Closing the Nuclear Fuel Cycle
Implications for Nuclear Waste Management and Disposal

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The EnergySolutions Team Perspective
Introducing the team
Why close the fuel cycle?

• **Solves the nuclear waste disposal problem**
  – Reduces amount, toxicity and heat of high level waste
  – Opens alternative repository options
  – Reduces need for multiple HLW repositories
  – Will lower future HLW disposal costs

• **Provides additional waste confidence for nuclear new build to proceed**

• **Improves the security of US energy supplies**
  – Recovers and recycles valuable nuclear materials
Our Approach

- Incremental approach to deployment of fuel cycle facilities
  - Near-term development of Generation III+ Commercial LWR fuel recycling– Industry and National Labs collaborate on focused development of a US design
  - Medium-term development of Generation IV Advanced Recycle Reactors and advanced fuel recycling - National Labs lead, Industry supports
  - Longer-term commercial deployment of Advanced Recycle Reactors

- Action needed now to be able to close the fuel cycle in the future
  - Develop legislative, regulatory and financial enablers
  - Establish New Government Entity to manage back-end fuel cycle
  - Undertake activities to support licensing requirements
  - Industry & National Labs work together on focused development needs
  - Select Site(s) for interim storage and fuel cycle facilities, based on volunteer states and communities
  - Study alternative nuclear waste repository options

ENERGY SOLUTIONS
Our Approach

- Use advanced, yet proven, processes and equipment for LWR recycling and product re-use (incorporate lessons learned from existing baseline processes)
  - EnergySolutions NUXE recycling process, 1,500 metric ton (MT) per year throughput facility, MOX fuel in existing LWRs, recycled uranium (RU) in existing CANDU reactors
  - Option for separation of Am/Cm for burning/transmutation in CANDU or LWR reactors
  - Mitigates technical and commercial risk by advancements to proven processes and equipment
  - Allows progress on used fuel disposition while awaiting transformational technologies
Our Approach

- Ability to re-use RU in CANDU reactors or existing/new build LWRs
- Ability to re-use U/Pu as MOX fuel in existing or new-build LWRs
- Ability, if required, to burn Am/Cm (as targets) in existing thermal (CANDU or LWR) reactors
- This approach “fills the gap” before Advanced Recycle Reactors enter commercial operation
Our Facility

- Light Water Reactor Recycling Center situated on a 330 acre site
Our Separations Technology

- NUEX Flowsheet is designed specifically for advanced US recycling – major changes from current baseline flowsheet
- Equipment based on proven design, minimizes technical risk

**Head End Processes**
- Fuel Receipt & Storage
- Chop - Leach
- Feed Clarification

**NUEX**
- Primary Separation
- Conversion to U & Pu oxides

**Conversion to UO₃**

**Conversion to U & Pu oxides**

**Repository Storage**

- Hulls, Insol FPs, C-14, I-129
- Kr-85, H-3
- Ln: Lanthanides (Rare Earths)
- FP: Fission Products

**Engineered Delay Store**

- Additional uranium as required for fuel fabrication
- Np can be removed as a separate stream or combined with the U and Pu
- To be removed as a separate stream or combined with HA Waste

**To allow Cs,Sr decay**

FPs
Wastes from Recycling

- Recycling reduces the HLW volume for disposal by 75%
- Recycling produces GTCC waste that is about 35% of the original used fuel volume
- Recycling produces low level solid waste
- Recycling using the NUEX flowsheet predicted to result in
  - zero radioactive liquid discharges
  - near-zero aerial discharge

US NUEX recycling facility expected to have significant advancements in waste management compared to Sellafield, La Hague and Rokkasho
Wastes from Recycling

- **Advances in Waste Management**
  - High level waste incorporation rates into Glass reduces HLW volumes
    - Cs, Sr and Tc along with all other FPs incorporated into glass by advanced joule ceramic melters
  - Gaseous effluent treatment/capture (Kr, I, C-14) with goal of near-zero aerial discharge facility
    - Kr captured using cryogenic distillation, decay stored prior to discharge
    - I captured on silver mordenite media and disposed as solid waste
    - C-14 captured in barium carbonate and disposed as solid waste
  - Tritium treatment/Solidification of Liquid Effluents resulting in zero liquid discharge facility
    - Tritium in liquid effluents encapsulated in cement based matrix
  - Volume reduction of all Low level waste (GTCC and Class A/B/C)
    - Supercompaction
Our Advancement Approach

- Advancements in NUEX Flowsheet and Waste Management do not significantly affect size and complexity of facility
Wastes from Recycling

• **Liquid Effluent**
  – Baseline commercial design is already a near zero liquid discharge facility
  – Improvements identified through:
    • Evaporation
    • Ion Exchange systems
    • Liquid waste stream recycling for reagent make-up – excess (including tritiated water) is encapsulated
    • All liquid wastes discharged will be compliant with federal and local regulatory requirements

• **Aerial effluent**
  – Includes technologies for I-129, C-14 and K-85 removal

• **Solid waste**
  – High level waste
    • Liquid waste evaporated prior to vitrification
    • Removal of Am/Cm from HA wastes to minimize long term heat load and radiotoxicity
    • Delay stored on site for up to 100 years prior to disposal to allow Cs/Sr decay
    • Intrinsically safe passively cooled HA product store
Wastes from Recycling

- RH TRU or GTCC wastes
  - Primarily hulls and ends
  - Suitable for WIPP type repository with change in legislation
  - Volume minimized through compaction
  - Suitable for disposal in existing transport containers (development of alternative to RH-72B recommended)

- CH TRU
  - Suitable for WIPP type repository with change in legislation
  - Provision of decontamination facility to minimize volumes generated
  - Supercompaction to reduce waste volume

- MLLW & LLW
  - Supercompaction to reduce waste volume
  - Sub-surface commercial disposal
Wastes from Recycling

- The wastes produced from recycling the nuclear fuel that has provided the **annual electricity needs for over 250,000 family homes**

Radioactivity content 100%  
10.9m³  
Cost to dispose $6 million

Radioactivity content 99%  
0.8m³  
Cost to dispose $1.2 million

Radioactivity content 0.9%  
3.9m³  
Cost to dispose $0.5 million

Radioactivity content 0.1%  
71m³  
Cost to dispose $0.1 million

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**EnergySolutions**
Wastes from Recycling

• Or to put it another way:
  – If all the electricity consumed by an average US household over their lifetime was generated by nuclear fuel, then the resulting wastes from recycling would be:

Radioactivity content 99%
Half a Soda Can of Vitrified HLW Waste
7 fl oz

Radioactivity content 0.9%
Milk container of GTCC low level waste
0.25 gallons

Radioactivity content 0.1%
Paint can of low level waste
5 gallons
## Waste Streams

<table>
<thead>
<tr>
<th>Source Type</th>
<th>Source Description</th>
<th>Volume m³/yr</th>
<th>Mass Kg/MTIHM</th>
<th>Containers #/yr</th>
<th>Disposal Container</th>
<th>Disposal Method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Level Waste</strong></td>
<td>Highly active liquid waste</td>
<td>97</td>
<td>181</td>
<td>119</td>
<td>HLW canister</td>
<td>Geologic repository</td>
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<tr>
<td><strong>Class C waste</strong></td>
<td>Maintenance and clean up operations</td>
<td>113</td>
<td>60</td>
<td>282</td>
<td>100/55 gallon drums</td>
<td>Commercial disposal</td>
</tr>
<tr>
<td><strong>Class A waste</strong></td>
<td>Maintenance and clean up operations</td>
<td>1,335</td>
<td>764</td>
<td>3,602</td>
<td>100/55 gallon drums</td>
<td>Commercial disposal</td>
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<tr>
<td></td>
<td>Grouted tritiated water plus C-14 slurry &amp; salt concentrate</td>
<td>11,122</td>
<td>16,400</td>
<td>672</td>
<td>Half-height 20’ cargo containers</td>
<td>Commercial disposal</td>
</tr>
<tr>
<td></td>
<td>Pyrolized Solvent Ash</td>
<td>132</td>
<td>133</td>
<td>349</td>
<td>100 gallon drums</td>
<td>Commercial disposal</td>
</tr>
<tr>
<td></td>
<td>Spent Ion Exchange Resin</td>
<td>11</td>
<td>7</td>
<td>2.1</td>
<td>210-Liners</td>
<td>Commercial disposal</td>
</tr>
<tr>
<td><strong>Contact Handled TRU waste</strong></td>
<td>Maintenance and clean up operations</td>
<td>130</td>
<td>69</td>
<td>326</td>
<td>100/55 gallon drums</td>
<td>Salt repository</td>
</tr>
<tr>
<td><strong>Remote Handled TRU and GTCC waste</strong></td>
<td>Fuel assembly hulls and ends plus I-129 waste</td>
<td>371</td>
<td>639</td>
<td>419</td>
<td>RH-72B</td>
<td>Salt repository</td>
</tr>
<tr>
<td><strong>Kr 85</strong></td>
<td>Dissolver Off-gas</td>
<td>3</td>
<td>N/A</td>
<td>103</td>
<td>Gas bottles</td>
<td>Decay storage and discharge</td>
</tr>
</tbody>
</table>
Throughput and Lessons Learned Assessment

- Operational Research (OR) Model used to analyze baseline commercial design to identify major bottlenecks and incorporate design solutions
  - Fuel handling
    - 2 fuel removal machines instead of one
  - BWR fuel handling
    - Handling of multiple assemblies for concurrent shearing
  - Dissolver acid heat up times
    - Pre heat of dissolver acid
  - Fuel campaigning
    - Campaigning assumed not required
  - Use of Reliability Centered Maintenance processes to maximize operability of key equipment and identify preventative maintenance regimes.

- The model assumes a realistic 2 month outage annually, plus reliability/availability data from UK operational facilities

- Significant experience in increasing production on 2nd and 3rd generation facilities
  - AMWTP versus WTC supercompaction throughput increased sixfold using similar equipment
  - Sellafield 3rd vitrification line versus lines 1&2 throughput increased twofold
OR model dynamic simulation
Closing the Fuel Cycle- Conclusions

• Closing the fuel cycle will:
  – Solve the nuclear waste problem
  – Significantly reduce amount, heat load and toxicity of high level nuclear waste
  – Minimize risk of proliferation, plutonium is consumed and pure plutonium never produced
  – Improve US energy security, reduce dependence on foreign energy supplies

• Recycling will be paid for by the nuclear industry not the government

• Allows carbon emissions to be reduced by supporting the nuclear renaissance

• Create thousands of much needed US jobs – many in manufacturing and construction