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Sandia National Laboratories

Managing Commercial Spent Nuclear Fuel from Generation to Disposal: Integration of the Back-End of the Commercial Nuclear Fuel Cycle

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Back End of Commercial Nuclear Fuel Cycle

- “Back End of NFC” starts when Commercial Spent Nuclear Fuel is pulled out of reactor and ends with its permanent disposal in a deep geologic repository
- BENFC today not what was contemplated 10 years ago
- BENFC highly compartmentalized from the technical, operational and regulatory perspectives
- Current CSNF management practices might force technically possible, but sub-optimal solutions with considerable implications in terms of cost, schedule, and other issues, such as social and political acceptability

US CSNF Management System: 2006- 2010

- Geologic Disposal at Yucca Mountain, NV
- BENFC "integrated" primarily by use of Transportation, Aging and Disposal canister (TAD)
  - ~90% of CSNF assemblies (~56K MTHM) loaded directly from pools into TADs at reactor sites, transported to YM, aged and disposed of without need to open TADs and repackage the fuel. TADs loaded to meet disposal regulatory requirements.
  - ~10% of CSNF (~7K MTMH) transported to YM in dual-purpose (i.e., storage & transportation) casks (DPCs) or truck casks (uncanistered) loaded into TADs at the Waste Handling Facility.

	TADs	DPCs	Truck Casks
Average Time out of Reactor	14 Years	41 Years	23 Years
Average Burn Up	48.4 GWD/MT	29.9 GWD/MT	41.9 GWD/MT
Total Number	6494	308	2,650
Total MTHM	55,565	2,992	4,442

US CSNF Management System: Now

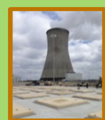
- 99 operating reactors at 61 sites in 2015
  - 65 pressurized water reactors (PWR)
  - 34 boiling water reactors (BWR)
- Because of no final disposal site and continued safe at-reactor storage, Independent Spent Fuel Storage Facilities (ISFSI's) at operating and shutdown reactor sites is the current practice
- At end of 2013, 71K MTHM in storage at reactor sites
  - 49K MTHM in wet storage & 22K MTHM in dry storage
- At mid 2015, ~ 78K MTHM in storage at reactor sites
  - ~53K MTHM in wet storage & >25K in dry storage
- ~140K MTMM by 2048 when a new CSNF repository is expected to be available (US DOE, January 2013)

Yucca Mountain repository statutory limit 70K MTHM total; 63K MTHM CSNF.

US CSNF Management System: Now (Continued)

UTILITY-OWNED

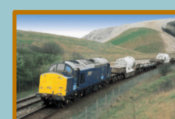
Spent Fuel Pools
(10 CFR Part 50)



ISFSIs
(10 CFR Part 72)

DOE-OWNED

Transportation:
(10 CFR Part 71)



DOE OR PRIVATELY-OWNED

Centralized Interim Storage
(10 CFR Part 72)

DOE-OWNED

Transportation:
(10 CFR Part 71)

DOE-OWNED

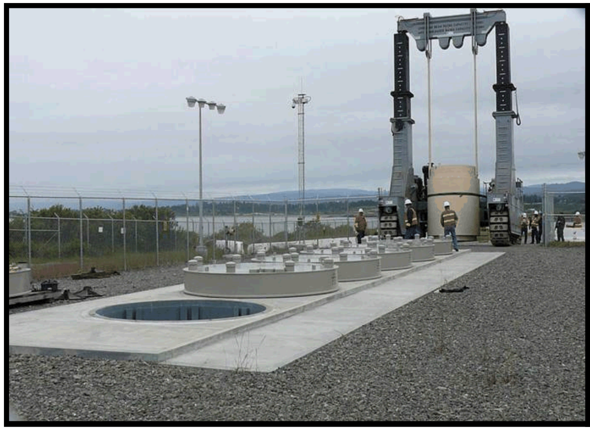
Unknown Disposal Site(s)
(10 CFR Part 60/63)

CSNF Path to Disposal

- Additional components in CSNF Management System
- Each component governed by different NRC regulation
- Hand-offs between different entities

Several types of ISFSI designs in US

- **Vertical below ground**
- **Horizontal bunker**
- **Vertical (most common)**
- **1 Vault: DOE site in Colorado for Fort St. Vrain SNF (high temperature gas cooled reactor)**



Humboldt Bay
Holtec below grade

Rancho Seco
TN horizontal

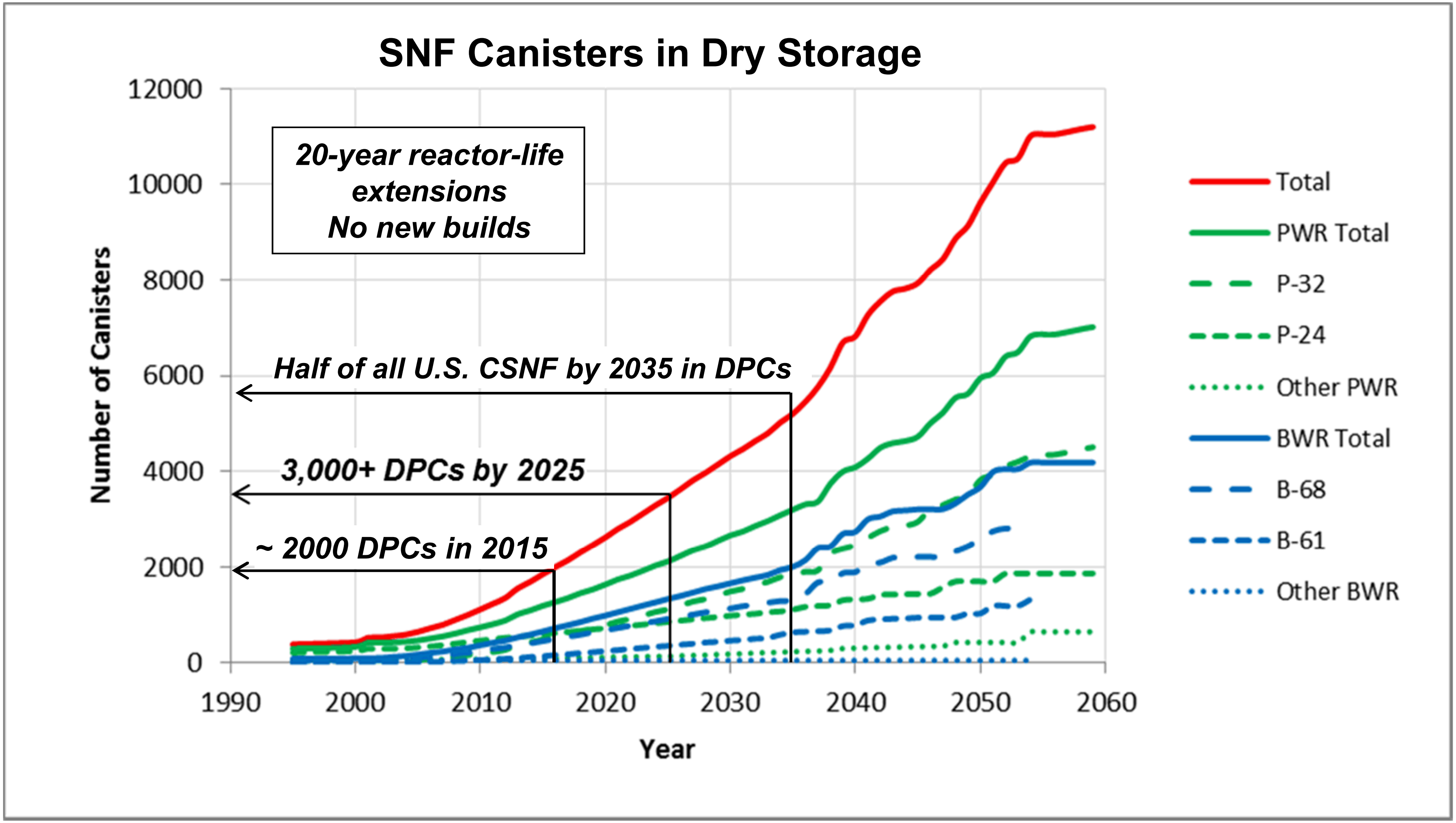
Maine Yankee
NAC vertical

SNF Currently Stored in Different Large Canister Designs

Dry Storage Dual-Purpose Canisters

- Large cylindrical canisters with passive cooling systems
- Can be loaded after 5 – 10 years of cooling in pool
- Incorporate criticality controls
- Can hold up to 37 PWR assemblies or 89 BWR assemblies
- Can accommodate SNF with burnup up to 66 GWd/mtU
- Weigh 58 tons when loaded with fuel (without cask)
- Most are designed to be used with transfer cask, storage cask, and transport cask (dual-purpose canister)
- Most are welded shut, although some are bolted
- Certificate of compliance is good for 20 years; extensions possible
- Each costs between $750,000 and $1,000,000

Current and Projected Accumulation of Used Commercial Reactor Fuel in Dry Storage (DPCs)



Implications of Loading CSNF into DPCs

- **Loading CSNF into large DPCs implies an unavoidable commitment to:**
  - **All SNF placed in DPCs will eventually need to be repackaged into purpose-built casks for disposal, or**
  - **The US will need to construct one or more repositories that can directly accommodate DPCs for disposal, or**
  - **The fuel will be left in-place at the existing ISFSIs and repackaged approximately every 100 years for storage according to the NRC Continued Storage Rule**
- **These alternatives are technically possible, but not envisioned 10 years ago.**
- **They all introduce potentially significant uncertainties and cost of addressing uncertainties can range between $100B to $250B.***

*** Hardin, E.L. and Kalinina, E.A.** ***COST ESTIMATION INPUTS FOR SPENT NUCLEAR FUEL GEOLOGIC DISPOSAL CONCEPTS,*** SAND2015-0687**, Sandia National Laboratories, 2015**

Re-Packaging of CSNF for Disposal

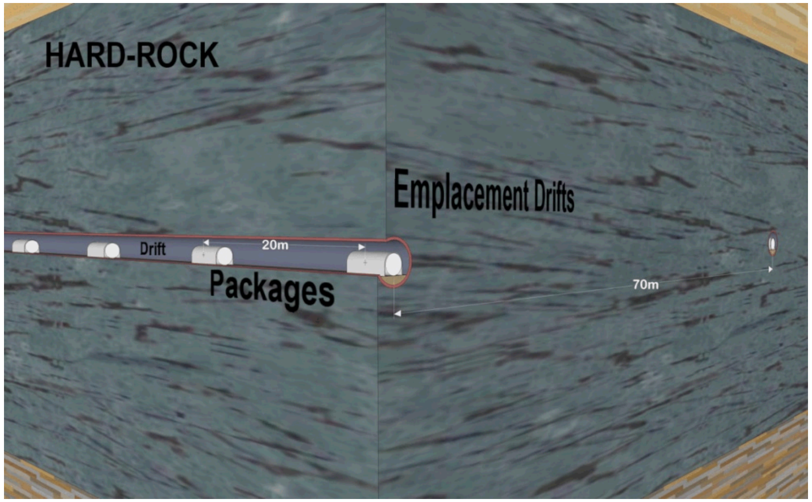
- World-wide, no repositories have been designed to dispose of DPCs without repackaging
  - Yucca Mountain came closest, with TADs that held 21 PWR assemblies
    - Current DPC designs take up to 37 PWR assemblies
  - Most other nations limit disposal package size to 4 PWR assemblies, primarily for thermal load management
- ROM Cost of Repackaging for 140K MTHM > 2055: ~$36B*

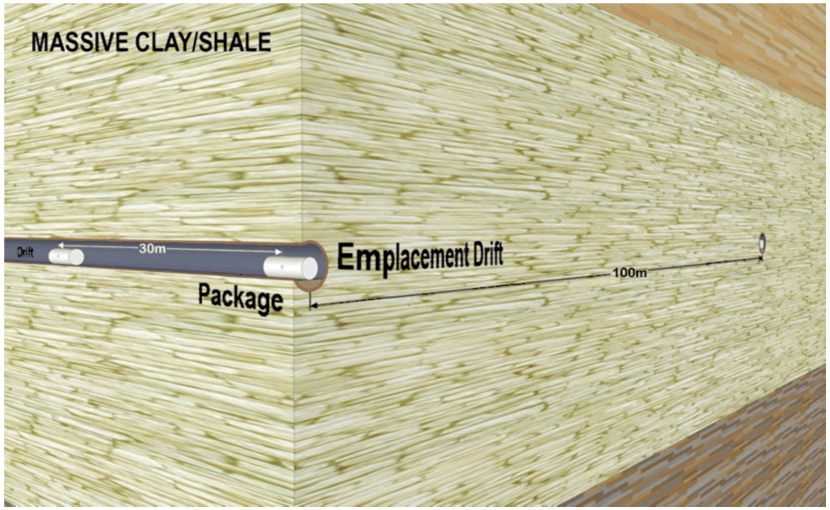
	Unit Cost	CSNF Qty. (MTMH)	Avg. DPC Capacity (MTHM)	# DPCs	Cost $B
Projected sunk costs based on DPC status quo:					
Procure, load and store existing DPCs ($/MTU)	100,000	25,000	12	2100	3
Cost to continue status quo through >2055 ($/MTU)	100,000	115,000	16.7	6895	11.5
Re-packaging costs for all fuel, current fleet estimate:					
Unload all DPCs ($/MTU)	10,000	140,000		8995	14
Transport and dispose of each DPC hull ($/DPC)	150,000			8995	1
Re-canister for disposal ($/MTU)	100,000	140,000			14
Re-packaging facility capital cost					5
Re-packaging facility operating cost for 30 years $/yr)	200,000,000				6
Total cost to make CSNF ready for disposal					36

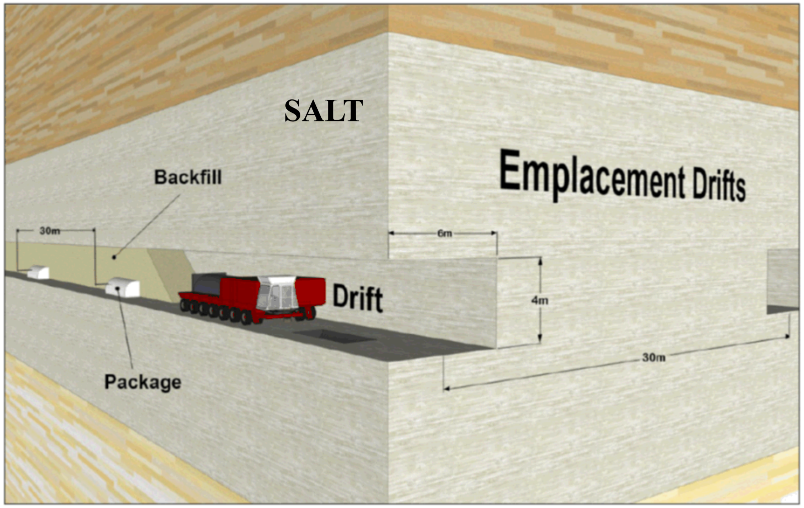
*"Investigations of Dual-Purpose Canister Direct Disposal Feasibility", E. Hardin and E. Kalinina, Sandia National Laboratories; K. Banerjee, J. Clarity, R. Howard and J. Scaglione, Oak Ridge National Laboratory; J. Carter, Savannah River National Laboratory; SAND2015-1804 C, Waste Management 2015

DPC Direct Disposal Concepts

- Engineering challenges (Shaft or ramp transport)
- In-drift emplacement
- Repository ventilation (except salt)
- Backfill prior to closure (except unsaturated)







(Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 1)

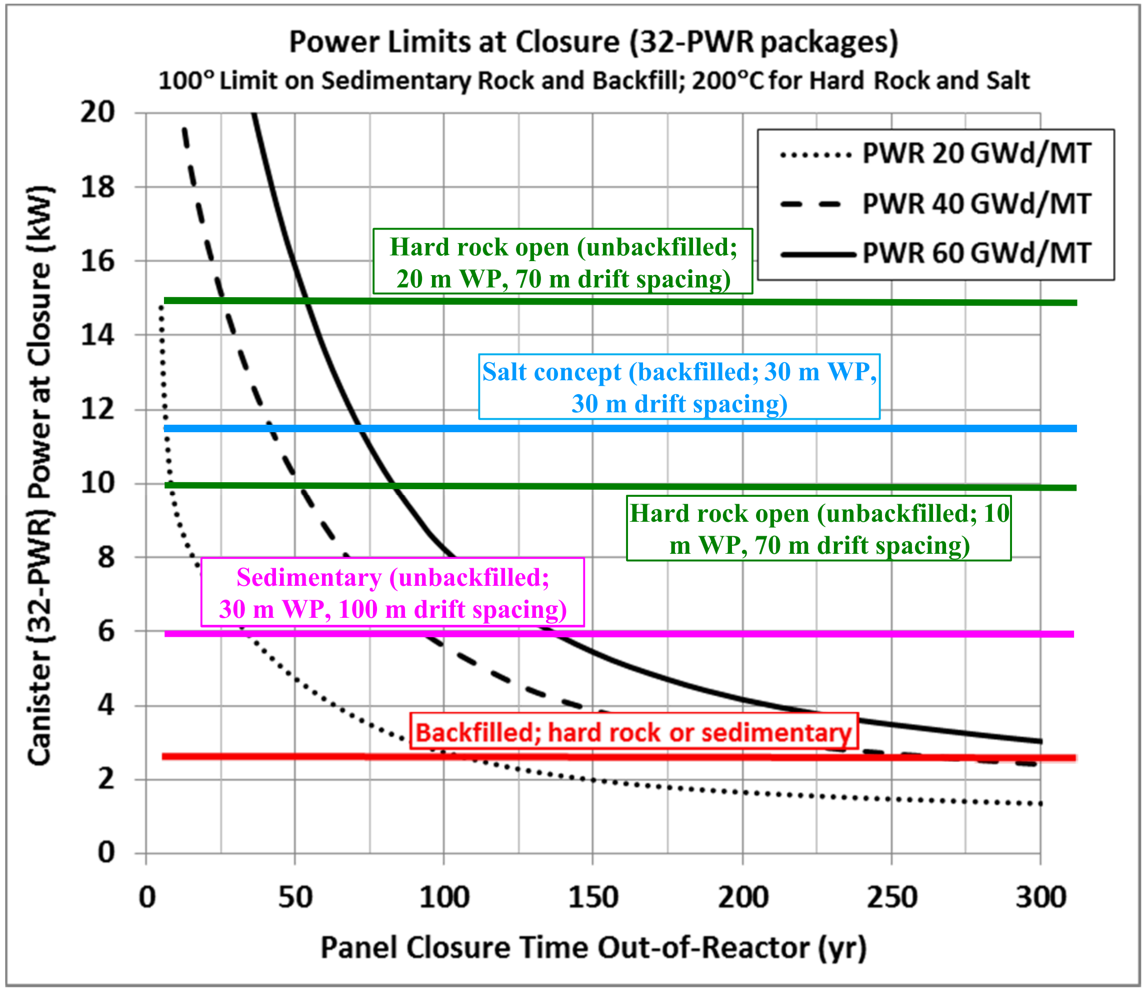
Time to Repository (Panel) Closure for Representative Disposal Concepts

32-PWR size packages

Hard rock concept (unbackfilled, unsaturated, with small and large spacings)

Salt concept

Clay/shale concept and any backfilled concept require much longer aging



Hardin et al. 2013. *Collaborative Report on Disposal Concepts.* FCRD-UFD-2013-000170 Rev. 0.

Other Considerations: Criticality Control in Repository Environments

- Some already-loaded DPCs pose complications for licensing analyses of postclosure criticality control
  - Flooding by groundwater following canister degradation is a pre-requisite for criticality in any waste package
  - Al-based neutron absorbers used in some DPCs will degrade in water
  - Resulting reactivity increase can be offset by
    - High-reliability disposal overpacks
    - Uncredited margin in SNF configurations
    - High chloride content in groundwater (e.g., in salt)
  - Other options include
    - Open DPCs before disposal to add criticality controls
    - Include consequences of postclosure criticality in long-term performance estimates
  - Case-by-case analysis of individual DPCs may be needed for licensing (function of enrichment and burn-up)

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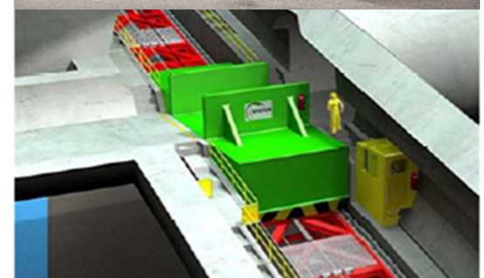
Other Considerations: Waste Package Size

- **DPCs are massive, but not unprecedented**
  - **TAD canisters proposed for YM are in the range of sizes of existing DPCs**
  - **With disposal overpack and transport shielding, total mass could be on the order of 150 metric tons**
- **Size poses engineering challenges for handling during both transportation and disposal, but options are available**



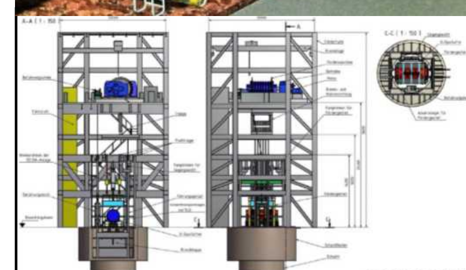


Image sources:
(upper two) Fairhurst, C. 2012. Current Approaches to Surface-Underground Transfer of High-Level Nuclear Waste. Itasca Consulting Group, Minneapolis, MN.
(middle) www.wheelift.com
(lower) Hardin, et. al. FCRD-UFD-2013-000170, 2013.

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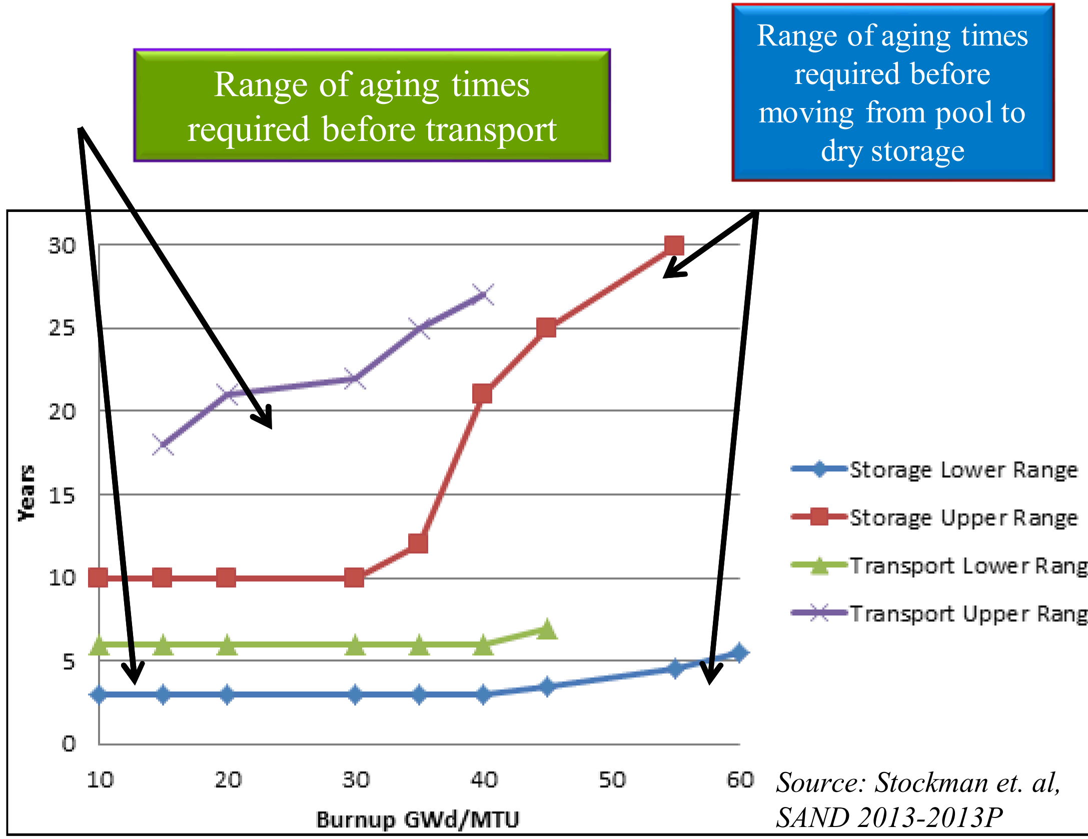
Other Considerations: Transportation

- **DPCs may require decades of aging to cool spent fuel before they can be transported**
  - **High-burnup fuels may require longer aging**
  - **Cooling times are design-specific (i.e., larger DPCs require longer cooling times)**



Source: Stockman et. al, SAND 2013-2013P

Minimum cooling times for multiple cask/canister systems, based on NRC certificates of compliance for specific designs.
Variation in times is due to the diversity of the current inventory, dominated by DPC size and heat transfer capabilities.

Possible Options

- Introduce a standardized canister to be loaded at reactors in the future (work in progress led by ORNL)
  - Selection of a standardized transportation, aging, and disposal canister (STAD) is repository-design specific
  - Loading STADs directly from reactor pools (as was originally envisioned for the YM TADs) is unlikely to happen before perhaps 2030, by which time more than 50,000 MTHM of SNF will be in DPCs
    - Later dates for repository and STAD selection will mean more fuel in DPCs
  - Lack of present incentive for utilities to use standardize canister
- Repackaging of SNF from DPCs to STADs at a consolidated storage facility?
  - Cost and schedule of repackaging
  - Management of additional LLW stream (DPCS carcasses)
- Disposal of DPCs and STADs in separate repositories?
- Cost considerations–number of handling operations, number of packages, repository design, and complexity of licensing

Consolidated interim storage may be path to integrating SNF management system

Possible advantages of consolidated interim storage:

- Flexible siting criteria by implementing schemes to lower thermal output
  - Buffer storage for hot canisters, or
  - Mixing SNF fuel in disposal canister
  - Re-packaging of DPCs
- Ease burden of aging inspections at shutdown sites and operating sites
- Accommodate shipment of bare fuel currently in wet storage
- Consolidated interim storage facility way for the US waste system to be more flexible to changing situations
- Blue Ribbon Commission on America's Nuclear Future Emphasized interim storage to integrate waste management

Summary and Conclusions

- Due to the lack of a final disposal site, the current US CSNF management system is relying on wet and dry storage at operating and shutdown reactor sites
- The current CSNF inventory in storage is ~78K MTHM and is expected to double to 140K MTHM by 2048 when the current US strategy calls for a geologic repository to begin operations
- Utilities are storing CSNF, with higher burnups, in larger dual purpose storage casks; currently ~2000 DPCs and 9000 to 10000 are projected by 2048. This practice presents numerous challenges to insuring integration of the three main components of waste management (storage, transportation and disposal)
- Lack of integration causes issues that increase cost and/or incur delays
- A consolidated interim storage, a key component of current US strategy for SNF management, presents an opportunity for integration and flexibility