Fuel Cycle Based on Integral Fast Reactor and Pyroprocessing

International Symposium
Present Status and Future Prospective for Reducing Radioactive Waste
-- Aiming for Zero Release --

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Argonne Has Been a Pioneer of Nuclear Energy

- Enrico Fermi and his team achieved the first controlled chain reaction in Chicago Pile-1 (CP-1): December 2, 1942.
- Enrico Fermi first introduced the fast reactor idea in 1944 and Walter Zinn completed a concept design in 1946.
- Experimental Breeder Reactor-I (EBR-I) started operation in 1951, producing the first electricity from nuclear, and demonstrated the breeding principle in 1953.
Experimental Breeder Reactor-II (EBR-II)

- First pool-type fast reactor, started operation in 1964
- Fuel cycle closure demonstration during 1965-69
- Inherent safety demonstration in April 1986

Argonne-West facilities, now merged into Idaho National Laboratory
The Integral Fast Reactor (IFR)

- Developed at Argonne National Laboratory (1984-1994) as a next-generation reactor concept.

- Key innovations: metal fuel and pyroprocessing
  - Uranium resource utilization is improved by a factor of 100 compared to current commercial reactors, making nuclear almost limitless energy source.
  - Unique inherent passive safety has been demonstrated.
  - Lifetime of radiological hazard of nuclear waste is reduced from ~300,000 years to ~300 years.
  - Proliferation-resistant and economic fuel cycle closure based on pyroprocessing.
Metal Fuel Performance

- Reliable >20% burnup demonstrated
- Superior Run-Beyond-Cladding-Breach performance
- Injection-casting fabrication is simple and remotization of actinide containing fuel is straightforward.
- Inherent safety potential for unprotected loss-of-flow demonstrated.
Pyroprocessing Flowsheet

- Spent Fuel
  - Oxide Reduction
  - Electrorefiner
  - Cathode Processor
  - Uranium + Actinides
  - Salt, Cd
  - Refabricate for Recycle
  - Glass Frit
  - Ceramic Waste
  - High Level Waste

Main Process Line
Cleanup and Waste

- Salt + Actinides
- New Salt
- Cladding + Noble Metal FPs
- Filters
- Melting Furnace
- Particulate Filter
- Salt + FPs
- Salt Recycle
- Zeolite + FPs
- Zeolite Columns
- Metal Waste
Pyroprocessing equipment and facility are compact
More favorable capital cost and economics
# Weapons Usability Comparison

<table>
<thead>
<tr>
<th></th>
<th>Weapon Grade Pu</th>
<th>Reactor Grade Pu</th>
<th>IFR Grade Actinide</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production</strong></td>
<td>Low burnup PUREX</td>
<td>High burnup PUREX</td>
<td>Fast reactor Pyroprocess</td>
</tr>
<tr>
<td><strong>Composition</strong></td>
<td>Pure Pu 94% Pu-239</td>
<td>Pure Pu 65% Pu-fissile</td>
<td>Pu + MA + U 50% Pu-fissile</td>
</tr>
<tr>
<td><strong>Thermal power w/kg</strong></td>
<td>2 - 3</td>
<td>5 - 10</td>
<td>80 - 100</td>
</tr>
<tr>
<td><strong>Spontaneous neutrons, n/s/g</strong></td>
<td>60</td>
<td>200</td>
<td>300,000</td>
</tr>
<tr>
<td><strong>Gamma rad r/hr at ½ m</strong></td>
<td>0.2</td>
<td>0.2</td>
<td>200</td>
</tr>
</tbody>
</table>
Radiological Toxicity of LWR Spent Fuel

- Transuranic Elements (Actinides)
- Current Waste
- Natural Uranium Ore
- Fission Products
- IFR Waste
LWR Spent Fuel Radioactivity Normalized to EPA Cumulative Release Limits

<table>
<thead>
<tr>
<th>Radio-nuclide</th>
<th>Activities at 10 years</th>
<th>Activities at 1,000 years</th>
<th>Activities at 10,000 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr-90</td>
<td>60,000</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>Cs-137</td>
<td>90,000</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>I-129</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Tc-99</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Other F.P.</td>
<td>1,050</td>
<td>5.1</td>
<td>4.4</td>
</tr>
<tr>
<td>Actinides</td>
<td>76,000</td>
<td>19,000</td>
<td>4,000</td>
</tr>
</tbody>
</table>
Long-term Release from Repository

Long-term Limit
1 mSv/yr

Near-Term Limit
0.15 mSv/yr
Actinide Removal Allows 5-10 Times More Spent Fuel Disposal for a Given Repository Space

Unit: MW-yr/10,000 T
Key Conclusions on Spent Fuel Management

- All 3 different approaches (radiological toxicity, EPA Standards, and repository performance assessment) indicate that a factor of 500-1,000 reduction of actinides (or 99.5-99.9% removal) would be essential for the long-term nuclear waste disposal:
  - Repository requirements can be met on *a priori* basis without the source term.
  - It is our responsibility to free our future generations from the burden of radioactive nuclear waste legacy.
  - Spent fuel is not the best waste form and removing actinides is technologically the best option.

- However, there are two questions raised:
  - Do we have a feasible and economically viable technology?
  - Can we transmute the actinides recovered from the spent fuel?
The original EBR-II FCF was refurbished with electro-refining based pyroprocessing equipment systems.
Engineering-Scale Equipment Demonstrated

Electrorefiner  Cathode Processor  Metal Waste Furnace
Engineering-Scale Pyroprocessing Has Been Successfully Demonstrated Through EBR-II Spent Fuel Treatment
Pilot-scale (100 T/yr) Pyroprocessing Facility for LWR Spent Fuel

- For pyroprocessing of LWR spent fuel, a front-end oxide to metal conversion and a scale-up of batch size are required.

- The technology feasibility has been established and ANL is currently developing a conceptual design of a pyroprocessing facility for the purpose of engineering details and capital and operating cost estimates.

- If cost estimate is reasonable, a pilot-scale demonstration of a regional solution for spent fuel management can be envisioned.
Summary

- The public views adequate nuclear waste management as a critical linchpin in further development of nuclear energy. Nuclear energy has been utilized over a half century without a definite solution to the back end of the fuel cycle. Examples of metaphors:
  - “Building a house without a toilet!”
  - “A plane taking off without its landing gear!”

- Interim storage is obviously a near-term imperative but should be pursued consistent with a longer-term roadmap, which has a higher priority.

  “If you don't know where you are going, you'll end up someplace else.” -- Yogi Berra

- The longer-term roadmap should be developed in a systems approach including the next-generation reactor options.