Advanced Spent Fuel Processing Technologies for the Global Nuclear Energy Partnership

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Elements of GNEP: Reprocessing

- Fuel leasing and take-back by supplier nations for reprocessing
- No separated plutonium
- Deployment after 2020 in the United States
The U.S. Situation

- 103 LWRs in commercial operation for generation of electricity
- Approximately 2,000 tons of spent nuclear fuel generated each year
- U.S. utilities have now accumulated about 52,000 tons of spent fuel; awaiting disposal in the Yucca Mountain geologic repository, which will be over-subscribed by 2015
- Want to avoid the need for a second repository
Projected Spent Fuel Accumulation without Recycling

Year

Commercial Spent Fuel Inventory, metric tons

MIT Study 2003 (~3.2%)

EIA 1.8% growth

Repository Technical Capacity Based on Limited Exploration

Legislated Capacity of Repository
U.S. GNEP Spent Fuel Processing Scheme

LWR Spent Fuel → Aqueous Processing → Advanced Burner Reactor → Pyroprocessing

Advanced Burner Reactor → Aqueous Processing
Requirements for LWR Spent Fuel Processing

- Ability to accommodate very high throughputs (>2,000 t/y) economically
- Ability to achieve very high decontamination of the actinide products from lanthanide fission products
- No separated plutonium stream
- Flexibility to adapt to thermal reactor recycle of mixed oxide fuel if required

- Led to choice of an aqueous solvent extraction process as the reference process
  - Suite of UREX+ processes
## Suite of UREX+ Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Prod #1</th>
<th>Prod #2</th>
<th>Prod #3</th>
<th>Prod #4</th>
<th>Prod #5</th>
<th>Prod #6</th>
<th>Prod #7</th>
</tr>
</thead>
<tbody>
<tr>
<td>UREX+1</td>
<td>U</td>
<td>Tc</td>
<td>Cs/Sr</td>
<td>TRU+Ln</td>
<td>FP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UREX+1a</td>
<td>U</td>
<td>Tc</td>
<td>Cs/Sr</td>
<td>TRU</td>
<td>All FP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UREX+2</td>
<td>U</td>
<td>Tc</td>
<td>Cs/Sr</td>
<td>Pu+Np</td>
<td>Am+Cm+Ln</td>
<td>FP</td>
<td></td>
</tr>
<tr>
<td>UREX+3</td>
<td>U</td>
<td>Tc</td>
<td>Cs/Sr</td>
<td>Pu+Np</td>
<td>Am+Cm</td>
<td>All FP</td>
<td></td>
</tr>
<tr>
<td>UREX+4</td>
<td>U</td>
<td>Tc</td>
<td>Cs/Sr</td>
<td>Pu+Np</td>
<td>Am</td>
<td>Cm</td>
<td>All FP</td>
</tr>
</tbody>
</table>

Notes: (1) in all cases, iodine is removed as an off-gas from the dissolution process.
(2) processes are designed for the generation of no liquid high-level wastes

- **U**: uranium (removed in order to reduce the mass and volume of high-level waste)
- **Tc**: technetium (long-lived fission product, prime contributor to long-term dose at Yucca Mountain)
- **Cs/Sr**: cesium and strontium (primary short-term heat generators; repository impact)
- **TRU**: transuranic elements (Pu: plutonium, Np: neptunium, Am: americium, Cm: curium)
- **Ln**: lanthanide (rare earth) fission products
- **FP**: fission products other than cesium, strontium, technetium, iodine, and the lanthanides
Projected LWR Spent Fuel Processing Criteria

- Generation of no high-level liquid wastes requiring extended underground tank storage
- “Limited emissions” goal
  - Recovery of I, Kr, $^3$H, $^{14}$CO$_2$
- Added fuel cycle costs to amount to no more than 10% increase in the busbar cost of electricity
- Efficient removal and immobilization of long-lived fission products (specifically iodine and technetium)
- Ten-fold or greater reduction in high-level waste volume relative to direct disposal of spent fuel
- $\geq 99.9\%$ removal of transuranics and short-lived fission products (Cs, Sr)
**Relative Increase in Repository Capacity by Recycling**

**Assumptions**
- Burnup: 50 GWd/MT
- Separation: 25 years
- Emplacement: 25 years
- Closure: 100 years

Limited by 200 ºC Drift Wall Temp. at Emplacement

Limited by 200 ºC Drift Wall Temp. at Closure

Limited by 96 ºC Mid-Drift Temp. >1600 yrs

UREX+1a Process

Chopped, Nitric Dissolve

Alloying / Compaction
(hulls + Tc + sludge / balance of hulls)

Iodine, Kr, $^3$H, $^{14}$CO$_2$
Tc Metal Product from Pyrolysis in Wet Argon

(Work done by UNLV and LANL)
## Laboratory-Scale Testing of the UREX+1a Process

(July 2006, 1 kg LWR spent fuel; Cooper [BWR, 34 GWD/t] and H.B. Robinson [PWR, 76 GWD/t])

<table>
<thead>
<tr>
<th>Element</th>
<th>Recovery Eff.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranium</td>
<td>99.9992%</td>
<td>Non-TRU (&lt;100 nCi/g)</td>
</tr>
<tr>
<td>Technetium</td>
<td>98.3%</td>
<td>Soluble Tc</td>
</tr>
<tr>
<td>Cesium</td>
<td>&gt;99.2%</td>
<td></td>
</tr>
<tr>
<td>Strontium</td>
<td>&gt;99.9%</td>
<td></td>
</tr>
<tr>
<td>Plutonium</td>
<td>&gt;99.99%</td>
<td>Total lanthanide content of transuranics &lt;0.05% (DF&gt;2,000)</td>
</tr>
<tr>
<td>Neptunium</td>
<td>&gt;99.99%</td>
<td></td>
</tr>
<tr>
<td>Americium</td>
<td>&gt;99.99%</td>
<td></td>
</tr>
<tr>
<td>Curium</td>
<td>&gt;99.999%</td>
<td></td>
</tr>
</tbody>
</table>
Pyroprocess Applications

- Reduction of UREX+1a oxide product to metal using an electrochemical reduction process (for transuranic recycle as metallic ABR fuel)

- Electrochemical processing of metallic ABR spent fuel for recovery and recycle of transuranics

- Processing of oxide ABR spent fuel
  - Alternative to aqueous process
  - May require aqueous polishing step to reduce lanthanide content of product
Pyrochemical Processing of FR Spent Fuel

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Future Directions of the U.S. Program

- Construction and operation of the Consolidated Fuel Treatment Center (CFTC) by 2020
  - 500 – 2,500 tons per year
- Decision by the Secretary of Energy on proceeding in June 2008
- (Alternative) Engineering-scale demonstration of the UREX+1a process at reduced scale
- Complete development of UREX+1a process in 2009
- Continue development of pyroprocessing technology