Fuel Cycle Technologies

System Architecture Evaluation

Mark Nutt, Argonne National Laboratory
Deputy National Technical Director
DOE-NE Used Fuel Disposition Campaign

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In the 1990s the U.S. DOE completed a number of systems analyses investigating consolidated interim storage as part of the waste management solution.

These analyses are “dated” and conditions have changed:
- Utility evolution and progress loading dry storage systems
- Consideration of different geologic disposal environments

Need to update back-end system architecture studies

Need to update tools for evaluating the back-end of the fuel cycle

Need recognized by both the NWTRB and the BRC
Considerations for a Future UNF Management System

- Direct disposal of dual-purpose canisters (DPCs) is highly uncertain
  - Feasibility would have to be demonstrated and suitable site identified/selected
  - Re-packaging of DPCs will be required if direct disposal is not feasible
  - Multi-year feasibility evaluation required; initiated in FY12
    • Complex problem (recall, YM did not accept DPCs for direct disposal)

- Implementation of standardized canisters
  - Could have system-level benefit, depending on when deployed
  - Uncertainty regarding standard canister size; repository media unknown
  - Still would have to manage legacy DPCs
  - Multi-year evaluation/implementation required; initiated in FY12

- Legacy and continued use of dual purpose canisters (and single purpose storage casks) must be managed
  - Wide range of systems in use (vertical, horizontal; ~ 30 different vendors/designs)
  - Inventory and mix (vertical/horizontal) depends on start date of UNF acceptance and acceptance rate
  - Influences future storage facility design
  - Affects magnitude of future re-packaging
Central Storage Facility (CSF) concepts can differ, depending on UNF management approach taken

- Start dates of CSF and repository
- Acceptance and disposal rate
- Fuel receipt - canisters, bare fuel
- Storage method – dry (vertical/horizontal canisters, vaults); bare fuel storage (pools)
- Imposed capacity limits of facility

Strategy for managing UNF in fuel pools once CSF begins operation will affect CSF design and future waste packaging/re-packaging

<table>
<thead>
<tr>
<th>All Canistered</th>
<th>Canistered and Bare</th>
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<tbody>
<tr>
<td>• Transport all fuel in DPCs</td>
<td>• Transport fuel from pools in re-useable casks</td>
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<tr>
<td>• Dry canister storage</td>
<td>• Dry canister + bare fuel storage</td>
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<tr>
<td>• Re-packaging of all DPCs</td>
<td>• Reduced number of DPC re-packaging + bare</td>
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<td>fuel packaging</td>
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Objectives of the UFD System Architecture Effort

- Provide quantitative information with respect to the broad UNF management considerations
- Develop an integrated approach to evaluating storage, transportation, and disposal options, with emphasis on flexibility
- Evaluate impacts of storage choices on disposal options
- Identify alternative strategies and evaluate with respect to cost and flexibility
- Considerations include repository emplacement capability, thermal constraints, repackaging needs, storage and transportation alternatives, impacts on utility operations, etc.
Developed framework of potential UNF disposition pathways from at-reactor storage (wet → dry) through interim storage to ultimate disposal
  - Assuming that canisters will need to be re-packaged into disposal canisters
Selected disposition pathways for evaluation in FY12
Determined evaluation assumptions, boundary conditions, and system inputs (acceptance rates, start dates)
Developed UFD Transportation Storage Logistics (TSL) simulation tool from legacy codes (CALVIN and TOM)
Conducted UNF logistic evaluations of selected disposition pathways
Developed modular design concepts for Centralized Storage Facilities (CSF) and packaging/re-packaging plant
Utilized logistic simulation results and modular design concepts to lay out facilities needed for each case evaluated

Objective of FY12 Activities:
  1) Develop methodologies, approaches, and tools (Capability Development)
  2) Evaluate select UNF disposition scenarios (Capability Demonstration)
Disposition Pathway Overview

At-Reactor Fuel Management: Options
1. Wet Storage Fuel Management:
   1a. Transfer to dry storage to maintain full core off-load capability
   1b. Accelerate transfer to dry storage (age ≤ 5 yr)
2. Continue off-loading of fuel in wet storage pools into existing sized dry storage systems
3. Initial off-loading of fuel in wet storage pools into existing sized dry storage systems – transition to WP compatible sized dry storage system at T = 20xx
4. Transport all fuel in wet storage pool to CSF (when operational and has bare fuel storage capacity) in re-usable transportation cans
5. Consistently fuel in wet pool for direct shipment to CSF (when operational and does not have bare fuel handling capability)
   5a. Existing dry storage systems
   5b. WP compatible sized dry storage systems

CSF Fuel Management: Options
1. Wet storage capability at CSF:
   1a. Maintain fuel in wet storage
   1b. Transfer to existing dry storage systems
   1c. Transfer to WP sized canisters
2. Re-packaging locations
   2a. At CSF
   2b. At repository
3. Re-packaging technology alternatives
   3a. Wet
   3b. Dry
4. Received fuel at CSF in existing dry storage system sized canisters
   4a. Store as-is
   4b. Repackage into WP compatible size canisters and store

Repository

Dry Repackaging into WP Compatible Sized Canisters

Wet Repackaging into WP Compatible Sized Canisters

Canisterized Fuel – WP Compatible Size

Dry Storage Existing Systems

Cansisterized Fuel --- For Direct Shipment

Transport Fuel in Re-Usable Transportation Casks (Bare Fuel)

Bare Fuel --- For Direct Shipment

Canisterized Fuel --- For Direct Shipment

Dry Storage: WP Compatible Size Canisters

Dry Storage Existing Systems

Canisterized Fuel --- For Direct Shipment

Transport Fuel in Re-Usable Transportation Casks

Repackaging

Repository

Waste Package

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Identified 9 potential disposition cases (and minor variants) that consider

- At-reactor UNF management
  - Transport all UNF in canisters or transport bare fuel in pools in re-useable transportation casks
  - Transition to loading disposable canisters at-reactor
- Packaging/Re-Packaging
  - At CSF or at repository
  - Upon receipt at CSF or upon shipment to the repository

Selected disposition cases for evaluation in FY12

- At-reactor UNF management
  - Transport all UNF in large canisters or transport bare fuel in pools in re-useable transportation casks
- Packaging/Re-Packaging
  - At CSF or at repository
  - Upon shipment to the repository

Down-select considered commonality of capability requirements, level of complexity, and flexibility
Assumptions and Input / Boundary Conditions

Assumptions
- Disposition of Used LWR Fuel in a Once-Through Fuel Cycle
- Reactor fleet is limited to the current 104 operating reactors
- Reactors will receive life extensions to operate for 60 years
- Projected fuel inventory at reactor; wet and dry
- Oldest-Fuel-First (OFF) allocation priority (determines which sites ship in a given year)
- Youngest-Fuel-First (YFF) shipment from reactors (determines which fuel is shipped from each site)
- First-In-First-Out (FIFO) shipment from storage facility
- Reactors complete off-load of pools to dry storage 5 years after shutdown

Input/Boundary Conditions
- Single CSF and geologic repository
- CSF/geologic repository available: 2020/2040, 2020/2055, 2035/2055
- Geologic repository available: 2040, 2055
- Acceptance rates: 1500, 3000, 6000 MT/yr
- Waste package sizes: 4/9, 12/21, 21/44 PWR/BWR assembly capacity
  - Covers range of disposal concepts under consideration by UFD to date; feasibility of direct disposal of large DPCs are part of ongoing investigations

Did not evaluate all combinations in FY12
Logistics Modeling

Utilized the UFD Transportation Storage Logistics (TSL) simulation tool to evaluate the cases and input/boundary conditions
- Modified and coupled two existing software tools
  - Civilian Radioactive Waste Management Analysis and Logistics Visually INteractive Model (CALVIN)
  - Transportation Operations Model (TOM)
- Fuel discharge projection revised based on 2011 EIA forecast
  - Everything is projection forward from 2002 (last RW-859 data)

TSL tracks individual fuel assemblies through their disposition pathway
- Used fuel pool → dry storage casks (by reactor, vendor model, size)
- At-Reactor Storage → storage at a Consolidated Storage Facility (CSF)
- CSF → repository
- Packaging/Re-packaging into disposal canisters

Logistics results used to establish requirements for UNF management facilities (storage, packaging, re-packaging)

End state: Production of Disposal Canisters

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<tr>
<th></th>
<th>4-PWR/9-BWR</th>
<th>12-PWR/24-BWR</th>
<th>21-PWR/44-BWR</th>
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<tbody>
<tr>
<td>PWR Waste Packages</td>
<td>52,250</td>
<td>17,417</td>
<td>9,952</td>
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<tr>
<td>BWR Waste Packages</td>
<td>30,333</td>
<td>11,375</td>
<td>6,205</td>
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<tr>
<td>Total Waste Packages</td>
<td>82,583</td>
<td>28,792</td>
<td>16,157</td>
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Higher throughput rates lead to larger facilities
- 1500 MT/yr: smaller storage and re-packaging facilities; larger/longer at-reactor storage
- 3000 MT/yr: larger storage and re-packaging facilities; smaller/reduced at-reactor storage
- 6000 MT/yr: large storage and re-packaging facilities; marginally smaller/small additional reduction in at-reactor storage

UNF acceptance priority (i.e., OFF, YFF), acceptance start date, acceptance rate, and UNF management strategy will impact the overall UNF management system, facility design concepts, and facility configuration
- At-reactor UNF management and shipment defines the “boundary condition” to which the system will “respond”
- Lower the acceptance rates or delay in start of acceptance “hardens” this “boundary condition,” resulting in reduced flexibility later
  - More UNF will be placed in at-reactor dry canister storage system
- Affects timing of downstream receipts (arrival of canisters, and bare fuel casks if included)
Start of acceptance and the acceptance rate will impact on-site dry storage requirements

- Significant decrease between 1500 MT/yr and 3000 MT/yr acceptance rate; reduced decrease between 3000 MT/yr and 6000 MT/yr
- Higher acceptance rates may not eliminate need for additional on-site dry storage when reactor fleet begins to shut down unless acceptance is “managed”
  - YFF still requires additional dry storage when reactors shut down
  - Straight OFF would require additional on-site dry storage

Alternate strategies for acceptance from reactors and subsequent shipment to a repository may also allow for optimization of down-stream facilities

- FIFO from CSF to repository is an initial assumption that may not be how the system is operated
- Treat consolidated storage facility as an integrated UNF management facility to act as a buffer between at-reactor UNF management needs and future repository requirements
  - Optimize shipments from reactors to minimize additional on-site dry storage requirements
  - Optimize shipments from the CSF to the repository to meet repository requirements while minimizing processing facility requirements
- May require additional CSF storage capacity
- Additional evaluation needed
- Processing rates and inventories scale with UNF throughput rate
- High acceptance rates (i.e., 6000 MT/yr) lead to large facilities and supporting infrastructure
  - Large capacity storage facilities
  - High processing capability that may only be needed for a relatively short time; under-utilized facilities
  - Available fuel transported relatively quickly – rate then matches discharge

**Peak CSF Canister Receipt Rate**
All Canisters, Re-Package at Repository

**Cumulative CSF Canister Receipt**
All Canisters, Re-Package at Repository

Note reduction in actual receipt rate for 6000 MT/yr
Dry storage at a CSF will be required for dry storage systems loaded at-reactor.

Acceptance rate and duration between start of CSF and repository operations affects storage capacity requirements:
- Any additional decay storage would increase requirements.

Maintaining bare UNF can reduce canister storage at a CSF:
- Trade-off is bare fuel storage.
A large-scale UNF handling effort will be needed regardless of the UNF management strategy, acceptance rates, and acceptance start dates

- There will always be a need to re-package large canisters unless the direct disposability of such canisters is shown to be feasible
- If all UNF is placed in such canisters, ~11,200 could have to be re-packaged
- Handling bare fuel at central storage facilities can reduce the number of canisters that would have to be re-packaged
  - Any potential benefit of not having to re-open canisters reduces for lower acceptance rates and/or delay in the start of acceptance
  - Have to store and package bare fuel
Facility Concepts

- Developed modular design concepts for dry (vertical and horizontal casks) and wet (pool)
- Modular approach allows for constructing facility lay-outs for different scenarios and logistics results
- Unit operation times estimated for all handling/processing steps

**Vertical Dry Storage**

**Packaging/Re-Packaging**
Insights Gained from Evaluating Facility Concept Configurations

(Preliminary results)

- Total storage footprint increases with acceptance rate and duration between start of CSF and repository operations
- Bare fuel storage can reduce facility storage footprint
- Storage facility size likely to increase if it is used for decay storage

- Vertical pad:
  - 30 ft x 80 ft
  - 8 Canisters per Pad

- Horizontal module:
  - 52 ft x 89 ft
  - 12 Canisters per Module

- Pool Basin:
  - 158 ft x 60 ft (x 55 ft deep)
  - 3500 Assemblies per Basin

NOTE: Does not include footprint that would be needed for infrastructure and support facilities or required spacing
Larger UNF throughput rates lead to larger processing bay requirements
- Into/out of storage
- Packaging/re-packaging facility stations (receipt, welding, release)
- Observation: Higher acceptance rate (6000 MT/yr) does not fully utilize all bays for an extended duration

Placing the entire UNF inventory in large canisters does not appear to require an increase in the packaging/re-packaging facility capabilities versus maintaining bare fuel
- Always a need to re-package canisters – capability will always be required

Use of large canisters for the entire inventory of UNF increases the number of canisters that would have to be opened, unless their disposability can be demonstrated
- Could have a broader system impacts
- ~11,200 canisters versus a reduced number – see Slide 16
  - Peak arrival occurs early, then decreases significantly
Conclusions

Nuclear Energy

- **FY12 Objectives achieved**
  - Developed methodologies, approaches, and tools (Capability Development)
  - Evaluated select UNF disposition scenarios (Capability Demonstration)
  - Re-established important, foundational capability to assess potential UNF management options

- **FY12 Evaluation provided insight into potential UNF disposition pathways and identified areas where additional work are needed**
  - Logistics and facilities report to be completed as draft October 30th, 2012

- **FY13 activities**
  - Develop worker exposure methodology and implement in TSL
    - Assess FY12 cases
  - Continued TSL development to implement blending/aging at the CSF and alternative UNF shipment strategies from the CSF
    - Assess FY12 cases
  - Identify and evaluate bare fuel storage alternatives at CSF (i.e., vaults, single purpose casks)
  - Inclusion of cask/fleet maintenance facilities in framework
  - Evaluate sensitivity regarding CSF wet pool density
  - Initiate assessment of advanced re-packaging techniques, gaps (dry, automated, remote)
  - Initiate process flow diagram/process node descriptions

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