Fuel Cycle Research and Development

The US DOE R&D Program on Minor Actinide Separations

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The current U.S. fuel cycle is a once-through fuel cycle using enriched uranium fuel in LWRs.

The fuel cycle is not yet complete:
- Disposal paths for spent fuel and depleted uranium are not currently implemented.
Current U.S. Fuel Cycle Performance

The current U.S. fuel cycle generates two major waste streams requiring geologic disposal or similar isolation, along with LLW:

- 2,000 MT per year of spent fuel – planned disposal path: geologic repository
- 16,000 MT per year of depleted uranium – no disposal path identified at this time, but will also require long-term isolation due to buildup of radioactive decay products
DOE chartered the Evaluation and Screening Study (12/15/2011) to strengthen the basis for making R&D decisions

- Identify the potential for a nuclear fuel cycle to provide substantial improvements as compared to the current U.S. fuel cycle, including both benefits and challenges for development
  - Complete nuclear fuel cycle system from mining to disposal
  - Comprehensive set of fuel cycles with respect to performance
  - Based on STEADY-STATE fuel cycle, did not consider transition issues

Four groups of fuel cycles selected as “Most Promising Options”
- Based on substantial improvements in reduction of the amount of waste generated and fuel resources needed
  - Continuous recycle of U/Pu with new natural-U fuel in fast critical reactors or
  - Continuous recycle of U/TRU with new natural-U fuel in fast critical reactors
  - Continuous recycle of U/TRU with new natural-U fuel in both fast and thermal critical reactors
  - Continuous recycle of U/Pu with new natural-U fuel in both fast and thermal critical reactors


https://inlportal.inl.gov/portal/server.pt/community/nuclear_science_and_technology/337/nuclear_fuel_cycle_evaluation_and_screening_final_report/11118
A Closed Fuel Cycle Could Offer Substantial Benefit

- **Substantial improvement possible**
  - > 10x reduction in amount of high-level waste disposal
  - > 1000x reduction in amount uranium disposal
  - > 100x improvement in uranium utilization

- **The most promising fuel cycles all share the following characteristics**
  - Recycle of either U/Pu or U/TRU
  - Use of fast critical reactors, either alone or supporting thermal reactors
  - No uranium enrichment required
    - *No further creation of depleted uranium inventories*

- **Recycle fast reactor fuel cycles can also use the current inventory of depleted uranium as fuel resource**
  - Eliminates the need to dispose of the current inventory of 700,000 MT of depleted uranium
  - Eliminates the need for mining new uranium resources for 1000 years or more

- **R&D is needed to develop such a future fuel cycle**
The identification of closed fuel cycles as “most promising” is good news for the US P&T community, but....

The benefits for both U/Pu and U/TRU recycle, based on this study, are very similar – DOE is asking “why go to the extra effort, and expense of separating the minor actinides?”

- R. Wigeland leading study in 2015 to understand benefits of MA recycle
- Major driver for fast reactors and recycle in US is uranium utilization
- The benefits of minor actinide recycle are mostly associated with disposal
  - Significantly reduces the long term heat load to a repository (major contributors to heat after ~100 yrs)
  - The footprint of a repository can be reduced (up to a factor of ~8)
  - Waste forms from recycle are more robust and durable than the used fuel itself

See presentation at 11:50 by Dr. C. Poinssot for a compelling explanation on sustainability!
So, where is the US R&D Program going from here???

- We will continue to research new minor actinide separation technologies via the Minor Actinide Sigma Team

- Results of 2015 Wigeland MA study may impact future priorities, but research is needed to reduce the risk and uncertainty of MA recycle

- International collaborations, such as SACSESS and bi-lateral DOE collaborations (e.g. CEA, JAEA, NNL), will be extremely important for the US to maintain a robust MA recycle R&D program

- We will continue to support SACSESS and look forward to participate in the follow on EU program (hopefully)
Where have we been, and what did we learn???

- The US DOE GNEP program in the mid-2000s focused on extensive separations (UREX+).
- Engineering studies showed that this approach was very operationally complex and costly:
  - 5 different solvent systems with 4 different solvent compositions
  - 3 to 4 different waste forms and processes, as well as interim storage facilities for each
- Need to minimize processing and number of systems (solvents, waste forms, etc) to be cost effective
Early approach to minor actinide separations in the US

The primary method developed in the US over the past few decades was a two process approach to separate transition metal fission products, then separate the trivalent actinides from the lanthanides.

**TRUEX** (TransUranium EXtraction) - TALSPEAK (Trivalent Actinide Lanthanide Separation by Phosphorus reagent Extraction from Aqueous Komplexes)

- CMPO: octyl(phenyl)-N,N-diisobutylcarbamoyl-methylphosphine oxide

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\text{CMPO} \quad \text{(di(2-ethylhexyl)phosphoric acid)}
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**Examples of reagents**:

- HDEHP
- DTPA

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The current goal of the US research program is to develop a **simplified, robust** method for minor actinide separation.

The two primary approaches being investigated involve selective complexation of An(III) over the Lns, and the oxidation of Am(VI) to enable a group actinide separation.

Both “GANEX” and “SANEX” approaches are supported by these approaches, in a much simplified system from the UREX+ approach.

Note: The GANEX approach involving Am (VI) extraction does not extract Cm.
The US Fuel Cycle R&D program has a modest, multi-laboratory (and university) effort dedicated to separation of americium and curium (initiated in late 2009)
- Led by Dr. Bruce Moyer, ORNL
- Participants from ORNL, ANL, INL, LANL, SRNL, PNNL, WSU and several other universities

Several approaches to separation of Am/Cm are being investigated
- Early focus more on science, now developing flowsheets

The goal of the research is to develop a simplified, robust method for minor actinide separation
- Less reliance on sensitive pH control (more acidic regime for separations)
- Simplified processing method over 2-step solvent extraction process using different solvents
- Potential for group actinide separation
Highlights of Recent Progress

- **Advanced TALSPEAK**
  - Evolutionary improvement in performance of TALSPEAK
  - HEH[EHP] extractant, HEDTA aqueous complexant in citrate buffer
  - Much flatter pH dependence on Ds, citrate more predictable over lactate

- **ALSEP process (Actinide/Lanthanide Separation)**
  - Combines TRUEX/TALSPEAK functionality into a single process
  - Solvent formulation and preliminary flowsheet developed
  - Gregg Lumetta will present today at 13:50, Alena Paulenova Thursday at 11:50

- **Extraction of Am(VI)**
  - Extraction of Am(VI) demonstrated in batch contacts using sodium bismuthate as oxidant
  - Limited flowsheet test of Am(VI) extraction concept demonstrated
  - Investigations in alternative oxidants have been made (preliminary results look promising, but much work left to do)
  - Bruce Mincher will present Thursday at 09:45
Recent trends in MA separations

- For the past few decades, different “nationalized” approaches were developed and pursued by US and European research teams.
- There is now a common approach between US and European research teams to reduce the number of processes needed to separate minor actinides.
  - *Simplification is a goal, but one must remember that combining processes may also mean more complexity in the single process.*
- US and European research approaches include both “SANEX”- and “GANEX”-type approaches.
- Diglycolamide extractants\(^1\) are being investigated in a number of new approaches, such as ALSEP, i-SANEX, 1C-SANEX and Euro-GANEX (\(^1\)Sasaki et al. Solv. Extr. Ion Exch. 2001).
- Some commonalities in scrubbing and stripping reagents:
  - e.g. CDTA, hydrophilic stripping complexants, etc.

*It appears that US and European approaches to minor actinide separation are converging on some common themes.*
“Everything should be made as simple as possible, but not simpler”
- Albert Einstein