



U.S. DEPARTMENT OF
ENERGY

Nuclear Energy

Fuel Cycle Research and Development

The US DOE R&D Program on Minor Actinide Separations

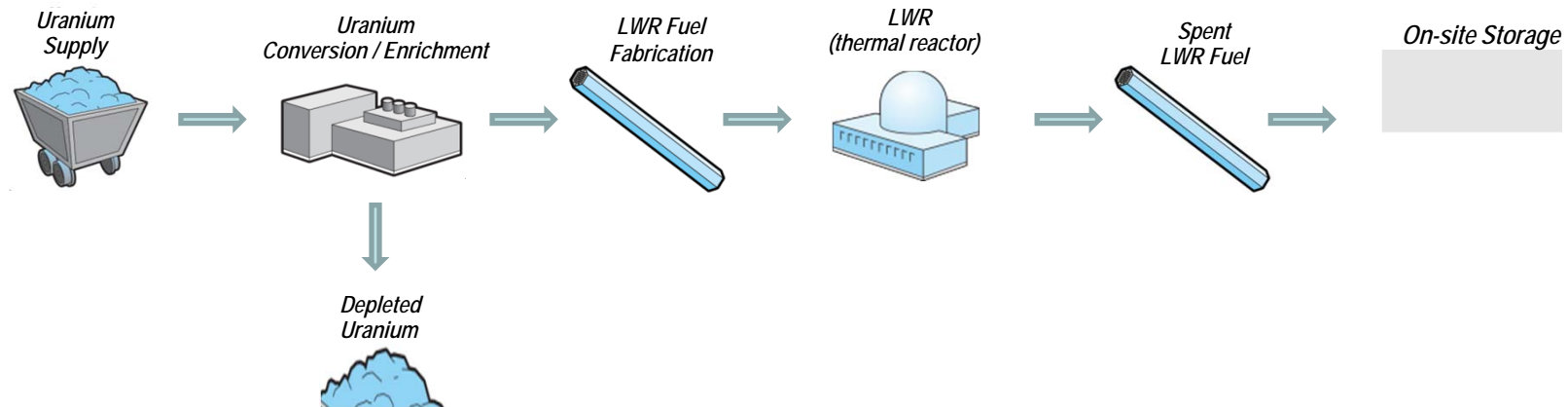
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**1st SACSESS Int. Workshop
Warsaw, Poland
April 22, 2015**



Current U.S. (Open) Fuel Cycle

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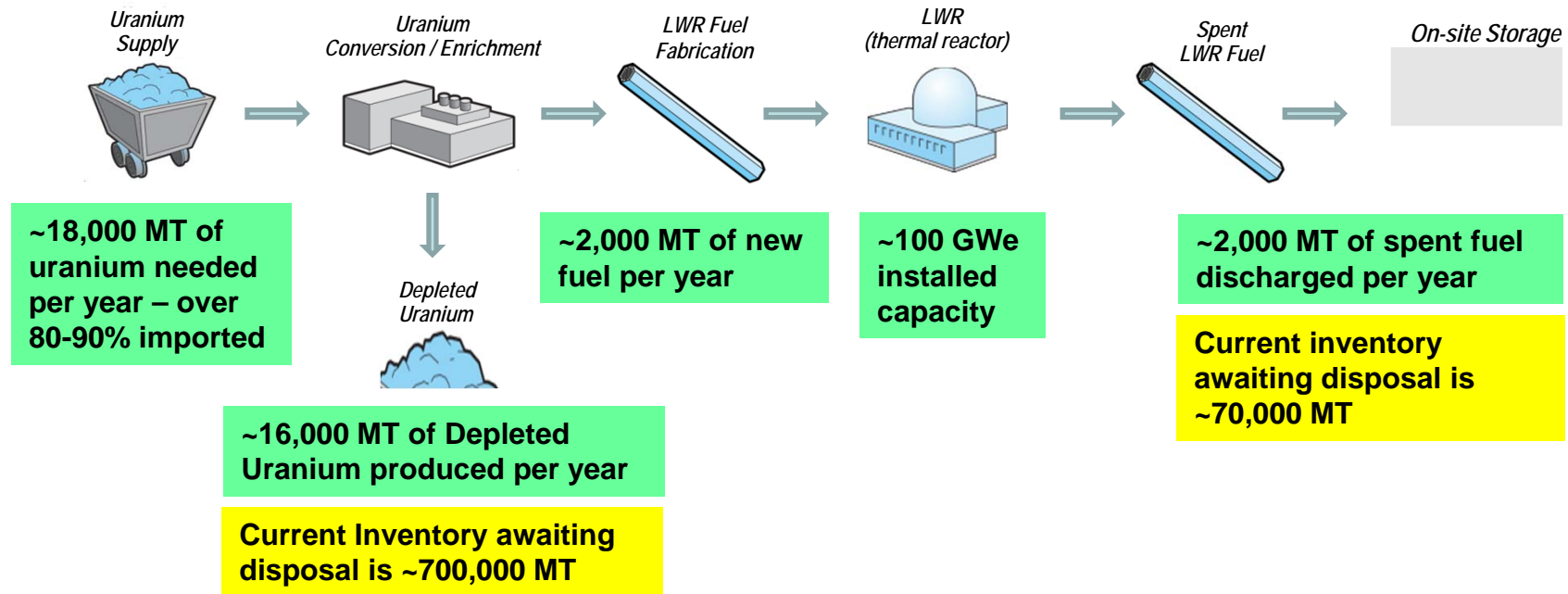


- **The current U.S. fuel cycle is a once-through fuel cycle using enriched uranium fuel in LWRs**
- **The fuel cycle is not yet complete**
 - Disposal paths for spent fuel and depleted uranium are not currently implemented



Current U.S. Fuel Cycle Performance

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- **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



The US DOE Nuclear Fuel Cycle Evaluation and Screening Study (2014)

- **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**

R. A. WIGLAND, et al., “Nuclear Fuel Cycle Evaluation and Screening- Final Report,” INL/EXT-14-31465, Idaho National Laboratory (2014).

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)



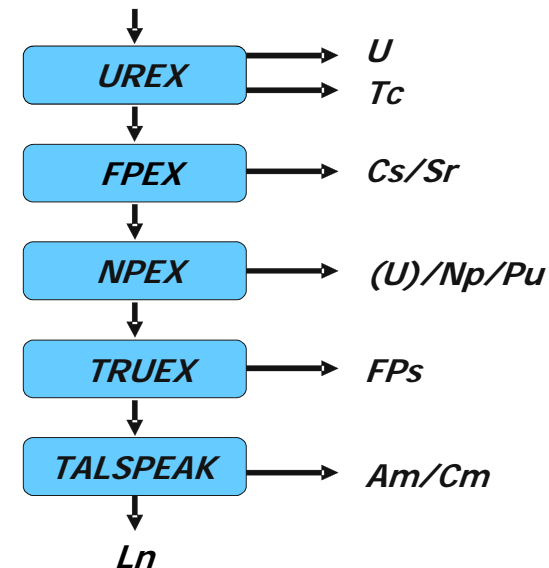


Where have we been, and what did we learn???

- 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*

UREX⁺3a

Dissolved Fuel

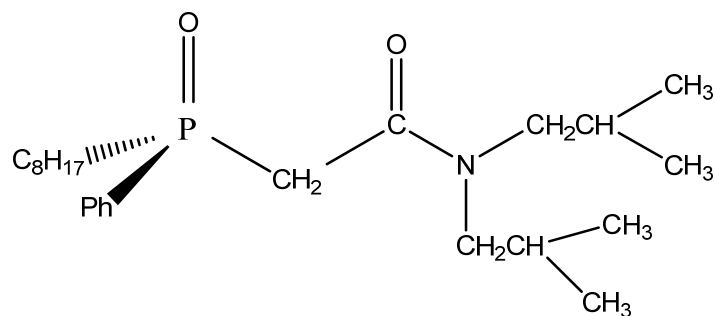




Early approach to minor actinide separations in the US

- 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

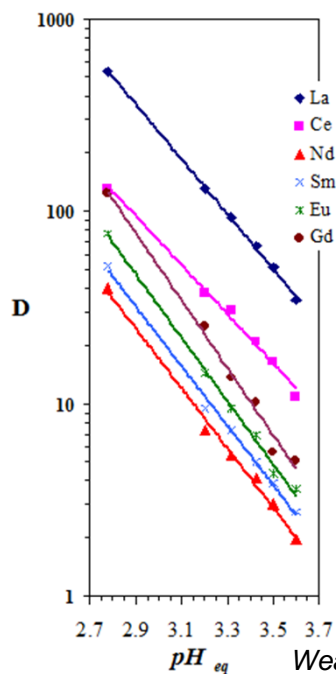
TRUEX (TRansUranium EXtraction)



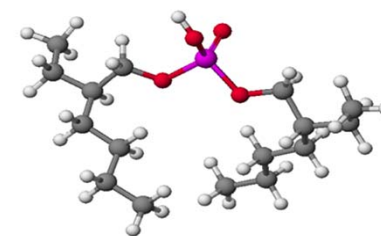
CMPO
octyl(phenyl)-N,N-diisobutylcarbamoyl-
methylphosphine oxide

Horwitz, E. P.; Kalina, D. G.; Diamond, H.; Vandegriff, G. F.; Schulz, W. W. *Solvent Extr. Ion Exch.* (1985)

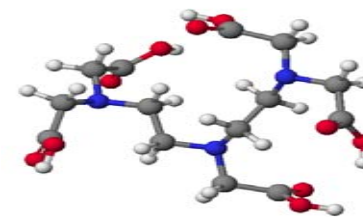
TALSPEAK (Trivalent Actinide Lanthanide Separation by Phosphorus reagent Extraction from Aqueous Komplexes)



Weaver, Kappelmann. *J. Inorg. Nucl. Chem.*, (1968)



HDEHP
(di(2-ethylhexyl)phosphoric acid)

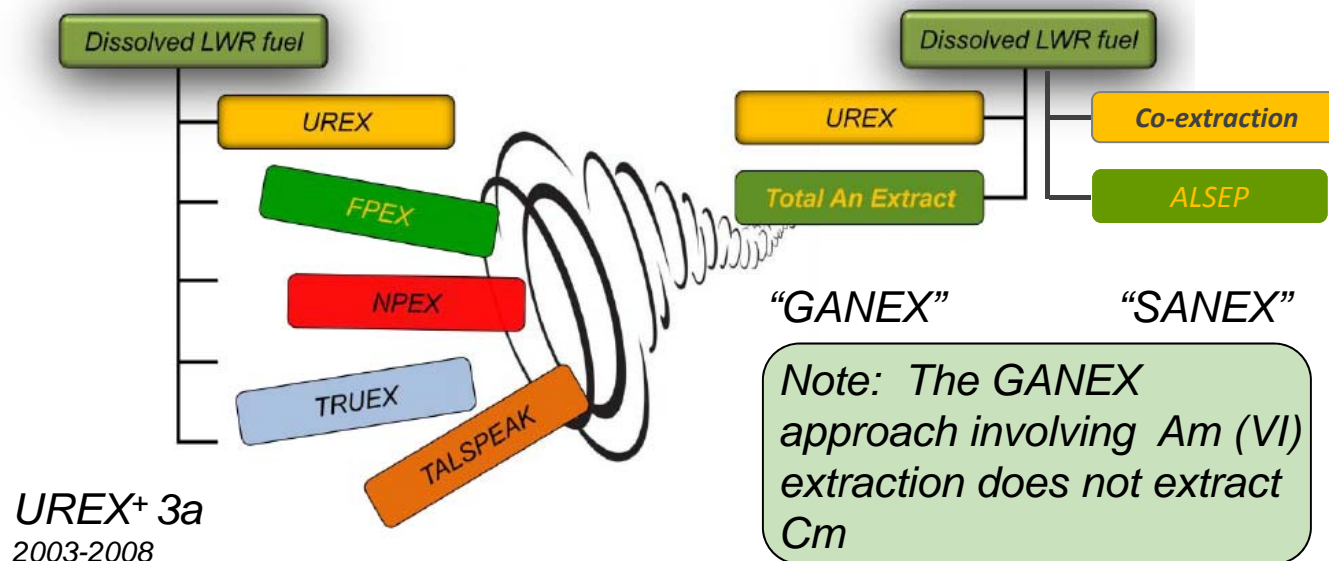


DTPA
diethylenetriaminepentaacetic acid



Current Focus of US Minor Actinide Separations R&D

- 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





Minor Actinide Sigma Team

- **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





■ **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

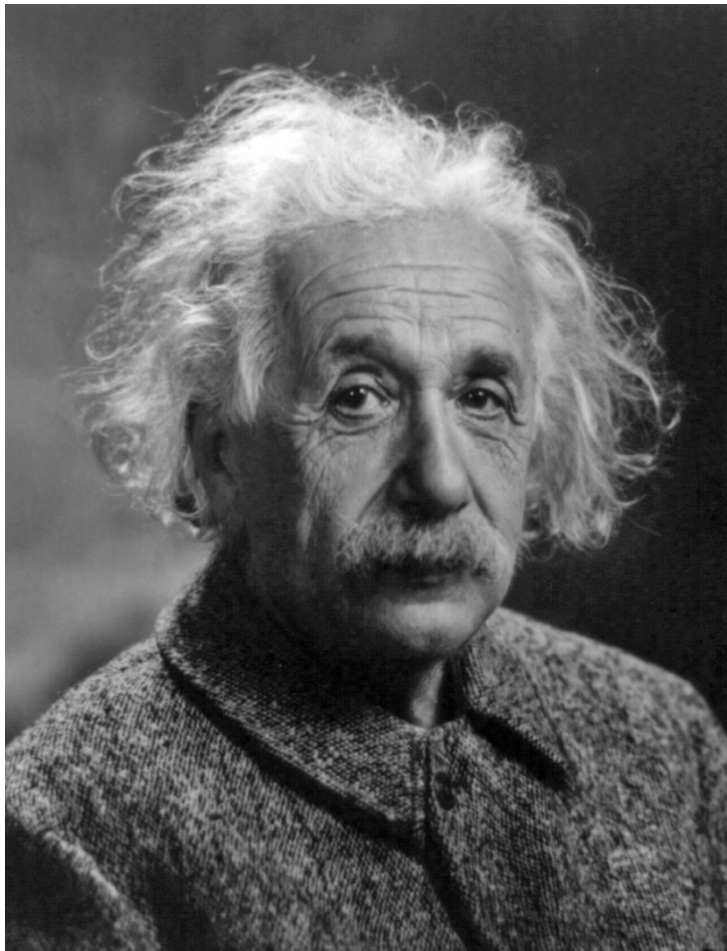
- For the past few decades, different “nationalized” approaches were developed and pursued by US and European research teams
- There is now a common approach between US and European research teams to reduce the number of processes needed to separate minor actinides
 - *Simplification is a goal, but one 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 extractants¹ are being investigated in a number of new approaches, such as ALSEP, i-SANEX, 1C-SANEX and Euro-GANEX (¹Sasaki 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



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***“Everything should be
made as simple as
possible, but not simpler”
- Albert Einstein***