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Implications of the Direct Disposal of Large Dry-Storage System Designs for Repository Design

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U.S. Nuclear Waste Technical Review Board
Technical Workshop on the Impacts of Dry-Storage Canister Designs on Future Handling, Storage, Transportation and Geologic Disposal of Spent Nuclear Fuel in the United States

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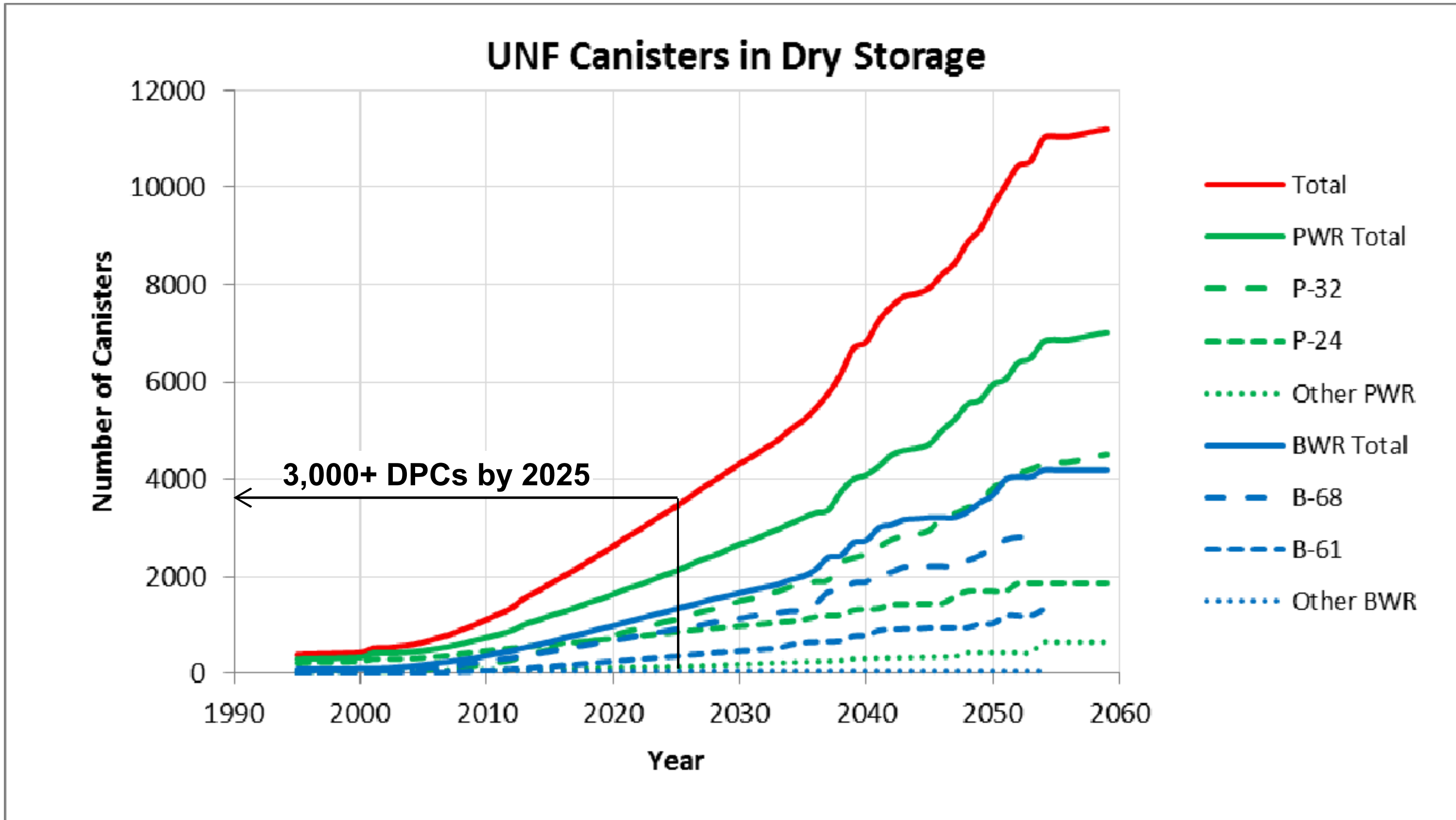
Implications for Repository Design: Outline

- **Assumptions**
- **Design Options**
  - Thermal
  - Criticality control
  - Engineering challenges
- **Example Disposal Concepts**
- **Thermal Management Analysis**
- **Reactivity Scoping Analysis (e.g., Maine Yankee)**
- **Preliminary Logistical Analysis**
- **Summary and Conclusion**

Dry Storage Projection*
Accumulation of Canisters (TSL-CALVIN)



Assume Presently Used DPC Types, No Fuel Shipments from Existing ISFSIs, and 20-yr Life Extensions for the Currently Operating Reactor Fleet.

*Simulation with TSL-CALVIN: Nutt et al. (2012)

Spent Fuel Projection*
Accumulation in Dry Storage & Pools

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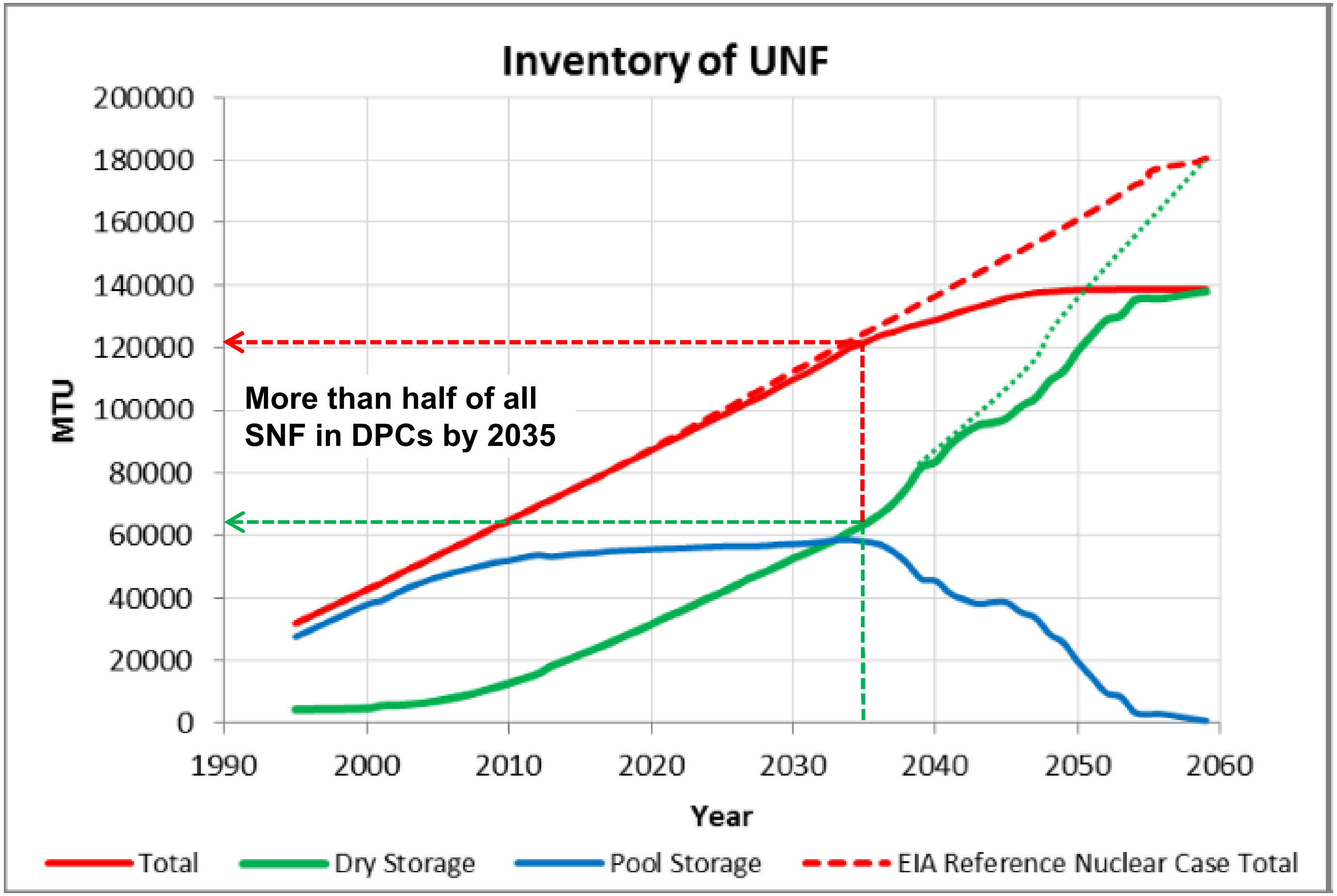

Assume 20-yr Life Extensions for the Currently Operating Reactor Fleet.

*Simulation with TSL-CALVIN: Nutt et al. (2012)

DPC Direct Disposal Study Assumptions and Conditions

Key Assumptions for This Analysis

- Complete disposal (repository panel closure) at/before fuel age of 150-years out-of-reactor
- Fuel and canister condition will be suitable for transport and disposal, 50 to 100 years out-of-reactor
- Regulatory context similar to 40CFR197 and 10CFR63 (e.g., probabilistic treatment of features, events & processes)

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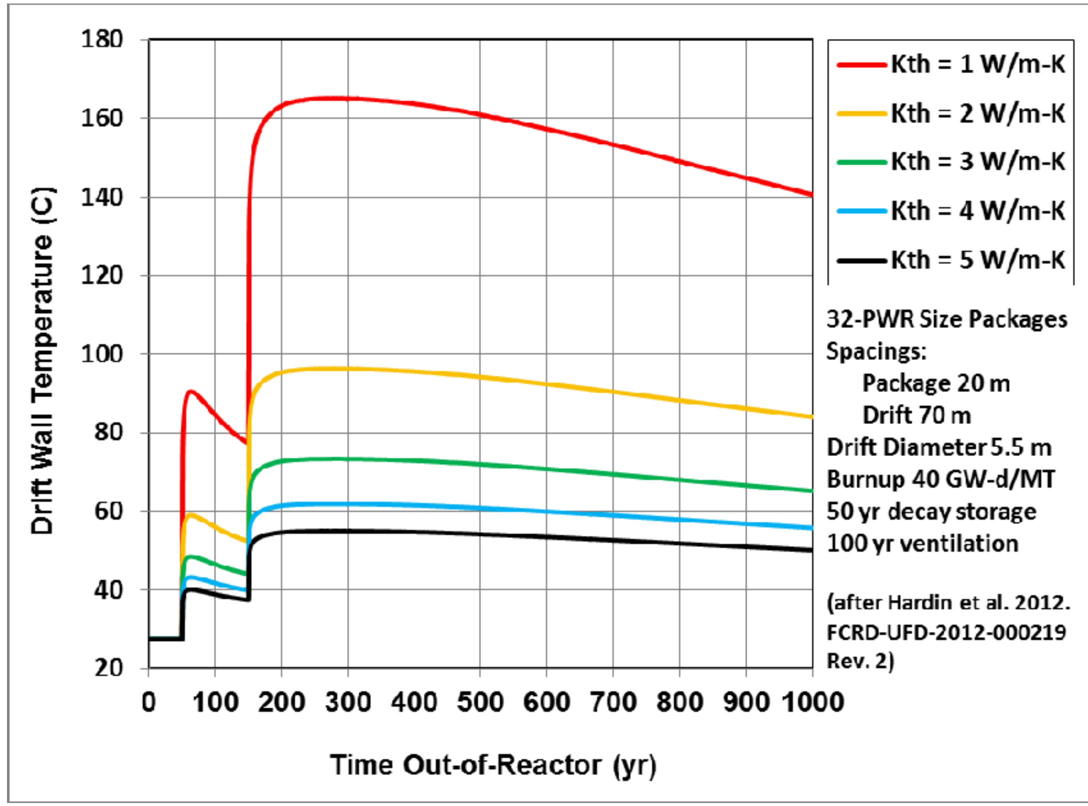
Design Options for Thermal Management

- **For a Given Waste Package Capacity and SNF Burnup:**
  - Choice of host rock
    - Salt
    - Hard rock
    - Sedimentary (clay-rich)
  - Repository spacings
  - Surface decay storage duration
  - Ventilation
  - Use of backfill



Effect of rock K_{th} on drift wall temperature for a typical 32-PWR, average burnup case.

Design Options for Nuclear Reactivity Control

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- **Disposal Environment**
  - Groundwater availability
  - Salinity
  - Package integrity
- **Moderator Exclusion**
  - Package integrity
- **Moderator Displacement**
  - Fillers (e.g., boron carbide loaded grout)
- **Reactivity Analysis Methodology**
  - Burnup credit, as-loaded, degradation cases

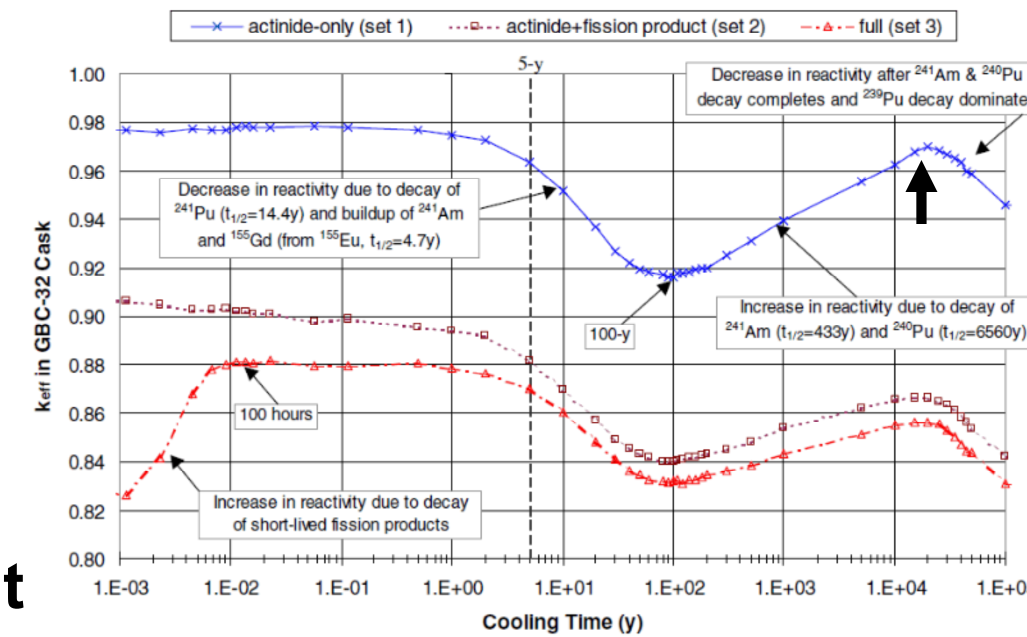

Figure source:
Wagner and Parks 2001. NUREG/CR-6781.(Fig. 3)
Generic burnup credit 32-PWR cask
PWR fuel (4% enriched, 40 GW-d/MT burnup)

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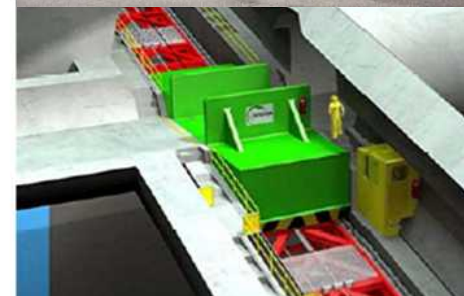
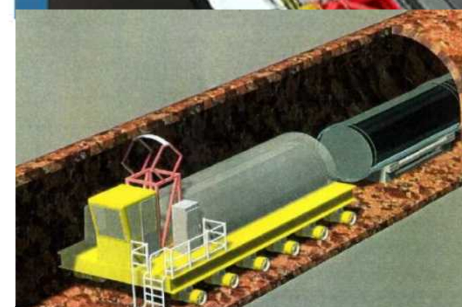
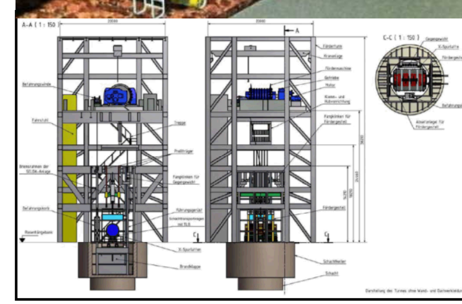
Design Options to Address Engineering Challenges







- **Handling/Packaging Using Current Practices**
- **Surface-Underground Transport**
  - Heavy shaft hoist
  - Spiral ramp (≤10% grade for rubber-tires)
  - Linear ramp (>10% possible with funicular)
  - Shallow ramp (≤ 2.5% for standard rail)
- **Opening Stability Constraints**
  - Salt (a few years with minimal maintenance)
  - Hard rock (50 years or longer)
  - Sedimentary (50 years may be feasible; longer may require special geologic settings)

Sources:
Fairhurst 2012
www.wheelift.com
Nieder-Westermann et al. 2013

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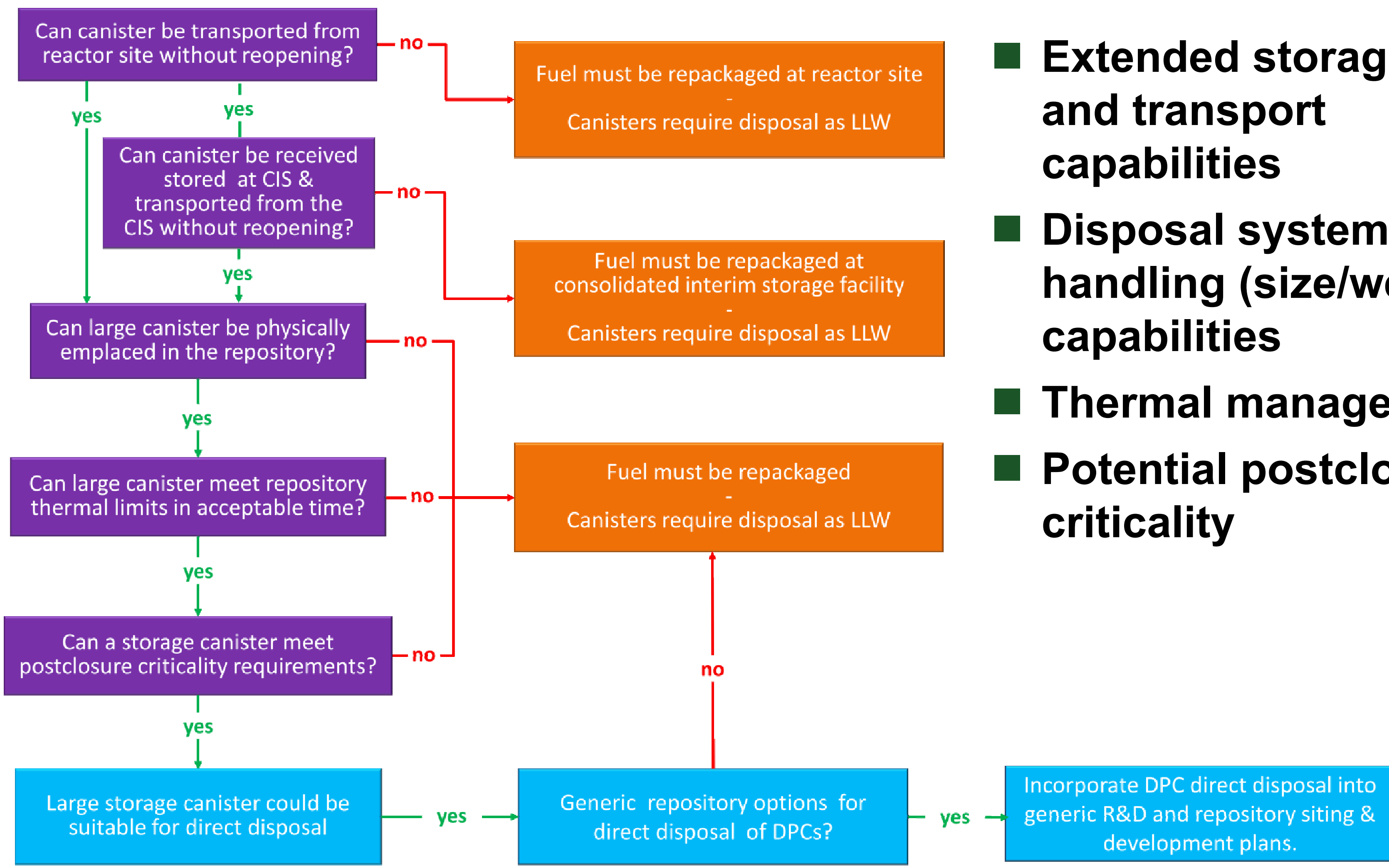
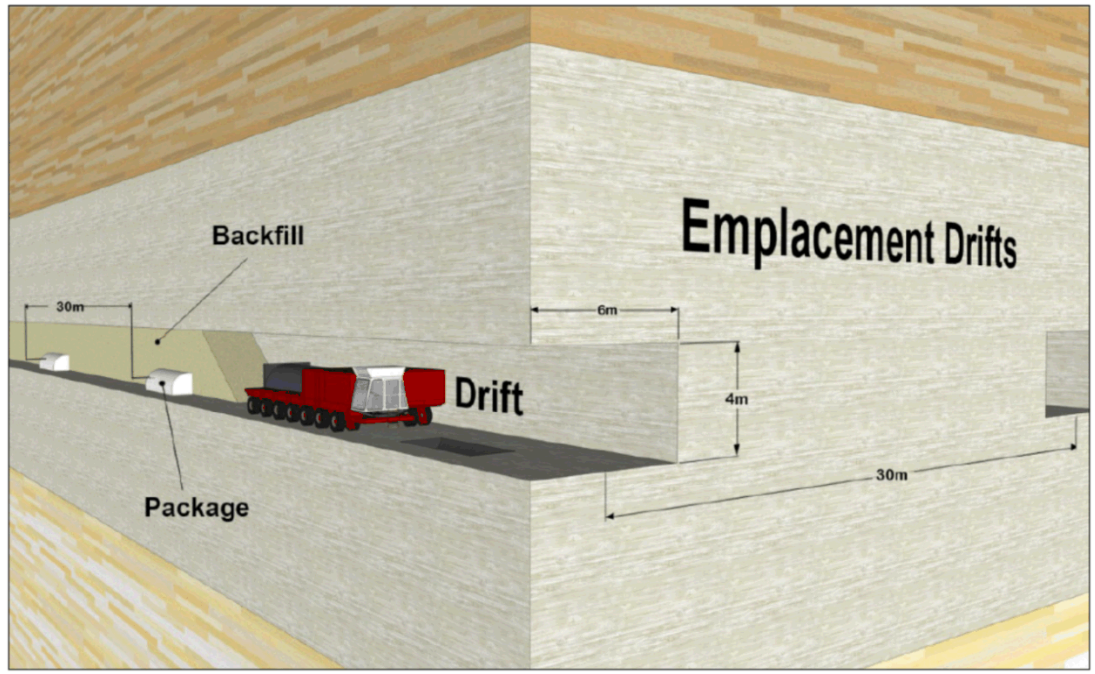
Path to Direct Disposal of SNF in Dual-Purpose Canisters

- Extended storage and transport capabilities
- Disposal system handling (size/weight) capabilities
- Thermal management
- Potential postclosure criticality



Example: Generic Concept for a SNF Repository in Salt

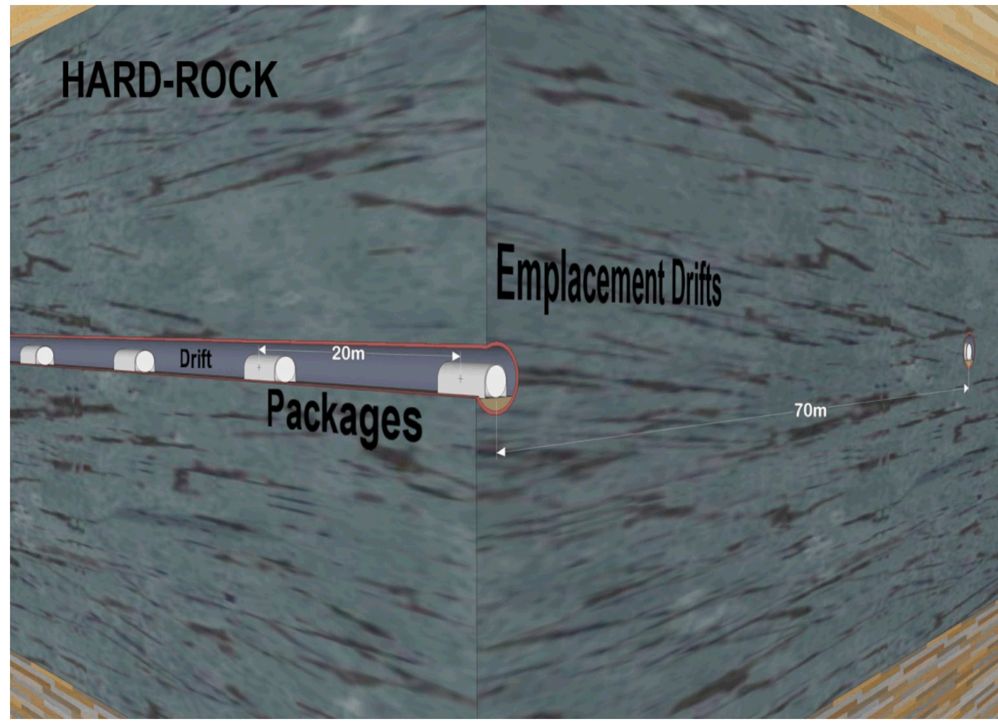
- 32-PWR size or larger
- Emplace SNF at 50 to 70 years out-of-reactor (OoR)
- Crushed salt backfill at emplacement
- Bedded or domal salt
- Shaft or ramp access (~175 MT payload with shielding and cart)
- Handling equipment and shaft/ramp conveyance development needed



Source: Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 0)

Example: Hard-Rock Unbackfilled Open Concept

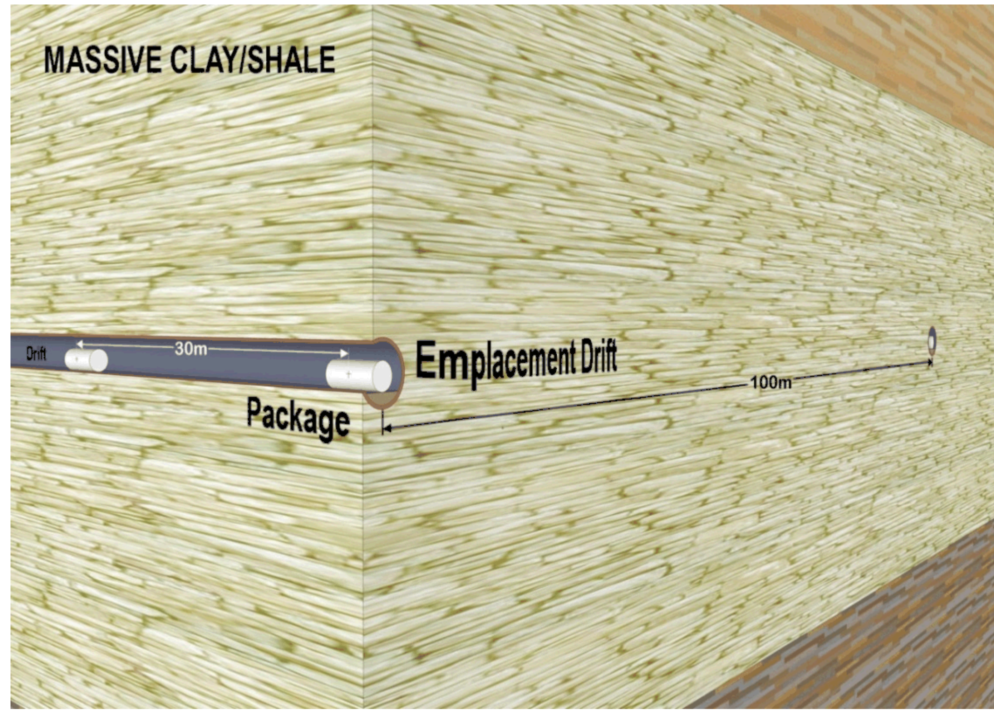
- 32-PWR size or larger
- Emplace SNF at 50 to 100 years OoR
- Ventilate up to 50 yr, closure at <150 years OoR
- Unbackfilled, for unsaturated settings (or include backfill for saturated settings)
- Corrosion resistant waste packaging
- Additional engineered barriers may be installed at closure (e.g., drip shields)
- Long-term opening stability can be expected through the postclosure thermal peak



Source: Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 0.

Example: Sedimentary Backfilled Open Concept

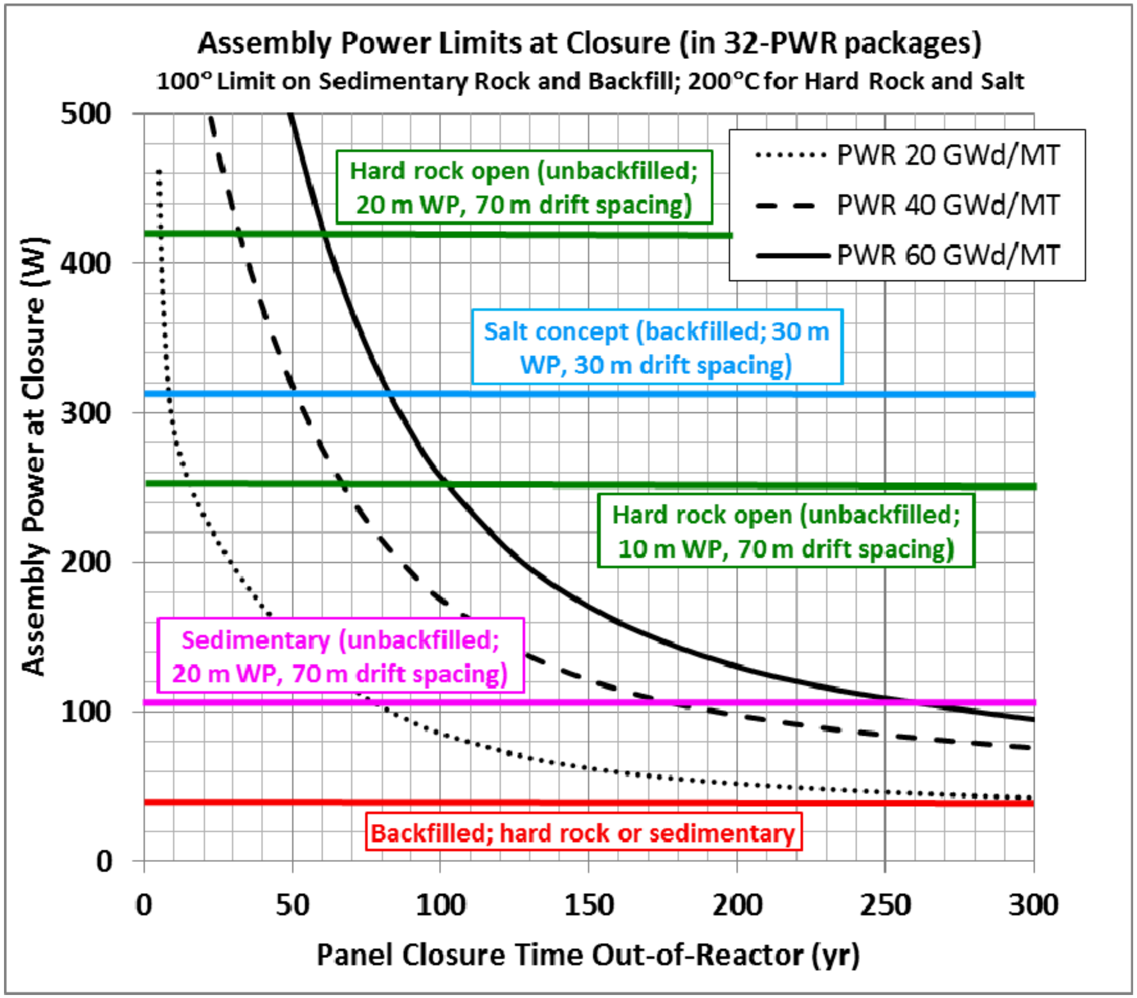
- Massive, soft clay/shale
- In-drift emplacement
- 32-PWR size or larger
- Emplace SNF at 50 to 100 years OoR
- Backfilling at closure (peak backfill T >> 100°C)
- Closure at 100 to >200 years OoR (limited by host rock)
- Possible local heating of host rock >100°C
- Steel or corrosion resistant waste packaging as needed



Source: Hardin et al. 2013. FCRD-UFD-2013-000171 Rev. 0.

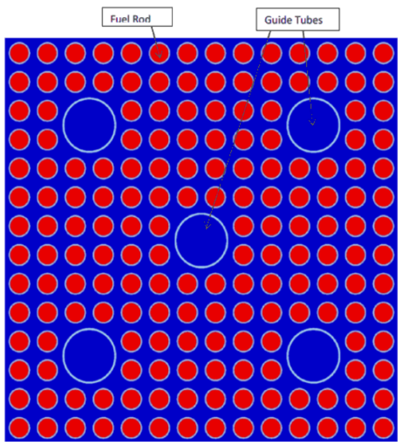
Time to Repository Panel Closure for Representative Disposal Concepts

32-PWR size packages



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

Numerical Model of TSC-24 Canister, Maine Yankee



- **Numerical Model of TSC-24 Canisters (31 analyzed)**
- **ORNL Database SNF-ST&DARDS**
- **Software/Data**
  - SCALE code system (ORNL 2011)
  - Details: see Clarity and Scaglione (2013)
- **Also Analyzed: 26 canisters at Sequoyah (MPC-32 type)**

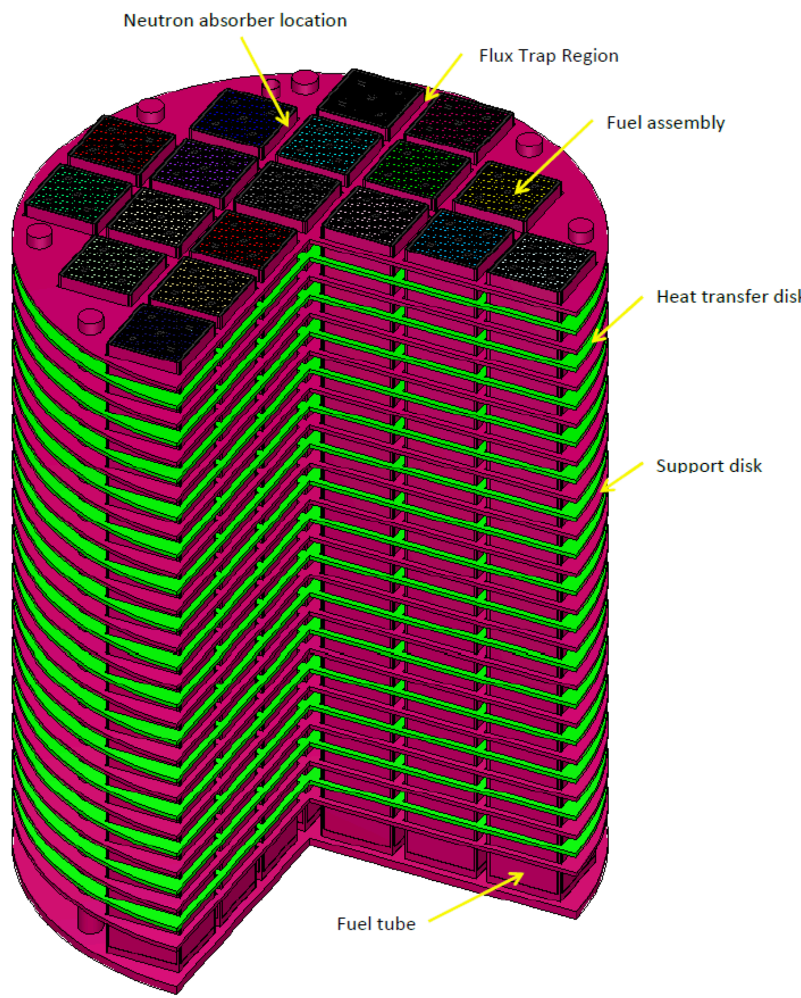
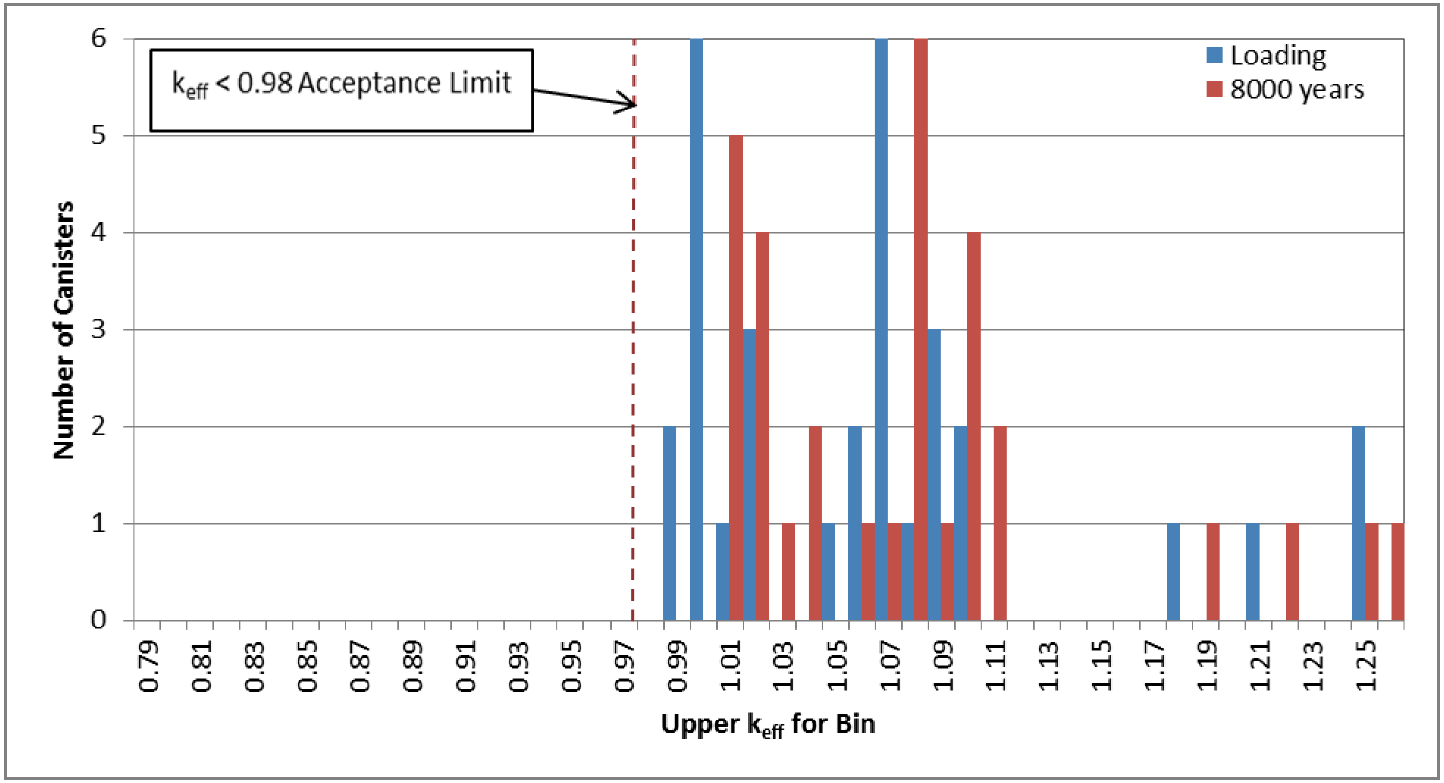


Figure 8-3. Cut-away view of the TSC-24 design basis KENO model

Reactivity Scoping Analysis Results, Maine Yankee

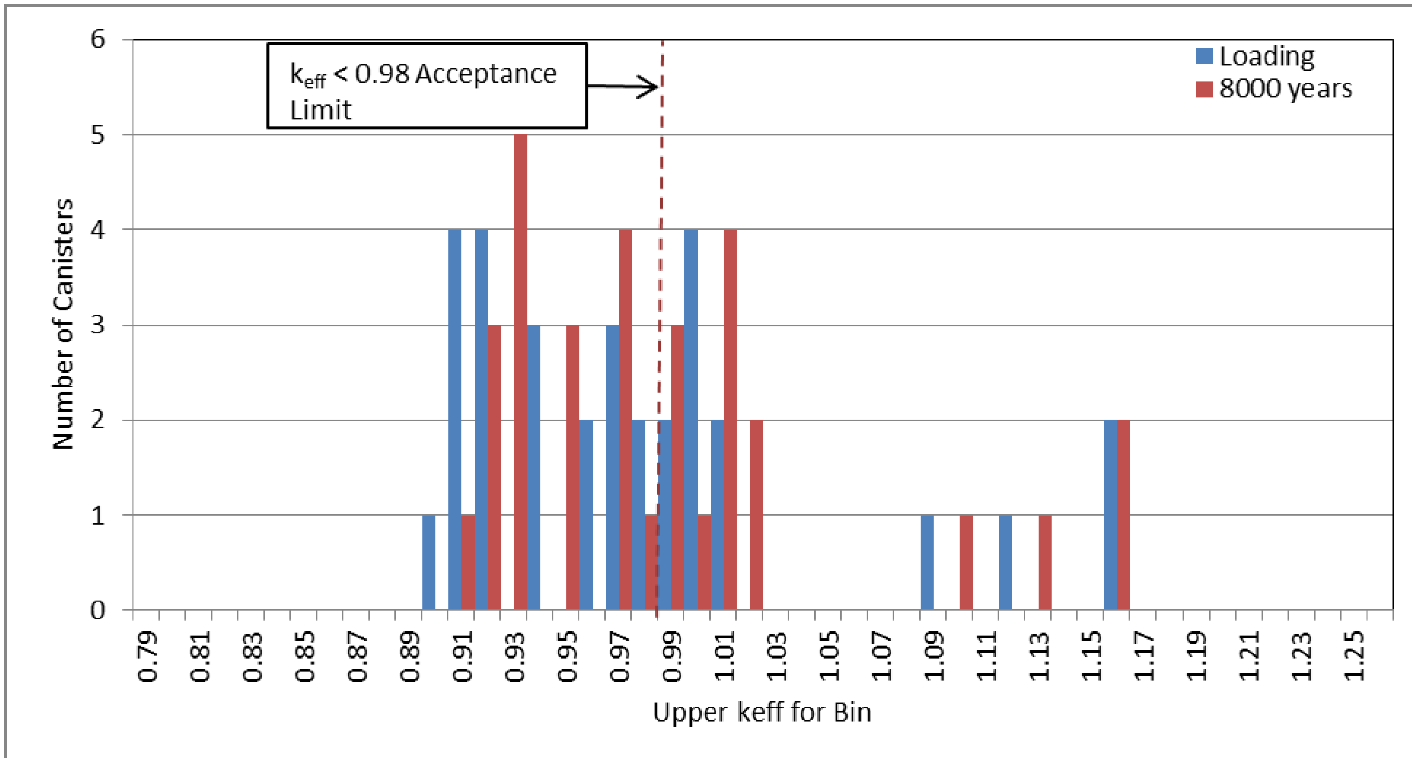
- **Degraded basket case (and loss of absorber), <u>flooded with fresh water</u>**
- **Analyzed as-loaded, with burnup credit**



Source: Clarity, J. and J. Scaglione 2013. ORNL/LTR-2013/213.

Reactivity Scoping Analysis Results, Maine Yankee

- **Degraded basket case (and loss of absorber), <u>flooded with 1 molal NaCl brine</u>**
- **Analyzed as-loaded, with burnup credit**



Source: Clarity, J. and J. Scaglione 2013. ORNL/LTR-2013/213.

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Preliminary Logistical Analysis of DPC Direct Disposal Scenarios

- **Objectives:**
  - Forecast when DPCs loaded with SNF from the existing fleet could be emplaced in a repository, for emplacement thermal power limits of 4, 6, 8, 10, and 12 kW/canister
  - Project repository acceptance (throughput) rates
  - Estimate the incremental costs that would be required to store DPCs at a centralized interim storage (CIS) facility for cooling
  - Compare with estimates of the cost to re-package the SNF into smaller canisters for disposal

Use TSL-CALVIN code, developed originally for Yucca Mountain repository studies, adapted with additional features to generic studies (Nutt et al. 2012).

Source: Nutt, W.M. 2013. *Preliminary System Analysis of Direct Dual Purpose Canister Disposal*. FCRD-UFD-2013-000184.

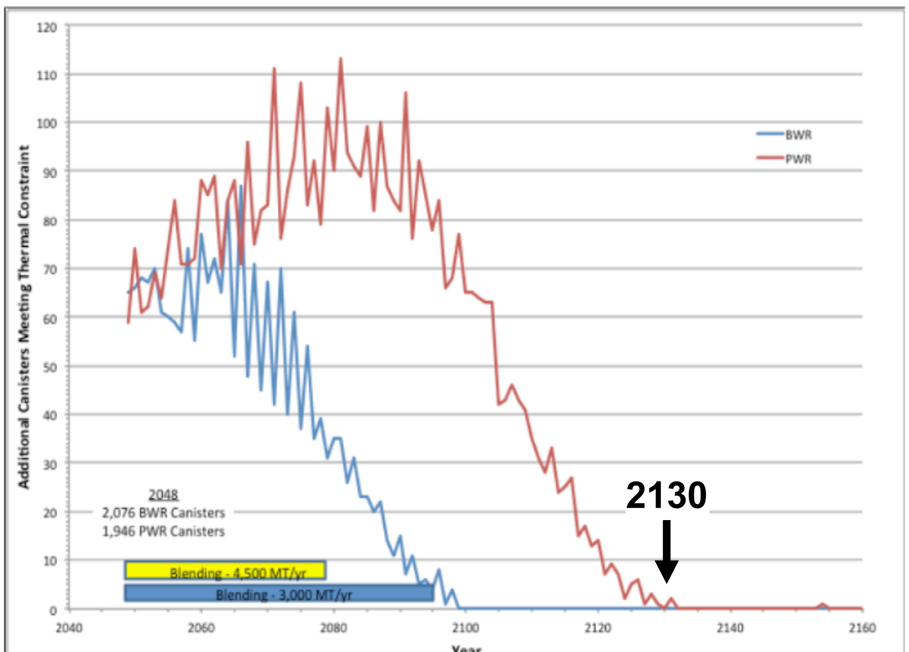
Preliminary Logistical Analysis: Assumptions

- **Modeling from the Present Until Repository Closure:**
  - SNF will be generated at all currently operating power plants, with 20-year life extensions, and gradual increases in burnup.
  - All SNF would be put in dry storage as plants are decommissioned.
  - Shipment of DPCs from reactor sites to an CIS would begin in 2025.
  - A repository would open and begin to emplace DPCs underground in 2048.
  - Once the repository is operating, DPCs cool enough for disposal would be shipped from reactor sites or from the CIS.

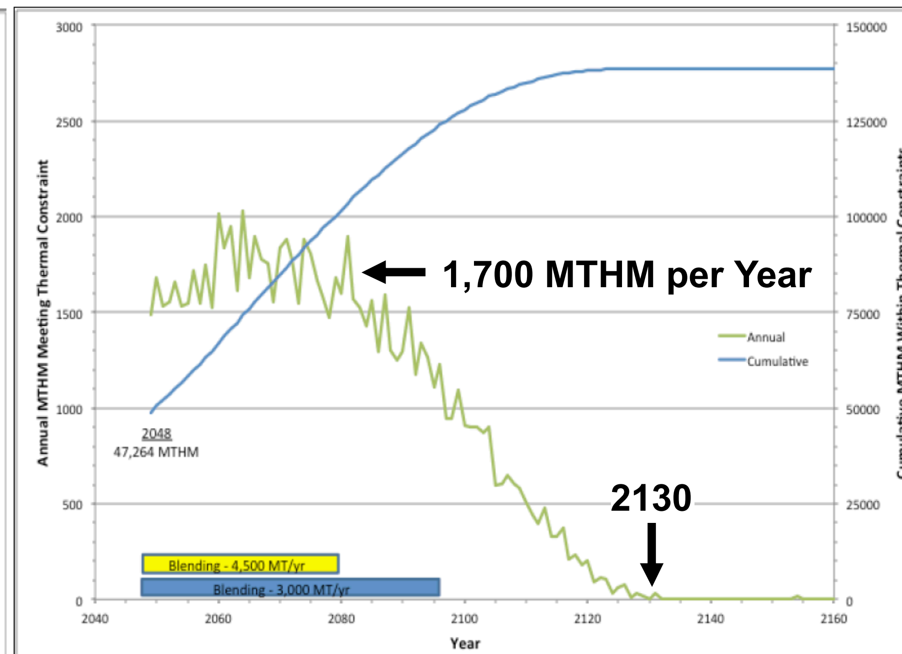
Source: Nutt, W.M. 2013. *Preliminary System Analysis of Direct Dual Purpose Canister Disposal*. FCRD-UFD-2013-000184.

Preliminary Logistical Analysis: 10 kW Emplacement Power Limit

- 10 kW is a typical emplacement power limit for salt disposal
- Emplacement operations would be substantially done by 2130
- Additional ventilation time would be needed for hard rock (up to 50 yr) and sedimentary (100 to >200 yr) concepts



Number of canisters per year, vs. calendar year



SNF emplaced per year (MTHM), vs. calendar year

Source: Nutt, W.M. 2013. FCRD-UFD-2013-000184.

Implications for Repository Design
Summary and Conclusions

- **Summary of Design Options**
  - Thermal, criticality, and engineering challenges
- **Example Disposal Concepts for DPC-Based Waste Packages**
  - Salt (backfilled at emplacement)
  - Hard rock (unsaturated/unbackfilled or saturated/backfilled)
  - Sedimentary (clay-rich)
- **Thermal Results**
  - Repository panel closure <150 yr fuel age out-of-reactor (salt and hard rock, and low-to-moderate burnup SNF in sedimentary)
  - For sedimentary settings and higher burnup SNF: need some combination of longer repository operations, local heating of host rock > 100°C, and larger repository spacings
  - Backfill temperature potentially >> 100°C (if used)

Implications for Repository Design
Summary and Conclusions, cont.

Reactivity Scoping Results

- Reactivity margin available with burnup credit analysis, as-loaded assembly information
- Preliminary results show some, but not all, DPCs could be sub-critical for the degraded cases as defined
- Saline water (^{35}Cl) provides significant absorption
- Other options (e.g., fillers) are being investigated

Preliminary Logistical Result

- At 10 kW power limit, emplacement could be complete at 2130, with average emplacement rate of 1,700 MTHM/yr

Preliminary results indicate DPC direct disposal could be technically feasible, at least for certain concepts. They also suggest that cost savings might be realized compared to re-packaging, although further analysis is needed. Feasibility evaluation and related R&D activities are planned to continue.

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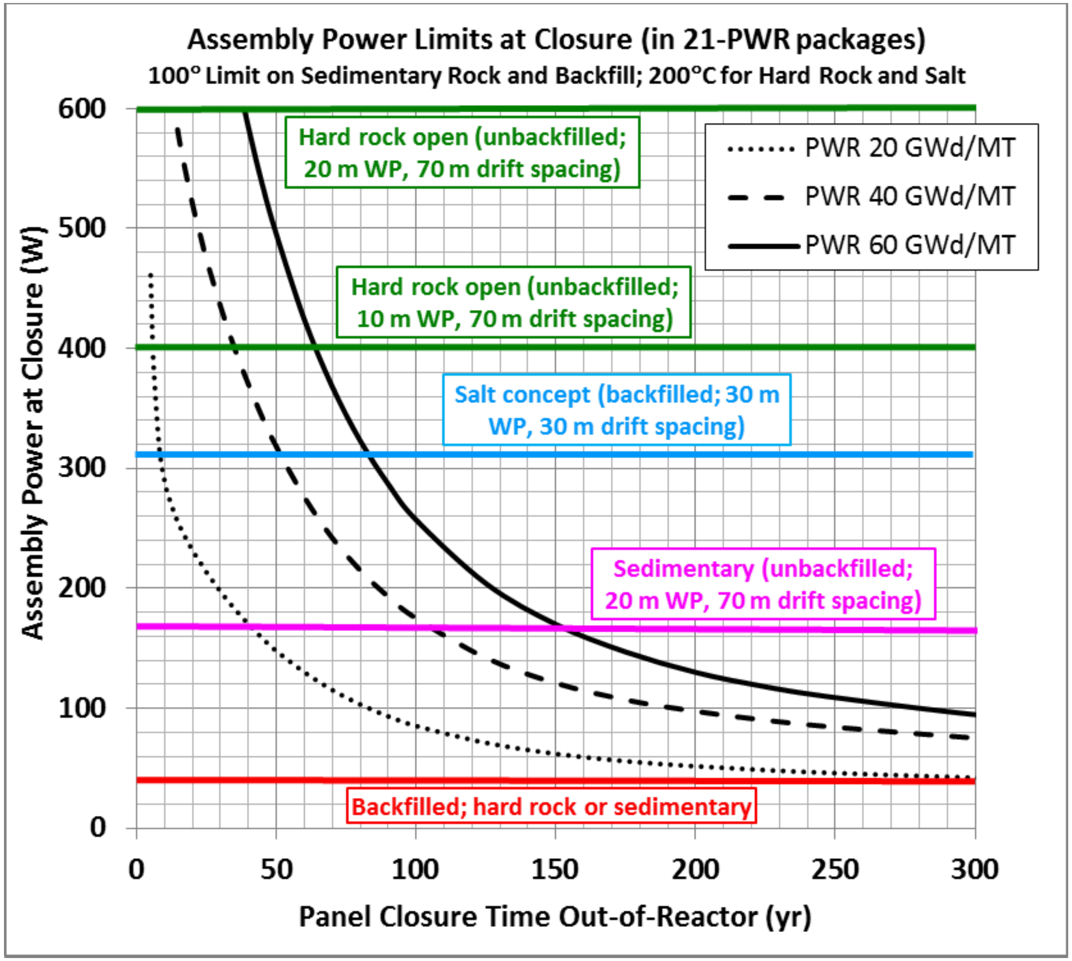
Backup

Time to Repository Panel Closure for Representative Disposal Concepts

21-PWR size packages



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