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

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(SAND2015-4254 PE)

IAEA International Conference on Management of Spent Fuel from Nuclear Power Reactors: An Integrated Approach to the Back End of the Fuel Cycle

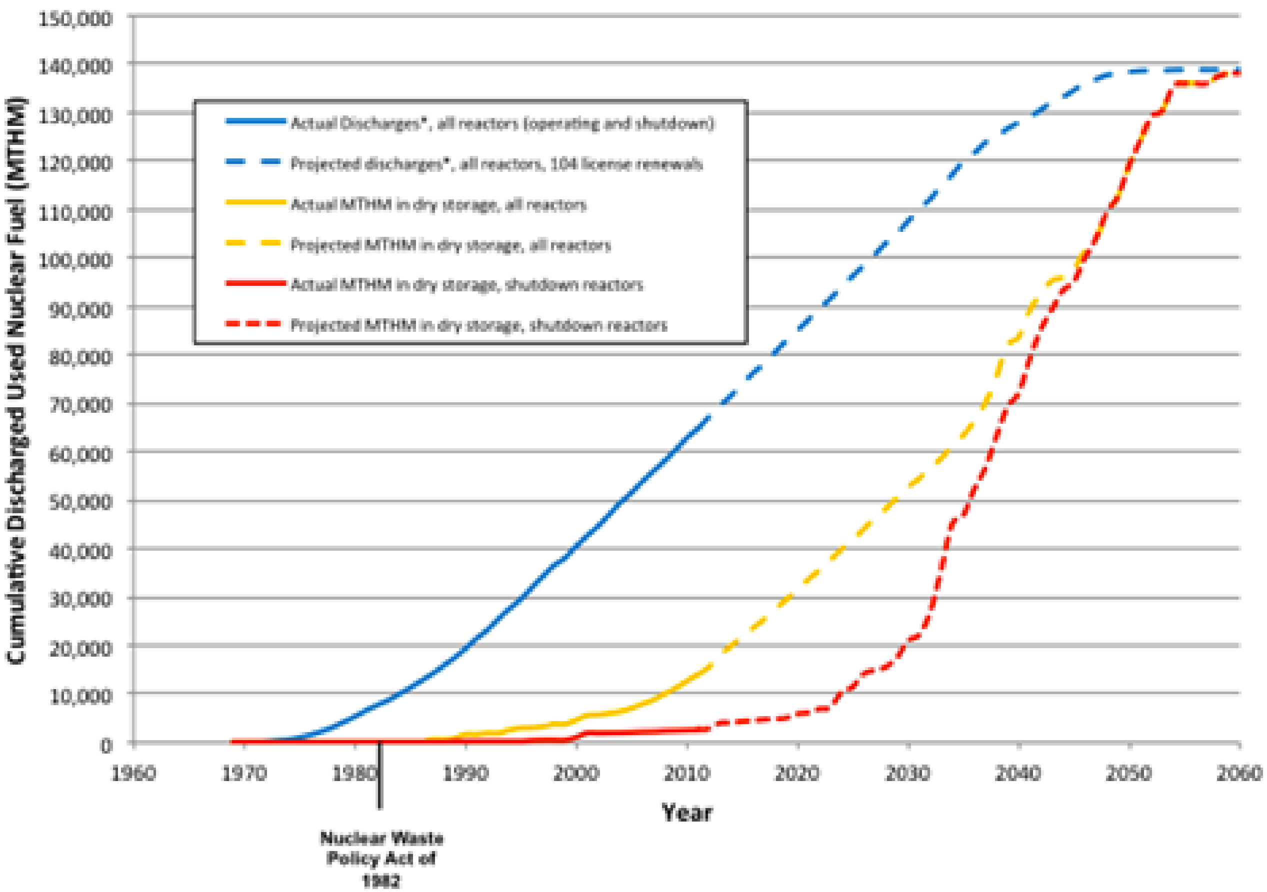
Vienna, Austria

15-19 June 2015

Current US waste management system uses at-reactor storage

- 100 operating reactor at 62 sites in 2014
  - 65 pressurized water reactors (PWR)
  - 35 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
- As of 2013, 71K MTHM in storage at reactor sites
  - 49K MTHM in wet storage & 22K MTHM in dry storage
- Current US fleet generating ~2K MTHM annually

Projections of Future SNF and HLW



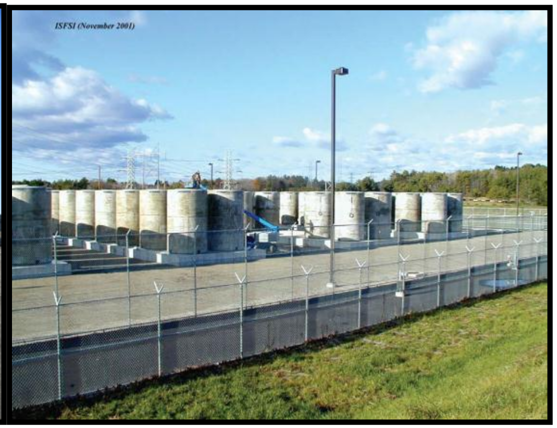
Source: *Based on actual discharge data as reported on RW-859s through 12/31/02, and projected discharges, in this case for 104 license renewals

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)

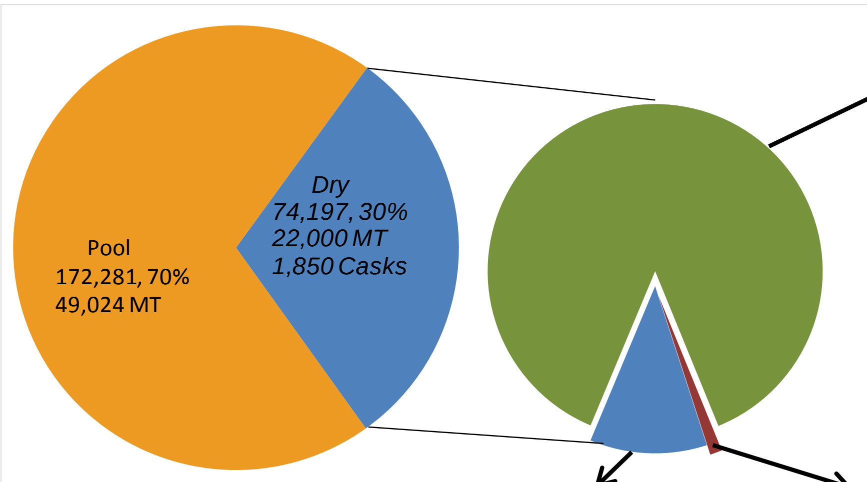
Humboldt Bay
Holtec below grade

Rancho Seco
TN horizontal



Maine Yankee
NAC vertical

Dry Storage Inventory



1,655 Welded Metal Canisters In Vented Concrete Overpacks
65,102 Assemblies, 87.5% of Dry

Transnuclear (34%)
Holtec (41%)
NAC (10%)

183 Bare Fuel Casks
8,406 Assemblies, 11.3% of Dry

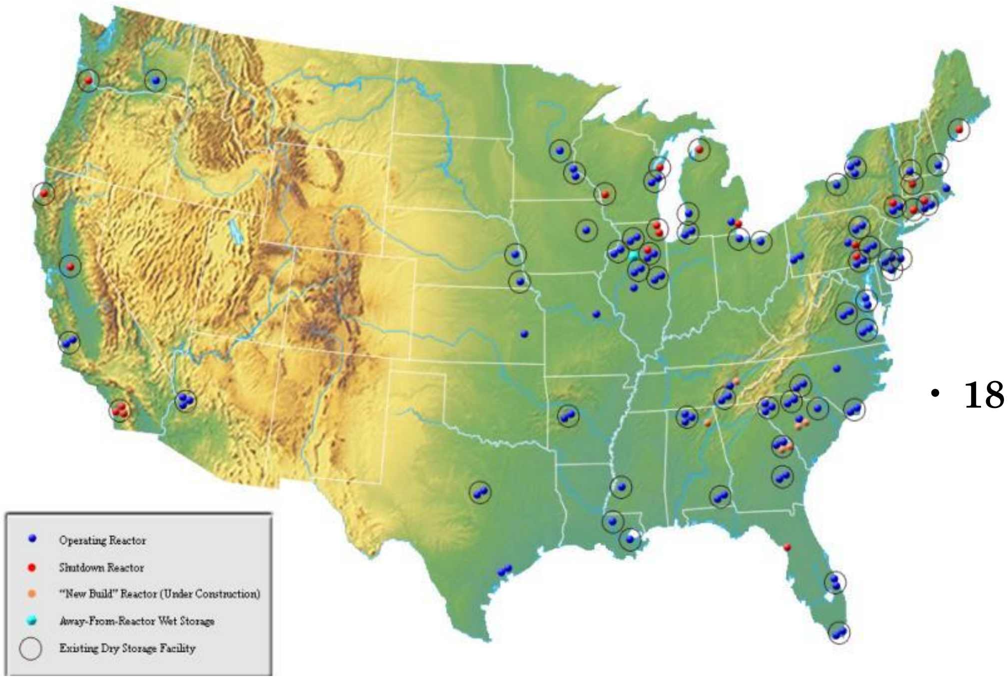
12 Welded Metal Canisters in Transport Overpacks
866 Assemblies, 1.2% of Dry

- *Majority is in Large Welded Canisters*
- *Current dry storage inventory is diverse*
- *Trend toward higher capacities*

Transnuclear TN-32

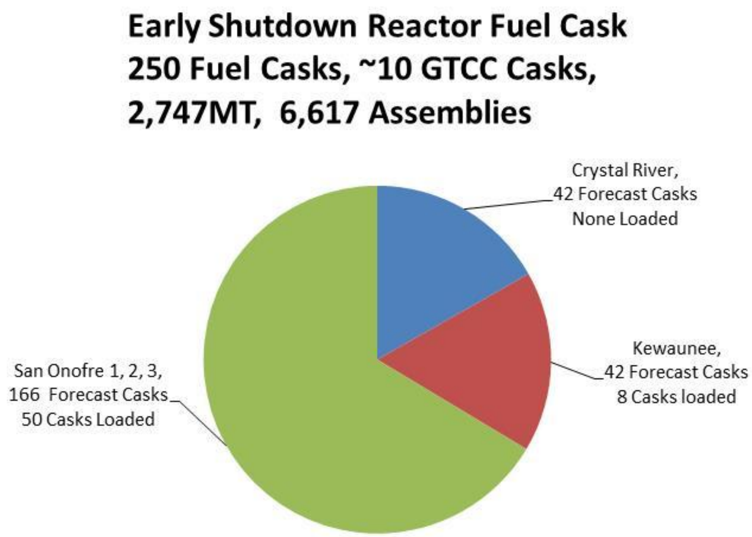
Holtec Hi-Star 100

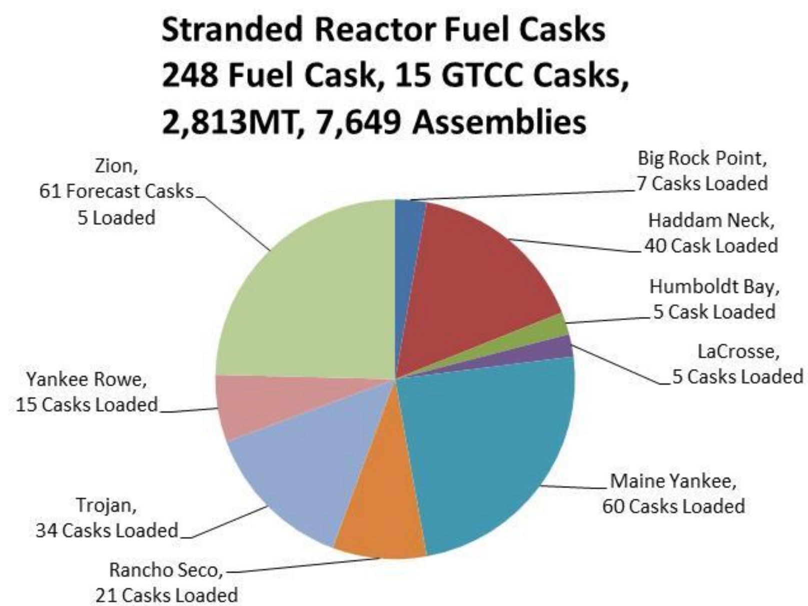
Shutdown Reactors with Fuel on Site



- **18 Reactors Ceased Operations**
  - **Fuel on site**
  - **3 reactors on sites with other active reactors**
  - **15 reactors on 12 sites with no other nuclear operations**
    - **12 stranded reactors (9 sites)**
    - **3 early shutdown reactors (3 sites)**

Shutdown Reactor Sites Use Several Different Storage Designs

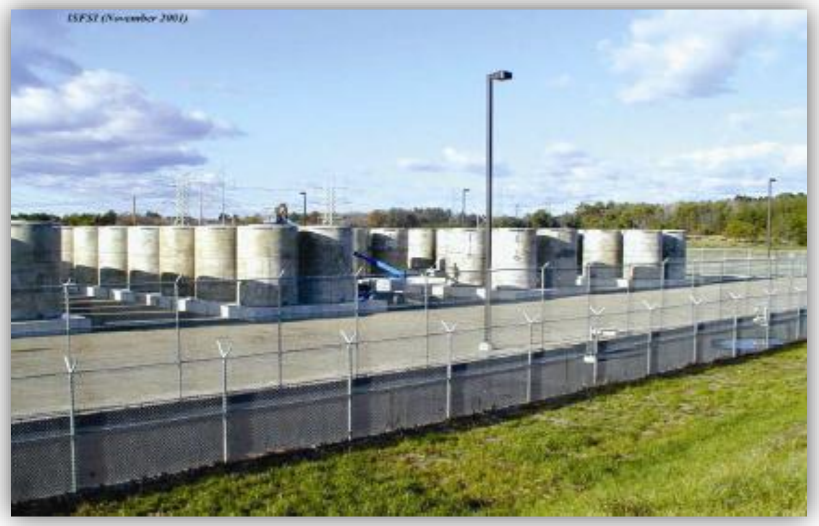




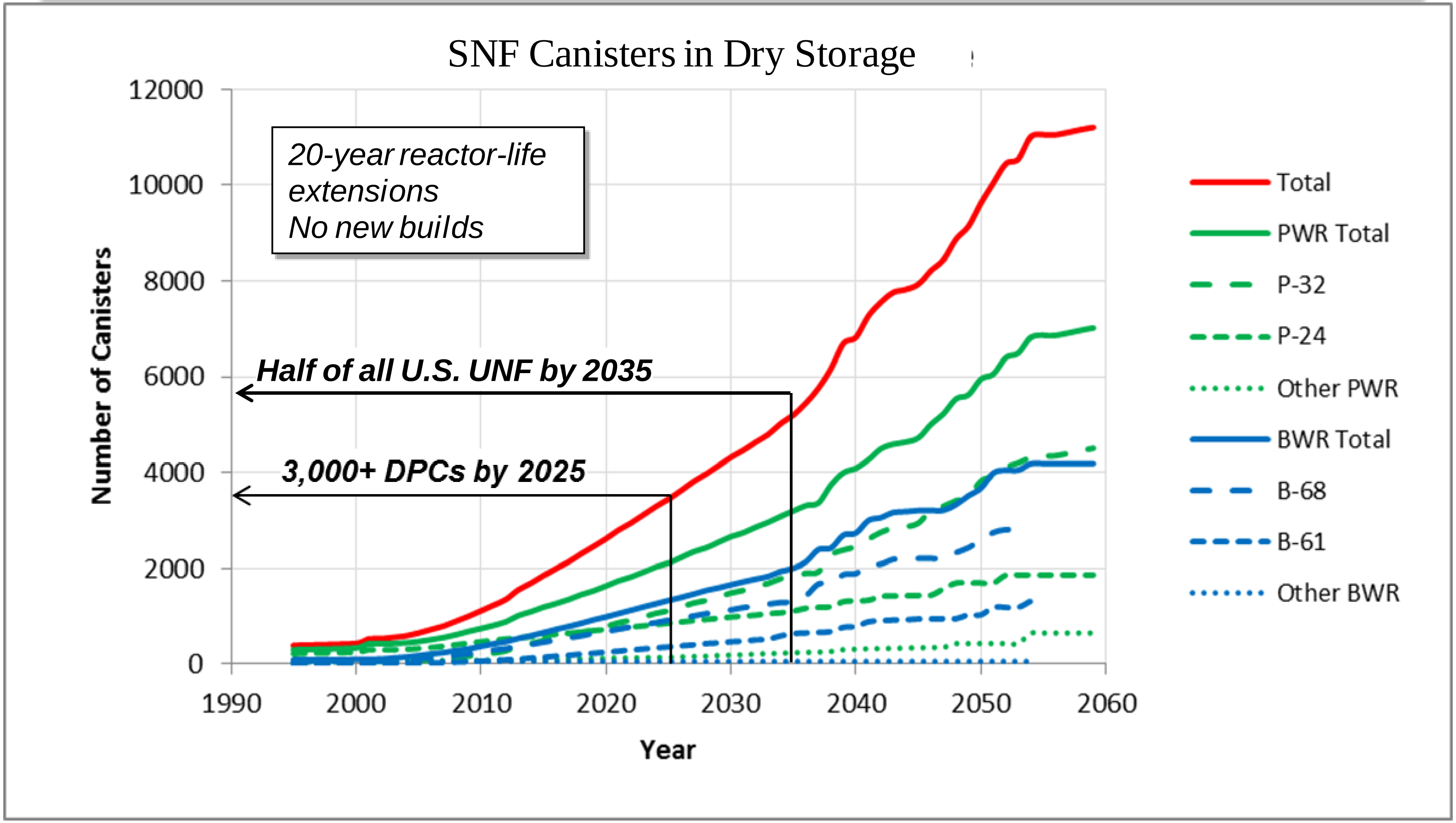
Dry Storage Canisters

- 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

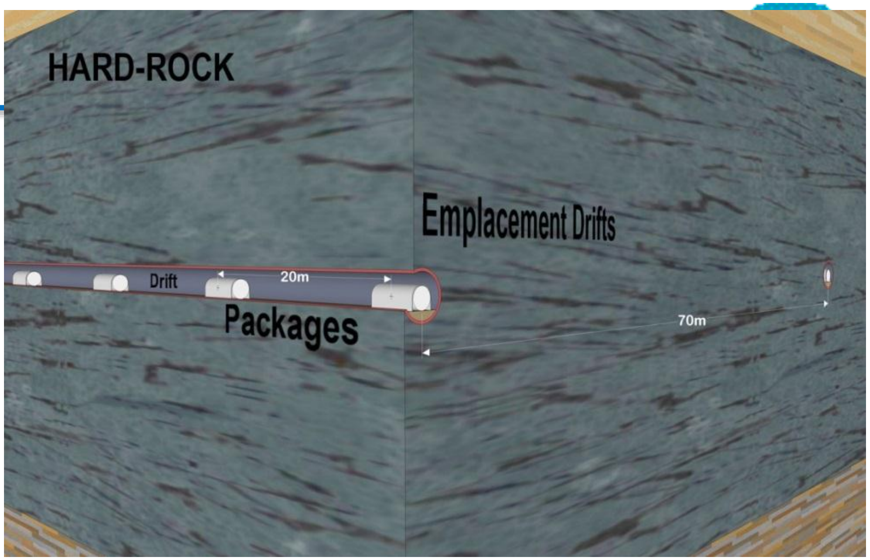
SNF Currently Stored in Different Large Canister Designs



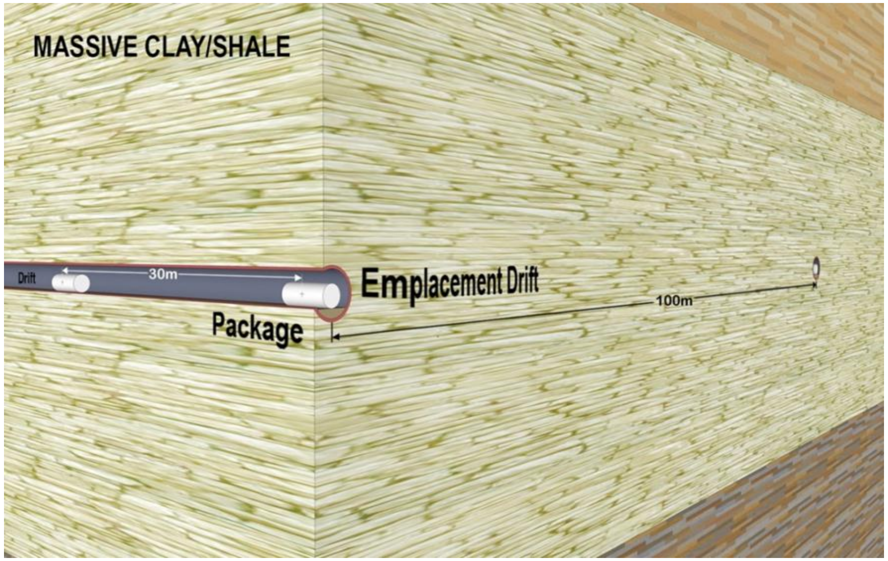
Current and Projected Accumulation of Used Commercial Reactor Fuel in Dry Storage (DPCs)

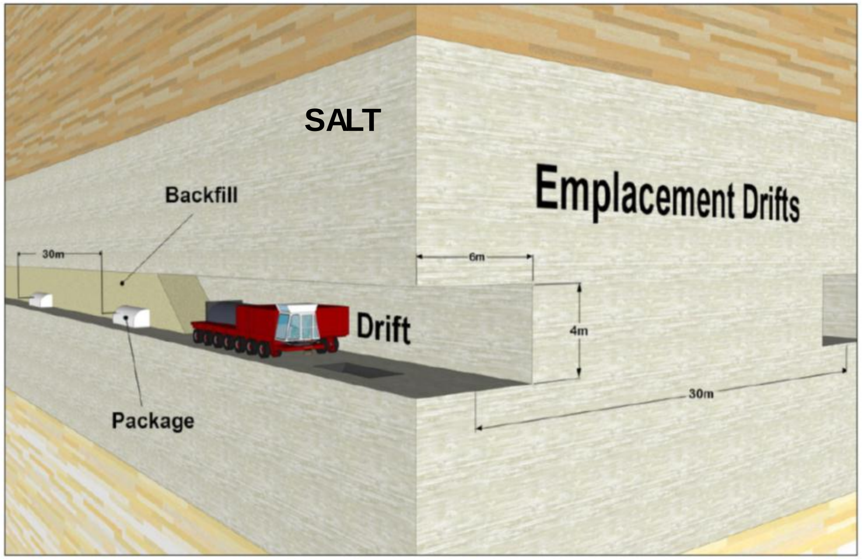


DPC Direct Disposal Concepts



- 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)

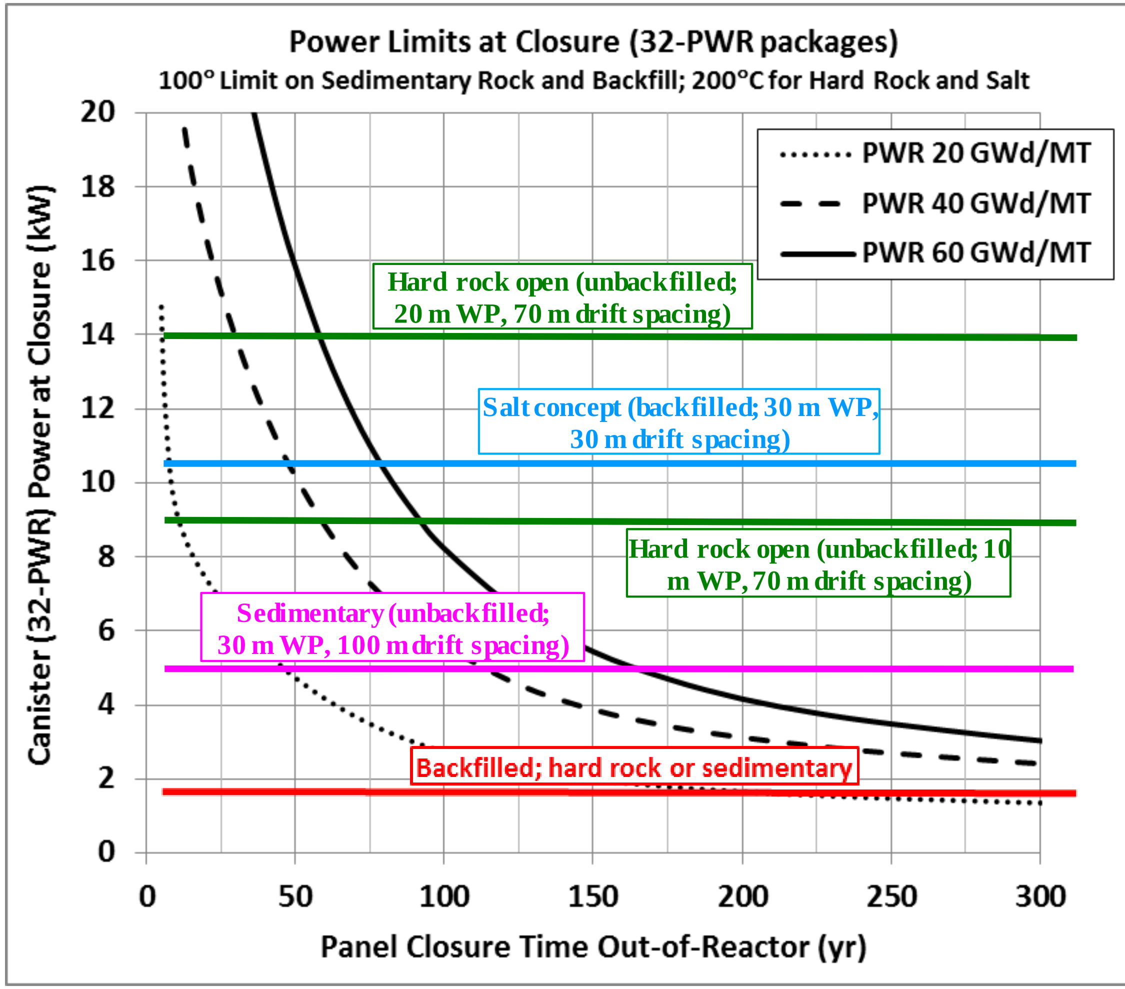
Time to Repository (Panel) Closure for Representative Disposal Concepts

32-PWR size packages

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

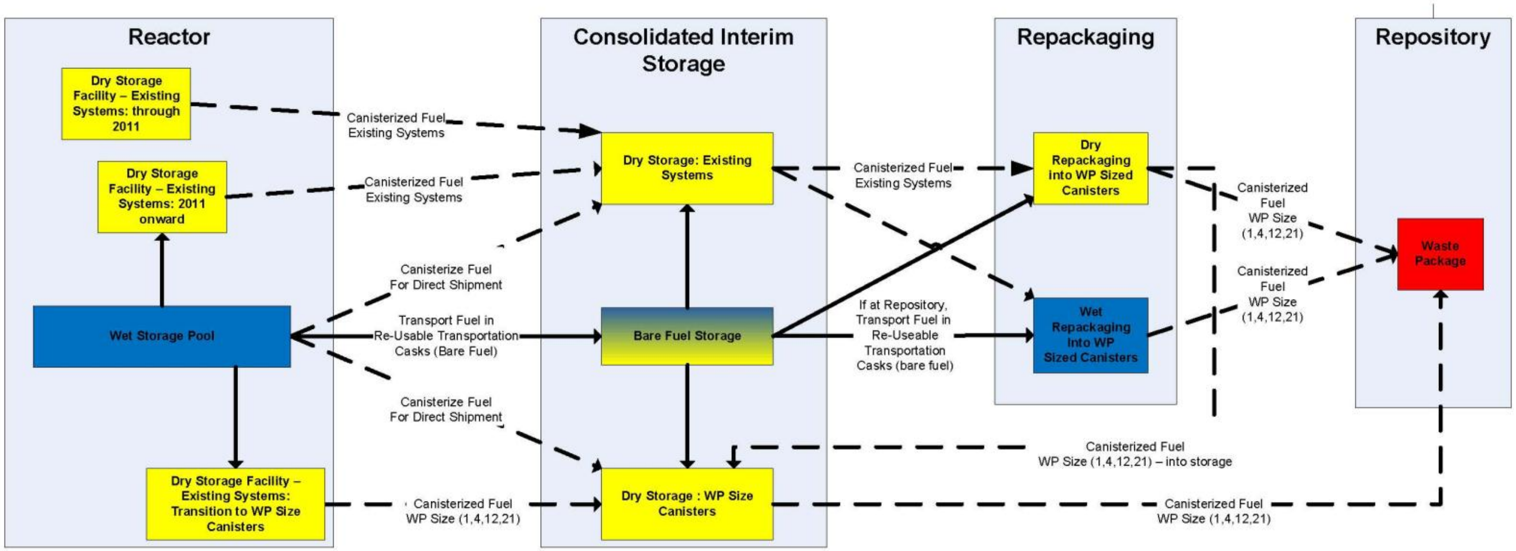
Salt concept

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.

Integrated Storage, Transportation & Disposal System



At-Reactor Fuel Management: Sub-Case 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-sized dry storage system at T = 20xx.
4. Transport all fuel in wet storage pool to ISFSI (when operational and has wet storage pool) in re-useable transportation casks
5. Canisterize fuel in wet pool for direct shipment to ISFSI (when operational and does not have a wet storage pool)
   - 5a. Existing dry storage systems
   - 5b. WP-sized dry storage systems (1,4,12,21)

CIS Fuel Management: Sub-Case Options

1. Bare fuel storage capability at CIS
   - 1a. Maintain fuel in bare storage
     - 1a-1. Wet storage pool
     - 1a-2. Bare fuel vault
   - 1b. Transfer to existing dry storage systems
   - 1c. Transfer to waste package compatible sized canisters
2. Re-packaging locations
   - 2a. At CIS
     - 2a-1. At receipt
     - 2a-2. Prior to transport to repository
   - 2b. At repository
3. Re-packaging technology alternatives
   - 3a. Wet
   - 3b. Dry
4. Received fuel at CIS in existing dry storage system sized canisters
   - 4a. Store as-is
   - 4b. Repackage into waste package compatible size canisters and store

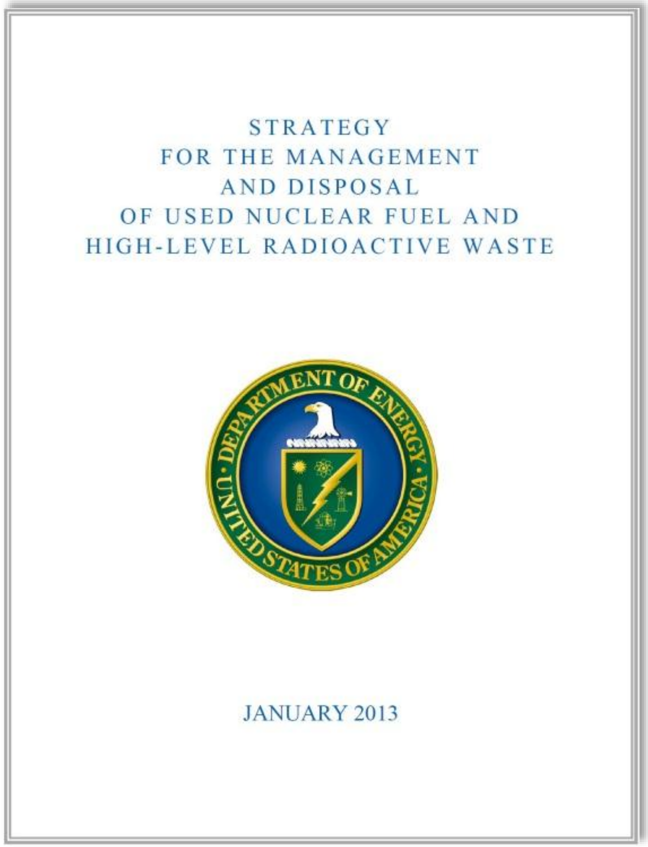
Nutt et al., *Used Fuel Management System Architecture Evaluation, Fiscal Year 2012*, FCRD-NFST-2013-000020 Rev. 0, 2012.

Some Issues Related to Lack of Integration

- Size of DPCs
  - Transport – fitting under underpasses on highways
  - Disposal – complicates handling in underground spaces and placement in drifts
- Thermal output of DPCs
  - Transport – significant cooling time (~25 years) may be required prior to transport
  - Disposal – significant cooling time (up to 178 years) before disposal
- Criticality
  - Disposal - Probably cannot screen out criticality from postclosure performance assessment on basis of probability, except in a salt repository
  - Disposal – Either include criticality in postclosure PA or exclude on basis of consequence or open DPCs and add criticality controls
- Aging Management During Storage
  - Fuel is being stored longer than originally planned
  - Uncertainty as to whether fuel stored for an extended period of time can be transported as-is
  - Uncertainty as to whether fuel stored for an extended period of time, and then transported, can be certified for storage again
- Integration of canister requirements
  - QA controls on fabrication, transit and drying of DPCs sufficient for storage and transport, but perhaps not for disposal requirements

Increasing Integration in the Waste Management System

- **US DOE Strategy outlines a 10-year program of work that:**
- **Sites, designs, licenses, constructs and begins operations of a pilot interim storage facility (operating 2021)**
- **Advances toward the siting and licensing of a larger interim storage facility (operating 2025)**
- **Makes demonstrable progress on the siting and characterization of geologic repository sites (sited 2026, operating 2048)**


STRATEGY
FOR THE MANAGEMENT
AND DISPOSAL
OF USED NUCLEAR FUEL AND
HIGH-LEVEL RADIOACTIVE WASTE

JANUARY 2013

Can consolidated interim storage provide opportunities for integrating the waste management system?

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 SNF management system is relying on wet and dry storage at operating and shutdown reactor sites
- The current SNF inventory in storage exceeds 71K 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 SNF, with higher burnups, in larger dual purpose storage casks; currently ~2000 DPCs and ~11000 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