Challenges for transport and storage
IAEA Technical Meeting on Back End of the Fuel Cycle Considerations for Small Modular Reactors

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Unrestricted
Content

1. Package design requirements for transport

2. Front-end transport packages

3. Back-end transport and storage packages
A great diversity of materials

Diversity of reactor technology implies diversity of fuel technology

- Physical form
- Fissile content
- Radioactivity

Fuel types
- Oxide/ceramic fuels with cladding
- TRISO fuels
- Metallic fuels
- Liquid fuel salts

Fissile material
- LEU ≤ 5% enriched U-235
- LEU+ [5%;10%] enriched U-235
- HALEU [10%;20%] enriched U-235
- HEU ≥ 20% enriched U-235
- Mixed U & Pu (oxide, metal, or salt)
- Thorium (oxide, metal, or salt)

"How to transport these materials?"
Transport regulations

National regulations based on IAEA Safety Standard

Radioactive material characteristics (radioactivity, fissile material) => defines the type of package => defines the safety requirements and tests

Design features for fissile material

- Assumption of water ingress inside the package shall be considered in the criticality analysis
- Unless the package is double barrier design => complexity of design and operations
Front-end package design

Package design of fresh fuel with high fissile content shall be considered as well as all its by-products from the manufacturing chain

- For example, UF6 transport with enrichment higher than 5% (HALEU...)

Simple barrier design (water ingress)

- With high fissile content (HALEU, high Pu content) subcriticality may reduce the payload capacity
- Example of a fresh UO2 powder package (French license)

<table>
<thead>
<tr>
<th>Enrichment</th>
<th>UO2 powder</th>
</tr>
</thead>
<tbody>
<tr>
<td>e ≤ 5%</td>
<td>74.5 kg per cavity</td>
</tr>
<tr>
<td>5% &lt; e ≤ 10%</td>
<td>16.5 kg per cavity</td>
</tr>
</tbody>
</table>

- Package designed for 5% enrichment may not be optimized for higher fissile content

Double barrier design (water exclusion)

- Enhanced payload => reduction of package numbers and transport cost
- Complexity of the design and additional operations (closure, leak tightness test...)

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Fresh fuel existing packages

Diversity of form, weight depending on the content

Simple barrier design
- Criticality control by geometry and poison material

Impact limiter and fire insulation materials

Light or no shielding

Fuel integrity protection
Back-end transport and storage

Heavy cask due to shielding requirements with high density materials (steel, lead…)

Large cask with impact limiters for transport

Compatibility with the loading facility process (weight limits, interfaces…)

Existing solutions like TN-EAGLE® and NUHOMS EOS® and systems, licensed for LWR fuel, can be adapted/modified for such needs
**EOS® Storage System**

- 37 PWR / 89 BWR / 50 kW
- Faster Offload from Pool
- Optimize Spent Fuel Management

**Innovative design**
- Patented Basket layout
- High performance materials

**State-of-the art methods**

**Proven horizontal storage**

Next generation storage system
TN Eagle Dual purpose Cask

Licensed in France for Transportation

Initial Application Submitted to NRC 12/2020 (RAI Response in Progress)

- EOS® DSCs included as contents

TN-EAGLE has TWO Models

- TN EAGLE-STC (LC) (Large Canister)
- TN EAGLE-STC (SC) (Standard Canister)

Versatile Universal Transportation Cask
# Interim storage and transportation

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Comparison with LWR fuel</th>
<th>Potential impacts</th>
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<tbody>
<tr>
<td>Oxide/Ceramic</td>
<td>Similar fuel form and materials</td>
<td>More demanding sub-criticality requirements</td>
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<tr>
<td></td>
<td>Higher enrichment and burnup</td>
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<td></td>
<td>Advanced cladding materials</td>
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<tr>
<td>Metallic</td>
<td>Rodded form with shorter active fuel length</td>
<td>Higher power density, thermal &amp; radiation source terms, reactivity</td>
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<tr>
<td></td>
<td>Higher enrichment and burnup</td>
<td>Additional processing prior to interim storage and transportation</td>
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<tr>
<td></td>
<td>Sodium-bonding</td>
<td>Fuel cladding integrity (accident conditions)</td>
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<tr>
<td>TRISO</td>
<td>Different fuel form with large graphite content</td>
<td>Possible to store/move large quantities</td>
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<tr>
<td></td>
<td>Higher enrichment and burnup</td>
<td>Well-sized cylinders to manage sub-criticality</td>
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<tr>
<td></td>
<td>Very low power density</td>
<td></td>
</tr>
<tr>
<td>Liquid</td>
<td>Highly different fuel with significant change in physical/material characteristics during storage</td>
<td>Significant modifications needed, like:</td>
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<td></td>
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<td>- Design features to deal with potential impact of phase change (between liquid and solid phases)</td>
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<td>- Corrosion resistant materials</td>
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<tr>
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<td>- Temperature and gas monitoring during storage</td>
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<td>- Fission gas getters</td>
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</table>
Interim storage and Transportation are critical parts of the overall front-end and back-end management.

Licensed solutions must be available for the various fuel types to be transport.

Anticipating the package solution is key to optimized transport scenario, and should be integrated early in the reactor design phase.

"Thank you for your attention"

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