Waste Generated from Recycling of Used Nuclear Fuel

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Should U.S. consider recycling?
• Recycling makes sense, especially if it can be financed through the NWF
• Responsibility for an integrated nuclear waste management strategy for the U.S. should be transferred to a new government entity

What is required for private financing?
• Commercial model with existing fleet (e.g., LWR recycling)
• Investment grade with guarantees (e.g., proven technology)
• Rulemaking (one-step licensing)
Study Results based on Technology Readiness and Business Plan

Consolidated Recycling Facility (CRF)

- Based on state-of-the-art, proven (50 years) technology/experience
  La Hague/Melox, Rokkasho, Thorp
  - COEX™ process - no pure plutonium stream
- Co-location of separation and fuel fabrication
- Capacity based on market for recycled fuel
- Flexible to allow deployment of new technology

Sodium Fast Reactor (SFR)

- Commercial Demo Required
- Existing roadmap for commercializing fast reactors in Japan provides a solid foundation
  - Based on technology/experience from JOYO, MONJU, Phenix, SuperPhenix
  - R&D required to make commercial design cost-competitive and enhance reliability and safety
- Start with oxide fuel but can burn metal fuel
- Homogeneous or target transmutation fuel

Note: Adapted from “JAEA-Research 2006-042”, Fig 2.1.1-4, p. 69 (2006)
Recycling Experience

- Pre-conceptual design of the initial US Facility based on proven state-of-the-art processes and technologies from France, UK and Japan (50 years of commercial experience and continuous improvements)
  - to mitigate the risks (schedule, costs, licensing, safety)
  - to guarantee process efficiency and technology reliability
  - to minimize the impact on the environment
  - to allow flexibility (evolutions of the plant during operation)
Assumptions for Closed Fuel Recycling Studies

- **Technical**
  - Geological Repository - Yucca Mountain
  - Reference fuel: PWR fuel – 50 GWd/t – 4 years cooling time for maximum benefit to repository (reduced Am, therefore, Np content)
  - Treatment of UNF of any burn-up (UOx and MOX) from LWR possible
  - No pure Pu stream and mature technologies to reduce risk
  - Fabrication of LWR and SFR MOX fuels
  - Advanced processes to be implemented when mature, working with National Labs to develop and implement

- **Business**
  - Commercial facility
Recycling Scenarios

► Commercial Scalable Reference Design
  ◆ COEX™ process
  ◆ Any burn-up/age UNF
  ◆ FP and MA in glass
  ◆ LWR and SFR fuel fabrication

► Evolutions
  ◆ Capacity increase (800 to 2,500 Mt/y)
  ◆ Advanced MA separation when mature
  ◆ Transmutation fuel fabrication
    ◆ Homogeneous / heterogeneous

(1): Demonstration
(2): Commercial scalable
Solid Waste From Recycling
Facility operational feedback, combined with ongoing R&D programs have resulted in a reduction of HLW volume generated by a factor >5 in operational facilities.
Waste Management Overview

- Main categories of waste from recycling plants
  - Conventional waste (non nuclear waste)
  - Nuclear waste
    - Maintenance waste, arising from plant operation
    - Process waste, produced as part of the recycling process itself

### Process waste
- Fission Products
- Hulls & End pieces
- Spent resins
- Spent solvent
- Liquid effluents
- Gaseous effluents

### Maintenance/operations waste
- Alpha waste
- Valves
- Gloves
- Telemannipulator & Rotating machines components

### Vitrification
- Compaction
- Cementation
- Pyrolysis

### Incineration
- Compaction
- Cementation

### Conditioning / Packaging

### Nuclear area waste

### Conventional area waste
- Special industrial waste
- Common industrial waste
- Conventional waste
Waste Management Principles

► Main objective is to ensure the final conditioning of every waste stream with robust waste forms and defined disposal paths

► Goal is to reduce the quantity and the radiotoxicity of the final waste to be disposed of (especially in deep geological repository)

► Main principles for limiting waste volumes
  ◆ Untreated Waste Minimization:
    • Design and performance of the recycling plant
      - Modular equipment
      - High equipment reliability
      - Maintain equipment as long as possible (decontamination and repair)
    • Sorting at the source of the waste and classification of the waste according to activity level
  ◆ Application of most suitable treatment process
    • Vitrification, Compaction, Cementation, …
  ◆ Recycle liquid streams where possible
Waste Volumes from Recycling: HLW

**Direct Disposal**
*Used Nuclear Fuel*

```
45 cu ft/MTHM
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**Recycling**
*Vitrified FP/MA + Compacted Hulls & End Pieces*

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10 cu ft/MTHM
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**Recycling option:**
At least 4 times less space needed for deep underground disposal
Solid Waste Volumes from Recycling

Deep Repository (HLW/GTCC)

- Alpha Waste
- HIC Cemented
- Vitrified FP and MA
- Compacted Hulls and End Pieces

10 cu ft/MTHM

*Based on 800 MT/y recycling facility
Recycling of 2,500 MTHM generates approx. 2% of US Market
Solid Waste Volumes from Recycling

Surface Disposal (Class A, B or C)

120l Drum

Compacted Waste

Cemented Waste

HIC Container

50 cu ft/MTHM

*Based on 800 MT/y recycling facility

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Solid Waste Disposition

Vitrified Glass / Compacted Waste Canisters

TRU Waste

Mixed LLW Iodine Traps

Waste Treatment Process

LLW Wastes

Job Control/Equipment

TBD (based on classification)

DOE or Commercial LLW Disposal Site

DOE Disposal Site (WIPP)

NRC-licensed Disposal Site

HLW Geological Repository

Consolidated Recycling Facility

DOE Disposal Site
Culture of Continuous Improvement

AREVA adopts a corporate policy of continuous improvement, as such new technology is continuously being developed, industrialized and deployed to improve plant performance, reduce waste volumes and increase plant safety.
Projected Releases from Recycling: Dose Impact and Regulatory Considerations

- Projected releases from facility well below dose limits in 40CFR190.10a

<table>
<thead>
<tr>
<th></th>
<th>EPA Limit (mrem/yr)</th>
<th>Air (mrem/yr)</th>
<th>Liquid (mrem/yr)</th>
<th>Total (mrem/yr)</th>
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</thead>
<tbody>
<tr>
<td>Whole Body</td>
<td>25</td>
<td>0.5</td>
<td>1.41</td>
<td>1.91</td>
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<tr>
<td>Thyroid</td>
<td>75</td>
<td>0.22</td>
<td>2.39</td>
<td>2.61</td>
</tr>
<tr>
<td>Other organ</td>
<td>25</td>
<td>0.46</td>
<td>1.40</td>
<td>1.86</td>
</tr>
</tbody>
</table>

Note: exact values are site dependent and will need to be confirmed after site selection

- 40CFR190.10b quantity limits based on GW-yr of electricity produced for fuel cycle:
  - Recycling exceeds current limits for $^{85}$Kr (based on newly discharged UNF) and $^{129}$I
  - Revise/update regulation to be risk based consistent with International Commission on Radiation Protection and or update with current cost and dose bases
  - Advanced Design Working Group between industry and National Labs to identify new technology for capture/conditioning of $^{85}$Kr – perform risk and cost/benefit analysis
Engineering Challenges

- Recovering small amounts of volatile fission products from large volumetric flow rates presents many challenges. Stack flow 150,000 m$^3$/hr of air - trace amounts of $^{129}$I contamination.

- To achieve a reduction of risk to the public, the volatile fission products must be conditioned in a stable form, and stored or disposed safely.

- Recovering and concentrating readily dispersible material introduces potential new risk of exposure and contamination to the workers.
Environmental / Waste Management (1/4)

$^{85}$Kr

◆ Noble gas. It is a non-soluble and chemically inert produced in trace amounts in nuclear fuel in a reactor. With a half-life of 10.7 years, the concentration of the gas will be dependent upon the age of the fuel recycled.

◆ Control technology options
  - Cryogenic Distillation
    - Technology available
    - Safety Risk
  - Waste conditioning
    - Vacuum Pressure Swing Adsorption
    - Ion Implantation & Sputtering
  - Engineering Scale Demonstrated at the Tokai Facility in Japan by JNFL

◆ Costly to implement
129I

**Environmental / Waste Management (2/4)**

- Half-life of 15.7 million years. During dissolution, the majority of the iodine is released as I₂ into the dissolver off-gas where most will be trapped in the off-gas treatment. Trace amounts find its way into the active cell ventilation system and the rest remains in the dissolution liquors and will follow the liquid waste streams in the process.
  - Rokkasho Recycling Plant implementing traps on solid media (silver beds) to capture trace amounts that pass the off-gas treatment – similar process under investigation for WTP
  - Evaluating conditioning for solid media

- Further reductions will be considered as part of the overall ALARA goals for facility design
Environmental / Waste Management (3/4)

14C

- Half life of approximately 5,700 years. During dissolution, part of the 14C is released as CO₂ into the dissolution off-gas. However, a large fraction of 14C remains in solution during this process step and is released into the off-gas stream during subsequent processing steps within the facility. Trapping 14C will also trap CO₂.

- Trapping techniques for small amounts of the 14C will also trap the large amounts of CO₂ present in the air flow resulting in large volumes of material to be stabilized.

- Complies with current regulations
3H

- Half-life of approximately 12.3 years, is present as tritiated water exhibiting physical and chemical characteristics very close to water. It is difficult for effluent treatment processes to separate tritium from the water at the concentrations that will be present in a recycling facility.

- 96% removal with current controls and conditioned as solid waste.

- Remaining capture if required is an engineering issue not technical issue.
  - Technology would be energy intensive
D&D Waste From Recycling
The design of modern nuclear facilities including recycling plants integrates the lessons learned from previous D&D operations to ensure final waste volumes are minimized. This is achieved by considering how to D&D a facility during the initial design.

The waste generated by decommissioning a 2,500 ton/yr recycling plant can be put into context by comparing it to the waste generated over the 50 year life of the facility.

- LLW: less than 20% of cumulated LLW generated during operations
Advanced Separations
Engineering Considerations for Advanced Separation

Criteria for final geological repository

Commercial facility

- Each separated product stream adds additional complexity in process operations, plant design and cost
  - Cs, Sr
    - Short half-life and will decay in vitrified HLW during interim storage of canisters at the recycling facility
  - Tc
    - Current plan to send to vitrified HLW
  - Am and Cm
    - Complexities with handling Cm - current plan to send to vitrified HLW
    - Am could be recycled as a transmutation fuel/target – multiple recycles in SFR to burn
Technology Evolution

Industry engaged with National Labs in campaign managers meetings
Summary: A Sustainable Back-End Solution

Integrated used fuel management strategy needed in U.S. – recycling should be included as an option

Enabling steps near-term (e.g., rulemaking for recycling, regulatory on effluents, legislative, financing)

No matter the back-end strategy, a repository is needed
Expected Waste Streams for Recycling Facility (1/2)

*Based on 800 MT/y recycling facility
Expected Waste Streams for Recycling Facility (2/2)

- **Waste Streams**
  - Hulls and end pieces
  - Spent resins
  - Fission Products
  - Fines
  - Alkaline Waste
  - Spent Solvent
  - Liquid Effluent

- **Treatment**
  - Compaction
  - Cemation
  - Vitrification
  - Mineralization and Cementation
  - Nitrate Solidification

- **LLW Repository**
  - CBF-C2
  - C0
  - Drums

- **Deep Repository**
  - UC-C
  - UC-V

*Based on 800 MT/y recycling facility*
## Comparison of HLW Canister to Defense Waste Canister

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>R7T7 Waste Form (CSD-V)</th>
<th>U.S. Defense HLW Canister</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canister height</td>
<td>~1.34 m</td>
<td>3.0 or 4.5 m</td>
</tr>
<tr>
<td>Canister outer diameter</td>
<td>0.43 m</td>
<td>0.61 m</td>
</tr>
<tr>
<td>Filled canister weight</td>
<td>&lt; 500 kg</td>
<td></td>
</tr>
<tr>
<td>Weight of glass in canister</td>
<td>~ 400 kg</td>
<td>up to 2000 kg</td>
</tr>
<tr>
<td>Maximum heat output at the time of shipment</td>
<td>2 kW</td>
<td>1.5 kW</td>
</tr>
<tr>
<td>Dose rate</td>
<td>Can be &gt; $10^5$ rad/h</td>
<td></td>
</tr>
<tr>
<td>Canister material</td>
<td>Stainless steel</td>
<td>Stainless steel</td>
</tr>
<tr>
<td>Closure method</td>
<td>Welding</td>
<td>Welding</td>
</tr>
<tr>
<td>Handling features</td>
<td>Concentric neck and flange allow the use of grapples</td>
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