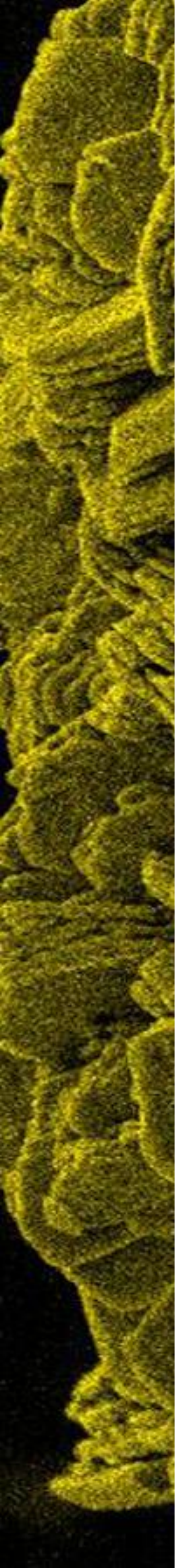

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Future of aqueous processing of spent fuel

Gregg J. Lumetta and Stuart T. Arm

U.S. DEPARTMENT OF ENERGY BATTELLE

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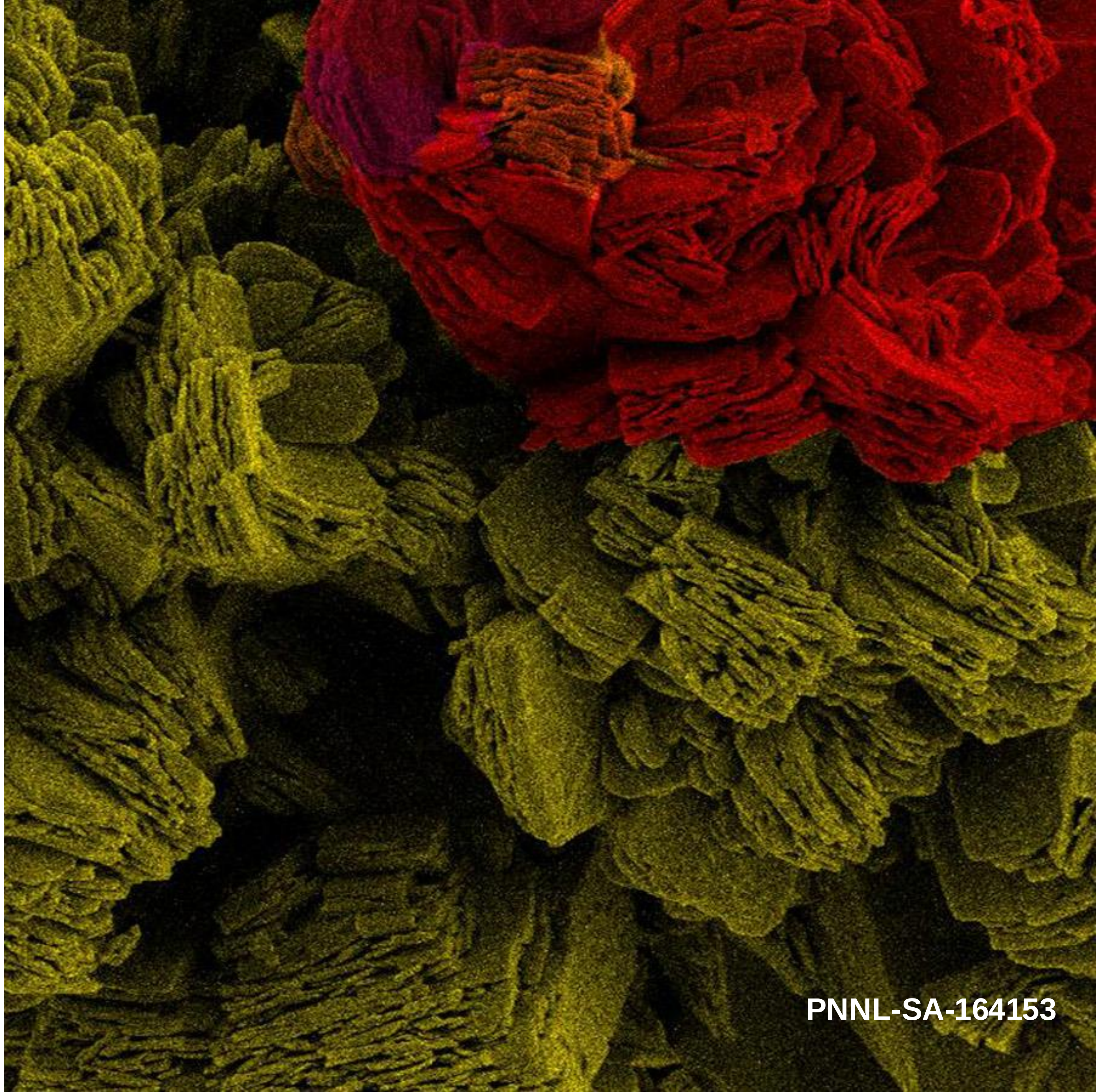

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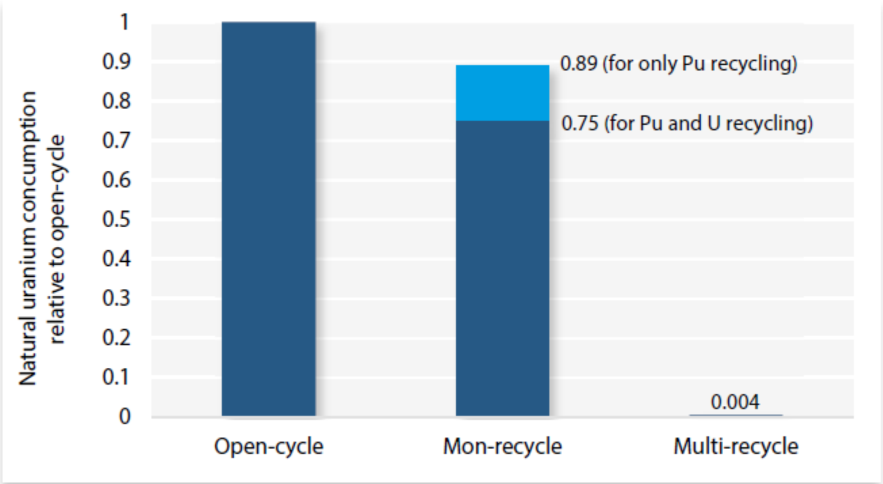
Blue Sky Vision

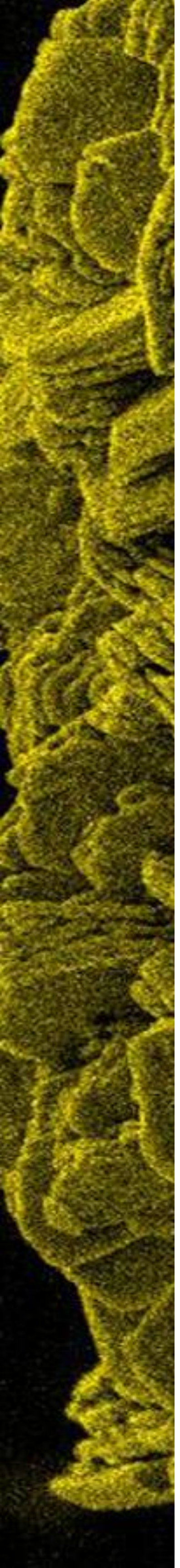
- Sustainable nuclear power *system*
  - Fleet of thermal and fast reactors
  - Multi-recycle of U and Pu
  - Separation and transmutation of minor actinides
  - Only fission products geologically disposed

Figure 4. **Natural uranium consumption relative to open-cycle**

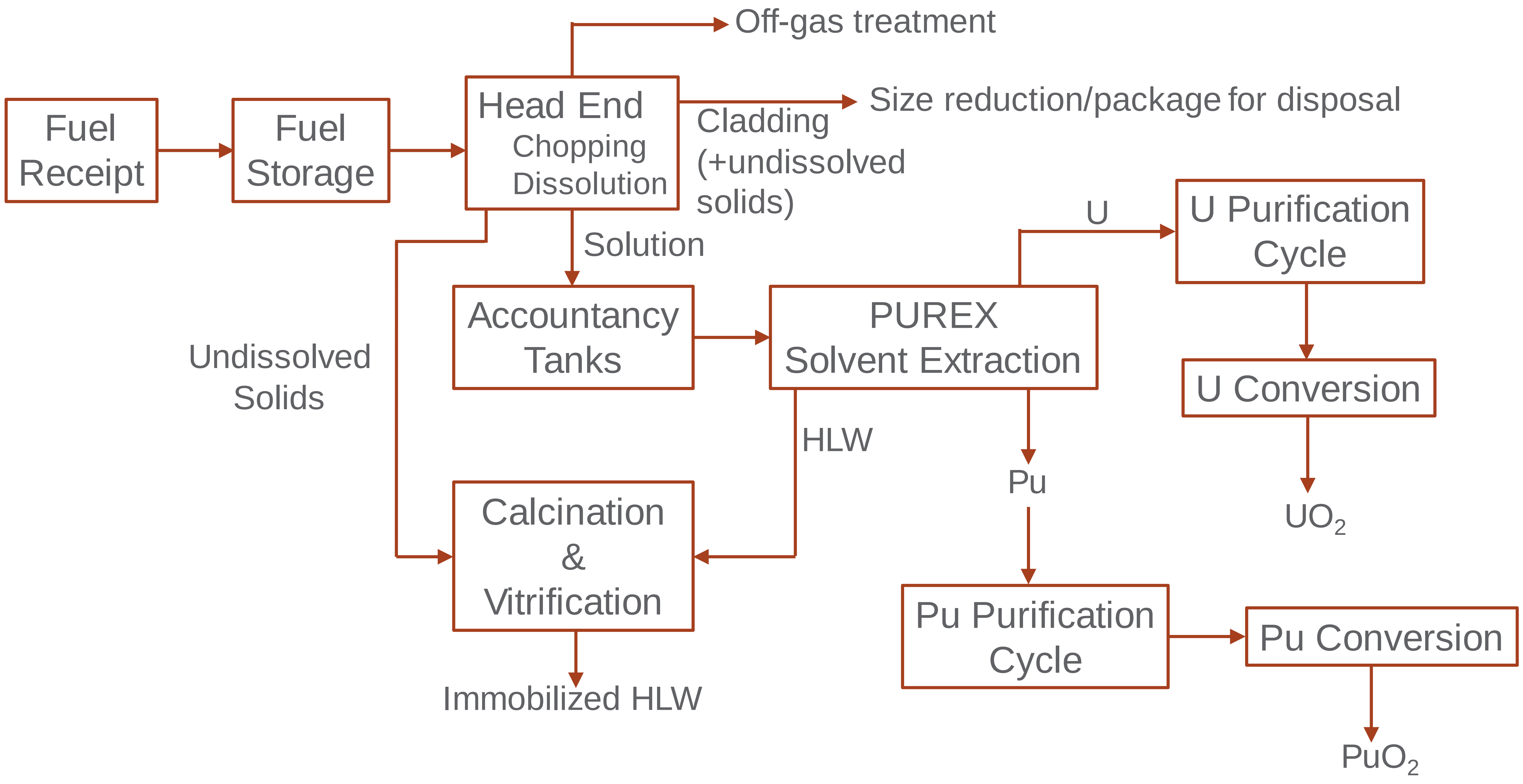


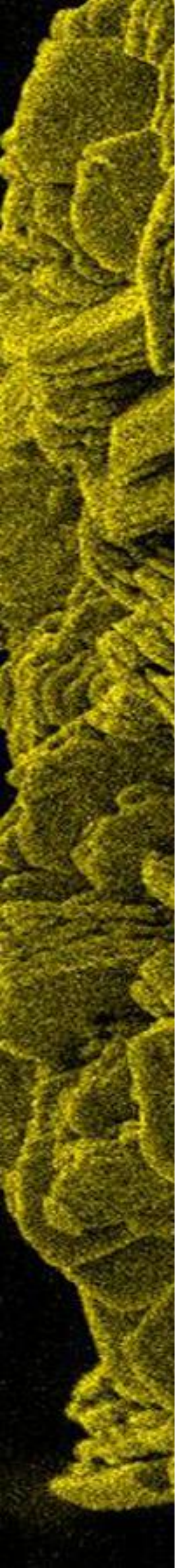
Source: NEA, 2006; Zohuri and McDaniel, 2018.

From *Strategies and Considerations for the Back End of the Fuel Cycle*, NEA No. 7469, Nuclear Energy Agency, Organisation for Economic Co-Operation and Development (2021)



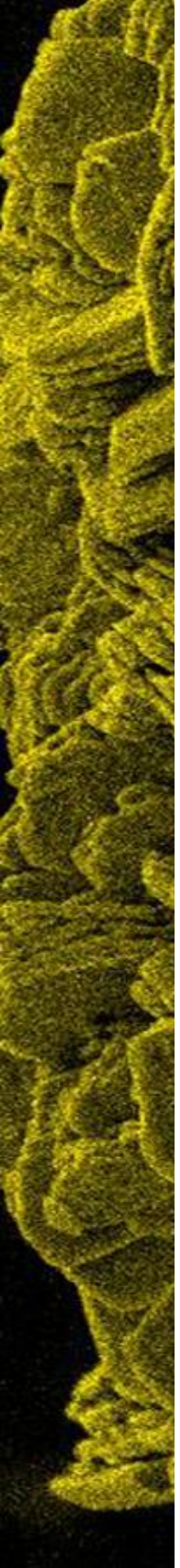
Key features of a late 20th Century reprocessing facility (typically located adjacent an ocean)





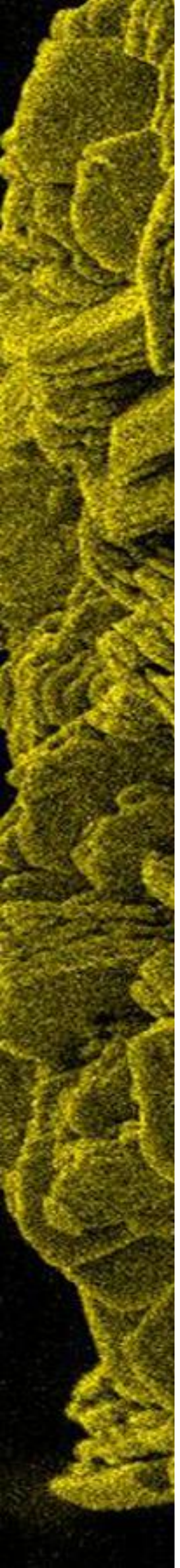
Disadvantages of current reprocessing facilities

- Substantial mechanical handling to expose fuel for dissolution
- Fuel dissolution is a batch process
- Tank space requirements substantially drive facility size (and cost)
  - Accountancy tanks, feed tanks, product tanks, surge tanks, solvent holding tanks, etc.
- Nitric acid and NOx management
  - Evaporators, calciners
  - Recycling and management of contaminated HNO_3 within the facility
- Tritium management
  - Current technology results in widespread distribution of ^{3}H throughout the plant
  - Tritiated water discharged to the environment
- Large amount of secondary waste from solvent washing
- Krypton capture
  - Might or might not be a problem depending on the scenario
    - ✓ Large centralized facility
    - ✓ Short cooled fuel



Aqueous processing has advantages for a 21st century reprocessing plant

- Engineering principles extremely well understood
  - Scalable
  - Industrially applied in the nuclear industry for over 60 years
- Separations amenable to continuous operation with minimal mechanical handling and ‘moving parts’ requiring maintenance
- Highly selective separations possible
  - Very high decontamination factors can be achieved
- The same generic liquid-liquid extraction process technology and equipment can be used to separate multiple target constituents
- Waste streams are understood with TRL 9 technologies available for immobilization



Opportunities for improvement

- Process simplification

To paraphrase Andreas Geist...We must reduce the number of boxes.

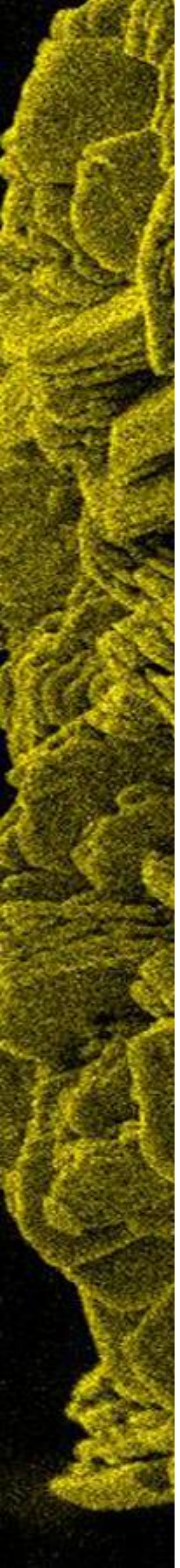
  - Eliminate purification cycles
    - ✓ One cycle to give
      - Pure U
      - U/Pu or U/Np/Pu
    - ✓ Reduced solvent inventory and secondary liquid effluent volumes
  - Group actinide separation
    - ✓ Why not just let the Pu go with the U, and recycle the lot into new fuel?
      - What advanced reactors could use such a fuel directly?
      - For LWRs the U enrichment would be too low and not enough Pu to make up for it
        - Could recycle U from used HALEU fuel to boost up the U enrichment
        - Could tap into existing excess Pu stocks
    - ✓ Co-recovery of Z 92 – 95
      - Similar questions to above

Opportunities for improvement (2)

- Real-time monitoring of process streams
  - Can the need for accountancy tanks be eliminated, along with the delay caused by safeguards driven analyses?
  - Can the need for surge tanks be reduced, or even eliminated, by real-time process feedback and control?
  - Can process monitoring and automated control be used to produce products within particular characteristics (e.g., a specifically targeted U/Pu product)?
- Development of highly selective ligands
  - Eliminate co-extraction of traditionally problematic elements
    - ✓ Zr, Tc
  - Selective extractants
  - Selective holdback reagents
  - Liquid extraction systems with high capacity for metals (reduce plant size)

Opportunities for improvement (3)

- Environmental Impact
  - Capture and isolate tritium, iodine and noble gas fission products
  - Capture and transmute high heat-producing minor actinides to improve geologic repository utilization
  - Alternative CHO-based extractants
  - Reduce number of secondary liquid effluent streams



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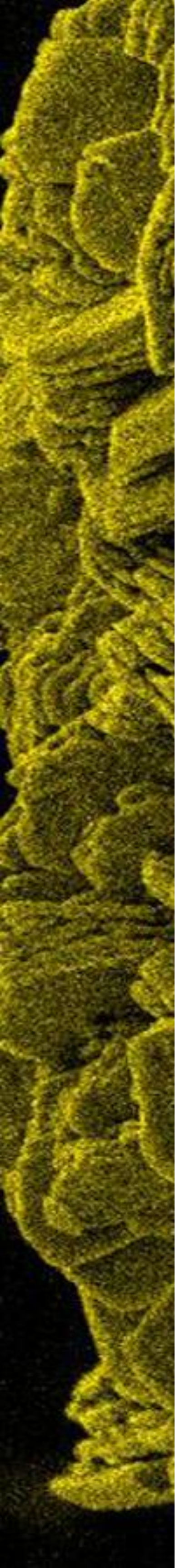
Small Modular Recycling Facilities (SMRFs)

- Idea floated at ARPA-E workshop on “Reducing the Impact of Used Nuclear Fuel for Advanced Reactors” in December 2020
- Extend the modular concept adopted for small modular reactors to fuel recycling
  - Prefabricated modules manufactured under controlled QA conditions, transported to the fuel recycling location, and connected as needed to meet the recycling needs
  - Example modules could include
    - ✓ Chop/leach
    - ✓ Solvent extraction
    - ✓ Product conversion
    - ✓ HLW immobilization
    - ✓ Off-gas treatment

Potential SMRFs advantages

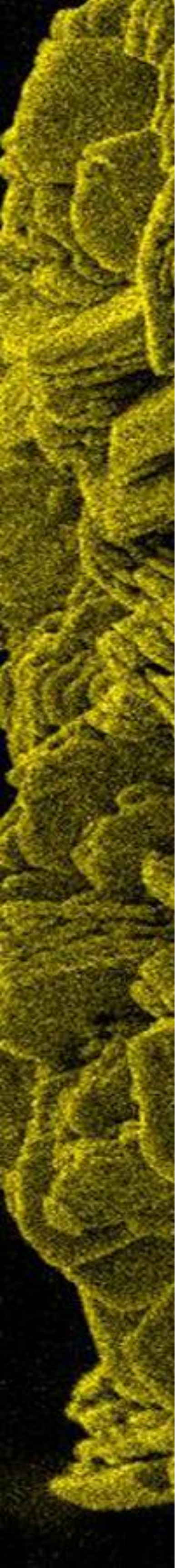
- Flexible
  - Modules for
    - ✓Aqueous
    - ✓Pyrochemical
    - ✓Molten salt
- Scalable
  - Single modules
  - Multiple modules
- Adaptable
  - Modules can be updated with new technology

- Capital and licensing costs can be expected to be decreased by standardization of design, and controlled manufacturing process
- Safeguards by design can be built in
- Nonproliferation: Facility can be right-sized to meet the specific reprocessing needs (no excess capacity)
- Some regulatory burden can be relaxed by the smaller scale (e.g., Kr capture unnecessary)
- Flexible siting options; recycle facility could be co-located with the reactor or fuel fabrication plant



Key takeaways

- Solvent extraction is still the gold standard for recycling of fissile material from spent nuclear fuel
- Opportunities for improvement
  - Process simplification
  - Robust, real-time, process monitoring and control
  - Secondary waste minimization
- SMRFs
  - Offers the opportunity for the U.S. to get back into the game with minimal risk
    - ✓ Start out small
    - ✓ Build up as needed



Thank you