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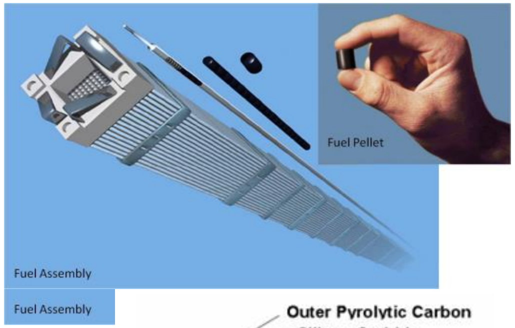
Aqueous Processing of Advanced Reactor Used Fuel

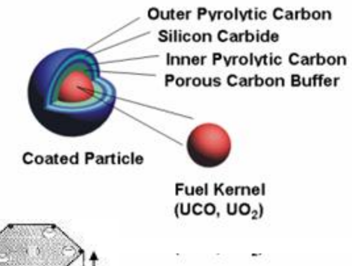
ARPA-E Workshop on Reducing Disposal Impact from Advanced Reactor Fuel Cycles

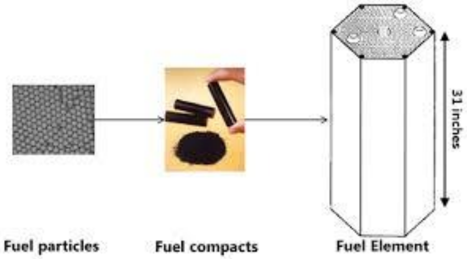
Idaho National Laboratory

Advanced Reactor Fuels

- Current LWR fuel is <5% enriched UO_2 pellets inside zircalloy tubing
  - Accident tolerant fuels may have slightly higher enrichment and used coated zircalloy or other cladding materials
- Proposed advanced reactors use different fuels
  - MOx ceramic fuel
  - Tristructural isotropic particle fuel (TRISO)
    - UO_2 or UCO fuel
    - In compacts or pebbles
  - Metallic fuel
  - Molten-salt fuel
- Many advanced reactor fuels utilize HALEU (uranium enriched up to 19.75%)
- Of these fuel types, MOx and TRISO are the most amenable to recycle by aqueous processing

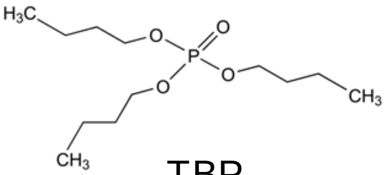




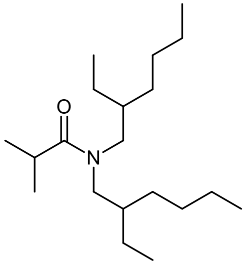


Aqueous uranium recovery/recycle approaches

- There have been a number of technologies demonstrated for the recovery of uranium and/or plutonium
  - Solvent extraction, ion exchange/extraction chromatography, precipitation
  - Of these, solvent extraction has been used to recover fissile material from used fuel at an industrial-scale for more than 70 years
    - The most widely used method is the PUREX process (plutonium uranium reduction extraction)
    - Variations of the PUREX process have also been demonstrated (e.g., UREX to recovery only U not Pu)
    - Other solvent extraction processes have been developed that use different extractants than PUREX (e.g., monoamides)

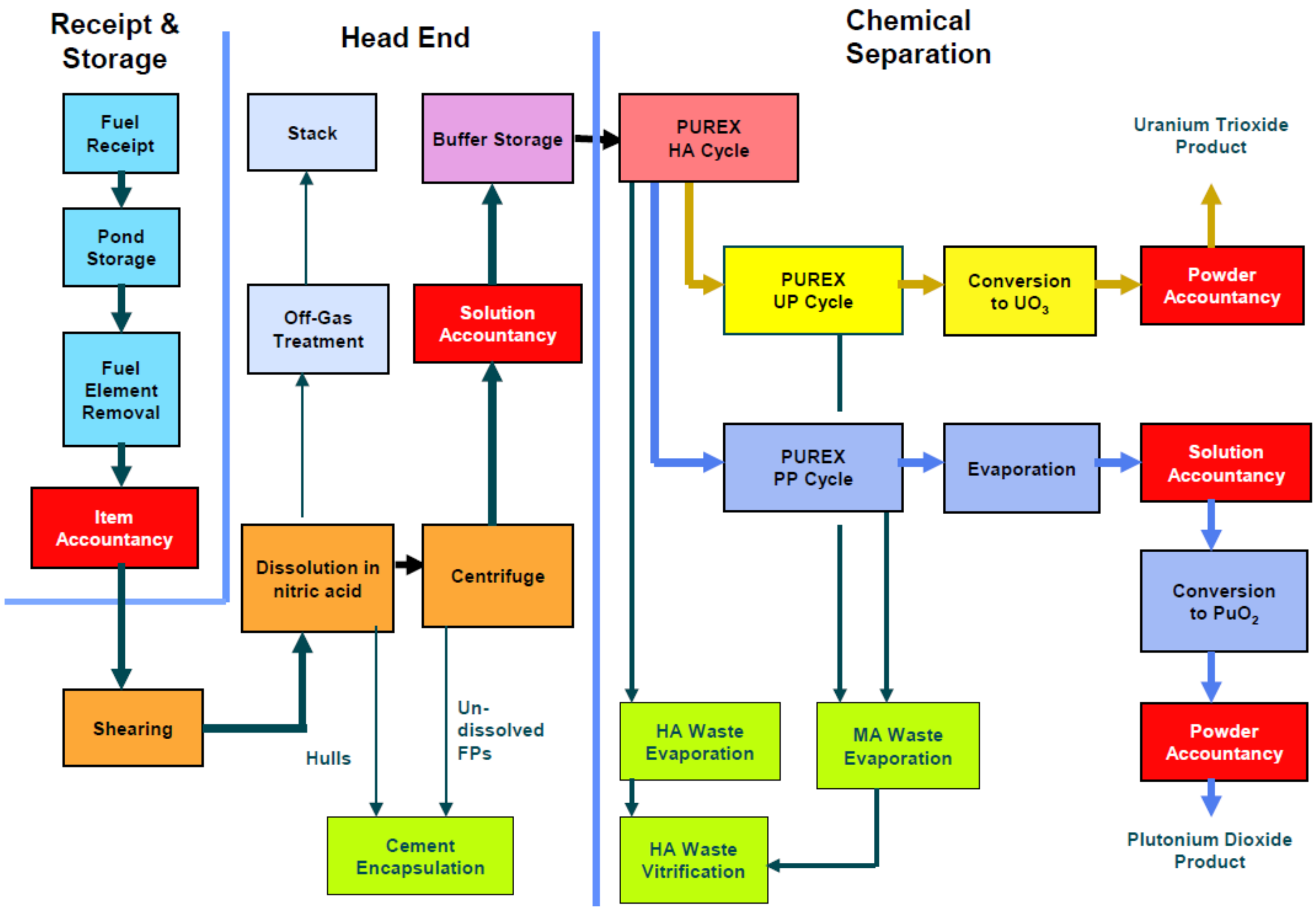


TBP



DEHiBA

Typical Commercial LWR PUREX Operations

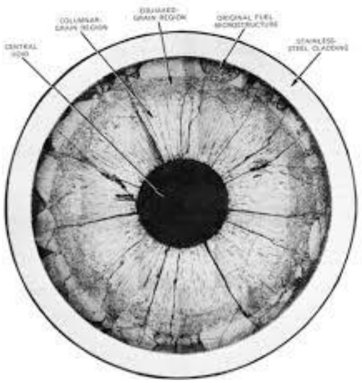


Waste Products of PUREX process

- PUREX processing produces two primary waste streams
  - High-level waste
    - Liquid raffinate containing all fission products, inert metals, minor actinides (Np, Am, Cm)
      - This stream is converted to a stable waste form, such as glass or ceramic, for eventual geologic disposal
    - The fuel cladding is considered HLW in the US (Intermediate-level waste in most other countries)
  - Low-level waste
    - Any contaminated by-product of running the process or facility
      - Does not require disposal in geologic repository
      - Some LLWs are encased in cement, others directly disposed
  - Wastes from the capture and immobilization of volatile off-gas constituents (these wastes would be either HLW or LLW depending on their characteristics and regulations)

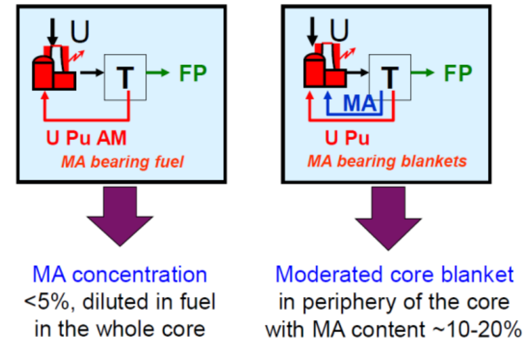
MOx fuel

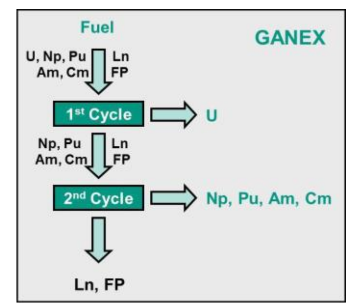
- MOx fuel (mixed oxide) is a ceramic fuel containing both UO_2 and PuO_2
- Because of Pu isotopics, MOx fuel is typically only burned once in a thermal (LWR) reactor
  - LWR MO_X typically has about 7-10% PuO_2 and the remainder UO_2
- Recycled Pu can be burned indefinitely in a fast reactor over several cycles
  - Fast reactor MO_X can have as much as 30% PuO_2
- Processing MO_X fuels is similar to processing LWR fuels with a few exceptions
  - The fuel is higher burnup and dissolving the fuel is more difficult
  - The extraction process has to be adjusted to account for the higher amounts of Pu
- ~70 MT of MOx fuel has been processed at the La Hague reprocessing facility in France

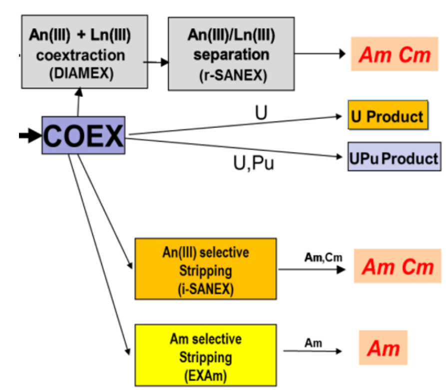


Processing Advanced Reactor Fuels

- **MOx Fuel** (for fast reactor recycle)
  - Challenges are dissolving high-burnup fuel and accommodating high Pu content
  - European approach (heterogeneous or homogeneous recycle)
  - GANEX (group actinide extraction for homogeneous recycle)
    - Two step process
      - Separate U using DEHiBA extractant
      - Separate Np, Pu, Am, and Cm using Euro-GANEX process
  - SANEX (selective actinide extraction for heterogeneous recycle)
    - Multiple approaches
    - Similar approaches internationally (e.g., ALSEP process in US)





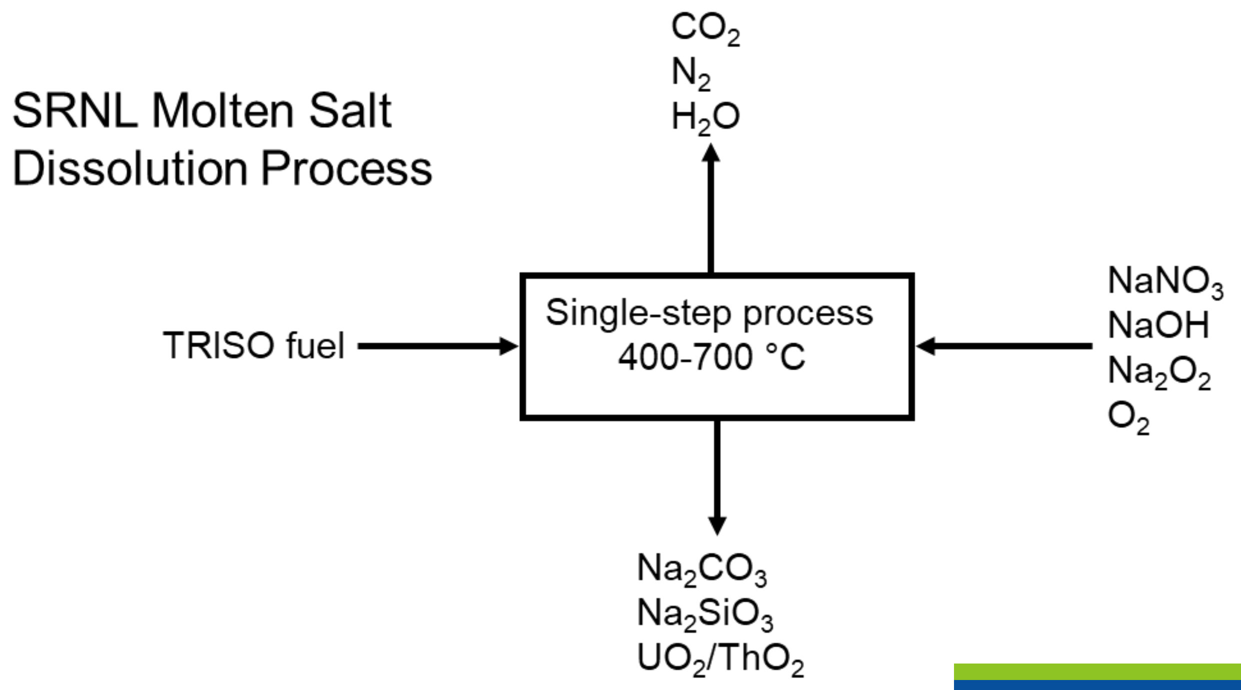


Processing Advanced Reactor Fuels

- **TRISO Fuel**
  - It is challenging to destroy the outer coatings of TRISO particles to access the uranium
  - Historically, a grinding, burning, and leaching approach was developed, but burning the graphite releases C-14
  - Besides the carbon coating of the particles, there is a very large mass of contaminated graphite in the compacts, prisms, or pebbles that will require disposal
  - Methods that need developed are:
    - Separating TRISO particles from the graphite material
    - Accessing the uranium inside the TRISO particle
      - SRNL molten nitrate salt
      - Electrochemical method
      - Sonication
      - Others ?

Processing Advanced Reactor Fuels

- **TRISO Fuel continued**
  - Once the TRISO particle is breached, the fuel can easily be leached out and conventional solvent extraction processes employed
  - Graphite waste disposal and possible waste forms have not been addressed sufficiently



Research areas that could be potential game changers

- Headend processes
  - Advanced methods to remove cladding that would enable it to be disposed as LLW rather than HLW
    - For oxide fuels, this could be Zr or SS volatility
    - For TRISO fuel, separation of fuel particles from graphite
  - Advanced separation processes
    - Key is simplification for waste minimization
      - Can we go from 2 or 3 extraction cycles to 1 cycle and significantly reduce facility size and operational costs?
  - Advanced waste forms
    - Ceramic or glass ceramic waste forms have the potential to increase waste loading (reduce volume) and be more durable than borosilicate glass
  - Volatile off-gas capture and immobilization
    - Enabling technologies for all processing methods

Summary

- Advanced reactor fuels have differences from current LWR fuels that create new challenges
  - Headend processing to access fissile material
  - Waste management
- There are a number of research opportunities that could make significant advancements in aqueous processing and waste management that are currently not being addressed by any R&D program
  - NE program funding for material recovery has decreased for the past several years and is at or near unsustainable levels
- The development of advanced reactors without the development of their associated fuel cycles creates additional programmatic risk