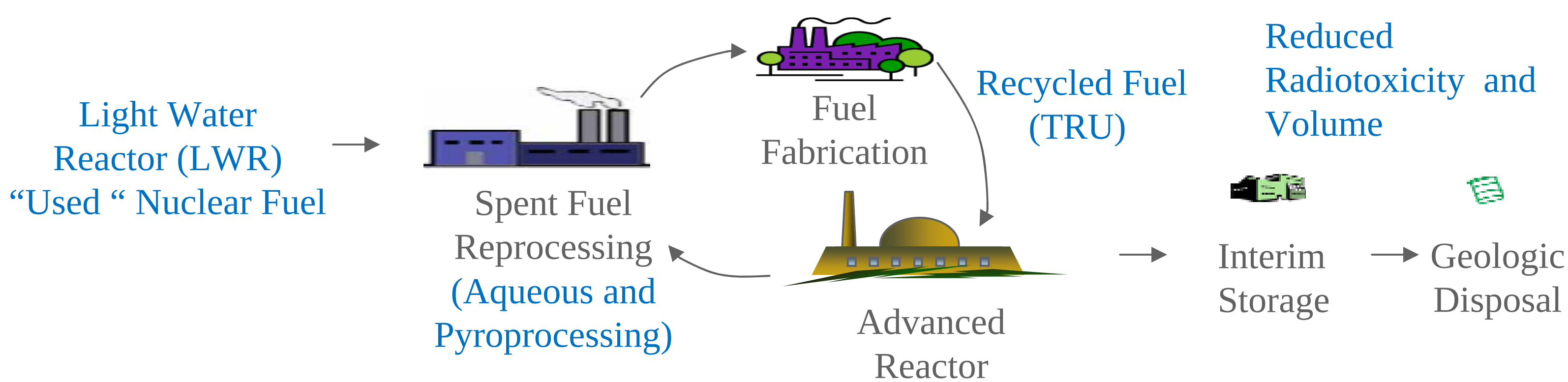
Currently SNF Management is Centered at Reactor Sites

- Spent nuclear fuel (and high-level radioactive wastes) is located at 121 sites in 39 states
- Most commercial reactor sites had a design capacity for a few decades of water basin storage
- Many utilities have added dry cask storage to handle overcrowding of these pools
- All of this spent nuclear fuel was slated for geologic disposal (Yucca Mountain)
- The Department's recent motion to "stay" all proceedings on the Yucca Mountain nuclear waste repository and withdraw the License Application effectively means expansion of on-site dry cask storage
- DOE's announcement of a Blue Ribbon Commission to develop a new strategy for used nuclear fuel and nuclear waste management and disposal will bring renewed attention to the nuclear fuel cycle.

Open (or Once-Through) Nuclear Fuel Cycle



Closed Nuclear Fuel Cycle (or Reprocessing/Recycling)



What are the incentives for recycling and "closing the nuclear fuel cycle"?

- Source of energy
  - Residual fissile materials can be recycled to new fuel
- Resource conservation
  - Low-cost uranium supplies were assumed to be finite
- Repository and waste management
  - Superior storage and disposal forms relative to SNF
    - *Tailored waste forms to improve fission product (FP) retention*
  - Separate transuranics (TRU or actinides) for transmutation
    - *Reduced long-lived radionuclides enables optimal utilization of future geologic disposal site(s)*
- Non-proliferation objectives
  - Avoid sending fissile materials to repository or long-term storage

While there has not been a strong market driver for recycling (e.g., extensive high-grade ores availability; thermal MOX fuel recycle is more expensive than UO2 fuels; uncertain economics of advanced reactor concepts, etc.), these factors are expected to change in future

Fuel Cycle R&D Challenges

- **Separations and Reprocessing**
  - Front-end technical and regulatory issues around volatile fission products (FP: Iodine, Krypton, Xenon, C-14, and Tritium)
  - Modeling and simulation of improved flow sheets/processes with minimized losses
  - Integrated safeguards and inventory control systems
  - Cost reductions in FP and TRU separations

- **Advanced Fuels**
  - High-burnup fuels to minimize waste and maximize resource utilization
  - Qualified transmutation fuels for advanced concepts to “burn” recycled TRU

- **Advanced Reactors**
  - Cost reduction with enhanced safety/security design features
  - Advanced concepts capable of higher burnups and/or transmutation

- **Robust waste forms tailored to**
  - Optimized reprocessing flow sheets
  - Understanding performance in range of geological repository environments

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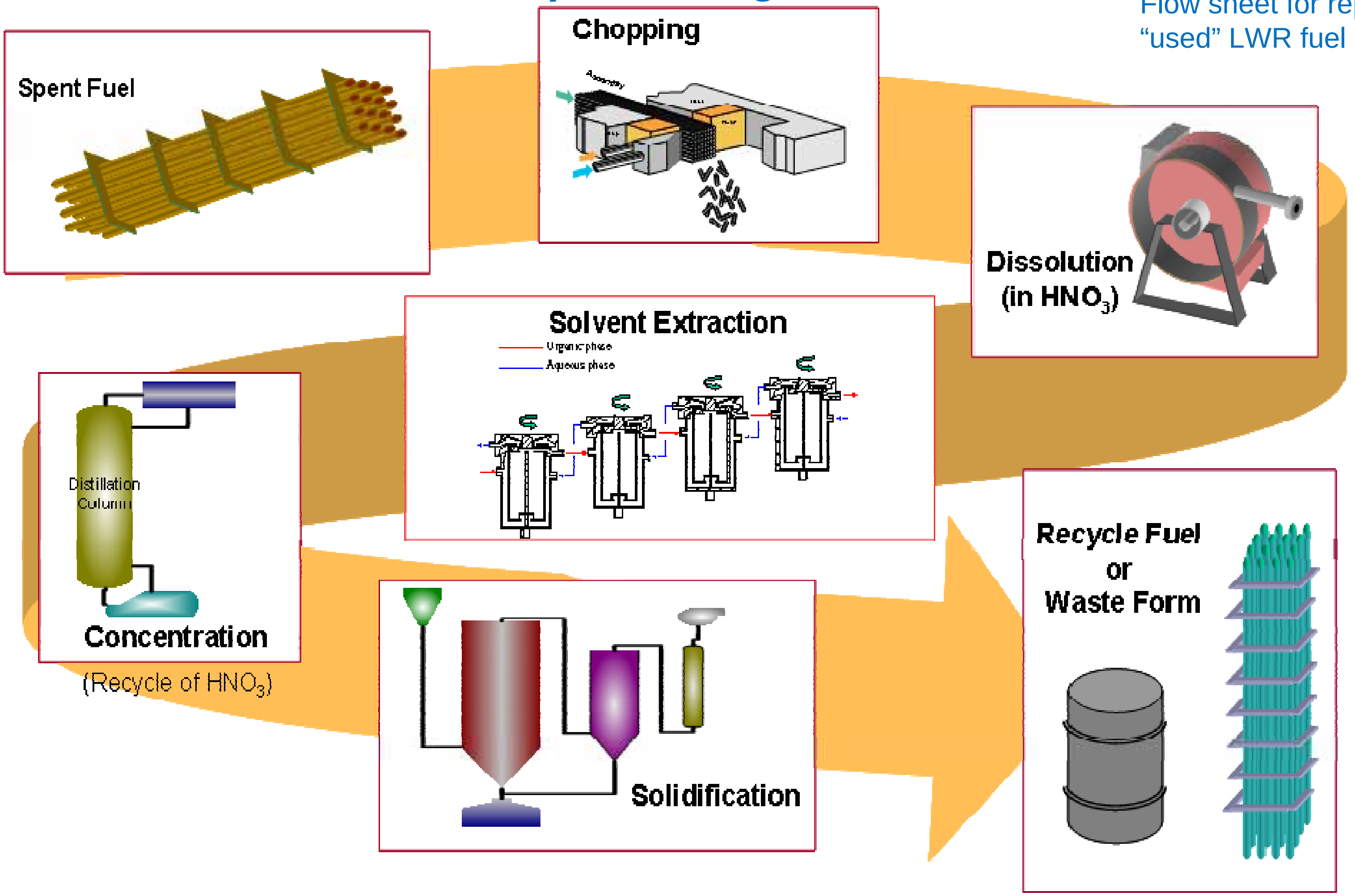
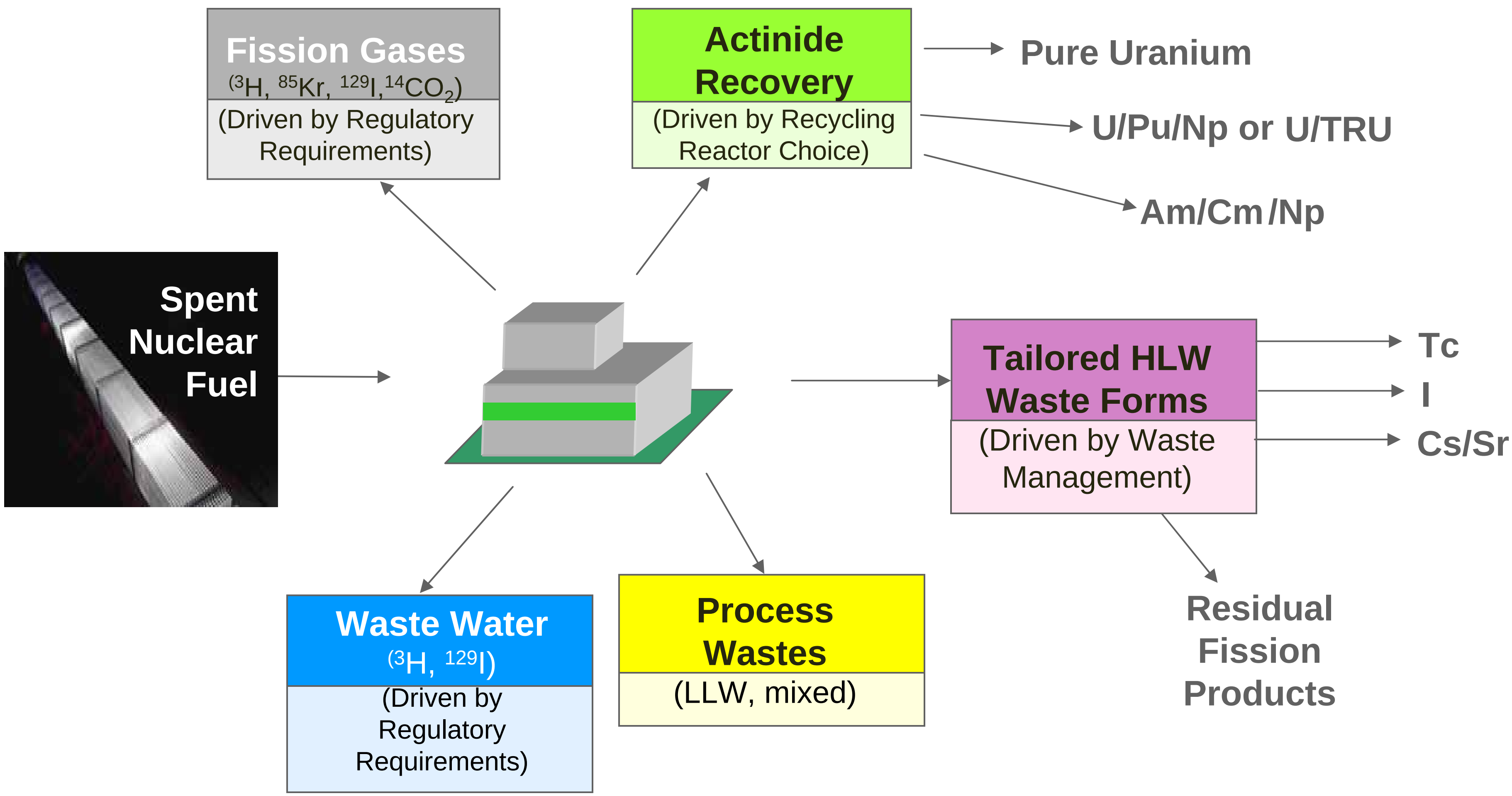
Aqueous Spent Nuclear Fuel Treatment (UREX+) for Proliferation-Resistant Reprocessing

Flow sheet for reprocessing “used” LWR fuel



Multiple bench-scale demonstrations with SNF successfully completed

Potential Products of UREX+ Recycling of LWR SNF



Advanced Reactors

A key issue for Advanced Reactors is capital and life cycle costs - large uncertainties remain vs. LWRs

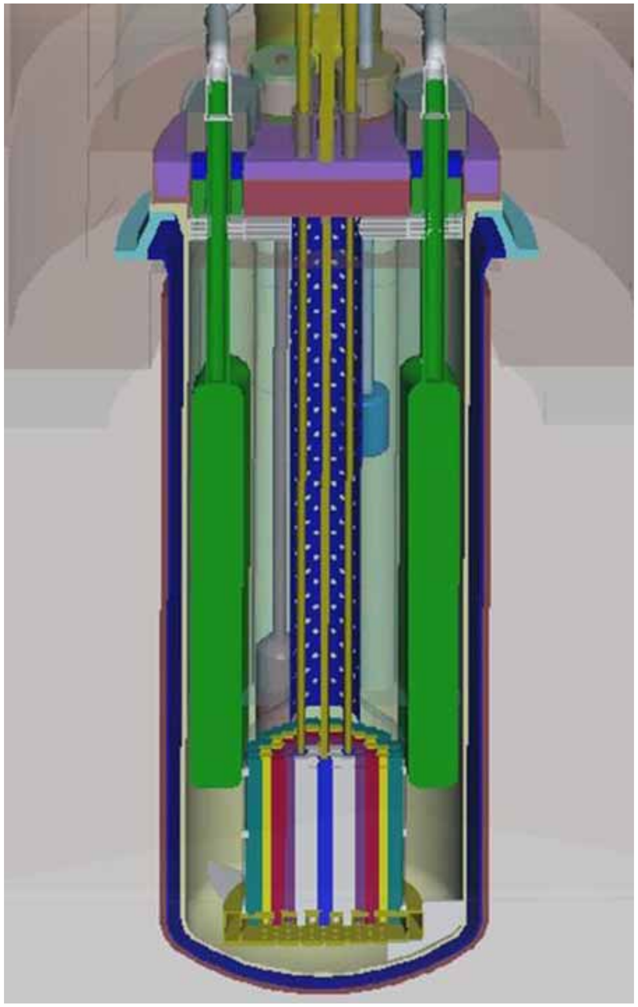
Near-term technology demonstration

•Test and evaluation of components

  – Component testing, driver fuel fabrication, validation and verification of design methods, etc.

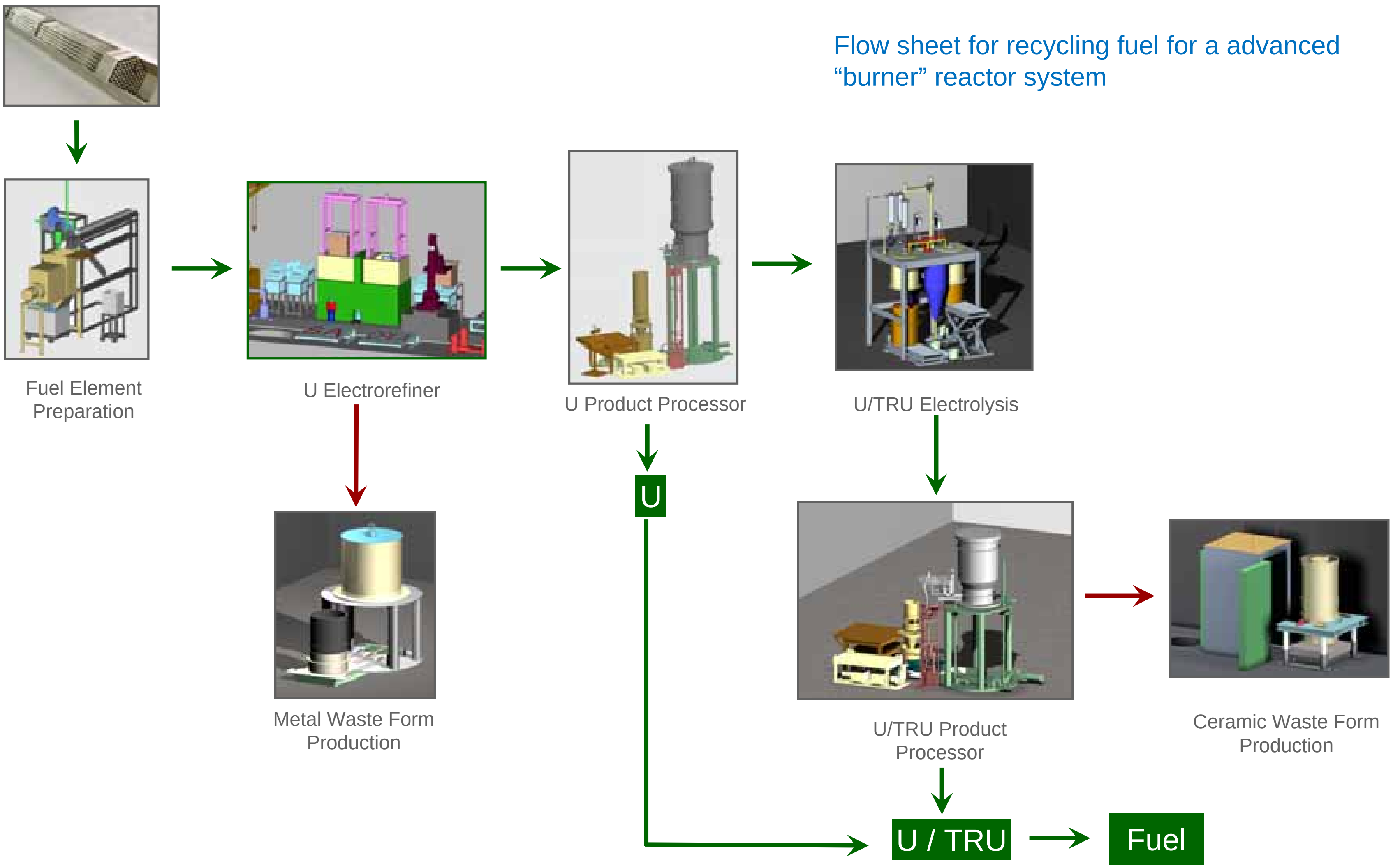
Long-term research and development

- Cost reduction technologies
  – Advanced fuels and materials, compact heat exchangers, improved energy conversion systems, etc.
- Renewed infrastructure to support this development
- International collaborations may play a key role
- New generation of HPC-based reactor modeling and simulation, and design tools



Fuel Fabrication and Recycling: Pyroprocessing

Flow sheet for recycling fuel for a advanced "burner" reactor system



Summary

Nuclear power can play an expanded role in clean electricity generation and energy security in a carbon-constrained world; this warrants along with life extension of the existing fleet and new builds, a more comprehensive, systems approach to advanced reactor concept development and managing ("closing") the nuclear fuel cycle:

- Advanced reactor system designs that optimize safety, performance, economics, and fuel cycle options; and
- Science-based R&D and demonstration of advanced nuclear fuel and waste management technologies that will enable a safe, proliferation-resistant, and economic fuel cycle that optimizes waste and resource management (including geologic repositories).